A Practical Guide to Junos Routing and Certification

2nd Edition
Revised & Updated

Junos® Enterprise Routing

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Peter Southwick, Doug Marschke & Harry Reynolds

Junos Enterprise Routing

SECOND EDITION

Junos Enterprise Routing

Peter Southwick, Doug Marschke, and Harry Reynolds

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by Peter Southwick, Doug Marschke, and Harry Reynolds

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About the Authors

Peter V. Southwick has spent the last 30 years in telecommunications—designing, implementing, and training on voice, data, and security systems. He is a Proteus Networks professional services senior engineer specializing in the deployment of high-end Juniper routers and service gateways. He has led deployments of SRXs, MXs, and J-series routers for major enterprise and carrier customers. He is also a veteran Juniper Networks Certified Instructor and has developed multiple courses for the various Juniper product lines. Peter is an author of *Telecommunications: A Beginner's Guide* and coauthor of *ISDN: Concepts, Facilities, and Services* (both published by McGraw-Hill) and contributing author to *The Handbook of Local Area Networks* (CRC Press). Peter holds a B.S.E.E. from Clarkson University. He is a member of IEEE and has Juniper Certifications including JNCIS-FWV, JNCIA-SSL, JNCIE-M/T #473, JNCIS-ER, and JNCIP-SEC.

Doug Marschke is an engineering graduate from the University of Michigan and currently a principal partner at Proteus Networks. He is JNCIE-ER #3, JNCIE-M #41, JNCIS-FW, and JNCIA certified. He has written various Juniper certification exams, is a cowriter of the JNCIE Enterprise Exam, and coauthored *Junos Enterprise Switching* (O'Reilly). Doug currently spends his time working with both service providers and enterprises to optimize their IP networks for better performance, cost, and reliability, and he has spent the last six months working on a next-generation government satellite network. He also flies around the world and back to share his knowledge in a variety of training classes and seminars on topics such as troubleshooting, design, and certification preparation. If Doug is not on the road, you can find him at his bar in San Francisco, Taco Shop at Underdogs, discussing a wide variety of topics. He recently started a new company called Funny How Films, producing independent films such as *Amsterdam Heavy* and *Mad Cow*.

Harry Reynolds has more than 25 years of experience in the networking industry, with the last 15 years focused on LANs and LAN interconnection. He is CCIE #4977 and JNCIE #3 certified, and he also holds various other industry and teaching certifications. Harry was a contributing author on the *Juniper Network Complete Reference* (McGraw-Hill), and wrote the JNCIE and JNCIP study guides for Sybex Books. Prior to joining Juniper, Harry served time in the US Navy as an avionics technician, worked for equipment manufacturer Micom Systems, and spent much time developing and presenting hands-on technical training curriculums targeted to both enterprise and service provider needs. Harry has presented classes for organizations such as American Institute, American Research Group, Hill Associates, and Data Training Resources. Harry is currently employed by Juniper Networks, where he is a senior test engineer performing customer-specific testing. Harry's other roles at Juniper have included test engineer in the core protocols group, consulting engineer on an aerospace routing contract, and senior education services engineer, where he worked on courseware and certification offerings.

About the Technical Reviewers, Second Edition

The second edition was reviewed by several Junos engineers, including the authors of the first edition, Doug Marschke and Harry Reynolds. Rob Cameron of Juniper Networks was kind enough to give the new chapters added to this second edition a careful reading, and Chris Jones of Accuvent also reviewed the new chapters.

About the Lead Technical Reviewers, First Edition

Mario Puras is a Juniper Networks Systems Engineer Manager supporting major enterprise and state government accounts in the Atlantic region. He has more than 13 years experience in the networking industry and focuses on datacenters, enterprise mobility, and security solutions. He is JNCIP #119 and holds various other industry certifications. Prior to joining Juniper Networks, he served in the US Army and worked at Metrolink, Duro Communications, and Solunet Inc. He is grateful to his wife and best friend of 15 years, Stacy.

Jack W. Parks has more than 15 years experience in information technology, and he has worked in almost every position known in the realm of IT. Most recently he has focused on enterprise routing and switching, service provider routing, and MPLS and VPNs. He holds a B.S. in Business Information Systems from John Brown University and has received several industry certifications, including JNCIE-M #666 and CCIE#11685. After serving eight years in the US Air Force, Jack transitioned into the corporate world, working for service providers in the enterprise and ISP market spaces. Jack is currently a Juniper Systems Engineer based in Atlanta.

Preface

The world of enterprise routing with Juniper Networks devices is getting very exciting—new technologies, products, and network developments are making the enterprise network environment one of the most dynamic places to be. However, we, the authors, hope to focus that energy by providing you with a detailed and practical foundation that ensures effective use of the Junos operating system in your day-to-day job.

Juniper has rounded out its line of enterprise products to include not only routers but also switches and security devices, so drawing from our professional services experiences, this new edition provides you with design guidelines and comparisons of device capabilities. Our hope here is not to give you a single way to design a network but plenty of ideas that allow you to get the most from your network design, whatever it is.

Because we are also involved in the development and testing of certification exams, including those for enterprise routing, this book does double duty. It is both a field guide and a certification study guide. Readers who are interested in attaining a Juniper Networks certification level would be wise to note that we discuss and cover topics that are relevant to the official exams (hint, hint) and that the end of each chapter provides a listing of examination topics covered as well as a series of review questions that allow you to test your comprehension.

Regardless of one's certification plans, this one-of-a-kind book will not be obsolete just because you pass an exam. In fact, we wrote this material to serve as a useful field guide almost any time you log on to a Juniper Networks router. The extensive use of tutorials, samples of actual command output, and detailed theoretical coverage go well beyond any certification exam, to provide you with something that can't be tested—getting things to work the right way, and the first time. When plan A fails, the material also provides the steps needed to monitor network operation and quickly identify and resolve the root cause of malfunctions.

As trainers who deal with large numbers of both experienced and inexperienced users on a regular basis, we have seen it all. Within this guide, you will find the many pearls of our accumulated wisdom, any one of which can easily pay for this book many times over in increased network uptime and performance.

Some of our chapters tend to be on the longer side, simply because they are packed with detailed information regarding theory, configuration, and troubleshooting for each topic. Rather than create more chapters, we've included "soft breaks" and summaries within the chapters to identify boundaries in the material that afford a convenient place to take a breather, or as we often provide in our training classes, a "biology break and stretch." Dog-ear the pages, write notes in the margins, augment the topology illustrations with something more akin to your network—just remember that this is a beastly Junos book: part design guide, part exam, part training class, part knowledge base. It's meant to be used, abused, and put to work. There's a reason you're holding the best-selling Junos book of all time. Let's get going.

What Is Enterprise Routing?

After you've spent some time in the networking field, you tend to notice that there is rarely a single way to do things, and in many cases, rarely a single, precise definition for terms. After all, often a network engineer's best answer is "it depends." Such is the case with enterprise routing, so let's start off with a definition question: what is an enterprise network? Is it a large multinational network used by a manufacturing company; is it a government network supporting a state or a county; is it a regional network used by a parts distributor; or is it a network that supports your local dentist's office?

Of course, it's probably all of these, and many more. At a very high level, you can state that an enterprise network is one that is used to support activities as opposed to generating revenue, as in a service provider's network. Some might say that if someone pays you to access your network, you are providing a service to him and you're no longer an enterprise network. But that sweeping statement doesn't really apply if that someone is paying you to cover your costs to provide that service. So, as you can see, it depends.

Defining an enterprise network also manifests itself in how Juniper Networks defines its products within the enterprise world. On the one hand, Juniper designates certain hardware platforms as enterprise, but then many enterprise networks require density and throughput options from a platform listed as a service provider product. From the software side of things, the same issue arrives. Whereas a technology such as IPSec is used by all types of networks around the globe, is it used more by enterprise networks than by service provider networks? Some engineers would answer yes to that question, but then, you can't say that a service provider will never use IPSec.

From the perspective of hardware platforms, Juniper Networks has designated the following as enterprise products:

- J-series routers to include the J2320, J2350, J4350, and J6350
- M-series to include the 7i, M10i, and M120 routers
- MX Universal Edge routers to include the MX-80 and MX-240

- SRX Services Gateway to include the Branch Office and the Data Center models
- EX Ethernet switches to include the EX2200, EX2500, EX3200, EX4200, EX4500, and EX8200

However, larger enterprise networks might find platforms such as the M320 and MX960/480 very useful for their environments. In fact, the reverse is also true, in that a traditional service provider network might very well find an appropriate need and use for platforms designated as enterprise routers.

The good news in all this is that you have a well-thought-out operating system, because Junos has a single train of features that operates across all of the various routing platforms. So, whether you run an enterprise network or a service provider network, and regardless of your actual hardware platform, there is a single version of software code to load. Although this single code train has lots of hidden benefits, such as stability, ease of expandability, lower total operational costs, and more, what it really means is the ability to have the same base features available on all devices. So, from a learning perspective, we can talk about the software and its features without having to constantly caveat our discussion with "except for on this platform" or "only on these particular platforms." Although such exceptions do occur, and they result from hardware enhancements that are unique to a particular platform, these cases tend to be exceptions and are infrequent enough to remember.

Throughout this book, we will attempt to simplify the discussion by limiting ourselves to those services and features that are found on all devices in the Juniper enterprise lineup. We also focus on those topics that the vast majority of enterprise networks care about and actually use. We will also define an enterprise network as one that uses an Internet connection as opposed to a network that provides connectivity to the Internet as its sole function.

Juniper Networks Technical Certification Program (JNTCP)

This book is a study guide for the JNTCP Enterprise tracks. Use it to prepare and study for the JNCIA-Junos, JNCIS-ENT, JNCIP-ENT, and JNCIE-ENT certification exams. For the most current information on Juniper Networks' Enterprise certification tracks, visit the JNTCP website at *http://www.juniper.net/certification*.

How to Use This Book

Let's look at some specifics on how this book can help you. We'll talk about what we cover in the various chapters, how the book is laid out, and some resources to help you along the way. To start, let's discuss what you should know before you begin to read this book.

We are assuming a certain level of knowledge on the reader's part. This is important because we assume you are conversant in the following topic areas:

OSI model
: The Open Systems Interconnection (OSI) model defines seven different layers of technology: Physical, Data Link, Network, Transport, Session, Presentation, and Application. This model allows network engineers and network vendors to easily discuss and apply technology to a specific OSI level. This segmentation lets engineers divide the overall problem of getting one application to talk to another into discrete parts and more manageable sections. Each level has certain attributes that describe it and each level interacts with its neighboring levels in a very well defined manner.

Switches
: These devices operate at Layer 2 of the OSI model and use logical local addressing to move frames across a network. Devices in this category include Ethernet, Asynchronous Transfer Mode (ATM), and Frame Relay switches.

Routers
: These devices operate at Layer 3 of the OSI model and connect IP subnets to each other. Routers move packets across a network in a hop-by-hop fashion.

Ethernet
: These broadcast domains connect multiple hosts together on a common infrastructure. Hosts communicate with each other using Layer 2 media access control (MAC) addresses.

Point-to-point links
: These network segments are often thought of as WAN links in that they do not contain any end users. Often, these links are used to connect routers together in disparate geographical areas. Possible encapsulations used on these links include ATM, Frame Relay, Point-to-Point Protocol (PPP), and High-Level Data Link Control (HDLC).

IP addressing and subnetting
: Hosts using IP to communicate with each other use 32-bit addresses. Humans often use a dotted decimal format to represent this address. This address notation includes a network portion and a host portion, which is normally displayed as 192.168.1.1/24.

TCP and UDP
: These Layer 4 protocols define methods for communicating between hosts. The Transmission Control Protocol (TCP) provides for connection-oriented communications, whereas the User Datagram Protocol (UDP) uses a connectionless paradigm. Other benefits of using TCP include flow control, windowing/buffering, and explicit acknowledgments.

ICMP
: Network engineers use this protocol to troubleshoot and operate a network, as it is the core protocol used (on some platforms) by the ping and traceroute programs. In addition, the Internet Control Message Protocol (ICMP) is used to signal error and other messages between hosts in an IP-based network.

Junos CLI
: The command-line interface (CLI) used by Juniper Networks routers, which is the primary method for configuring, managing, and troubleshooting the router. Junos documentation covers the CLI in detail, and it is freely available on the Juniper Networks website.

What's in This Book?

The ultimate purpose of this book is to be the single most complete source for working knowledge related to Juniper Networks enterprise routing. Although you won't find much focus on actual packet formats and fields, topics for which there is already plentiful coverage on the Internet and in bookstores, you will find how to deploy Junos technology effectively in your network.

Here's a short summary of the chapters and what you'll find inside:

Chapter 1, *Junos in the Enterprise Network*
: This chapter provides an overview of the hardware and software architecture on Juniper enterprise routers, as well as an overview of the Junos CLI for both new and experienced users. It then provides a description of the Juniper enterprise devices, walking through the various model families and providing a brief definition of the services, capabilities, and usages of each device.

Chapter 2, *Enterprise Design*
: This chapter provides a set of design guidelines for the enterprise network. It presents the methodology for enterprise design and a series of network scenarios that illustrate the changes you can make to networks to improve their efficiency, security, and connectivity.

Chapter 3, *Juniper Switching and Routing Platforms*
: This chapter provides the usage recommendations for Juniper enterprise devices. Many devices offer overlapping features and capabilities, and this chapter looks at these capabilities and positions the devices within the enterprise network.

Chapter 4, *Interfaces*
: This chapter provides an overview of Junos interface organization. Then, it dives into some of the most common interface types and configurations seen in networks today. Finally, it concludes with a troubleshooting section with real-life scenarios seen every day.

Chapter 5, *Protocol Independent Properties and Routing Policy*
: This chapter provides a condensed but comprehensive overview of Junos Protocol Independent Properties (PIPs), such as static and aggregate route, and of the Junos routing policy, which is used to control route advertisement, redistribution, and attribute manipulation.

Chapter 6, *Interior Gateway Protocols and Migration Strategies*
: This chapter provides a detailed review of Interior Gateway Protocol (IGP) operation, and then focuses on multivendor deployments of the Routing Information Protocol (RIP) and Open Shortest Path First (OSPF). The material also focuses on IGP migration strategies and includes an EIGRP-to-OSPF migration case study.

Chapter 7, *Border Gateway Protocol and Enterprise Routing Policy*
: After providing a detailed review of what the Border Gateway Protocol (BGP) is and how it can benefit an enterprise, this chapter provides a series of case studies that build in complexity, starting with a single homed network with no Internal BGP (IBGP) speaker and ending with a multihomed-to-multiple-providers scenario, to include a redundant IBGP route reflection design that avoids running IBGP on all internal routers. The policy treatment is focused on practical enterprise routing goals, and it details both inbound and outbound policy, including autonomous system (AS) path regex matching and BGP attribute manipulation.

Chapter 8, *Access Security*
: This chapter provides an overview of a large variety of security concepts and the tools available to deploy them. These tools include user authentication and authorization, remote access, firewall filters, policers, Unicast Reverse Path Forwarding, the Simple Network Management Protocol (SNMP), and syslog.

Chapter 9, *Junos Layer 2 Services*
: This chapter provides an overview of the Layer 2 services that can be deployed on a Juniper Networks router. Layer 2 services include features such as link bundling, Generic Routing Encapsulation (GRE), and link aggregation.

Chapter 10, *Class of Service*
: This chapter provides an overview of IP class of service (CoS) and includes a detailed primer on IP DiffServ. The material then details the similarities and differences in CoS handling between the different platforms, which is a common source of confusion. A practical CoS case study serves as the foundation for CoS deployment and operational verification. The chapter also demonstrates the Virtual Channel CoS feature.

Chapter 11, *IP Multicast in the Enterprise*
: Multicast tends to see little deployment and is a common area of confusion. This chapter details IP multicast concepts, provides an overview of multicast protocols, and then demonstrates several Physical Interface Module (PIM) sparse mode scenarios, to include PIM sparse mode with static, bootstrap, and Anycast-RP. Through all the examples, practical verification and fault isolation steps are provided.

Chapter 12, *Junos Security Services*
: This chapter includes descriptions of the security services found in the J-series Services Routers and SRX Services Gateways. NAT, VPNs, UTM, and security policies are explained with configuration examples of each.

Appendix A, *Junos Layer 3 Services*
: This appendix covers the legacy Layer 3 service set as found on older Junos versions and the M-series devices, hence its appendix status. NAT, IPSec VPNs, and stateful filters are covered, as well as configuration examples for each. This appendix also covers interface and next-hop service sets, with a comparison of where each should be used.

Appendix B, *Upgrading Junos*
: This appendix covers the methods that are available for upgrading a Junos device to a newer version of the operating system. Storage cleanup methods and memory extension capabilities are covered, and examples are provided for maximizing a device's flash memory.

In addition, you can also use this book to attain one of the Juniper Networks certification levels related to enterprise routing. To that end, each chapter includes a set of review questions and exam topics that have been covered, all designed to get you thinking about what you've just read and digested. If you're not in the certification mode, the questions will provide a mechanism for critical thinking, potentially prompting you to locate other resources to further your knowledge.

Topology of This Book

Figure P-1 displays this book's routing topology, which appears beginning in Chapter 4. It consists of 11 J-series routers running version 10.4R1.9 and 2 Cisco routers running IOS Release 12.3(15b). The Cisco routers are primarily employed in Chapter 6, where they are used for both RIP interoperability and as part of an EIGRP-to-OSPF migration exercise. The topology uses only Gigabit Ethernet and T1 interfaces; however, other interface types are examined in Chapter 4. You might recognize the hostnames of the routers, which all relate to a beverage that was created more than 7,000 years ago (with evidence to consumption) in Mesopotamia. The names are chosen due to the international appeal of the resultant product and for its food value only, as beer is an excellent way to preserve the nutritional value of grain.

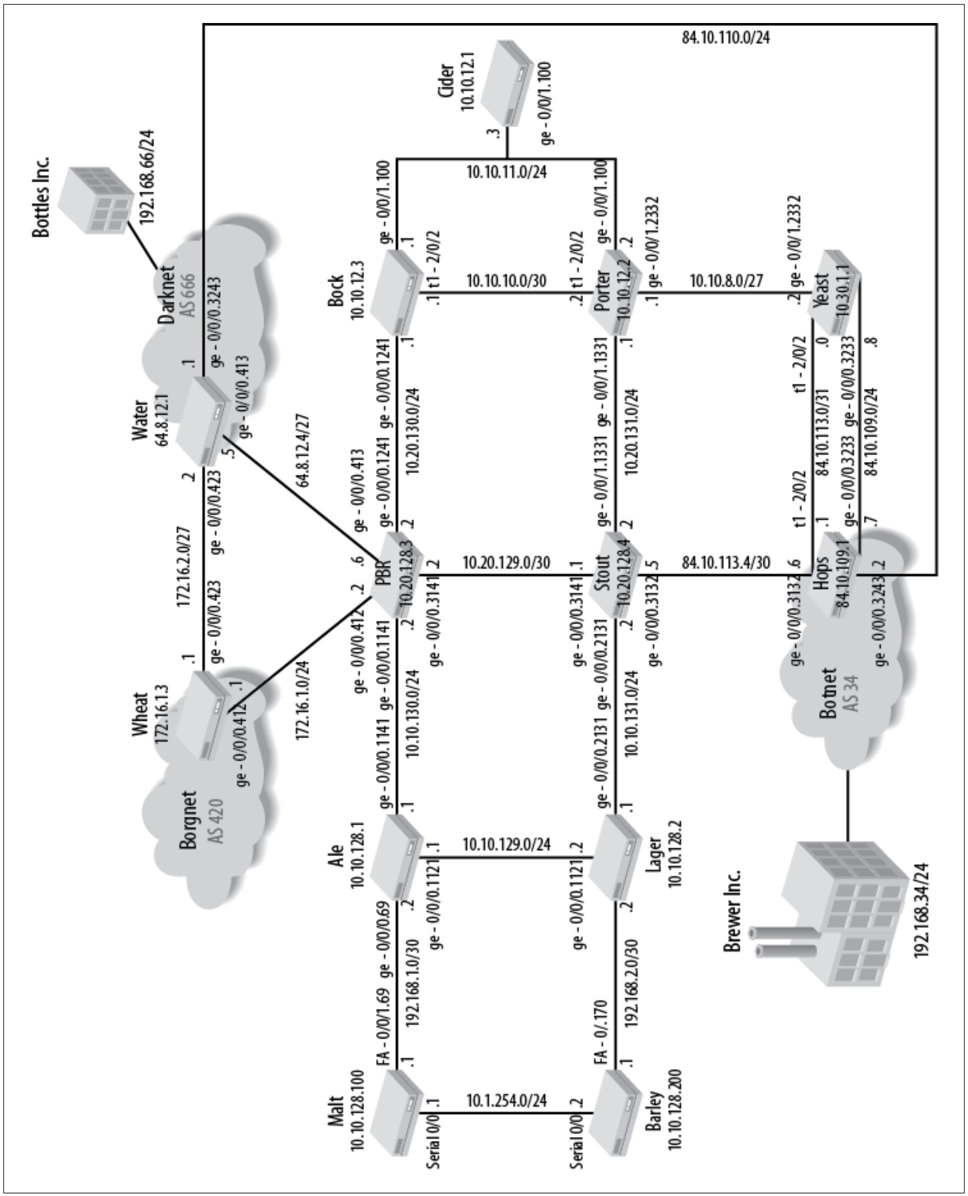

Figure P-1. This book's topology

Conventions Used in This Book

The following typographical conventions are used in this book:

Italic
: Indicates new terms, URLs, email addresses, filenames, file extensions, pathnames, directories, and Unix utilities

`Constant width`
: Indicates commands, options, switches, variables, attributes, keys, functions, types, classes, namespaces, methods, modules, properties, parameters, values, objects, events, event handlers, XML tags, HTML tags, macros, the contents of files, and the output from commands

`Constant width bold`
: Shows commands and other text that should be typed literally by the user, as well as important lines of code

`Constant width italic`
: Shows text that should be replaced with user-supplied values

This icon signifies a tip, suggestion, or general note.

This icon indicates a warning or caution.

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Please address comments and questions concerning this book to the publisher:

O'Reilly Media, Inc.
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Acknowledgments

From the First Edition

The authors would like to gratefully and enthusiastically acknowledge the work of many professionals who assisted us in the development of the material for this book. Although our names are printed on the book as authors, in reality no author works alone. The contributions of many people have made this book possible, and others have assisted us with their technical accuracy, typographical excellence, and editorial inspiration.

Many thanks are owed to the official technical editors of this material. Mario and Jack were extremely responsive to the demanding needs of our schedule. Your attention to detail and wealth of knowledge no doubt saved us many an embarrassing bit of errata. To this end, we also thank Colleen Gorman for her fine developmental editing, and Audrey Doyle for her thorough copyediting, which resulted in a much-improved experience for you, the reader.

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From Doug Marschke

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From Harry Reynolds

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For the Second Edition

From Doug Marschke and Harry Reynolds

Welcome to the updated version of *Junos Enterprise Routing*! Much has changed in Junos since we wrote the first edition of this book, mostly related to the J-series and SRX devices moving from packet-based to flow-based devices. This adds many changes in the security features of the devices, but because our book is still titled "routing," we left the new security aspects to the *Junos Security* book recently published by O'Reilly. We did keep in legacy services as an appendix since these are still relevant to MX and M devices.

We really would like to thank Peter Southwick for taking the time to revise and update this book. He did the majority of the update, with us just keeping a watchful eye and adding to each chapter when we could. We have to say that he did quite an amazing job!

Enjoy the new edition, and keep on becoming Junofied.

From Peter Southwick

The authors acknowledge with great praise the work of the professionals who assisted us in developing the material for this book. We are engineers and actually do fall into the stereotype of that group, and so the editorial cleanup, formatting, and graphical conformity are all performed by people not listed as authors. It is they who deserve the acknowledgments.

We are grateful to Mike Loukides, senior O'Reilly editor, who was responsive to our availability and understanding of our sporadic schedules. His technical expertise and attention to detail made this experience better than the individual contributions of us authors. We also thank Genevieve d'Entremont for her copyediting and Robert

Romano for his artwork; their contributions have made this a better experience for you, the reader.

Again we acknowledge the contributions of Juniper Networks in general, for the assistance provided on various fronts, and specifically Chris Jones and Rob Cameron for their technical reviews of the new material in this edition.

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Finally, I offer heartfelt thanks to my family—Michele, my patient and loving wife, and Gabriella and Victoria, the two best daughters in the world—for their understanding during this project. My professional services role takes me away from my family for a good part of the year, and this project demanded that I be "away" even when I was home. Girls, thank you for understanding and supporting me. Without you, I would never be able to do this.

CHAPTER 1

Junos in the Enterprise Network

The Junos operating system is the common element in Juniper enterprise platforms. It enables the features and capabilities that distinguish the Juniper Networks line of equipment from others in the enterprise space. The flexibility of this standards-based operating system provides a robust foundation onto which multiple platforms have been built. The modular nature of the operating system allows it to support any number of specialized capabilities such as switching, security, and, of course, routing platforms. The devices can be used at the enterprise edge, the core, as firewalls, or as access devices. A central theme for all of these devices is their routing capability, which is not surprising given the origins of Juniper Networks.

This chapter takes a brief look at the devices that are found in the enterprise network and that run the Junos operating system. So much has changed since the first edition of this book that Junos in the enterprise needs its own introductory chapter.

Introduction to Junos Enterprise Routing

When the founding engineers of Juniper decided to create routers, they took the view of forwarding packets as quickly as possible (line rate) with services enabled, which spawned the marketing decree "Service without Compromise."

All Juniper Networks devices that run on the Junos operating system share the same common design philosophy, which is to have a clean separation of the control and forwarding planes. In the high-end devices (for example, M-series routers, MX edge devices, and Data Center SRXs), this separation is created in hardware, whereas the other devices (J-series routers and Branch Office SRXs) maintain this division in software. The forwarding plane is referred to as the Packet Forwarding Engine (PFE), and the control plane is called the Routing Engine (RE).

The RE's primary functions are to manage the PFE, control the device's software (Junos operating system), manage the command-line interface (CLI), provide troubleshooting tools, and maintain the route tables (both the route table and the route forwarding table). The forwarding table, a subset of the route table, is passed down to the PFE and is used to forward traffic. In this way, the RE never has to be directly involved in packet forwarding, which allows more resources for the actual control functions (see Figure 1-1). One example of the benefits of separating the control and forwarding functions is the ability to issue "traceoptions" commands (similar to debug) without degrading the throughput performance of the router.

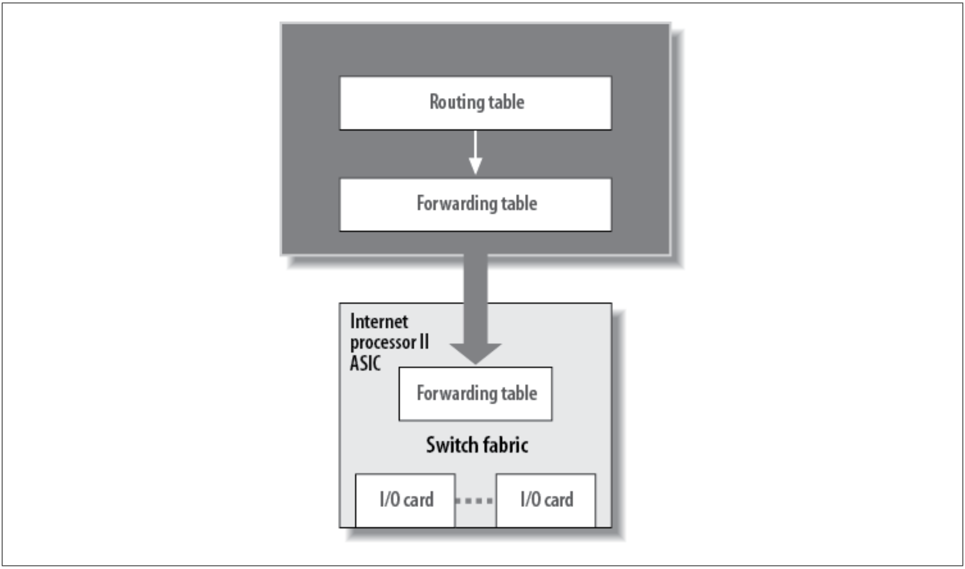


Figure 1-1. Juniper's architecture design philosophy

Junos Overview

Junos is pretty cool once you understand it. It creeps up on you, especially if you're coming from another vendor or from Cisco IOS. That's because the designers of Junos put tremendous thought into making a stable, robust, and scalable operating system for networking devices. They were able to learn from previous vendors' mistakes and created an operating system that other companies will forever use as their model.

The core philosophy of Junos was to create a modular and stable operating system. The modularization was created by the use of software daemons, and the stability was achieved by choosing a well-known, open source, and stable kernel of FreeBSD. This kernel is usually hidden from the user, but many features of FreeBSD have been ported to the command line of Junos.

The kernel also maintains the forwarding table synchronization between the RE and the PFE.

Riding on top of the kernel are all the fully independent software processes for routing, CLI, interfaces, and so forth. Figure 1-2 shows a small subset of these processes; you can show a complete list in the device by issuing the `show system processes` command.

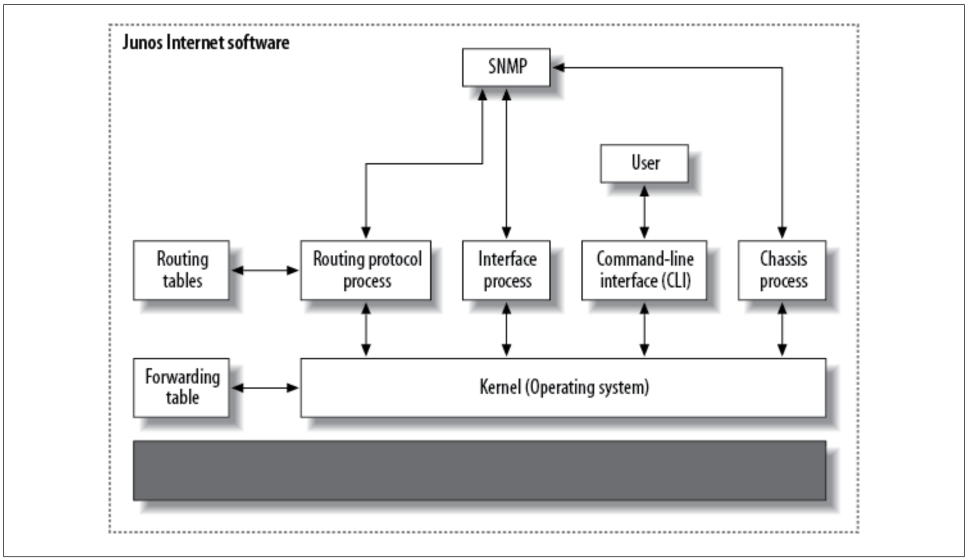
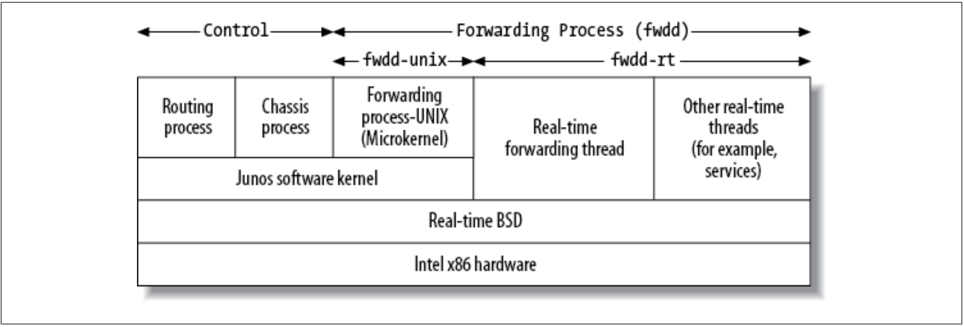


Figure 1-2. Junos software architecture

These processes are fully independent, so a failure of one process does not affect the other. For example, Figure 1-2 shows the Simple Network Management Protocol (SNMP) process pulling information from the interface, chassis, and routing processes. If this SNMP process fails or contains a software bug, it affects only this process and not the others. This is a major shift from other routing vendors that operated monolithic code where one change in the interface code could affect just about anything without reason.

Every Juniper Networks device running Junos is created from the same code base. Since all devices do not share common hardware, a new image has to be created for each device type. This is still Junos, however, with the same base feature set across all devices (routing, CLI, services, etc.). This means that there is a single image per version for all M/T-series devices and all MX edge devices, regardless of model number, and a single image per version for all J-series routers. The exception for image release is for the EX and SRX devices. There is an image for each of the EX models, and the SRXs have three individual images. The days of creating and maintaining large spreadsheets or lists for each router are now gone.

The differences in architecture between the M-series routers and the J-series routers show one of the reasons for the separation from a single image. The major difference in the J-series image is the inclusion of a software process called *fwdd* (forwarding devices daemon), which acts as the virtualized PFE. It is essentially a series of real-time threads operating over the kernel, as shown in Figure 1-3. Instead of an application-specific integrated circuit (ASIC) providing the functionality of the PFE, sockets and APIs interface with the kernel, providing a deterministic performance.



Control
Forwarding Process (fwdd)
fwdd-unix
fwdd-rt
Routing process
Chassis process
Forwarding process-UNIX (Microkernel)
Real-time forwarding thread
Other real-time threads (for example, services)
Junos software kernel
Real-time BSD
Intel x86 hardware

Figure 1-3. J-series software architecture

Junos Releases

One of the key advantages of Junos is the single release train. This release train offers administrators of Juniper Network devices a predictable schedule for network upgrades. The release train follows a strict calendar for initial release, end of engineering support, and end of life. Table 1-1 is an excerpt from the Juniper Networks website.

Table 1-1. Junos release support

Product	FRS date	EOE	End of Life (EOL)
Junos 10.4	12/08/2010	12/08/2013	06/08/2014
Junos 10.3	08/15/2010	05/15/2011	11/15/2011
Junos 10.2	05/15/2010	02/15/2011	08/15/2011
Junos 10.1	02/15/2010	11/15/2010	05/15/2011
Junos 10.0	11/15/2009	11/15/2012	05/15/2013
Junos 9.6	08/06/2009	05/06/2010	11/06/2010
Junos 9.5	04/14/2009	02/15/2010	08/15/2010
Junos 9.4	02/11/2009	11/11/2009	05/11/2010
Junos 9.3	11/14/2008	11/14/2011	05/14/2012
Junos 9.2	08/12/2008	05/12/2009	11/12/2009
Junos 9.1	04/28/2008	01/28/2009	07/28/2009
Junos 9.0	02/15/2008	11/15/2008	05/15/2009

The first released shipments (FRS) are offered on a quarterly basis throughout the year. With each version of an image, there are releases and builds. The full naming convention for Junos releases is given in Figure 1-4.

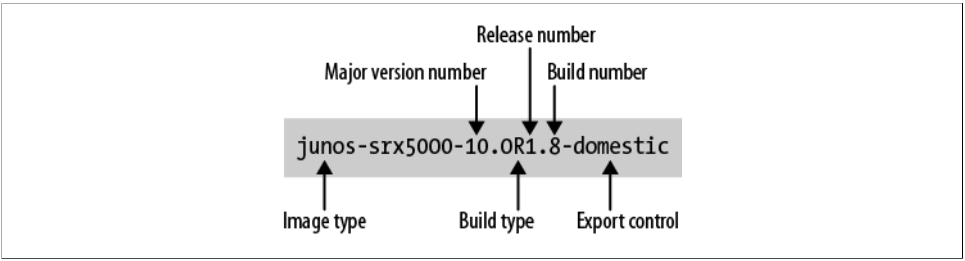


Figure 1-4. Junos image naming convention

Once a new version of Junos is issued, it undergoes multiple maintenance releases (for example, 10.0R1.8, 10.0R2.5, and 10.0R3.1). For any version, Juniper Networks recommends the latest maintenance release for a device, and the website provides a list of recommended releases for various equipment.

Juniper recognizes three levels of support for a Junos version:

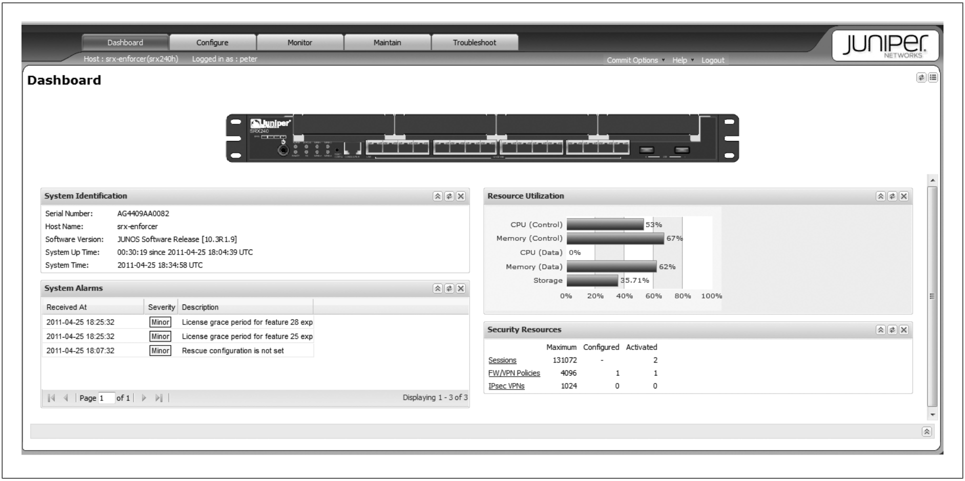
End of Engineering (EOE)
: Active engineering support is provided during the period covering the current version and the next two versions, or 18 months from the first released shipment. Because the versions are released on a quarterly basis, active support is typically available for 9 months after first release shipment, which essentially means that no further maintenance releases are created for the version after this date.

Juniper Technical Assistance Center (JTAC)
: JTAC provides troubleshooting and workaround support for identified problems in a version from the time that EOE begins until two further versions are released or up to an additional year.

End of Life (EOL)
: Once EOL is reached for a version, JTAC typically requests that the customer update his or her image. If support is still requested, it is provided on a "commercially reasonable effort basis."

To assist customers who see no need to upgrade Junos on a regular basis, Juniper Networks has created what is called a Junos Extended End of Life (EEOL) release. These versions, which provide additional time for engineering and JTAC support, are released in the fourth quarter. EEOLs provide three years of engineering support and an additional six months of JTAC support.

In addition to the first shipment releases and the maintenance releases, Juniper also provides service and incident releases. These releases are not for general distribution, but might be recommended by an engineer or JTAC to solve specific problems. Service releases (for example, *jinstall-ex-4200-10.0S6.1-domestic*) are created to address specific problems found in an image and span the time between builds. Internal releases



System Identification

Serial Number:	AG4409AA0082
Host Name:	srx-enforcer
Software Version:	JUNOS Software Release [10.3R1.9]
System Up Time:	00:30:19 since 2011-04-25 18:04:39 UTC
System Time:	2011-04-25 18:34:58 UTC

System Alarms

Received At	Severity	Description
2011-04-25 18:25:32	Minor	License grace period for feature 28 exp
2011-04-25 18:25:32	Minor	License grace period for feature 25 exp
2011-04-25 18:07:32	Minor	Rescue configuration is not set

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CPU (Control)	53%
Memory (Control)	67%
CPU (Data)	0%
Memory (Data)	62%
Storage	35.71%

	Maximum	Configured	Activated
Sessions	131072	-	2
FW/VPN Policies	4096	1	1
IPsec VPNs	1024	0	0

Figure 1-5. J-Web

(for example, *junos-srx5000-10.1I20100513_0739_schung-domestic*) are often troubleshooting tools created by Juniper Network engineering when investigating a problem and trying different fixes. The problems solved by service and internal releases are incorporated into the next general release builds.

According to some Juniper forums, service (S) releases are the recommended releases for specific devices deployed in certain scenarios. Until the newer versions of Junos are tested and verified, these network engineers are more comfortable with the S release.

CLI Review

The tool that will most often be used to configure and troubleshoot Juniper devices is the command-line interface (CLI). The Junos software CLI is one of the most user-friendly and feature-rich in the industry. Most administrators spend years attempting to master other router vendors' CLIs, whereas Junos software can be mastered in just a few hours.

Other configuration methods do exist, such as a web GUI called J-Web (see Figure 1-5), which is available on all Juniper devices. The J-Web is enabled by default on most enterprise devices and can be activated for all devices. It's a robust way of monitoring and configuring your devices, and it even has a point-and-click CLI component. Note that the operation of J-Web is beyond the scope of this book, so all configuration examples are shown via CLI commands instead. Learn the CLI first, and the J-Web is a snap to implement.

General CLI features

The CLI has two modes: operational and configuration. Operational mode is where you can troubleshoot and monitor the software, router, and network. Configuration mode is where the actual statements for interfaces, routing protocols, and others are placed.

Every command that can be run in operational mode can also be used in configuration mode with the additional keyword `run`. For example, if the `show route` command is issued in operational mode, it can be issued as `run show route` in configuration mode.

When a user first enters the router via Telnet, Secure Shell (SSH), or direct console access, the user sees a login prompt. After entering the correct username and password, the user is placed directly into the operational mode. Operational mode is designated by the `>` (chevron) character at the device prompt of *`username@hostname`*. As shown here, user `doug` logs into a router called `Hops`:

```
Hops (ttyd0)
login: doug
Password:
--- Junos 10.4R1.9 built 2010-12-08 16:25:40 UTC
doug@Hops>
```

An exception to this automatic placement into operational mode occurs when you log in as user `root`. In this case, you are placed into the shell (designated by the percent sign) and will have to start the CLI process manually:

```
Hops (ttyd0) login: root
Password:
--- Junos 10.4R1.9 built 2010-12-08 09:22:36 UTC
root@Hops% cli
root@Hops>
```

Most of the commands that you run in operational mode are show commands, which allow you to gather information about the routing protocols, interfaces, and the device's software and hardware. Ping, traceroute, telnet, and ssh can also be performed from this mode. Finally, some very Junos-specific commands, such as `request`, `restart`, and `test`, can be issued. Request commands perform system-wide functions such as rebooting, upgrading, and shutting down the device. Restart commands are similar to the Unix-style kill commands, which allow you to restart certain software processes. Test commands allow verifications for saved configuration files, proactive testing of policies, and interface testing methods such as BERT (bit error rate testing) and FEAC (far-end alarm and control) loopbacks.

You should use the `restart` command with great caution! Depending on the software process being restarted, the consequences could be severe. Restarting the SNMP process would probably get you a slap on the wrist, but restarting the routing process could be a reason to go into hiding on a remote island!

To actually configure the Junos device, enter configuration mode by typing the word `configure` in operational mode. The device prompt changes to the octothorpe (#) symbol:

```
doug@Hops> configure
Entering configuration mode
[edit]
doug@Hops#
```

By default, multiple users can enter the configuration mode on a device and make changes at the same time. To avoid any issues that may arise, you can use the `configure exclusive` or `configure private` command. The former command allows only a single user to configure the router, whereas the latter command allows multiple users to change different pieces of the configuration. If you use `configure exclusive`, no other users can make changes to the configuration besides the single user who entered exclusively. Using private mode, each user will get a copy of the current configuration and only the changes that they make will be applied. If two users attempt to make the same change, such as adding an IP address to the same interface, the change is rejected and both users will exit configuration mode to resolve their conflict by some other means.

In configuration mode, you can add configuration by using a `set` command. For example, to enable the Telnet server application on the device, issue this command:

```
doug@Hops# set system services telnet
```

Other useful commands in the configuration mode are:

`delete`
: Opposite of the `set` command, this subtracts configuration items:

```
    doug@Hops# delete system services telnet
```

`replace pattern`
: Performs an exact match and replace for a string in the configuration:

```
    doug@Hops# replace pattern 10.1.1.1/32 with 10.1.1.1/24
```

`insert`
: In a configured list (rules or policies), allows an item to be moved from the bottom of the list to a different position:

```
    doug@Hops# insert policy permit_all before policy deny_all
```

`save`
: Writes the configuration to a file named in the command:

```
doug@Hops# save test_configuration
```

`edit`
: Moves the user to a different level of the configuration:

```
[edit]
doug@Hops# edit system services
[edit system services]
doug@Hops#
```

`exit`
: Moves the user to the next level up in the configuration (a user can also use the `up` command), or if the user is at the top of the configuration, it will put the user into operational mode:

```
[edit system services]
doug@Hops# exit
[edit system]
doug@Hops# up
[edit]
doug@Hops# exit
doug@Hops>
```

`rename`
: Assigns a new name to a configured object:

```
doug@Hops# rename interface ge-0/0/1 to interface ge-10/0/1
```

`copy`
: Copies the attributes of a configured object to another object:

```
doug@Hops# copy interface ge-0/0/1 to ge-0/0/2
```

`commit`
: Performs a semantic and completeness check of the changes made to the configuration, and if the changes pass these checks, the changes are written to the device's running configuration:

```
doug@Hops# commit
```

A full treatment of the capabilities and operation of the CLI is beyond the scope of this book, as mentioned in the Preface, but the operational capabilities of the CLI are explored throughout this book by building and showing hundreds of examples.

Routing Features

Let's continue our tour of Junos in the enterprise with the routing features found in most Junos-based devices, keeping in mind that many of the details of these features and example configurations are found in later chapters.

The first product produced by Juniper Networks was an IP router, and since that initial launch, all Juniper Networks products based on Junos have had routing capabilities at their core.

The principles for routing transit traffic are handled in the same way in all devices:

1. The routing functions are divided between the RE and the PFE.
2. The RE is responsible for determining the best route to a prefix.
3. This information is passed to the PFE.
4. All transit traffic is handled by the PFE.
5. When the RE determines that the conditions in the network have changed enough to warrant a change in packet routing, a new set of instructions is forwarded to the PFE.

The network prefixes and the routes to them are kept in a set of tables stored in the RE and the PFE. Chapter 5 explores the full set of routing tables and the use for each, so here the focus is only on the table that is used for IPv4 traffic. This table is called the *inet.0 table*, and it contains a list of all known network prefixes and the attributes for each prefix. The attributes maintained for a prefix are determined by the way that prefix was learned by the device. So if a prefix was entered as a static route, only the information that was manually entered would be stored with the prefix, or if the route was learned via a routing protocol (e.g., OSPF), the additional information associated with the prefix would be stored with the route. The inet.0 table is also referred to as the *master routing table* when this table is identified from another table for static routes. The following shows example output of an inet.0 table:

```
doug@Hops> show route
inet.0: 23 destinations, 23 routes (22 active, 0 holddown, 1 hidden)
+ = Active Route, - = Last Active, * = Both
1.12.1.0/24                *[Direct/0] 00:33:41
                                    > via ge-1/0/0.0
1.12.1.1/32                *[Local/0] 00:33:41
                                    Local via ge-1/0/0.0
10.255.66.0/24          *[OSPF/10] 00:32:53, metric 1
                                    > to 1.12.1.2 via ge-1/0/0.0
192.168.102.0/23      *[Static/5] 5d 02:42:28
                                    > to 192.168.71.254 via ge-1/0/0.0
```

This table has been reduced in size, but it shows that the device knows four prefixes. The prefix 1.12.1.0/24 is a directly connected network on interface ge-1/0/0.0, the interface ge-1/0/0.0 has an address of 1.12.1.1/32, prefix 10.255.66.0/24 was learned via OSPF from another device connected via interface ge-1/0/0.0, and the prefix 192.168.102.0/23 was statically added to the configuration.

The entries in the inet.0 table are analyzed, and the active routes (all the routes in the preceding example are active, as indicated by the *) are sent to the forwarding table. The forwarding table is then sent to the PFE (refer to Figure 1-1). The forwarding table does not contain the prefix attributes that are contained in the inet.0 table, just the key elements for how to handle traffic destined for a network prefix. The following shows an example forwarding table entry:

```
doug@Hops> show route forwarding-table destination 10.255.66.1
Routing table: inet
Internet:
Destination        Type RtRef Next hop       Type Index NhRef Netif
10.255.66.0/24    user     0 1.12.1.2        ucst   286     2 ge-1/0/.0
```

The determination of which routes are sent to the forwarding table from the routing table follows a simple rule: *the route must be the active route with the lowest cost and route preference*. If a single prefix has multiple routes that have equal costs and preferences, one of the next hop interfaces is chosen in a pseudorandom manner (the exception to this is equal cost routing, explained in the next section).

Once this process is complete and all prefixes are loaded in the PFE, transit traffic can be handled. The destination address from an incoming packet is compared to the forwarding table, looking for the longest match. Once a match is found, the next hop and interface information are used to handle the egress processing for the packet. If no match is found for the destination address and no default route is established for the device, the packet is dropped.

Routing modifiers

The determination of which route gets sent to the forwarding table can be manipulated by other parts of the configuration. Most attributes of a prefix entry can be modified by policies and rules. These configurable features allow an administrator to customize how traffic is handled within the device.

Route policies can be applied as routes enter the routing table (import) or as routes are sent to neighbors (export). The policies can accept or reject routes, and for accepted routes, the attributes of the routes can be modified. When prefixes are learned by one routing protocol (for example, BGP) and wish to be advertised in another (say, OSPF)—a process known as route redistribution—a routing policy is used. If routes learned from one source are to be preferred to routes learned from another source, again, policies can be used to accomplish this. Full treatment of routing policies is found in Chapter 5.

Filter-based forwarding, which is similar to what other vendors call policy-based routing, allows incoming (ingress) or outgoing (egress) traffic to be compared to a set of match criteria defined in a filter. When the traffic matches the filter, the action defined in that filter area is applied to that packet. One such action would be routing the packet based on the rules of a nondefault routing table, allowing scenarios to be created where matching traffic is routed over a different set of next hops/links based on local policy rather than conventional longest match. In a simplistic example, privately addressed traffic can be sent to a private.inet.0 table where a default route shunts them to a specific next hop or server, while public addresses can be sent to the default inet.0 routing table.

Load balancing, or equal cost multipath (ECMP) routing, is turned off by default on Juniper devices. The default routing mechanism chooses a single next hop destination for every prefix, but load balancing can be configured on the devices and can be set either as a global feature for all traffic on the device or for specific traffic. The load-balancing algorithm uses a hash function to determine the link to use for traffic. The load balancing is on a per-flow basis and is calculated based on a configurable Layer 3 and/or Layer 4 hash. A configuration example for ECMP and a full explanation can be found in Chapter 5.

Multitopology routing enables the router to participate in an environment that has different routing rules for different traffic types. It uses the concepts of filter-based forwarding with configured topologies. The topologies create different forwarding information bases (FIBs) for each traffic type. Each FIB can use a different instance of a routing protocol as well as different attributes (costs and preferences) for prefixes. When traffic enters the device, the filter-based forwarding allocates the traffic to a specific FIB. The information in that FIB is used to route the traffic. This capability, when deployed across an enterprise network, allows a single network infrastructure to support multiple traffic types on logically separate networks. Configuration examples for multitopology routing and a full explanation of its capabilities are discussed in Chapter 6.

Switching Features

Let's quickly define some of the more common switching features found in Junos devices. While the full details of these features and configuration examples are beyond the scope of this book, its companion volume, *Junos Enterprise Switching*, by Harry Reynolds and Doug Marschke (O'Reilly), is an excellent resource for both the administrator and the network designer.

The design of an enterprise network requires the use of routing, switching, and security devices. When Juniper decided to enter the enterprise market, it did so with the determination that these other networking requirements would be added to Junos. Today, Ethernet switching is a feature for the EX product line, the MX product, and the SRX product line. All of these products offer both Ethernet switching capabilities and IP routing capabilities in a single device.

The choice between switching and routing is dependent on the nature of the traffic and the device's configuration. For the most part, when both switching and routing are present, the device routes traffic that is addressed (at the MAC layer) to it and switches all other traffic. Switching features are configured in different devices in different manners. For instance, in the high-end Data Center SRXs, switching is enabled in what is called *transparent mode*, whereas in the Branch Office SRX and EX switches, specifying the `Ethernet-switching` family on an interface enables switching.

Let's look at some of the switching features you'll likely encounter in enterprise networks.

Transparent mode is enabled for the high-end Data Center SRX Series Services Gateways (SRX 3xxx and 5xxx) via configuration mode and allows interfaces to operate in an Ethernet switch mode. The device can be configured to support both routed interfaces and switched interfaces. Transparent mode devices support options for flooding unknown MAC addresses, bridge domains (broadcast domains), and virtual LANs. The full capabilities of transparent mode can best be discovered in the book *Junos Security*, by Rob Cameron et al. (O'Reilly).

Learning MAC addresses is the means by which all Ethernet switching devices determine where to switch frames in a network. The size of the switching table is a measure of the power of the switching devices, and the Juniper switches support table sizes from 8,000 entries for the low-end EX2200 to 160,000 entries for the enterprise-level EX8200 (the MX edge routers are capable of having a million MAC addresses). When a frame is received that contains a destination MAC that is not in the forwarding table, that frame is flooded to all the interfaces of the specific bridge domain on the switch. Juniper switches support two flooding options for unknown traffic: conventional flooding and the more secure address resolution protocol (ARP) flooding capability.

Virtual switch constructs allow single Ethernet switches to support multiple logical divisions in an enterprise. These constructs include:

Bridge domain
: A bridge domain is defined by a virtual LAN (VLAN) and a group of interfaces that form a broadcast domain for Ethernet traffic. Multiple bridge domains can be created on a single platform, providing for a separation of traffic.

VLAN
: A VLAN allows traffic from a common community of interest to communicate in an Ethernet-switched environment. VLANs segment the traffic and provide security from other VLANs.

Virtual chassis
: A virtual chassis allows the interconnection of multiple physical switches to form a single administered unit. The individual switches act as a routing engine, a backup routing engine, or a line card in the grouping of switches.

Ethernet protocols govern the interaction of Ethernet switches in an enterprise network. They allow redundancy while avoiding broadcast storms, thereby bringing survivability to an Ethernet environment. The protocols supported by Juniper Networks switches running Junos are:

Spanning Tree
: Spanning Tree Protocol (STP) and its variations, RSTP and MSTP, operate between Ethernet switches to ensure a loop-free network. Multiple Spanning Tree Protocol (MSTP) incorporates the concepts of VLANs into the protocol, whereas Rapid Spanning Tree Protocol (RSTP) operates on a single VLAN but improves the time to recover from a network failure.

Link Aggregation
: Link Aggregation Control Protocol (LACP) and 802.3ad provide link aggregation capabilities for devices. Up to 16 links can be bound into a single bundle. This provides a high-bandwidth, survivable link between devices. Link aggregation also supports a MAC hashing function to support load balancing, which assures that traffic in a single flow follows the same link in the 802.3ad bundle.

Ethernet switching also supports a number of other capabilities on the Junos platforms, such as multicast support and 802.1X port-based authentication.

Security Features

Let's briefly cover the security features found in Junos-based devices, keeping in mind that the full details of these features and configuration examples are beyond the scope of this book. For in-depth coverage, seek out *Junos Security*.

Starting in the mid-9 release of Junos, SRX devices and J-series routers incorporated session-based processing, which is the single unique feature in the SRX Series devices.

> For the J-series routers, Junos 9.3 incorporated the first of these security features, and 9.4 offered no packet-based option for the J-series. For the Data Center SRXs, Junos 9.2 was the first flow-based offering, whereas Junos 9.4 was the first flow-based offering for the Branch Office SRXs.

Rather than processing each packet as an independent entity, packets are grouped together in unidirectional flows, and flows are paired into a session. Consequently, a majority of the processing is performed at the session level rather than the packet level. Once a session is created and additional packets are received that match the session parameters, the session attributes are used to handle the packet.

Session-based processing enables these security features found in Junos:

Security zones
: A security zone is a set of interfaces and the addresses found on those interfaces that are grouped together as a single security element. All security policies are written *from* a security zone *to* a security zone.

Stateful security policies
: Junos-based security devices are prudent security devices, starting with the fact that all traffic through the device is blocked unless explicitly permitted. Security policies are created to determine what traffic is allowed and what should be blocked. The match criteria for traffic are the source and destination addresses and the application-level identification found in the traffic. Policies are unidirectional at the session level. They are defined for sessions that are initiated from a single zone destined for a zone. Reverse traffic that is associated with the session does not

need a reverse policy, but sessions that follow the reverse path do need a policy matching the session's direction.

Application layer gateways (ALGs)
: ALGs provide proxy support for certain applications, allowing the proper operation of applications that would not operate successfully through a firewall. One example of such an application layer protocol is the session initiation protocol (SIP) used in voice over IP (VoIP) implementations. When used in a secured scenario, SIP requires a firewall to parse its messages and perform actions on behalf of the SIP server and client. These actions could include network address translation, opening additional ports through the firewall, and providing proxy services. The services are all performed by the ALG defined for SIP. ALG support is enabled by default on Junos-related security products, except for the Data Center SRXs.

Network Address Translation (NAT)
: One of the most common security features, NAT allows an administrator to hide the inside of the enterprise network from prying eyes. The Junos-based security systems support dynamic and static NAT, as well as source-based and destination-based NAT.

Intrusion Detection and Protection (IDP)
: IDP is a sophisticated security feature that relies on attack signatures and observation of enterprise traffic. Junos security devices can perform either a passive alarm-only role or an active alarm and deter role. The IDP features require an administrator to monitor the state of the signature database and tune the IDP rules to the traffic that is seen on the enterprise. IDP features are integrated into the SRX product line or can be deployed in purpose-built IDP devices.

User authentication
: User authentication and user access control enable a Junos security device to activate rules based on the users that are creating traffic. Teaming Juniper network access control devices with the Junos security devices creates a dynamic pair for recognizing users and modifying the security policies to accommodate these users.

Virtual private networks (VPN)
: IPsec VPNs are a mainstay for site-to-site and remote access security. They provide encryption and authentication services as well as data integrity capabilities for the transmitted traffic. The Junos security devices offer a full range of IPsec VPN capabilities.

Screen functions
: When the full capabilities of IDP are not warranted, the screen functions can be considered an IDP-lite capability. These attack-deterrent functions protect the device from common hacks and denial of service attacks. They are implemented at the zone level and provide a first line of defense.

Unified Threat Management (UTM)
: UTM is a set of security features that includes anti-virus protection, anti-spam filtering, URL filtering, content filtering, and user authentication. These services are available on the J-series routers and the lower-end Branch Office SRX Series.

When session-based processing was introduced into Junos, a new traffic-processing algorithm was needed because the existing packet-based processing performed in hardware would not suffice for this new paradigm. Figure 1-6 shows the order for processing traffic in a session-based environment. Class of Service (CoS) and filter functions are performed first and last at the line card level. For incoming traffic, session matching is performed next. If an existing session is found for the traffic, "fast path" processing is performed based on the attributes of the session. In the fast path, screen functions are performed, NAT and ALGs complete their actions, and the traffic is sent for egress processing.

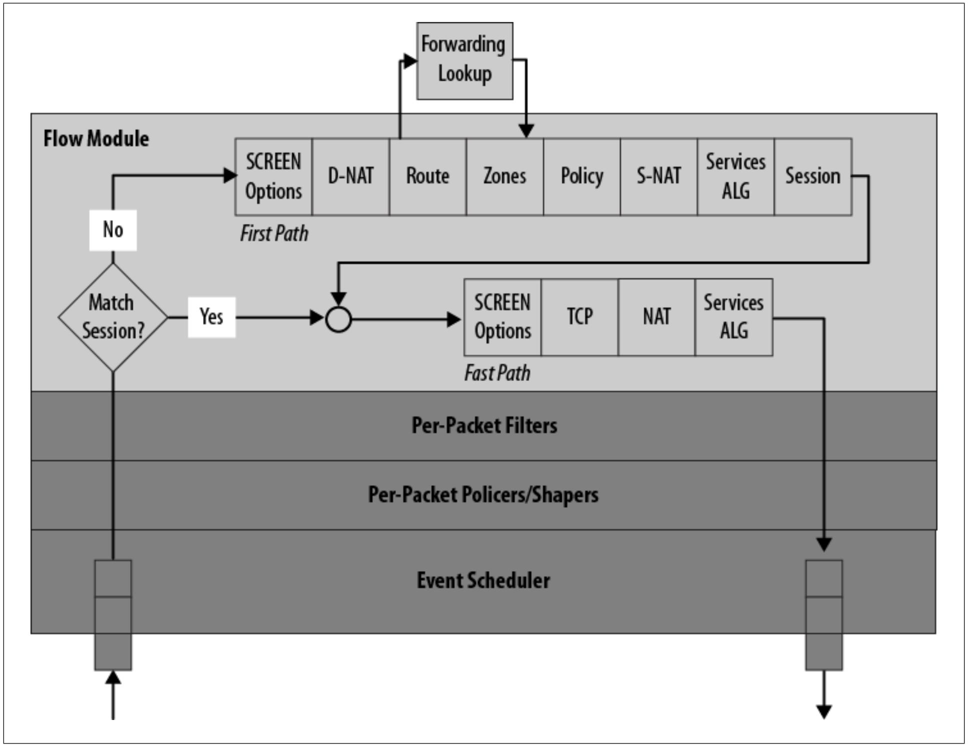


Figure 1-6. Session-based processing

If the packet is not part of an existing session, new session processing is performed. This entails the initial routing, policy lookup, any NAT that needs to be performed, ALGs, and finally entering the information into the session table. Once this is complete, the packet is processed as it is in the fast path for egress.

Routing Platforms

Over 15 years ago Juniper Networks designed their first Internet router. This device was unique in its packet processing power, low electrical power consumption, and small physical size. The reliability of the Junos operating system also became a selling point in the era of "reboot" troubleshooting. That initial router is the parent of the current M-series routers, and even though the M-series has gone through many revisions since the initial offering, they are still the "highest throughput for the least power in the smallest package" on the market today.

The M-series routers and their larger cousins, the T-series routers, offer service providers and enterprises a stable platform for routing IP traffic. They offer support for most standards-based routing protocols and support Layer 3 and Layer 2 provider-based VPN services.

The current lineup of the Juniper Networks M-series is:

M7i Multiservice Edge Router
: 10 Gbps of throughput makes this router a perfect edge device for SMB applications or Internet gateway or aggregation router for branch locations.

M10i Multiservice Edge Router
: At 16 Gbps of throughput, this compact and redundant router provides a stable platform for growing enterprise networks.

M40e Multiservice Edge Router
: This 40 Gbps platform offers flexibility and survivability for medium-sized enterprises.

M120 Multiservice Edge Router
: With a throughput of 120 Gbps, this platform will support multimedia and service aggregation for an enterprise or service of any size.

M320 Multiservice Edge Router
: The 320 Gbps throughput allows this platform to handle the largest backbone core routing and the most demanding multiplay applications.

The J-series routers were added to meet the demands of the smaller enterprise. The architecture of the J-series is slightly different than that of the M-series, in that the separation between the control plane and the forwarding plane is virtual rather than physical. In an M-series router, the packet-forwarding plane consists of specialized hardware designed for packet handling; in the J-series, the forwarding plane is a virtualized real-time thread with various application program interfaces and sockets modeling the specialized functionality. This difference allows Juniper to field a router with the same OS as the established M-series, but at a better price point for the enterprise. Firewall and security features have been added to the routing capabilities of the J-series routers.

The current Juniper J-series routers are:

J2320
: Three PIM slots and 90 Mbps of throughput for routing and firewall features

J2350
: Five PIM slots and 105 Mbps of throughput for routing and firewall features

J4350
: Six PIM slots and 115 Mbps of throughput for routing and firewall features

J6350
: Six PIM slots and 205 Mbps of throughput for routing and firewall features

The J-series routers are designed for enterprises that are connecting desktops to servers for office automation and back office applications. The Physical Interface Module (PIM) slots can be used for LAN connectivity, various WAN connectivity options (Serial, T1/E1, FE, DS3/E3, ISDN, ADSL2/2+, G.SHDS), and Avaya VoIP gateway and/or WAN acceleration.

> With the advent of the SRX Series Services Gateways, the J-series routers are now preferred for their interface selection rather than performance or features.

Speeds and Feeds

Most of the routers fielded by Juniper are modular in design, allowing them to be configured for any role in the enterprise. The modular components add interface choices, service accelerators, and tunneling options to their base capabilities as routers. The available modules can be divided into various categories, each with supporting multiple port densities and interface speeds. The module categories are:

SONET/SDN physical interface cards (PICs)
: Rates from OC-3 (155 Mbps) to OC-768 (40 Gbps)

Ethernet PICs
: Rates from 100 Mbps to 10 Gbps, 1 port to 48 ports

ATM PICs
: E3, DS3, OC-3 to OC-48 ATM interfaces

Channelized PICs
: E1, T1, DS3, OC-3, OC-12, and OC-48

Nonchannelized PICs
: E1, T1, DS3, E3

Serial PICs
: EIA-530, 2-port

Services PICs
: Encryption Services (ES), Monitoring Services, Multiservices, Link Services, Tunnel

WAN PIMs
: E1, T1, Serial, DS3, ISDN BRI, SHDSL, G.SHDSL

Ethernet PIMs
: 100 Mbps and 1 Gpbs copper and fiber

Services PIMs
: Avaya Media Gateway, Juniper WXC WAN Accelerator

A full definition of each of these modules can be found at *http://www.juniper.net/us/en/products-services/routing/m-series/m7i/#modules*.

From an architectural perspective, these devices' interface flexibility, protocol options, and scalable throughput allow the routers to be deployed in a collapsed backbone or a distributed core. The virtualization capabilities allow the routers to be placed in multitopology and multiclient environments, maintaining security via separation of traffic and services. Finally, the wide range of backplane speeds and throughputs (90 Mbps to 320 Gbps) allows a scalable and cost-effective Juniper router to be deployed for just about every network design.

MX Series 3D Universal Edge Routers

Juniper MX edge routers have the three dimensions required in today's enterprises and service providers: scaling, availability, and agility. The first of these scaling factors is the maximum performance of the devices. The MX platforms support Ethernet traffic rates from 50 Mpps to 1.98 Bpps, allowing an MX platform to meet most routing and switching demands. Add to this the capability of arraying the MX in a virtual chassis, which reduces the management burden while increasing the connectivity capability compared to standalone switches. The mid-range MX line offers a pay-as-you-go scalability. The MX5 can be upgraded to the MX20, MX40, or the MX80 with the addition of a software license. This allows an enterprise to purchase the device that fits its needs today and migrate as those requirements grow.

The next dimension is the availability of the MX platform, which exceeds the Metro Ethernet Forum's carrier grade switch specifications. The high-end MX platforms support redundant routing engines, redundant switching planes, virtual chassis operation, redundant power, and redundant cooling. Uptime is also maintained by the use of graceful restart, nonstop routing, fast reroute (FRR), unified in-service software upgrade (ISSU), and virtual private LAN switching (VPLS) multihoming.

The final dimension is the agility of the MX product line. The MX can perform routing and switching functions, and these platforms also support security features and virtualization features. This suite of capabilities allows the MX to operate as a core Ethernet switch, an MPLS edge router, an Ethernet aggregation point, or a distribution router. In many design scenarios, the agility of the MX allows multiple layers of a legacy design to be collapsed into a single layer. The addition of WAN optical interfaces to the MX expands its agility in the enterprise. No longer is the MX destined for the interior of the enterprise; it can operate as an enterprise edge device as well as an all-Ethernet core device.

The MX product line is composed of the following devices:

Mid-range MX
: The mid-range chassis covers the MX5, MX20, MX40, and MX80 models. The chassis is a compact unit (3.5 inches high) with four built-in 10 Gbps Ethernet ports and up to two Modular Interface Cards (MICs). (The MX5 has a single MIC port.) The size and port density of the mid-range MX makes it ideal for small sites that need a feature-rich environment, such as mobile backhaul, metro Ethernet access, and field multimedia aggregation. Future support for virtual chassis will allow the mid-range MX to operate like the larger devices with redundant routing engines. The mid-range MXs are software upgradable, with the upgrade supporting higher throughput rates on the chassis. The MX80 also is available in a 48-port gigabit Ethernet configuration. The base throughput of the mid-range MXs starts at 20 Gbps for the MX5, 40 Gbps for the MX20, 60 Gbps for the MX40, and 80 Gbps for the MX80. All models handle 50 Mpps of mixed traffic.

MX240
: The MX240 supports the MX feature set and adds survivability to the mix with redundant REs, switch fabric, power, and fans. This device can handle up to 480 Gbps of throughput and supports up to 120 gigabit Ethernet ports.

MX480
: The 480 fills the need for high-density Ethernet aggregation in a survivable chassis. The platform can support 1.4 Tbps and a total of 240 GE ports. Each of the six card slots can handle 120 Gbps. The MX480 is designed to support large points of presence in enterprise networks.

MX960
: At 2.6 Tbps, the MX960 can fill any role in a campus network that requires massive throughput. The throughput and feature set allows the MX960 to function at the core of the network as the Internet gateway for a campus or as an aggregation edge device for a large business park. The virtualization capabilities allow the MX960 to handle the traffic from multiple customers in a safe and dependable manner.

The MX edge routers support technologies and features that allow a separation between the physical deployment of devices and their logical capabilities. No longer is it necessary to deploy overlay networks for different services, different customers, or different media. By using network service virtualization (Layer 2 VPNs [L2VPN], Layer 3 VPNs [L3VPN], and virtual private LAN service [VPLS]), virtual devices (virtual chassis, virtual routers, and switching domains), and virtual link technologies (VLAN, link aggregation, pseudowire, and tunnels), the MX product line can act as any number of networks or devices, each providing a consistent quality of service (QoS) and security while increasing device utilization and lowering overall cost.

TRIO DPC

The introduction of the MX80 also brought along a new family of dense port concentrators (DPCs) supporting the TRIO chip set. The TRIO DPCs support greater onboard features than the older DPCs and offer a higher level of programmability for future capabilities. The upgraded features on the DPC include: enhanced load balancing, flexible multicast support, integrated Ethernet functions, inline packet services (tunnel encapsulation and de-encapsulation), Cflowd, NAT, deep packet inspection (DPI), and a beefed-up QOS. The TRIO DPCs are initially supported in the mid-range MX line, and they will be supported in other MX platforms in the future.

However, until the TRIO DPC is fully integrated into the MX product line, there are severe limitations related to the deployment of TRIO and non-TRIO DPCs in the same chassis. Consult the Juniper knowledge base for possible scenarios: *http://www.juniper.net/kb*.

Switching Platforms

Ethernet switches and bridges have been present in the enterprise space for 30 years, but Juniper Networks EX Series switches follow the classical design with the addition of a few routing layer features and a number of virtualization options. Juniper Networks offers the EX Series switches in options from the standalone EX2200, with its fixed 24 ports, to the EX 8216, which can be combined into a virtual chassis that can support over 2,000 gigabit interfaces. As an example of the flexibility of the product line, the EX4200s can be deployed in standalone, physically stacked, and top of data cabinet virtual chassis configurations. This offers flexible deployment options for all Juniper switches.

The Juniper EX Series switch line includes:

EX2200 Ethernet Switches
: An economy-minded branch or campus switch with features usually found in higher-cost switches.

EX2500 Ethernet Switches
: High-density 1/10 Gbps interfaces in a compact solution.

EX3200 Ethernet Switches
: A choice of 24- or 48-port models allows this switch to be sized for remote offices or small and medium businesses (SMBs).

EX4200 Ethernet Switches
: Scalability via the virtual chassis operation allows this device to serve most access scenarios from 24 to 480 ports.

EX4500 Ethernet Switches
: Up to 48 10 Gbps interfaces and 715 Mpps throughput positions this device as a high-speed server access device.

EX8200 Ethernet Switches
: Up to 768 1 Gbps ports and 1.92 Gpps throughput allow this modular chassis switch to function as a core switch in the largest data centers and campuses.

The virtual chassis operation supported on the EX 4000 Series and the EX8000 Series of switches allows multiple switches to be combined to form an extended switch operating under the control of a single routing engine. This capability creates deployment options that have not been possible until now. One example is the rack top deployment model (shown in Figure 1-7) where the devices in a rack gain access to network resources via the EX4200 in that rack. Placing the EX4200s in a virtual chassis arrangement with other EX4200s in other racks offers survivable single-switch connectivity for users in any of the racks. By adding virtual LANs, security and traffic separation is assured for all users in the racks. This deployment saves ports, increases efficiency, and simplifies management of access.

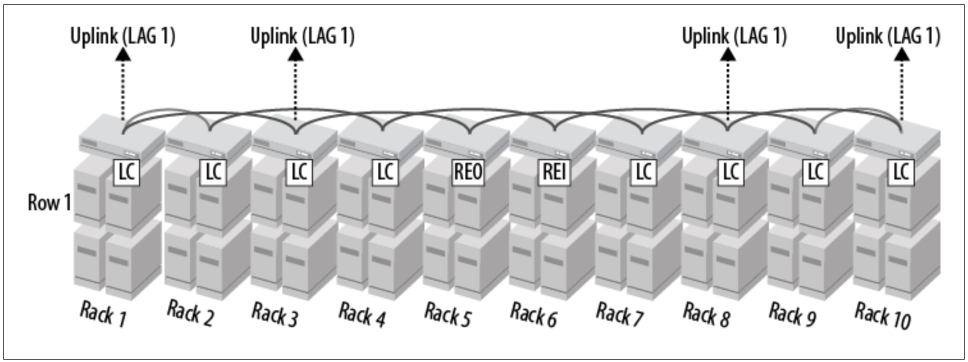


Figure 1-7. Rack top implementation

Up to five of the EX4200s can be connected while maintaining full speed connectivity across the backplane (physical and virtual).

The EX8000 series of switches offers the highest density of Ethernet ports and also the lowest per-port cost of any Juniper device. Add to this a full set of router features, and the EX8000 can be deployed as the data center core switching system and distribution system in a single chassis. (Chapter 2 contains a couple of deployment examples of the Juniper EX switches.)

SRX Series Services Gateways

The SRX Series Services Gateways are the most recent entries into the enterprise stable of devices. The SRX has a hardware lineage based on the J-series routers and the MX edge routers, while their software features are based on the security features of ScreenOS and the routing features native to Junos. Juniper calls the SRX a *services gateway* rather than a firewall because it is a stateful firewall with additional security services. It also has an Ethernet switching capability, WiFi support, 3G support, VoIP support, and, finally, a full set of routing features. These added features and functions earn the nomenclature.

The SRX is offered in two architectures, commonly referred to as the Branch Office gateways and the Data Center gateways, or as low-end SRXs and high-end SRXs.

The SRX Branch Office gateways offer the routing capabilities and the interface flexibilities that are found in J-series routers. The Branch Office SRXs are being deployed to replace edge and local routers. Why have two devices when a single device can handle both functions while reducing complexity and administration?

The Branch Office SRX models are:

SRX100
: This small, low-cost firewall offers 650 Mbps of firewall throughput. Its eight fixed 10/100 Ethernet ports are ideally suited for deployment scenarios in home offices and remote enterprise locations with a limited number of users.

SRX210
: This award-winning SMB firewall can offer 750 Mbps of throughput. 3G WAN support allows for creative connectivity and/or survivability options. The SRX210 has eight fixed Ethernet ports and a single WAN card slot.

SRX220
: The SRX220 supports 950 Mbps in a 3.5-pound form factor. It supports eight 10/100/1000 Ethernet ports and a pair of expansion slots. It is ideal for securing SMB locations that need redundant connectivity to the enterprise.

SRX240
: The SRX240 is the workhorse of the SRX Branch Office line. Supporting 1.5 Gbps of secure throughput, this device can handle most branch office applications. The 16 fixed 10/100/1000 Ethernet ports and four expansion cards will provide support for most installations.

SRX650
: Another award-winner, the SRX650 can hardly be called a branch office device. It can handle 7 Gbps of secure traffic in a two-RU size. The SRX650 supports four

fixed 10/100/1000 Ethernet ports and a combination of expansion cards that can provide additional Ethernet ports or WAN connectivity. The SRX650 can support remote offices, aggregation locations, and primary gateway services for medium to large enterprises.

The Data Center SRX models are based on the MX chassis, and they focus on throughput and interfaces rather than UTM security features. That's because it is safe to assume that additional devices to perform UTM features would be cost-prohibitive in a branch office. This same assumption is not valid in the data center.

The high-end Data Center SRX models include:

SRX1400
: The newest SRX model is designed on the Data Center architecture but at a branch office scale. This device is perfect where serious firewall processing is needed without the high port concentrations. The SRX1400 is effectively one half of a SRX3400 and offers performance up to 10 Gbps.

SRX3400 and SRX3600
: These medium-sized firewalls offer 10 and 30 Gbps of secure throughput respectively. Both offer survivable clustering for loss-free service. They support eight fixed 100/1000 Ethernet ports, four fixed SFP ports, and four or six input/output card (IOC) expansion slots. The 3000 series uses a combination of service processor cards (SPC) and network processor cards (NPC) to allow customization of the service requirements. Install more SPCs for service-heavy scenarios and more NPCs for interface-heavy scenarios.

SRX5600 and SRX5800
: These are two of the highest-powered firewalls in the industry. The SRX5800 supports 120 Gbps of secure throughput and 30 Gbps of either IDP or IPSec service. The 5000 series can be clustered with redundant control and fabric links, and the devices can be interconnected by fiber to allow physical separation to the nonstop processing. This capability offers survivability for large data center installations, campus-level firewalls, or large enterprise virtual gateways between data centers.

A lot of devices were called out in this chapter. Depending on when you are reading this book during its natural shelf life, new and novel devices will have been added to this chapter's lists. Be sure to check out the Juniper Networks website for the most current list and lineup.

Conclusion

Juniper Networks has entered the enterprise network market with a strong lineup of devices that can meet those networks' routing, switching, and security requirements. This chapter looked at the overall structure of the Junos devices, the feature sets supported by each device type, and software image releases. Many of the features that were described in this chapter can be performed by the various devices. In the next two chapters we look at enterprise scenarios and identify which devices match the different roles in the enterprise.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- List the enterprise product line.
- Describe transit and host processing.
- Identify key differences between the M-series, J-series, MX, EX, and SRX devices.
- Describe configuration management.
- Identify the features of the Junos CLI (CLI modes, prompts, and auto-complete).
- Identify the commands used in configuration mode (`edit`, `set`, `delete`, and `commit`).
- Identify options for manipulating "saved" configuration files. Include rollback options, load options, and rollback file locations.
- Describe the features of Juniper devices.

Chapter Review Questions

1. Which of the following two Juniper Networks routers are classified as enterprise routers? (Choose two.)
   A. T640
   B. M7i
   C. J4350
   D. M320
2. Which hardware component controls debugging on the router?
   A. Packet Forwarding Engine
   B. Route Processor
   C. System Control Board
   D. Routing Engine
3. True or False: Because the J-series has only a single processor, there is no Packet Forwarding Engine.
4. Which command would be issued to reboot the router?
   A. `request system reboot`
   B. `reload`
   C. `reboot`
   D. `restart router`

5. What is the default password to enter the configuration mode on the router?
    A. `juniper`
    B. `enable`
    C. There is no password
    D. `root`
6. Which CLI command should be issued to navigate to the *[edit protocols ospf]* directory?
    A. `cd protocols ospf`
    B. `edit protocols ospf`
    C. `cd /edit/protocols/ospf`
    D. `dir protocols ospf`
7. Which CLI command must be issued to activate configuration changes in the router?
    A. `apply`
    B. `copy`
    C. `save`
    D. `commit`
8. What is the top level of the configuration tree called?
    A. *C:/*
    B. */var*
    C. *edit*
    D. *root*

Chapter Review Answers

1. Answer: B, C. The T640 and M320 are valid Juniper Networks router models but are usually deployed in service provider networks.
2. Answer: D. The Routing Engine is the component in the router that controls all management functions, including commands that would be used to debug the router.
3. Answer: False. The J-series routers do contain a virtualized PFE, with API and sockets replacing the ASICs that are found in the M-series routers.
4. Answer: A. `request` commands are used to issue system-wide functions such as rebooting the router. The rest of the options are invalid CLI commands.
5. Answer: C. There is no password to enter configuration mode. Users are allowed into configuration mode based on access privileges.
6. Answer: B. To change the directory in configuration mode, use the `edit` command.

7. Answer: D. To activate the changes in the router, issue a `commit` command. Of the remaining options, `copy` and `save` are valid CLI commands but are used for configuration management.
8. Answer: C. When at the top level of the configuration tree, the CLI banner will display the `[edit]` prompt.

CHAPTER 2

Enterprise Design

Changes made to network traffic patterns, server architectures, and traffic types in the past couple of years have caused existing network design philosophies to become outdated. Preexisting multitiered network designs are no longer able to meet the scaling, management, or survivability demands of the current enterprise; in the following pages we present new network designs that utilize the capabilities of the Juniper Networks Junos-based equipment that expressly meet these new demands.

This chapter examines the new network design guidelines that are being implemented in the enterprise today, as well as the goals and benefits of these designs when compared to the legacy architectures. The chapter concludes with a series of design scenarios and solutions at large enterprises that use Juniper equipment.

To focus on the design aspects of the network without getting bogged down in the technical details of the services and protocols, this chapter is tightly connected to Chapters 1 and 3. The previous chapter looked at the Juniper Networks devices that are offered at the enterprise level, and the next chapter delves into the details of this equipment's technical capabilities. But in this chapter we focus on the outcome of the design, not the details of the implementation. For those details, refer to the other chapters in this book.

Design Guidelines

The design guidelines for an enterprise network follow a similar set of principles as designing a home. There is not a single home design that will meet the needs of all people, because their requirements will differ in too many areas. However, drawing from the history of house design and construction, there is a common set of design guidelines that can be applied to any home design.

For any home design, there are several factors to consider: what are the available materials and technologies, and what are the components of the home itself that must meet the lifestyle requirements of the occupants? Only when these elements are combined into the total home design will it be a home for a lifetime.

Designing an enterprise network should be done along the same lines. An enterprise network should consider the following factors:

Set goals for the network
: The network design goals have to mesh with the corporate goals of the enterprise. What are the growth expectations, what are the security requirements, and what are the access requirements? These goals have more to do with the expectations of the enterprise than with the technologies of the network.

What technologies have historically been used to meet the network requirements?
: A historical perspective allows a designer to learn the whys of a network element and provides an understanding of the how. Any design has to look at the universe of design elements and cull the possibilities, separating what is needed to meet the overall design goals from what can be discarded as not required. As an example, a four-tiered network design has been the standard data center design for the last decade, but if the majority of traffic is east to west, not north to south, this design element is not necessary.

What new technologies are available, and what efficiencies and capabilities do they enable?
: Do relatively new technologies such as virtualization and cloud computing have a place in the enterprise? Can the hardware and software that currently exist in the enterprise support these new technologies?

Design for manageability of the network
: This might be as simple as staying with a known vendor or a known operating system, or as complex as having a management suite that can communicate to all elements and is extensible to new technologies and capabilities.

Technological Goals of Network Design

As stated, the economic goals of the enterprise have to be reflected in the goals of the enterprise network. The goals also have to meet certain technical standards, which include:

Manageability
: A design must meet the demands of minimizing both capital expenses (CAPEX) and operating expenses (OPEX). A network that requires constant upgrades (both hardware and software), regardless of how fast it is, is not feasible in these economically conservative times. Any network must have sufficiently trained technicians to maintain the network at peak performance. A common set of languages across the equipment scope reduces the training costs and ultimately the operating expenses of a network. The same is true for any management system that requires the deployment of vendor-specific management platforms; again, this is not feasible in any economy. The management systems should be based on an open system that uses standard protocols and allows integration between multiple vendors.

Scalability

The goal of any enterprise is to make money. Most enterprises do this by growth in their product, services, and offerings. Any network design must be able to handle the same growth expectations as the enterprise. The popularity of growth cloud computing is an example of this trend. Why invest in application server hardware when the servers are undersized immediately upon deployment? Why not rent server space and run your applications on someone else's hardware? Any network design has to be able to scale up and down easily (avoiding forklifts if possible). Because of the frequency of mergers and acquisitions, any design should have an ease of integration with other equipment, deploying open standards for protocols at application program interfaces (APIs). Because not all network growth comes with a guarantee of capital expenses growth, incremental boundaries in the network should have a minimum impact on the budget (again avoiding the forklift).

> When devices that were deployed in the past cannot be used in the current design, they must be replaced wholesale for the new design to function. So a forklift is necessary to remove the old equipment and bring in the new equipment. When examples of technologies and vendors cannot scale, they are referred to as *forklifts*.

Efficiency

There is an inherent trade-off between survivability and efficiency in a network design. If enough hardware and connectivity is added to survive failures, each element is underutilized. Maximize the efficiency from each element, and when a failure occurs, there is not enough capacity to handle all the traffic without a loss. Within an enterprise network, transmission links are not the only areas where efficiency must be measured. Network nodes, servers, application silos, and entire data centers are being analyzed to determine their efficiency and survivability. The alternative to redundant passive elements is to incorporate load-sharing and/or load-balancing technologies to equally spread the enterprise load over all elements of the network. This allows the network to absorb traffic spikes and outages more easily. A benefit of spreading the load over all elements is that all elements are in constant use. (Networking is rife with stories of how standby facilities failed to operate as expected just at the time when they were needed.) A crisis is not the time to find out that the backup system is not operational!

Connectivity

The principal goal of any network is to provide any-to-any connectivity, but the design considerations tend to be more restrictive than just optimal connectivity. It would be cost-prohibitive to provide full bandwidth between all devices in an enterprise. The goal of connectivity is a trade-off between cost and connectivity. The connectivity goal should be that all communities of interest will have bandwidth to perform their functions. Additional goals, or possibly challenges for connectivity, include a reduction in latency for traffic and the ability to maintain connectivity in the event of a failure. The goals for connectivity span many other goals as well (e.g., efficiency, security, multiservices).

Security

Security and connectivity work together in the enterprise network. The goals associated with security form two distinct camps. The first type of security is associated with the survivability of the network. Will the network continue to operate in the face of hardware, software, link, or node failures? If possible, will the network converge in a timely manner as a result of a failure, either automatically or manually, and at what cost in failover facilities?

Informational security is the other camp. Does the network provide the integrity, confidentiality, and availability of information as required by corporate security plans? What about federal and industry guidelines? Can the traffic be segmented into security silos, allowing intra-silo connectivity but restricting inter-silo traffic? What are the requirement for user access control and dynamic allocation of connectivity based on user roles and profiles? All these elements fall under the goals of security.

Traffic types

Compared to the goals of security and connectivity, the challenge of handling differing traffic types seems trivial. Most enterprise networks are based on the transport of IPv4 traffic (although other protocols can still be found). Most enterprises have some requirements based on the IPv6 standard, but most have not yet deployed this set of protocols. Although the majority of traffic today is unicast, multicast is becoming a common design criteria for enterprise networks.

The depletion of IPv4 addresses will be a critical issue. At the time of this writing, the last of the unassigned addresses have been deployed!

Multiservice

Although an argument could be made for or against the need for IPv6, there is no such debate when it comes to the differentiation of traffic within the enterprise network. In the trade-off between connectivity and efficiency, load balancing is a means to meet the goals of both. Differentiation of traffic is another way to approach that trade-off. If traffic can be classified and differentiated in the network, only high-priority traffic passes during a failure. The definitions of which traffic is high priority and which traffic is afforded special handling are rooted in the corporate goals for the network as much as the connectivity goals.

The other aspect of multiservice networks is the differentiation of services that share a common enterprise network. Voice, video, and data have all converged to become bits on the enterprise network. As long as unlimited bandwidth is not free, enterprise networks have to treat traffic types differently within the enterprise.

Legacy Network Design

A look at the history of data communications network design, like the study of any other history, follows a circular pattern in which history repeats itself. In initial communication patterns, 100% of the traffic was between desktops and mainframe computers in data centers. The introduction of the workgroup server changed that pattern to reflect an 80/20 rule: only 20% of the traffic was slated to the data centers, with 80% remaining in the workgroup (see Figure 2-1). As enterprises realized the value of the data stored on these servers, they were "secure" in the data center. This change once again altered the communications ratio to a 20/80 split (80% to/from the data center, 20% within the workgroup). Today the traffic patterns in the enterprise cannot be explained by a simple ratio of traffic to and from the workgroup; instead, they contain server-to-server traffic, peer-to-peer traffic, Internet traffic, and the legacy client-server traffic.

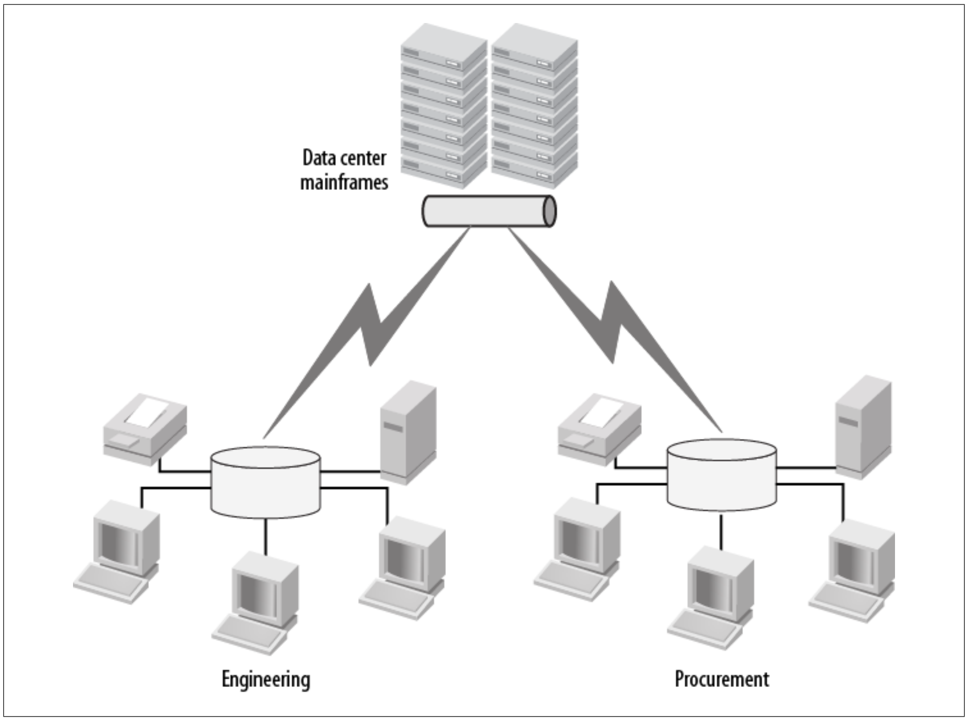


Figure 2-1. 80/20 traffic pattern

In the 1990s, during the migration from the 80/20 to the 20/80 traffic pattern, the three-tier data center design was developed, representing the core, distribution, and access tiers (see Figure 2-2). The design was based on the current traffic patterns, limitations in that period's state-of-the-art equipment design, and the need for security. The design

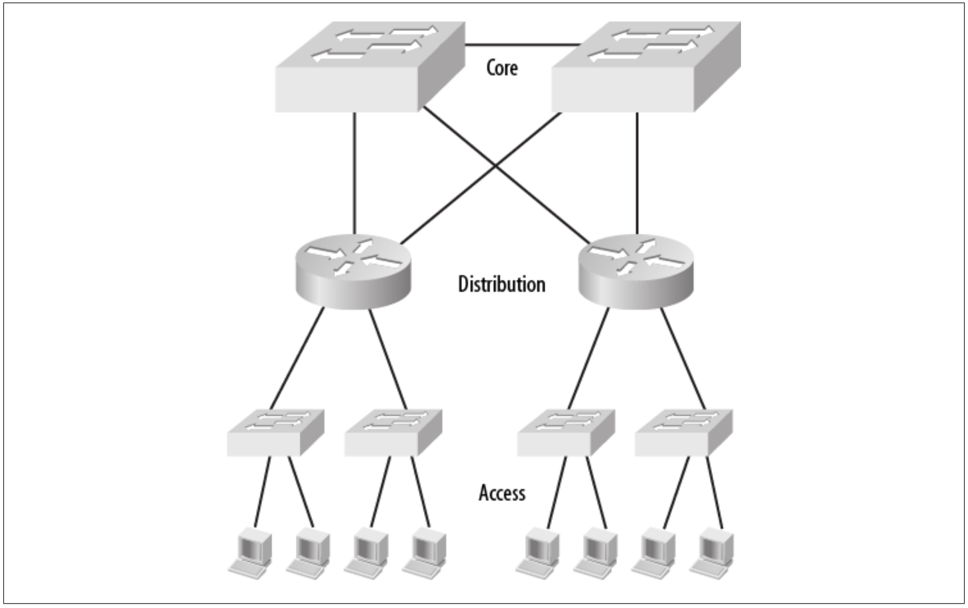


Figure 2-2. Three-tier design

was championed by Cisco Networks and has formed the basis of most enterprise installations by that company.

The functions of the tiers are:

Core layer
: The core layer is a high-speed switched backbone. Since routers at the time could impact performance, high-speed switching is employed. The core is typically comprised of a relatively small number of high-end switches connected in a full mesh topology. Scaling in the core is performed by replacing the switches with higher-speed devices (and forklifts). The core is responsible for connecting traffic between the various distribution layer routers.

Distribution layer
: The distribution layer, sometimes called the aggregation layer, provides the connectivity between the core and access layers. This layer is comprised of routers and firewalls that interconnect the various technologies of the access layers to the high-speed core switches. The distribution layer is responsible for securing the various enterprise groups and summarizing and aggregating routes between enterprise subnets found in the access layers.

Access layer
: The access layer provides the connections to the end stations and servers. The access layer, like the core, is a switched layer that offers reliable connectivity to the distribution layer. Redundancy in the access layer is accomplished with the use of multiple uplinks to the distribution servers.

The WAN layer, which is not commonly associated with the three-tier design, provides inter-site communications and Internet access. The WAN layer uses redundant links to the core layer for reliability and can provide security as well as connectivity. The WAN layer is considered a routed layer.

The rationale for the three-tier design is based on a number of technological facts of the period. The predominant factor was the cost of processing power; affordable routers were not capable of handling the full throughput requirements of large enterprises. Another factor was the relative simplicity of Ethernet switches, which offered high speed at the cost of functionality. "Dumb" switches forwarded traffic in a nondeterministic fashion limited only by table sizes and the speed of a shared Ethernet link.

Survivability in the three-tier design is supported by redundancy. Back-up routed links and multiple switched links offer failure protection from both link and node failure. Redundant switched links create the possibility of broadcast storms with their associated outages. To avoid this devastating situation, the spanning tree protocol (STP) is employed. STP ensures a storm-free network at a cost of efficiency on the links.

In a full mesh four-switch network with STP running, one third of the links are blocked from carrying traffic (Figure 2-3).

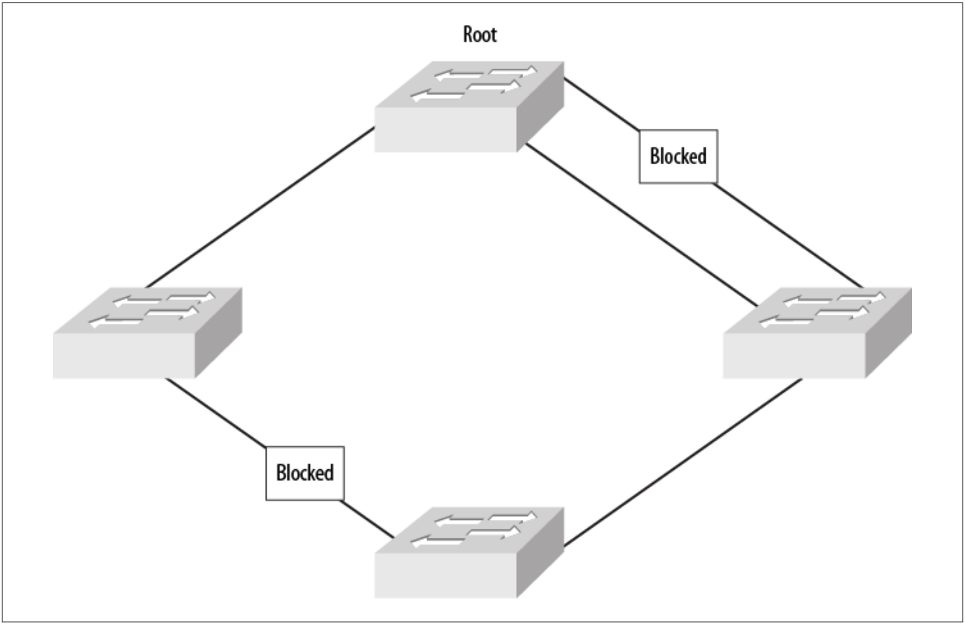


Figure 2-3. Loop-free switched network

STP recovers from link failure by means of a series of timers that monitor the health of links and nodes. Once these timers expire, the network converges to another loop-free topology. The convergence time can cause disruption to communications for 10 seconds or more. Although RSTP can shorten this disruption time, the amount of time that it takes to recognize a failure and recover is not acceptable in the enterprise today.

Scaling in the three-tier network is limited. The core layer is limited by the requirement for full mesh connectivity, the distribution layer is limited by convergence intervals and interfaces, and the access layer is limited by the number of uplinks and access interfaces per device. These limitations dictate a scaling by multiplication. As the enterprise network grows, additional vertical silos are added to the design to accommodate the added traffic (see Figure 2-4).

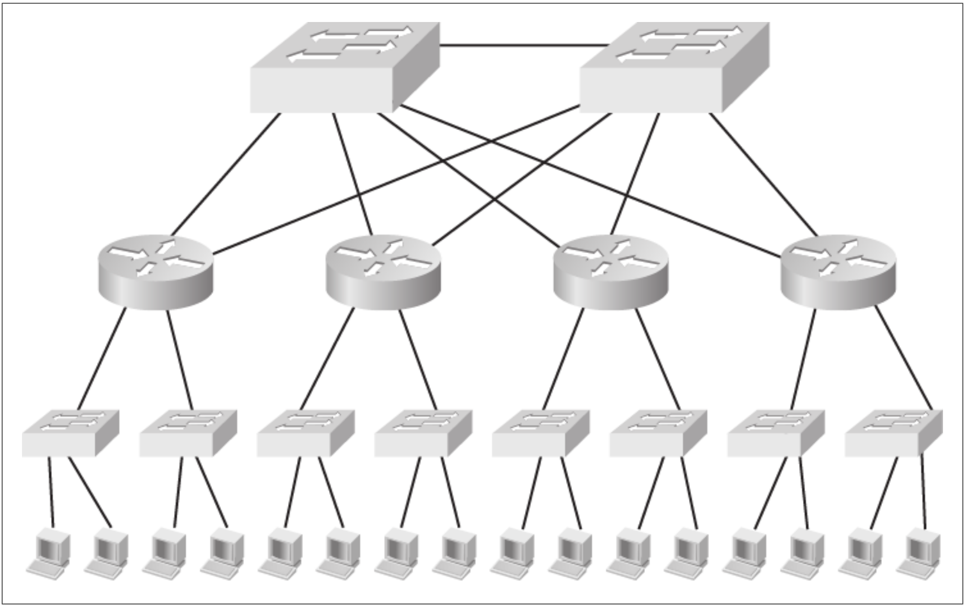


Figure 2-4. Three-tier scaled

This scaling philosophy increases the number of interfaces and links at the core layer, the amount of traffic between silos, and the number of routed hops between access devices. If the adjacent silo is geographically separated, all the traffic has to be sent through the WAN layer.

The technical issues inherent in the three-tier design that make it unsuitable for the enterprise today also include:

- A change in the traffic patterns in the enterprise makes the three-tier design inefficient.
- The convergence times associated with STP are inconsistent with nonstop computing.

- The repeated routing latency associated with the three-tier design is not acceptable to low-latency server-to-server communications.
- Security must be integrated at all layers of the design, not only at the edges.
- The low-link utilization associated with STP and redundant alternate route paths is uneconomical.
- The three-tier design does not offer a common classification of services for traffic.
- The scalability costs of the design are very high.

The New Network

The design philosophy presented in this book provides a means to migrate the legacy enterprise design and embrace the new technologies offered by Juniper Network devices. The changes to the designs meet the new financial and technological realities of the enterprise network. The design philosophy is to reduce the three-tier (plus WAN) design from three tiers to two tiers, to possibly a single tier (see Figure 2-5).

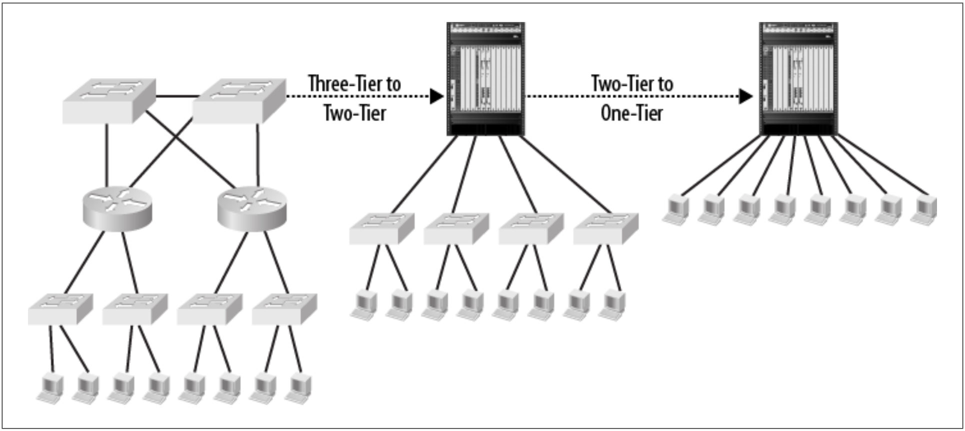


Figure 2-5. Design migration

These new realities include but are by no means limited to:

The 70/30 traffic model
In the new network design, 70% of the traffic is peer-to-peer traffic from devices (users or servers) at the access layer, and the remaining 30% of traffic is to and from the access layer. Peer-to-peer networking and server-to-server traffic form a greater part of the enterprise traffic model than legacy client-server traffic. One example is the use of HTTP for most enterprise functions. A client kicks off a transaction by connecting to a server (possibly filling out a form or requesting a service). The HTTP server takes this request for service, communicates to other back-office servers to verify the user, communicates to possibly another server to place the request, receives the response to the service request, stores the response on another

server for security, and finally responds to the requesting client. The minor input from the client causes a torrent of information flowing between the servers.

Security

Because of security restrictions imposed by corporate and governmental policies, most enterprise networks must segment their servers into processing silos. Access to and communications between silos must be secured. Enterprise data centers are more vulnerable today than ever before. Data center storage typically is measured in *petabytes* of data. Backing up these systems can cause congestion and network traffic spikes that must be handled.

Minimize delay

In today's corporate environment, milliseconds count. Whether the enterprise network is used for electronic trading, inventory control, financial dealings, or server backups, each function relies on subsecond response times. Delays in the network are additive, and so as traffic passes between clients and servers and between servers, each stop causes an added delay. What's more, routers in the path also cause delays. The former is a result of the processing scenario, and the latter the result of the network design. In the past, the processing delay associated with a router was small compared to the serialization delay associated with putting a frame on the wire. As the bandwidth of links grows, the serialization delay shrinks. As bandwidth continues to grow, the delay associated with routing traffic becomes the gating factor of the equation. In any enterprise design the number of routed hops must be minimized to reduce the inherent delay.

Effortless scaling

Corporate mergers, acquisitions, failures, and bankruptcies are all a fact of life, which means no network is in a steady state for any length of time. Any enterprise design must be able to grow or shrink as the requirements of the enterprise change while being mindful of the bottom line, since all assets are pared to the minimum. Link utilization, port densities, power usage, and occupied space are all concerns of the enterprise network, but any design must also have a smooth migration strategy that allows high utilization at a minimal incremental cost.

Virtualization

A one-to-one alignment of a device to a function is no longer valid. Because of virtualization, a single device can provide multiple functions, or a single function can be spread over multiple devices. Virtualization is appearing in the data center and the network, and the virtualization of applications in the data center allows a new level of scalability and reliability in an area that has historically lacked both. Virtual services can be installed, moved, expanded, and accessed across any number of physical servers. In the networking environment, virtualization allows single devices to act as physically separate devices or physically separate devices to act as a single device. Enterprise network virtualization capabilities reduce the costs associated with the devices (both OPEX and CAPEX) and allow the flexibility needed to meet the demands of the service virtualization.

With these new-network facts of life stuck in your mind, let's look at what happens when existing network designs are presented alongside these new goals of the enterprise. For each example, a new design is presented that meets the existing goals and acknowledges the new realities of technology.

Dual Star Internet Access

As enterprises grow, the need for Internet access grows accordingly. As the enterprise takes on more of a public-facing Internet presence, access becomes an important corporate asset rather than an employee perk. In this scenario, our sample enterprise offers a host of web-based services to the general public. It also relies on secured web-based portals for remote offices and employees who are in the field. For this enterprise, the Internet has become the access mechanism for most day-to-day business traffic, and without it, the enterprise would suffer greatly.

Recognizing the importance of the Internet and the threats that exist in this environment, all access to and from the Internet is secured. Firewalls are placed to prevent unwanted traffic, intrusion detection and prevention systems (IDP) are in place to monitor for security threats in the permitted traffic, and content filters are in place to ensure that enterprise use policies are adhered to. The two Internet feeds are from different ISPs and are terminated in facilities that are in the same metropolitan area.

Existing Internet Access Design

The existing Internet access, as shown in Figure 2-6, is an evolved design that has expanded as additional requirements have been added to the enterprise. Each functional addition was implemented in a separate device. VLANs provide traffic segmentation in the Ethernet switches through the use of independent interfaces on the routers and firewalls.

The design incorporates multiple layers of switches and routers, the result of incremental growth and its reliance on the Internet rather than a single design philosophy. The enterprise core switches connect to a series of egress switches. The inside-egress switches support trusted traffic, while the outside-egress switches handle a mixture of trusted and untrusted traffic. Both sets of switches are interconnected with Ethernet trunks that are provisioned over dedicated fiber between the data centers.

Each enterprise function that relies on Internet connectivity has a separate firewall. All firewalls are provisioned in a primary/secondary relationship, with all traffic passing through the primary device. A dedicated connection between the primary and secondary provides a keepalive for failure detection. In the event of a failure of one device, the other is activated and starts responding to ARP requests (both firewalls have the same IP addresses).

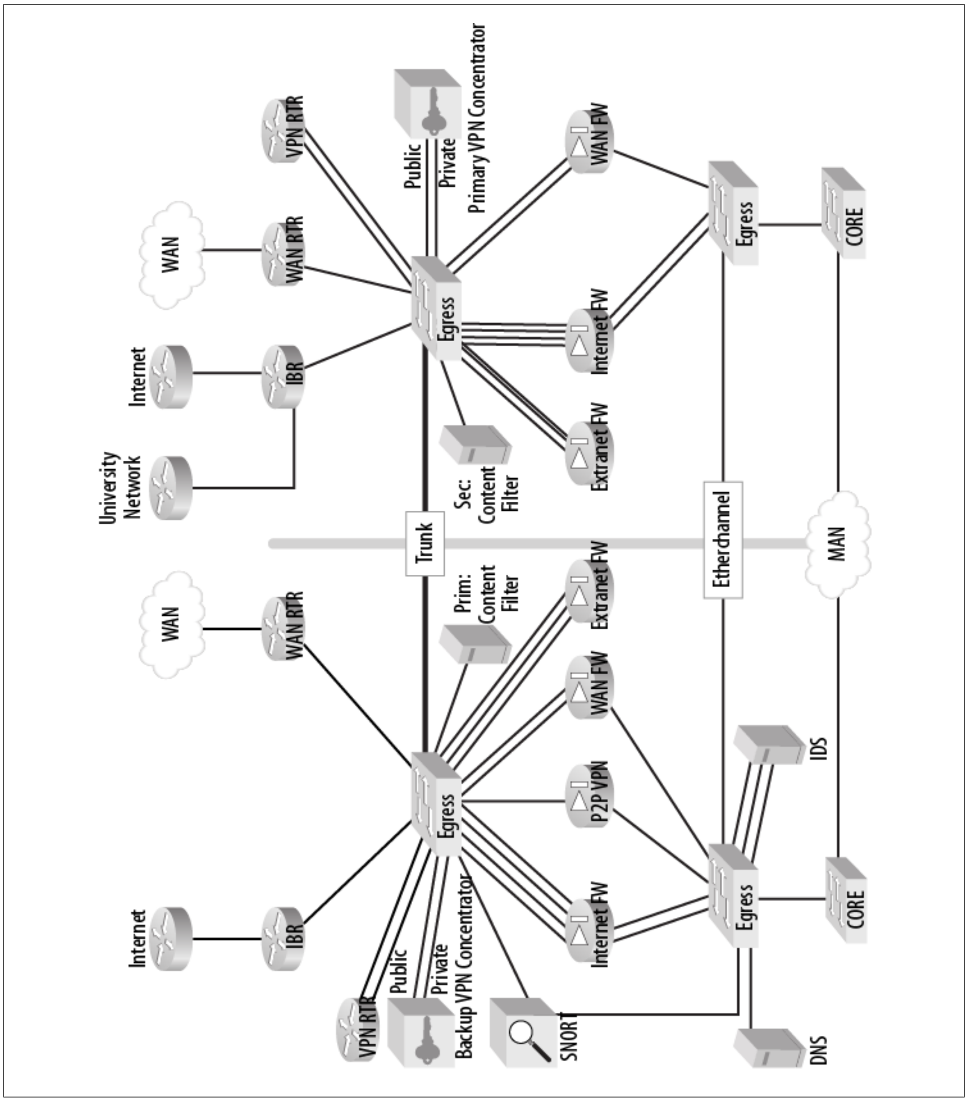


Figure 2-6. Existing dual Internet access design

HTTP traffic is routed through a content filter server that allows or blocks access to Internet pages. The content filter servers also are deployed in a primary/secondary relationship based on which Internet access point is active.

Design Goals and Constraints

This enterprise, like most today, is constrained by its budget. Funds for capital improvements are allocated once a year, and operating budgets are fixed. Any improvements involving Internet access have to show a return on investment in either improved services or a reduction in operating expenses.

The enterprise is having a management crisis because auditors require that all changes to the firewall policies have a paper trail and that all traffic be logged. Each firewall is managed by a different group, and a change in Internet policy could affect as many as three active firewalls and their backups.

One would also assume that the enterprise needs to increase the speed of Internet access (from 100 Mbps to 1 Gbps) and wishes to use both ISPs as active links. They want to increase the speed of the links to the core by the same amount—an intermediate step in the long-range plan of having multiple 10 Gbps links to the Internet.

Solution: Dual Internet Access Design

The solution to this design, as shown in Figure 2-7, addresses three critical goals of the enterprise: security, management, and scalability.

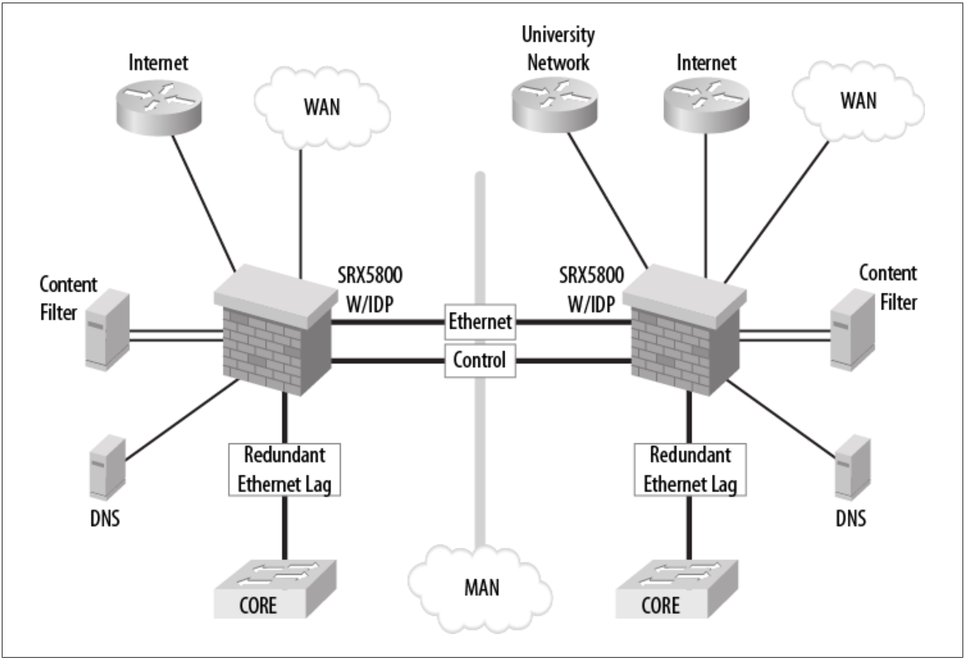


Figure 2-7. Dual Internet access solution

As Figure 2-7 illustrates, the security for the enterprise has been consolidated into two firewalls, each handling the policy, IDP, and content filtering functions.

The various firewalls and their separate logging, access, and policies are now incorporated into a clustered pair of SRX5800s. Separate security zones are created for internal and external interfaces. The interconnecting links carry both the inter-SRX traffic and the control information, allowing both firewalls to maintain the traffic session information. The firewalls operate in an active/active configuration, both passing traffic to and from the ISPs. All outgoing traffic to the Internet is network address translated to an address pool that is preferred by the local ISP. All traffic to incoming servers is also translated from global addresses that are preferred on one ISP. This use of NAT and route preference limits the amount of asymmetrical traffic to and from the Internet.

The HTTP content filtering is implemented by the use of filter-based forwarding. All outgoing requests for HTTP content are forwarded by the SRX to one of the two content filter servers. This arrangement allows both filters to operate independently of each other and carry greater amounts of traffic.

The IPS capabilities of the SRX are now employed to replace the standalone IDS devices and the SNORT device. IDP is employed as necessary for traffic that passes through security policies in the firewall. Traffic that does not warrant IDP bypasses this function.

VPN users are accommodated as well within the SRX, because the SRX5800 can handle 30 Gbps of encrypted traffic for both point-to-point (P2P) and remote users.

The survivability aspect of the security is provided by a combination of Layer 3 failover and clustering. Because of the requirement of using both ISPs, an active/active configuration is deployed. In this configuration, both firewalls are actively passing traffic and also monitoring the traffic passed on the other device. In the event of an SRX failure, the other SRX will transmit an ARP and handle all existing sessions. The Layer 3 failover performance is improved by the use of bidirectional forwarding detection (BFD). This RFC-based protocol assures failure detection in subseconds, thereby reducing convergence on OSPF and BGP links.

The scalability requirements are met with a combination of interfaces and protocols. The SRX supports both 1 and 10 gigabit Ethernet interfaces, and the SRX5800 will handle a minimum of 30 Gbps throughput (all traffic going through IDP). For those connecting devices that do not have 10 Gbps interface capability, the SRX offers Ethernet link aggregation.

The management nightmare of the enterprise is solved by a single source for audit and traffic logs. All Junos devices maintain a cache of previous configurations, and each previous configuration lists the time, date, and person who performed the change. The onboard stored configuration plus the archive-on-commit feature ensure that no changes can be made without a proper paper trail. Access to the firewall is controlled by a RADIUS server that controls users and permissions within the firewall. Finally, traffic logs and IDP logs are stored off-board on secured syslog servers (a Juniper Networks STRM device).

The migration between the old design and the new is performed in a phased manner. The initial cut-over of the Internet firewall and Internet border router allows a clean division of functions and a secure rollback position if necessary. Once the Internet traffic is passing through the SRX, all other traffic is migrated one function at a time. This scenario allows each function to be fully tested and verified prior to moving onto the next change.

Data Center and Disaster Recovery (DR) Architecture

Data centers that were designed around the 80/20 traffic concept cannot easily handle traffic patterns seen in today's data center. Traffic between server silos must pass up from the access layer, through the distribution layer, through the core, and back down again. This increased processing affects scalability and latency.

In our next design scenario, the distribution layer adds another set of routers and a firewall into the mix. All in all, the increase in processing contributes to a six-hop path for traffic between the servers in different silos.

The servers and the storage area networks (SANs) in this network are the product for this example enterprise. Without secure, reliable access to these servers and their content, the enterprise can neither function nor make a profit. The current design is based on the concept of nonstop secure computing in order to provide back-office services for area corporations. All services are reached via IPSec VPNs or SSL VPNs. All traffic passes through firewalls as an added protection against unintended users. The enterprise maintains two data centers that are geographically separated and mirror each other, and through the use of virtual services, either site can serve a customer equally well.

Multitier Data Center Design

The data center network design shown in Figure 2-8 is typical for server performance and survivability. All traffic to or from the servers and the SAN is filtered by firewalls and segmented by virtual segmentation (VLANs). Traffic from a customer's location enters the data center through the egress firewall pair. Once past initial screening, the traffic is routed to one of the outside distribution routers for processing. The outside distribution router determines which silo to access and routes the traffic through the firewalls and the inside distribution routers to the access switches (load-balancing algorithms associated with the outside distribution routers ensure an equal load for all servers). Each functional service and each customer's service is secured by the use of VLANs within a stack. Traffic between stacks uses a Q-in-Q metro-Ethernet service for connectivity.

Because of the high demands of data sharing and backups between the data centers, a second means of connectivity is established to interconnect the SANs. This interconnection is a private IP service that transports fiber channel over IP traffic between the SAN switches.

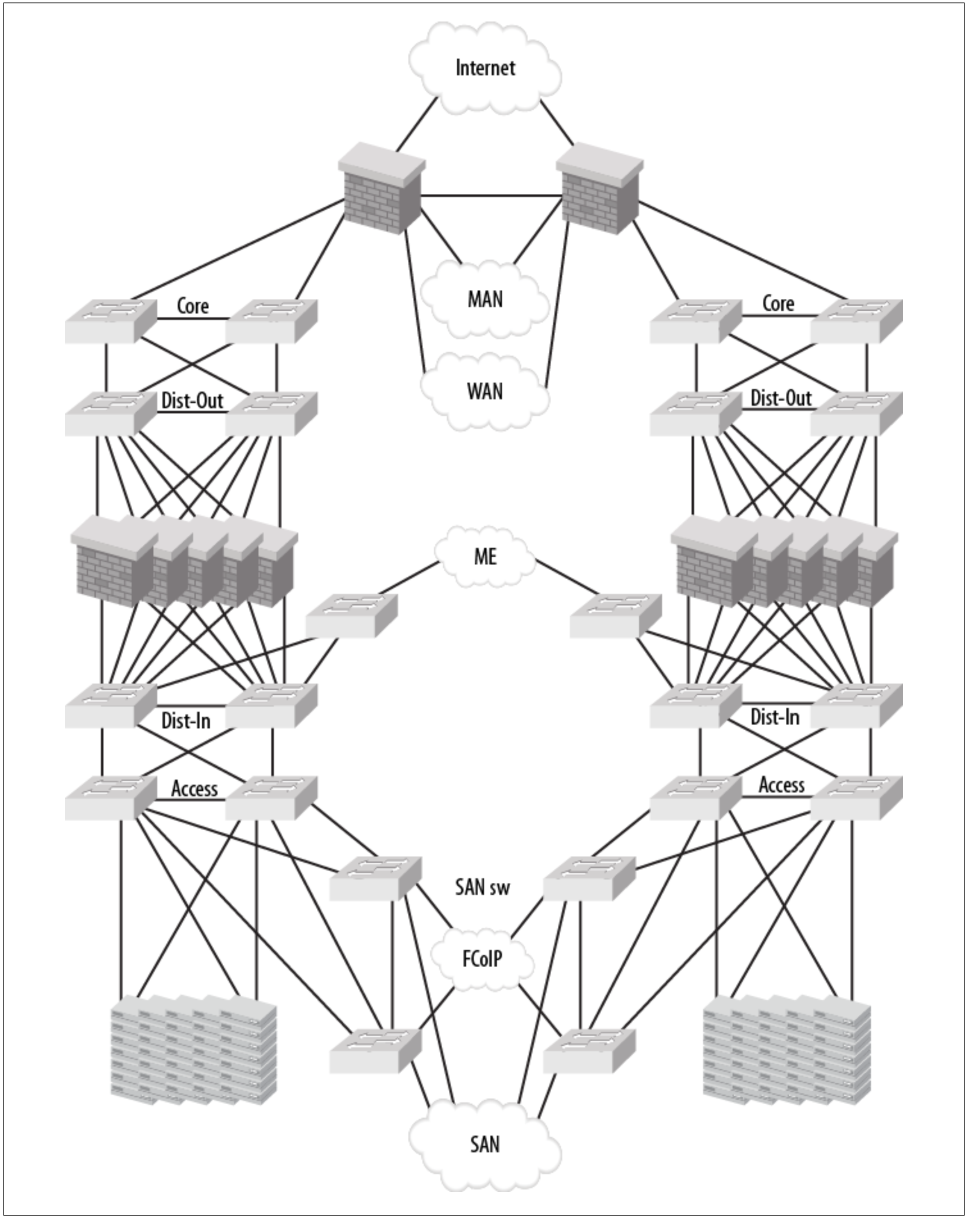


Figure 2-8. Legacy data center design

The survivability of the system is achieved through routing protocols. Exterior BGP (EBGP) is used extensively throughout the data center design, so it is possible to tailor the routes between the distribution routers (inside and outside), the firewalls (egress and internal), and the access switches. In the event of a failure of any link or device, BGP will use a secondary route to the destination.

East-to-west traffic is determined by the egress firewall or by the outside distribution routers. If the outside distribution routers determine that the traffic is to traverse the network, a VLAN on the metro-Ethernet link is used.

All links between the devices carry all the virtual instances, except for the internal firewalls. In this case, each firewall is dedicated to a customer or function. The firewalls operate independently of each other, both in one stack and between east and west. The BGP routing ensures that asymmetrical routing does not occur.

The management of the design is very labor intensive. The BGP policies and the firewall policies keep the management team busy. Traffic monitoring, design modifications, and moves, adds, and changes for customers and functions is another full-time job.

Goals and Constraints

The goals and constraints found in the data center can be grouped into the following parameters:

Physical plant limitations
: When the costs associated with leasing space in a data center are compounded with the cost of power and cooling, you have an incentive to go "green." Every time a device can be eliminated from a design, the cost savings in real estate, power, and cooling can be added to the bottom line of project. Unless an enterprise has the luxury of owning the data center and its own power plant, the size and efficiency of the devices are critical considerations.

Server virtualization and load balancing
: To fight the hardware limitations of servers, load balancing and server virtualization are used to smooth applications over many servers and to put users where the CPU cycles are available. The use of virtualization and load balancing changes the traffic patterns.

Simplicity
: Management of a data center is getting more and more complex. As more applications and more users access the center, more virtualization and horizontal traffic appears. Tracing processes might span multiple servers and multiple silos. Any simplification in the infrastructure will reduce troubleshooting burdens.

Data centers consolidation
: As this enterprise will attest, more and more services and applications are moving to the data center and away from workgroups and local servers. Cloud computing is nothing more than the consolidation of more user information in fewer data centers.

Performance and scale
: The original design of the data center was limited in scale by its architecture. As more servers are added, more switches are added, and as more switches are added, more distribution ports, firewalls, and core ports are needed. At some point a new stack will be required because of the limitation of the hardware. This book's figures would need to be viewed in three dimensions to clearly see all the interconnectivity.

Availability and agility
: The original design presented a high-availability design with little agility. The use of EBGP and routing policies to control routes and recover from failures provided high availability but suffered from the unknown. It is not agile enough to cope with the unexpected failure or the unplanned expansion.

Solution: Data Center Design

The alternative to the multitier data center design is to consolidate and reduce. The new design, as shown in Figure 2-9, addresses most of the goals and concerns of the enterprise without sacrificing availability or security. The design is a two-tier approach composed of a core distribution tier implemented in an MX960 and an access tier implemented in a virtual chassis arrangement of EX4200s.

Security is now provided by an SRX3600 operating as a firewall-on-a-stick for traffic. The SRX is provisioned with a virtual router per customer or function and can provide IPSec VPN termination support as needed.

The design uses the same load balancer as the previous design, but attached to the MX chassis to ensure even distribution of traffic across the servers. Routing in the design is per-instance OSPF, with BFD for reduced convergence times. The MX is virtualized on a per-VLAN (silo) basis. All inter-VLAN traffic flows through the SRX, while all intra-VLAN passes through the MX without the SRX.

East-to-west traffic flows over an MPLS connection that mimics the MX virtualization with L2VPNs per customer. These connections will handle both user traffic and SAN traffic.

The access switches reduce the total number of links to the distribution network while maintaining a better utilization than the original design. The links are Ethernet aggregation links between the MX and the EX virtual chassis. The design of the chassis allows the individual links to be on separate devices and still participate in a link aggregation group (LAG). STP is not run here, so full utilization is possible on all links.

Access to the SAN is also provided via the EX4200. The switch supports fiber channel over Ethernet interfaces, allowing direct connections to the storage area network.

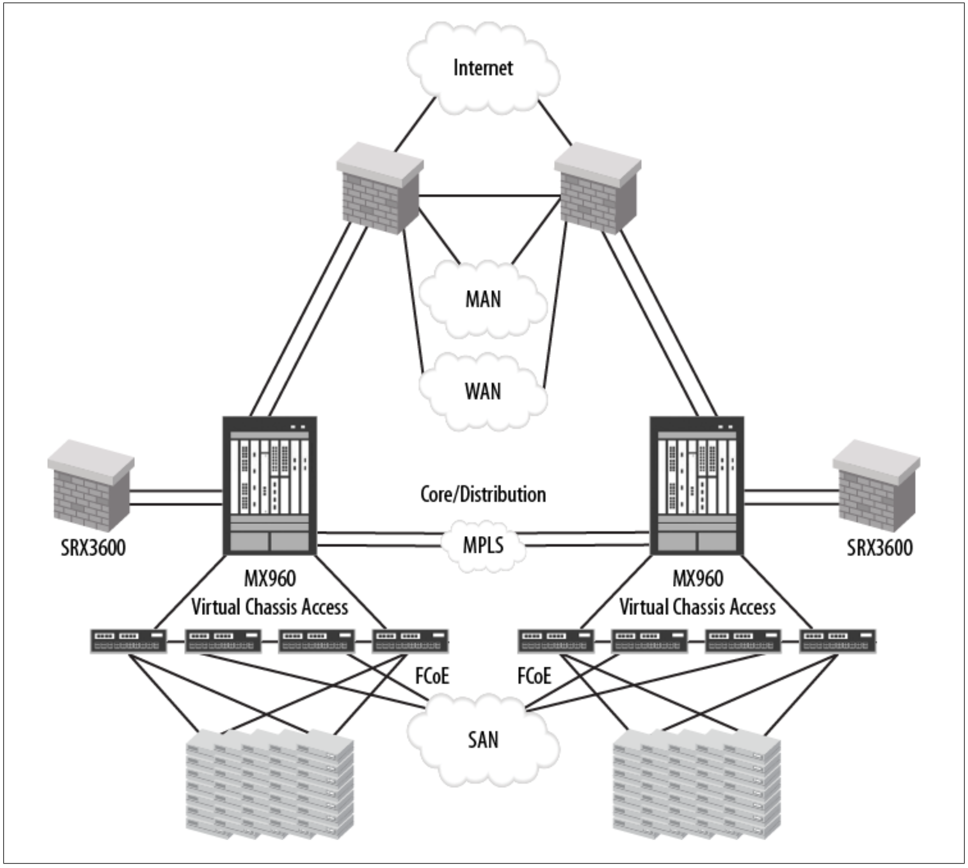


Figure 2-9. Consolidated data center design

This new network design flattens the data center and provides these benefits:

- Reduced equipment count, saving floor space, power, and cooling
- Reduced hop count, so user-to-server and server-to-server communications have minimal processing
- Reduction in links and routes simplifies the architecture while maintaining availability and reliability
- Scalability by using MPLS and a two-tier design, so scaling becomes a matter of merely adding greater access switches

From a survivability perspective, the new design could become even more robust by clustering the SRX3600s, and the MXs could be set in a virtual cluster. These capabilities, while costly in equipment, space, power, and cooling, would provide another level of survivability that might be deemed necessary by the enterprise.

What is not necessary is the associated increase in the number of links between these survivable elements and the other devices, as shown in Figure 2-10. When the links are provisioned as either LAG links or redundant Ethernet links, they can reside on either member of the pair of devices, providing the same availability and efficiency as the previous design with an increase in survivability.

The MX960 is available with redundant routing engines, switch fabric, power supplies, and cooling systems. The virtual chassis arrangement guards against a chassis failure.

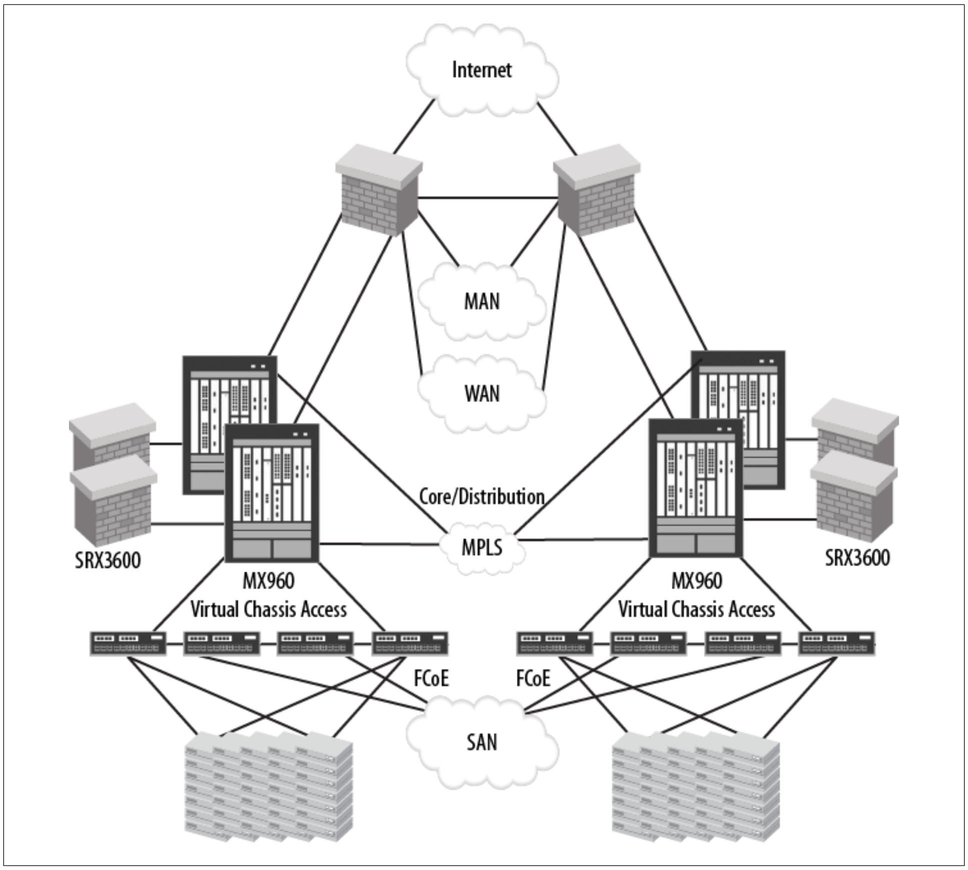


Figure 2-10. Ultra-survivable data center

Campus Architecture

University campuses have not been immune to the changes in Internet use. Social networking, file sharing, and peer-to-peer networking are all aspects of a university campus's internal network, and the days of using the Internet solely for research and development are long gone. One campus security administrator stated that he had two untrusted networks to deal with: the campus and the Internet. Security and bandwidth concerns are such that universities and corporations have deployed standalone R&D networks, such as the Internet2.

The challenges facing campuses today are similar to those faced by enterprises, but with the addition of tens of thousands of users who often have free time on their hands and an affinity for social networking. The challenges can be divided into security, classes of service, and availability. The case that is presented here is for a large university.

Legacy Campus Backbone

Our campus network is divided into three areas: the common backbone network, the departmental networks, and the inter-university backbone. Each department maintains its own data center and office connectivity. Some departments maintain Internet and extranet access and firewalls for protection (an enterprise within the campus). Other departments use the services of the backbone network for outside access (Internet and inter-university).

There are 80 departments on the campus and some 20,000 students in dormitories. The legacy network, as shown in Figure 2-11, was designed to act as a common backbone between all buildings, and as you can quickly guess, as departmental demands for bandwidth and security grew, more overlays were added to the network. What is depicted in Figure 2-11 is just one of the overlay networks; five such overlays exist. Most buildings are connected to one or more of the overlay networks, and all of the networks are routed, with public addressing being used throughout the campus.

A single ISP provides Internet access, with each firewall dedicated on a per-department basis. In an attempt to avoid viruses and other nasties, a stack of IDS devices are installed to monitor traffic.

By the way, there is no centralized management for the network; each department has its own management system, as does the backbone.

Goals and Constraints

Universities, like enterprises, are budget-constrained, and both CAPEX and OPEX budgets are under close observation by each department and the central administration. The backbone network must "bill back" to the departments and colleges for its services, adding another budget-related complication.

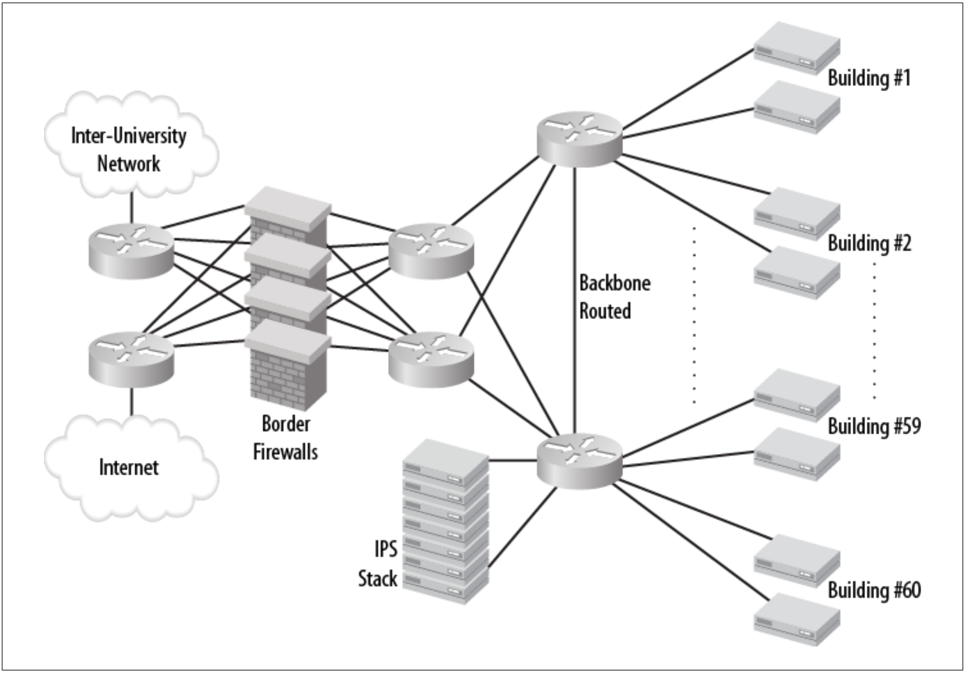


Figure 2-11. Legacy campus networks

The management of the network is complicated by pressure from groups such as the Recording Industry Association of America (RIAA). The RIAA has been pressuring the university to monitor music trafficking and show due diligence in stopping copyright infringements.

It seems that students always find ways to utilize all the available bandwidth on the backbone networks and the Internet, and the university must install a service classification system that will limit the amount of traffic accepted onto the backbone from the dormitories. This allows departments to have adequate bandwidth to perform their assigned functions and education requirements.

One of the services offered by the backbone to the departments is a managed firewall service, and the university needs an easy way to handle adds, moves, and changes for firewall policies and user communities.

Solution: Campus Network

The solution to the campus backbone is replacing technology and relying on virtualization. The routed networks are being replaced by a single Ethernet switch backbone, as shown in Figure 2-12. Six EX8208s are used as the backbone for the campus. Each EX8208 is dual-connected to other backbone switches, and each is running VSTP. Each building is served by an EX4200. Geographically adjacent buildings are interconnected

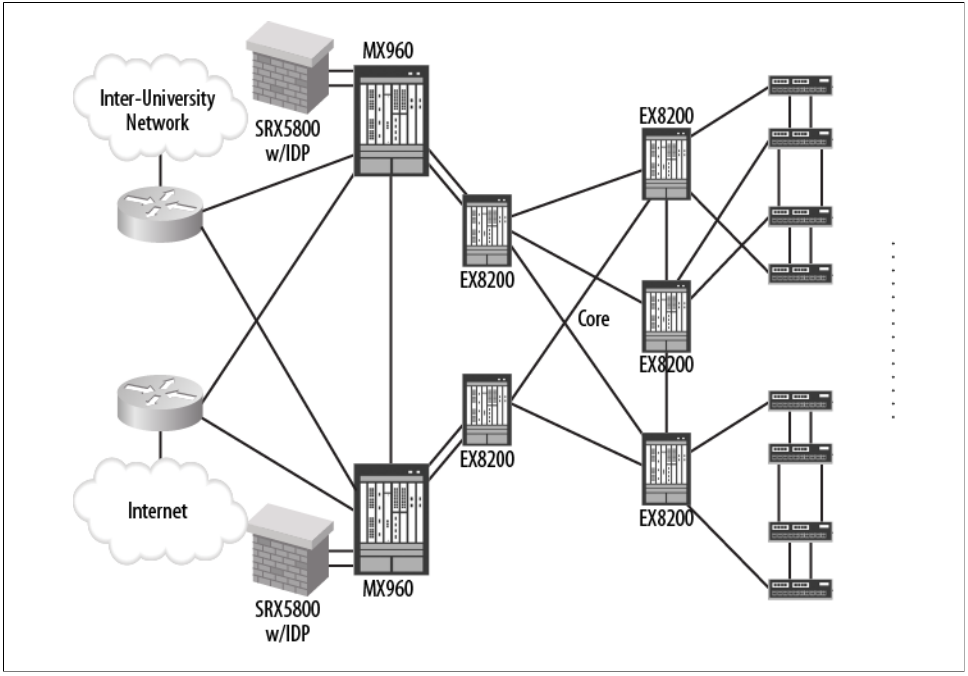


Figure 2-12. Campus network solution

with fiber to form an inter-building virtual chassis. Each virtual chassis is connected to multiple backbone switches with a LAG bundle, and the EX4200s form the access tier for departmental and dormitory traffic.

The backbone is connected in a dual-star configuration to a pair of MX960s. The MXs are the next hop router for all departmental traffic and connect via BGP to the Internet and the inter-university network.

Associated with each MX is an SRX5800 running IDP services. The MX/SRX pairs are operating in a primary/secondary mode, with either capable of handing the entire load of the university.

Virtualization provides the security and controls departmental traffic, as each department is assigned a VLAN that appears in the EX4200s only when members of the departments are attached to that switch. The VLANs are mapped to a separate virtual router in the MX960 and the SRX5800. Intra-VLAN traffic is switched locally in the backbone, whereas inter-VLAN traffic must traverse the MX/SRX pair. The Internet is on its own virtual router, as is the inter-university network. A common routing instance on the MX allows the interconnection of all the other virtual routers.

Traffic to and from the Internet and the intra-university network is monitored by the IDP policies. All policies are logged (IDP and security) to a secured syslog system, and any of the traffic in the backbone can be mirrored to traffic-capture servers.

The EX4200s support a four-level class of service capability that allows traffic to be policed at the ingress point. Traffic from the dormitories is classified and policed. The ingress interfaces on the MXs also have thresholds set for student traffic and perform a tail-drop function on excess traffic.

Within the SRX, each department has a slice of the firewall. Each department can contract with the backbone office for firewall service or perform its firewall functions in the department network. In the latter case, the firewall policies in the SRX are permissive. If the department elects to use the backbone services, then a full set of interdepartmental policies are created. Each department has two security zones: the trusted zone contains the interfaces (and VLANs) to the department, and the untrusted zone has an interface to the common routing instance on the MX. Traffic always passes through two firewall policies when it leaves the department (the original department's policy and the destination department's policy). The same is true for Internet and interuniversity traffic. This arrangement allows full flexibility and control of all traffic.

Conclusion: Design Best Practices

The solutions in these new network designs all adhere to a common set of design principles:

- First, every design is secured, both from an informational security perspective and from a reliability perspective.
- Second, they combine the functions of the distribution and core tiers into a single tier where possible.
- And finally, they simplify the network architecture to the base elements, thus reducing management, CAPEX, and OPEX.

For any enterprise design, nothing beats homework. Today, networks are complex arrangements that cannot be left to chance. Each design must be researched, assembled, proven, and then implemented. This cycle never ends; as one design is implemented, another is in the research stage. That's because technology is moving at such a fast pace; if a network is left to its own devices, it will be obsolete in a very short time.

All of our network redesigns used Juniper Networks EX switches, MX edge routers, and SRX Services Gateways. Juniper has created design guides for most enterprise installations; see *http://www.juniper.net/techpubs*.

CHAPTER 3

Juniper Switching and Routing Platforms

In the previous chapters of this book, we examined Juniper Networks enterprise devices and designs to bring you up to date on what is happening in enterprise networking. However, we did not cover which devices should be used, where in the designs they can be used, and why those devices are best situated for such positions. Investigating and answering those questions is the role of this chapter.

Enterprise Network Roles

Rather than revisit each design from the last chapter, let's use a simpler reference design. Our new reference design contains five types of devices, each used to describe the device roles in the enterprise network. Listing them from the outside of the enterprise network to the inside, the five devices are: the screening router, the security gateway, the Internet border router, core routers, and the access routers (see Figure 3-1). The term "router" is used here very loosely; in some cases an Ethernet switch is implemented in the reference position in enterprise networks.

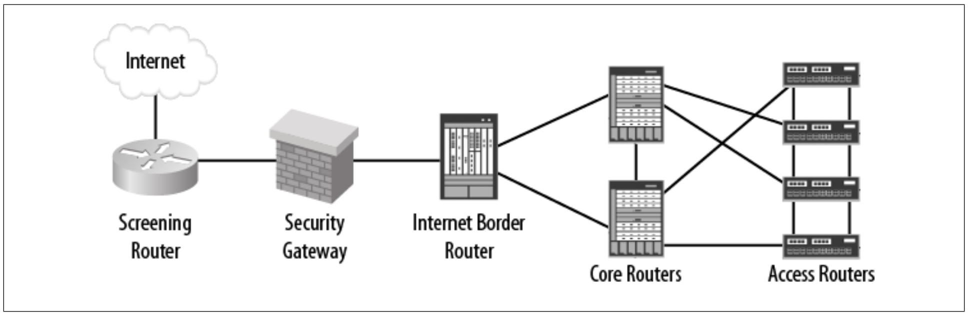


Figure 3-1. Enterprise reference diagram

Of course, enterprise networks vary widely in their implementations. Some networks do not have all these reference devices, and some have other devices not defined here. The choice of device type is often decided in the topmost layers of the protocol stack (sometimes called layers 8 and 9, or politics and cost). Our device recommendations are primarily based on features and size, and take into account those wide-swinging variables, politics and cost.

Screening Router

The classical screening router provides a buffer between the "private" networks and the Internet, with its principal function to protect the other devices from attacks originating on the Internet. These functions include but are not limited to:

Firewall filters
: The screening router implements a series of protective firewall filters that stop unwanted traffic from entering the enterprise network.

Network address translation
: If the enterprise uses private addressing for internal operations, the screening router is a prime choice for implementing that function.

Routing
: The screening router typically will not implement BGP and full-size routing tables, because it has routing priorities to allow differentiating between internal traffic and possibly traffic for a demilitarized zone (DMZ). Such routing is often implemented in static routes.

Screen options
: Denial of service attacks can be thwarted by the use of the screen options found in select Juniper devices. These enhanced firewall options recognize common attacks and stop them from affecting internal devices. (A full listing of the available screen options and the devices that support them can be found in the Juniper Networks knowledge base at *http://kb.juniper.net*. Look for KB16618.)

Although the need for a screening router might be debated, the functions performed by this device cannot be eliminated from the enterprise network. For network engineers who deploy a screening router, the choices are determined by the device's required interfaces, the Internet access speeds, and the security feature set that is required.

The J-series routers and the Branch Office SRXs are preferred for this role. Both can handle Ethernet and WAN interfaces. The WAN interfaces range from T-1 speeds to DS-3s.

The choice between either the J-series or the SRX is one of cost and throughput. Both have the same feature set and almost identical WAN interfaces. The J-series are more traditional routers, whereas the Branch Office SRX models offer cost savings but have a lower throughput.

A J2320 with high memory (1 GB DRAM and 512 MB Flash) has a rated throughput of 600 Mbps with large packets and 400 Mbps with mixed packet sizes. The SRX220 with high memory (1 GB DRAM and 1 GB Flash) has a rated throughput of 950 Mbps with large packets and 300 Mbps with mixed packet sizes. The SRX220 lists for roughly half the cost of the J2320.

The political decision of whether this is a firewall to be managed by the security group or a router to be managed by the network group might be the deciding factor in which device type you choose.

Security Gateway

The next device type in our reference network is the security gateway. Although the usefulness of the screening router might be debated, the requirement of a security gateway cannot. Due to the unruly nature of the Internet today, no enterprise, SMB, or residence can be connected without the protection offered by a security gateway.

One of the major distinctions between security gateways (aka firewalls) is their underlying treatment of traffic. The two major divisions in traffic handling are packet-based processing and flow-based processing. In a packet-based system, each packet is treated as an individual entity. Each is allowed or denied based on the attributes of the packet (and possibly the history of packets of similar structure). These types of devices are referred to as *stateless firewalls*.

The flow-based devices look at traffic as part of a sequence of packets working together in a session. These devices are referred to as *stateful firewalls*. The distinction is easier to understand with an example, as in Figure 3-2, illustrating the state diagram for a normal TCP session. Here, a session is initially opened when a SYN message is received. When acknowledgment is received, the session moves from the opening to the open state. In the open state, data is passed between the devices engaged in the session. Once the data has been exchanged, the session closing is initiated with the sending of a FIN message. The closed state is the final (idle) state for TCP, and is indicated by the receipt of the FIN acknowledgment message.

A stateless device would look at each TCP message individually and act on it based on the information contained in the message. These attributes are compared to a security policy of some kind and either allowed or denied based on the action specified in the policy. The advantage of the stateless devices is their simplicity. No history is needed, and only the present packet is known. The disadvantage with these devices is that many attacks are performed with well-groomed packets that can pass any attribute test because they are legal packets; they are simply out of sequence or are causing state transitions that are not good. For example, a device sending thousands of SYN messages without acknowledging them could give the receiving server heartburn. Each SYN message is fine, but when tens or hundreds of thousands of these are received at the

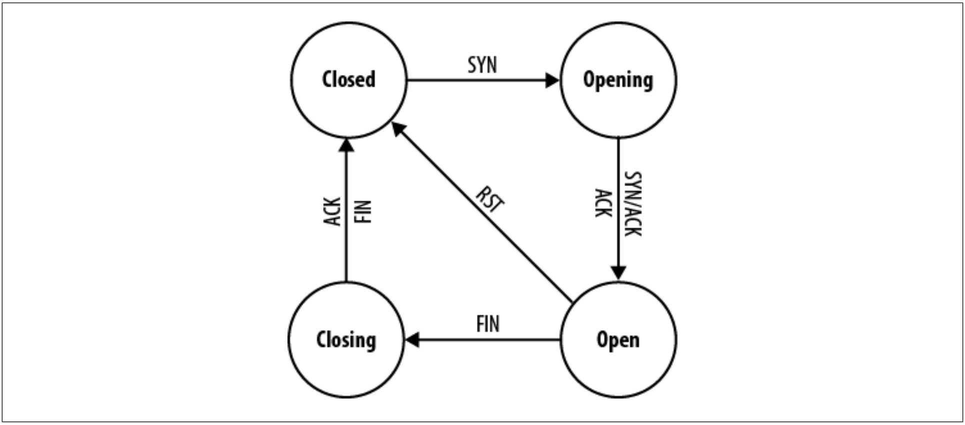


Figure 3-2. TCP session states

same time, there is a problem, and stateless devices do not filter against this type of attack.

> A communications session is defined by the source and destination IP addresses and the source and destination UDP or TCP port numbers. This quad of addresses associates a single computer to a single server application.

Stateful security gateways look at each packet and compare it to the other packets received in that session. If messages are out of sequence (receipt of a FIN ACK prior to a FIN, or multiple SYNs without ACKs), the stateful device will block these packets, even if everything is fine with the attributes of the packet. The advantages of stateful security gateways are that they can recognize a greater variety of attacks and can provide a higher throughput than stateless gateways. The increase in throughput is due to the reduced processing performed on a per-packet basis. In a stateful scenario, the originating packet of the session is subjected to the full-lookup processes of the gateway. Once the packet passes policies and routing, it is entered into a session table. All subsequent packets are first compared to the session table. If a match is found, the same treatment as the fist packet can be applied to these later packets, reducing the overall processor load for the gateway.

As noted, the primary function of the security gateway is to provide protection to the enterprise network. This protection is offered in many forms, all of which overlap in functionality, increasing the chances of catching attacks prior to them causing harm:

- Network address translation masks the internal network structure.
- Stateless filters block obvious attacks.

- Screen functions block denial-of-service (DOS) attacks.
- Stateful filters block attacks that are designed to disrupt devices.
- Intrusion detection and protection policies root out and stop known threats.
- Unified threat management software looks at the content of the allowed traffic and searches for malicious content.
- Management devices monitor the network as a whole, looking for trends and abnormalities.

The device choices for security gateways are the SRX Services Gateway product lines (the J-series routers might be considered as an option, but they are a stretch). The SRX line of security gateways is typically divided between the Branch Office SRXs and the Data Center SRXs, the distinctions being features and throughput.

The high-end Data Center SRXs support throughput rates that would satisfy the largest enterprise Internet appetite. Their feature list includes the full suite of services, except the UTM capabilities (anti-spam, anti-virus, content filtering, and URL filtering). The high-end SRXs support only Ethernet interfaces, limiting the positioning of these devices in the network (they cannot directly connect to a WAN circuit).

The Branch Office SRXs have the same feature set as the Data Center SRXs but with the added capabilities of UTM. The Branch Office SRXs also can incorporate WAN interfaces directly into the device. Another area of flexibility is their support for other technologies. The devices include power over Ethernet (POE) and voice over IP (VoIP) protocol support (the SRX can act as a VoIP switch in an emergency). The Branch Office SRXs can also control a WiFi access point.

The choice between these two device families in your network boils down to the features and throughput you need. For enterprises that need massive throughput, the Data Center SRXs are the better choice, and any omitted features needed can be provided by other devices in the enterprise. These devices accept a full BGP route table and provide a 10-gigabit interface to the Internet.

For those enterprises that do not have massive Internet requirements but would like to have a single point for all security concerns, the Branch Office SRX is a logical choice. These devices can be the network's focal point for security in the enterprise. Additionally, they can be the controllers for voice, WiFi, and wired traffic in the enterprise.

Although not considered here, the J-series routers offer a full set of security features, as do the legacy Netscreen firewalls. These products are still available from Juniper and will fill the roles described previously. For full details on the capabilities of these products, check out the Products and Services tabs at *http://www.juniper.net*.

Once the feature versus throughput battle is decided, the model within the family has to be chosen. This decision is based on three factors: the number of interfaces, the type of interfaces, and the expected throughput for the security gateway. Table 3-1 provides a look at the SRX Branch Office choices. The throughput numbers are given in bits per second and connections per second, and the port options show the number of onboard fixed Ethernet ports and the number of optional card slots that can be used. The I/O cards for the Branch Office SRXs support one WAN interface per mini-PIM, except for the slots in the SRX650, which can accommodate Ethernet cards (up to 24 ports per card) or a WAN card.

Table 3-1. Branch Office SRX options

	SRX100	SX210	SRX220	SRX240	SRX650
Firewall performance (max)	650 Mbps	750 Mbps	95 Mbps	1.5 Gbps	7 Gbps
Connections per second	2,000	2,000	2,500	9,000	30,000
Fixed Ethernet ports	8	8	8	16	4
WAN/LAN I/O slots	N/A	1	2	4	8
POE ports	N/A	4	8	16	48

The Data Center SRXs lack the WAN interfaces and the POE support but sport higher performance numbers and can handle large numbers of connections per second. Table 3-2 lists the specifications for the Data Center SRXs.

Table 3-2. Data Center SRX options

	SRX1400	SRX3400	SRX3600	SRX5600	SRX5800
Firewall performance (max)	10 Gbps	10Gbps	20Gbps	30Gbps	60Gbps
Connections per second	45,000	175,000	175,000	350,000	350,000
LAN I/O slots	1[a]	4[a]	6[a]	5[b]	11[b]
Fixed Ethernet ports	12	12	12	N/A	N/A

[a] Up to 16 port Ethernet IOCs

[b] Up to 40 port Ethernet IOCs

The choice between these devices is made based on the expected load to and from the Internet. There are no recognized guidelines for the number of connections per second per user, and experience dictates that when a better Internet connection is installed, more users will take advantage of it (which makes historical data almost useless). Best practice guidelines are typically to size the gateway for the enterprise needs and then restrict recreational use to an acceptable limit.

Internet Border Router

Like the security gateway, the Internet border router is an integral part of any enterprise network because the Internet is a routed network that requires a routed interface. The ISP must have a routed next hop to reach the enterprise, and the enterprise must have a default gateway to reach the Internet. The Internet border router offers this function. It is the external/internal demarcation for routing protocols and possibly the public/private demarcation for IP addressing (if the enterprise is using RFC-1918 addressing for internal addresses).

Private IP addressing, also referred to as RFC-1918 addressing, uses the addresses in the range of 10.0.0.0/8, 172.16.0.0/12, or 192.168.0.0/16. These addresses are not assigned in the Internet. As such, they can be used in an enterprise as needed. When traffic leaves the enterprise, the RFC-1918 addresses are translated to a public address at the Internet edge. Typically the security gateway device performs the translation, but it can be performed in the Internet border router.

The principal functions of the Internet border router deal with routing traffic from the Internet to the enterprise, and vice versa. This function can vary wildly in complexity, as illustrated in the various scenarios discussed here, but additional functions of the Internet border router deal with access security, which includes both information security and survivability.

The information security functions of the Internet border router focus on limiting the exposure of the enterprise network to probes and scans generated on the Internet. The Internet border router should:

- Not respond to requests from ICMP, HTTP, Telnet, or SSH
- Have authentication for all routing protocols, to limit the exposure to spoofing attacks
- Employ reverse-path lookup for all received traffic
- Have an up-to-date martian/bogon address list and block all traffic from or to these addresses
- Employ prudent route policies that strictly define the acceptable routes to be received or advertised

The survivability functions of the Internet border router should protect against single points of failure between the ISP and the enterprise. The more survivable the Internet access, the more complex the routing becomes. Figure 3-3 provides a quick look at four options. The simplest option (shown on the far left) provides no survivability, whereas the most complex option (far right) can survive the loss of any Internet access component.

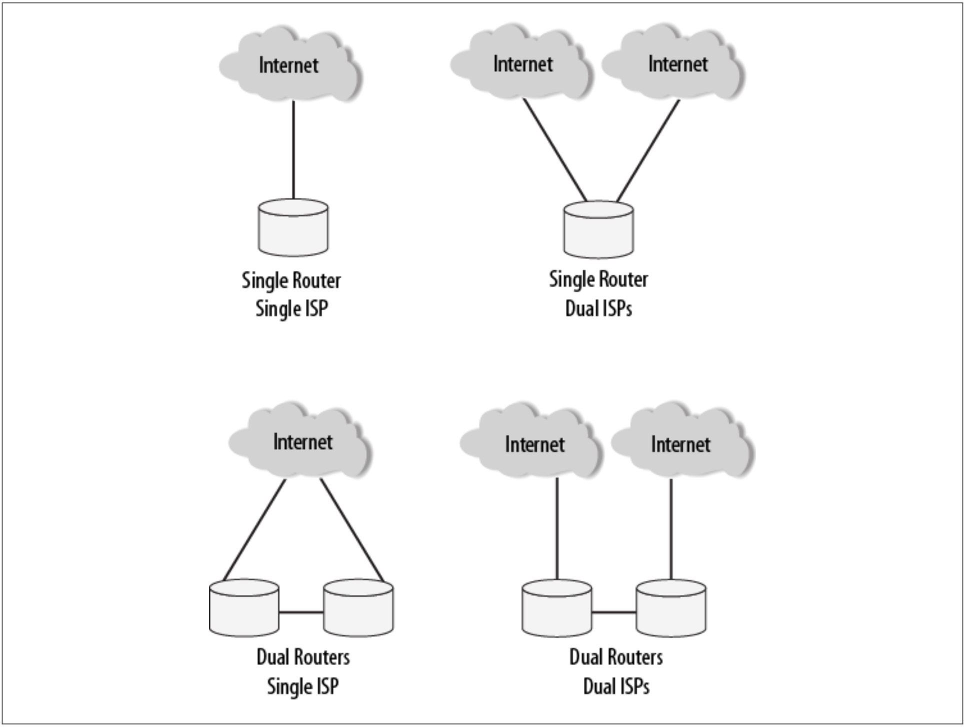


Figure 3-3. Internet border router survivability options

The routing functions of an Internet border router depend on the routing mechanisms in use for the Internet connection and the survivability.

The configuration examples for the routing and survivability are found in Chapter 6.

Single link

If a single ISP link and static routing are employed (the first example in Figure 3-3), the routing operation is obviously straightforward. All internal devices use a default route to the Internet, and the ISP advertises the enterprise's address blocks to the Internet. The Internet border router uses a static default route for all traffic and readvertises that default route to the internal routers. In the event of an Internet link or Internet router failure, the static route would be withdrawn, and the traffic destined for the Internet would be discarded at the originating router.

If a single ISP link and the BGP protocol are employed, the configuration is a little more complex, with the enterprise and the Internet border router advertising the enterprise address blocks to the ISP (note that the survivability is the same as with static routing).

Dual links, single router

When multiple links to the Internet are used, the survivability options and the routing complexity increase. On the survivability front, a failure of an interface or a link will not cause a loss of Internet access. On the routing front, the use of static routes or the BGP protocol can be implemented to provide a primary/secondary relationship between the ISP links. Although load sharing between the ISP links is possible, it presents a number of issues that have to be resolved, the most complicated of which is the resolution of asymmetrical routing (traffic leaving on one Internet link and returning on the other). Typically asymmetrical routed traffic is blocked if stateful security devices are used.

When multiple links are employed in a primary/secondary relationship, a single default route is advertised to the internal routers. If one of the Internet links becomes unavailable, the other would be used in its place and the internal routing would not be altered.

Dual links, dual routers

This option offers the best protection from failures and involves the most complex routing configurations. The possible scenarios for multiple links are the same as those in the dual links, single router option, but in this case multiple default routes are provided to the Internet. Each router advertises its own route to the Internet to the internal routers, and when one link fails, that route is withdrawn and the secondary route is used.

When multiple ISPs are used, the use of BGP is required. That's because the enterprise advertises its block of addresses to one ISP as the primary route from the Internet to the enterprise, and the advertisement to the secondary ISP contains attributes that spoil those primary routes. All traffic to the Internet is handled as with dual links, single router: all traffic from the Internet follows the path to the primary ISP, and in the event of a failure of the primary ISP, Internet traffic follows the path through the secondary ISP.

Internet border router device options

Choosing an Internet border router device is best determined by considering the following factors:

Bandwidth of the Internet link
: The amount of bandwidth required by the enterprise is an economic decision. Enterprises will use all the available bandwidth to the Internet, regardless of the speed of the interface. The router must be able the handle the peak loads of the Internet link.

BGP routes
: If the enterprise receives the full routing table from the Internet, the router must be powerful enough to quickly store and handle the more than 330,000 prefixes that are being passed today in the Internet.

Security functions
: Sometimes the Internet border router and the Internet security gateway are the same device. In this case, the router needs to be able to handle security roles as well as the router roles.

Interface options
: The router will often need to interface to the Internet over a wide area link, which requires the use of WAN interfaces and protocols.

Given all the possible choices of Juniper devices that can be used as an Internet border router, a few standouts appear, as you can see in Table 3-3.

For enterprises with Internet feeds less than 1 Gbps that want a consolidated device to perform both Internet router and security functions, the SRX650 is the preferred device. If security functions are not required (i.e., an Internet security gateway is being deployed), the best selection is the M7i.

For enterprises with Internet feeds greater than 1 Gbps that are consolidating routing and security, the high-end Data Center SRXs are the right choice. If security functions are not required at this juncture, the M10i is the choice. If the Internet border router and the core router are going to be collapsed into a single device, the best selection is an MX model.

Table 3-3. Internet border router choices

	SRX240	SRX650	SRX (dc)	J2320	J2350	J4350	J6350	M7i	M10i	MX
Internet link										
10 Mbps	X	X	X	X	X	X	X	X	X	X
100 Mbps	X	X	X		X	X	X	X	X	X
500 Mbps		X	X					X	X	X
1 Gbps		X	X					X	X	X
Over 1 Gbps			X							X
Security										
Stateless	X	X	X	X	X	X	X	X	X	X
Stateful	X	X	X	X	X	X	X			
NAT	X	X	X	X	X	X	X			
Routing										
EBGP (full feed)		X	X			X	X	X	X	X
IBGP	X	X	X	X	X	X	X	X	X	X
Policies	X	X	X	X	X	X	X	X	X	X
OSPF	X	X	X	X	X	X	X	X	X	X
Interfaces										
WAN support	X	X		X	X	X	X	X	X	X
Ethernet 1 Gbps	X	X	X	X	X	X	X	X	X	X
Ethernet 10 Gbps			X							X

Core Routers

The core routers of an enterprise network are the principal devices that provide connectivity (some architects consider them the only routers) and hold the center of the network together. They are responsible for the speed and "reach" of the enterprise network and are the principal focus of the high-speed Juniper product line. As the number of layers in the enterprise network is compressed, the core layer remains and absorbs the responsibilities of the other layers.

Those responsibilities include:

IBGP
: For enterprise networks that have multiple Internet points of presence, or for very large enterprises, BGP is used to handle prefixes.

IGP
: OSPF (or possibly ISIS) is the principal standards-based interior gateway protocol (IGP) used by enterprises. The core routers need to be able to support all aspects of these protocols and the supporting functions (filters, policies, etc.) that allow them to provide controlled connectivity.

CoS
: The bandwidth of the enterprise is under attack from applications and services that simply weren't around just a few years ago. Instant messaging supports video, music downloads are 30Mb per song, and YouTube videos are used for political campaigns. Any of these can usurp the bandwidth of the core. CoS assures that enterprise-critical traffic is not blocked.

WAN
: The core of the enterprise connects all other network components, including the wide area network. The core router must be able to interface to legacy WAN protocols (ATM, frame relay, PPP) as well as the newer VPN protocols (L3VPN, VPLS, L2VPNs).

Survivability
: Because of the core's critical role in an enterprise, it must support features that ensure the survivability of the network. Hardware and software redundancy, link aggregation, and short convergence are all features that will protect the network.

Core router device options

Similar to the other devices in our reference network, the selection of a core router depends on a number of factors, although they can be reduced to just a few key traits: forwarding technology, total throughput, and interface types.

Depending on the overall architecture of the enterprise network, the core devices are routers or switches. If the enterprise network follows the legacy design philosophies, the core will consist of Ethernet switches. In this case, the choice of devices is between the EX8000s and the MXs, both of which offer switching capabilities that can handle the demands of the core. If the enterprise implements a more collapsed design, such as one of the examples in the previous chapter, the core device would be a router, in which case the selection would be based on the throughput and interface offerings shown in Table 3-4.

Because of the collapsed nature of the enterprise network and its fundamental need for survivability, all core routers should be able to handle the full load of the enterprise. With today's applications, that throughput requirement could easily reach 10 Gbps, so today's selection of a core router should be made with that figure in mind.

The M7i and the M10i are fully capable of handling any requirements of the core router for total throughputs less than 10 Gbps, but they quickly run out of horsepower for throughputs approaching that number. The mid-range MXs are a new option that can replace the M7i and the M10i. The throughput for these new devices begins at 20 Gbps, allowing them to handle even greater amounts of traffic than the enterprise M-series routers.

The MX series and the EX 8000s are built to support throughputs above 10 Gbps, as shown in Table 3-4.

Table 3-4. 10 Gbps core router options

	MX240	MX480	MX960	EX8000
Backplane	480 Gbps	1.4 Tbps	2.6 Tbps	6.2 Tbps
Throughput	440 Mpps	1.3 Bpps	2.4 Bpps	1.92 Bpps
WAN interfaces?	Yes	Yes	Yes	No

The specifications in Table 3-4 need further explanation. The backplane figures are the system capacities of the various devices and represent the total throughput that the device can handle fully loaded, with cards. However, this number typically double-counts the traffic (so that a 100 Mbps interface can handle 200 Mbps of traffic). The actual system throughputs of these devices are considerably lower than these numbers because of the constraints of the protocols and the traffic patterns seen in a network, but all of these devices will handle traffic load well above 10 Gbps. The throughputs are calculated with a fixed frame size and represent, again, a perfect environment. For the MX devices, the frame size calculates out to 136 octets per frame; for the EX8000, that number is 400 octets per frame.

The interface type supported by the device is the other factor when choosing a core router. If the core is totally Ethernet, which is a fair assumption for many enterprises, any of the devices shown in Table 3-4 will fill the role. If legacy WAN support is required for the core device, the MX platforms are the better choice.

Out of all the core router or switch choices, the EX8200 supports the greatest throughput per dollar spent.

Access Router

As described for other devices in our reference diagram, the exact requirement for a distinct access layer in the architecture is debatable. Regardless of whether the layer is implemented in separate devices, the functions associated with the layer must be provided in the enterprise network. Assuming that an access layer router is part of the design, its functions include class of service (CoS) definitions, server and client device handling, security, and routing functions.

Class of service functions deal with the classification, marking, and queuing of traffic to and from the end devices. If proper class of service marking is performed at this point in the enterprise, all other devices can provide a consistent quality of service to designated traffic. The classification and queuing aspect of CoS is needed only for terminating traffic to servers attached to the access layer. The primary purpose of the access router is to connect user computers and terminals to the resources of the network and to connect the network to the servers of the enterprise. To fulfill this purpose, the router has to have a mechanism to:

- Provide survivable access for all users (client or server). This is accomplished by means of a virtual router redundancy protocol (VRRP). This allows multiple devices to provide gateway services to access devices with failover capability.
- Provide an automated management function that provisions IP addresses, default gateways, DNS and NTP servers, etc., on the end devices. This function is accomplished by use of a dynamic host configuration protocol (DHCP).
- Provide a means to ensure that traffic from one information silo cannot gain access to the information in another silo. Virtual LANs is a means for segmenting traffic.
- Provide a primary and alternate path from the access devices to the enterprise's resources. This is accomplished by the use of dynamic routing protocols and link aggregation.

A secondary function of the access router is to provide a connection between the storage systems of the data center and the resources of the enterprise network. Storage area networks and network attached storage systems have their own distinct protocols (i.e., fiber channel and SCSI) that need to be incorporated into the enterprise network. The full treatment of these important protocols is beyond the scope of this book, but a good reference is *Data Center Network Connectivity with IBM Servers*, which is freely available at *http://www.juniper.net/books*.

The difference between the legacy design approach (Figure 3-4) and those advocated by Juniper Networks is the consolidation of the enterprise design's access and distribution layers.

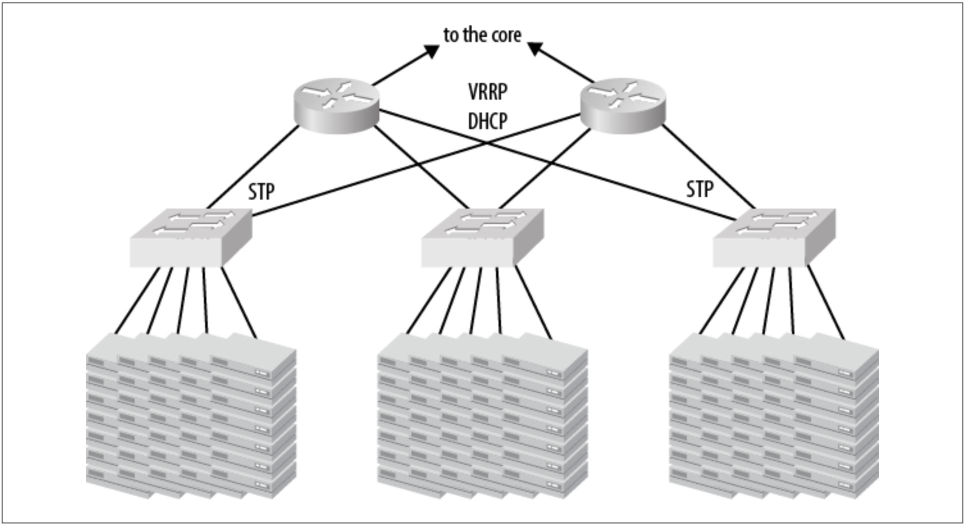


Figure 3-4. Legacy access/distribution design

In the legacy design, the access layer is an Ethernet-switched layer providing fast access to distribution routers. When these layers are consolidated, as shown in Figure 3-5, the functions of the distribution layer (for example, VRRP, DHCP, OSPF) are also consolidated into the combined devices.

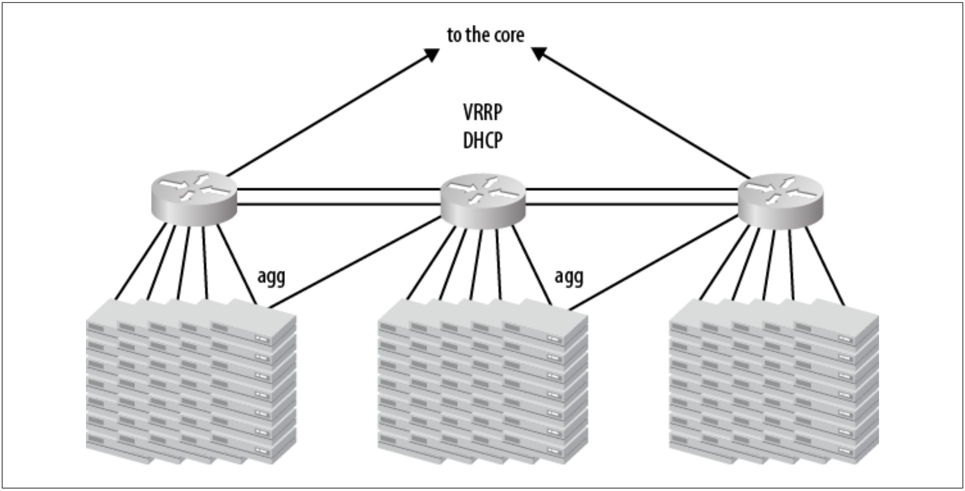


Figure 3-5. Consolidated access layer

The nature of the access layer is to allow large numbers of users to reach the services of the enterprise network. This requires either a large single device accompanied by a massive wiring plan or a group of devices. The devices offered by Juniper networks will satisfy both of these implementation scenarios. The use of virtual chassis technology allows these access devices to provide:

- Redundancy for the routing engine where each member of the virtual chassis has a routing engine, but only one is active and one is in standby mode. In the event of a failure of the active RE, the standby can take over control of the virtual chassis.
- Survivable aggregate Ethernet links are terminated on different switches of the virtual chassis. This offers greater bandwidth than redundant links with the same reliability.
- A single default gateway for the user devices is provisioned from the virtual chassis. All switches look like a single router to the user (server or client) devices.
- Options for the uplinks to the network core include redundant Ethernet links, equal cost routed links, primary/secondary routed links, and simple switched links. These options allow the virtual chassis access devices to operate in any scenario.

Access router options

The Juniper Networks options for the access router lie between its EX platform and its MX platform. Both device platforms are equipped with the required functions and have models that will fit the bandwidth requirements of small to large enterprises:

EX4200 virtual chassis
: Best choice for a top-of-rack installation, as up to ten 48-port EX4200s can be interconnected for a single access device. The EX4200 can be configured with switching and routing functions. The throughput limit on the EX4200 virtual chassis is tested at 128 Gbps, which should allow it to handle most enterprise applications. Additionally, the EX4500 can be added to the EX4200s virtual chassis, adding high-density 10 Gbps connectivity.

EX8200 (EX8208 and EX8216)
: Best choice for a collapsed access scenario, because the EX8216 can handle a maximum of 768 1 Gbps interfaces or 128 10 Gbps interfaces. The 16 slots can be provisioned with a combination of 10/100/1000 Mbps cards or 10 Gbps cards. The EX8200 series has full redundancy of critical modules but can be placed into a two-unit virtual chassis to further expand the port count and reliability capabilities.

MX960
: Best choice for a fully integrated device, as the MX960 supports up to 480 1 Gbps Ethernet ports and a total backplane throughput of 2.6 Tbps. All critical modules are redundant, and like the EX8200s, two MX960s can be interconnected in a virtual chassis.

The difference between the EX8200s and the MX960 could be described as follows: the EX is a massive switch with a routing fetish, whereas the MX is a massive router with a switching fetish. Although they both operate the Junos operating system and both platforms have a similar switching and routing configuration, the devices discussed are either scalable to the maximum (EX4200) or have smaller devices (mid-range MX, MX240, and MX480) that can be deployed.

Multiservices Gateway

As more and more applications are mapped to the IP infrastructure of the enterprise network—such as voice, multimedia conferencing, surveillance, video broadcasts, and more—our network devices have to support these services as well. The multiservice gateway is a new class of device designed to operate in this multiservice network, and a prime example of this trend is the Juniper Networks SRX240 Services Gateway. This modular device provides routing, switching, firewall functions, UTM, VoIP, WiFi control, and CoS. It could function as the only networking device for a remote office or can serve as any one of these functions for a larger department.

As the integration of services matures in the enterprise in the very near future, networking devices must be able to support the following functions:

- Multicast support for video and multimedia streams
- Class of service queuing, traffic shaping, and marking
- VoIP survivability support

Device Limitations

Any device analysis focuses on the advantages and benefits of the devices rather than the limitations of the devices, but best practice needs to consider the limitations, if only to ensure survivability, not to mention understanding how to design for network scalability. In the following sections, we address the notable limitations for each Juniper Networks series of devices.

M-series

The M-series enterprise routers are based on the architecture of the service provider platforms. Although this architecture offers significant advantages for routing packets, it creates limitations for supporting additional services and for troubleshooting.

One advantage and limitation of the M-series is the number of physical interface card (PIC) choices for the platform. The datasheets list the options for each model, but not the services that are supported on each module. There are services PICs, IQ PICs, IQE PICs for ATM, Ethernet, and serial protocols. The advantage is the flexibility inherent in the platform, and the limitation is having the right PIC for the implemented service.

One example is the note for the configuration of a VPLS interface: "On M Series routers (except the M320 router), the 4-port Fast Ethernet TX PIC and the 1-port, 2-port, and 4-port, 4-slot Gigabit Ethernet PICs can use the Ethernet VPLS encapsulation type." The other Ethernet PICs will not (or might not) support the required ethernet-vpls, extended-vlan-vpls, or the vlan-vpls encapsulation types. So for each advanced feature, the correct PICs must be in place for their proper operation.

Another limitation of the M-series (and other distributed-architecture Juniper devices) is the lack of visibility at the port level for traffic troubleshooting. There are few mechanisms for actually seeing what traffic is transiting the M-series interfaces. This limitation causes administrators to install external test and monitoring equipment for troubleshooting purposes. An alternative to external test equipment is installing a passive monitor PIC. If you have passive monitoring PICs and SONET/SDH PICs installed in an M160 or M40e router, you can monitor IPv4 traffic from another router.

J-series

The most significant limitation of the J-series is its age in the Juniper Networks product line. When the SRX was introduced and its security features integrated into Junos, the J-series took a back seat in the enterprise. Today an SRX running in packet mode is faster and often cheaper than J-series routers of equivalent port densities. In addition, these security features require more operating memory, thus reducing the capabilities of the J-series (for example, the routing table sizes are reduced).

MX edge routers

The MX series of edge routers have evolved from the gigantic MX960 down to the affordable MX5. Initially the I/O cards were limited to either Ethernet switching or IP routing, but later cards supported either routing or switching. The newest of the cards, the Trio, is capable of multiple functions but is not compatible with older cards. Like the M-series, the selection of MX I/O cards must be made with care. For the mid-range MXs, the upgrade paths and costs should be studied carefully to make sure that you are getting the device that fits your application.

EX switches

The EX switch series offers Ethernet switching capabilities and limited routing capabilities. The limiting factor for routing and other advanced features is based on the EX model rather than the OS. The EX2200 and EX2500 have very limited routing capabilities, whereas the EX8000s have full router capabilities. An additional caution is that only the EX3200 and EX4200 series support MPLS in Junos 9.5R1, limiting the use of these devices in L3VPN and L2VPN implementations.

SRX Services Gateway

The SRX is primarily a security device operating as a session-based router. In flow mode, the Branch Office SRXs cannot operate as an MPLS node. When in packet mode, the SRX continues to allocate memory to the flow-based processes.

Another limitation is the operation of Ethernet switching in the Branch Office SRX devices. When ports are enabled as Ethernet switching ports, they do not participate in the session processing. Traffic between Ethernet switch ports cannot be passed through security policies.

L2 and L3 Deployments

The early chapters of the second edition of this book focus on some of the newer Juniper Networks device features and capabilities found in the new enterprise network that blur the distinction between routing and switching. And this section continues that focus by defining the features that are not covered in the remainder of this book, which concentrates on enterprise routing and the routing capabilities you will find in your MX, EX, and SRX devices.

Here, before we launch into an in-depth look at enterprise routing, we take a quick look at the blurred features. Where the following features are better defined in another work, we reference that work rather than repeat the content here.

Link Aggregation Groups

Link aggregation groups (LAGs) are a means to increase bandwidth and redundancy between devices in the enterprise. These devices can be switches, routers, or servers. The LAG implementation in Junos follows the 802.3ad standard and can support up to eight interfaces. When LAGs are added to a virtual chassis operation, the links can be supported from different devices in the virtual chassis, increasing redundancy.

Figure 3-6 depicts a LAG configuration example where two interfaces, `ge-0/0/0` and `ge-0/0/1`, are part of a LAG called `ae0`. A LAG requires three separate settings: the chassis has to have the device count defined, the aggregate Ethernet (ae) interface must be defined, and the Ethernet interfaces must be associated with the `ae0` interface. If the link activation control protocol (LACP) were used, it would be applied to the `ae0` interface as an ether-option.

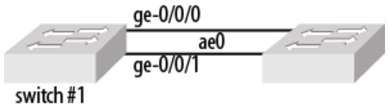


Figure 3-6. LAG example

To configure such a LAG:

```
[edit]
    peter@switch1# show chassis
    aggregated-devices {
        ethernet {
            device-count 1;
        }
    }
    [edit]
    peter@switch1# show interface ae0
    unit 0
    family ethernet-switching {
        port-mode trunk;
            vlan {
                members [all];
               }
        }
    }
    [edit]
    user@switch1# show interface ge-0/0/0
    ge-0/0/0
        ether-options {
            802.3ad ae0
        }
    }
    [edit]
    user@switch1# show interface ge-0/0/1
        ether-options {
            802.3ad ae0
        }
    }
```

Virtual chassis form a major component in the enterprise network architecture. Chapter 4 of *Junos Enterprise Switching*, by Reynolds and Marschke (O'Reilly), contains a full description of this capability. Virtual chassis capabilities have been added to the EX8200 and MX platforms, in addition to the EX4200 and EX4500 devices, as described in the switching reference book.

VPLS Implementation

Routing instances allow the Juniper routing platforms to support multiple routing and forwarding tables. They are commonly used to provide separation of routing protocol instances and customer instances for VPN deployments. In the campus environment and the data center, virtual private LAN service (VPLS) offers full connectivity between the devices running this VPN technology. The implementation of VPLS offers a good example of a virtual routing instance in a device.

Although a full treatment of VPLS is beyond the scope of this book, the bare essentials are provided here for one site of a two-site VPLS implementation, as shown in Figure 3-7. In this example, RSTP is used for signaling (LDP can be used as well). The interior-facing (VPLS) interface is ge-0/0/0, and the exterior-facing (LAN) interface is ge-0/0/1. All traffic entering into the ge-0/0/1 interface will be bridged to the corresponding interface on the other device (192.168.1.2).

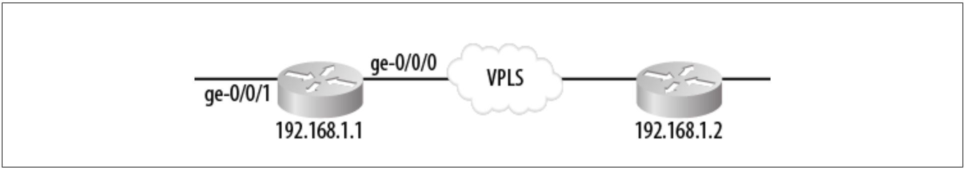


Figure 3-7. VPLS example

To configure such a VPLS implementation:

```
 [edit]
peter@M7i#show
.
.
.
interfaces {
    ge-0/0/0 {
        unit 0 {
            family inet {
                address 10.10.10.1/24;
            }
            family mpls;
        }
    }
    ge-0/0/1 {
        unit 0 {
            family vpls;
        }
    }
    lo0 {
        unit 0 {
            family inet {
                address 192.168.1.1/32;
            }
        }
    }
}
routing-options {
    autonomous-system 65001;
}
protocols {
    rsvp {
        interface ge-0/0/0.0; {
        }
        interface ge-0/0/1.0;
    }
    mpls {
        no-cspf;
        label-switched-path vpls {
            to 192.168.1.2;
        }
```

```
            interface ge-0/0/0.0;
            interface ge-0/0/0.0; {
            }
        }
        bgp {
            group ibgp {
                type internal;
                local-address 192.168.1.1;
                family inet {
                    unicast;
                }
                family l2vpn {
                    signaling;
                }
                neighbor 192.168.1.2;
            }
        }
        ospf {
            area 0.0.0.0 {
                interface ge-0/0/0.0;
                interface ge-0/0/1.0;
                }
            }
        }
    }
    routing-instances {
        vpls {
            instance-type vpls;
            interface ge-0/0/1.0;
            route-distinguisher 192.168.1:1;
            vrf-target target:65001:100;
            protocols {
                vpls {
                    site-range 8;
                    site ce1 {
                        site-identifier 1;
                    }
                }
            }
        }
    }
```

Miscellaneous Protocols

A few miscellaneous protocols are discussed here.

Spanning tree protocol

Spanning tree protocol and its variations, rapid spanning tree protocol and multi-instance spanning tree protocol, are covered in full detail in *Junos Enterprise Switching*.

Fibre channel

Fibre channel is a storage area network standard protocol that can operate over Ethernet (FCoE). The EX4500 supports FCoE to allow interconnection between data centers over Ethernet while preserving the Fibre Channel protocol and features.

Bidirectional forwarding detection

Bidirectional forwarding detection (BFD) allows a quicker failover between a primary and a secondary routed path. The protocol runs along with the routing protocol and tests the operational status of the interface multiple times per second. BFD provides for configuration timers and thresholds for failure detection. For example, if the minimum interval is set for 50 ms and the threshold uses the default value of three missed messages, a failure will be detected on an interface within 200 ms of the failure. This greatly reduces the times for OSPF and BGP failure detection.

BFD is configured on a per-interface basis:

```
[edit]
peter@M7i#show protocol ospf area 0 interface ge-0/0/0.0
bfd-liveness-detection {
     minimum-interval 50;
     multiplier 3;
 }
```

All-in-One Versus Components

The capabilities of the routers offered by Juniper Networks allow the same devices to be placed in many positions on the enterprise reference design. The MX can operate as an access, core, IBR, or screening router. The SRXs can fill the roles of every device between the users and the Internet. There is an underlying question as to which function should be combined and which should be separated, as illustrated in Figure 3-8.

From a security-in-depth point of view, the more individual devices there are, the higher the potential to thwart a hacker. A design that originates from the desk of a CISSP will have multiple layers of security, each implemented in a different device, operating system, reporting system, and control means. The CFO, on the other hand, would probably choose a design that provides the most features for the dollars spent.

So far in this chapter, the separate-is-better approach has been presented. Each function of the reference diagram is allocated to a unique device, and the options for each device have been examined.

But there is another option for the enterprise: the Data Center SRX, which provides the capabilities and features to operate as an all-in-one device for an enterprise. The SRX5800 supports security, routing, and switching functions in the same chassis. Although it has limited support for MPLS or non-Ethernet interfaces, it can interoperate with the devices that support these WAN capabilities. The SRX allows the configura-

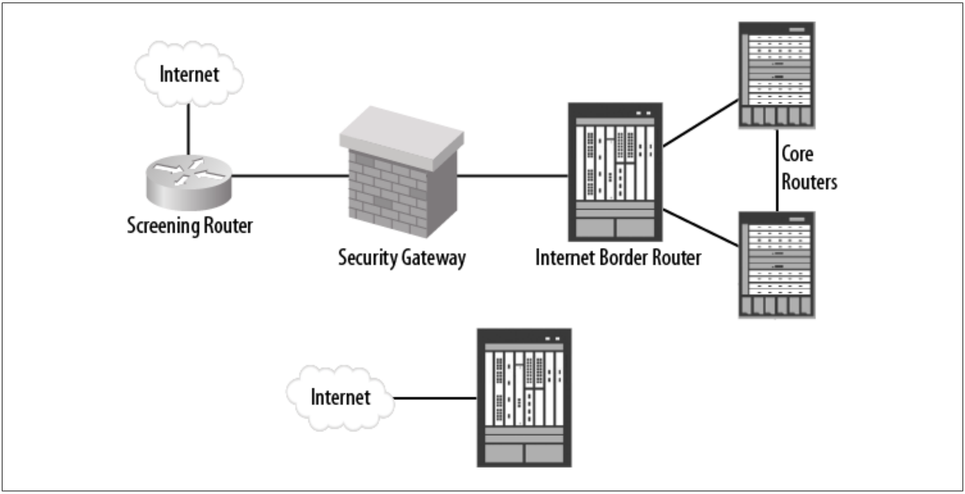


Figure 3-8. All-in-one

tion of multiple syslog and traffic logs, supports virtual systems for routing separation, and even supports IDP policies.

In a cluster, the SRX offers failure recovery without the loss of traffic and provides true survivability for all major components. The SRX can be managed from the command line, the J-web interface, the Network and Security Manager (NSM), or Juniper Space. And best of all, the routing functionality detailed in the rest of this book is as applicable on the SRX as it is on the MX or M-series routers.

The choice between all-in-one versus a component design for your enterprise comes down to a question of security-in-depth versus unified functionality and manageability.

For some security managers, the SRX has not yet earned its place in the network, because it is too new and not yet proven. Yet for many routing administrators who have worked with Junos for the last decade, the SRX is a opportunity to replace many devices from multiple vendors with a single Junos-ready device.

But the really good news is that everything in Figure 3-8 can run on Junos, a single network operating system that has the security, switching, and routing functionalities built in. The choice is yours.

The first three chapters of this book have focused on the new enterprise network and the new devices capable of meeting the challenges of enterprise networking in the next decade. Going forward, this book focuses on Junos enterprise routing, no matter which Juniper device or platform you have chosen.

Chapter Review Questions

1. What is the proper order for an Internet-facing enterprise network?
    A. Screening router→firewall→IBR
    B. IBR→firewall→screening router
    C. Screening router→core router
    D. Firewall→core routers
2. What type of firewall is more secure: stateless or stateful?
    A. Stateless
    B. Stateful
    C. Neither; an Internet border router is required
    D. Neither; both offer the same security
3. Which Juniper devices offer only stateless firewall support?
    A. M-series
    B. J-series
    C. SRX
    D. MX
4. For the access layer of a data center, the Juniper approach includes:
    A. Multilayer switches running STP
    B. A three-tier approach using OSFP and BGP
    C. A single-tier approach using virtual chassis switching
    D. Replacing all routing with switching and VPLS
5. A benefit of the all-in-one approach to Internet access is:
    A. Security in depth
    B. Distributed processing
    C. Management ease
    D. All of the above

Chapter Review Answers

1. Answer: A. Although D would work, separating the devices improves security.
2. Answer: B. In addition to tracking which packets are allowed, a stateful firewall can also look for attacks in allowed packets.
3. Answer: None. Sorry for the trick question; all Junos devices listed can offer both stateful or stateless services.

4. Answer: C. The use of virtual chassis connectivity between EX switches allows a scalable solution with survivability.
5. Answer: C. The single device solution reduces the training and management required to secure your network.

CHAPTER 4

Interfaces

This chapter describes the interface configurations for a Juniper Networks router. It starts with a description of the types of interfaces, the naming conventions, and the interface properties. It then identifies how to configure a large variety of interface media, such as T1 interfaces, Ethernet, and Serial interfaces. Lastly, it examines common interface problems, concentrating on the tools available to detect these issues.

Before you begin to design a network's routing topology, you should ensure that all the proper physical connections are in place and are operational. With such a large variance in interface types, this can often be a challenging task, so it is important to understand how an interface is organized within the Junos network operating system.

Juniper Networks routers contain two major categories of interfaces: *permanent* and *transient*. Users cannot remove permanent interfaces, whereas they can move, change, and remove transient interfaces. Other technical differences exist that are evident when you examine the applications for each interface type.

The interface topics covered in this chapter include:

- Permanent interfaces
- Transient interfaces
- Interface properties
- Interface configuration examples
- Interface troubleshooting

Permanent Interfaces

A permanent interface is any interface that is always present on the router (it cannot be altered). These interfaces can be management interfaces such as Ethernet, software pseudointerfaces such as tunnel interfaces, or fixed-port LAN/WAN interfaces.

On Junos routers, two management interfaces exist:

`fxp0`
: This is an Out of Band (OOB) management Ethernet interface. It is connected to the router's Routing Engine (RE) and can be used for Out of Band management access to the router. It can also be used to send management messages such as syslog or Simple Network Management Protocol (SNMP) traps. This interface is a *nontransit interface*, which means that traffic cannot enter this interface and exit via a LAN/WAN interface, nor can it enter a LAN/WAN interface and exit through the management interface. On EX switches, the management interface is called the `me0` interface; on all other routers, it is the `fxp0` interface.

> When running routing protocols, be very careful when using the `fxp0` interface. If you don't configure the routing protocol correctly, you could have a route in your route table that points to the `fxp0` interface and black hole traffic, since this is a nontransit interface. To protect yourself from these types of situations, you should not run any routing protocols over this interface.

`fxp1`
: This is an internal Fast Ethernet or Gigabit Ethernet (depending on the model of router) interface between the RE and the Packet Forwarding Engine (PFE). This interface is never configured but can be helpful when troubleshooting router issues. It is only in application-specific integrated circuit (ASIC) platforms (M/T-series) and not in the virtualized PFE J-series platforms. In clustered or virtual chassis devices, the fxp1 port is extended between devices on the VC cables or the fab links.

Many software pseudointerfaces that the router will create at startup also exist. A short list of these interfaces is as follows:

`lo0`
: This is a loopback interface that ties to the router itself and not to any one physical interface. This is often assigned an address to provide a stable address for management traffic and routing protocols, which allows your router to adapt to network and physical interface failures. Also, when configured with firewall filters, this interface serves to protect the RE from attacks destined to the router.

`pd`
: This Physical Interface Module (PIM) de-encapsulation interface allows a multicast rendezvous point (RP) to process PIM register messages.

`pe`
: This PIM encapsulation interface is used in multicast to create a unicast PIM register message to send to the RP.

`ip`
: This is an IP-over-IP encapsulation interface to create IP-in-IP tunnels.

`dsc`
: This is a discard interface, which can be used to silently discard packets. This is often used to create a choke point for denial of service (DoS) attacks.

`tap`
: This is a virtual Ethernet interface historically used for monitoring on FreeBSD systems. This interface could be used to monitor discarded packets on a router but is no longer officially supported.

The last type of permanent interface is the fixed LAN/WAN ports found on Juniper routers. We will examine these in depth in the next section.

Transient Interfaces

Transient interfaces are any interfaces that the user can remove, move, or replace. These include ports on the removable cards (PICs, PIMs, IOCs, etc.). Examples of transient interfaces are Fast Ethernet, gigabit Ethernet, Asynchronous Transfer Mode (ATM), SONET, and T1/E1, as well as service PICs such as tunnels, multilinks, link services, Adaptive Services PICs (ASPs), and passive monitoring.

Interface Naming

All Junos interfaces follow the same naming convention—the interface name followed by three numbers that indicate the location of the actual interface. The general convention is illustrated by the interface sequence MM-F/P/T, where:

MM
: Media type

F
: Chassis slot number

P
: PIC slot number

T
: Port number

Media type

The first part of the interface name is the interface media name (MM), indicating the type of interface. Common interface media names include:

`ae`
: Aggregated Ethernet, a logical linkage of multiple Ethernet interfaces defined in the IEEE 802.3ad standard.

`at`
: ATM, which sends fixed 53-byte cells over the transport media. This interface could also be used for ATM over digital subscriber line (DSL) connections.

`br`
: Physical Integrated Services Digital Network (ISDN) interface.

`e1`
: Standard digital communication standard over copper at a rate of 2.048 Mbps, used mostly in Europe.

`e3`
: Standard digital communication standard over copper at a rate of 34.368 Mbps, used mostly in Europe.

`t1`
: Basic physical layer standard used by the digital signal level 1 at a rate of 1.544 Mbps, used extensively in North America.

`t3`
: Basic physical layer standard used by the digital signal level 3 at a rate of 44.736 Mbps, used extensively in North America.

`fe`
: 100 Mbps standard initially created by Xerox in the 1970s for connecting multiple computers together; referred to as a LAN today.

`ge`
: Higher-speed Ethernet standard at 1 Gbps.

`xe`
: Higher-speed Ethernet standard at 10 Gbps.

`se`
: Interface used for serial communications (one bit at a time). Serial interfaces include standards such as EIA 530, V.35, and X.21.

`ct1`
: T1 interface that is channelized by splitting the interface into 24 DSO channels.

Chassis slot number

The next part of the interface name is F, a chassis slot number represented by a Flexible PIC Concentrator (FPC) slot number on an M-series router, a PIM slot number on a J-series router, the IOC slot number on an SRX, or the DPC slot number on an MX.

The M-series routers have two possible FPC alignments: horizontal slots or vertical slots. The larger M-series routers (M40e, M320) have vertically mounted FPCs with slot numbers starting at slot 0 and counting from left to right (see Figure 4-1). The smaller M-series routers (M7i, M10i) have horizontal slots starting at slot 0 and counting from top to bottom (see Figure 4-2).

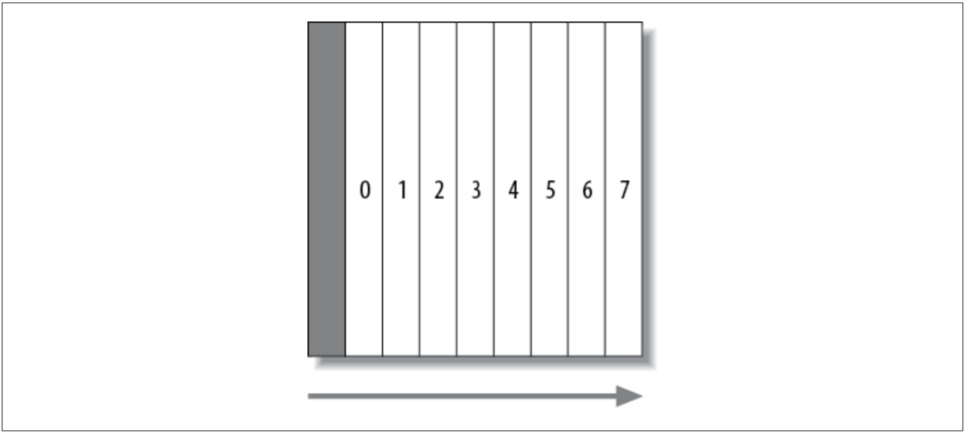


Figure 4-1. Vertical FPC slots (M40e and M320)

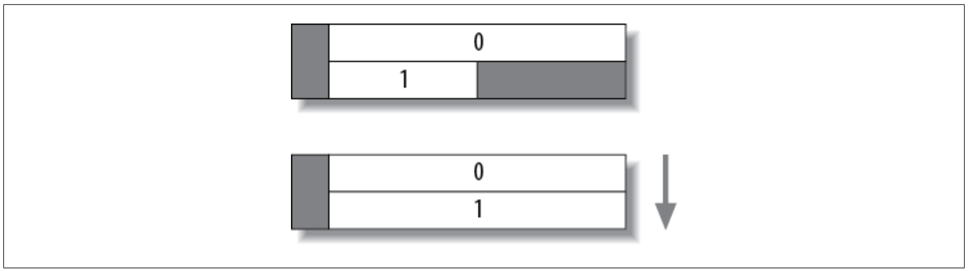


Figure 4-2. Horizontal FPC slots (M7i and M10i)

The M7i slot 1 is reserved for the Fixed Interface Card slots.

A J-series router does not contain any FPCs but does have PIM slots that are represented by the variable F. All fixed-port slots are always assigned slot 0, and PIM slots are assigned 1–6 numbering from top to bottom and left to right (see Figure 4-3).

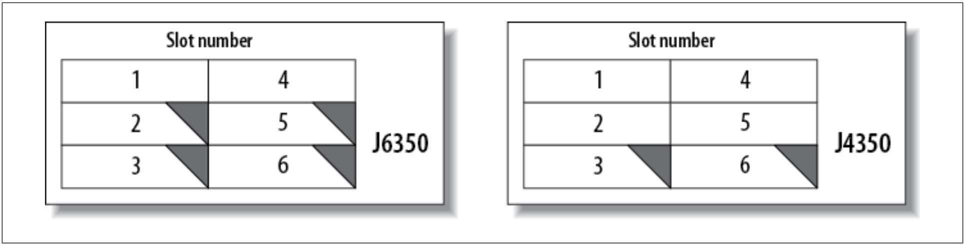


Figure 4-3. J6350 and J4350 PIM slot numbers

The SRXs support IOCs, not FPCs, and the slot numbers are dependent on the model types. For the SRX5800 series, the IOCs are mounted vertically and are numbered left to right, starting at slot 0, whereas the SRX5600s are numbered from top to bottom (see Figure 4-4).

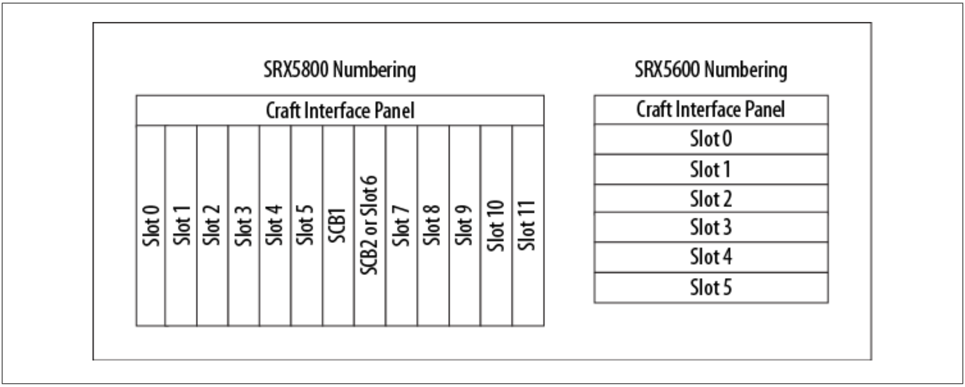


Figure 4-4. SRX5000 series slot numbers

The SRX 3000 series are numbered in two rows, front and rear (Figure 4-5). There are limitations on where IOCs can be placed in the chassis; refer to the hardware guides for these locations.

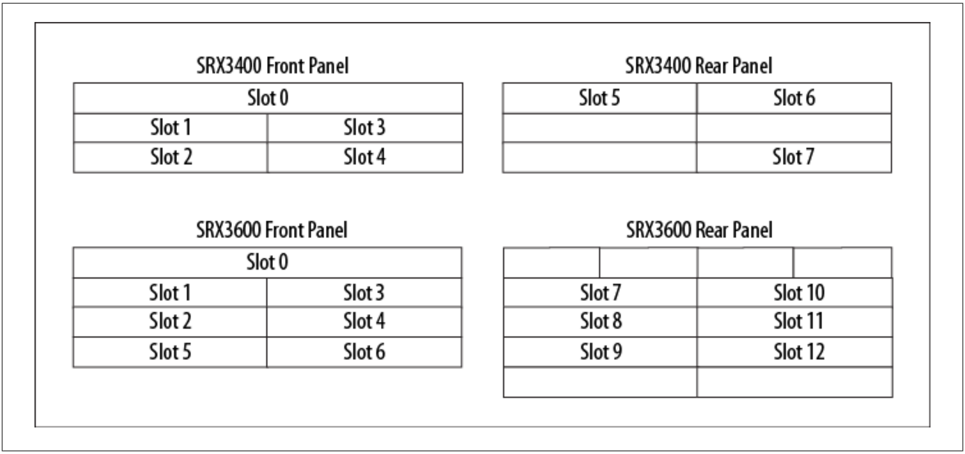


Figure 4-5. SRX3000 series slot numbers

The branch office SRX series are numbered like the J-series routers, with the fixed interfaces on slot 0 and the remaining interfaces numbered in a left to right, top to bottom manner.

The MXs support interfaces on the dense port concentrators (DPCs) and modular port concentrators (MPCs). These are inserted into slots of the MX chassis. Similar to the SRX line, the MX slot-numbering system is model dependent. The MX960 is numbered identically to the SRX5800, whereas the MX480, MX240, and mid-range MXs are numbered from bottom to top (see Figure 4-6).

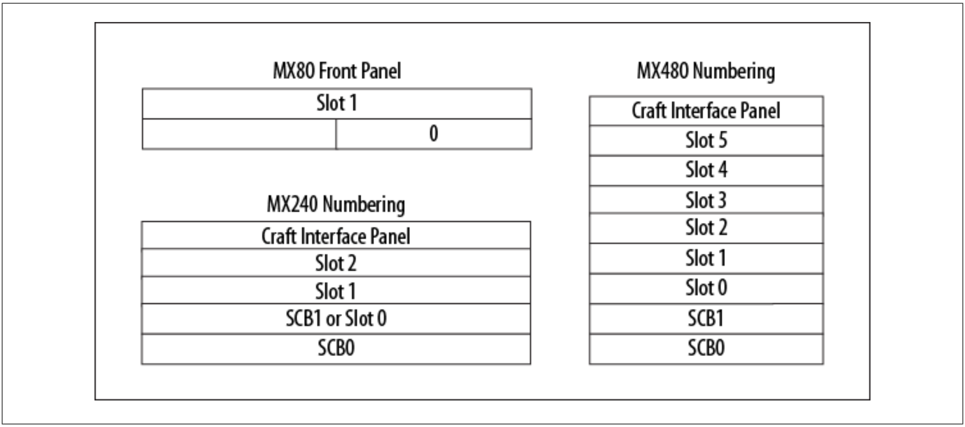


Figure 4-6. MX slot numbering

PIC slot number

The next part of the interface name is the PIC slot number, represented by the variable P. In M-series routers, four PICs can fit into a single FPC slot. The slot numbers begin at 0 and continue to the final slot, 3. In M-series routers, the direction of PIC slot numbering depends on whether the chassis slots are vertically or horizontally aligned. In a vertically aligned M-series router, the PIC slot number is counted from top to bottom, as shown in Figure 4-7.

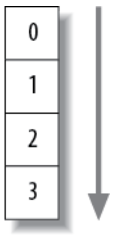


Figure 4-7. PIC slot numbers for M40e and M320

PIC slot numbering in horizontally aligned systems such as the M7i and M10i is a little less standard. In these systems, the PIC slot numbering goes from right to left, starting at 0 and ending at slot 3, as shown in Figure 4-8. The M7i's second FPC slot contains only two possible PIC slot numbers, and as shown in Figure 4-9, slot 2 is used for the built-in tunnel interface, or Adaptive Services Module (ASM), and slot 3 is used for the fixed Ethernet interfaces.

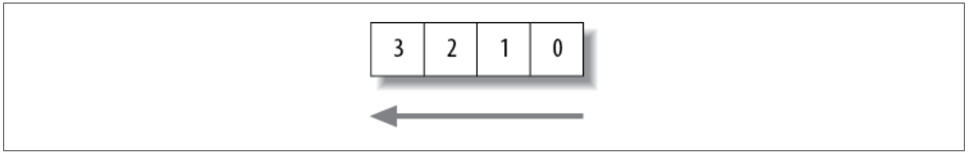


Figure 4-8. PIC slot numbers for M7i, M10i, and M20

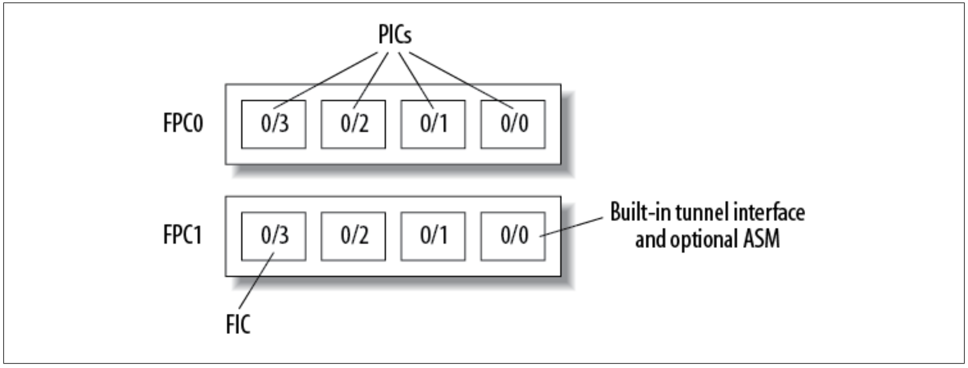


Figure 4-9. M7i PIC slot numbering

In the SRX and MX devices, the PIC identifiers are based on the type of cards used. For the full-size slot cards (IOCs and DPCs), there are four PICs assigned to the slot (0, 1, 2, 3) in a top to bottom, left to right fashion when the cards are held vertically. For the smaller cards (MICs, PIMs, etc.), there are no PIC slots; thus, the interface naming (F) convention is always set to a value of 0.

It seems counterintuitive that PIC slot numbering is counted from right to left. The reason harkens back to the first routers (M40), which were vertically aligned FPC slots with PIC slot numbering from top to bottom. Next came the horizontally aligned FPC slot (M20), which was essentially a vertically aligned router turned on its side, which caused the PIC slot to shift to right to left.

Port number

The last part of the interface name is represented by the variable T, or the actual physical port number. M-series routers have port numbers with a variety of schemes, depending on the PIC and the router model (horizontal versus vertical slots). For vertical FPC routers (m40e, M320), port numbers start from the top right and continue from the bottom to the top and then move right to left. For horizontal FPC routers (m20, m7i, m10i), port numbers start from the bottom right and then move right to left and from the bottom to the top. It's easier to see by examining Figures 4-10 through 4-13, which show this sequence in the different chassis types.

To avoid any confusion or spontaneous brain combustions, remember that the port number is always written on the PIC itself.

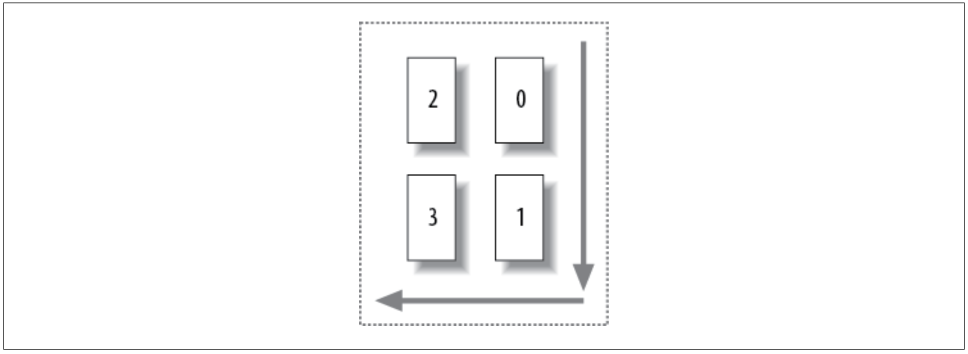


Figure 4-10. Port numbers on a vertical FPC chassis starting at the top right

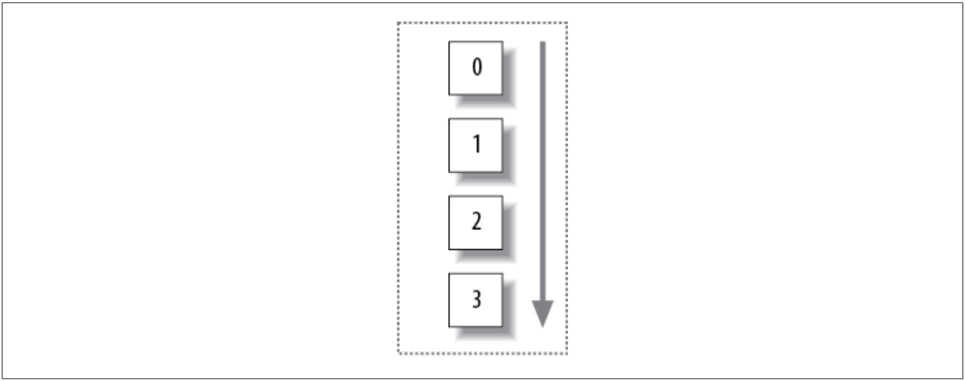


Figure 4-11. Port numbers on a vertical FPC chassis starting at the top

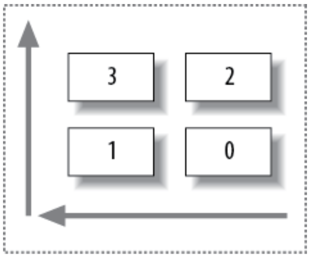


Figure 4-12. Port numbers on a horizontal FPC chassis starting at the bottom right

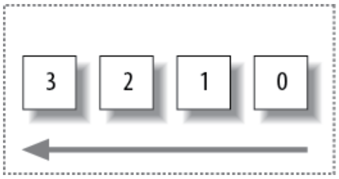


Figure 4-13. Port numbers on a horizontal FPC chassis starting on the right

The fixed Ethernet ports on the M7i follow the convention of Figure 4-13 and count from right to left, starting at port 0.

Port numbers are greatly simplified in J-series routers and Branch Office SRXs, as all ports are always numbered from left to right. This includes ports on a PIM (see Figure 4-14) as well any fixed ports on the chassis (see Figure 4-15).

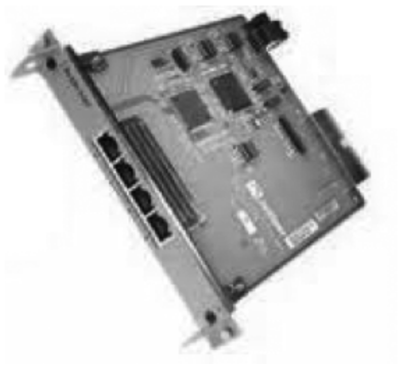


Figure 4-14. Four-port Fast Ethernet E-PIM

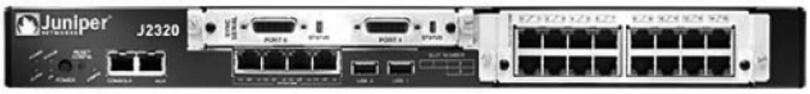


Figure 4-15. J2320 FE ports with right-to-left numbering

Here are a few M-series example interfaces:

`se-1/0/0`
: Serial interface in FPC slot 1, PIC slot 0, and port 0

`fe-0/2/1`
: Fast Ethernet interface in FPC slot 0, PIC slot 2, and port 2

`t1-1/0/1`
: T1 interface in FPC slot 1, PIC slot 0, and port 1

Logical unit and channel numbers

Interfaces also have a logical portion of the name represented by either a unit number or a channel number. A *logical unit* is a number that represents the subinterface properties of the router and can be configured in the range of 0–16,385. This is designated by a period (`.`) in the interface name. For example:

`ge-0/0/0.0`
: Unit 0 configured on the Gigabit Ethernet interface

`e3-1/0/2.12`
: Unit 12 configured on the `e3` interface

The other logical division could be a channel number—for example, when breaking up a T1 interface into multiple DS0 channels (up to 24). Channel values are represented using a colon (`:`). For example:

`ct-1/1/2:14`
: Channel 14 on a channelized T1 interface

We will cover logical units in depth in "Logical Properties" on page 90.

Interface Properties

Each interface has two types of properties assigned to it: physical properties and logical properties. *Physical properties* are tied to the entire physical port, whereas *logical properties* affect only that logical portion of the interface represented by unit numbers or channel numbers.

Physical Properties

A physical property on an interface is any property that should be assigned to the entire physical port. Depending on the interface media, a large range of properties can be configured, but they can be divided into a few major categories:

Clocking
: This aligns the bits as they are transmitted out of the interface. The clocking can be learned either from an external source or from the router itself.

Encapsulation
: This is the Layer 2 encapsulation that is going to be used on the interface. Examples include Frame Relay, Point-to-Point Protocol (PPP), and Cisco High-Level Data Link Control (HDLC).

MTU
: This is the maximum transmission unit, which is the maximum size of the frame transmitted from the interface.

Keepalives
: These are mechanisms used to verify the operation of the interface. Most encapsulations have keepalives enabled by default, but you can disable them to aid in troubleshooting.

Layer 1/2 options
: These are various bit and byte settings for the interface media. For a T1 interface, this includes byte encodings, framing, frame check sequences (FCSs), and line buildouts. In comparison, a Fast Ethernet interface might have options such as flow control, loopbacks, and source address filters.

A physical property should always be configured before any logical identifier, such as a unit number. For example, the following is a serial interface with *no* logical properties configured but with physical properties of `encapsulation cisco-HDLC` and `no-keepalives`, and with clocking set to `internal`:

```
se-0/0/2 {
    no-keepalives;
    encapsulation cisco-hdlc;
    serial-options {
        clocking-mode internal;
    }
    unit 0;
}
```

Logical Properties

All router interfaces that will send and receive transit traffic require a logical unit to be configured. This logical unit creates a division of the physical interface into multiple parts. For instance, an Ethernet interface can be subdivided into multiple virtual LANs (VLANs), each requiring its own logical unit.

Many router vendors refer to a logical unit as a *subinterface*; they do not require a subinterface on every physical interface, whereas a Juniper Networks router does.

Some interface types, such as point-to-point interfaces and non-VLAN-tagged Ethernet interfaces, still require a logical unit to be configured. This is a unique feature of Junos and may take a little getting used to if you're coming from other router vendors' hardware. These interfaces require a unit number because any logical property that needs to be configured *must* be defined after the unit number definition. The most common types of logical properties include:

Protocol family
: Indicates which Layer 3 protocols can be sent and received on the interface. The router can have one protocol family per logical unit or multiple families per logical unit configured. The most common family configured is `family inet`, which enables the sending and receiving of all packets in the Transmission Control Protocol/Internet Protocol (TCP/IP) suite (e.g., TCP, User Datagram Protocol [UDP], Internet Control Message Protocol [ICMP], and IP). Other common families are inet6 (IPv6), Multiprotocol Label Switching (MPLS), and ISO (ISIS packets). The families `multilink-frame-relay-end-to-end` and Multilink PPP are used to create multilink interfaces.

Protocol address
: The Layer 3 family address, such as a `family inet` IP address.

Virtual circuit address
: Circuit identifier used when dividing the physical interface into multiple logical interfaces. These could be the VLAN ID, Frame Relay data-link connection identifiers (DLCIs), or ATM Virtual Channel Identifier VCIs).

The logical unit number when configuring VLAN, Frame Relay, or ATM can be any value from 0–16,385. The current best practice, however, is to keep the circuit address the same as the unit number for easier troubleshooting. So, if you have a VLAN ID of 40 configured on your interface, the logical interface should also be a unit of 40, although it's not required. If you are configuring a point-to-point circuit or non-VLAN-tagged Ethernet, the logical unit number *must* be zero. Think of this unit as a placeholder for all the logical properties that will need to be configured on that interface.

Here is an example of a T1 interface configuration with the default parameters (PPP encapsulation), `family inet` support, and an IP address of 66.32.3.2/30. Note that since this is a point-to-point circuit, the unit number must be configured as `unit 0`:

```
t1-2/0/2 {
    unit 0 {
        family inet {
            address 66.32.3.2/30;
        }
    }
```

Interface Configuration Examples

A walkthrough of configuration examples, starting with basic examples and then getting into a few more complex configurations, will help to put this into perspective. The order of the walkthrough uses the following configuration examples:

- Gigabit Ethernet interfaces
- Gigabit Ethernet with VLAN tagging
- T1 interface with Cisco HDLC
- Serial interface with PPP
- Serial interface with Frame Relay
- DSL
- MLPPP
- Aggregated Ethernet interfaces
- GRE Tunnel Interfaces

Initially, we will use a step-by-step approach to establish the configuration fundamentals. Then the walkthrough will move toward configuration results that build on the fundamentals and become advanced. Once you grasp the fundamentals, you should be able to follow the advanced configurations. At the end of this section, we will discuss the use of the Virtual Router Redundancy Protocol (VRRP).

Gigabit Ethernet Interface

First, let's build an interface on router `Lager` that connects directly to router `Ale` over the `ge-0/0/0` interface.

Check the status of the `ge-0/0/0` interface by issuing a `show interfaces ge-0/0/0 terse` command. Junos interfaces are automatically "enabled" when the physical connection is wired:

```
root@Lager> show interfaces terse ge-0/0/0
Interface               Admin Link Proto    Local           Remote
ge-0/0/0                up    up
```

If an interface needs to be administratively disabled, issue the `set interfaces` *`<interface name>`* `disable` command.

The interface appears to be physically up, so next, configure the interface to allow IP traffic to flow as well as add an IP address. Begin by entering configuration mode, dropping down to the hierarchy of the interface, and configuring the correct family and local IP address:

```
root@Lager> configure
Entering configuration mode
[edit]
root@Lager# edit interfaces ge-0/0/0

[edit interfaces ge-0/0/0]
root@Lager# set unit 0 family inet address 10.10.20.122/24
```

Since this is a non-VLAN-tagged Ethernet interface, unit 0 *must* be used when configuring the logical properties of family inet.

Also, note that Junos requires a mask for every IP address in the classless interdomain routing (CIDR) "slash" notation. An absence of the mask can lead to the less desirable result of configuring a /32 subnet on your interface. (Look for other Junos address issues in "Interface Troubleshooting" on page 108.)

Verify the configuration and activate the changes by issuing a `commit and-quit` command:

```
[edit interfaces ge-0/0/0]
root@Lager# show
unit 0 {
    family inet {
        address 10.10.20.122/24;
    }
}

[edit interfaces ge-0/0/0]
root@Lager# commit and-quit
commit complete
Exiting configuration mode
```

Verify the status of the interface. Note that the status now includes the logical portion as well as the physical portion of the interface:

```
root@Lager> show interfaces terse ge-0/0/0
Interface               Admin Link Proto    Local                Remote
ge-0/0/0                up    up
ge-0/0/0.0              up    up   inet     10.10.20.122/24
```

Lastly, test connectivity by issuing a `ping` command toward the other end of the link of `Ale`:

```
root@Lager> ping 10.10.20.121
PING 10.10.20.121 (10.10.20.121): 56 data bytes
64 bytes from 10.10.20.121: icmp_seq=0 ttl=64 time=7.758 ms
64 bytes from 10.10.20.121: icmp_seq=1 ttl=64 time=10.394 ms
^C
```

```
--- 10.10.20.121 ping statistics ---
2 packets transmitted, 2 packets received, 0% packet loss
round-trip min/avg/max/stddev = 7.758/9.076/10.394/1.318 ms
```

Notice the Ctrl-C sequence used to break out of the `ping` command. Junos will send an endless number of pings unless a break is issued or a specific number of ping packets are specified with the `count` command.

```
root@Lager> ping 10.10.20.121 count 3

PING 10.10.20.121 (10.10.20.121): 56 data bytes

64 bytes from 10.10.20.121: icmp_seq=0 ttl=64 time=16.822 ms

64 bytes from 10.10.20.121: icmp_seq=1 ttl=64 time=20.382 ms

64 bytes from 10.10.20.121: icmp_seq=2 ttl=64 time=10.370 ms


--- 10.10.20.121 ping statistics ---

3 packets transmitted, 3 packets received, 0% packet loss

round-trip min/avg/max/stddev = 10.370/15.858/20.382/4.144 ms
```

Gigabit Ethernet with VLAN Tagging

Continuing with our example, let's add VLAN tagging between `Lager` and `Ale`, which is already configured with a VLAN ID of 100. The first step is to enable VLAN tagging on the physical interface of `Lager`:

```
root@Lager> configure
Entering configuration mode

[edit]
root@Lager# edit interfaces ge-0/0/0

[edit interfaces ge-0/0/0]
root@Lager# set vlan-tagging
```

Next, add a VLAN ID of 100 on logical unit 0:

```
 [edit interfaces ge-0/0/0]
root@Lager# set unit 0 vlan-id 100

[edit interfaces ge-0/0/0]
root@Lager# show
vlan-tagging;
unit 0 {
    vlan-id 100;
    family inet {
        address 10.10.20.122/24;
    }
}
```

Juniper routers do not have a default VLAN, as every VLAN must be explicitly configured. Many switches use a default VLAN of 1, so make sure you explicitly configure a `vlan-id` of 1 on the router for connectivity.

Although this is a valid configuration on unit 0, the best practice is to always keep the same unit number as the VLAN tag, so let's change the unit number with the `rename` command:

```
[edit interfaces ge-0/0/0]
root@Lager# rename unit 0 to unit 100

[edit interfaces ge-0/0/0]
root@Lager# show
vlan-tagging;
unit 100 {
    vlan-id 100;
    family inet {
        address 10.10.20.122/24;
    }
}
```

Lastly, activate the changes, verify the interface status, and test connectivity:

```
[edit interfaces ge-0/0/0]
root@Lager# top

[edit]
root@Lager# commit
commit complete

[edit]
root@Lager# run show interfaces terse ge-0/0/0
Interface               Admin Link Proto    Local           Remote
ge-0/0/0                up    up
ge-0/0/0.100            up    up   inet     10.10.20.122/24

[edit]
root@Lager# run ping 10.10.20.121 count 1
PING 10.10.20.121 (10.10.20.121): 56 data bytes
64 bytes from 10.10.20.121: icmp_seq=0 ttl=64 time=46.668 ms

--- 10.10.20.121 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 46.668/46.668/46.668/0.000 ms

 [edit]
root@Lager# run show interfaces terse ge-0/0/0
```

```
Interface               Admin Link Proto    Local           Remote
ge-0/0/0                up    up
```

Notice the use of the command `run` to issue the operational mode command `ping` in configuration mode.

Also notice the use of the `top` command prior to the `commit` command. In some cases a commit can be issued only from the top. Using `top` will save time otherwise spent issuing multiple commit commands.

T1 Interface with Cisco HDLC Encapsulation

The T1 interface is the most popular basic physical layer protocol used by the Digital Signal level 1 (DS1) multiplexing method in North America. For point-to-point interfaces on Juniper Networks routers, the default Layer 2 encapsulation is PPP, which differs from many other vendors' default behavior. To quickly interoperate with those vendors, change the encapsulation to the default setting, which is usually Cisco HDLC. Since we already showed the step-by-step configuration in the previous configuration, we show here only the result of adding the correct encapsulation:

```
t1-2/0/2 {
    encapsulation cisco-hdlc;
    unit 0 {
        family inet {
            address 10.200.8.9/30;
        }
    }
}
```

An inquiring mind may wonder why the encapsulation has the word *cisco* in it. Is there a non-Cisco HDLC? As a matter of fact, there is! There is a standard HDLC protocol (ISO 13239), used in protocols such as X.25 and SDLC. The original specification did not have multiprotocol support, so Cisco decided to create its own version with this support with different header fields and definitions. Although this protocol is officially proprietary, the workings are open and have been implemented by many different router vendors.

Serial Interface with PPP

A serial interface can come in a variety of different physical forms, such as V.35, X.21, and EIA-530. The choice of physical media often depends on geographical location; V.35 is the most common choice in the United States and Europe, and X.21 is more common in Japan. Regardless of physical media, all serial interfaces have the same idea of defining a data circuit-terminating equipment (DCE) device and a data terminal equipment (DTE) device. The DTE device is the end unit that receives data encoding, clocking, and signal conversion from the DCE device. In modern communications, the

DCE device often takes the form of a channel service unit/data service unit (CSU/DSU) or a modem; however, when connecting two routers in a back-to-back fashion, one of the routers takes the role of a DCE.

Router Ale and router Bock have a back-to-back serial connection using V.35 with the default encapsulation of PPP. Normally, a router will default to DTE mode, but in this case, Ale is automatically chosen as the DCE based on the detection of a DCE cable. You can observe this detection in the Local mode field of the show interfaces command:

```
root@ale# run show interfaces se-1/0/0 extensive | find "serial media"
  Serial media information:
    Line protocol: v.35
    Resync history:
      Sync loss count: 0
    Data signal:
      Rx Clock: Not Detected
    Control signals:
      Local mode: DCE
      To DTE: CTS: up, DCD: up, DSR: up
      From DTE: DTR: up, RTS: up
    DCE loopback override: Off
    Clocking mode: loop-timed
    Loopback: none
    Tx clock: non-invert
    Line encoding: nrz
```

Since one of the roles of the DCE is to provide clocking to the DTE, an internal clocking mode needs to be configured on Ale. This allows Ale to generate a clocking signal toward Bock using the internal clock with a default clock rate of 8 MHz:

```
[edit interfaces]
root@ale# show se-1/0/0
serial-options {
    clocking-mode internal;
}
unit 0 {
    family inet {
        address 172.16.1.1/30;
    }
}
```

Bock has no clocking mode configured and takes the default clock mode of loop-timed, which takes the transmitted clock from Ale. Bock could also have been configured for DCE mode, which would have the same result in this case. Here is the Bock configuration:

```
[edit interfaces se-1/0/1]
root@Bock# show
unit 0 {
    family inet {
        address 172.16.1.2/30;
    }
}
```

You can verify the local mode, clocking mode, and clock rate on Bock by using the show interfaces command:

```
[edit interfaces se-1/0/1]
root@Bock# run show interfaces se-1/0/1 extensive | find "serial media"
  Serial media information:
    Line protocol: v.35
    Resync history:
      Sync loss count: 0
    Data signal:
      Rx Clock: OK
    Control signals:
      Local mode: DTE
      To DCE: DTR: up, RTS: up
      From DCE: CTS: up, DCD: up, DSR: up
    Clocking mode: loop-timed    Clock rate: 8.0 MHz
    Loopback: none
    Tx clock: non-invert
    Line encoding: nrz
```

Clocking can often be a confusing topic for many users. For back-to-back router connections, Juniper made it simple by allowing multiple different clocking modes to be configured and still "do the right thing." The only combinations that will not work for back-to-back connections are the DCE in loop mode and the DTE in loop or DCE mode. However, when connecting to a CSU/DSU or a modem, proper care must be taken to configure the correct clock mode.

Serial Interface with Frame Relay

Frame Relay is a Layer 2 encapsulation that enables the connection of your LAN via a WAN connection to a Frame Relay node. Frame Relay creates a tunnel called a permanent virtual circuit (PVC) over a private or leased line to provide connectivity to other sites over the Internet service provider's (ISP's) infrastructure. With the emergence of DSL and IP-based networks, Frame Relay is not often seen anymore, except in rural areas as a cheaper, "always on" connection.

To establish a Frame Relay connection with the Frame Relay node, the proper encapsulation of frame-relay (RFC 1490) must be configured as well as the local circuit identifier for the PVC represented by the logical property of a dlci number:

```
se-1/0/0 {
    encapsulation frame-relay;
    unit 645 {
        description "to R3";
        dlci 645;
        family inet {
            address 172.17.24.130/30;
        }
    }
}
```

The router can also support back-to-back router connections by configuring one router to operate in DCE mode or by turning off keepalives on each router. If keepalives are disabled, the router will not wait for any local management messages to enable that interface. Also, turning keepalives off can help in troubleshooting by allowing for loop-back testing, which we'll discuss later in this chapter.

ADSL Using PPPoE over ATM

DSL is one of the more popular connection media for both companies and consumers because the local service is provided via a normal phone line with a DSL modem. This connection terminates at the telco digital subscriber line access multiplexer (DSLAM), a device that concentrates multiple DSL connections together. Some J-series routers have support for ATM over asymmetrical digital subscriber line (ADSL)—Annex A for DSL over POTS or Annex B for DSL over ISDN—and symmetric high-speed digital subscriber line (SHDSL) configurations that allow them to act as the DSL modem at the customer site. The interfaces appear to be ATM connections but do not support native ATM, only the use of ATM over a DSL connection.

Router `PBR` has an ADSL Annex A PIM installed in slot 6 and will act as a client to the DSLAM. This connection is using Point-to-Point Protocol over Ethernet (PPPoE) over ATM for the DSL connection, which requires that two different interfaces be configured. The first interface that is configured is the physical ATM interface of `at-6/0/0`. To configure the interface, the ATM virtual path and virtual channel identities must be the same values that are provisioned at the DSLAM. The rest of the parameters can be learned from the DSLAM by setting an operating mode of auto. Since `PBR` will be using PPPoE, the encapsulation *must* be configured at *both* the physical and the logical layers:

```
 [edit]
doug@PBR# show interfaces
at-6/0/0 {
    encapsulation ethernet-over-atm;
    atm-options {
        vpi 0;
    }
    dsl-options {
        operating-mode auto;
    }
    unit 0 {
        encapsulation ppp-over-ether-over-atm-llc;
        vci 0.39;
    }
}
```

The next interface that must be configured is the PPPoE internal router interface. This interface maps the physical interface where PPPoE will be running, sets the access server's name and underlying service to be requested, and sets an IP address. The IP address can be learned automatically from the access server by specifying the negotiate-address command, as seen in the configuration of PBR that follows, or by setting the IP address to be static:

```
ppo {
    unit 0 {
        pppoe-options {
            underlying-interface at-6/0/0.0;
            access-concentrator mgmgrand;
            service-name "pppserv@mgmgrand";
            auto-reconnect 5;
        }
        family inet {
            negotiate-address
            }
        }
    }
}
```

You can verify the correct operation of the PPPoE negotiation by issuing the show pppoe interfaces command:

```
[edit]
doug@PBR# run show pppoe interfaces
pp0.0 Index 68
  State: Session up, Session ID: 4,
  Service name: pppserv@mgmgrand, Configured AC name: mgmgrand,
  Session AC name: mgmgrand, AC MAC address: 00:05:85:ca:7a:a8,
  Session uptime: 00:22:43 ago,
  Auto-reconnect timeout: 5 seconds, Idle timeout: Never,
  Underlying interface: at-6/0/0.0 Index 66
```

MLPPP

To incrementally increase the speed of individual PPP links without adding speed to the physical interfaces, the Multilink Point-to-Point Protocol (MLPPP) was created under RFC 1990. This is essentially a "software" bond of multiple physical PPP interfaces to form one larger logical link, called a *bundle*. Junos allows for up to eight physical interfaces to be assigned to a bundle.

To support MLPPP on any Juniper Networks router, the router must support this special service. This support could be in the form of an additional hardware PIC on an M-series router, or it could inherit software support on other Juniper routers.

The first step is to configure the pseudolink service interface, which takes the form of lsq-0/0/0 on J-series, MX, and SRX routers, or an ml, lsq, or ls interface on an M-series router, depending on the PIC type. This interface will take all the same characteristics of a normal PPP interface, such as an IP address, but will have a logical encapsulation of multilink-ppp. This is configured at the logical layer of the interface to allow multiple bundles and types of bundles on the same router by configuring multiple unit numbers. As shown here, the bundle is assigned to logical unit 0:

```
lsq-0/0/0 {
    unit 0 {
        encapsulation multilink-ppp;
        family inet {
            address 172.8.17.30/30;
        }
    }
}
```

Next, configure the physical interfaces to link the newly created link service interface. In the following example, interfaces `se-1/0/0` and `se-1/0/1` are linked to the logical bundle unit 0 on the `ls-0/0/0` interface:

```
se-1/0/0 {
    unit 0 {
        family mlppp {
            bundle lsq-0/0/0.0;
        }
    }
}
se-1/0/1 {
    unit 0 {
        family mlppp {
            bundle lsq-0/0/0.0;
        }
    }
}
```

To verify the status, issue the `show interfaces terse` command. Notice that both the serial interfaces and the link service interfaces are tracked. The link service will be in the up state as long as one of the physical interfaces is also in the up state. You can modify this by configuring the `minimum-links number` command under the link service interface. This command sets the number of physical links that must be in the up state for the bundle to be labeled up:

```
root@Bock# run show interfaces terse | match "se|lsq-"
lsq-0/0/0               up    up
lsq-0/0/0.0             up    up   inet     172.17.8.30/30
se-1/0/0                up    up
se-1/0/0.0              up    up   mlppp    lsq-0/0/0.0
se-1/0/1                up    up
se-1/0/1.0              up    up   mlppp    lsq-0/0/0.0
```

Notice the use of an "or" statement in the match criteria. The use of quotes and the pipe symbol denotes an or statement for the match, looking for lines that contain either `se` or `lsq-`.

Aggregated Ethernet

The IEEE 802.3ad standard defines a means to bundle multiple Ethernet interfaces into an aggregate group. Traffic is passed over all members of the group in a load-balancing arrangement. The link aggregation control protocol (LACP) can be added to monitor the bundle, allowing interfaces to be added or subtracted from the bundle without loss of traffic.

The use of 802.3ad allows multiple connections between a router and a switch without the possibility of a broadcast storm. This improves performance and has a quicker recovery time than using a spanning tree protocol.

The configuration of 802.3ad has three parts: setting the chassis parameters, the aggregate interface, and the participating interfaces. The chassis parameters define the total number of aggregate interfaces that will be set on the router. In this example, we are installing only a single aggregate interface:

```
root@Lager> show configuration chassis
aggregated-devices {
    ethernet {
        device-count 1;
    }
}
```

The aggregate interface uses an internal interface type of ae0. This interface carries the logical interface properties for the interface—in this case, the IP address for the bundle:

```
root@Lager> show configuration interfaces ae0
unit 0 {
    family inet {
        address 4.4.4.1/24;
    }
}
```

Finally the participating interfaces are added to the configuration. Up to 10 Ethernet interfaces can be added to an aggregate bundle. These interfaces can be in any location on the router:

```
root@Lager> show configuration interfaces ge-0/0/2
gigether-options {
    802.3ad ae0;
}

root@Lager> show configuration interfaces ge-0/0/3
gigether-options {
    802.3ad ae0;
}
```

Once the configuration is entered and committed, the ae0 interface is monitored as any other interface on the router. The `show interfaces ae0` command shows the interface's bandwidth and status. The `show interface terse` command shows the addresses of the aggregate interface and the bundle of the aggregated Ethernet interfaces:

```
root@Lager> show interfaces ae0
Physical interface: ae0, Enabled, Physical link is Up
  Interface index: 146, SNMP ifIndex: 142
  Link-level type: Ethernet, MTU: 1514, Speed: 2000mbps, BPDU Error: None,
  MAC-REWRITE Error: None, Loopback: Disabled, Source filtering: Disabled,
  Flow control: Disabled, Minimum links needed: 1, Minimum bandwidth needed: 0
  Device flags   : Present Running
  Interface flags: SNMP-Traps Internal: 0x4000
root@Lager> show interfaces terse | match "ge-|ae0"
....
ge-0/0/2                up    up
ge-0/0/2.0              up    up   aenet    --> ae0.0
ge-0/0/3                up    up
ge-0/0/3.0              up    up   aenet    --> ae0.0
ae0                     up    up
ae0.0                   up    up   inet     4.4.4.1/24
```

GRE

Generic Routing Encapsulation (GRE) is a tunneling protocol that enables the transport of a variety of Layer 3 protocols. The tunnel created by GRE was designed to be "stateless" with no monitoring of the tunnel endpoint. GRE tunnels are used for a variety of applications, including providing backup links, transporting non-IP protocols over an IP network, and connecting "islands" of IP networks.

To create a GRE tunnel on a Juniper Networks router, the router must be equipped with Layer 2 service capabilities, which are native in the J-series, MX, and SRX routers and are available via a hardware PIC in an M-series router. When these services are enabled on a router, a pseudointerface called `gr` is created. The interface must be configured with the source IP address for the GRE packets, the destination of the tunnel, and the families of protocols that will be carried in the protocol. The GRE tunnel configured in the following case is carrying IP traffic and is using a source IP address of 10.20.1.38 and a destination of 172.66.13.1. An IP address for the `gr-0/0/0` interface is not required but could be useful for management purposes:

```
gr-0/0/0 {
    unit 0 {
        tunnel {
            source 10.20.1.38;
            destination 172.66.13.1;
        }
        family inet
    }
}
```

It is important not to mistake the internal `gre` interface with the `gr` interface on the router. The `gre` interface is used by the router internally and should not be configured to create GRE tunnels.

The final piece is mapping actual traffic for use by the GRE tunnel. This is accomplished in a variety of methods depending on the type of traffic entering the GRE tunnel. Common mapping examples for IP include creating a static route with a next-up of the `gr` interface or even running a routing protocol such as Open Shortest Path First (OSPF) over the interface!

VRRP

Anybody using a PC for Internet surfing, music downloads, or gaming uses IP as the network protocol. The PC will have an IP address assigned as well as a default gateway address to reach any destinations that are not on the local subnet. In the following code snippet, a PC is using an IP address of 10.70.129.36 with a mask of 255.255.255.0 and a default gateway of 10.70.129.1:

```
Microsoft Windows [Version 6.0.6002]
Copyright <c> 2006 Microsoft Corporation

C:\Documents and Settings\Douglas Marschke>ipconfig

Ethernet adapter Local Area Connection 3:

        Connection-specific DNS Suffix  . : eu-af.regus.local
        IP Address. . . . . . . . . . . . : 10.70.129.36
        Subnet Mask . . . . . . . . . . . : 255.255.255.0
        Default Gateway . . . . . . . . . : 10.70.129.1
```

This default gateway address is either statically defined by the user or learned via the Dynamic Host Configuration Protocol (DHCP) process. Regardless of the method, the default gateway will be used as the next hop address for the default route that will be created to reach remote destinations:

```
Microsoft Windows [Version 6.0.6002]
Copyright <c> 2006 Microsoft Corporation

C:\Documents and Settings\Douglas Marschke>netstat -r

Route Table
================================================================
Interface List
0x1 ........................ MS TCP Loopback interface
0x2 ...00 12 f0 ac 46 d5 ..... Intel(R) PRO/Wireless 2200BG Network
Connection - Packet Scheduler Miniport
0x3 ...00 12 3f 12 d7 59 ...... Broadcom NetXtreme 57xx Gigabit
Controller - Packet Scheduler Miniport
0x20005 ...00 ff e8 25 91 85 ..... Juniper Network Connect Virtual
Adapter
================================================================
Active Routes:
Network Destination        Netmask      Gateway    Interface  Metric

          0.0.0.0          0.0.0.0  10.70.129.1 10.70.129.36     20
      10.70.129.0    255.255.255.0 10.70.129.36 10.70.129.36     20
     10.70.129.36  255.255.255.255    127.0.0.1    127.0.0.1     20
   10.255.255.255  255.255.255.255 10.70.129.36 10.70.129.36     20
        127.0.0.0        255.0.0.0    127.0.0.1    127.0.0.1     1
        224.0.0.0        240.0.0.0 10.70.129.36 10.70.129.36     20
```

```
  255.255.255.255  255.255.255.255 10.70.129.36 10.70.129.36     1
  255.255.255.255  255.255.255.255 10.70.129.36            2     1
  255.255.255.255  255.255.255.255 10.70.129.36        20005     1
Default Gateway:       10.70.129.1
===============================================================
Persistent Routes:
  None
```

If the default gateway was a single device and that device failed, a PC would not be able to reach destinations outside the local subnet. In a fault-tolerant network, it would be ideal to have a backup gateway device, without having to modify the configuration on the PC, as well as being able to load-share with multiple PCs on the LAN.

VRRP was created to eliminate single points of behavior that are inherent to static default routed networks. VRRP creates a logical grouping of multiple physical routers to a "virtual" router that will be used as the default gateway for end hosts. This allows the PC to always maintain the same gateway address even if the physical gateway has changed (see Figure 4-16). The routers that are part of the same VRRP logical group will share this "virtual" IP address as well as a "virtual" media access control (MAC) address. Essentially VRRP describes an election protocol to maintain ownership of this virtual IP (VIP) address and MAC address. One router in the VRRP group will be the master router, which controls this VIP address unless a failure occurs that results in a release of that ownership. This failure causes another router to claim ownership of the VIP by issuing a VRRP message and a gratuitous Address Resolution Protocol (ARP) to claim the virtual MAC address. Once a router becomes the master, it will periodically advertise VRRP messages to indicate its overall health and reachability.

When configuring VRRP for the first time on a Juniper Networks router, it can seem like locating the configuration is similar to trying to find a needle in a haystack. The configuration will be within the logical property and will be configured after the family inet address. A VRRP group value (1–255) is assigned on every router that needs to be part of the virtual router. Also, a VIP address is assigned that the hosts will use as their gateway address. This could be an address owned by one of the routers in the group or an address taken out of the address block owned by the LAN. Lastly, a priority value can be configured to change the default value of 100, which is used to elect the master router of the VRRP group. The router with the highest priority value becomes the master for that group; if the priorities are equal, the tiebreaker goes to the highest local LAN IP address:

```
lab@LAGER# show interfaces
ge-0/0/1 {
    vlan-tagging;
    speed 100m;
    link-mode full-duplex;
    unit 1115 {
        description LAGER-to-ALE;
        vlan-id 1115;
        family inet {
            address 10.40.1.2/24 {
                vrrp-group 1 {
                    virtual-address 10.40.1.200;
                    priority 200;

                }
            }
        }
    }
```

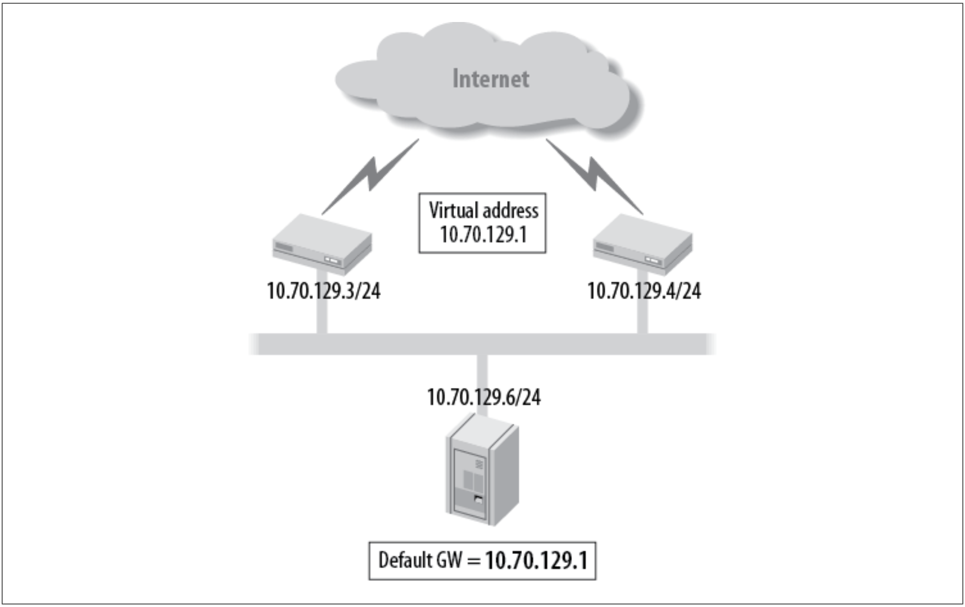


Figure 4-16. VRRP example

Verify the operation of VRRP with the `show vrrp summary` command. Router `Lager` is the master for group 1 because it has a higher priority:

```
[edit interfaces ge-0/0/1]
lab@LAGER# run show vrrp summary
Interface     State       Group   VR state       VR Mode    Type   Address
ge-0/0/1.0    up              1   master          Active    lcl    4.4.4.1
                                                            vip    4.4.4.100
```

Priority values range from 0–255; however, only values 1–254 are configurable. Priority 0 is reserved for the master router to issue an immediate release of mastership. A priority of 255 is used if the VIP is an actual interface IP that is owned by that router.

Another option that can be configured is the ability to track the interface priority settings. If an interface goes down, the advertised priority will be subtracted by a configured value. This could result in a new master router for the virtual router. This is very useful to ensure upstream reachability. In the example on Lager, a T1 interface is being tracked. If this interface goes down, 150 will be subtracted from the configured priority of 200:

```
lab@LAGER# show interfaces
ge-0/0/1 {
    vlan-tagging;
    unit 1115 {
        description LAGER-to-ALE;
        vlan-id 1115;
        family inet {
            address 10.40.1.2/24 {
                vrrp-group 1 {
                    virtual-address 10.40.1.200;
                    priority 200;

                    track {
                        interface t1-2/0/2.0 priority-cost 150;
                    }
                }
            }
        }
    }
```

You can force an interface failure by administratively disabling the T1 interface:

```
lab@LAGER# top set interfaces t1-2/0/2 disable

[edit]
lab@LAGER# commit
commit complete
```

The result of this failure is a mastership change, as Lager is now the backup router:

```
[edit]
lab@LAGER# run show vrrp summary
Interface     State       Group   VR state       VR Mode    Type   Address
ge-0/0/1.0    up              1   backup          Active    lcl    4.4.4.1
                                                            vip    4.4.4.100
```

Notice in the show vrrp track command that Lager has a configured (cfg) priority value of 200, but a priority of 50 is currently being used because we've subtracted the cost of 150 from the downed T1 interface:

```
lab@LAGER# run show vrrp track
Track Int   State         Speed   VRRP Int   Group   VR State      Current prio
t1-2/0/2.0  down              0   ge-0/0/1.0     1   backup                  50
```

The default behavior of VRRP is to use *preemption*, which causes a router with a higher priority to become the master at any time. When Lager's T1 interface is reenabled, it will again become the master for the virtual router:

```
[edit]
lab@LAGER# rollback 1
load complete
```

```
[edit]
lab@LAGER# commit
commit complete

[edit]
lab@LAGER# run show vrrp track
Track Int    State        Speed   VRRP Int    Group   VR State      Current prio
se-1/0/0.0   up           16384k  ge-0/0/3.0     1    master                 200
```

Since preemption could cause a temporary disruption in the network, a `no-preempt` command can also be configured.

Lastly, according to RFC 3768, "A VRRP router SHOULD not forward packets addressed to the VIP Address(es) it becomes Master for if it is not the owner." That means if we have an IP address that is not owned by any router and is simply an address from the subnet that was used as the VIP, operational issues may appear. The most common issue is not being able to ping the virtual address. In the case just examined, 10.40.1.200 was the VIP address chosen out of the 10.40.1/24 subnet, but it was not actually configured on either `Lager` or `Ale`. Juniper routers allow you to break this rule by configuring the `accept-data` command to allow the master router to respond to the VIP address. This will allow testing to occur toward the VIP; however, care must be taken to avoid unnecessary traffic on the LAN.

Interface Troubleshooting

Interfaces can have a variety of issues depending on the actual interface type, and listing all the possibilities would require a separate book! Instead, in this section, we will discuss a few common issues that illustrate the types of troubleshooting commands available on the router.

Address Configuration Issues

Since Juniper Networks routers allow multiple IP addresses to be configured on a single logical unit, configuration errors can occur if care is not taken. `Lager` has an IP address of 10.10.20.122 configured on its gigabit Ethernet interface with a subnet mask of /24. This was noticed to be a configuration error, as the mask should have been configured for /27:

```
[edit interfaces ge-2/0/1]
root@Lager# show
vlan-tagging;
unit 100 {
    vlan-id 100;
    family inet {
        address 10.10.20.122/24;
    }
}
```

Here, the address of 10.10.20.122 is added with the correct subnet of /27:

```
[edit interfaces ge-2/0/1]
root@Lager# set unit 100 family inet address 10.10.20.122/27
```

When you view the resultant interface configuration, the router appears to contain the duplicate IP addresses with varying subnet masks. This illustrates the fact that IP addresses are not overridden per logical unit, but simply are added to the logical unit:

```
[edit interfaces ge-2/0/1]
root@Lager# show
vlan-tagging;
unit 100 {
    vlan-id 100;
    family inet {
        address 10.10.20.122/24;
        address 10.10.20.122/27;
    }
}
```

To correct this, the old address with the /24 mask is removed by use of the `delete` command:

```
[edit interfaces ge-2/0/1]
root@Lager# delete unit 100 family inet address 10.10.20.122/24
```

Another solution with the same result is to use the `rename` command to change the subnet mask from /24 to /27:

```
[edit interfaces ge-2/0/1 unit 100]

root@Lager# rename address 10.10.20.122/24 to address 10.10.20.122/27
```

Since Juniper Networks routers allow placement of multiple addresses on a single logical interface, care must also be taken to allow for the router to choose the correct source IP address for outgoing packets on that interface. By default, the source IP address is chosen by using the primary and preferred addresses assigned to the interface. Each unit can have only one primary address, but each interface can have multiple preferred addresses. Simply put, a primary address is the address chosen to source local packets out of the interface destined for a remote network. As shown in the following output, 10.20.20.122 is the only address on the interface, and as such, it contains both a primary and a preferred flag:

```
root@Lager# run show interfaces ge-2/0/1.100
  Logical interface ge-2/0/1.100 (Index 67) (SNMP ifIndex 45)
   Flags: SNMP-Traps 0x4000 VLAN-Tag [0x8100.100] Encapsulation: ENET2
    Input packets : 2215
    Output packets: 23
    Protocol inet, MTU: 1500
      Flags: None
      Addresses, Flags: Is-Preferred Is-Primary
        Destination: 10.10.20.96/27, Local: 10.10.20.122,
        Broadcast: 10.10.20.127
```

Now configure two additional IP addresses, 6.6.6.6 and 6.6.6.4, on the interface and observe the results:

```
root@Lager# set address 6.6.6.4/24
root@Lager# set address 6.6.6.6/24
[edit interfaces ge-2/0/1 unit 100 family inet]
root@Lager# commit
commit complete

[edit interfaces ge-2/0/1 unit 100 family inet]
root@Lager# run show interfaces ge-2/0/1.100 | find protocol
    Protocol inet, MTU: 1500
      Flags: None
      Addresses, Flags: Is-Preferred Is-Primary
        Destination: 6.6.6/24, Local: 6.6.6.4, Broadcast: 6.6.6.255
      Addresses
        Destination: 6.6.6/24, Local: 6.6.6.6, Broadcast: 6.6.6.255
      Addresses, Flags: Is-Preferred
        Destination: 10.10.20.96/27, Local: 10.10.20.122,
        Broadcast: 10.10.20.127
```

The primary address has changed to 6.6.6.4, and now two addresses contain the preferred flag: addresses 6.6.6.6 and 10.10.20.122. The preferred address is used as the source IP address if you're trying to reach a network that is locally attached. In this case, if traffic is destined for 172.16.1.2, the source IP address of 6.6.6.4 is used, but if the destination address is 10.10.20.121, the source IP address of 10.10.20.122 will be used. Junos by default will choose the primary and preferred addresses based on the lowest IP address that is configured. The primary address will be the lower IP address configured on the interface, and the preferred address will be the lowest IP address configured for each local subnet. In the earlier example, traffic destined to a host on the 6.6.6/24 subnet is sourced from 6.6.6.4. You can modify these defaults by configuring the appropriate flag (primary or preferred) to the address of choice:

```
[edit interfaces ge-2/0/1 unit 100 family inet]
root@Lager# set address 10.10.20.122/27 primary

[edit interfaces ge-2/0/1 unit 100 family inet]
root@Lager# commit
commit complete
```

The 10.10.20.122 address has now been configured for the primary address of the interface, as indicated by the `show interfaces` command:

```
[edit interfaces ge-2/0/1 unit 100 family inet]
root@Lager# run show interfaces ge-2/0/1.100 | find protocol
    Protocol inet, MTU: 1500
      Flags: None
      Addresses, Flags: Is-Preferred
        Destination: 6.6.6/24, Local: 6.6.6.4, Broadcast: 6.6.6.255
      Addresses
        Destination: 6.6.6/24, Local: 6.6.6.6, Broadcast: 6.6.6.255
      Addresses, Flags: Primary Is-Preferred Is-Primary
        Destination: 10.10.20.96/27, Local: 10.10.20.122,
        Broadcast: 10.10.20.127
[edit interfaces ge-2/0/1 unit 100 family inet]
root@Lager# set address 6.6.6.6/24 preferred
```

Encapsulation Mismatches

For two routers' interfaces to communicate properly, the same Layer 2 encapsulation must be configured on each device; depending on the type of encapsulation, this could be a difficult error to determine. A common interface medium where this could occur is Ethernet. The interface on router `Lager` is configured to send VLAN tagged frames on the 10.10.20/24 subnet; however, a ping to router `Hangover` in that segment fails:

```
[edit interfaces ge-2/0/1 unit 100]
root@Lager# run ping 10.10.20.121
PING 10.10.20.121 (10.10.20.121): 56 data bytes
^C
--- 10.10.20.121 ping statistics ---
3 packets transmitted, 0 packets received, 100% packet loss
```

Looking at the statistics on `Lager`'s Ethernet interface, a number of Layer 2 channel errors are recorded:

```
root@Lager# run show interfaces ge-2/0/1 extensive
Physical interface: ge-2/0/1, Enabled, Physical link is Up
  Interface index: 142, SNMP ifIndex: 37, Generation: 143
  Link-level type: Ethernet, MTU: 1514, Link-mode: Full-duplex Speed: 1000mbps,
  BPDU Error: None, MAC-REWRITE Error: None, Loopback: Disabled,,
  Source filtering: Disabled, Flow control: Enabled, Auto-negotiation: Enabled,
  Remote fault: Online
  Device flags   : Present Running
  Interface flags: SNMP-Traps Internal: 0x4000
  Link flags     : None
  CoS queues     : 8 supported, 8 maximum usable queues
  Hold-times     : Up 0 ms, Down 0 ms
  Current address: 00:12:1e:76:1e:29, Hardware address:
00:12:1e:76:1e:29
  Last flapped   : 2010-04-05 22:01:18 UTC (1w0d 10:11 ago)
  Statistics last cleared: 2010-04-13 08:10:48 UTC (00:02:18 ago)
  Traffic statistics:
   Input  bytes  :                    0                    0 bps
   Output bytes  :                  230                    0 bps
   Input  packets:                    0                    0 pps
   Output packets:                    5                    0 pps
  Input errors:
   Errors: 0, Drops: 0, Framing errors: 0, Runts: 0, Policed discards:
   0, L3 incompletes: 0, L2 channel errors: 42, L2 mismatch timeouts:
   ,0 FIFO errors: 0, Resource errors: 0
 Output errors:
   Carrier transitions: 0, Errors: 0, Drops: 0, Collisions: 0, Aged
   packets: 0, FIFO errors: 0, HS link CRC errors: 0, MTU errors: 0,
   Resource errors: 0
 Egress queues: 8 supported, 8 in use
.....
```

To see whether the Layer 2 channel errors are currently increasing or whether they are older counters that have not been cleared, the `monitor interface ge-2/0/1` command is issued. The second column in the following code snippet shows the interface counter statistics, and the current delta column indicates real-time statistics recorded since issuing the `monitor` command. Layer 2 channel errors are currently increasing, as the current delta counter indicates:

```
Lager                           Seconds: 14         Time: 08:13:54
                                                  Delay: 0/0/50
Interface: ge-2/0/1, Enabled, Link is Up
Encapsulation: Ethernet, Speed: 1000mbps
Traffic statistics:                                 Current delta
  Input bytes:                    0 (0 bps)                   [0]
  Output bytes:                 230 (0 bps)                   [0]
  Input packets:                  0 (0 pps)                   [0]
  Output packets:                 5 (0 pps)                   [0]
Error statistics:
  Input errors:                   0                           [0]
  Input drops:                    0                           [0]
  Input framing errors:           0                           [0]
  Policed discards:               0                           [0]
  L3 incompletes:                 0                           [0]
  L2 channel errors:            105                          [18]
  L2 mismatch timeouts:           0  Carrier transit          [0]
```

An additional `monitor` command is now used to verify that the router is sending out the correct packets. The `monitor traffic` command is the router's tcpdump* utility that allows local router traffic to be observed on a particular interface. Since Ethernet requires the IP address to MAC address mapping before sending the FRAME, a series of ARP requests with an 802.1Q (VLAN) header are sent out to the interface with no response received. The `layer2-header` switch is used to obtain some Ethernet header information as the `monitor` command is usually Layer 3 and Layer 4 only:

```
[edit interfaces ge-2/0/1 unit 100]
root@Lager# run monitor traffic interface ge-2/0/1 layer2-headers
verbose output suppressed, use <detail> or <extensive> for full protocol decode
Address resolution is ON. Use <no-resolve> to avoid any reverse lookup delay.
Address resolution timeout is 4s.
Listening on ge-2/0/1, capture size 96 bytes.
....

08:18:09.764757 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
08:18:10.564781 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
08:18:12.214889 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
08:18:12.814634 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
```

* tcpdump is a common debugging tool that allows the user to intercept and display IP packets being transmitted or received over a network interface.

```
08:18:13.414648 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
08:18:14.314858 Out 0:12:1e:76:1e:29 > Broadcast, ethertype 802.1Q (0x8100), length
46: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.121 tell 10.10.20.122
^C
7 packets received by filter
0 packets dropped by kernel

[edit interfaces ge-2/0/1 unit 100]
root@Lager#
```

Router `Hangover` is then accessed and a ping command toward `Lager` is issued. The `monitor traffic` command is issued at `Hangover` with similar output, except for a single important difference. While router `Lager` is sending out the ARP packets with an 802.1Q header (0 × 8100), router `Hangover` appears to be sending a non-VLAN-tagged Ethernet frame (0 × 0806), which is the cause of the Layer 2 channel errors that were previously discovered:

```
doug@hangover> monitor traffic interface ge-2/0/0 layer2-headers
verbose output suppressed, use <detail> or <extensive> for full protocol decode
Listening on ge-2/0/0, capture size 96 bytes
....
08:20:32.901733 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:33.801530 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:34.601659 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:35.301622 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:36.001475 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
08:20:36.941611 Out 0:12:1e:75:fa:28 > Broadcast, ethertype ARP (0x0806), length 42:
arp who-has 10.10.20.122 tell 10.10.20.121
^C
7 packets received by filter
0 packets dropped by kernel
```

After correcting the configuration error on `Hangover` to allow for VLAN encapsulation with the correct VLAN ID, the ping succeeds and is verified:

```
root@Lager# run monitor traffic interface ge-2/0/1 layer2-headers
verbose output suppressed, use <detail> or <extensive> for full protocol decode
Listening on ge-2/0/1, capture size 96 bytes
...

08:20:55.076174  In 0:12:1e:75:fa:28 > Broadcast, ethertype 802.1Q (0x8100), length
60: vlan 100, p 0, ethertype ARP, arp who-has 10.10.20.122 tell 10.10.20.121
08:20:55.076308 Out 0:12:1e:76:1e:29 > 0:12:1e:75:fa:28, ethertype 802.1Q (0x8100),
length 46: vlan 100, p 0, ethertype ARP, arp reply 10.10.20.122 is-at 0:12:1e:76:1e:
29
```

```
08:20:55.096237  In PFE proto 2 (ipv4): 10.10.20.121 > 10.10.20.122: ICMP echo
request seq 0, length 64
08:20:55.096272 Out 0:12:1e:76:1e:29 > 0:12:1e:75:fa:28, ethertype 802.1Q (0x8100),
length 102: vlan 100, p 0, ethertype IPv4, 10.10.20.122 > 10.10.20.121: ICMP echo
reply seq 0, length 64
```

Path MTU Issues

When an IP packet is transiting a network, it is often fragmented so that it can transverse interfaces with varying sizes of MTUs. However, some applications do not allow this fragmentation, so you must ensure that the ingress MTU is not larger than a transit MTU for those applications. One simple tool you can use to test whether the proper MTU is assigned is the *packet internet groper* (`ping`) command. Connectivity to a remote system is confirmed on router `Lager` by issuing a `ping` command to an address of 172.17.20.2:

```
root@Lager> ping 172.17.20.2
PING 172.17.20.2 (172.17.20.2): 56 data bytes
64 bytes from 172.17.20.2: icmp_seq=0 ttl=62 time=7.133 ms
64 bytes from 172.17.20.2: icmp_seq=1 ttl=62 time=10.375 ms
^C
--- 172.17.20.2 ping statistics ---
2 packets transmitted, 2 packets received, 0% packet loss
round-trip min/avg/max/stddev = 7.133/8.754/10.375/1.621 ms
```

Issue the `traceroute` command to check the path these packets take to reach the destination. Router `Lager` appears to be located two IP systems away from the destination of 172.17.20.2:

```
root@Lager> traceroute 172.17.20.2
traceroute to 172.17.20.2 (172.17.20.2), 30 hops max, 40 byte packets
 1  10.10.20.121 (10.10.20.121)  18.572 ms  12.953 ms  35.782 ms
 2  172.17.20.2 (172.17.20.2)  9.804 ms  9.497 ms  10.003 ms
```

The application that is being tested requires an MTU of 1,508 bytes, so a ping of size 1,500 is sent with 8 bytes of overhead to the remote station:

```
root@Lager> ping 172.17.20.2 size 1500 count 3
PING 172.17.20.2 (172.17.20.2): 1500 data bytes
1508 bytes from 172.17.20.2: icmp_seq=0 ttl=63 time=11.591 ms
1508 bytes from 172.17.20.2: icmp_seq=1 ttl=63 time=10.580 ms
1508 bytes from 172.17.20.2: icmp_seq=2 ttl=63 time=20.939 ms

--- 172.17.20.2 ping statistics ---
3 packets transmitted, 3 packets received, 0% packet loss
round-trip min/avg/max/stddev = 10.580/14.370/20.939/4.663 ms
```

The ping succeeds, and at first glance, all appears well, but let's not count our chickens before they hatch! Some examination into the operation of the `ping` command is needed before giving the green light of approval. By default, the ping packet will be sent out with the `do-not-fragment` bit cleared in the IP header. This means that although the ping packet will exit the router with a size of 1,508 bytes, it could be fragmented along the way. So, now issue the `ping` command with the `do-not-fragment` flag set and observe the results:

```
root@Lager> ping 172.17.20.2 size 1500 count 3 do-not-fragment
PING 172.17.20.2 (172.17.20.2): 1200 data bytes
36 bytes from 10.10.20.121: frag needed and DF set (MTU 1119)
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 04cc af90   2 0000  40  01 a809 10.10.20.122  172.17.20.2

36 bytes from 10.10.20.121: frag needed and DF set (MTU 1119)
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 04cc af91   2 0000  40  01 a808 10.10.20.122  172.17.20.2

^C
--- 172.17.20.2 ping statistics ---
2 packets transmitted, 0 packets received, 100% packet loss
```

It appears that the intermediate station cannot handle a packet larger than 1,119 bytes on its outgoing interface toward the destination, as observed by the ICMP message that is returned. Luckily, we found this out before the application was deployed, so we were able to correct this problem!

If the *outgoing* interface on an intermediate system did not contain the proper MTU size, an ICMP error message will be generated. If the *incoming* interface was configured with a smaller-than-needed MTU, the observation will be different. Since the packet is dropped at input, no ICMP MTU message will be received. Instead, oversize frame errors would increase on the intermediate system's input interface.

Looped Interfaces

Creating a physical loop on an interface has been a troubleshooting tool for many years. Since the physical path of a leased line frequently consists of multiple segments, often a problem can be localized by testing the circuit segment by segment. The idea is to create a loop at the endpoint of the circuit and send a series of tests toward that endpoint that can determine whether packets are lost or corrupted during transmission. Two types of loops are supported on most types of interfaces: a remote loop and a local loop. A *local loop* creates a loop toward the router, whereas a *remote loop* is a line loop that is created toward the downstream network device (see Figure 4-17).

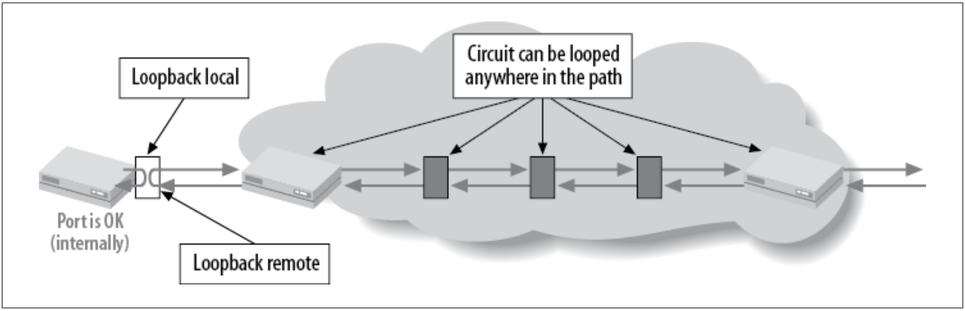


Figure 4-17. Loopback types

Often, the local LEC will go through a series of tests during the provisioning process to ensure that the circuit integrity includes loopback testing. The circuit may also be left in the looped state to avoid any local alarm generation. To see whether a loop is still in place, issue a ping toward the remote end of the circuit. If the remote end is looped (remote), the ping packets will continue until the Time to Live (TTL) expires, resulting in ICMP TTL expiration messages:

```
[edit]
doug@PBR# run ping 10.200.8.10
PING 10.200.8.10 (10.200.8.10): 56 data bytes
36 bytes from 10.200.8.9: Time to live exceeded
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 0054 30e2   0 0000  01  01 6325 10.200.8.9  10.200.8.10
36 bytes from 10.200.8.9: Time to live exceeded
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 0054 30e3   0 0000  01  01 6324 10.200.8.9  10.200.8.10

36 bytes from 10.200.8.9: Time to live exceeded
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 0054 30e6   0 0000  01  01 6321 10.200.8.9  10.200.8.10

^C
--- 10.200.8.10 ping statistics ---
4 packets transmitted, 0 packets received, 100% packet loss
```

On the remote device, a loop will be indicated (remote or local) by examining the `loopback` flag in the `show interfaces` command:

```
dougl@closing_time# run show interfaces  t1-2/0/2
Physical interface: t1-2/0/2, Enabled, Physical link is Up
  Interface index: 139, SNMP ifIndex: 37
  Link-level type: Cisco-HDLC, MTU: 1504, Clocking: Internal, Speed: T1,
  Loopback: Remote, FCS: 16, Framing: ESF
  Device flags   : Present Running
  Interface flags: Point-To-Point SNMP-Traps 16384
  Link flags     : No-Keepalives
  CoS queues     : 8 supported
  Last flapped   : 2007-04-17 16:55:37 UTC (00:02:01 ago)
  Input rate     : 200 bps (0 pps)
  Output rate    : 224 bps (0 pps)
```

```
    DS1   alarms   : None
    DS1   defects  : None
```

Conclusion

An interface is the fundamental building block of any router with a large variety of possible interface types. Although the Junos OS allows for many different interface types, the general configuration process is consistent across each type. This also helps when it is time to troubleshoot the problem interface. The specifics of the media signals will vary, but the operational commands used are the same. Once a router has all its interfaces, operational routes to remote networks can be configured via routing protocols. We will examine these protocols in subsequent chapters.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Identify valid options for interface names, logical units, and protocol families within the Junos OS.
- Describe how to monitor interfaces in real time.
- Describe the information contained within the `show interfaces extensive` command.
- Describe the uses of network utilities such as ping and traceroute.
- Configure MLPPP.
- Configure IPv4 addressing.
- Implement Frame Relay.
- Create VLAN-tagged interfaces.
- Provide redundancy and high availability with VRRP.
- Configure link bundling and aggregated interfaces.
- Establish point-to-point or point-to-multipoint links with a variety of Layer 2 encapsulations.

Chapter Review Questions

1. On a J-series router interface, what are the possible values for the PIC slot number?
   A. 1
   B. 0
   C. Variable, depending on the physical location of the interface
   D. A range of 0–4

2. Which two interfaces are considered permanent interfaces on a Juniper Networks router? (Choose two.)
   A. `lo0`
   B. `ge-0/1/0`
   C. `fxp3`
   D. `fxp0`
   E. `loopback0`
3. On a point-to-point interface, which logical unit(s) can be assigned to an interface?
   A. None
   B. 4095
   C. 100
   D. 0
4. Which interface name indicates that it is a serial interface in a J-series router that is located in PIM slot 1 and port number 1?
   A. `se-1/1`
   B. `se-1/0/1`
   C. `serial1/1`
   D. `se-0/1/1`
5. Which Junos command allows for real-time display of interface statistics?
   A. `monitor interface`
   B. `show interface statistics`
   C. `monitor traffic`
   D. `monitor statistics`
6. True or False: An interface must be administratively enabled before it is operationally in the up status.
7. What is the default Layer 2 encapsulation for a serial interface?
   A. SDLC
   B. HDLC
   C. X.121
   D. PPP
8. What is the maximum number of interfaces that can be added to an MLPPP bundle?
   A. 8
   B. 6
   C. 16
   D. 4

9. What is the default clocking mode on a serial interface?
   A. DCE
   B. Internal
   C. Loop
   D. DTE
10. Which CLI command would administratively disable the `ge-0/0/0` interface?
    A. `no shutdown`
    B. `set interface ge-0/0/0 disable`
    C. `deactivate interface ge-0/0/0`
    D. `disable interface ge-0/0/0`
11. True or False: All Juniper Networks routers contain an `fxp0` OoB management interface.
12. Which type of interface would be used to create a GRE tunnel?
    A. `gre`
    B. `tunnel.0`
    C. `gr`
    D. `ip.0`

Chapter Review Answers

1. Answer: B. J-series routers do not contain PICs, so this value in the interface name is always set to zero and is sometimes referred to as the virtual PIC value.
2. Answer: A, D. `ge-0/1/0` is a transient interface, whereas `fxp3` and `loopback0` are invalid media types.
3. Answer: D. A point-to-point interface has only one valid logical unit number, which is unit 0.
4. Answer B. Every transient interface always takes the form of MM-F/P/T, with F indicating the PIM slot and T representing the port number.
5. Answer: A. The `monitor statistics` command is an invalid command, whereas `monitor traffic` displays local TCP/IP traffic and `show interfaces` does not display information dynamically.
6. Answer: False. Juniper interfaces are always administratively enabled when installed.
7. Answer: D. The default encapsulation is PPP on all point-to-point interfaces.
8. Answer: A. As of Junos version 8.3, eight interfaces are allowed in a single bundle.

9. Answer: C. A serial interface always attempts to obtain its transmit timing from the line itself, using what is called *loop timing*. Other valid options that can be configured include `internal` and `dce`. DTE is not a configurable option.
10. Answer: B. The only other valid Junos command listed in the answer choices is the `deactivate` command. This command comments out the configuration that the running system will ignore.
11. Answer: False. Only M/T-series routers contain an `fxp0` OoB management interface. J-series routers must be managed via console, auxiliary ports, or regular PFE interfaces.
12. Answer: C. The software pseudointerface that is used to create GRE tunnels is the `gr` interface. The `gre` interface is used internally by the router and should not be configured. The `ip.0` and `tunnel.0` interfaces are not valid interface types.

CHAPTER 5

Protocol Independent Properties and Routing Policy

This chapter is divided into two main sections. The first section details routing capabilities and features that are not specific to any particular routing protocol, hence the phrase *protocol independent*. Although termed *independent*, these features often interact with one or more routing protocols, and in some cases may be required for proper protocol operation! The second half of the chapter investigates Junos software routing policy. Routing policy provides a toolbox that facilitates the control of route distribution, including route filtering and route attribute manipulation.

In many cases, you combine the functions of Protocol Independent Properties (PIPs) and routing policy to achieve some goal. For example, a static route is defined using PIP, but this same static route can then be redistributed, perhaps with a modified attribute such as a route tag or Border Gateway Protocol (BGP) community, as a result of routing policy.

This chapter exposes the reader to PIP and routing policy in a manner that is analogous to a mechanic being introduced to each tool comprising a complete toolbox. To continue the analogy, the ways in which tools can be used, either alone or in combinations, are virtually limitless. For example, your hammer can be used as part of the repair of a hole in a boat's hull, or it can be used to make the hole, perhaps in an effort to scuttle the craft. Although the boat may have some opinion, it's safe to say that the tool—the hammer, in this case—is just happy to be used, with no real concern as to the nature of the task.

The routing and service examples covered in subsequent chapters of this book all make use of the PIP and policy tools to solve some requirement specific to the example being discussed in that chapter. Since practical PIP and policy-related applications are provided throughout the remainder of this book, the goal of this chapter is to expose the reader to the general capabilities and configuration of PIP and policy so that subsequent case study examples are fully understood.

The PIP topics include:

- Static, aggregated, and generated routes
- Global preference
- Martian routes
- Route tables and routing information base (RIB) groups
- Autonomous system (AS) number and router ID

Routing policy topics include:

- Policy overview, import and export policy
- Policy components (terms, match conditions, actions, policy chains)
- Route filters
- Advanced policy concepts

Protocol Independent Properties

PIPs are used for a variety of functions, such as static and aggregate routes, protocol preferences, route tables, router ID, and so forth. The range of PIPs is configured at the `[edit routing-options]` hierarchy.

Static, Aggregate, and Generated Routes

Although the use of static routing is sometimes considered bad form, especially during a routing-protocol-based practical examination, there are many practical applications for static routes, along with their aggregate/generated counterparts.

Static routing suffers from a general lack of dynamism (though Bidirectional Forwarding Detection [BFD] can mitigate this issue), which often leads to loss of connectivity during network outages due to the inability to reroute. Static routes can quickly become maintenance and administration burdens for networks that have frequent adds, moves, or changes. With that said, static routing is often used at the network edge to support attachment to stub networks, which, given their single point of entry/egress, are well suited to the simplicity of a static route.

Static routes are often used to promote stability through advertisement into a routing protocol, such as BGP, where a single route that is always up is used to represent the connectivity of numerous, more specific routes, which individually may come and go (flap) because of instability in the attached network's infrastructure. By suppressing the specifics in favor of a single static route, the world is shielded from the day-to-day flapping while overall connectivity is preserved.

Static, aggregate, and generated routes are similar in that all are defined statically, and all can have mask lengths that represent *super-nets* (aggregated network prefixes) or *subnets* (extending the network ID into the host field of a classful address to gain more networks, each with fewer hosts). As such, there is often confusion about the differences, and why all three types of static routing are needed. Table 5-1 summarizes how these route types differ.

Table 5-1. Static, aggregate, and generated route comparison

Route type	Next hop type	Comment
Static	Discard, reject, IP/interface next hop, label-switched path (LSP) next hop	Global preference of 5; can be used for forwarding. Supports qualified and indirect next hops. Activated by valid next hop.
Aggregate	Reject (default), discard	Global preference of 130; not used for forwarding, activated by contributing route. Default reject for matching traffic.
Generated	Preferred contributor (default) or discard	Global preference of 130; default forwarding next hop based on preferred contributor. Activated by a contributing route.

Next hop types

Static and aggregate routes support various next hop types, some of which provide forwarding and others which do not. Understanding the differences between one next hop type and another is critical to achieving desired goals. Here are the specifics for each type of next hop:

Discard

A discard next hop results in the silent discard of matching traffic. *Silent* here refers to the fact that no Internet Control Message Protocol (ICMP) error message is generated back to the source of the packet. You normally choose a discard next hop when the goal is to advertise a single aggregate that represents a group of prefixes, with the expectation that any traffic attracted by the aggregate route will longest-match against one of the more specific routes, and therefore be forwarded according to the related next hop rather than the reject or discard next hop of the aggregate route itself.

The use of discard is best current practice when advertising an aggregate because the generation of ICMP error messages can consume system resources and may end up bombarding an innocent third party, as in the case of spoofed source addressing as part of a distributed denial of service (DDoS) attack.

Reject

A reject next hop results in the generation of an ICMP error message reporting an unreachable destination for matching traffic. This is the default next hop type of an active aggregated route. When a generated route is kept active in the route table by means of the passive command rather than a contributing route, the entry is marked by default with a reject next hop.

Forwarding

A forwarding next hop is used to move traffic to a downstream node, and it is typically specified as the IP address of a directly connected device. Matching traffic is then forwarded to the specified next hop. On a multiaccess network such as a

LAN, this involves the resolution of the IP address to a link layer address through the Address Resolution Protocol (ARP) or some form of static mapping. When directing traffic over a point-to-point interface, the next hop can be specified as an interface name; however, LAN interface types require an IP address next hop because of their multipoint nature.

Forwarding next hop qualifiers. When defining a static route with a forwarding next hop, you can use qualifiers that influence how the next hop is resolved and handled. Specifically:

`resolve`
: The `resolve` keyword allows you to define an indirect next hop for a static route, which is to say an IP forwarding address that does not resolve to a directly connected interface route. For example, you could specify a static route that points to a downstream neighbor's loopback address. In this case, matching traffic will result in a recursive lookup against the specified (`lo0`) next hop to select a directly connected forwarding next hop. If a parallel connection exists, the failure of the currently used link results in a new recursive lookup and selection of the remaining link for packet forwarding.

`qualified-next-hop`
: The `qualified-next-hop` keyword allows you to define a single static route with a list of next hops that are individually qualified with a preference. In operation, the most preferred qualified next hop that is operational is used. An operational next hop is one that can be resolved and is associated with an up interface. When that next hop is no longer usable, the next-best-qualified next hop is selected. That is to say, when the primary link is down, the router selects the next preferred next hop, which may point to a low-speed backup facility.

`retain`
: The `retain` keyword allows you to define a static route that remains in the forwarding table, regardless of the state of the route. The `retain` flag should be used with caution because traffic destined for this next hop is lost if the next hop is not reachable. This function is similar to the `passive` keyword used with generated routes.

Static versus aggregate routes

Simply realizing that an aggregate/generated route supports a subset of the next hop options supported by a simple static route does not really explain the real operational mode differences between these route types. A static route is active whenever it has a viable next hop. This next hop can take the form of discard/reject, which effectively nails the route up.

Aggregates need contributing routes. In contrast, both aggregate and generated routes require at least one *contributing* route to become active. A contributing route is simply a more specific route that is learned through some other mechanism, such as static definition or dynamic learning through a protocol such as Open Shortest Path First (OSPF). A route is more specific and is therefore able to contribute to an aggregate route (when it has a mask length longer than the associated aggregate) while sharing the same prefix as the aggregate (as indicated by the aggregate route's mask length). For example, the aggregate route 10.1/16 can be activated by route 10.1.1/24 because it has a longer (more specific) mask and shares the same 16 high-order prefix bits as the aggregate route. In contrast, the route 10.2.2/24 does not contribute to a 10.1/16 aggregate, as it does not share the same aggregate prefix.

You can use routing policy to filter the set of routes that are allowed to contribute to an aggregate, which helps you control when the corresponding aggregate becomes active. Because only active routes are subject to routing policy, this in turn can influence when a given aggregate is advertised in a routing protocol. For example, you can filter all other contributors so as to advertise an aggregate for 10.1/16 into BGP based strictly on the absence or presence of a 10.1.1.0/30 route. By default, the preferred or primary contributing route is selected from the pool of viable candidates based on global preference. To break preference ties, the numerically smallest contributing route is preferred.

A given route can contribute only to a single aggregate route. However, an active aggregate route can recursively contribute to a less specific matching aggregate route. For example, an aggregate route to the destination 10.1.0.0/16 can contribute to an aggregate route to 10.0.0.0/8.

Aggregate versus generated routes

People often get confused about aggregate and generated routes—because both require contributors to become active and both are assigned the same routing preference of 130. The key difference between the two types of routes is that an aggregate route is *never* used for forwarding. Although it may attract plenty of traffic, the next hop of an aggregate route is either a discard or a reject—no ifs, ands, or buts. In contrast, a generated route installs the next hop associated with the preferred contributor, and therefore can be used to forward matching traffic. For this reason, a generated route is sometimes called a route of last resort. This is because in the general case, traffic typically matches a more specific route and is routed appropriately, just as in the case of an aggregate route—when the most specific (longest) match is against the generated route itself, it is forwarded to a gateway of last resort, as identified by the next hop associated with the currently preferred contributor route.

These operational differences are shown via the command-line interface (CLI) at `Cider` using a 10.10/16 aggregate versus a 10.10/16 generated route:

```
[edit routing-options]
lab@Cider# show aggregate
route 10.10.0.0/16;

[edit routing-options]
lab@Cider# run show route protocol aggregate detail
```

```
inet.0: 10 destinations, 10 routes (10 active, 0 holddown, 0 hidden)
10.10.0.0/16 (1 entry, 1 announced)
           *Aggregate Preference: 130
                Next hop type: Reject
                Next-hop reference count: 2
                State: <Active Int Ext>
                Age: 1:50
                Task: Aggregate
                Announcement bits (1): 0-KRT
                AS path: I (LocalAgg)
                Flags:                Depth: 0        Active
                AS path list:
                AS path: I Refcount: 2
                Contributing Routes (2):
                10.10.11.0/24 proto Direct
                10.10.12.1/32 proto Direct
```

A 10.10/16 aggregate is activated by the presence of directly connected routes that contribute to the aggregate. Direct routes for multiaccess networks cannot contribute to a generated route because a forwarding next hop cannot be derived from the mere presence of the local interface, as is possible in the case of a point-to-point link, where the interface itself can be specified as a next hop.

Both the aggregated routes and the generated routes are displayed in the route table with the `show route protocol aggregate` command.

To reiterate, a generated route remains hidden when only direct multiaccess routes are present to contribute:

```
[edit routing-options]
lab@Cider# show generate
route 10.10.0.0/16;

[edit routing-options]
lab@Cider# run show route protocol aggregate detail hidden

inet.0: 10 destinations, 10 routes (9 active, 0 holddown, 1 hidden)
10.10.0.0/16 (1 entry, 0 announced)
         Aggregate
                Next hop type: Reject
                Next-hop reference count: 1
                State: <Hidden Int Ext>
                Age: 3:10
                Task: Aggregate
                AS path: I
                            Flags: Generate Depth: 0        Inactive
```

This is because the next hop for a generated route is based on the forwarding next hop of the preferred contributor, and for a multiaccess type of network, this requires a static or learned route that identifies a next hop on one of the direct interface routes. In this example, a static route with a forwarding next hop pointing out Cider's ge-0/0/1.100 interface toward Bock is used to activate the generated route:

```
[edit routing-options]
lab@Cider# set static route 10.10.1/24 next-hop 10.10.11.1

[edit routing-options]
lab@Cider# commit
commit complete

[edit routing-options]
lab@Cider# run show route 10.10.1/24 detail

inet.0: 11 destinations, 11 routes (11 active, 0 holddown, 0 hidden)
10.10.1.0/24 (1 entry, 1 announced)
        *Static Preference: 5
                Next-hop type: Router, Next-hop index 500
                Next-hop reference count: 5
                Next hop: 10.10.11.1 via ge-0/0/1.100, selected
                State: <Active Int Ext>
                Age: 17
                Task: RT
                Announcement bits (2): 0-KRT 1-Aggregate
                AS path: I

[edit routing-options]
lab@Cider# run show route protocol aggregate detail

inet.0: 11 destinations, 11 routes (11 active, 0 holddown, 0 hidden)
10.10.0.0/16 (1 entry, 1 announced)
        *Aggregate Preference: 130
                Next-hop type: Router, Next-hop index 501
                Next-hop reference count: 5
                Next hop: 10.10.11.1 via ge-0/0/1.100, selected
                State: <Active Int Ext>
                Age: 11:34
                Task: Aggregate
                Announcement bits (1): 0-KRT
                AS path: I
                              Flags: Generate Depth: 0        Active
                Contributing Routes (1):
                        10.10.1.0/24 proto Static
```

Note that both the 10.10.1.0/24 static route and the resultant generated route share the same forwarding next hop. As the only viable contributing route, the 10.10.1.0/24 route is the preferred contributor in this example.

Route attributes and flags

When you define a static route, you can include various route attributes such as AS path, BGP community, route tag, metric, and so forth. These attributes may or may not come into play later when the route is redistributed into a specific routing protocol.

For example, OSPF has no notion of a BGP community or AS path, and therefore these attributes are not injected into OSPF despite being attached to the route. The route attributes can be defined individually for each route or as part of a default template that is inherited by all related routes, unless specifically overwritten by a competing attribute.

You can also attach flags to a static route that controls various aspects of how the route is handled or operates. For example, the `no-advertise` flag prevents the associated route from being exported into routing protocols, even when the policy configuration otherwise selects that route for redistribution. You can display the list of available route attributes and flags with the CLI's **?** feature:

```
[edit routing-options]
lab@Cider# set static route 10/8 ?
Possible completions:
  active               Remove inactive route from forwarding table
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> as-path              Autonomous system path
> bfd-liveness-detection  Bidirectional Forwarding Detection (BFD) options
> color                Color (preference) value
> color2               Color (preference) value 2
+ community            BGP community identifier
  discard              Drop packets to destination; send no ICMP unreachables
  install              Install route into forwarding table
> lsp-next-hop         LSP next hop
> metric               Metric value
> metric2              Metric value 2
> metric3              Metric value 3
> metric4              Metric value 4
+ next-hop             Next hop to destination
  next-table           Next hop to another table
  no-install           Don't install route into forwarding table
  no-readvertise       Don't mark route as eligible to be readvertised
  no-resolve           Don't allow resolution of indirectly connected next hops
  no-retain            Don't always keep route in forwarding table
> p2mp-lsp-next-hop    Point-to-multipoint LSP next hop
  passive              Retain inactive route in forwarding table
> preference           Preference value
> preference2          Preference value 2
> qualified-next-hop   Next hop with qualifiers
  readvertise          Mark route as eligible to be readvertised
  receive              Install a receive route for the destination
  reject               Drop packets to destination; send ICMP unreachables
  resolve              Allow resolution of indirectly connected next hops
  retain               Always keep route in forwarding table
> tag                  Tag string
> tag2                 Tag string 2
```

The reader is encouraged to consult Junos software documentation for details on the various attributes and flags that can be attached to static or aggregated routes. The commonly used attributes are demonstrated either in this chapter or within the various scenarios demonstrated throughout this book. Figure 5-1 illustrates a typical application of a static route via a sample routing topology.

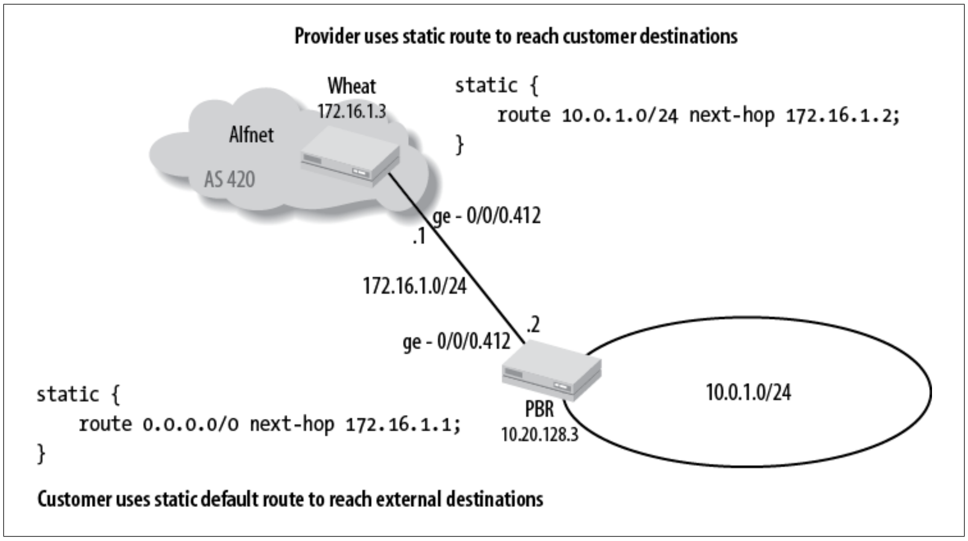

Provider uses static route to reach customer destinations
Wheat
172.16.1.3
Alfnet
AS 420
static {
    route 10.0.1.0/24 next-hop 172.16.1.2;
}
ge - 0/0/0.412
.1
172.16.1.0/24
.2
ge - 0/0/0.412
PBR
10.20.128.3
10.0.1.0/24
static {
    route 0.0.0.0/0 next-hop 172.16.1.1;
}
Customer uses static default route to reach external destinations

Figure 5-1. Static routing configuration

Global Route Preference

Routing information can be learned from multiple sources. In order to break ties among equally specific routes learned through multiple sources, each source is assigned a global preference. It can be said that the global preference determines the overall believability or "goodness" of a routing source. As such, routes that are learned through local administrative action—for example, static routes—are more believable than the same routes learned through a routing protocol such as OSPF. In Cisco IOS, this concept is called *administrative distance*. Table 5-2 shows the default protocol preferences for Junos software.

Table 5-2. Global protocol preference values

Source	Purpose	Default preference
Local	Local IP address of the interface	0
Directly connected network	Subnet corresponding to the directly connected interface	0
System	Routes installed by Junos	4
Static	Static routes	5
RSVP	Routes learned from the Resource Reservation Protocol used in Multiprotocol Label Switching (MPLS)	7
LDP	Routes learned from the Label Distribution Protocol used in MPLS	9
OSPF internal route	OSPF internal routes such as interfaces that are running OSPF	10
IS-IS Level 1 internal route	Intermediate System–to–Intermediate System Level 1 internal routes such as interfaces that are running ISIS	15
IS-IS Level 2 internal route	Intermediate System–to–Intermediate System Level 2 internal routes such as interfaces that are running ISIS	18
Redirects	Routes from ICMP redirect	30
Kernel	Routes learned via route socket from kernel	40
SNMP	Routes installed by Network Management System through the Simple Network Management Protocol	50
Router discovery	Routes installed by ICMP Router Discovery	55
RIP	Routes from Routing Information Protocol (IPv4)	100
RIPng	Routes from Routing Information Protocol (IPv6)	100
PIM	Routes from Protocol Independent Multicast	105
DVMRP	Routes from Distance Vector Multicast	110
Aggregate	Aggregate and generated routes	130
OSPF AS external routes	Routes from Open Shortest Path First that have been redistributed into OSPF	150
IS-IS Level 1 external route	Routes from Intermediate System–to–Intermediate System Level 1 that have been redistributed into ISIS	160
IS-IS Level 2 external route	Routes from Intermediate System–to–Intermediate System Level 2 that have been redistributed into ISIS	165
BGP	Routes from Border Gateway Protocol	170
MSDP	Routes from Multicast Source Discovery Protocol	175

As with a route metric, numerically lower preference values are preferred. You can alter the default preference values when needed to accommodate some specific goal, such as route redistribution during an Interior Gateway Protocol (IGP) migration, which is demonstrated in Chapter 6.

Readers familiar with Cisco Systems may note a few differences between how the two vendors assign distance/preference. For example, Cisco has a separate distance for Internal BGP (IBGP) versus External BGP (EBGP) (200 versus 20), whereas Juniper uses the same value. In this case, there is no operational impact because in the route selection process Junos software prefers EBGP over IBGP, resulting in the same behavior for both vendors. One area where the vendors differ is in regard to IGP versus EBGP distance. Here, Cisco assigns an OSPF IGP distance of 110; since this is higher than the EBGP distance of 20, it results in the selection of an EBGP route over an equivalent OSPF route. In the same setup, a Juniper router chooses the OSPF route, owing to the preference values shown in Table 5-2.

Although you could alter Junos software preference to mimic IOS behavior, Juniper created a compatibility knob for this situation, called `advertise-inactive`. When applied to an EBGP peering session, this knob results in the advertisement of the best BGP route that happens to be inactive because of IGP preference. When using the `advertise-inactive` option, the Junos device continues to use the OSPF copy for forwarding, and the IOS device uses the EBGP copy to forward. However, from the perspective of an EBGP peer in a neighboring AS, both vendors appear to behave the same.

Floating static routes

A floating static route is nothing more than a static route that has a modified preference, causing it to be less preferred than a dynamically learned copy. The defaults cause a static route to always be preferred over a dynamic route. A floating static route is often used to provide backup in the event of a network or protocol malfunction. When all is operating normally, the static route remains idle because the dynamically learned routing is preferred. When routing protocol disruption results in the loss of a learned route, the previously inactive static route becomes active.

The following code sample creates a floating static route by assigning a modified preference that makes the route *less* preferred than an OSPF internal route, which has a default preference of 10:

```
[edit routing-options static route 0.0.0.0/0]
lab@PBR# show
next-hop 172.16.1.1;
preference 11;

[edit routing-options static route 0.0.0.0/0]
lab@PBR# run show route 200.0.0.0

inet.0: 12 destinations, 12 routes (12 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[Static/11] 00:00:06
                    > to 172.16.1.1 via ge-0/0/0.412
```

Martian Routes

Junos software supports the concept of martian routes, which is a euphemistic way to describe a route that should not be present. Most network operators consider local use addressing, as defined in RFC 1918, “Address Allocation for Private Internets,” as an example of martian routes, at least when received outside of the context of a virtual private network (VPN).

Routes contained in the martian table are excluded from route update processing, which prevents them from ever being installed into the route table. The martian mechanism provides a consolidated way to filter bogus routing information from all protocol sources without the use of explicit policy.

You can display martian entries with a `show route martians` command. In this example, only entries for the main `inet.0` route table are displayed through the `table` keyword:

```
[edit routing-options]
lab@Bock# run show route martians table inet.0

inet.0:
             0.0.0.0/0 exact -- allowed
             0.0.0.0/8 orlonger -- disallowed
             127.0.0.0/8 orlonger -- disallowed
             128.0.0.0/16 orlonger -- disallowed
             191.255.0.0/16 orlonger -- disallowed
             192.0.0.0/24 orlonger -- disallowed
             223.255.255.0/24 orlonger -- disallowed
             240.0.0.0/4 orlonger -- disallowed
```

The default entries permit private use of RFC 1918 private addressing space while filtering prefixes that should never appear in a route update—for example, the 127.0.0.1 loopback address or the IANA reserved 192.0.0.0/24 network block. You can add entries to the table, which can later be removed using `set` and `delete`, respectively. You cannot explicitly remove predefined martian entries, but you can add new entries that negate their effect. For example, rather than trying to delete the `0/0 exact allow` entry, you negate its effect by *adding* a new entry with a competing action. For instance, the default martian table allows the default route, which in this example is being advertised via OSPF from `Bock` to `Cider`:

```
[edit]
lab@Cider# run show route protocol ospf

inet.0: 11 destinations, 11 routes (11 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 00:00:07, metric 0, tag 0
                    > to 10.10.11.1 via ge-0/0/1.100
. . .
224.0.0.5/32       *[OSPF/10] 00:00:27, metric 1
                      MultiRecv
```

The martian table for the `inet.0` route table is modified with a `set 0/0 exact deny` statement, which overrides the previous entry for the 0/0 exact route. Note that a `deny` action is the default for any entry in the martian table:

```
[edit routing-options martians]
lab@Cider# set 0/0 exact

[edit routing-options martians]
lab@Cider# show
0.0.0.0/0 exact;
```

After the change is committed, the results are confirmed:

```
[edit routing-options martians]
lab@Cider# run show route martians table inet.0

inet.0:
                        0.0.0.0/0 exact -- disallowed
                        0.0.0.0/8 orlonger -- disallowed
                        127.0.0.0/8 orlonger -- disallowed
                        128.0.0.0/16 orlonger -- disallowed
                        191.255.0.0/16 orlonger -- disallowed
                        192.0.0.0/24 orlonger -- disallowed
                        223.255.255.0/24 orlonger -- disallowed
                        240.0.0.0/4 orlonger -- disallowed

[edit routing-options martians]
lab@Cider# run show route protocol ospf | match 0.0.0.0
```

The lack of an OSPF-learned default route at `Cider` confirms the modified martian table results in ignoring routing information for the 0/0 route.

Routing Tables and RIB Groups

Do

All Junos-based routers maintain a number of route tables that are used for specific purposes. In addition to the automatically created tables, you can create your own route tables, either indirectly through the use of virtual routers or Layer 2/Layer 3 VPNs and the related Virtual Route and Forwarding (VRF) tables, or directly through the use of RIB groups.

Generally speaking, each route table/RIB populates a designated portion of the forwarding table. This creates a single forwarding table that is partitioned based on a specific route table context. Packets are forwarded based on this route table context, which allows for distinct forwarding behavior on a per-route-table basis. It's a key component of any VPN type of service, where per-VRF (per VPN site) route tables are maintained along with a corresponding VPN-specific forwarding table context.

You can view the contents of a particular route table using the command `show route table <`*`table name`*`>`. The general naming convention for route tables takes the form of the protocol family such as `inet` (Internet) or `inet6`, `iso` (ISO), or `mpls`, followed by a period and a nonnegative integer. Routing instance table names are somewhat the exception here, taking the form of `instance-name.inet.0`, where the first part consists of a user-assigned symbolic name, followed by the protocol family and table ID, which is `inet.0` in this example.

Default route tables

The default route tables created by Junos software include:

`inet.0`
: The `inet.0` table is the default unicast route table for the IPv4 protocol. This is the main route table used to store unicast routes such as interface local/direct, static, or dynamically learned routes.

`inet.1`
: The `inet.1` table serves as a multicast forwarding cache. This table constrains the various IPv4 (S,G) group entries that are dynamically created as a result of join state.

`inet.2`
: The `inet.2` table houses unicast routes that are used for multicast reverse path forwarding (RPF) lookup, typically as learned through MP-BGP using SAFI 2. The IPv4 unicast routes stored in this table can be used by multicast protocols such as the Distance Vector Multicast Routing Protocol (DVMRP), which requires a specific RPF table. In contrast, PIM does not need an `inet.2` because it can perform RPF checks against the `inet.0` table. You can import routes from `inet.0` into `inet.2` using RIB groups, or install routes directly into `inet.2` from a multicast routing protocol.

`inet.3`
: The `inet.3` table contains MPLS LSP information. This table contains the egress address of the MPLS LSP, along with the LSP name and outgoing interface, and is populated by both RSVP and LSP. The `inet.3` table is used when the local router functions as the ingress to an LSP.

`instance_name.inet.0`
: When you configure a VRF or VR routing instance, the resultant instance creates a route table based on the routing instance's name. For example, defining a Layer 3 VPN instance called `ce1` results in the creation of a route table named `ce1.inet.0`. A routing instance differs from a logical router in that various routing instances share a single instance of the routing protocol daemon (rpd), whereas each LR gets its *own* instance of rpd, which in turn provides greater isolation. Note that LRs are not supported on J-series platforms with the 10.3 release used to write this book.

`inet6.0`
: The `inet6.0` table is used to house IPv6 unicast route tables.

`bgp.l3vpn.0`
: The `bgp.l3vpn.0` table contains routes learned from other Provider Edge (PE) routers in a Layer 3 VPN environment via BGP. Routes in this table are copied into a particular Layer 3 VRF when there is a matching route table.

`bgp.l2vpn.0`
: The `bgp.l2vpn.0` table contains routes learned from other PE routers in a Layer 2 VPN environment via BGP. The related Layer 2 routing information is copied into Layer 2 VRFs based on matching target communities.

`mpls.0`
: The `mpls.0` table houses the MPLS label-switching operations used when the local router is acting as a transit label-switching router (LSR) in support of LSPs.

`iso.0`
: The `iso.0` table houses IS-IS routes, which consist of a network entity title (NET) and a host ID. When using IS-IS in support of IP routing, you can expect to see only the routers' NETs, which are typically assigned to the loopback interface, because in this context the IS-IS protocol is used to convey IP, not IS-IS routes.

`juniper_private`
: Junos software needs to communicate internally with service Physical Interface Cards (PICs). The `juniper_private` tables are created as needed to facilitate these internal communications between the RE and service PIC hardware. These tables are not seen by default in the `show route` command but can be seen in the `show route forwarding table` command.

When you issue a `show route` command, all tables are listed chronologically starting with `inet.0`. Within each table, you will also see the total number of routes in the table and a listing further breaking down active routes and hidden routes. The following sample output from a `show route` command displays many of the tables described earlier, and it is taken from a router configured to support a BGP-signaled Layer 3 VPN using RSVP-based LSP transport. The router also has the `inet6` and `iso` families enabled on its loopback interface.

The purpose of the following output display is simply to show a real-world example in which many of the default route tables are populated and used. The specific details of which routes are present or how a given entry in some particular table is actually used, are not the focus here, hence a related topology diagram is not needed for the purpose of simply observing the presence of multiple route tables. Subsequent chapters in this book expand on these specifics as needed in the context of enterprise routing:

```
user@L3_VPN_router> show route
inet.0: 23 destinations, 23 routes (22 active, 0 holddown, 1 hidden)
+ = Active Route, - = Last Active, * = Both

1.12.1.0/24        *[Direct/0] 00:33:41
                    > via ge-1/0/0.0
1.12.1.1/32        *[Local/0] 00:33:41
                      Local via ge-1/0/0.0
```

```
. . .
10.255.66.50/32    *[OSPF/10] 00:32:53, metric 1
                    > to 1.12.1.2 via ge-1/0/0.0
. . .
192.168.64.0/21    *[Direct/0] 5d 02:42:28
                    > via fxp0.0
192.168.66.47/32   *[Local/0] 5d 02:42:28
                      Local via fxp0.0
192.168.102.0/23   *[Static/5] 5d 02:42:28
                    > to 192.168.71.254 via fxp0.0
. . .
224.0.0.5/32       *[OSPF/10] 00:33:41, metric 1
                      MultiRecv

ce1.inet.0: 3 destinations, 3 routes (3 active, 0 holddown,
0 hidden)
+ = Active Route, - = Last Active, * = Both

1.1.1.0/24         *[Direct/0] 00:33:41
                    > via ge-1/2/0.0
1.1.1.2/32         *[Local/0] 00:33:41
                      Local via ge-1/2/0.0
10.255.66.52/32    *[BGP/170] 00:33:24, localpref 100
                      AS path: I
                    > to 1.1.1.1 via ge-1/2/0.0

iso.0: 1 destinations, 1 routes (1 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

47.0005.80ff.f800.0000.0108.0001.0102.5506.6047/152
                   *[Direct/0] 5d 02:42:28
                    > via lo0.0

mpls.0: 3 destinations, 3 routes (3 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0                  *[MPLS/0] 00:33:41, metric 1
                      Receive
1                  *[MPLS/0] 00:33:41, metric 1
                      Receive
2                  *[MPLS/0] 00:33:41, metric 1
                      Receive

inet6.0: 2 destinations, 2 routes (2 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

abcd::10:255:66:47/128
                   *[Direct/0] 5d 02:42:28
                    > via lo0.0
fe80::2a0:a5ff:fe12:47ed/128
                   *[Direct/0] 5d 02:42:28
                    > via lo0.0
```

User-defined RIBs and RIB groups

You can define additional route tables with the `rib` keyword. This capability is rarely used, but it is demonstrated here for completeness. In the following example, the user has configured a custom IPv4 RIB called `inet.69`, in which a single static route had been defined:

```
[edit routing-options]
lab@PBR# show
rib inet.69 {
    static {
        route 10.1.0.0/16 discard;
    }
}
```

The contents of the user-defined RIB are displayed with a `show route table <table name>` command:

```
[edit routing-options]
lab@PBR# run show route table inet.69

inet.69: 1 destinations, 1 routes (1 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.1.0.0/16        *[Static/5] 00:15:53
                      Discard
```

You can group together multiple route tables (RIBs) to form a *route table group*. Within a group, a routing protocol can import routes into all the route tables in the group, and it can export routes from a single route table. Simply put, RIB groups provide a way to copy routing information from one route table to another. In operation, a RIB group consists of one primary and one or more secondary route tables—the first route table specified is the *primary* route table, and any additional route tables function as *secondary* route tables. The primary route table determines the address family of the route table group. To configure an IPv4 route table group, specify `inet.0` as the primary route table. To configure an IPv6 route table group, specify `inet6.0` as the primary route table.

Each RIB group must contain one or more route tables that Junos software uses as the source of any imported routes, as specified with the `import-rib` statement.

In the following example, a `rib-group` called `my_interface_routes` is configured to import interface route entries from `inet.0` into `inet.2`. The `my_interface_routes` RIB group is defined under the `interface-routes` hierarchy, which specifies the protocol (direct) that is used to match against when copying the routes into `inet.2`:

```
[edit routing-options]
lab@PBR# show
interface-routes {
    rib-group inet my_interface_routes;
}
rib-groups {
    my_interface_routes {
        import-rib [ inet.0 inet.2 ];
    }
}
```

The result of the interface routes RIB group definition is confirmed with a display of the `inet.2` table both before and after the changes are committed:

```
[edit routing-options rib-groups]
lab@PBR# run show route table inet.2

[edit routing-options rib-groups]
lab@PBR# commit
commit complete
```

After the commit, the `inet.2` table is correctly populated with interface routes, as copied from the `inet.0` table:

```
[edit routing-options rib-groups]
lab@PBR# run show route table inet.2

inet.2: 11 destinations, 11 routes (11 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.130.0/24     *[Direct/0] 00:00:04
                    > via ge-0/0/0.1141
10.10.130.2/32     *[Local/0] 00:00:04
                      Local via ge-0/0/0.1141
10.20.128.3/32     *[Direct/0] 00:00:04
                    > via lo0.0
10.20.129.0/24     *[Direct/0] 00:00:04
                    > via ge-0/0/0.3141
10.20.129.2/32     *[Local/0] 00:00:04
                      Local via ge-0/0/0.3141
10.20.130.0/24     *[Direct/0] 00:00:04
                    > via ge-0/0/0.1241
. . .
```

If desired, you can use import policy to add additional control over which routes are copied between RIBs.

Router ID and Antonymous System Number

The last PIP-related configuration to be discussed is related to the router ID (RID) and BGP AS number.

Router ID

Many routing protocols require that the source of routing information be uniquely identified using the concept of a RID. A RID normally takes the form of an IPv4 address, and in most cases does not have to be reachable to correctly function as a RID. Stated differently, a router can receive a BGP or OSPF route update from a router identified as 1.1.1.1, and correctly process the related routing information, even though it may not have a route to 1.1.1.1. With that said, it is common to use a routable IP address as the RID because this can simplify operations by enabling pings or telnet to the RID.

You can specify only one RID, and the same value is used by all protocols that require a RID (OSPF, OSPFv3, and BGP). The current best practice is to base the RID on the router's globally routable `lo0` address. You explicitly configure a RID as follows:

```
[edit routing-options]
lab@PBR# set router-id 1.1.1.1

[edit routing-options]
lab@PBR# show
router-id 1.1.1.1;
```

When you explicitly configure a RID that is based on an address assigned to the router's `lo0` interface, you will have to run an explicit IGP instance (typically passive) on that interface to advertise reachability to the RID, when desired. When a RID is not explicitly configured, the router obtains its RID from the primary address of the first interface that comes online. This is typically the loopback interface, when it has been assigned a nonmartian (non-127.0.0.1) address. Because changes in RID are disruptive to protocol operation, it's a good practice to manually configure a RID to ensure that changes to `lo0` addressing do not cause unanticipated churn.

Historically, Junos software automatically advertised a stub route to the interface from which the RID is obtained. This meant that you did not need to run an IGP instance on the loopback interface to advertise reachability to the RID. Starting with Junos Release 8.5, this behavior has changed. Now, whether you use an explicit or an automatically generated RID that is `lo0`–based, you need to enable OSPF on the loopback interface to advertise reachability to the related loopback address, even when it is the source of an automatically selected RID.

Autonomous system number

An autonomous system (AS) number is required for BGP operation; you cannot commit a BGP-related configuration without also defining the local router's AS number. In this regard, it can be said that the AS number is not really protocol-independent, but for whatever reason it can be configured under `[routing-options]`, rather than under BGP itself.

Chapter 7 provides a detailed description of what an AS number is and how BGP uses it. The following is a sample AS number configuration:

```
[edit routing-options]
lab@PBR# set autonomous-system ?
Possible completions:
  <as_number>          Autonomous system number (1..65535)
  loops                Maximum number of times this AS can be in an AS path
[edit routing-options]
lab@PBR# set autonomous-system 100
```

```
[edit routing-options]
lab@PBR# show
autonomous-system 100;
```

The `loops` option allows you to configure tolerance for occurrences of the local ASN in received route updates; normally such an occurrence indicates a BGP routing loop and results in the related route being discarded. There are certain corner-case scenarios, mostly related to VPNs and the support of EBGP on the PE-CE customer links, where you might need to alter the default value. Note that the default value of 1 indicates that a route with a single instance of the local ASN should be discarded. Therefore, to support reception of routes with a single instance of the local ASN, specify a loop value of 2.

Summary of Protocol-Independent Properties

This section discussed common PIPs that are typically used in enterprise networks. Topics included the creation of static, aggregate, and generated routes, along with their differences and associated various next hop options. Global preference, which is used to break ties between competing sources of routing information, was discussed, as was the configuration of a floating static route—which is simply a static route with an altered global preference that makes it less preferred than a route learned via a dynamic routing protocol. This section also described the use and purpose of the default Junos software route tables, and how RIBs and RIB groups are used to create and link route tables. We ended with a description of how the RID can be explicitly configured or automatically computed, in addition to how the local AS number is configured to support BGP operation.

The next section delves into Junos software routing policy, which provides you with complete control over route exchanges and attribute modification.

Routing Policy

This section details Junos software routing policy operation and configuration. The actual application of policy to solve some specific networking requirement is generally left to the protocol-specific coverage found in subsequent chapters. You configure policy-related options and statements at the `[edit policy-options]` hierarchy. Routing policy and firewall filters have a similar syntax in Junos software. The former deals with routes in the control plane, whereas the latter deals with packets in the data plane. Firewalls are covered in detail in a later chapter.

What Is a Routing Policy, and When Do I Need One?

Simply put, routing policy is used to:

- Control what routes are installed into the route table for possible selection as an active route
- Control what routes are exported from the route table, and into which protocols
- Alter attributes of routes, either at reception or at the time of advertisement to other peers

Given that routing policy is used to control the reception and transmission of routing information and to alter route attributes, it's safe to say that you need routing policy when the default policy does not meet your requirements.

The specifics of the various default policies are covered later, but to provide an example, consider that, by default, directly connected routes are not advertised into any routing protocol; in the case of RIP, not even when RIP is configured to run on those directly connected interfaces. If your goal is to get direct routes advertised into RIP, the default policy obviously does not meet your needs, and a custom policy must be written, and applied, to achieve your goal of redistributing direct routes into RIP.

Where and How Is Policy Applied?

You can apply policy in one of two places: either at import or at export. Generally speaking, use a command of the form `set protocols <protocol-name> import` to apply an import policy, or use `set protocols <protocol-name> export` to apply an export policy. Figure 5-2 illustrates this concept.

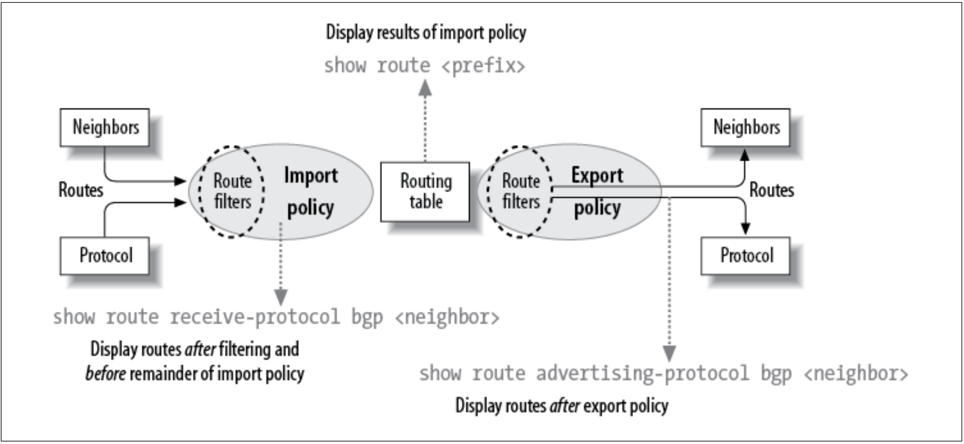

Display results of import policy
show route <prefix>
Neighbors
Routes
Protocol
Route filters
Import policy
Routing table
Route filters
Export policy
Neighbors
Routes
Protocol
show route receive-protocol bgp <neighbor>
Display routes *after* filtering and *before* remainder of import policy
show route advertising-protocol bgp <neighbor>
Display routes *after* export policy

Figure 5-2. Policy application and monitoring points

Figure 5-2 shows routes being received through some protocol, and how import policy serves to filter and adjust route attributes before they are copied into the route table.

In contrast, export policy comes into play when routes are being selected from the route table for inclusion in transmitted route updates. Once again, the export policy serves to filter and adjust route attributes to meet the specific needs of the networking environment.

It is worth noting that distance vector protocols such as RIP and path vector protocols such as BGP actually support the notion of received and transmitted routes. These protocols support the `show route receiving-protocol` *`<protocol-name> <neighbor-address>`* and `show route advertising-protocol` *`<protocol> <neighbor-address>`* commands, which are very useful when troubleshooting or analyzing policy operation. Figure 5-2 shows how the receiving-protocol form of the command is used to display routes *after* route filtering, but *before* attribute manipulation. In contrast, the advertising-protocol form of the command is executed after all export policy operations, including route filtering and attribute modification. Simply issue a `show route` *`<prefix>`* command to display a route as it exists in the route table, which will include any modified attributes resulting from import policy operations.

Applying policy to link state routing protocols

Link state (LS) protocols such as OSPF and IS-IS do not send and receive routes directly. Instead, they flood link-state advertisement (LSA) packets, which are used to build a topological database from which each router computes a route table. As such, LS protocols do not support much in the way of import policy. OSPF import policies can filter external routes from the route table or assign a relative priority for route restoration (for more on applying policies to OSPF, see *http://www.juniper.net/techpubs/en_US/junos10.3/topics/usage-guidelines/routing-applying-policies-to-ospf-routes.html*).

If you wish to filter LSAs, protocol-specific mechanisms are required to ensure that LS database consistency is maintained. Chapter 6 covers the concepts of OSPF stub areas and LSA filtering.

You can apply export policy to an LS protocol to effect route redistribution, but the external route is still flooded in an LSA rather than being sent outright; the result is that the `show route receiving protocol` and `show route-advertising protocol` commands are not effective when dealing with LS protocols.

When you apply policy to an LS protocol, you do so globally, which is to say the policy is not applied to particular interfaces or areas. In the case of OSPF, you apply export policy at the `[edit protocol ospf]` hierarchy:

```
[edit protocols ospf]
lab@PBR# show
export test_export; ## 'test_export' is not defined
```

The CLI warning provides a nice reminder that the related `test_export` policy does not yet exist. Because the presence (or absence) or a policy can have a dramatic effect on overall network operation, you will not be able to commit a configuration with this type of omission. You can define a policy that is never applied—but once applied, the policy must exist before you can commit the changes.

Applying policy to BGP and RIP

Both BGP and RIP support the application of import and export policy, and both support policy application at different hierarchies. Focusing on BGP for the moment, you can apply a policy at one of three different hierarchies—global, group, or neighbor. The following code snippet provides an example of this concept:

```
[edit protocols bgp]
lab@PBR# show
export global_export;
group internal {
    export internal_export;
    neighbor 1.1.1.1 {
        export neighbor_1.1.1.1_export;
}
    neighbor 2.2.2.2;
}
group other {
    neighbor 3.3.3.3;
}
```

In this example, a policy named `global_export` is applied at the global level, another policy named `internal_export` is applied at the group level, and yet a third policy named `neighbor_1.1.1.1_export` is applied at the neighbor level.

A key point, and one that is often misunderstood and that can lead to problems, is that in such a configuration, *only* the most explicit policy is applied. A neighbor-level policy is more explicit than a group-level policy, which in turn is more explicit than a global policy. Hence, neighbor 1.1.1.1 is subjected only to the `neighbor_1.1.1.1_export` policy, whereas neighbor 2.2.2.2, lacking anything more specific, is subjected only to the `internal_export` policy. Meanwhile, neighbor 3.3.3.3 in group `other` has no group- or neighbor-level policy, so it uses the `global_export` policy.

So, what if you need to have neighbor 1.1.1.1 perform the function of all three policies? Simple—you could write and apply a new neighbor-level policy that encompasses the functions of the other three, or simply apply all three *existing* policies, as a chain, to neighbor 1.1.1.1. Note the use of brackets in the following command to open a set of values; if desired, each policy can be specified individually:

```
[edit protocols bgp group internal]
lab@PBR# set neighbor 1.1.1.1 export [global-export internal_export]

[edit protocols bgp]
lab@PBR# show group internal neighbor 1.1.1.1
export [ neighbor_1.1.1.1_export global_export internal_export];
```

As with access control lists (ACLs) or firewall filters, chained policy statements are evaluated in a specific left-to-right order and only up to the point when a route is either accepted or rejected. As a result, you must consider factors such as whether a policy makes use of a match-all deny term at its end, which is common for a standalone policy. However, when applied at the front of a policy chain, the match-all aspect of such a policy prevents route processing by any remaining policies. To help illustrate this point, consider two policies, one named *deny*, which denies all, and another named *accept*, which accepts all. Given the nature of the two policies, you will see a dramatic difference between these two policy chains, even though they are composed of the same parts:

```
export [accept deny];
export [deny accept];
```

Here, the first policy chain results in *all* routes being *accepted*, whereas the reverse application results in *all* routes being *denied*. You can use the CLI's insert feature to rearrange the order of applied policies, or simply delete and reapply the policies to get the order needed. Note that a newly applied policy always takes the leftmost place in a policy chain, where it becomes the first in line for route evaluation.

We covered a few critical points here, so much so that they bear repeating in another form. The first point is that when multiple policies are applied at different CLI hierarchies for the same protocol, only the most specific application is evaluated, to the exclusion of other, less specific policy applications. Second, a given route is evaluated against a chain of policies starting with the leftmost policy, up until the route meets a terminating action of either accept or reject. This leads to ordering sensitivity of both terms within a policy, and for policies when they are chained together.

Although these points always seem to make sense when you are learning them, they are somehow easily forgotten during router configuration, when two policies that individually worked as expected suddenly break when they are combined, or when you mistakenly believe that a neighbor-level policy is combined with a global or group-level policy, only to find that your policy behavior is not as anticipated.

Policy Components

Generally speaking, a policy statement consists of one or more named terms, each consisting of two parts: a `from` statement that defines a set of match criteria, and a corresponding `then` statement that specifies the set of actions to be performed for matching traffic. It is possible to create a policy with a single term, in which case the term can be unnamed, such as in these two examples:

```
[edit policy-options]
lab@PBR# show
policy-statement explicit_term {
    term 1 {
        from protocol direct;
        then accept;
    }
}
policy-statement implict_term {
    from protocol direct;
    then accept;
}
```

The two policy statements perform identical functions; both have a match criterion of `direct`, and both have an associated action of `accept`. The explicit term format is generally preferred, because new terms can be added without the need to redefine the existing term. Note that any new terms are added to the end of the policy statement, as shown here, where, oddly enough, a new term named `new` is added to the `explict_term` policy statement:

```
[edit policy-options]
lab@PBR# set policy-statement explicit_term term new from protocol direct

[edit policy-options]
lab@PBR# set policy-statement explicit_term term new then reject

[edit policy-options]
lab@PBR# show policy-statement explicit_term
term 1 {
    from protocol direct;
    then accept;
}
term new {
    from protocol direct;
    then reject;}
```

As with policy chains, term ordering within a policy is significant. In the example, `explict_term` policy, term `1`, and term `new` are diametrically opposed, with one accepting and the other denying the same set of direct routes. Although making little practical sense, it does afford the opportunity to demonstrate term resequencing with the `insert` function:

```
[edit policy-options]
lab@PBR# edit policy-statement explicit_term

[edit policy-options policy-statement explicit_term]
lab@PBR# insert term new before term 1

[edit policy-options policy-statement explicit_term]
lab@PBR# show
term new {
    from protocol direct;
    then reject;}
term 1 {
    from protocol direct;
    then accept;
}
```

There is no practical limit to the number of terms that can be specified in a single policy, or to how many policies can be chained together.

Logical OR and AND functions within terms

It's possible to define a term with multiple match criteria defined under a single `from` statement. For a match to occur, all of the `from` conditions must be met, which is a logical AND. However, for a specific match type, such as `protocol`, you can specify multiple values, in which case each protocol match condition functions as a logical OR. Consider this example:

```
[edit policy-options]
lab@PBR# show
policy-statement test {
    term 1 {
        from {
            protocol [ bgp rip ]; ##logical OR within brackets
            interface ge-0/0/0.0; ## logical AND with other match criteria
        }
        then next term;
    }
}
```

In this case, a match will occur when a route is learned over the `ge-0/0/0` interface *and* is learned from BGP *or* RIP.

Policy Match Criteria and Actions

Junos software policy provides a rich set of criteria you can match against, and an equally rich set of actions that can be performed as a result of a match. The various match and action functions are well documented, so the goal here is not to re-create the wheel by rehashing each option—as noted at the beginning of this chapter, the object is to acquaint you with a box of tools; later chapters will provide specific examples of those tools being used.

Policy match criteria

The list of available match criteria is long in the Junos software 10.3 release:

```
lab@PBR# set policy-statement test term 1 from ?
Possible completions:
  aggregate-contributor  Match more specifics of an aggregate
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  area                 OSPF area identifier
+ as-path              Name of AS path regular expression (BGP only)
+ as-path-group        Name of AS path group (BGP only)
  color                Color (preference) value
  color2               Color (preference) value 2
+ community            BGP community
+ condition            Condition to match on
> external             External route
  family
  instance             Routing protocol instance
+ interface            Interface name or address
```

```
  level                 IS-IS level
  local-preference      Local preference associated with a route
  metric                Metric value
  metric2               Metric value 2
  metric3               Metric value 3
  metric4               Metric value 4
> multicast-scope    Multicast scope to match
+ neighbor              Neighboring router
+ next-hop              Next-hop router
  next-hop-type         Next-hop type
  origin                BGP origin attribute
+ policy                Name of policy to evaluate
  preference            Preference value
  preference2           Preference value 2
> prefix-list        List of prefix-lists of routes to match
> prefix-list-filter  List of prefix-list-filters to match
+ protocol              Protocol from which route was learned
  rib                   Routing table
> route-filter          List of routes to match
  route-type            Route type
> source-address-filter  List of source addresses to match
  state                 Route state
+ tag                   Tag string
  tag2                  Tag string 2
```

The key takeaway here is that you can match on things such as interface, protocol, route tag, AS path, communities, source address, metric, and so on. Route filtering based on prefix and mask length is performed with the `route-filter` keyword. There is significant power (and complexity) in router filtering, and it is covered in the section "Route Filters" on page 148.

Policy actions

When a match occurs, a wide range of actions are available:

```
[edit policy-options]
lab@PBR# set policy-statement test term 1 then ?
Possible completions:
  accept                Accept a route
+ apply-groups          Groups from which to inherit configuration data
+ apply-groups-except   Don't inherit configuration data from these groups
 >as-path-expand        Prepend AS numbers prior to adding local-as (BGP only)
  as-path-prepend       Prepend AS numbers to an AS path (BGP only)
  class                 Set class-of-service parameters
> color                 Color (preference) value
> color2                Color (preference) value 2
> community             BGP community properties associated with a route
  cos-next-hop-map      Set CoS-based next-hop map in forwarding table
  damping               Define BGP route flap damping parameters
  default-action        Set default policy action
  destination-class     Set destination class in forwarding table
> external              External route
  forwarding-class      Set source or destination class in forwarding table
> install-nexthop       Choose the next hop to be used for forwarding
```

```
    label-allocation     Set label allocation mode
  > load-balance         Type of load balancing in forwarding table
  > local-preference     Local preference associated with a route
  > map-to-interface     Set output logical interface
  > metric               Metric value
  > metric2              Metric value 2
  > metric3              Metric value 3
  > metric4              Metric value 4
    next                 Skip to next policy or term
  > next-hop             Set the address of the next-hop router
    origin               BGP path origin
  > preference           Preference value
  > preference2          Preference value 2
    priority             Set priority for route installation
    reject               Reject a route
    source-class         Set source class in forwarding table
  > tag                  Tag string
  > tag2                 Tag string 2
    trace                Log matches to a trace file
```

Actions include AS path prepending, changing route color (internal tiebreaker), evoking damping, altering local preference, specifying metric and community, altering a packet's forwarding class, adding a route tag, and so forth. Key actions include `accept` and `reject`, which are termination actions. The `next` keyword allows you to skip to the next term, or policy in the chain, and it is useful for shunting routes from one term or policy into another.

Route Filters

The ability to match on specific routes to accept or reject them or to modify some attribute is a critical aspect of virtually any networking scenario. The majority of Junos software routing policy strikes most users as intuitive and logical, given the easy-to-follow *if*, *then* construct of policy syntax.

The exception always seems to be route filtering, because to truly understand how this is performed in Junos software, you must first understand the binary radix tree nature of the route lookup table and how the binary tree is used in conjunction with route filters.

Binary trees

Binary trees have been used in computer science for several decades as a way to quickly locate a desired bit of information. In the case of route lookup, the goal is to quickly find the longest match for some prefix, with the corresponding next hop being the information that is sought. The Juniper Networks implementation of a binary tree is called the J-Tree, and it forms the basis of both route lookup and policy-based route filtering. Figure 5-3 shows the root of a binary tree, along with a few of its branches.

Figure 5-3 shows a binary to powers of a decimal chart, to help with understanding the structure of the J-Tree. For example, the binary sequence 0100 0000 equates to a

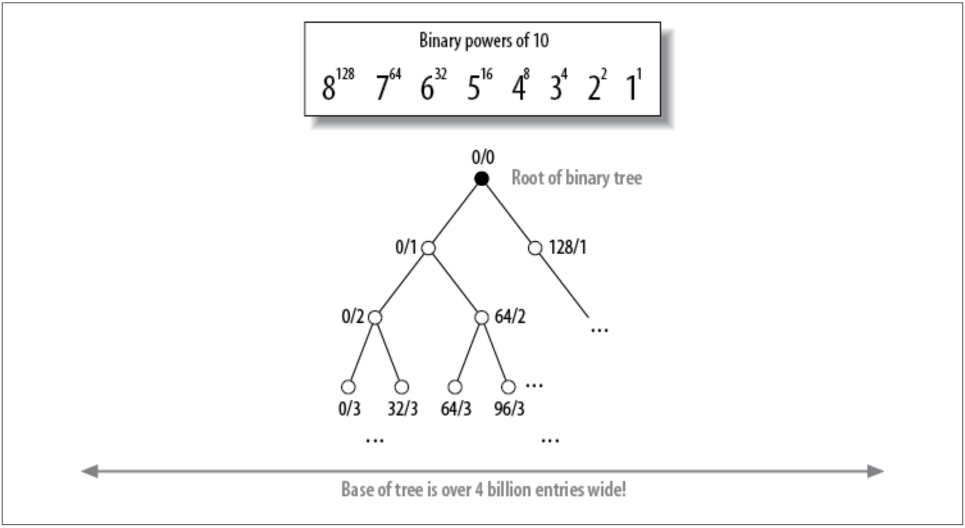


Figure 5-3. A binary tree

decimal 64, whereas 0110 0000 codes a decimal 96. In this example, bit 8, which has the decimal power of 128, represents the second set of nodes from the top of the tree. The top of the tree represents no bit, and the first pair of nodes down represents a test of the MSB, which is bit 8 in this example, as either 0 (0), or 1 (128).

The binary tree is based on nodes that test the state of a particular bit that makes up the 32-bit IP address or route prefix. The bit being tested is indicated by the related prefix (mask) length. For example, the top of the tree is testing no bits, as indicated by the /0 prefix length. All prefixes match when you do not bother to test any bits, so the top of the tree effectively represents a default route, which is to say when no other patterns match you are guaranteed to match the first node. Whether such a match actually results in forwarding depends on whether a default route has been installed, but that is another story.

The tree branches to the left when a given bit is a 0, and it branches to the right for a 1. As a result, the first two nodes below the root represent the state of the most significant bit in the most significant byte, which is either a 0 or a 1. If it is a 0, you have a 0/1 match, which codes a decimal 0. If that bit is a 1, you have a 1/1 match, which codes a decimal 128. Each node then branches out, based on the test of the next bit, until you reach the bottom of the tree, which represents a test of all 32 bits (which is *sometimes* necessary when doing a route lookup or route filter that is based on a /32 prefix length).

In actual operation, the J-Tree is optimized and can quickly jump to a longest match when other portions of the tree are eliminated. It could be said that the act of finding a longest match against a binary tree is not so much finding what you seek as it is quickly eliminating all that cannot be what you want, and then simply looking at what is left.

By way of example, a 32-bit IP address can take more than 4 billion combinations. However, half of these (2 billion) will have a 0 in the high-order bit position, whereas the other half will have a 1. By simply testing the status of one bit, you have effectively eliminated one-half of the tree as not being possible to match. With each subsequent bit test eliminating one-half of the remaining possibilities, you quickly arrive at a node that either matches all 32 bits of the prefix, or does not match the prefix being evaluated, in which case you back up one node. That is the longest match for this prefix.

Route filters and match types

When you configure a route filter, you specify a starting prefix and initial prefix length, and then include a match type to indicate whether routes with prefixes longer than the initial value should be considered as matching. Put another way, a route filter is based on a match against the specified prefix bits, as based on the provided mask, in addition to the overall mask length of the prefix being evaluated. As such, it can be said that a Juniper route filter cares as much about the prefix *length* as it does the *prefix itself*.

Figure 5-4 illustrates the supported `route-filter` match types in the context of a J-Tree; it was said before, and is stated here again, that you cannot effectively use route filters if you do not first understand the operation of the J-Tree. This is especially true for the `through` match type, which 99.9% of the time is applied incorrectly, and therefore does *not* do what the operator wanted.

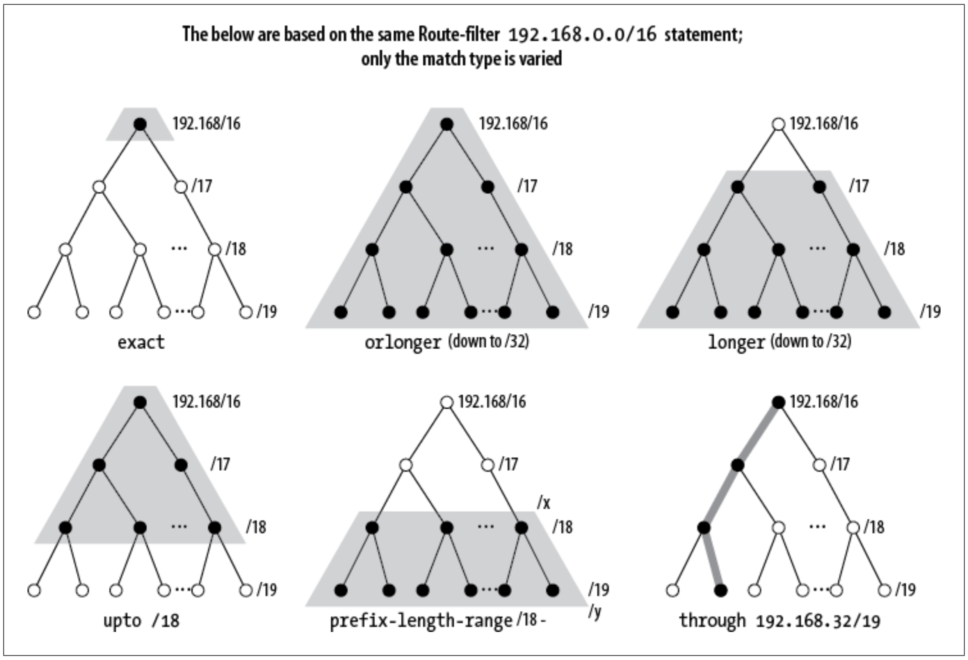

The below are based on the same Route-filter 192.168.0.0/16 statement;
only the match type is varied
192.168/16
/17
/18
/19
exact
orlonger (down to /32)
longer (down to /32)
upto /18
/x
/y
prefix-length-range /18 -
through 192.168.32/19

Figure 5-4. Route filter match types and the J-Tree

Figure 5-4 is based on a portion of the J-Tree that represents route 192.168/16. Entries below the starting node all share the same high-order 16 bits of 192.168, but differ from the root prefix in that they have longer mask lengths, as shown by the two nodes below the first, each of which is testing bit 17, therefore indicating a /17 mask length.

Each route filter match type is described against the corresponding portion of the figure:

`exact`
: The `exact` match type is just what it sounds like. To match with `exact`, both the initial prefix bits must match, and the prefix length must be equal to the value specified. If the prefix bits do not match, or if the prefix length is either shorter or longer, the `exact` match type does not match. Figure 5-4 shows that route filter 192.168.0.0/16 `exact` matches only on that node of the J-Tree, to the exclusion of all others.

`or-longer`
: The `or-longer` match type matches the specified prefix and initial mask length and matches on prefixes with longer mask lengths when they share the same high-order bits, as indicated by the specified prefix. In this example, the result is a match against 192.168.0.0/16 itself, as well as 192.168.0/17 and 192.168.128/18 and all longer mask lengths, up to /32.

`longer`
: The `longer` match type excludes the exact match and catches all routes with the same prefix bits, but only when their masks are longer than the prefix length specified. The difference between `or-longer` and `longer` is shown in Figure 5-4, where the latter excludes the `exact` match, which is prefix 192.168.0.0/16 in this case.

`upto`
: The `upto` match type matches against the initial prefix and mask length, as well as matching prefixes with masks that are longer than the initial value, `upto` the ending mask length value. In the example, the initial prefix of 192.168.0.0/16 matches, as well as all other 192.168 prefixes that have mask lengths `upto` the specified value, which is 18 in this example. Therefore, 192.168.192/18 will match, whereas 192.168.1/24 will not.

`prefix-length-range`
: The `prefix-length-range` match type matches against routes with the same prefix as specified in the initial mask length, but only when the associated mask falls between the starting and ending values. The result is that the `exact` match is excluded, whereas routes with the same high-order prefix bits, but masks that fall within the specified range, are accepted. This match type is especially useful when the goal is to filter the route based on mask length alone, which is a common policy within service provider networks, as many refuse to carry routes with masks longer than 28 in an effort to keep route table size manageable. To prevent installation of any route with a mask length longer than /28, you can use a `route-filter 0/0 prefix-length-range /28-/32 reject` statement. Because the initial prefix length

is 0, all prefix values match, making the decision to reject one that is based strictly on mask length.

It's worth noting that route-filter syntax supports a short form of action linking, in which the related `then` action can be specified directly on the `route-filter` line. Functionally there is no difference between the short form and adding an explicit `then` action.

`through`

The `through` match type is generally misunderstood, and it rarely works the way folks think it should. This is not to say that it is broken, but it has led to this somewhat humorous rule of thumb: "When you are thinking of using `through`, think again." In most cases, when people use `through`, what they wanted is more of the `upto` or `prefix-length-range` type of match. The statement is intended to warn the user that in most cases, `through` is not what you really want, and that the decision to use it should be carefully thought, pardon the pun, through.

A `through` match type matches the initial prefix and mask length exactly, as well as the ending prefix and mask length, and matches on the *contiguous* set of nodes between the two points. The `through` match type was originally offered to meet a corner case, in which a customer was found to be using 32 exact matches, all based on some form of a default route. Although a true default is 0/0, the customer wanted to ensure that no 0.0.0.0 prefixes were installed, regardless of mask length. So, rather than a `0.0 exact`, `0/1 exact`, `0/2 exact` ... `0/32 exact`, the `through` match type was created to allow the same effect with a single `0/0 through 0/32` statement. This matches the top of the tree, all the way down the left side to the very bottom, and all contiguous points in between.

In Figure 5-4, the `through` match type is specified as 192.168.0.0/16 through 192.168.32.0/19. The line shows the sequence of contiguous matches between the two points, which in this case includes 192.168.0.0/16, 192.168.0.0/17, 192.168.0.0/18, and 192.168.32.0/19. Now ask yourself (and be honest): is this what you expected a 192.168/16 through 192.168.32/19 to match?

Longest match wins, but may not.... As with routing in general, route filter processing is based on finding a longest match, and then performing the action associated with that match. There are cases where this may lead to unexpected behavior because users do not always take into account the consequences of different match types. Recall that the longest-match function is based on the high-order prefix bits, whereas the match type focuses more on mask length. Consider this route-filter example, and what will happen when route 200.0.67.0/24 is evaluated against it:

```
[edit policy-options policy-statement test_me]
user@host# show
from {
    route-filter 200.0.0.0/16 longer reject;
    route-filter 200.0.67.0/24 longer;
```

```
        route-filter 200.0.0.0/8 orlonger accept;
    }
    then {
        metric 10;
        accept;
    }
```

The question is, will route 200.0.67.0/24 match this term, and if so, is it accepted, is it rejected, or does it have its metric set to 10 before being accepted? Think carefully, and consider how longest matching is performed, along with how the match type comes into play.

If you answered "The route does not match, and is neither accepted, nor rejected, and no metric modification is made," give yourself a well-deserved pat on the back. It's quite OK if you answered differently—this little tidbit alone may well justify the expenditure for this book (you did pay for this book, right?). The key here is that the longest match, as based on specified prefix, is against the second route-filter statement—here the first 24 bits of the prefix do in fact match 200.0.67/24, which is more exact than either 200/8 or 200.0/16. However, the longest match in this example has a match type of `longer`, meaning that only a route with a mask length of /25–/32 with the 24 high-order bits set to 200.0.67 is considered to match.

Because this route has a mask length that is equal to the value specified, it does not match. A given route is only evaluated against the longest match in a given term. This is to say that if the longest match ends up not really matching, as shown in this example, other route-filter statements within that same term are not evaluated. Instead, the route falls through to the next term or policy—or lacking any of those, to the default policy for the routing protocol in question.

Default Policies

The last hurdle in understanding Junos software policy is to be familiar with the default policy associated with each protocol used in your network. Understanding the default policy is important because it ultimately decides the fate of any route that is not matched against in your user-defined policy. Some operators rely on the default policy to do something, and others prefer to ensure that their policy is written to match on *all* possible routes, which means the default policy is negated because it never gets a chance to come into play.

OSPF (and IS-IS) default policy

The default import policy for LS protocols is to accept all routes learned through that protocol. OSPF supports input policies to filter external routes from being installed into the route table and to assign priority for route restoration. The filter import policies do not filter external route LSAs from the database; they only restrict the routes from being installed in the route table.

The default LS export policy is to reject everything. LSA flooding is not affected by export policy, and it is used to convey routing in an indirect manner in an LS protocol. The result of this flooding is the advertisement of local interfaces that are enabled to run OSPF, as well as the readvertisement (flooding) of LSAs received from other routers. Export policies are used to insert other (non-OSPF) routes into the OSPF database. These routes are then handled as external routes within OSPF.

RIP default policy

The default RIP import policy is to accept all received RIP routes that pass a sanity check. In contrast, the default export policy is to advertise no routes. None, zip, nada, zilch. Not even RIP learned routes are advertised with the default RIP export policy. Although it may be an odd choice of default behavior, the net effect is that for any practical RIP deployment, you will need to create and apply a custom export policy to readvertise RIP learned and direct routes for interfaces running RIP to other RIP speakers.

BGP default policy

The default BGP import policy is to accept all received BGP routes that pass a sanity check—for example, those routes that do not have an AS loop, as indicated by the AS path attribute.

The default BGP export policy is to readvertise all active learned BGP routes to all BGP speakers, while obeying protocol-specific rules that prohibit one IBGP speaker from readvertising routes learned from another IBGP speaker, unless it is functioning as a route reflector.

Advanced Policy Concepts

Congratulations. You have made it to this point, and therefore you now possess an in-depth and practical understanding of routing policy. This section explores some advanced policy concepts, some of which are quite interesting but rarely used. The use of regular expressions (regexes) is treated as an advanced topic, but differs from the remaining topics because the use of AS path or community regex matching is somewhat common, especially in large networks such as those operated by service providers.

Testing policy results

Making a mistake in a route-filter statement can have a dramatic impact on network stability, security, and overall operation. For example, consider the operator that does not notice that, in the following policy example (appropriately called `whoops`), rather than adding the `then accept` to term 1, as intended, the `accept` action is mistakenly added as part of a final, *unnamed* term. Because this term has no `from` statement, it matches on *all* possible routes and routing sources!

```
[edit policy-options]
lab@Wheat# show policy-statement whoops
term 1 {
    from {
        route-filter 0.0.0.0/0 prefix-length-range /8-/24;
    }
}
then accept; ###this action is part of an unnamed match all term!
```

Applying a broken policy such as this in a production network that deals with multiple live BGP feeds could result in network meltdown when all routes, rather than the expected subset, are suddenly advertised within your network.

Junos software offers a test policy feature that is designed to avoid this type of problem. You use the `test` command to filter routes through the identified policy to determine which routes are accepted (those displayed) versus rejected.

The `test policy` command is primarily useful for `route-filter` testing. You cannot test route redistribution policies, because the default policy for a policy test is to *accept all* protocol sources. This means that a given route filter policy might match against static routes, but the same policy when applied to BGP may *not* result in the advertisement of the same static routes. This is because the default policy for BGP does not accept static routes, whereas the default for the test policy does. As an example, consider this policy:

```
[edit policy-options]
lab@Wheat# show policy-statement test_route_filter
term 1 {
    from {
        route-filter 0.0.0.0/2 orlonger;
    }
    then next policy;
}
term 2 {
    then reject;
}
```

With the `test_route_filter` policy shown, the test policy command will match on and accept static, direct, OSPF, BGP, and routes that match the route filter (routes in the range of 0–63), while the same policy applied to BGP results in the advertisement of only BGP routes that match the filter. Again, this is because the matching routes are not explicitly accepted by the `test_route_filter` policy in this example, and would therefore be subjected to the default policy for BGP.

A number of static routes that range from 0–192 have been added to router `Wheat`. The `test_route_filter` policy is run against these routes:

```
lab@Wheat> test policy test_route_filter 82.137.128.0/18

Policy test_route_filter: 0 prefix accepted, 1 prefix rejected
```

The result confirms that a prefix outside the range of 0–63 is rejected:

```
lab@Wheat> test policy test_route_filter 6.1.0.0/16

inet.0: 815 destinations, 1500 routes (815 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

6.1.0.0/16         *[Static/5] 00:44:51
                      Discard

Policy test_route_filter: 1 prefix accepted, 0 prefix rejected
```

This result confirms that a prefix inside the range of 0–63 is accepted. To test against all possible routes, use `0/0`:

```
lab@Wheat> test policy test_route_filter 0/0

inet.0: 815 destinations, 1500 routes (815 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

6.1.0.0/16         *[Static/5] 00:45:05
                      Discard
6.2.0.0/22         *[Static/5] 00:45:05
                      Discard
. . .
10.0.0.0/8         *[BGP/170] 20:42:56, localpref 100
                      AS path: 1282 I
                    > to 172.16.1.2 via ge-0/0/0.412
                    [BGP/170] 20:42:44, localpref 80
                      AS path: 666 1282 I
                    > to 172.16.2.2 via ge-0/0/0.423
12.0.48.0/20       *[Static/5] 00:45:05
                      Discard
. . .
                      Discard
63.207.252.0/22    *[Static/5] 00:45:05
                      Discard

Policy test_route_filter: 58 prefix accepted, 759 prefix rejected
```

The output confirms that both static and BGP routes are matching the `route-filter` in the `test_route_filter` policy. Note again that the policy being tested does not have an explicit accept action, and instead uses the next policy for matching routes; the acceptance in this case is the result of the default accept-all policy for the test policy. It's worth stating again that the same policy applied to BGP will advertise only BGP routes that match the filter, unless you add an explicit accept action to the first term.

Community and AS path regex matching

Complete coverage of regex matching is outside the scope of this book. The reader should consult technical documentation for a full description of supported matching operators (e.g., *http://www.juniper.net/techpubs/en_US/junos10.3/topics/usage-guide* *lines/policy-configuring-as-path-regular-expressions-to-use-as-routing-policy-match-conditions.html*, which describes AS path regex matching).

Here are some general things to be aware of when dealing with regex matching:

- Regex matching provides a powerful tool to filter routes based on virtually any conceivable pattern of AS path or community attributes.
- In Junos software, community regex matching is POSIX 1003.2-compliant. In contrast, AS path regex matching is not, because in an AS path regex, a dot, `.` (the wildcard character), represents an entire AS number, rather than an atom or specific digit in the AS number.
- You can test your regular expression syntax against routes *already* present in the route table using a `show route community` *`<community-regex>`* or `show route aspath-regex` *`<as-path-regex>`* command. Once you feel the expression syntax results in the matches you expect, you can write a policy that uses the same regex.
- To use a community of AS path regexes in a policy, you must first define the regex using a symbolic name, which is then referenced in the policy.

The following example demonstrates a basic AS path regex:

```
[edit policy-options]
lab@PBR# show
policy-statement as_path_filter {
    term 1 {
        from {
            protocol bgp;
            as-path sample_as_regex;
        }
        then reject;
    }
}
as-path sample_as_regex "^. 1234 . 1111$";
```

Note that the symbolic name `sample_as_regex` is defined outside of any particular policy statement. In this example, the specified regex will match when the associated route has an AS path consisting of exactly four entries. The AS path can begin with any AS number, as indicated by the `.` wildcard (a wildcard matches a complete AS number in Junos software). The second AS number has to be 1234 and can be followed by any other AS number, but the final AS number entry must be 1111 to match. The ^ and `$` characters are anchors, which force the initial and final matches to be against the beginning and end of the line, respectively.

The `as_path_filter` policy statement makes use of the defined AS path regex by matching against it in term 1. Here the result of an AS path regex match is rejection.

Here is a community regex matching example:

```
[edit policy-options]
lab@PBR# show
policy-statement community_regex_test {
    term 1 {
        from community comm_regex;
        then accept;
    }
}
community comm_regex members "^(.*):(.*)1:(11.1)(.*):(.*)$";
```

In this example, the `comm_regex` expression is written to match on a sequence of three community strings, but only when the first is from any AS number and any community value, and the second is from AS 1 with a community value of 11*x*1, where the *x* represents any decimal value between 0 and 9. This example shows that for community regex matching, the `.` wildcard represents a single digit, rather than a complete AS number, as was the case with AS path regex matching. Lastly, a match occurs in this example only when the first two matches are followed by a third community value, and like the first, respectively. Note that because communities are acted upon as a single value, rather than as a sequence or set (as is the case with AS matching), you cannot easily match against a community list based on some specific count, as you can with an AS regex. As a result, in this example, the beginning and end of line markers (^ and $, respectively), do not result in a match occurring when exactly three matching communities are present. In fact, in this case, a string of 10 communities will match as long as any three consecutive values match the regex.

Additional details and examples of community regex matching are available at *http://www.juniper.net/techpubs/en_US/junos10.3/topics/usage-guidelines/policy-defining-bgp-communities-and-extended-communities-for-use-in-routing-policy-match-conditions.html#id-10223306*.

Policy subroutines (nesting)

Routes that match a given term in a policy can reference another policy as the associated action. The policy is called a policy *subroutine*, or a *nested policy*. This is a powerful capability that allows you to build modular policies that, rather than being applied as a policy chain, are called from within a master policy.

A common usage of a policy subroutine takes the form of a martian or bogon filter. Rather than applying the same martian filter as part of each policy chain, or rather than adding the complete martian filter logic to every policy you write, you could simply have a term in all your policies that calls the martian policy as a subroutine.

The key to effectively using policy subroutines lies in understanding the result code that is handed back from the calling policy by the called policy. Figure 5-5 illustrates policy subroutine behavior.

In Figure 5-5, things begin in the upper left, where a route is handed to the *master* or *calling policy* for evaluation. In this example, the first term in the calling policy has a match criterion specifying `from policy <sub-routine-name>`. This directive evokes the called policy for route evaluation; meanwhile, the main policy suspends its processing

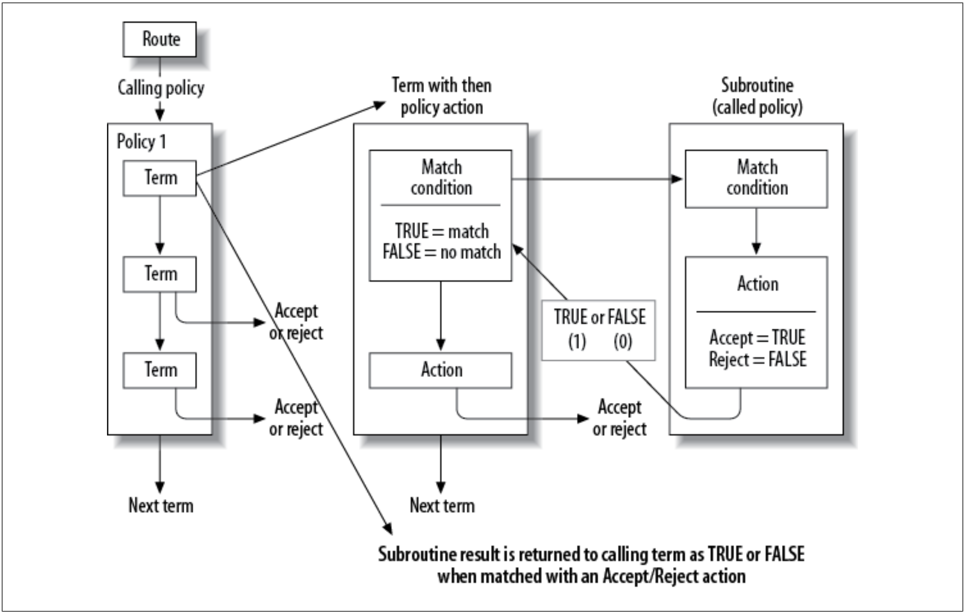


Figure 5-5. Policy subroutines

pending a result code that is handed back to the calling policy once the called policy completes its evaluation.

When the called policy/subroutine completes its evaluation, the result is either a 1 or a 0. Here, the former indicates an `accept` action by the called policy, and the latter represents a `reject` action. When the result code is handed back to the calling policy, a 1 is interpreted as a positive match, which results in the execution of the calling term's `then` action. A return of 0 indicates no match, and policy processing continues with the next term.

For reliable operation, you must make sure that all policy subroutines match *all* routes with either an `accept` or a `reject` action.

You will encounter inconsistent behavior with policy subroutines if the subroutine is not written to match against *all* possible routes. This is because when a route is not matched, the subroutine cannot perform an `accept` or a `reject` action, and therefore returns an empty value to the calling policy. The lack of a definitive result from the called policy often leads to unpredictable operation in the calling policy.

Boolean grouping

We covered the use of policy chains previously—a policy chain is a grouping of policies evaluated in sequence until an `accept` or `reject` action is encountered. Junos software also supports policy expressions, which provide Boolean grouping functionality. This is a fancy way to say you can logically AND, OR, or NOT a given policy. You can find details on policy expressions at *http://www.juniper.net/techpubs/en_US/junos10.3/topics/usage-guidelines/policy-applying-policy-expressions-to-routes-exported-from-routing-tables.html*.

By way of an example, consider the following policy:

```
[edit policy-options]
lab@PBR# show
policy-statement community_regex_test {
    term 1 {
        from community comm_regex;
        then accept;
    }
}
community comm_regex members "^(.*):(.*)1:(11.1)(.*):(.*)$";
```

As previously described, this policy matches on, and as a result, accepts routes with a particular community sequence. What do you expect will be the result if a `community_regex_test` policy is applied as an import with a Boolean NOT?

```
[edit protocols bgp]
lab@PBR# set import (!community_regex_test)

[edit protocols bgp]
lab@PBR# show
import ( ! community_regex_test );
```

If you guessed that all routes that were formerly accepted will now be rejected, you are correct. The Boolean NOT inverts the results of policy evaluation, changing an `accept (1)` to a `reject (0)`, and vice versa.

As a final example, consider this policy expression:

```
[edit protocols ospf]
lab@PBR# show
export ( policy1 && policy2 );
```

The use of the logical AND indicates that for a route to be exported into OSPF, it must be evaluated as true by *both* `policy1` and `policy2`. Any route that is evaluated as false or rejected by either policy is not considered viable for export into OSPF.

Summary of Routing Policy

We just detailed Junos software routing policy. The policy framework provides a consistent and easy-to-fathom environment for all of your route-exchange and attribute-manipulation needs. Although route filters and the whole J-Tree thing can be a bit daunting when first encountered, the overall logic of a Junos policy is easy to follow, and the consistent way in which they are applied to routing protocols makes network administration that much easier. With Juniper policy rather than a collection of network statements, default-information-originate statements, distribute lists, route maps, and so on, you create and advertise a static route into OSPF, or BGP, or RIP, using the same approach and syntax.

Advanced features such as regex-based AS path and community matching, policy subroutines, and policy expressions ensure that you can never run out of creative and elegant ways to meet your network's policy goals.

This section also covered the commands and procedures used to monitor and debug the operation of your import and export policies.

Conclusion

Junos software PIPs and routing policy may not be very sexy by themselves, but together they form the foundation of virtually all sophisticated network configurations.

The PIP toolbox provides many useful tools that allow you to create static and aggregate routes, create and group route tables, and alter protocol preferences. Routing policy provides a powerful and consistent set of rules and syntax that supplies fine-grained control over the exchange of routes, along with modification of route attributes. Once you understand the basic concepts of import and export policy, you quickly come to appreciate the elegance of being able to perform similar tasks on different protocols, using the same policy framework, rather than a collection of mechanisms such as route maps, distribute lists, network statements, and so on, which may or may not work in a given protocol context.

When combined, PIP and policy yield a powerful mechanism that enables you to bend a network's operation to suit your will. The skills and concepts covered in this chapter are demonstrated throughout the remainder of this book, in various real-world and practical scenarios.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- PIPs:
  - —Identify static, aggregate, and generated routes.
  - —Describe the configuration of static routes.
  - —Describe the purpose of the default Junos software route tables.
  - —Describe global route preference and the concept of a floating static route.
- Routing policy:
  - —Identify the two types of policy application.
  - —Identify policy components (terms, match conditions, actions, and policy chains).
  - —Identify points where routing policy may be applied.

—Describe the processing of routing policies.

—Evaluate the result of a given routing policy.

Chapter Review Questions

1. After defining an aggregate route for 0/0, you note that the M7i's system board CPU utilization increases. What might account for this?
   A. The default route is attracting traffic that is not specifically matched, leading to a `reject` action and corresponding ICMP error packet generation
   B. The default route is attracting traffic that is not specifically matched, leading to discard and ICMP error packet generation
   C. The default route is attracting traffic that matches more specific prefixes and is being forwarded, hence the increased CPU usage
   D. The default route is attracting traffic that matches more specific prefixes and is being dropped, hence the increased CPU usage
2. Which of the following defines a floating static route that backs up an OSPF externally learned route?
   A. Set static route 1.1.10/24, next hop `t1-2/0/2`
   B. Set static route 1.1.10/24, next hop `t1-2/0/2`, preference 11
   C. Set static route 1.1.10/24, next hop `t1-2/0/2`, preference 151
   D. Set static route 1.1.10/24, next hop `t1-2/0/2`, qualified next hop
   E. None of the above
3. You issue the command `set routing-options autonomous-system loops 3`. What does it do?
   A. Tolerates as many as three instances of the local AS number in transmitted route updates
   B. Tolerates as many as three instances of the local AS number in received route updates
   C. Tolerates as many as two instances of the local AS number in transmitted route updates
   D. Tolerates as many as two instances of the local AS number in received route updates
4. After defining a generated route for 10/8, you find that the route is inactive, despite having interfaces that are locally numbered from the 10.*x*. *x*.0/24 space. What could account for this?
   A. Your interfaces are all multipoint, and you have not learned any routes over any of them, so there is no forwarding next hop for the generated route

B. Your interfaces are all point-to-point, and you have not learned any routes over any of them, so there is no forwarding next hop for the generated route

C. You must define an explicit policy to list which routes are allowed to contribute

D. Your interfaces are all multipoint, and you have learned routes over them, which makes the generated route unneeded

5. What command displays the route table for a Layer 3 VPN routing instance named `l3_vpn`?

   A. `show route`

   B. `show route table l3_vpn`

   C. `show route table l3_vpn.inet.0`

   D. All of the above

6. You have configured RIP between three routers connected in a serial chain, but no RIP routes are being learned. Which policy results in full RIP connectivity for all direct routes?

   A. A RIP import policy of the form:

   ```
   term 1 {
        from protocol [ rip direct ];
        then accept;
   }
   ```

   B. A RIP export policy of the form:

   ```
   term 1 {
        from protocol [ rip direct ];
        then accept;
   }
   ```

   C. A RIP import policy of the form:

   ```
   term 1 {
        from protocol direct;
        then accept;
   }
   ```

   D. A RIP export policy of the form:

   ```
   term 1 {
        from protocol direct;
        then accept;
   }
   ```

7. What happens when the static route 192.168.10/24 is evaluated by this policy?

   ```
   [edit policy-options policy-statement test]
   lab@PBR# show
   term 1 {
        from {
            protocol bgp;
   ```

```
            route-filter 192.168.0.0/16 orlonger reject;
            route-filter 192.168.10.0/24 exact {
                metric 10;
                accept;
            }
        }

    }
```

A. Nothing, because no match occurs

B. The route is longest-matched against the first route filter and rejected

C. The route is longest-matched against the second route filter and has its metric set to 10

D. Both B and C

8. What happens if the `not` policy matches a route with a reject action in the following policy expression?

```
[edit protocols ospf]
lab@PBR# show
export (( ! not ) && and );
```

A. The result is inverted to an accept, and the second policy is evaluated

B. The reject action in the `not` policy ensures that the AND condition cannot be met, so the second policy is never evaluated

C. Both policies are evaluated, and the logical result, which is false because of the reject in the `not` policy, is inverted, so the route is accepted

D. None of the above

9. What type of import policy can you apply to OSPF?

A. None; LS protocols do not support the notion of import policies because it breaks database consistency

B. You can apply policy to filter certain LSA types, such as AS externals to create a stub area

C. Import policy for OSPF can only be used to filter AS external LSAs from being flooded

D. Import policy for OSPF can be used to prevent installation of AS external routes into the route table, but has no effect on flooding

10. In the following configuration, which export policy is peer 1.1.1.1 subjected to?

```
[edit protocols bgp]
lab@PBR# show
import ( ! community_regex_test );
export globalize;
group internal {
    export keep_it_on_down_low;
    neighbor 1.1.1.1;
    neighbor 1.1.1.2 {
```

```
                export bad_peer_filter;
            }

        }
```

A. The `globalize` policy
B. The `keep_it_on_down_low` policy
C. The `bad_peer_filter` policy
D. The `globalize` and `keep_it_on_down_low` policies
E. First the `keep_it_on_down_low`, and then the `globalize` policy

11. From where does a Juniper router obtain its RID?
    A. From explicit configuration at the `[edit routing-options]` hierarchy
    B. From the first nonmartian address found on the first interface that is found
    C. Both A and B
    D. Either A or B
12. You were provided a network diagram that told you to number your network from the 191.255.0.0/16 space. OSPF is enabled and adjacencies are up, but no routers are learning any routes. What can explain this?
    A. The default OSPF export policies advertise nothing, so you need to apply export policy
    B. The default OSPF import policy rejects all OSPF routes, so you need to apply import policy
    C. You need to modify the martian table with a `191.255.0.0/16 accept` statement
    D. You need to enable OSPF on the `lo0` interface to provide a route to the RID of each router in the network

Chapter Review Answers

1. Answer: A. The default next hop type for an aggregate route is `reject`, which when matched does result in the M7i's system board having to create an ICMP error. Even with rate-limiting safeguards, these messages consume system processing, but not forwarding resources.
2. Answer: C. A floating static needs to have a preference that is less preferred than the route it backs up. OSPF externals have a preference of 150, so you need a value that is higher; otherwise, the static route will take precedence over the OSPF route.
3. Answer: D. The `loops` argument to the `autonomous-system` statement affects received route updates only. Further, whatever value is specified, subtract one for the number of local AS instances that are permitted. The default setting of 1 will reject any route with 1 instance of the local AS number.

4. Answer: A. Point-to-point interfaces can contribute to a generated route because an explicit next hop is not required. LAN interfaces require some route—either static or learned—to activate an aggregate or generated route. Policy is used to exclude routes from contributing, not to include.
5. Answer: D. All of the commands listed will display the Layer 3 VPN instance route table. Some are simply more verbose or more direct by displaying only the table desired.
6. Answer: B. The default RIP import policy accepts RIP routes. To send direct routes, you need the direct protocol, and to readvertise RIP learned routes, you need the RIP protocol. The default RIP export policy is to reject all.
7. Answer: A. A static route can never match a from protocol BGP condition, so it does not match the term. There is a logical AND for distinct conditions such as `route-filter` and `protocol` when listed under the same statement.
8. Answer: A. The negative/reject result of the `not` policy is inverted, which becomes true, and this enables the evaluation of the second policy. When the first policy is false, a logical AND can never be satisfied, so without the `!` function, the second policy would not be evaluated in this case.
9. Answer: D. You cannot use policy to control LSA flooding. Import policies can either filter external routes from the route table or assign priority to routes for recovery.
10. Answer: B. Only the most explicit policy is executed, which in this case is the group-level policy because neighbor 1.1.1 has no neighbor-level export policy.
11. Answer: D. There can be only one RID in effect at any time, and it is disruptive to change it. The router uses an explicit value when present; otherwise, it automatically derives one. There is no need to be able to route to the RID, at least not for proper protocol operation.
12. Answer: C. You really have to watch those pesky martians...

CHAPTER 6

Interior Gateway Protocols and Migration Strategies

This chapter reviews key concepts and characteristics of Interior Gateway Protocols (IGPs) commonly deployed in enterprise networks. It starts with a brief description of the three most common enterprise IGPs and provides examples of IGP configuration and operational analysis in a Junos environment. The chapter also discusses current best practices to minimize network disruption when migrating from one IGP to another, with configuration examples for Routing Information Protocol to Open Shortest Path First (RIP to OSPF) and Enhanced Interior Gateway Routing Protocol to OSPF (EIGRP to OSPF) migration. The topics discussed in this chapter include:

- IGP overview
- RIP deployment case study
- IGP migration
- RIP to OSPF migration case study
- EIGRP migration case study

From an IGP perspective, a Juniper Networks router supports RIP, the OSPF protocol, and the Intermediate System–to–Intermediate System (IS-IS) routing protocols. This chapter does not address IS-IS, as it is normally seen in service provider networks and rarely is found in the enterprise.

It should be noted that Juniper Networks routers do not support the Cisco Systems proprietary Interior Gateway Routing Protocol (IGRP), or the updated version known as EIGRP. Technical merits aside, licensing restrictions combined with the closed nature of these protocols prevent Juniper Networks from implementing either of these IGPs. Given that IGRP/EIGRP was commonly deployed in many small to medium-size enterprises, a large portion of this chapter focuses on migration strategies designed to ease such a transition between the two vendors.

IGP Overview

As its name would imply, the role of an IGP is to provide routing connectivity *within* or *interior* to a given routing domain (RD). An RD is defined as a set of routers under common administrative control that share a common routing protocol. An enterprise network, which can also be considered an autonomous system (AS), may consist of multiple RDs, which may result from the (historic) need for multiple routed protocols, scaling limitations, acquisitions and mergers, or even a simple lack of coordination among organizations making up the enterprise. *Route redistribution*, the act of exchanging routing information among distinct routing protocols, is often performed to tie these RDs together when connectivity is desired.

IGP functions to advertise and learn network prefixes (routes) from neighboring routers to build a route table that ultimately contains entries for all sources advertising reachability for a given prefix. A route selection algorithm is executed to select the best (i.e., the shortest) path between the local router and each destination, and the next hop associated with that path is pushed into the forwarding table to affect the forwarding of packets that longest-match against that route prefix. The IGP wants to provide full connectivity among the routers making up an RD. Generally speaking, IGPs function to promote, not limit, connectivity, which is why we do not see IGPs used between ASs—they lack the administrative controls needed to limit connectivity based on routing policy. This is also why inter-AS routing is normally accomplished using an Exterior Gateway Protocol (EGP), which today takes the form of Border Gateway Protocol (BGP) version 4. We discuss enterprise application of BGP in Chapter 7.

When network conditions change, perhaps due to equipment failure or management activity, the IGP both generates and receives updates and recalculates a new best route to the affected destinations. Here, the concept of a "best" route is normally tied to a route metric, which is the criterion used to determine the relative path of a given route. Generally speaking, a route metric is significant only to the routing protocol it's associated with, and it is meaningful only within a given RD. In some cases, a router may learn multiple paths to an identical destination from more than one routing protocol. Given that metric comparison between two different IGPs is meaningless, the selection of the best route between multiple routing sources is controlled by a route preference. The concept of route preference is explored in detail in "IGP Migration: Common Techniques and Concerns" on page 206 and is also known as *administrative distance* (AD) on Cisco Systems routers.

In addition to advertising internal network reachability, IGPs are often used to advertise routing information that is external to that IGP's RD through a process known as *route redistribution*. Route redistribution is often used to exchange routing information between RDs to provide intra-AS connectivity. Route redistribution can be tricky because mistakes can easily lead to lack of connectivity (black holes) or, worse yet, routing loops. To ensure identical forwarding paths, you may also need to map the metrics used by each routing protocol to ensure that they are meaningful to the IGP into which they are redistributed. Route redistribution is performed via routing policy in Junos. We use routing policies later in this chapter and cover them in detail in Chapter 5. On Cisco Systems platforms, redistribution is often performed through some combination of the `redistribute` command, through distribute lists, or through route maps and their associated IP access lists. Although there is a learning curve, it's often a delight for those familiar with the IOS way of performing redistribution when they realize that Junos routing policy provides the same functionality with a consistent set of semantics/syntax, for all protocols, and all in one place!

The reader of this book is assumed to have an intermediate level understanding of the IP protocol and the general operation and characteristics of IGPs that support IP routing. This section provides a review of major characteristics, benefits, and drawbacks of the IGPs discussed in this chapter to prepare the reader for the configuration and migration examples that follow.

Routing Information Protocol

RIP is one of the oldest IP routing protocols still in production network use and is a true case of "if something works, why fix it?" The original specification for RIP (version 1) is defined in RFC 1058, originally published in June 1988! RIP version 2 (RIPv2) was originally defined in RFC 1388 (1993) and is currently specified in RFC 2453 (1998).

RIP is classified as a Distance Vector (DV) routing protocol because it advertises reachability information in the form of distance/vector pairs—which is to say that each route is represented as a cost (distance) to reach a given prefix (vector) tuple. DV routing protocols typically exchange entire route tables among their set of directly connected peers, on a periodic basis. This behavior, although direct and easy to understand, leads to many of the disadvantages associated with DV routing protocols. Specifically:

- Increased network bandwidth consumption stemming from the periodic exchange of potentially large route tables, even during periods of network stability. This can be a significant issue when routers connect over low-speed or usage-based network services.
- Slow network convergence, and as a result, a propensity to produce routing loops when reconverging around network failures. To alleviate (but not eliminate) the potential for routing loops, mechanisms such as split horizon, poisoned reverse, route hold downs, and triggered updates are generally implemented. These stability features come at the cost of prolonging convergence.
- DV protocols are normally associated with crude route metrics that often will not yield optimal forwarding between destinations. The typical metric (cost) for DV protocols is a simple hop count, which is a crude measure of actual path cost, to say the least. For example, most users realize far better performance when crossing several routers interconnected by Gigabit Ethernet links, as opposed to half as many routers connected over low-speed serial interfaces.

On the upside, DV protocols are relatively simple to implement, understand, configure, and troubleshoot, and they have been around *forever*, allowing many network engineers a chance to become proficient in their deployment. The memory and processing requirements for DV protocols are generally less than those of a link state (LS) routing protocol (more on that later).

To help illustrate what is meant by *slow to converge*, consider that the protocol's architects ultimately defined a *hop count* (the number of routers that need to be crossed to reach a destination) of 16 to be infinity! Given the original performance of initial implementations, the designers believed that networks over 16 hops in dimension would not be able to converge in a manner considered practical for use in production networks—and those were 1980s networks, for which demanding applications such as Voice over IP were but a distant gleam in an as yet grade-school-attending C-coder's eye. Setting infinity to a rather low value was needed because in some conditions, RIP can converge only by cycling through a series of route exchanges between neighbors, with each such iteration increasing the route's cost by one, until the condition is cleared by the metric reaching infinity and both ends finally agree that the route is not reachable. With the default 30-second update frequency, this condition is aptly named a *slow count to infinity*.

Stability and performance tweaks

Hold downs serve to increase stability, at the expense of rapid convergence, by preventing installation of a route with a reachable metric, after that same route was recently marked as unreachable (cost = 16) by the local router. This behavior helps to prevent loops by keeping the local router from installing route information for a route that was *originally* advertised by the local router, and which is now being *readvertised* by another neighbor. It's assumed that the slow count to infinity will complete before the hold down expires, after which the router will be able to install the route using the lowest advertised cost.

Split horizon prevents the advertisement of routing information back over the interface from which it was learned, and poisoned reverse alters this rule to allow readvertisement back out the learning interface, as long as the cost is explicitly set to infinity: a case of "I can reach this destination, NOT!" This helps to avoid loops by making it clear to any receiving routers that they should not use the advertising router as a next hop for the prefix in question. This behavior is designed to avoid the need for a slow count to infinity that might otherwise occur because the explicit indication that "I cannot reach destination X" is less likely to lead to misunderstandings when compared to the absence of information associated with split horizon. To prevent unnecessary bandwidth waste that stems from bothering to advertise a prefix that you cannot reach, most RIP implementations use split horizon, except when a route is marked as unreachable, at which point it is advertised with a poisoned metric for some number of update intervals (typically three).

Triggered updates allow a router to generate event-driven as well as ongoing periodic updates, serving to expedite the rate of convergence as changes propagate quickly. When combined with hold downs and split horizon, a RIP network can be said to receive bad news fast while good news travels slow.

RIP and RIPv2

Although the original RIP version still works and is currently supported on Juniper Networks routers, it's assumed that readers of this book will consider deploying only RIP version 2. Although the basic operation and configuration are the same, several important benefits are associated with RIPv2 and there are no real drawbacks (considering that virtually all modern routers support both versions and that RIPv2 messages can be made backward-compatible with v1 routers, albeit while losing the benefits of RIPv2 for those V1 nodes).

RIPv2's support of Variable Length Subnet Masking/classless interdomain routing (VLSM/CIDR), combined with its ability to authenticate routing exchanges, has resulted in a breath of new life for our old friend RIP (pun intended). Table 6-1 provides a summary comparison of the two RIP versions.

Table 6-1. Comparing characteristics and capabilities of RIP and RIPv2

Characteristic	RIP	RIPv2
Metric	Hop count (16 max)	Hop count (16 max)
Updates/hold down/route timeout	30/120/180 seconds	30/120/180 seconds
Max prefixes per message	25	25 (24 when authentication is used)
Authentication	None	Plain text or Message Digest 5 (MD5)
Broadcast/multicast	Broadcast to all nodes using all 1s, RIP-capable or not	Multicast only to RIPv2-capable routers using 224.0.0.9 (broadcast mode is configurable)
Support for VLSM/CIDR	No, only classful routing is supported (no netmask in updates)	Yes
Route tagging	No	Yes (useful for tracking a route's source, i.e., internal versus external)

Open Shortest Path First

The OSPF routing protocol currently enjoys widespread use in both enterprise and service provider networks. If OSPF can meet the needs of the world's largest network operators, it's safe to say that it should be more than sufficient for even the largest enterprise network. OSPF version 2 is defined in RFC 2328, but numerous other RFCs define enhanced capabilities for OSPF, such as support of not-so-stubby areas (NSSAs) in RFC 3101, Multiprotocol Label Switching (MPLS) Traffic Engineering Extensions (MPLS TE) in RFC 3630, and graceful restart extensions that minimize data plane disruption when a neighboring OSPF router restarts in RFC 3623. OSPF supports virtually all the features any enterprise could desire, including VLSM, authentication, switched circuit support (suppressed hellos), and MPLS TE extensions, among many more.

OSPF is classified as an LS routing protocol. This is because, unlike a DV protocol that exchanges its entire route table among directly connected neighbors, OSPF exchanges *only* information about the local router's links, and these updates are flooded to *all routers* in the same area. Flooding ensures that all the routers in the area receive the new update at virtually the same time. The result of this flooding is a link-state database (LSDB) that is replicated among all routers that belong to a given area. Database consistency is critical for proper operation and the assurance of loop-free forwarding topologies. OSPF meets this requirement through reliable link-state advertisement (LSA) exchanges that incorporate acknowledgment and retransmission procedures. Each router performs a Shortest Path First (SPF) calculation based on the Dijkstra algorithm, using itself as the root of the tree to compute a shortest-path graph containing nodes representing each router in the area, along with its associated links. The metrically shortest path to each destination is then computed, and that route is placed into the route table for consideration to become an active route by the path selection algorithm.

OSPF advertises and updates prefix information using LSA messages, which are sent only upon detection of a change in network reachability. LSAs are also reflooded periodically to prevent their being aged out by other routers. Typically, this occurs somewhere between 30 and 45 minutes, given the default 3,600-second LSA lifetime. In addition, rather than sending an entire route table or database, these LSAs carry only the essential set of information needed to describe the router's new LS. Upon sensing a change in their local LSDBs, other routers rerun the SPF and act accordingly.

OSPF dynamically discovers and maintains neighbors through generation of periodic hello packets. An adjacency is formed when two neighbors decide to synchronize their LSDBs to become routing peers. A router may choose to form an adjacency with only a subset of the neighbors that it discovers to help improve efficiency, as described in "Neighbors and adjacencies" on page 173.

It should be no wonder that OSPF has dramatically improved convergence characteristics when one considers its event-driven flooding of small updates to all routers in an area. This is especially true when contrasted to RIP's period exchange of the entire route table among directly connected neighbors, who then convey that information to their neighbors at the next scheduled periodic update.

The downside to all this increased performance is that CPU and memory load in routers are increased as compared to the same router running a DV protocol. This is because an LS router has to house *both* the LSDB and the resulting route table, and the router must compute these routes by executing an SPF algorithm each time the LSDB changes. Considering that router processing capability and memory tend to increase, while actual costs tend to decrease for the same unit of processing power, these drawbacks are a more-than-acceptable trade-off for the benefit of ongoing reduced network loading and rapid convergence. Another drawback to LS routing protocols is their relative complexity when compared to DV protocols, which can make their operation difficult to understand, which in turn can make fault isolation more difficult.

OSPF was designed to support Type of Service (ToS)-based routing, but this capability has not been deployed commercially. This means that a single route table is maintained, and that for each destination, a single path metric is computed. This metric is said to be *dimensionless* in that it serves only to indicate the relative goodness or badness of a path, with smaller numbers considered to be better. Exactly what is better cannot be determined from the OSPF metric, LSDB, or resulting route table. Whether the OSPF metric is set to reflect link speed (default), hop count, delay, reliability, or some combination thereof is a matter of administrative policy.

The default metric in Junos for OSPF is calculated by taking 100,000,000 and dividing it by the bandwidth of the interface. If the result is less than one, the metric is one. This number can be adjusted by adding the `reference bandwidth` statement to the configuration. A reference bandwidth of 10G is recommended for enterprises that contain high-bandwidth links (greater than 100 Mbps).

Neighbors and adjacencies

Previously, it was noted that OSPF dynamically discovers neighbors using a periodic exchange of hello packets. It should also be noted that OSPF contains sanity checks that prevent neighbor discovery (and therefore, adjacency formation) when parameters such as the hello time, area type, maximum transmission unit (MTU), or subnet mask are mismatched. The designers of the protocol felt it was much easier to troubleshoot a missing adjacency than the potential result of trying to operate with mismatched parameters, and having dealt with more than a few misconfigured OSPF networks, the protocol architects were absolutely right.

The designated router. To maximize efficiency, OSPF does not form an adjacency with every neighbor that is detected, because the maintenance of an adjacency requires compute cycles and because on multiaccess networks such as LANs, a full mesh of adjacencies is largely redundant. On multiaccess networks, an election algorithm is performed to first elect a designated router (DR), and then a backup designated router (BDR). The DR functions to represent the LAN itself and forms an adjacency with the BDR and all other compatible neighbors (DRother) on the LAN segment. The DRother routers form two adjacencies across the LAN—one to the DR and one to the BDR. The neighbor state for DRother neighbors on a DRother router itself is expected to remain in the "two-way" state. This simply means that the various DRothers have detected each other as neighbors, but an adjacency has not been formed.

The DR is responsible for flooding LSAs that reflect the connectivity of the LAN. This means that loss of one neighbor on a 12-node LAN results in a single LSA that is flooded by the DR, as opposed to each remaining router flooding its own LSA. The reduced flooding results in reduced network bandwidth consumption and reduced OSPF processing overhead. If the DR fails, the BDR will take over and a new BDR is elected.

OSPF elects a DR and BDR based on a priority setting, with a lower value indicating a lesser chance at winning the election; a setting of 0 prevents the router from ever becoming the DR. In the event of a tie, the router with the highest router ID (RID) takes the prize. The OSPF DR Election algorithm is nondeterministic and nonrevertive, which means that adding a new router with a higher, more preferred priority does not result in the overthrow of the existing DR. In other words, router priority matters only during active DR/BDR election. This behavior minimizes the potential for network disruption/LSA flooding when new routers are added to the network. Thus, the only way to guarantee that a given router is the DR is to either disable DR capability in all other routers (set their priority to 0), or ensure that the desired router is powered on first and never reboots. Where possible, the most stable and powerful router should be made the DR/BDR, and a router should ideally be the DR for only one network segment.

OSPF router types

OSPF describes various router roles that govern their operation and impact the types of areas in which they are permitted. To become proficient with OSPF operation and network design, you must have a clear understanding of the differences between OSPF area types and between the LSAs permitted within each area:

Internal router
: Any router that has all its interfaces contained within a single area is an internal router. If attached to the backbone area, the router is also known as a backbone router.

Backbone router
: Any router with an attachment to area 0 (the backbone area) is considered a backbone router. This router may also be an internal or area border router, depending on whether it has links to other, nonbackbone areas.

Area border router (ABR)
: A router with links in two or more areas is an ABR. The ABR is responsible for connecting OSPF areas to the backbone by conveying network summary information between the backbone and nonbackbone areas.

Antonymous system boundary router (ASBR)
: A router that injects external routing information into an OSPF domain is an ASBR.

Areas and LSAs

As previously noted, LS protocols flood LSAs to all routers in the same area in order to create a replicated LSDB from which a route table is derived through execution of an

SPF algorithm. The interplay of these processes can lead to a downward-scaling spiral in large networks, especially when there are large numbers of unstable links.

As the number of routers and router links within an area grows, so too does the size of the resulting LSDB. In addition, more links means a greater likelihood of an interface or route flap, which leads to greater need for flooding of LSAs. The increased probability of LSDB churn leads to an increased frequency of the SPF calculations that must be performed each time the LSDB changes (barring any SPF hold downs for back-to-back LSA change events). These conditions combine to form the downward spiral of increased flooding, larger databases, more frequent SPF runs, and a larger processing burden per SPF run, due to the large size of the LSDB.

But don't fear: OSPF tackles this problem through the support of areas, which provides a hierarchy of LSDBs. As a result, LSA flooding is now constrained to each area, and no one router has to carry LS for the entire RD. Because each area is associated with its own LSDB, a multiarea OSPF network will, for the average router, result in a smaller LSDB. Each router must maintain an LSDB only for its attached areas, and no one router need attach to every area. This is a key point, because in theory it means OSPF has almost unlimited scaling potential, especially when compared to nonhierarchical protocols such as Cisco's EIGRP or RIP. In addition, with fewer routers and links, there is a reduced likelihood of having to flood updated LSAs, which in turn means a reduced number of SPF runs are needed—when an SPF run is needed, it is now executed against a smaller LSDB, which yields a win-win for all involved.

Routers that connect to multiple areas are called ABRs and maintain an LSDB for each area to which they attach. An ABR has a greater processing burden than an internal router, by virtue of maintaining multiple LSDBs, but the processing burden associated with two small LSDBs can still be considerably less than that associated with a single, large database, for reasons cited earlier. It is common to deploy your most powerful routers to serve the role of ABRs, because these machines will generally have to work harder than a purely internal router, given that they must maintain an LSDB per attached area, and have the greater chance of a resulting SPF calculation. However, the trade-off is being able to use smaller, less powerful routers within each area (internal routers), because of the reduced LSDB size that results from a hierarchical OSPF design.

Interestingly, OSPF is truly link-state *only within* a single area due to the scope of LSA flooding being confined to a single area. An ABR runs SPF for each attached area's LSDB and then summarizes its intraarea LS costs into other areas in DV-like fashion. This behavior is the reason OSPF requires a backbone area that is designated as area 0—generally speaking, each ABR generates and receives summaries *only* from the backbone, which exists to provide a loop-free environment over which these summaries can be exchanged. Put another way, the backbone serves to prevent loop formation that could result from the information that is hidden by ABRs when they summarize the contents of their nonbackbone area LSDBs into simple distance/vector pairs. A router receiving a summary advertisement uses SPF against that area's LSDB to compute the shortest path to the router that generated the summary advertisement, and then it simply adds the summary cost, as originally calculated by the advertising router, to obtain the total path cost.

Having said all this, it is not unheard of to see large, globally spanning OSPF networks consisting of hundreds of routers successfully deployed within a single OSPF area. There simply are no hard rules regarding the age-old question of "how many routers can I put into a single area," because too many variables exist. In addition to a simple router count, one must also consider factors such as link count, link stability, router processing power, the percentage of external versus internal LSAs, and the general robustness of the protocol's implementation. The significance of the latter should not be underestimated. A poorly implemented OSPF instance running on the world's fastest hardware will likely not perform very well, unless, of course, you consider the number of core files dumped and/or reboots per unit of time, which is a significant IGP benchmark. Seriously, it's bad enough when one network node keeps rolling over to play dead, but it's worse when instability in a single node rapidly ripples out to affect the operation of other routers, even those with well-behaved code.

OSPF area types. OSPF defines several different area types. To truly understand OSPF operation, you must have a clear understanding of the differences between OSPF area types, and between the LSAs permitted within each area:

Backbone
: To ensure loop-free connectivity, OSPF maintains a special area called the backbone area, which should always be designated as area 0. All other OSPF areas should connect themselves to the backbone for interarea connectivity; normally, interarea traffic transits the backbone.

Stub
: Stub areas do not carry AS external advertisements, with the goal being a reduction of LSDB size for internal routers within that stub area. Because routers in a stub area see only LSAs that advertise routing information from *within* the OSPF RD, a default route is normally injected to provide reachability to external destinations. Stub area routers use the metrically closest ABR when forwarding to AS external prefixes.

Totally stubby area
: A totally stubby area is a stub area that *only* receives the default route from the backbone. Routers in the totally stubby area do not see OSPF internal routes from other OSPF areas. Their LSDBs represent their own area and the injected default route, which is now used to reach both AS external and interarea destinations.

NSSAs
: As noted previously, an OSPF stub area does not carry external routes, which means you cannot redistribute routes into a stub area because redistributed routes are always treated as AS externals in OSPF. An NSSA bends this rule and allows a special form of external route within the NSSA. Although an NSSA can originate AS externals into OSPF, external routes from other areas are still not permitted

within the NSSA. This is a case of having one's cake (small LSDB due to not being burdened by externals from other areas) while eating it, too (being allowed to burden other routers with the external routes you choose to generate). The NSSA's ABRs can translate the special form of external route used in an NSSA for flooding over the rest of the OSPF domain. NSSAs can be configured to receive only a default route from the ABR, becoming a Totally Not So Stubby Area. Who said the standards bodies do not have a sense of humor?

Transit areas
: Transit areas pass traffic from one adjacent area to the backbone or to another area if the backbone is more than two hops away from an area.

Primary LSA types. LSAs are the workhorse of OSPF in that they are used to flood information regarding network reachability and form the basis of the resulting LSDB. Table 6-2 describes the LSA types used by modern OSPF networks. It bears restating that a true understanding of OSPF requires knowledge of what type of routing information is carried in a given LSA, in addition to understanding each LSA's flooding scope. For example, an LSA with area scope is never seen outside the area from which it was generated, whereas an LSA with global scope is flooded throughout the entire OSPF RD, barring any area type restrictions; that is, AS externals are never permitted within a stub area. Figure 6-1 provides a graphical summary of the purpose and scope of the most common LSA types.

Table 6-2. Common OSPF LSA types

LSA type	Generated by/contents/purpose	Flooding scope
Type 1, router	Generated by all OSPF routers, the Type 1 LSA describes the status and cost of the router's links.	Area
Type 2, network	Generated by the DR on a LAN, the Type 2 LSA lists each router connected to the broadcast link, including the DR itself.	Area
Type 3, network summary	Generated by ABRs, Type 3 LSAs carry summary route information between OSPF areas. Typically, this information is exchanged between a nonbackbone area and the backbone area, or vice versa. Type 3 LSAs are not reflooded across area boundaries; instead, a receiving ABR generates its own Type 3 LSA summarizing its interarea routing information into any adjacent areas.	Area
Type 4, ASBR summary	Each ABR that forwards external route LSAs must also provide reachability information for the associated ASBR so that other routers know how to reach that ASBR when routing to the associated external destinations. The Type 4 LSA provides reachability information for the OSPF domain's ASBRs. As with Type 3 LSAs, each ABR generates its own Type 4 when flooding external LSAs into another area.	Area
Type 5, AS external LSA	Generated by ASBRs, the Type 5 LSA carries information for prefixes that are external to the OSPF RD.	Global, except for stub areas

LSA type	Generated by/contents/purpose	Flooding scope
Type 7, NSSA	Generated by ASBRs in an NSSA, the Type 7 LSA advertises prefixes that are external to the OSPF RD. Unlike the Type 5 LSA, Type 7 LSAs are not globally flooded. Instead, the NSSA's ABR translates Type 7 LSAs into Type 5 for flooding throughout the RD.	Area
Type 9, 10, and 11, opaque LSAs	Generated by enabled OSPF routers to carry arbitrary information without having to define new LSA types, the Type 9 LSA has link scope and is currently used to support graceful restart extensions, whereas the Type 10 LSA has area scope and is used for MPLS TE support.	Type 9, link; Type 10, area; Type 11, global scope

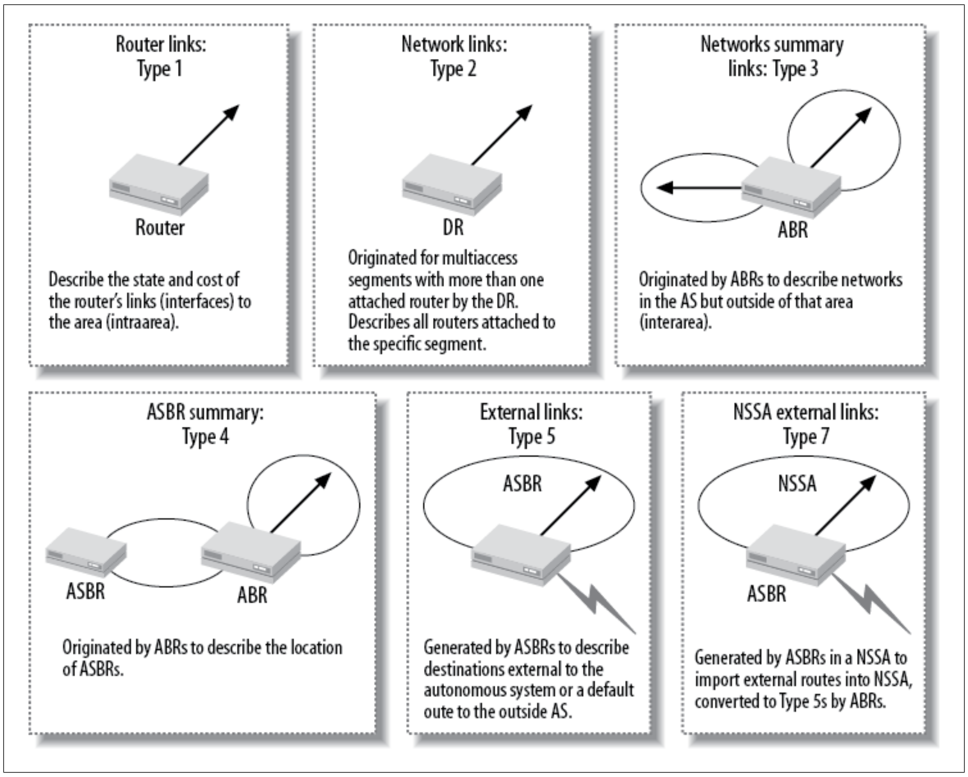

Router links: Type 1
Router
Describe the state and cost of the router's links (interfaces) to the area (intraarea).
Network links: Type 2
DR
Originated for multiaccess segments with more than one attached router by the DR. Describes all routers attached to the specific segment.
Networks summary links: Type 3
ABR
Originated by ABRs to describe networks in the AS but outside of that area (interarea).
ASBR summary: Type 4
ASBR
ABR
Originated by ABRs to describe the location of ASBRs.
External links: Type 5
ASBR
Generated by ASBRs to describe destinations external to the autonomous system or a default oute to the outside AS.
NSSA external links: Type 7
NSSA
ASBR
Generated by ASBRs in a NSSA to import external routes into NSSA, converted to Type 5s by ABRs.

Figure 6-1. OSPF LSA types and scope

OSPF stability and performance tweaks

Breaking a large OSPF domain into multiple areas can have a significant impact on overall performance and convergence. In addition, most OSPF implementations support various timers to further tune and tweak the protocol's operation.

The Juniper Networks OSPF implementation is quite optimized and lacks many of the timers and hold downs that readers may be familiar with in IOS. It is not uncommon to see users new to Juniper asking for Junos analogs and receiving the standard answer that "they do not exist because they are not needed." The development engineers at Juniper feel that artificially delaying transmission of an LSA—ostensibly to alleviate the processing burden associated with its receipt—does nothing except prolong network convergence.

Table 6-3 maps OSPF-related knobs from IOS to their Junos equivalent, when available.

Table 6-3. IOS versus Junos OSPF timers

IOS name	Junos OS name	Comment
`carrier-delay` (0)	`hold-time` (0)	Delay notification of interface up/down events to damp interface transitions. Default is 0, but notification times can vary based on interrupt versus polled.
`timers throttle spf (spf-start, spf-hold, spf-max-wait)`	`spf-delay` (200)	Control the rate of SPF calculation. In Junos, the value is used for as many as three back-to-back SPF runs, and then a 5-second hold down is imposed to ensure stability in the network.
`timers throttle lsa all (lsa-start, lsa-hold, lsa-max`*`((0, 5000, 5000))`*`)`	N/A	By default, Junos sends 3 back-to-back updates with a 50 msec delay, and then a five-second hold down.
`timers lsa arrival`	N/A	Controls the minimum interval for accepting a copy of the same LSA.
`timers pacing flood` (33 msec)	`transmit-interval` (30 msec)	Delay back-to-back LSA transmissions out the same interface.
`ispf`	N/A	Enable incremental SPF calculations; Junos does not support ISPF but does perform partial route calculations when the ospf topology is stable and only routing information changes.

The Junos OS has added an additional optimization in the form of a periodic packet management process daemon (ppmd) that handles the generation and processing of OSPF (and other protocol) hello packets. The goal of ppmd is to permit scaling to large numbers of protocol peers by offloading the mundane processing tasks associated with periodic packet generation. The ppmd process can run directly in the PFE to offload RE cycles on application-specific integrated circuit (ASIC)-based systems such as the M7i.

In addition to the aforementioned timers, both vendors also support Bidirectional Forwarding Detection (BFD), which is a routing-protocol-agnostic mechanism to provide rapid detection of link failures, as opposed to waiting for an OSPF adjacency timeout. Note that interface hold time comes into play only when a physical layer fault is detected, as opposed to a link-level issue such as can occur when two routers are connected via a LAN switch, where the local interface status remains up even when a physical fault occurs on the remote link. As of this writing, IOS support for BFD is limited and varies by platform and software release; Cisco Systems recommends that you see the Cisco IOS software release notes for your software version to determine support and applicable restrictions.

Enhanced Interior Gateway Routing Protocol

The EIGRP is an updated version of Cisco Systems' proprietary IGRP. The original version of EIGRP had stability issues, prompting the release of EIGRP version 1, starting in IOS versions 10.3(11), 11.0(8), and 11.1(3). This chapter focuses strictly on EIGRP because it has largely displaced IGRP in modern enterprise networks.

EIGRP is sometimes said to be a "DV protocol that thinks it's an LS." EIGRP does in fact share some of the characteristics normally associated with LS routing, including rapid convergence and loop avoidance, but the lack of LSA flooding and the absence of the resulting LSDB expose EIGRP's true DV nature. This section highlights the major operational characteristics and capabilities of EIGRP. The goal is not an exhaustive treatment of EIGRP's operation or configuration—this subject has been covered in numerous other writings. Instead, the purpose here is to understand EIGRP to the degree necessary to effectively replace this proprietary legacy protocol with another IGP, while maintaining maximum network availability throughout the process.

The operational characteristics of EIGRP are as follows:

- It uses nonperiodic updates that are partial and bounded. This means that unlike typical DV protocol operation, EIGRP generates *only* triggered updates, that these updates report *only* affected prefixes, and that the updates are sent to a bounded set of neighbors.
- It uses a Diffusing Update Algorithm (DUAL) to guarantee a loop-free topology while providing rapid convergence. The specifics of DUAL operation are outside the scope of this book; suffice it to say that DUAL is the muscle behind EIGRP's rapid converge and loop guarantees.
- It uses a composite metric that, by default, factors delay and throughput. Also, it supports the factoring of dynamically varying reliability and loading, but users are cautioned not to use this capability. EIGRP uses the same metric formula as IGRP, but it multiplies the result by 256 for greater granularity.
- It supports VLSM/CIDR and automatic summarization at classful boundaries by default.
- It supports unequal cost load balancing using a *variance* knob.
- It supports neighbor discovery and maintenance using multicast.
- It automatically redistributes to IGRP when process numbers are the same.
- It features protocol-independent modules for common functionality (reliable transport of protocol messages).

- It features protocol-dependent modules for IP, IPX, and AppleTalk that provide multiprotocol routing via the construction of separate route tables using protocol-specific routing updates.

At first glance, the multiprotocol capabilities of EIGRP may seem enticing. After all, this functionality cannot be matched by today's *standardized* routing protocols. There was a time when many enterprise backbones were in fact running multiple network protocols, and the lure of a single, high-performance IGP instance that could handle the three most common network suites was hard to resist. However, there has been an unmistakable trend toward IP transport for virtually all internetworking suites, including IBM's SNA/SAA. (We have a hard time recalling the last time we knew of an enterprise still deploying the native Netware or AppleTalk transport protocols.) In contrast, these proprietary-routed protocols are being phased out in favor of native IP transport, which serves to render EIGRP's multiprotocol features moot in this modern age of *IP* internetworking.

EIGRP can load-balance across paths that are not equal in cost, based on a variance setting, which determines how much larger a path metric can be as compared to the minimum path metric, while still being used for load balancing. This characteristic remains unique to IGRP/EIGRP, as neither RIP nor OSPF supports unequal cost load balancing.

EIGRP metrics

EIGRP uses a composite metric that lacks a direct corollary in standardized IGPs. EIGRP metrics tend to be large numbers. Although providing great granularity, these huge numbers represent a real issue for a protocol such as RIP, which sees any metric greater than 16 as infinity. It's quite unlikely that any enterprise would migrate from EIGRP to RIP anyway, given the relatively poor performance of RIP and the widespread availability of OSPF on modern networking devices, so such a transition scenario is not addressed in this chapter.

For reference, the formula used by EIGRP to calculate the metric is:

$$\text{Metric} = [\text{K1} \times \text{Bw} + \text{K2} \times \text{Bw}/(256 - \text{Load}) + \text{K3} \times \text{Delay}] \times [\text{K5}/(\text{Reliability} + \text{K4})]$$

Although the MTU is not used in the calculation of the metric, it is tracked across the path to identify the minimum path MTU. The K parameters are used to weigh each of the four components that factor into the composite metric—namely, bandwidth, load, delay, and reliability. The default values for the weighing result in only K1 and K3 being nonzero, which gives the default formula of Bw + Delay for the metric.

> Note that Cisco Systems does not recommend user adjustment of the metric weighting. So, in practical terms, EIGRP's metric is a 32-bit quantity that represents the path's cumulative delay (in tens of microseconds) and the path's minimum throughout in Kb/s, divided by 10^7 (scaled and inverted).

For EIGRP, the result is then multiplied by 256 to convert from IGRP's 24-bit metric to EIGRP's 32-bit metric. It should be obvious that one cannot perform a simple one-to-one mapping of legacy EIGRP metrics to OSPF, given that EIGRP supports a 32-bit metric and OSPF's is only 16-bit. This is not a significant shortcoming in practice, given that few enterprise networks are composed of enough paths to warrant 4 billion levels of metric granularity anyway!

Figure 6-2 shows an example network to help illustrate how EIGRP calculates a path metric.

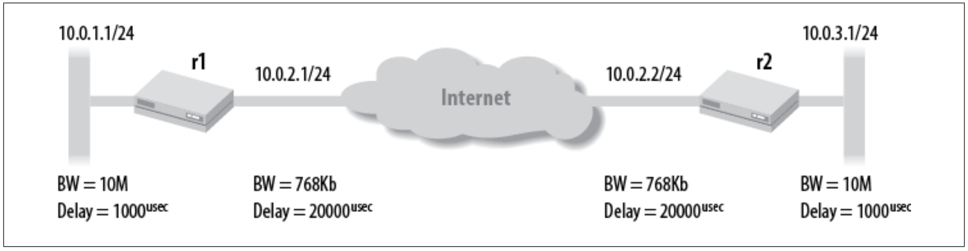


Figure 6-2. EIGRP metric example

Using the default composite metric weighting for the topology shown in Figure 6-2, router `r1`'s metric to reach 10.0.3.0/24 is computed based on the minimum bandwidth and the sum of the path delay, using the formula:

$$\text{Metric} = 256 \times (10^7/\text{minBW Kbs}) + (\text{delay sum usec}/10)$$

Plugging in the specifics for this example yields a path metric of 3,870,976 for the path to 10.0.3.0/24, from the perspective of `r1`:

$$\text{Metric} = 256 \times (10^7/768) + (20{,}000 + 1{,}000\ /10)$$
$$\text{Metric} = 256 \times (13021) + (2100)$$
$$\text{Metric} = 256 \times 15121$$
$$\text{Metric} = 3{,}870{,}976$$

By way of comparison, the same network running OSPF with Junos defaults for OSPF reference bandwidth yields a path metric of only 137! A key point here is that although 137 is certainly much smaller than the 3,870,976 value computed by EIGRP, the range of OSPF metrics, from 1 to 65,534, should be more than sufficient to differentiate among the number of links/paths available in even the largest enterprise network.

Also, recall that the OSPF metric is said to be dimensionless, which is to say that a smaller value is always preferred over larger values, but the exact nature of *what* is smaller is not conveyed in the metric itself. By default, OSPF derives its metric from interface bandwidth using a scaling factor, but the scaling factor can be altered, and the metric can be administratively assigned to reflect any parameter chosen by the administrator. When all is said and done, as long as a consistent approach is adopted when assigning OSPF metrics, the right thing should just happen. By way of example, consider a case where OSPF metrics are assigned based on the economic costs of a usage-based network service. The resultant *shortest path* measures distance as a function of economic impact and will result in optimization based on the least expensive paths between any two points. Thus, OSPF has done its job by locating the *shortest* path, which in this example means the *least expensive* path, given that the administration considers distance to equate to money. We revisit the subject of EIGRP to OSPF metric conversions in "EIGRP-to-OSPF Migration Summary" on page 243.

EIGRP: A grand past and a dubious future

It's worth restating that, unlike open standards protocols such as RIP and OSPF, EIGRP is proprietary to Cisco Systems. As a result, only Cisco Systems products can speak EIGRP, both because of the closed nature of the specification and because of the licensing and patent issues that prevent others from implementing the protocol. Most enterprise customers (and service providers, for that matter) prefer not to be locked into any solution that is sourced from a single vendor, even one as large and dominant as Cisco Systems.

EIGRP's lack of hierarchical support significantly limits its use in large-scale networks because of scaling issues. EIGRP lacks the protocol extensions needed to build a traffic engineering database (TED), as used to support MPLS applications. Although MPLS is still somewhat rare in the enterprise, it currently enjoys significant momentum and is in widespread use within service provider networks across the globe. Considering that many of the requirements of service providers three or four years ago are the same requirements that we are seeing in the enterprise today, an enterprise would be wise to hedge its bets by adopting protocols that can support this important technology, should the need later arise.

Support is an important factor that must be considered when deploying any protocol. At one point, it was difficult to find off-the-shelf or open source protocol analysis for IGRP/EIGRP. Cisco could change the specification at any time, making obsolete any such tools that exist. At the time of this writing, the Wireshark analysis program lists EIGRP support; however, it's difficult to confirm the decode accuracy without an open standard to reference against.

Given the drawbacks to a single-vendor closed solution, an enterprise should consider the use of open standard protocols. In the case of IGPs, you gain higher performance, vendor independence, and off-the-shelf support capabilities. EIGRP's multiprotocol capability aside, the largest IP networks on the planet (those of Internet service providers [ISPs]) generally run OSPF. Service provider networks are all about reliability, stability, rapid convergence at a large scale, and the ability to offer services that result in revenue generation—given these IGP requirements, the reader is left to ponder why service provider networks are never found to be running EIGRP within their networks.

IGP Summary

IGPs provide the indispensable service of maintaining internal connectivity throughout the myriad link and equipment failures possible in modern IP internetworks. IGP performance and stability in the face of large volumes of network change can provide a strategic edge by quickly routing around problems to maintain the highest degree of connectivity possible.

This section overviewed the RIP, OSPF, and EIGRP protocols to prepare the reader for the following deployment and IGP migration scenarios. Now is a good time to take a break before you head into the RIP deployment case study that follows.

RIP Deployment Scenario

OK, that's enough of an IGP overview. There's little doubt that the router-jockey readers of this book are champing at the bit to start routing some packets! Let's demonstrate basic RIP configuration and operational mode commands that assist in troubleshooting a RIP operation in a Junos environment.

Figure 6-3 depicts the topology for the Cisco Systems/IOS to Juniper Networks/Junos RIP integration scenario. It shows the existing Beer-Co RIP network, which currently consists of two Cisco Systems 2600 series routers running IOS version 12.3(15b) and interconnected by a serial link. Beer-Co is expanding its widget operation and plans to add two additional locations. Despite the existing infrastructure, the CIO has opted to become a multivendor shop, and a decision has been made to deploy two Juniper Networks J-series routers. The existing (and planned) IP addressing is shown and contains a mix of subnetted class A and class C addresses (just to keep things interesting). Each router's loopback address is also shown, along with a simulated customer network that is instantiated via a static route (labs commonly use a static route to represent a customer network for purposes of reducing equipment requirements). Note that the last digit of each router's loopback address is tied numerically to that router's simulated customer network to help ease requirements on the reader's memory.

As a reminder, recall that in this lab, each router's Fast Ethernet interface is tied to a virtual LAN (VLAN) switch, and VLAN tags are used to establish links between communicating routers. The subinterface/logical unit of each interface match the associated VLAN tag value, which is also shown in the figure. You may assume that all router interface properties are correctly configured to permit communication with directly attached neighbors. The following code snippets show the Fast Ethernet interface configuration at Cisco router `Malt` and Juniper router `Ale`.

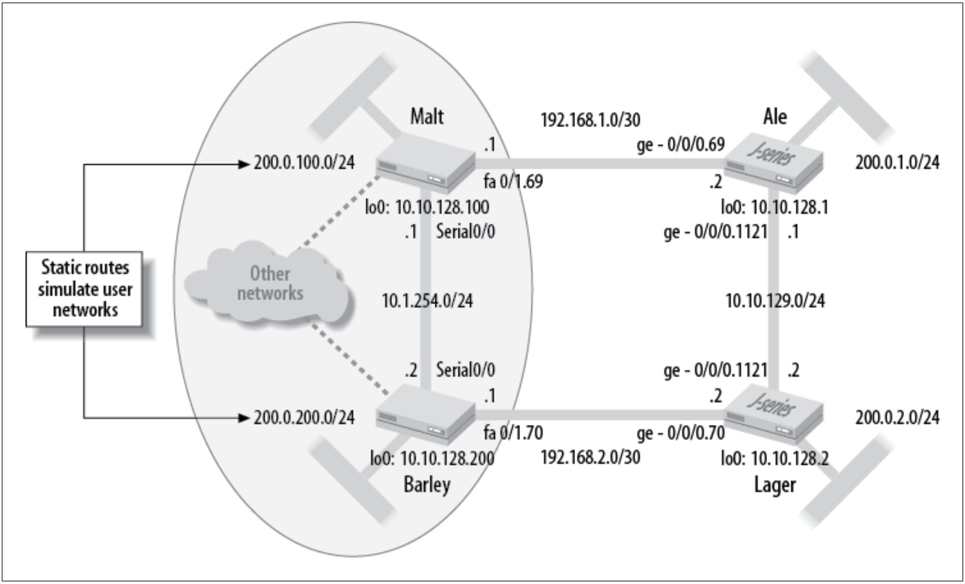


Figure 6-3. RIP topology

`Malt`'s `FastEthernet0/1` interface and subinterface configuration:

```
interface FastEthernet0/1
 no ip address
 duplex auto
 speed auto
!
interface FastEthernet0/1.69
 encapsulation dot1Q 69
 ip address 192.168.1.1 255.255.255.252
 ip rip authentication mode md5
 ip rip authentication key-chain test
 no snmp trap link-status
```

`Ale`'s `ge-0/0/0` interface and logical unit configuration:

```
[ge-0/0/0 {
    vlan-tagging;
    unit 69 {
        description Ale-to_Malt;
        vlan-id 69;
        family inet {
            address 192.168.1.2/30;
        }
    }
    unit 1121 {
        description Ale-to_Lager;
        vlan-id 1121;
        family inet {
            address 10.10.129.1/24;
        }
    }
}
```

Existing RIP Configuration

Before adding the new RIP routers, it makes sense to first inspect the related RIP configuration in the Cisco platform to get a feel for what RIP configuration tasks will be needed on the Juniper Networks boxes. The RIP-related configuration parts from router `Malt` are shown, along with some inline comment as to what each part is doing:

```
Malt# show run
Building configuration...
. . .
!
key chain test
 key 1
  key-string jncie
. . .
```

The key chain configuration is used to provide authentication to various routing protocols, ostensibly RIP, in this example. The named key chain has a single key that is numbered as `1` using a key value of `jncie`. Key chains provide the ability to rotate the current key, based on start and end times (which are not specified in this example). As of this writing, Junos supports authentication key chains only for the Label Distribution Protocol (LDP), OSPF, and BGP. RIP supports a single password-MD5 key, which is good for us because that is just what's needed here:

```
interface FastEthernet0/1.69
 encapsulation dot1Q 69
 ip address 192.168.1.1 255.255.255.252
 ip rip authentication mode md5
 ip rip authentication key-chain test
 no snmp trap link-status
!
. . .
```

The two subinterface-level `IP rip authentication` statements configure RIP authentication for messages sent out to or received from the related interface. The commands specify the associated key chain and authentication approach, which again is MD5 in this example:

```
router rip
 version 2
 redistribute connected
 redistribute static route-map TAGGING
 network 10.0.0.0
 network 192.168.1.0
 distribute-list 3 out static
 no auto-summary
. . .
```

This portion of the configuration actually enables the RIP process. Things begin with the specification that RIP version 2 is to be run. Considering the VLSM in effect, this is a very good choice. The `network` statements, which are assumed to fall on classful boundaries, define the set of interfaces on which RIP should operate. Rather than listing interfaces directly by name, they are indirectly identified through the interface's IP address. Notice the two forms of route redistribution in effect. The `redistribute connected` and `redistribute static` statements, the latter with an associated route map, serve to redistribute connected and static routes, respectively. A distribution list could also have been used to control the routes advertised into RIP. The connected routes will catch the router's serial, Fast Ethernet, and loopback interface subnets. You will have to wait and see what static route redistribution is doing when you inspect the related route map.

The `no-auto-summary` statement disables the default (Cisco) behavior of automatically summarizing at classful network boundaries. When combined with RIP version 2, which conveys a network mask, VLSM/CIDR is supported:

```
ip route 0.0.0.0 0.0.0.0 Null0
ip route 200.0.100.0 255.255.255.0 Null0
!
access-list 3 permit 200.0.100.0
access-list 4 permit 0.0.0.0
!
```

The whole classful addressing concept is totally alien to a Juniper Networks router, as the boxes were designed in an era well after the concept of class-based addressing had come and gone. To help illustrate this point, Junos has no need for an `ip classless` statement, as always seen in IOS, and consistently uses CIDR `/` notation for prefix lengths.

This portion of the configuration defines two static routes: the former is a default route and the latter is the simulated customer network associated with `Malt`. Both are pointed to `null0` as a next hop, which means that any traffic that longest-matches either of these two routes will be discarded.

This may strike the reader as odd, so some additional explanation is warranted. The assumption is that the real customer network will be assigned a mask longer than the /24 used by the static route that currently represents it—for example, a /28. Therefore, packets actually sent to hosts within the customer network will longest-match against the customer network interface route (longest-match rules), and are thereby spared the ignominious treatment of a one-way trip to `null0` land. If, on the other hand, the customer network interface is down, these packets are discarded as they now longest-match against the static route—meanwhile, the presence of the static route is preventing route churn in the rest of the network because it's always being advertised in RIP. This stability comes with the downside that, during a customer network interface outage, other routers in the RIP domain have a false belief that hosts on the customer network are still reachable, and the resultant traffic is forwarded over the enterprise network only to be discarded by the last hop. This technique is somewhat common in service provider networks, because control plane stability is generally more important than the network bandwidth that is wasted by forwarding packets across a network only to shunt them to `null0`.

In the RIP scenario, the two Cisco routers are attached to some other network cloud. Rather than run a routing protocol or define numerous static routes, the administrator relies on a default route to direct matching traffic into this cloud. The dotted lines on the drawing symbolize that this cloud is not part of the actual test bed.

Also, note the two related IP access control lists (ACLs), each matching on one of the two static routes. These ACLs are in turn referenced by the route map:

```
route-map TAGGING permit 10
 match ip address 3
 set metric 3
!
route-map TAGGING permit 20
 match ip address 4
 set tag 100
. . .
End
```

The `TAGGING` route map first matches against ACL 3 and sets the outgoing metric to 3 for matching prefixes (the simulated customer network route in this case). The default metric would be 1, so this action simulates a network that is two router hops farther away than it actually is. This might be done to cause another source of this route to be preferred (the lower hop count wins), or, perhaps, to limit the scope of stations that can reach this network (recall that in RIP, 16 means you cannot get there). Like it or not, this is an example of how route maps are used in IOS to alter route attributes, perhaps just to keep the scenario interesting.

The `permit 20` statement evokes ACL 4, which matches the default route for purposes of setting a route tag. In this example, the tag happens to be based on the router's loopback address. It's common to tag routes that are redistributed for purposes of tracking down the source of the route when troubleshooting, or for use in policy matching based on tag values. This is especially important when performing mutual route redistribution, which is a process prone to routing loops when route filtering precautions are not exercised.

Baseline Operation

A quick look at the state of the IP route table at router `Malt` is performed before any modifications are made. This will serve as the network baseline for future comparison:

```
Malt# show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
```

```
              i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
              ia - IS-IS inter area, * - candidate default, U - per-user static route
              o - ODR, P - periodic downloaded static route

       Gateway of last resort is 0.0.0.0 to network 0.0.0.0

       R    200.0.200.0/24 [120/3] via 10.1.254.2, 00:00:03, Serial0/0
       S    200.0.100.0/24 is directly connected, Null0
            10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
       C       10.10.128.100/32 is directly connected, Loopback0
       R       10.10.128.200/32 [120/1] via 10.1.254.2, 00:00:03, Serial0/0
       C       10.1.254.0/24 is directly connected, Serial0/0
       C       10.1.254.2/32 is directly connected, Serial0/0
            192.168.1.0/30 is subnetted, 1 subnets
       C       192.168.1.0 is directly connected, FastEthernet0/1.69
            192.168.2.0/30 is subnetted, 1 subnets
       R       192.168.2.0 [120/1] via 10.1.254.2, 00:00:04, Serial0/0
       S*   0.0.0.0/0 is directly connected, Null0
```

No real surprises here. `Malt` has several directly connected routes, in the form of its `FA 0/1.69`, loopback `0`, and serial `0/0` interfaces. And the two locally defined static routes, 0.0.0.0 and 200.0.0.100, are both pointing to `null0`. Lo and behold, `Malt` has learned three routes via RIP: `Barley`'s `FA 0/1.70` route (192.168.2.0), its loopback interface route (10.10.128.200), and the simulated customer route (200.0.200.0). Note that the customer route received from `Barley` demonstrates the effects of the route map. This route's received hop count is 3 whereas the other two routes advertised by `Barley` were received with the default value of 1. The hop count/metric is displayed just after the administrative distance, which for RIP is 120. Here is a summary view of the RIP routes at `Barley`:

```
       Barley# show ip route rip
       R    200.0.100.0/24 [120/3] via 10.1.254.1, 00:00:14, Serial0/0
            10.0.0.0/8 is variably subnetted, 4 subnets, 2 masks
       R       10.10.128.100/32 [120/1] via 10.1.254.1, 00:00:14, Serial0/0
            192.168.1.0/30 is subnetted, 1 subnets
       R       192.168.1.0 [120/1] via 10.1.254.1, 00:00:14, Serial0/0
```

With `Barley` displaying the same type and number of routes, baseline operation is confirmed.

Summary of RIP Requirements

The operational aspects of the RIP network design, as determined through analysis of the legacy RIP configuration, are as follows:

- RIPv2 (without auto-summarization).
- Defaults are in place for update, hold down, and route timeout timers.
- MD5 authentication is in effect using key ID 1 with string `jncie`.

- Direct networks are being redistributed.
- The static route representing an attached customer network is redistributed with an artificially escalated hop count of 3.

Enter Juniper Networks

Based on the analysis of the IOS RIP configuration, we know what needs to be done at `Ale` and `Lager`. To help mitigate any operational impacts, it is decided to first bring up the RIP peerings between `Ale` and `Lager` before attaching them to the existing RIP backbone.

Configure static routes

The configuration begins with the definition of the static route that simulates an attached customer network. The configuration steps for `Ale` are:

```
lab@Ale> configure
Entering configuration mode

[edit]
lab@Ale# edit routing-options

[edit routing-options]
lab@Ale# set static route 200.0.1/24 discard

[edit routing-options]
lab@Ale# show
static {
    route 200.0.1.0/24 discard;
}
```

With the static route defined, the change is committed and the result confirmed (while still in configuration mode). In this example, traffic matching the static route is directed to a discard next hop, which means that no responses will be generated for matching traffic—a true black hole from which nothing will escape. Another option would be `reject`, which generates an Internet Control Message Protocol (ICMP) error reporting that the destination is unreachable. This creates functionality similar to IOS's `null0`, in that matching traffic will generate host unreachable error messages. The `reject` option can assist in troubleshooting, but it consumes router resources in the form of message generation, which can be an issue during a large-scale denial of service (DoS) attack, making `discard` the preferred target for such a route:

```
[edit routing-options]
lab@Ale# commit
commit complete

[edit routing-options]
lab@Ale# run show route protocol static
```

```
inet.0: 6 destinations, 6 routes (6 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.1.0/24       *[Static/5] 00:00:37
                      Discard
```

Configure RIP

The RIP configuration is now added to `Ale`. Start by moving to the RIP configuration hierarchy, where the general options are shown:

```
[edit routing-options]
lab@Ale# top edit protocols rip

[edit protocols rip]
lab@Ale# set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  authentication-key   Authentication key (password)
  authentication-type  Authentication type
  check-zero           Check reserved fields on incoming RIPv2 packets
> graceful-restart     RIP graceful restart options
> group                Instance configuration
  holddown             Hold-down time (10..180 seconds)
+ import               Import policy
  message-size         Number of route entries per update message (25..255)
  metric-in            Metric value to add to incoming routes (1..15)
  no-check-zero        Don't check reserved fields on incoming RIPv2 packets
> receive              Configure RIP receive options
> rib-group            Routing table group for importing RIP routes
  route-timeout        Delay before routes time out (30..360 seconds)
> send                 Configure RIP send options
> traceoptions         Trace options for RIP
  update-interval      Interval between regular route updates (10..60 seconds)
[edit protocols rip]
lab@Ale# set
```

It should be apparent that many aspects of RIP are configurable within Junos. Some options are global, such as the authentication key/type or import/export policy, which means they apply to all groups (unless negated by a more specific group setting, if available). Other parameters can be specified only at a subsequent hierarchy. For example, a neighbor can be defined only within a group. You can quickly explore the options available under `send` and `receive` using the command-line interface's (CLI's) `?` help utility:

```
[edit protocols rip]
lab@Ale# set send ?
Possible completions:
  broadcast            Broadcast RIPv2 packets (RIPv1 compatible)
  multicast            Multicast RIPv2 packets
  none                 Do not send RIP updates
  version-1            Broadcast RIPv1 packets
[edit protocols rip]
lab@Ale# set receive ?
Possible completions:
  both                 Accept both RIPv1 and RIPv2 packets
  none                 Do not receive RIP packets
  version-1            Accept RIPv1 packets only
  version-2            Accept only RIPv2 packets
```

It's apparent from the display that the send and receive settings globally control the RIP version and whether multicast (default for v2) or broadcast packets are sent. It just so happens that these same settings can also be specified on a per-neighbor (interface) basis—recall that in Junos, the more-specific group-level configuration hierarchy settings override the less-specific global values. Let's take a quick look at the options available under a group, which is where you can define neighbors (interfaces) that run RIP:

```
[edit protocols rip]
lab@Ale# set group rip ?
Possible completions:
  <[Enter]>            Execute this command
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> bfd-liveness-detection  Bidirectional Forwarding Detection options
+ export               Export policy
+ import               Import policy
  metric-out           Default metric of exported routes (1..15)
> neighbor             Neighbor configuration
  preference           Preference of routes learned by this group
  route-timeout        Delay before routes time out (30..360 seconds)
  update-interval      Interval between regular route updates (10..60 seconds)
|                    Pipe through a command
```

Configuration options found at the neighbor level include the `import` or `export` keyword, which is used to apply routing policy to receive or transmit route updates, respectively. Note that when applied at the neighbor level, any globally defined import or export policies are negated. The router runs *either* the global or the group policy, never both, and the router always chooses the most specific application—a neighbor level is more specific than a global level, of course. You may recall that policy is used to control route exchange and alter route attributes. The global preference for routes learned from a particular neighbor can also be configured here. Note that in Junos, the concept of global preference is equivalent to that of IOS's administrative distance—this value is altered to make a source of routing information more (lower value) or less (higher value) preferred.

The terminology of groups and neighbors may seem a bit confusing at first, given the way RIP is configured in IOS. Junos is optimized when routing peers with similar export policy are placed into the same group. As a result, even if you have only one peer, that neighbor needs to belong to a RIP group. Also, the term *neighbor* here actually means *interface*, given that RIP messages are not unicast to specific machines, but instead are broadcast or multicast to all RIP speakers on a given link. This means that specifying a single neighbor in the form of a multiaccess interface results in RIP communications with all RIP-capable routers on that LAN segment.

Ale's RIP configuration. `Ale`'s RIP stanza is now configured in accordance with the RIP design guideline discovered when analyzing the legacy RIP configuration. Recall that the plan is to first establish RIP peerings between `Ale` and `Lager` before trying route exchanges to the Cisco routers (see Figure 6-3). Here is the resulting RIP stanza, along with the `set` commands used to create it courtesy of the `display set` function in the CLI:

```
[edit protocols rip]
lab@Ale# show
send multicast;
receive version-2;
authentication-type md5;
authentication-key "$9$cf3rK84oGiHm-VgJ"; ## SECRET-DATA
group rip {
    inactive: neighbor ge-0/0/0.69;
    neighbor ge-0/0/0.1121;
}
[edit protocols rip]
lab@Ale# show | display set
set protocols rip send multicast
set protocols rip receive version-2
set protocols rip authentication-type md5
set protocols rip authentication-key "$9$cf3rK84oGiHm-VgJ"
deactivate protocols rip group rip neighbor ge-0/0/0.69
set protocols rip group rip neighbor ge-0/0/0.1121
```

The global `send multicast` statement ensures that we will only speak to RIPv2 nodes, as RIPv1 routers will not see multicast updates. The `receive version-2` ensures that we process only multicast updates, thereby configuring the router for RIPv2-only operation. The authentication settings specify a (now ciphered) text string of `jncie` and indicates that MD5-based authentication should be used.

Junos always encrypts passwords; IOS requires that the password encryption service be enabled for the same functionality.

Lastly, notice the two `neighbor` statements that identify what interfaces RIP should run on. Note that the link to `Malt` is currently deactivated (inactive), which means that portion of the configuration will be ignored. This will result in `Ale` running RIP only on the `ge-0/0/0.1121` interface to `Lager`. Once RIP has been confirmed between `Ale` and `Lager`, this link will be activated to enable RIP exchanges with the Cisco routers.

The one part of `Ale`'s configuration yet to be addressed is the redistribution into RIP of its connected and simulated customer static routes. Recall that in Junos, control over what routes enter and leave the route table and the modification of attributes associated with these routes is controlled by routing policy. Here is an example of the Junos route policy needed to match the Cisco router's redistribution of connected (direct) routes and the route map function that sets the metric on a redistributed static route:

```
[edit policy-options policy-statement rip_export]
lab@Ale# show
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.1.0/24 exact;
    }
    then {
        metric 3;
        accept;
    }
}
[edit policy-options policy-statement rip_export]
lab@Ale# show | display set
set policy-options policy-statement rip_export term 1 from protocol direct
set policy-options policy-statement rip_export term 1 then accept
set policy-options policy-statement rip_export term 2 from protocol static
set policy-options policy-statement rip_export term 2 from route-filter 200.0.1.0/24
exact
set policy-options policy-statement rip_export term 2 then metric 3
set policy-options policy-statement rip_export term 2 then accept
```

The newly created RIP policy is applied to the RIP group (alternatively, it could be applied globally in this example) as `export`, where it will control the exchange of routes that are advertised into RIP. The default RIP import policy, which is to accept RIP routes, is left unaltered:

```
[edit]
lab@Ale# set protocols rip group rip export rip_export

[edit]
lab@Ale# show protocols rip
send multicast;
receive version-2;
authentication-type md5;
authentication-key "$9$cf3rK84oGiHm-VgJ"; ## SECRET-DATA
group rip {
    export rip_export;
    inactive: neighbor ge-0/0/0.69;
```

```
        neighbor ge-0/0/0.1121;
    }
```

You may assume that a compatible RIP policy configuration has been added to Lager and that the changes are committed.

Confirm RIP Operation: Ale and Lager

With the RIP and related static route/policy configuration in place at Ale and Lager, the operation of RIP can be confirmed. Start with the confirmation that RIPv2 is running, and that it is doing so on the expected interfaces:

```
lab@Ale> show rip neighbor
                     Source       Destination    Send   Receive    In
Neighbor       State  Address      Address        Mode   Mode       Met
--------       -----  -------      -----------    ----   -------   ---
ge-0/0/0.1121     Up 10.10.129.1  224.0.0.9      mcast  v2 only    1
```

The output of the show rip neighbor command confirms that Ale is set for v2 operation, and that RIP is running on its link to Lager. The Up status indicates that the interface is operational, but not that any particular neighbor has been detected. The In Met column displays the metric value that will be added to any route updates received over the associated interfaces; by default, each received update has its metric incremented by one before being placed into the route table.

The general RIP statistics confirm that updates are being sent and received, that no errors are occurring, and that in the case of Ale, three routes have been learned via RIP, indicating that RIP is operating correctly between Ale and Lager:

```
lab@Ale> show rip statistics
RIPv2 info: port 520; holddown 120s.
    rts learned  rts held down  rqsts dropped  resps dropped
            3              0              0              0

ge-0/0/0.1121:  3 routes learned; 3 routes advertised; timeout 180s;
update interval 30s
Counter                       Total   Last 5 min  Last minute
-------                   ----------- ----------- -----------
Updates Sent                     25          11            2
Triggered Updates Sent            1           0            0
Responses Sent                    0           0            0
Bad Messages                      0           0            0
RIPv1 Updates Received            0           0            0
RIPv1 Bad Route Entries           0           0            0
RIPv1 Updates Ignored             0           0            0
RIPv2 Updates Received           17          11            2
RIPv2 Bad Route Entries           0           0            0
RIPv2 Updates Ignored             0           0            0
Authentication Failures           1           0            0
RIP Requests Received             1           0            0
RIP Requests Ignored              0           0            0
```

And now we confirm the presence of RIP routes in Ale's route table:

```
lab@Ale> show route protocol rip

inet.0: 10 destinations, 10 routes (10 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.128.2/32     *[RIP/100] 00:09:54, metric 2, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
192.168.2.0/30     *[RIP/100] 00:09:54, metric 2, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
200.0.2.0/24       *[RIP/100] 00:09:54, metric 4, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
224.0.0.9/32       *[RIP/100] 00:10:57, metric 1
                      MultiRecv
```

Ale's route table contains the expected RIP routes, considering that RIP is not yet enabled to Malt and Barley. Notice that Lager has advertised its directly connected loopback interface (10.10.128.2) route to Ale. Also of note is that the Junos route table displays the local RIP cost, as opposed to the metric received in the route update. This differs a bit from IOS, which displays the received RIP metric rather than local cost (received + 1 by default). The 200.0.0.2/24 static route defined at Lager has been injected into RIP with a metric of 3 due to the action of its export policy—this route is installed in Ale's route table with a local cost of 3 + 1, or 4. You'll also see that the RIP global preference in Junos is 100.

A later section details additional operational mode commands that assist in debugging RIP operation. But right now, all seems to be working as expected, so there is not much to debug. Of course, things might change when tying into the Cisco portion of the network.

Confirm RIP: Juniper Networks to Cisco Systems Integration

With RIP operation in the Juniper and Cisco domains confirmed, it's time to fire up RIP between the two vendors' boxes to see what happens. RIP is a simple protocol, so what could go wrong? Things start with the activation of the RIP neighbor (interface) linking Ale to Malt. Similar steps are performed at Lager for its RIP interface to Barley:

```
lab@Ale> configure
Entering configuration mode

[edit]
lab@Ale# activate protocols rip group rip neighbor ge-0/0/0.69

[edit]
lab@Ale# commit
commit complete
```

Confirm route exchange

After a few minutes, RIP updates should have propagated. Let's start with a quick look at RIP statistics at router Lager, as any problems will likely manifest in the form of an incrementing error counter:

```
[edit]
lab@Lager# run show rip statistics
RIPv2 info: port 520; holddown 120s.
    rts learned  rts held down  rqsts dropped  resps dropped
             10              0              0              0

ge-0/0/0.1121:  3 routes learned; 3 routes advertised; timeout 180s;
update interval 30s
Counter                          Total   Last 5 min  Last minute
-------                    -----------  -----------  -----------
Updates Sent                        29           11            2
Triggered Updates Sent               1            0            0
Responses Sent                       0            0            0
Bad Messages                         0            0            0
RIPv1 Updates Received               0            0            0
RIPv1 Bad Route Entries              0            0            0
RIPv1 Updates Ignored                0            0            0
RIPv2 Updates Received              29           10            2
RIPv2 Bad Route Entries              0            0            0
RIPv2 Updates Ignored                0            0            0
Authentication Failures              0            0            0
RIP Requests Received                0            0            0
RIP Requests Ignored                 0            0            0

ge-0/0/0.70:  7 routes learned; 3 routes advertised; timeout 180s;
update interval 30s
Counter                          Total   Last 5 min  Last minute
-------                    -----------  -----------  -----------
Updates Sent                        29           11            2
Triggered Updates Sent               1            0            0
Responses Sent                       0            0            0
Bad Messages                         0            0            0
RIPv1 Updates Received               0            0            0
RIPv1 Bad Route Entries              0            0            0
RIPv1 Updates Ignored                0            0            0
RIPv2 Updates Received              31           11            2
RIPv2 Bad Route Entries              0            0            0
RIPv2 Updates Ignored                0            0            0
Authentication Failures              0            0            0
RIP Requests Received                0            0            0
RIP Requests Ignored                 0            0            0
```

The RIP statistics indicate that all is normal. Lager is confirming that 10 routes have been learned via RIP, with three coming from its link to Ale and the balance learned from its link to Barley. Authentication is clearly working, given the learned routes and no indication of message discards or errors.

Next, confirm whether any RIP routes are present in the route table of Lager:

```
[edit]
lab@Lager# run show route protocol rip

inet.0: 18 destinations, 18 routes (18 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[RIP/100] 00:16:35, metric 2, tag 200
                    > to 192.168.2.1 via ge-0/0/0.70
10.1.254.0/24      *[RIP/100] 00:16:35, metric 2, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
10.1.254.1/32      *[RIP/100] 00:16:35, metric 2, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
10.10.128.100/32    *[RIP/100] 00:16:35, metric 3, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
10.10.128.200/32    *[RIP/100] 00:16:35, metric 2, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
10.10.128.1/32     *[RIP/100] 00:16:29, metric 2, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
192.168.1.0/30     *[RIP/100] 00:16:29, metric 2, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
200.0.1.0/24       *[RIP/100] 00:16:29, metric 4, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
200.0.100.0/24     *[RIP/100] 00:16:35, metric 5, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
200.0.200.0/24     *[RIP/100] 00:11:44, metric 4, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
224.0.0.9/32       *[RIP/100] 00:16:50, metric 1
                      MultiRecv
```

RIP routes are present. The routes learned through RIP include the serial link between Malt and Barley (10.1.254.0/24 and associated host routes), the two simulated customer networks (200.0.100/24 and 200.0.200/24), and the RIP peering network for the link between Malt and Ale (192.168.2.0/30). Also present are the /32 routes for Malt's and Barley's loopback 0 interfaces (10.10.128.100 and 10.10.128.200). The default route is present, and it's correctly pointing to neighbor Barley, given the metric should be less via this path than forwarding through Ale to reach the default advertised by Barley.

The RIP routes at Barley are examined next:

```
Barley# show ip route rip
R    200.0.1.0/24 [120/4] via 10.1.254.1, 00:00:27, Serial0/0
R    200.0.2.0/24 [120/3] via 192.168.2.2, 00:00:25, FastEthernet0/1.70
R    200.0.100.0/24 [120/3] via 10.1.254.1, 00:00:27, Serial0/0
     10.0.0.0/8 is variably subnetted, 7 subnets, 2 masks
R       10.10.128.100/32 [120/1] via 10.1.254.1, 00:00:27, Serial0/0
R       10.10.129.0/24 [120/1] via 192.168.2.2, 00:00:25, FastEthernet0/1.70
R       10.10.128.1/32 [120/2] via 10.1.254.1, 00:00:27, Serial0/0
R       10.10.128.2/32 [120/1] via 192.168.2.2, 00:00:25, FastEthernet0/1.70
     192.168.1.0/30 is subnetted, 1 subnets
R       192.168.1.0 [120/1] via 10.1.254.1, 00:00:27, Serial0/0
```

The display confirms that RIP exchanges are working between the Juniper Networks routers and the Cisco boxes; `Barley` has a RIP route for both of `Ale`'s and `Lager`'s simulated customer networks (200.0.1/24 and 200.0.2/24) as well as the link between `Ale` and `Lager` (10.10.129.0/24), in addition to the /32 loopback addresses assigned to `Ale` and `Lager` (10.10.128.1 and 10.10.128.2).

Confirm forwarding path

A traceroute is performed from `Lager` to the simulated network on `Barley` to validate the data plane and resulting forwarding paths (the `no-resolve` switch ensures that the local router does not waste time trying to perform reverse Domain Name System [DNS] lookups on the resulting IP addresses in the event that DNS is not configured in the lab):

```
[edit]
lab@Ale# run traceroute no-resolve 200.0.200.1
traceroute to 200.0.200.1 (200.0.200.1), 30 hops max, 40 byte packets
 1  192.168.1.1  9.498 ms  9.705 ms  10.127 ms
 2  10.1.254.2  19.700 ms  20.004 ms  20.073 ms
 3  10.1.254.2  19.772 ms !H *  20.392 ms !H
```

The traceroute results are as expected; router `Ale` crossed two routers to reach the simulated customer network, and as previously noted, the `null0` action of the longest match resulted in ICMP host unreachable messages, as indicated by the `!H` in the return. The results seem to indicate that RIPv2 is working between Junos and IOS. Congratulations!

RIP troubleshooting scenario. Actually, nothing in the realm of internetworking works the first time. In fact, the results of that traceroute should have gotten you thinking a bit. Given the RIP topology, `Ale` *should* have two equal cost paths to the simulated customer network attached to `Barley`. After all, it's two hops to reach `Barley` via `Malt`, but also two hops to reach `Barley` via `Lager`. Knowing that Junos automatically performs load balancing over as many as 16 equal cost paths, you'd expect to see `Ale` with two equal cost routes for the 200.0.200/24 route. Unfortunately, previous displays confirm this is not the case. A similar condition exists at `Lager` with regard to the simulated customer route at `Malt`.

There are a few tools for troubleshooting this type of issue in Junos. One approach is protocol tracing, used to show the RIP messages being sent and received, and the overall results of RIP message processing. Tracing is similar to the IOS *debug* feature. Given that RIP is a DV protocol, you can also avail yourself of the `show route advertising-protocol` and the `show route receiving-protocol` commands. As their names imply, these commands display what routes the local router is advertising out a given interface or what routes are being received (learned) from a particular neighbor. The process begins at router `Lager`:

```
[edit]
lab@Lager# run show route advertising-protocol rip ?
Possible completions:
<neighbor>          IP address of neighbor (local for RIP and RIPng)
```

The command syntax help string of ? is useful here because it reminds us that for the RIP form of this command, you must specify the *local interface address*; recall that RIP generates broadcast or multicast updates to all neighbors on the link, so unlike BGP, where a specific neighbor address is specified, it's the local IP address for RIP:

```
[edit]
lab@Lager# run show route advertising-protocol rip 10.10.129.2

inet.0: 18 destinations, 18 routes (18 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.128.2/32     *[Direct/0] 02:31:29
                    > via lo0.0
192.168.2.0/30     *[Direct/0] 02:31:29
                    > via ge-0/0/0.70
200.0.2.0/24       *[Static/5] 02:32:10
                      Discard
```

The result leaves something to be desired—something such as a route advertisement for the 200.0.200/24 route, that is! The `receiving-protocol` form of the command is used to confirm that whatever is wrong is at least symmetrical:

```
lab@Lager# run show route receive-protocol rip ?
Possible completions:
  <peer>               IP address of neighbor
```

Note that for the `receiving-protocol` command, RIP requires the specification of a *specific neighbor IP* address, which in turn is reachable via a RIP-enabled interface (a good way to look at this is to consider that transmitted updates are sent to all neighbors, but received updates come from a specific neighbor—a source IP address is never of the multicast/broadcast form):

```
[edit]
lab@Lager# run show route receive-protocol rip 10.10.129.1

inet.0: 18 destinations, 18 routes (18 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.128.1/32     *[RIP/100] 01:01:13, metric 2, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
192.168.1.0/30     *[RIP/100] 01:01:13, metric 2, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
200.0.1.0/24       *[RIP/100] 01:01:13, metric 4, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
```

The preceding output proves that, like `Lager`, `Ale` is not readvertising the 200.0.100/24 route learned from `Malt`. For added verification, we configure RIP tracing at `Ale`:

```
[edit protocols rip]
lab@Ale# set traceoptions file rip_trace

[edit protocols rip]
lab@Ale# set traceoptions flag ?
Possible completions:
  all                  Trace everything
  auth                  Trace RIP authentication
  error                 Trace RIP errors
  expiration            Trace RIP route expiration processing
  general               Trace general events
  holddown              Trace RIP hold-down processing
  normal                Trace normal events
  nsr-synchronization   Trace NSR synchronization events
  packets               Trace all RIP packets
  policy                Trace policy processing
  request               Trace RIP information packets
  route                 Trace routing information
  state                 Trace state transitions
  task                  Trace routing protocol task processing
  timer                 Trace routing protocol timer processing
  trigger               Trace RIP triggered updates
  update                Trace RIP update packets
[edit protocols rip]
lab@Ale# set traceoptions flag update detail

[edit protocols rip]
lab@Ale# commit
```

No one wants a tool he can't use when he needs it. Junos protocol tracing is much like Cisco Systems' debug in that it's a great way to gain insight into the operation of a given protocol, especially when things are not working. The upside is that you can deploy tracing on a Juniper Networks router, in a production network, with little to no operational impact—that is, the manual does not warn against using tracing, which is the case for debug in IOS. With that said, it is a best practice to enable tracing only when needed and only at the level of detail needed, and then to remove the tracing configuration when the job is done.

Also note that the Juniper Networks architecture cleanly separates the control and forwarding planes, which means that you can monitor interface traffic (tcpdump) or trace protocol operation only when it is sourced from or destined to the local router's Routing Engine (RE). You cannot monitor or trace transit traffic unless a sampling configuration is used to sample/mirror such traffic out of a specific interface.

This example shows the RIP tracing options along with a sample RIP tracing configuration. Here, traffic matching the `update` flag is written to a file called *rip_trace*. Various other trace flags exist and are useful when dealing with specific issues, such as using the `auth` flag when you suspect an authentication problem. The *rip_trace* file is monitored in real time with the `monitor start` command:

```
[edit protocols rip]
lab@Ale# run monitor start rip_trace
. . .
Aug 15 02:00:30.039884 Update job: sending 20 msgs; nbr: ge-0/0/0.1121;
group: rip; msgp: 0x876a000.
Aug 15 02:00:30.039916  nbr ge-0/0/0.1121; msgp 0x876a000.
Aug 15 02:00:30.039985               0.84.1.20/0x46c25e20: tag 3, nh
0.0.0.0, met 0.
Aug 15 02:00:30.040011             10.10.128.1/0xffffffff: tag 0, nh
0.0.0.0, met 1.
Aug 15 02:00:30.040027             192.168.1.0/0xfffffffc: tag 0, nh
0.0.0.0, met 1.
Aug 15 02:00:30.040041               200.0.1.0/0xffffff00: tag 0, nh
0.0.0.0, met 3.
Aug 15 02:00:30.040053         sending msg 0x876a004, 4 rtes
(needs MD5)
Aug 15 02:00:30.040691 Update job done for nbr ge-0/0/0.1121
group: rip
Aug 15 02:00:32.560426 received response: sender 10.10.129.2,
command 2, version 2, mbz: 0; 5 routes.
Aug 15 02:00:32.560579      10.10.128.2/0xffffffff: tag 0, nh
0.0.0.0, met 1.
Aug 15 02:00:32.560645      192.168.2.0/0xfffffffc: tag 0, nh
0.0.0.0, met 1.
Aug 15 02:00:32.560694        200.0.2.0/0xffffff00: tag 0, nh
0.0.0.0, met 3.

*** monitor and syslog output disabled, press ESC-Q to enable ***
```

You can enter the Esc-q (or Ctrl-s) sequence to suspend trace output to the screen while information is still being written to the trace field. Pressing Esc-q again (or Ctrl-r) resumes output to the screen. It's nice to be able to enable tracing and suspend it on demand so that you can read what has been painted to the screen, without having to type something such as "undebug IP rip," all while your screen is overflowing with debug data. Use the `monitor stop` command to stop tailing the logfile. The `monitor list` command shows any logfiles that are being monitored.

The RIP tracing information relating to neighbor `ge-0/0/0.1121` confirms the results of the `show route-advertising protocol` command; namely that `Lager` is not readvertising routes that it learns via RIP to other RIP neighbors. Having seen what there is to be seen, RIP tracing is diligently removed:

```
[edit protocols rip]
lab@Ale# delete traceoptions
[edit protocols rip]
lab@Ale# commit
commit complete
```

The Problem

Think back to your knowledge of Junos routing policy; you'll recall that an export policy is the entity responsible for taking *active* routes from the route table and placing them into outgoing protocol updates. Because the problem route is in the route table, is active, and is confirmed as not being advertised to another RIP neighbor, it would seem to be a classic case of broken export policy. But why is our export broken?

In Junos, all protocols have a default import and export policy. The default import policy for RIP is to accept all (sane) RIP routes, as you might expect. However, the default RIP export policy is to *advertise nothing*; not even routes learned through RIP! Put another way, and for whatever reason, the configuration of RIP in Junos is not a simple matter of `router rip` combined with a few `network` statements. You will almost always want the RIP router to propagate routes learned via RIP; to do this you will need to add explicit export policy.

You already have a RIP export policy in effect to advertise the direct (connected) and the simulated customer static routes. Therefore, a quick modification will put things right again in RIP land:

```
[edit policy-options policy-statement rip_export]
lab@Ale# show
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.1.0/24 exact;
    }
    then {
        metric 3;
        accept;
    }
}

[edit policy-options policy-statement rip_export]
lab@Ale# set term 3 from protocol rip

[edit policy-options policy-statement rip_export]
lab@Ale# set term 3 then accept


[edit policy-options policy-statement rip_export]
lab@Ale# show
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.1.0/24 exact;
    }
    then {
        metric 3;
        accept;
    }
}
```

```
    term 3 {
        from protocol rip;
        then accept;
    }
```

A similar change is also made (and committed) to the export policy at Lager. After a few minutes, the results are confirmed:

```
[edit]
lab@Lager# run show route receive-protocol rip 10.10.129.1

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.1.254.2/32      *[RIP/100] 00:01:22, metric 3, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
10.10.128.100/32    *[RIP/100] 01:31:13, metric 3, tag 0
                      to 192.168.2.1 via ge-0/0/0.70
                    > to 10.10.129.1 via ge-0/0/0.1121
10.10.128.1/32     *[RIP/100] 01:31:07, metric 2, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
192.168.1.0/30     *[RIP/100] 01:31:07, metric 2, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
200.0.1.0/24       *[RIP/100] 01:31:07, metric 4, tag 0
                    > to 10.10.129.1 via ge-0/0/0.1121
200.0.100.0/24     *[RIP/100] 01:31:13, metric 5, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
                      to 10.10.129.1 via ge-0/0/0.1121

_  _juniper_private1_  _.inet.0: 2 destinations, 2 routes (2 active,
0 holddown, 0 hidden)
```

The `show route-receiving protocol rip` command at Lager confirms that Ale is now correctly readvertising RIP routes learned from Malt. You can also see the effects of the modified export policy in the `show route-advertising protocol rip` command issued at Lager:

```
[edit]
lab@Lager# run show route advertising-protocol rip 10.10.129.2

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[RIP/100] 01:31:24, metric 2, tag 200
                    > to 192.168.2.1 via ge-0/0/0.70
10.1.254.0/24      *[RIP/100] 01:31:24, metric 2, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
10.1.254.1/32      *[RIP/100] 01:31:24, metric 2, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
10.10.128.200/32    *[RIP/100] 01:31:24, metric 2, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
10.10.128.2/32     *[Direct/0] 03:05:21
                    > via lo0.0
192.168.2.0/30     *[Direct/0] 03:05:21
                    > via ge-0/0/0.70
```

```
200.0.2.0/24       *[Static/5] 03:06:02
                      Discard
200.0.200.0/24     *[RIP/100] 01:26:33, metric 4, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
```

Lager's output confirms that it too is now readvertising RIP learned routes. As a final verification, the route table at Lager is inspected for the customer network associated with Malt:

```
[edit]
lab@Lager# run show route 200.0.100.0

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.100.0/24     *[RIP/100] 01:33:57, metric 5, tag 0
                    > to 192.168.2.1 via ge-0/0/0.70
                      to 10.10.129.1 via ge-0/0/0.1121
```

The route's presence with two forwarding next hops confirms the earlier suspicion that there should be multiple equal cost paths for some RIP destinations in this lab topology. From Lager's there are now two equal cost paths to 200.0.100/24—one via Barley and the other through Ale.

RIP Deployment Summary

RIP really is a simple protocol, and configuring Junos to interoperate with IOS for RIP was, for the most part, pretty straightforward. The most common problem you'll encounter with this scenario is unfamiliarity with the default RIP export policy, which is not intuitive, to say the least. This section demonstrated basic RIP configuration and operational mode commands that assist in troubleshooting RIP operation in a Junos environment.

The next section addresses ways to migrate a network from one IGP to another, a concept called *IGP migration*. Once again, now is an opportune time to take a break before moving on.

IGP Migration

This section examines current best practices for IGP migration, referring to the exchange of a network's existing, or legacy, IGP with a different version of IGP. Generally, the overall goals are to minimize network disruption while also taking the opportunity to improve on the network's design and operation. The IGP plays a critical role in the operation of any IP network. Upgrading a legacy network's IGP can result in dramatic performance improvements and new service capabilities, and can align a company with an open standards-based solution, which in turn facilitates a best-of-breed decision among networking boxes.

IGP migration is an excellent time to clean house, so to speak, by reevaluating all aspects of the current network's design. Some factors to consider include:

- The potential for readdressing to better accommodate hierarchical design and route summarization
- The number and types of routers needed
- How those routers interconnect (WAN/LAN technologies may have evolved since the original network deployment)
- Ways to improve reliability

The need to maintain high network availability may preclude significant redesign. Usually a compromise must be reached between the need for availability versus potential optimizations, based on the specifics unique to each enterprise. In some cases, a new backbone is deployed in parallel (the integration model), which affords the luxury of complete redesign at the cost of additional gear.

IGP Migration: Common Techniques and Concerns

Before discussing specific migration approaches, it makes sense to examine some of the issues and considerations common to all approaches. General factors and concepts applying to IGP migrations include the following:

Global route preference

IGP transitions often touch on the concept of *global route preference*, which is known as *administrative distance* in IOS. A route's global preference indicates the overall *goodness* of a source of routing information and is used to break ties when two or more protocols announce reachability to the same prefix. Recall that longest match always rules; therefore, a longest-matching RIP route will always be preferred over a less specific version (a shorter netmask) that is learned from a more preferred protocol. For example, a /24 OSPF internal route will lose to a /32 RIP route every day of the week despite its much lower, and therefore preferred, preference. Global preference breaks ties *only* when routes with the *same level of specificity* are learned by multiple routing protocols.

Route redistribution

Route redistribution is the act of exchanging route information among different routing protocols and is a common aspect of most IGP migration strategies. In many cases, you will not configure all routers for the new IGP at the same time and will maintain connectivity between IGP domains by redistributing routes between the new and legacy IGPs at select routers. Because this will typically be mutual, also known as bidirectional route redistribution, you must remain ever-vigilant or else fall victim to the effects of routing loops. Accurate policy is needed to ensure that routes originating within IGP A that are sent into IGP B are never redistributed back into IGP A, and vice versa.

Concurrent IGP operation

Many migration scenarios will require that a device be configured to run instances of both the old and the new IGPs at the same time. The first issue here is whether the device offers support for both protocols. For example, running EIGRP on a Juniper Networks router is simply not an option. Then there are matters of performance—can the device be expected to run two instances of an IGP and still operate reliably? There are numerous cases of IGP migration (ones that were planned to occur with little or no disruption, we might add) that instead melted down when a box started rebooting or peers start flapping, all because of insufficient memory or CPU power when tasked with running both IGPs concurrently. This is something that is often not considered when testing a migration scenario in a lab, where boxes may be running at far lower memory and CPU levels than they would in the production environment.

As a general rule, you can safely run both IGPs concurrently if an existing device's CPU load is less than 50% while its memory load is less than 60%. If the device's CPU or memory load is higher, you should consider a device upgrade or a migration approach that does not place both IGPs in service at the same time.

Network cleanup and design

IGP migration is an opportune time to rid your network of excess baggage and poor design characteristics that may have evolved in an ad hoc fashion over the years. Before migration, you should make sure your network documentation is accurate and that you have reduced as much clutter as possible by removing any unauthorized or unneeded addresses, networks, peers, protocols, and so forth. Careful thought should be leveled at the design of the new IGP. Will it be flat or hierarchical? Does the existing addressing model accommodate? How will metrics be mapped between the old and new IGPs? Where will you place ABRs and ASBRs, and which routers should function as the DRs on LAN segments?

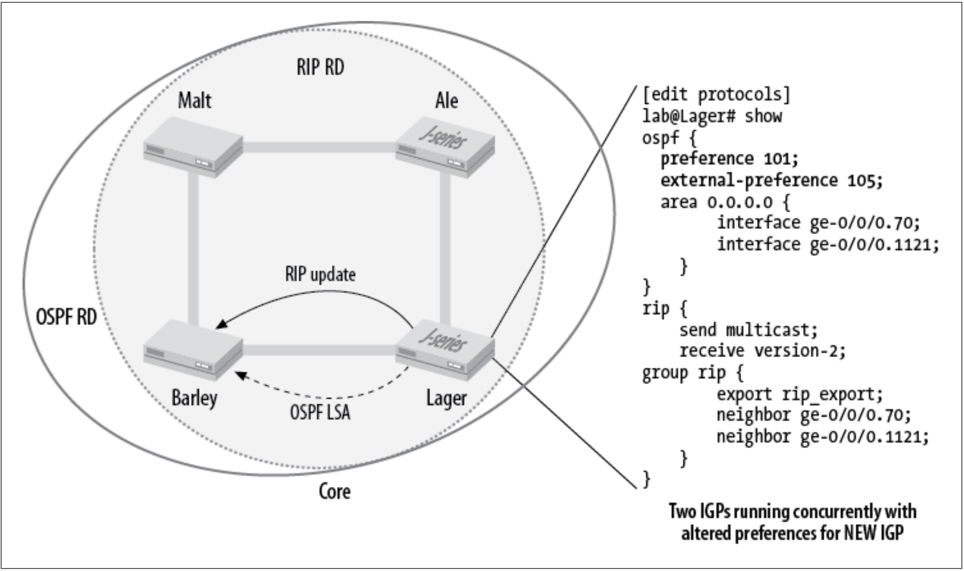
IGP Migration Models

Several proven approaches to IGP transitions have been developed over the years, and most of these approaches share common elements to one degree or another. Each enterprise network is unique, and the specifics of your network design, your standards for acceptable levels of disruption, and your budget will come into play when deciding on a specific approach. The migration strategies are presented in an order representing easiest to most difficult. The more difficult strategies are often combined with a more extensive network redesign given the work already being performed.

The Overlay Model

The overlay model is generally considered the most straightforward IGP migration approach. The overlay is best suited to networks that have a similar *before and after* logical topology. For example, if the legacy network is a flat RIP network and the proposed design is a single area OSPF network, logically both networks are flat and IGP migration will be straightforward. Using an overlay approach to move from a flat to a hierarchical network can be rife with difficulties. For example, a flat network's addressing scheme may not accommodate a sound hierarchical design, and the placement of nodes may not accommodate the desired location or level of redundancy for things such as ABRs.

Figure 6-4 illustrates a network running both the legacy (RIP) and the new (OSPF) IGPs. Because Layer 2 switching is often used in the access and aggregation layers, the focus of most IGP migrations is centered on the core layer—the techniques demonstrated here are applicable for access and aggregation layer migrations as well. Note how both IGPs are configured at the same time, that the new IGP is initially set to be less preferred (both OSPF preference values are larger than RIP's default 100), and that each router sends updates for both IGPs in a ships-in-the-night fashion, meaning that neither IGP is aware of the other's operation.



```
[edit protocols]
lab@Lager# show
ospf {
  preference 101;
  external-preference 105;
  area 0.0.0.0 {
        interface ge-0/0/0.70;
        interface ge-0/0/0.1121;
    }
}
rip {
    send multicast;
    receive version-2;
group rip {
        export rip_export;
        neighbor ge-0/0/0.70;
        neighbor ge-0/0/0.1121;
    }
}
```

Figure 6-4. The overlay model

The overlay model hinges on all devices having the ability to run both the old and the new IGPs concurrently, and it makes heavy use of route preference to keep the new IGP's routes from becoming active, and therefore installed in the forwarding table, until all aspects of the new IGP's operation are determined to be satisfactory. When ready to make the cutover, the route preference is altered to have the routers prefer the new IGP's routes. Ideally, this is all done in parallel, because having some devices use one IGP's routes while other routers use a different IGP's routes can lead to loops stemming from variances between each protocol's take on the best route. In many cases, the odds of which can be improved by the careful mapping of old to new metrics, the forwarding paths of both protocols will be identical and you can get away with an incremental, box-at-a-time shift in protocol preference. When the new IGP's operation is deemed stable, the old IGP is decommissioned by removing its configuration from each router (there is no need to perform this in parallel, as you are now using the new IGP). It's a good idea to keep a copy of the old configuration around, and you should consider using the `deactivate` function of the Junos CLI to comment out the old IGP's stanza, all the while knowing that you can safely bring it back at any time by activating that portion of the configuration.

The Redistribution Model

The redistribution model is often used when an overlay approach is not workable because of a migration from a flat to a hierarchical design or because some of the devices cannot run both IGPs concurrently. The latter condition may be due to lack of device support or because of performance limitations. Figure 6-5 illustrates a before-and-after view of a network that, given the shift to a hierarchical design, represents a good candidate for the route redistribution model.

The first phase of the migration from RIP to OSPF is shown in Figure 6-6. Here, backbone routers `Ale` and `Lager` are configured to run both RIP and OSPF concurrently, with the OSPF backbone being formed as a result. The arrow shows a RIP update sent by `Malt` and received by `Ale`, where it will be injected into the nascent backbone as a Type 5 AS external LSA. Though not shown, routes originating in the OSPF backbone undergo a similar process whereby they are injected into the RIP domain to maintain full connectivity. It is critical to stress that controls must be in place to ensure that routes are never redistributed back into the RD from where they originated, unless your goal is a network-wide test of the IP Time to Live (TTL) mechanism. A well-planned addressing approach always makes the filtering of route updates easier, as does a consistent approach to route tagging (where supported by the protocol). The use of route tags makes control over route redistribution much easier to configure and consequently far less prone to human error.

Once again, the OSPF preference is altered to be *less preferred* than that of the original IGP, as was the case in the overlay model. The default global preference for Junos is 100 for RIP and 10/150 for OSPF internal and AS external, respectively. Setting these preferences to 101/110 achieves the goal of ensuring that RIP is preferred. This step ensures that the backbone will always prefer routes in their native RIP form, thus avoiding routing loops and suboptimal routing. By way of example, consider that without this step, router `Barley`'s 200.0.200/24 route might be initially learned by `Lager` as an OSPF route, via a RIP update that was generated by `Malt` and then redistributed into OSPF by `Ale`. By this time, Lager should have also received a RIP update for the same prefix direct from `Barley`. If the preferences are such that `Lager` prefers OSPF externals over RIP, we would have an extra hop as `Lager` forwards packets for 200.0.200/24 route over the OSPF backbone through `Ale`, rather than the direct shot via `Barley`.

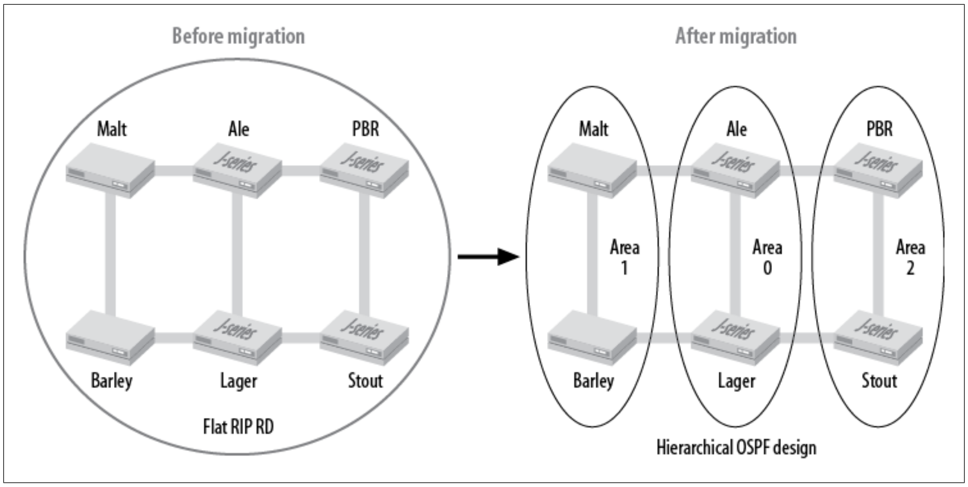


Figure 6-5. The redistribution model

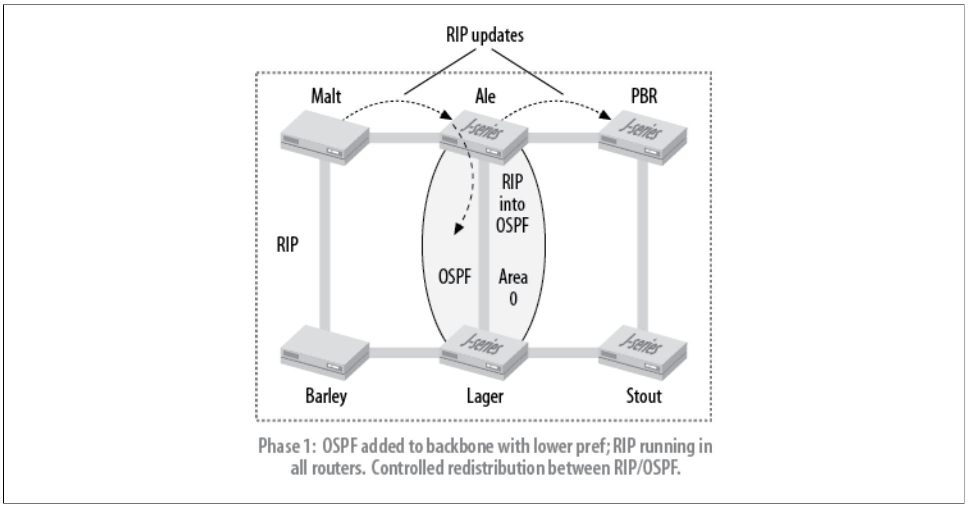

RIP updates
Malt
Ale
PBR
RIP
RIP into OSPF
OSPF
Area 0
Barley
Lager
Stout
Phase 1: OSPF added to backbone with lower pref; RIP running in all routers. Controlled redistribution between RIP/OSPF.

Figure 6-6. Route tagging in the redistribution model to control route exchange

In this example, the default Junos route preferences would have resulted in the desired behavior. When redistributed into OSPF, the RIP routes take the form of AS externals, which by default have a preference of 150, which makes them less preferred than RIP anyway. Nonetheless, it's recommended that you always explicitly set preferences. It's rarely a good idea to leave such things to chance in your network!

The next phase of the migration is depicted in Figure 6-7, where routers PBR and Stout have been converted to OSPF and placed into Area 2. The specific approach taken to make this change could have been that of an overlay, where the routers run RIP and OSPF concurrently, or as a hot cutover that removed the old and added the new IGP in one fell swoop. Such cutovers are made a little less stressful with the "nothing happens until you commit" nature of Junos OS. IOS users would likely paste such changes in from a configuration file to try to minimize disruption. It ends with routers Barley and Malt remaining in the RIP domain along with the associated interfaces on Ale and Lager. The next phase of the migration is an iterative process that repeats the same procedure on Barley and Malt to create Area 1. The IGP migration is completed with removal of any RIP remnants from the configurations of Area 0 routers Ale and Lager.

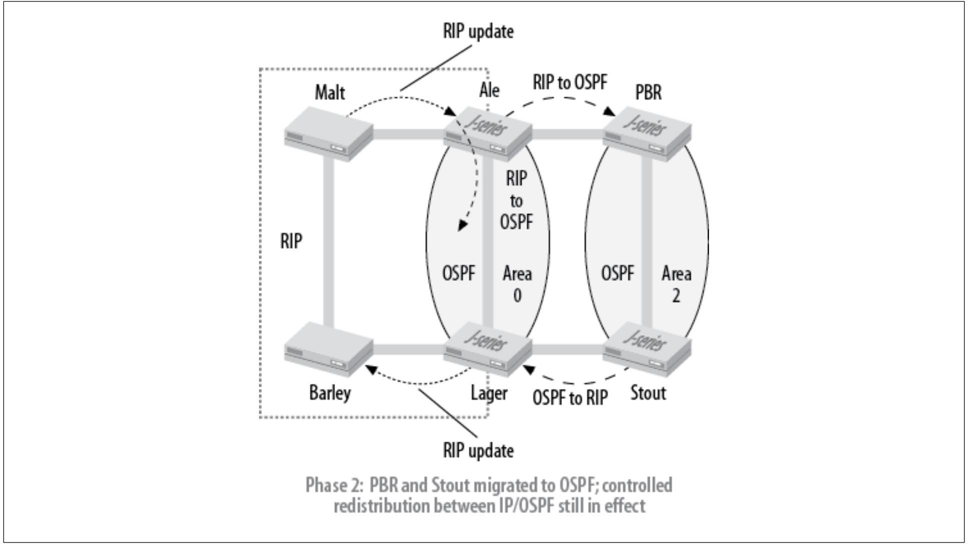

RIP update
Malt
Ale
RIP to OSPF
PBR
RIP
to
OSPF
RIP
OSPF
Area
0
OSPF
Area
2
Barley
Lager
OSPF to RIP
Stout
RIP update
Phase 2: PBR and Stout migrated to OSPF; controlled redistribution between IP/OSPF still in effect

Figure 6-7. Route redistribution IGP migration: Phase 2

The Integration Model

The integration model is also well suited to IGP migrations that transition from a flat to a hierarchical design, especially when a significant IP readdressing and/or network infrastructure upgrade is planned as part of the migration. In the integration model, a new backbone network is deployed and tied to the legacy backbone, where mutual route redistribution is performed. Portions of the legacy network are transitioned to the new backbone in a phased manner. This type of migration is not hitless, but it does afford a near green-field chance to redesign your IGP while confining down time to those segments that are actively being transitioned. Once all segments have been migrated to the new backbone, the legacy backbone is decommissioned. This process is shown in Figure 6-8, which begins with the legacy backbone and moves on to the buildout of a new backbone and the migration of one network segment. The process

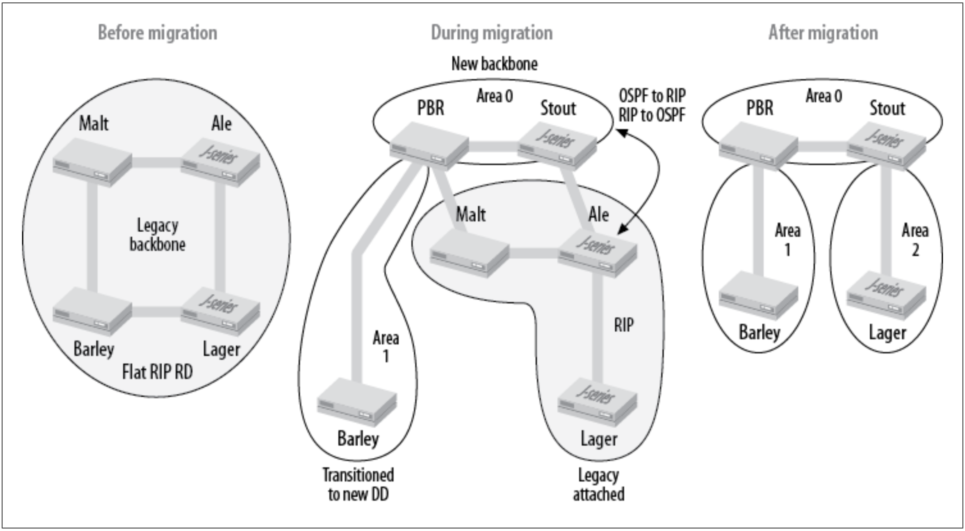


Figure 6-8. The integration model

ends with the rightmost diagram showing all network segments transitioned to the new backbone and removal of the legacy backbone infrastructure.

You'll again find mutual route redistribution at play, and also this requires strict control to prevent routes from being sent back to their originating IGP. As each network segment is transitioned, you may be able to deploy an overlay approach or you might be forced into a hot cutover based on equipment capability and the level of network redesign (e.g., any renumbering that is also planned).

It goes without saying, but we will state it here anyway, that the integration model represents the largest degree of effort and capital expenditure. There is the cost of new equipment and new backbone buildout, and then the sustaining costs of both the legacy and new backbones as segments are transitioned. During these transitions, there may be significant renumbering and a need to deploy the new backbone protocol on routers as they become part of the new IGP.

IGP Migration Summary

Networks, like people, evolve and change over time. Many networks are still running yesterday's IGP and could benefit from a facelift in the interior routing department. Or maybe your network is running some proprietary routing protocol and you have decided that it is time to add another vendor to the network, for whatever reason. Either way, the techniques and concepts discussed here can help to minimize disruption and make the shift to a new IGP as pain-free as possible.

In the next section, you will put this theory into practice as you migrate a network from RIP to the OSPF protocol.

Overlay Migration Scenario: RIP to OSPF

Just when you are considering some well-deserved time off, given the success of the recently deployed RIPv2 internetwork, you receive notification from the new CIO that the Beer-Co network must migrate to OSPF as part of a modernization initiative. Beer-Co has conducted a design review and determined that a single OSPF area with the ability to expand to a hierarchical design in the near future is required.

Considering the migration methods described in the previous section and the current design criteria, you propose an overlay-based migration. The reasons for this recommendation include the following:

- Both the legacy and planned networks are flat.
- Both the legacy Cisco and new Juniper Networks gear support the legacy and new IGPs.
- It's the most direct migration strategy, and you are still smarting from tilting at RIP.

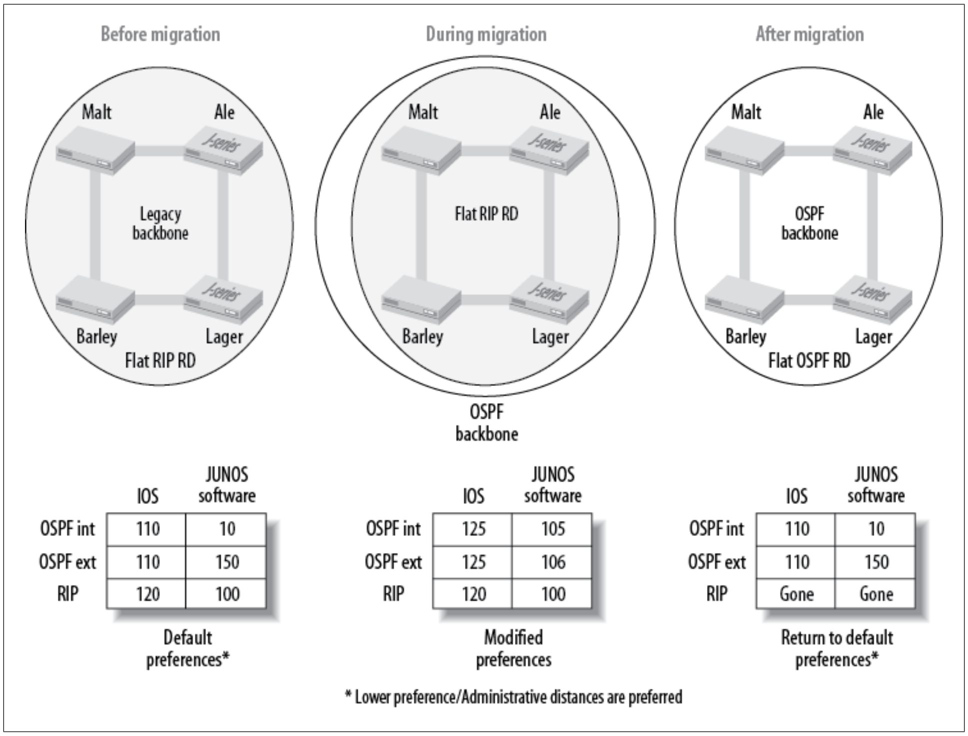
Figure 6-9 shows the before, during, and after networks. In the middle, both IGPs are running, but altered preferences ensure that RIP routes remain active, which provides you the chance to verify all aspects of OSPF *before* its routes become active. The key to the overlay model is altered protocol preferences, and the figure also shows the beginning, initial modification, and final preference values for RIP and OSPF internal/external routes.

The critical point occurs before OSPF is activated (especially in IOS, where changes take effect immediately as they are entered). Both the internal and external preferences are set so that RIP remains unperturbed until you are ready to retire it. Failing to ensure that OSPF external preference is set lower (is more preferred) than RIP leads to a Frankenstein-like forwarding model that has the simulated customer networks and redistributed loopback routes forwarding over OSPF paths while the internal routes continue to forward via RIP.

The Juniper boxes are configured first (recall that, until you commit, no change takes effect, so you have a safety net of rollback or commit confirmed in case you do not like the results). The OSPF stanza is displayed at `Ale` along with the associated `set` commands using the CLI's `show | display set` command. The authentication key value `jncie` is reused here. Also of note are the altered preference values for OSPF internal and external routes—that authentication is configured at the area level while the specifics are set on a per-interface basis:

```
[edit protocols ospf]
lab@Ale# show
preference 105;
external-preference 106;
export ospf_export; ## 'ospf_export' is not defined
area 0.0.0.0 {
    authentication-type md5;
    interface ge-0/0/0.69 {
        authentication {
            md5 1 key "$9$Yb4JD3nCuOI.PF/"; ## SECRET-DATA
        }
    }
    interface ge-0/0/0.1121 {
        authentication {
            md5 1 key "$9$WitXNbiHmTQn4ajq"; ## SECRET-DATA
        }
    }
}

[edit protocols ospf]
lab@Ale# show | display set
set protocols ospf preference 105
set protocols ospf external-preference 106
set protocols ospf export ospf_export
set protocols ospf area 0.0.0.0 authentication-type md5
set protocols ospf area 0.0.0.0 interface ge-0/0/0.69 authentication
md5 1 key "$9$Yb4JD3nCuOI.PF/"
set protocols ospf area 0.0.0.0 interface ge-0/0/0.1121 authentication
md5 1 key "$9$WitXNbiHmTQn4ajq"
```



	IOS	JUNOS software
OSPF int	110	10
OSPF ext	110	150
RIP	120	100

	IOS	JUNOS software
OSPF int	125	105
OSPF ext	125	106
RIP	120	100

	IOS	JUNOS software
OSPF int	110	10
OSPF ext	110	150
RIP	Gone	Gone

Figure 6-9. RIP-to-OSPF overlay topology

Like RIP, OSPF requires an export policy for route redistribution, and the CLI's copy feature is evoked to save some effort:

```
[edit protocols ospf]
lab@Ale# top edit policy-options

[edit policy-options]
lab@Ale# copy policy-statement rip_export to policy-statementospf_export

[edit policy-options]
lab@Ale# edit policy-statement ospf_export

[edit policy-options policy-statement ospf_export]
lab@Ale# show
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.1.0/24 exact;
    }
    then {
        metric 3;
        accept;
    }
}
term 3 {
    from protocol rip;
    then accept;
}
```

Looking over the copy of the RIP policy, now in its renamed `ospf_export` form, it seems that the only term that is out of place is `term 3` and the bit about matching RIP. You certainly do not want any RIP-to-OSPF redistribution in this example! We remove `term 3` (committing the changes) and make similar changes to `Lager`:

```
[edit policy-options policy-statement ospf_export]
lab@Ale# delete term 3
```

After a few moments, the OSPF adjacency status is confirmed between `Ale` and `Lager`. Recall that `Malt` and `Barley` have not been configured with OSPF at this time:

```
[edit]
lab@Ale# run show ospf interface
Interface           State     Area        DR ID          BDR ID        Nbrs
ge-0/0/0.1121       DR        0.0.0.0     10.10.128.1    10.10.128.2      1
ge-0/0/0.69         DR        0.0.0.0     10.10.128.1    0.0.0.0          0
```

The output from the `show ospf interface` command confirms that OSPF is running on the desired interfaces and that local router `Ale` has won the DR election on both of its interfaces. Considering that `Ale` is alone (zero neighbors have been detected) on its `ge-0/0/0.69` interface, its DR status on that segment should be no surprise. You can also verify the area 0 setting and that the only other router on the `fe0-0/0/0.1121` link has delegated itself to be the backup DR. Remember that priority and RID factor only during an active election. Given the matched priority and `Ale`'s lower RID (its `lo0` address is lower than Lager's), this must be a case of Ale having been configured for OSPF first. The first non-0 priority router up always becomes the DR:

```
[edit]
lab@Ale# run show ospf neighbor
  Address          Interface          State      ID            Pri  Dead
10.10.129.2      ge-0/0/0.1121      Full      10.10.128.2    128    38
```

The show ospf neighbor command verifies that a full adjacency has been formed between Ale and Lager, which is a very good sign indeed:

```
[edit]
lab@Ale# run show route protocol ospf

inet.0: 19 destinations, 22 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.128.2/32      [OSPF/105] 00:01:03, metric 1
                    > to 10.10.129.2 via ge-0/0/0.1121
192.168.2.0/30      [OSPF/105] 00:01:03, metric 2
                    > to 10.10.129.2 via ge-0/0/0.1121
200.0.2.0/24        [OSPF/106] 00:01:03, metric 3, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
224.0.0.5/32       *[OSPF/10] 00:07:52, metric 1
                      MultiRecv
```

Showing the routes learned via OSPF confirms several important points. One is simply that routes are being learned via OSPF (Lager's 10.10.126.2 loopback and the 192.168.2.0 link to Barley), and equally significant is that none of these learned OSPF route are currently active.

Unlike IOS, which requires that you run OSPF on the loopback interface to advertise its associated route, Junos automatically advertises a stub route to the *default* address used as the source of the RID, assuming that a RID has not been explicitly set under [routing-options]. Because the lo0 interface is the first to be activated, the lo0 interface's *primary* address is used as the RID. In contrast, for IOS it is common to either run a passive OSPF instance on the loopback interface or to redistribute the connected router into OSPF, as shown in the following example.

A final confirmation that our route preference changes are working comes when we display the route to Lager's customer network at Ale:

```
[edit]
lab@Ale# run show route 200.0.2.0

inet.0: 19 destinations, 22 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.2.0/24       *[RIP/100] 02:47:22, metric 4, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
```

```
                         [OSPF/106] 00:09:29, metric 3, tag 0
                         > to 10.10.129.2 via ge-0/0/0.1121
```

Perfect! Ale has both OSPF and RIP copies of the customer route. The key thing here is that the original RIP version is, and has always been, active. Unlike RIP, the displayed OSPF route metric does not reflect Ale's interface costs to reach Lager. With the default scaling factor of 100,000,000, the cost for Ale's Fast Ethernet interface is 1 (you can confirm this with a **show ospf interface detail** command), so you might expect to see Ale display a cost of 4 for the 200.0.0.2/24 prefix. The reason for this situation is that the OSPF_export policy at Lager did not bother to specify a Type 1 external metric, so the default Type 2 metric is generated, and by OSPF standards this metric is never incremented by other routers. A sample of a policy modification that alters the metric type is provided, along with the results observed back at Ale. These changes are then rolled back to restore the initial behavior:

```
[edit policy-options policy-statement ospf_export]
lab@Lager# show
term 1 {
    from protocol direct;
    then accept;
}
term 2 {
    from {
        protocol static;
        route-filter 200.0.2.0/24 exact;
    }
    then {
        metric 3;
        external {
            type 1;
        }
        accept;
    }
}
[edit]
lab@Ale# run show route 200.0.2.0

inet.0: 19 destinations, 22 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.2.0/24       *[RIP/100] 03:03:06, metric 4, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
                    [OSPF/106] 00:02:35, metric 4, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
```

With the OSPF overlay working on the Juniper Networks portion of the network, we place the equivalent configuration into effect at the Cisco boxes. It is critical that the modified OSPF preference (setting both the internal and external to a distance higher than RIP's) be the first thing configured to help ensure that RIP is not impacted—in IOS land, changes go into effect as soon as they are entered. By default, IOS assigns the same administrative distance to OSPF internals and externals (and interarea, for that matter), so we should adopt the same approach—as long as the distance for all OSPF routes is less preferred than RIP, it will be OK. The commands entered on `Malt` are shown. Similar commands are also entered on `Barley`:

```
Malt# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Malt(config)# router ospf 10
Malt(config-router)# distance 125
Malt(config-router)# area 0 authentication message-digest
Malt(config-router)# redistribute static route-map TAGGING
% Only classful networks will be redistributed
Malt(config-router)# network 10.0.0.0 0.255.255.255 area 0
Malt(config-router)# network 192.168.2.0 0.0.0.3 area 0
Malt(config-router)# default-information originate route-map FOO
Malt(config-router)# exit
Malt(config)# interface fastEthernet 0/1.69
Malt(config-subif)# ip ospf message-digest-key 1 md5 jncie
Malt(config-router)# exit
Malt(config)# interface serial 0/0
Malt(config-subif)# ip ospf message-digest-key 1 md5 jncie
Malt(config)# route-map FOO permit 20
Malt(config-route-map)# match ip address 4
Malt(config-route-map)# set tag 100
Malt(config-subif)# ^Z
Malt#
*Mar  1 04:01:28.603: %SYS-5-CONFIG_I: Configured from console by
console
*Mar  1 04:01:30.495: %OSPF-5-ADJCHG: Process 10, Nbr 10.10.128.1 on FastEthernet0/
1.69 from LOADING to FULL, Loading Done
```

The resultant OSPF portion of the configuration is shown next, along with the new route map. Note the log message in the previous capture reporting an up adjacency on `Malt`'s `fa 0/1.69` interface. This is a good indication that we have compatible OSPF settings between the Cisco and Juniper routers:

```
router ospf 10
 log-adjacency-changes
 area 0 authentication message-digest
 redistribute static route-map TAGGING
 network 10.0.0.0 0.255.255.255 area 0
 network 192.168.2.0 0.0.0.3 area 0
 default-information originate route-map FOO
 distance 125
!
. . .
route-map FOO permit 20
 match ip address 4
 set tag 100
!
```

The configuration creates an OSPF instance identified as 10, enables MD5 authentication in area 0, redistributes and route-maps the same routes used in the RIP example, and enables OSPF area 0 in the serial `0/0` and `fa 0/1.60` interfaces. Note that in the IOS implementation, OSPF will not redistribute a default static route. You must use the `default-information originate` command instead. Using the preexisting `TAGGING` route map did not work, so a new route map named FOO was created. It's things such as this that make you appreciate the consistent nature of Junos routing policy.

In an approach that is similar to Junos OSPF configuration, the specific MD5 key ID and key value are set under each interface. The difference is that for Junos, this was done within the OSPF configuration proper, whereas for IOS, it is under the interface configuration. The OSPF authentication settings are also shown for one of Malt's interfaces:

```
interface FastEthernet0/1
 no ip address
 duplex auto
 speed auto
!
interface FastEthernet0/1.69
 encapsulation dot1Q 69
 ip address 192.168.1.1 255.255.255.252
 ip rip authentication mode md5
 ip rip authentication key-chain test
 ip ospf message-digest-key 1 md5 jncie
 no snmp trap link-status
!
```

After a few moments, the OSPF status is analyzed on Malt:

```
Malt# show ip ospf interface fastEthernet 0/1.69
FastEthernet0/1.69 is up, line protocol is up
  Internet Address 192.168.1.1/30, Area 0
  Process ID 10, Router ID 10.10.128.100, Network Type BROADCAST,
Cost: 1
  Transmit Delay is 1 sec, State BDR, Priority 1
  Designated Router (ID) 10.10.128.1, Interface address 192.168.1.2
  Backup Designated router (ID) 10.10.128.100, Interface address
192.168.1.1
  Timer intervals configured, Hello 10, Dead 40, Wait 40,
Retransmit 5
    oob-resync timeout 40
    Hello due in 00:00:05
  Index 3/3, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 1, maximum is 1
  Last flood scan time is 0 msec, maximum is 4 msec
  Neighbor Count is 1, Adjacent neighbor count is 1
    Adjacent with neighbor 10.10.128.1  (Designated Router)
  Suppress hello for 0 neighbor(s)
  Message digest authentication enabled
    Youngest key id is 1
```

The show ip ospf interface command for Malt's fa 0/1.69 verifies the presence of a neighbor with RID 10.10.128.1 (Ale's loopback address/RID) and confirms the authentication and timer settings that are in effect. As expected, Ale remains the DR because in OSPF, this DR election is not revertive:

```
Malt# show ip ospf neighbor
Neighbor ID     Pri   State      Dead Time   Address      Interface
```

```
10.10.128.1     128   FULL/DR    00:00:38    192.168.1.2 FastEthernet0/1.69
10.10.128.200     0   FULL/  -   00:00:36    10.1.254.2  Serial0/0
```

The `show ip ospf neighbor` command confirms the expected adjacencies to both `Barley` and `Ale`. We next display a simulated customer route to confirm that the RIP copy is still being used at the Cisco boxes:

```
Malt# show ip route 200.0.2.0
Routing entry for 200.0.2.0/24
  Known via "rip", distance 120, metric 4
  Redistributing via rip
  Last update from 10.1.254.2 on Serial0/0, 00:00:03 ago
  Routing Descriptor Blocks:
  * 10.1.254.2, from 10.1.254.2, 00:00:03 ago, via Serial0/0
      Route metric is 4, traffic share count is 1
    192.168.1.2, from 192.168.1.2, 00:00:14 ago, via FastEthernet0/1.69
      Route metric is 4, traffic share count is 1
```

The output confirms that the RIP version of the route is still active. Unfortunately, IOS displays *only* the active route, making it hard to confirm that OSPF shadow versions also exist. The LSDB is inspected to make this determination:

```
Malt# show ip ospf database external adv-router 10.10.128.2

            OSPF Router with ID (192.168.1.1) (Process ID 120)

            OSPF Router with ID (10.10.128.100) (Process ID 10)

                Type-5 AS External Link States

  LS age: 97
  Options: (No TOS-capability, DC)
  LS Type: AS External Link
  Link State ID: 10.10.128.2 (External Network Number )
  Advertising Router: 10.10.128.2
  LS Seq Number: 80000006
  Checksum: 0x2858
  Length: 36
  Network Mask: /32
        Metric Type: 2 (Larger than any link state path)
        TOS: 0
        Metric: 0
        Forward Address: 0.0.0.0
        External Route Tag: 0

  Routing Bit Set on this LSA
  LS age: 397
  Options: (No TOS-capability, DC)
  LS Type: AS External Link
  Link State ID: 200.0.2.0 (External Network Number )
  Advertising Router: 10.10.128.2
  LS Seq Number: 80000006
  Checksum: 0x92B6
  Length: 36
  Network Mask: /24
        Metric Type: 2 (Larger than any link state path)
        TOS: 0
        Metric: 3
```

```
                    Forward Address: 0.0.0.0
                    External Route Tag: 0
```

The external (in fixed code) argument to the `show ip ospf database` command filters the output such that only AS LSAs sent by `Lager` are shown. The `adv-router` argument specified `Lager`'s OSPF RID to identify it from all other sources of AS external LSAs in the OSPF RD. The output confirms that `Lager`'s customer route (200.0.2/24) is being advertised into OSPF.

RIP-to-OSPF Migration: Cutover to OSPF

With various aspects of OSPF operation confirmed, it's time to make the cut from RIP to OSPF. This should be a nondisruptive process, but as with all IGP migration procedures, it's best to perform the cutover in a maintenance window as added insurance—the interplay of complex internetworking protocols is sometimes hard to predict. The actual transition normally occurs in two phases. First, make the OSPF routes active, and then, after you confirm proper operation, remove all traces of the legacy protocol and reset the new protocol to its default preference values.

To achieve the first goal you could reconfigure the OSPF internal and external preferences to be more preferred than RIP, or you could alter RIP's preference to be less preferred than OSPF. Either way, if something blows up, you can roll back or simply remove the OSPF configuration, and return to RIP operation while determining what went wrong. Given that IOS is now set with a single preference for both OSPF and RIP, the amount of change is a wash. On the Junos devices, it will be easier to change the one RIP preference rather than both OSPF values. Therefore, the plan is to set the RIP administrative distance to 126 on the IOS devices, while setting the RIP preference to 107 on the Junos devices. In both cases, the change will make RIP a less-preferred protocol.

The changes are shown for the Juniper router `Ale`. Similar commands are also executed at `Lager`:

```
[edit protocols]
lab@Ale# set rip group rip preference 107
```

The RIP administrative distance is altered on both IOS boxes:

```
Malt# conf terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Malt(config)# router rip
Malt(config-router)# distance 126
```

After a few moments, it's confirmed that the OSPF version of `Lager`'s 200.0.2.0 route is now preferred at `Barley`:

```
Barley# show ip route 200.0.2.0
Routing entry for 200.0.2.0/24
  Known via "ospf 10", distance 125, metric 3, type extern 2, forward
metric 1
```

```
     Last update from 192.168.2.2 on FastEthernet0/1.70, 00:03:42 ago
     Routing Descriptor Blocks:
     * 192.168.2.2, from 10.10.128.2, 00:03:42 ago, via FastEthernet0/1.70
         Route metric is 3, traffic share count is 1
```

Back at the Juniper side of things, you should make a similar determination as to which set of routes is preferred. Note how routes learned through multiple sources are clearly shown in Junos, and that the active versions of these routes are now OSPF-based:

```
lab@Ale# run show route

inet.0: 19 destinations, 26 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/106] 00:00:25, metric 1, tag 200
                    > to 10.10.129.2 via ge-0/0/0.1121
                    [RIP/107] 06:14:07, metric 2, tag 100
                    > to 192.168.1.1 via ge-0/0/0.69
10.1.254.0/24      *[OSPF/105] 00:08:03, metric 66
                    > to 10.10.129.2 via ge-0/0/0.1121
                    [RIP/107] 06:14:07, metric 2, tag 0
                    > to 192.168.1.1 via ge-0/0/0.69
10.1.254.1/32      *[RIP/107] 04:14:22, metric 3, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
10.1.254.2/32      *[RIP/107] 06:14:07, metric 2, tag 0
                    > to 192.168.1.1 via ge-0/0/0.69
10.10.128.100/32    *[OSPF/105] 00:08:03, metric 67
                    > to 10.10.129.2 via ge-0/0/0.1121
                    [RIP/107] 06:14:07, metric 2, tag 0
                    > to 192.168.1.1 via ge-0/0/0.69
10.10.128.200/32    *[OSPF/105] 00:08:03, metric 3
                    > to 10.10.129.2 via ge-0/0/0.1121
10.10.128.1/32     *[Direct/0] 3d 21:34:05
                    > via lo0.0
10.10.128.2/32     *[OSPF/105] 00:08:03, metric 1
                    > to 10.10.129.2 via ge-0/0/0.1121
                    [RIP/107] 05:45:43, metric 2, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
10.10.129.0/24     *[Direct/0] 2d 22:32:39
                    > via ge-0/0/0.1121
10.10.129.1/32     *[Local/0] 3d 21:34:05
                      Local via ge-0/0/0.1121
192.168.1.0/30     *[Direct/0] 2d 22:32:39
                    > via ge-0/0/0.69
192.168.1.2/32     *[Local/0] 3d 06:03:32
                      Local via ge-0/0/0.69
192.168.2.0/30     *[OSPF/105] 00:08:03, metric 2
                    > to 10.10.129.2 via ge-0/0/0.1121
                    [RIP/107] 05:45:43, metric 2, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
200.0.1.0/24       *[Static/5] 2d 07:10:57
                      Discard
200.0.2.0/24       *[OSPF/106] 00:08:03, metric 3, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
                    [RIP/107] 05:45:43, metric 4, tag 0
```

Do

```
                    > to 10.10.129.2 via ge-0/0/0.1121
200.0.100.0/24     *[OSPF/106] 00:08:03, metric 3, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
                    [RIP/107] 06:14:07, metric 4, tag 0
                    > to 192.168.1.1 via ge-0/0/0.69
200.0.200.0/24     *[OSPF/106] 00:08:03, metric 3, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
224.0.0.5/32       *[OSPF/10] 03:14:39, metric 1
                      MultiRecv
224.0.0.9/32       *[RIP/100] 00:08:03, metric 1
                      MultiRecv
```

The display shows the default route in its OSPF and RIP forms, both of which are tagged due to route-map actions. Here, `Ale` has installed the default generated by `Barley` (tag 200), with the RIP version learned directly from `Malt` also listed (tag 100). The Junos CLI's matching function is used to identify any remaining active RIP routes. The \ is used here to escape the * character, so it is not incorrectly expanded as a shell wildcard, rather than a specific match condition:

```
[edit protocols]
lab@Ale# run show route protocol rip | match \*
+ = Active Route, - = Last Active, * = Both
10.1.254.1/32      *[RIP/107] 04:16:48, metric 3, tag 0
10.1.254.2/32      *[RIP/107] 06:16:33, metric 2, tag 0
224.0.0.9/32       *[RIP/100] 00:10:29, metric 1
```

Besides the multicast route associated with RIPv2, only the /32 host routes from the `Malt`–`Barley` serial link are still active as a RIP route. This is not an issue, as the related subnet 10.1.254.0/24 is correctly advertised into OSPF (see the previous route display). These results confirm that it's safe to remove RIP from the internetwork. Things begin first at the Juniper Networks boxes:

```
[edit]
lab@Ale# delete protocols rip
```

And then the change occurs at the Cisco boxes:

```
Malt# conf terminal
Enter configuration commands, one per line.  End with CNTL/Z.
Malt(config)# no router rip
Malt(config)# ^Z
Malt#
```

Though not shown, the related RIP policy and route maps can now be safely removed. After a few moments of waiting, no angry users surface, and OSPF routing is verified at `Ale`. Perhaps it's now time for that vacation...

```
[edit]
lab@Ale# run show route protocol rip

inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)

_ _juniper_private1_ _.inet.0: 2 destinations, 2 routes (2 active,
0 holddown, 0 hidden)
```

No more RIP routes, as planned:

```
[edit]
lab@Ale# run show route 200.0.200.0

inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

200.0.200.0/24     *[OSPF/106] 00:16:20, metric 3, tag 0
                    > to 10.10.129.2 via ge-0/0/0.1121
```

The active route is still OSPF, and a traceroute confirms identical connectivity:

```
[edit]
lab@Ale# run traceroute 200.0.200.1 no-resolve
traceroute to 200.0.200.1 (200.0.200.1), 30 hops max, 40 byte
packets
 1  10.10.129.2  17.647 ms  14.877 ms  14.854 ms
 2  192.168.2.1  8.879 ms  10.982 ms  9.878 ms
 3  192.168.2.1  10.287 ms !H *  10.282 ms !H
```

Before You Go, Can You Set Up Area 1 Real Quick?

So, the CIO of Beer-Co is so impressed with the success of the RIP-to-OSPF migration that you have been asked to bring up an Area 1 attachment to router PBR. This is to be a stub area, with a default route injected by the area's ABR so that PBR can reach the various OSPF external destinations now present in the new network. Figure 6-10 shows the new topology. You may assume that interface parameters are correctly set.

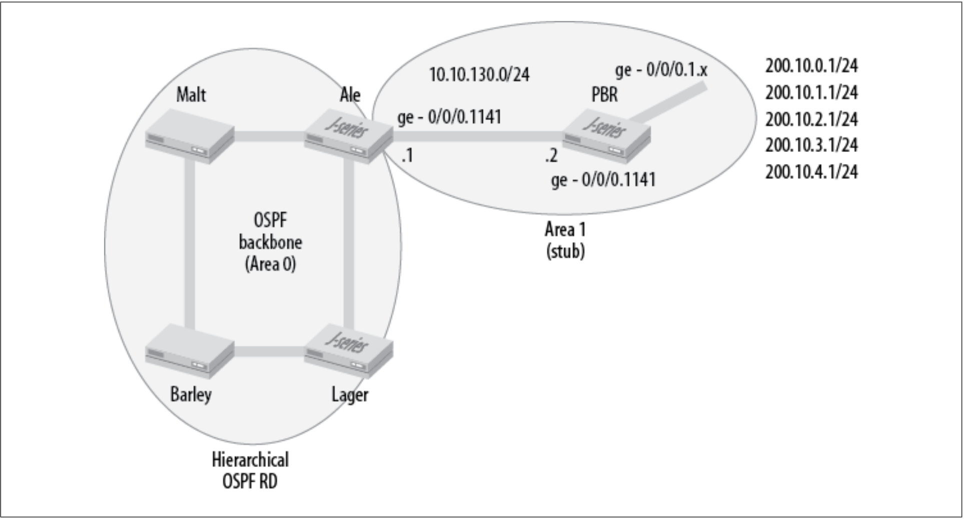


Figure 6-10. A hierarchical OSPF network

In Figure 6-10's example, PBR's `ge-0/0/1` interface has been looped back (to ensure that it's declared up, even if not connected), and five VLANs have been created, each with an IP address in the form of 200.10.*x*.1/24. All five of these logical interfaces have been placed into OSPF area 1, which has been set as a stub area. PBR's OSPF and `ge-0/0/1` configuration is as follows:

```
[edit]
lab@PBR# show interfaces ge-0/0/1
vlan-tagging;
fastether-options {
    loopback;
}
unit 1 {
    vlan-id 1;
    family inet {
        address 200.10.1.1/24;
    }
}
unit 2 {
    vlan-id 2;
    family inet {
        address 200.10.2.1/24;
    }
}
unit 3 {
    vlan-id 3;
    family inet {
        address 200.10.3.1/24;
    }
}
unit 4 {
    vlan-id 4;
    family inet {
        address 200.10.4.1/24;
    }
}
unit 5 {
    vlan-id 5;
    family inet {
        address 200.10.5.1/24;
    }
}

[edit]
lab@PBR# show protocols ospf
area 0.0.0.1 {
    stub;
    interface ge-0/0/1.1;
    interface ge-0/0/1.2;
    interface ge-0/0/1.3;
    interface ge-0/0/1.4;
    interface ge-0/0/1.5;
    interface ge-0/0/0.1141;
}
```

Meanwhile, a compatible OSPF area 1 configuration has been added at `Ale`:

```
[edit protocols ospf area 0.0.0.1]
lab@Ale# show
stub default-metric 10;
interface ge-0/0/0.1141;
```

Note that to inject a default route into the stub, you must specify a default metric. After a few moments, OSPF operation is confirmed at `PBR`. The `show ospf neighbor` command confirms that the adjacency to `Ale` is established:

```
[edit protocols ospf]
lab@PBR# run show ospf neighbor
  Address          Interface      State      ID               Pri  Dead
10.10.130.1      ge-0/0/0.1141    Full      10.10.128.1       128    39
```

The display of OSPF routes verifies the presence of the default route, injected by ABR router `Ale`, and reveals an absence of AS externals, which are not permitted in a stub network. *Only* LSA types 1, 2, and 3 are permitted in a stub area—the OSPF route table at `PBR` contains only intraarea and interarea routes, thus confirming this aspect of OSPF stub area operation:

```
[edit]
lab@PBR# run show ospf route
Prefix         Path   Route    NH   Metric  NextHop       Nexthop
               Type   Type     Type         Interface     addr/label
10.10.128.1    Intra  Area BR  IP   1       ge-0/0/0.1141 10.10.130.1
0.0.0.0/0      Inter  Network  IP   11      ge-0/0/0.1141 10.10.130.1
10.10.128.1/32 Intra  Network  IP   1       ge-0/0/0.1141 10.10.130.1
10.10.128.2/32 Inter  Network  IP   2       ge-0/0/0.1141 10.10.130.1
10.10.129.0/24 Inter  Network  IP   2       ge-0/0/0.1141 10.10.130.1
10.10.130.0/24 Intra  Network  IP   1       ge-0/0/0.1141
10.10.131.0/24 Inter  Network  IP   3       ge-0/0/0.1141 10.10.130.1
192.168.1.0/30 Inter  Network  IP   2       ge-0/0/0.1141 10.10.130.1
192.168.2.0/30 Inter  Network  IP   3       ge-0/0/0.1141 10.10.130.1
200.10.1.0/24  Intra  Network  IP   1       ge-0/0/1.1
200.10.2.0/24  Intra  Network  IP   1       ge-0/0/1.2
200.10.3.0/24  Intra  Network  IP   1       ge-0/0/1.3
200.10.4.0/24  Intra  Network  IP   1       ge-0/0/1.4
200.10.5.0/24  Intra  Network  IP   1       ge-0/0/1.5
```

`PBR` relies on the ABR-generated default route to reach external destinations because AS external LSAs are not advertised into stub areas:

```
[edit protocols ospf]
lab@PBR# run show route 200.0.200.1

inet.0: 21 destinations, 21 routes (21 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/10] 00:04:31, metric 11
                    > to 10.10.130.1 via ge-0/0/0.1141
```

You can add the `no-summaries` keyword to the area 1 configuration at the stub area's ABR (`Ale`) to also filter Type 3 network summary LSAs, which also result in the use of a default route for interarea destinations. With this change, a totally stubby area is born:

```
[edit protocols ospf area 0.0.0.1]
lab@Ale# set stub no-summaries

[edit protocols ospf area 0.0.0.1]
lab@Ale# commit
```

The results are confirmed at `PBR`, whose LSDB just got much smaller:

```
[edit]
lab@PBR# run show ospf route
Prefix          Path   Route    NH   Metric  NextHop        Nexthop
                Type   Type     Type         Interface      addr/label
10.10.128.1     Intra  Area BR  IP    1      ge-0/0/0.1141  10.10.130.1
0.0.0.0/0       Inter  Network  IP    11     ge-0/0/0.1141  10.10.130.1
10.10.128.1/32  Intra  Network  IP    1      ge-0/0/0.1141  10.10.130.1
10.10.130.0/24  Intra  Network  IP    1      ge-0/0/0.1141
200.10.1.0/24   Intra  Network  IP    1      ge-0/0/1.1
200.10.2.0/24   Intra  Network  IP    1      ge-0/0/1.2
200.10.3.0/24   Intra  Network  IP    1      ge-0/0/1.3
200.10.4.0/24   Intra  Network  IP    1      ge-0/0/1.4
200.10.5.0/24   Intra  Network  IP    1      ge-0/0/1.5

[edit protocols ospf]
lab@PBR# run show route 192.168.1.1

inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/10] 00:01:41, metric 11
                    > to 10.10.130.1 via ge-0/0/0.1141
```

A final task: Aggregate network summaries into the backbone

Area 1 is now quite optimized, but it has been called to your attention that the five 200.10.*x*.1/24 networks owned by `PBR` are being flooded into the backbone as individual Type 3 network summary LSAs. This is normal for OSPF, but your CIO wants to run a tight ship and has asked that you generate a single summary LSA into area 0 in place of the current five. Before making changes, you confirm that the CIO has correctly described the network summary situation by displaying Type 3 LSAs generated by ABR `Ale`. Note that these summaries are in backbone area 0:

```
[edit]
lab@Lager#run show ospf database netsummary advertising-router
10.10.128.1

    OSPF link state database, Area 0.0.0.0
 Type       ID            Adv Rtr         Seq       Age  Opt  Cksum  Len
Summary  10.10.130.0   10.10.128.1   0x80000003 421  0x22 0xc449  28
Summary  10.20.128.3   10.10.128.1   0x80000002 421  0x22 0x46bd  28
Summary  200.10.1.0    10.10.128.1   0x80000002 421  0x22 0xb11f  28
Summary  200.10.2.0   10.10.128.1  0x80000002 421  0x22 0xa629  28
Summary  200.10.3.0   10.10.128.1  0x80000002 421  0x22 0x9b33  28
Summary  200.10.4.0   10.10.128.1  0x80000002 421  0x22 0x903d  28
Summary  200.10.5.0   10.10.128.1  0x80000002 421  0x22 0x8547  28
```

Taking note of Lager's current area 0 LSDB state, you make a change to the area 1 portion of Ale, which results in the summarization of matching network summary LSAs:

```
[edit protocols ospf area 0.0.0.1]
lab@Ale# set area-range 200.10/16

[edit protocols ospf area 0.0.0.1]
lab@Ale# show
stub default-metric 10 no-summaries;
area-range 200.10.0.0/16;
interface ge-0/0/0.1141;
```

The area-range statement replaces individual network summaries that fall within the configured range with a single network summary representing the entire range. Adding the restrict keyword as part of the area-range statement serves to block any network summaries that are equal in length to the area-range's mask. In other words, the area-range is normally a *longer* function with regard to prefix length, but adding the restrict keyword alters this match type to that of orlonger. The latter results in filtering of any summaries *equal* in length to the specified area-range prefix length.

Your work is confirmed with a look at the network summaries now advertised into area 0 by Ale:

```
[edit]
lab@Lager# show ospf database netsummary advertising-router
10.10.128.1
    OSPF link state database, Area 0.0.0.0
 Type       ID            Adv Rtr       Seq      Age  Opt  Cksum  Len
Summary  10.10.130.0   10.10.128.1 0x8000000a   9  0x22 0xb650  28
Summary  10.20.128.3   10.10.128.1 0x80000009   9  0x22 0x38c4  28
Summary  200.10.0.0    10.10.128.1 0x80000001   9  0x22 0xbe14  28
```

As a final check, the connectivity from Cisco router Barley to one of the 200.10.*x*.1/24 networks on PBR is confirmed:

```
Barley# traceroute 200.10.1.1

Type escape sequence to abort.
Tracing the route to 200.10.1.1

  1 192.168.2.2 4 msec 4 msec 12 msec
  2 10.10.129.1 8 msec 4 msec 12 msec
  3 200.10.1.1 4 msec 8 msec 8 msec
```

Awesome! This result completes the RIP-to-OSPF migration. This example also touched on stub area and area-range summarization configuration.

RIP Migration with the Overlay Model Summary

This section demonstrated a typical RIP-to-OSPF IGP migration using the overlay model. This was demonstrated in a multivendor environment to help show that the principles and procedures are somewhat universal, albeit with slightly varied command syntax that serves only to confuse the innocent. The modification of global route preferences allowed a smooth, hitless transition. Once the new IGP was found to be operating as expected, a quick change of preference resulted in use of the new IGP's forwarding paths while retaining the legacy IGP's configuration (and legacy protocol neighbors/adjacency state), in the event that the change needs to be backed out quickly. The migration ends with the removal of all legacy IGP traces from the router configurations.

This section also showed the conversion of a flat OSPF network into a hierarchical design that included the function of stub networks, totally stubby networks, and area-range syntax to consolidate network summaries as they enter the backbone.

Now is a good time to take another break. The next section continues our discussion of IGP migration, but this time in the context of an EIGRP-to-OSPF scenario.

EIGRP-to-OSPF Migration

This section demonstrates a smooth migration from a legacy EIGRP network to a hierarchical OSPF IGP. You could take many approaches to facilitate such a migration. The best approach will depend on numerous factors, such as device support of old and new IGPs and whether new equipment is being added, and if so, whether it's added to replace or augment an existing network's infrastructure. Also of consideration is the legacy network's design with regard to addressing and hierarchy, in combination with the design goals for the new network's efficiency and scalability.

The tactic demonstrated here is of the route redistribution variety. But considering that Juniper Networks routers have never spoken EIGRP, a bit of the integration model has to be at work as well—after all, a new backbone is being built out. It is acknowledged that leveraging existing network infrastructure will be of prime concern for most enterprises, and therefore that a typical EIGRP-to-OSPF migration will center on the phased reconfiguration of existing IOS devices to begin running the new and stop running the old IGP. This chapter demonstrates a migration approach in which Juniper Networks routers are added to form a new OSPF backbone while *minimal* changes are made to the legacy infrastructure to accommodate communications between the EIGRP and OSPF domains.

The solution demonstrated accommodates graceful growth of the OSPF backbone while the legacy EIGRP backbone is phased out. The migration goals for this scenario are as follows:

- There should be a minimal impact to the existing IOS configurations and existing EIGRP backbone operation.
- The solution should accommodate a phasing out of the legacy backbone IGP (though not necessarily the current devices) toward an all-OSPF backbone.
- The solution should be as simple as possible and be workable for small-to-large-scale enterprise migrations.
- The design must minimize the impact of large numbers of AS external LSAs for low-end routers.

Mutual Route Redistribution

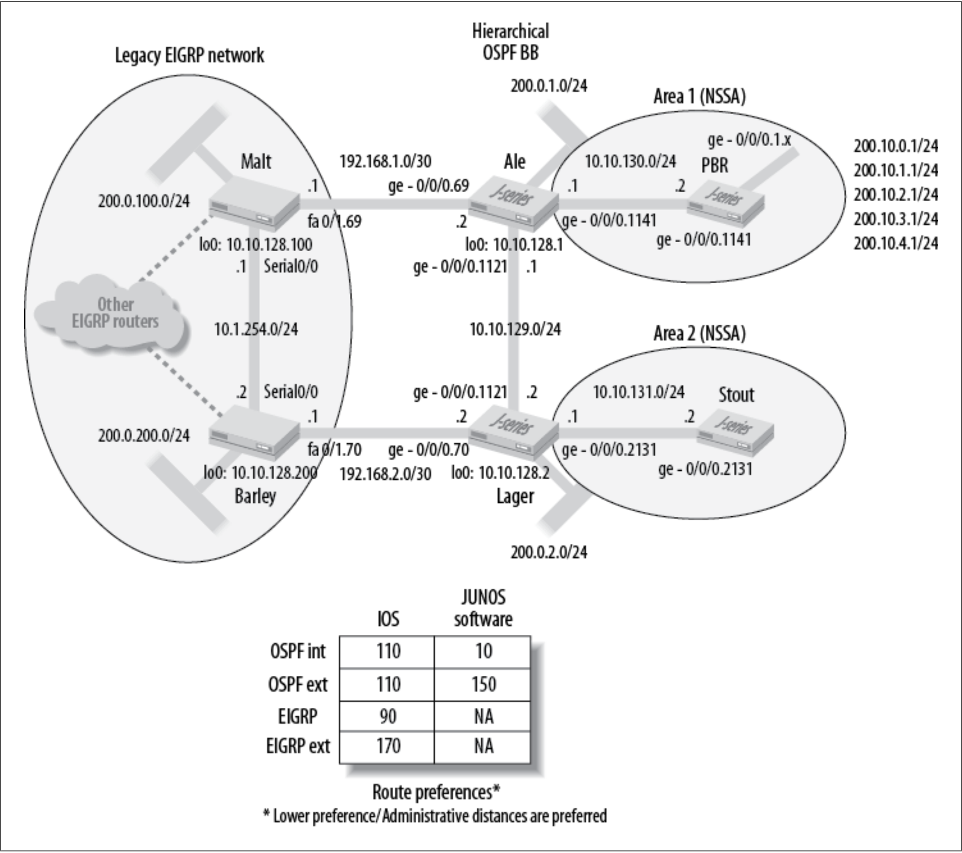
To make this scenario work, mutual route redistribution is needed between EIGRP and OSPF. As always, you must ensure that routes are redistributed only once, because loops will violate the "minimal impact to existing backbone" criterion. In addition, route preference adjustments may be needed to ensure optimal routing, depending on the default preferences for internal versus external EIGRP and OSPF between the two vendors.

As much as you might prefer to have all this happen on the Junos devices, the simple fact is that they cannot run EIGRP, while the Cisco boxes support both EIGRP and OSPF. This means the redistribution work will have to occur in IOS land. From the viewpoint of the Juniper routers, however, this is just another OSPF network, albeit one with a lot of tagged AS externals.

Figure 6-11 provides the topology and addressing specifics to assist the reader in tracking down which devices and IGPs own which routes.

Figure 6-12 provides the summary plan of action, as derived from the design criteria provided.

The overall plan is to *add* an OSPF process on the Cisco routers that redistributes connected, static, and EIGRP learned routes *after* adding a tag value to these routes. In this case, the tag chosen is based on the EIGRP domain's AS (process) number (it could be any unique value, however). In addition, the existing EIGRP configuration is modified to redistribute OSPF into EIGRP *after* tagging these routes in a similar fashion. In both cases, the *first* step in the respective route maps is to *deny* any routes that already have the EIGRP process tag value. It's critical that the deny action occur first, as the whole point of the route tags is to simplify the blocking of routes that originated in EIGRP from being redistributed back onto EIGRP from OSPF. Likewise, we need to



	IOS	JUNOS software
OSPF int	110	10
OSPF ext	110	150
EIGRP	90	NA
EIGRP ext	170	NA

Figure 6-11. EIGRP-to-OSPF migration topology

block routes that originated in OSPF from being sent back into OSPF by EIGRP; the same tag value is also used for this filtering requirement.

Recall that redistribution of connected, static, or EIGRP routes into OSPF results in Type 5 AS external LSAs, which are in turn flooded over the entire OSPF domain (except stub areas). This is a significant point, because one of the design goals is to minimize the impact of large numbers of external LSAs on low-end routers. This is why the new, nonbackbone OSPF areas are configured as NSSA areas in this example. As with the stub area example, the default route injected by the ABRs provides connectivity to the external destinations—for example, EIGRP—and the NSSA capability accommodates future placement of an ASBR to originate AS external routes from these areas as needed.

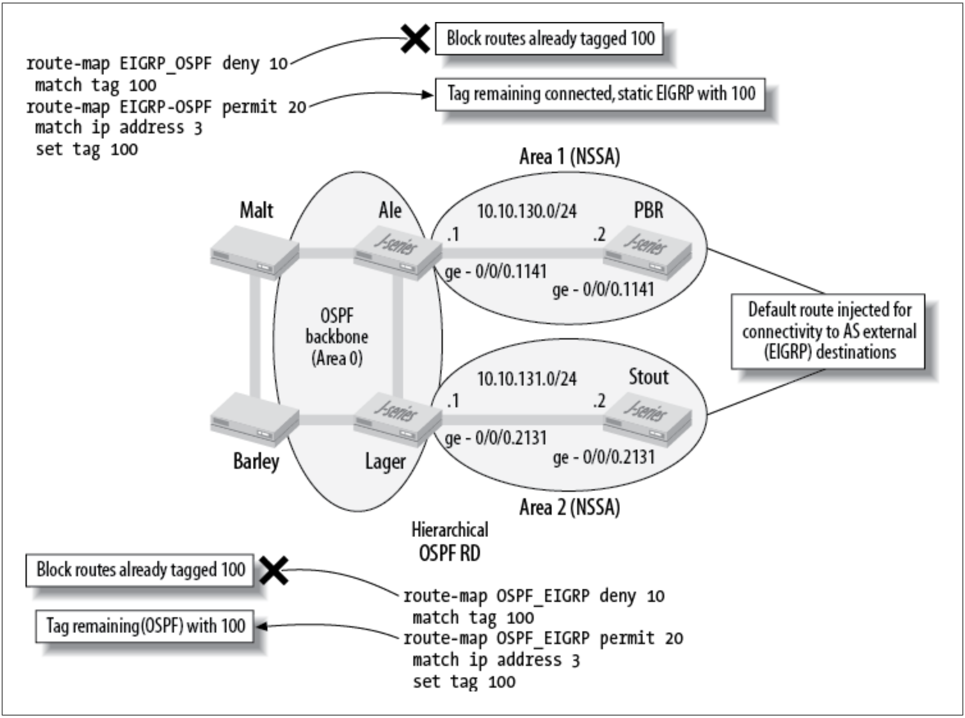

Block routes already tagged 100
route-map EIGRP_OSPF deny 10
match tag 100
route-map EIGRP-OSPF permit 20
match ip address 3
set tag 100
Tag remaining connected, static EIGRP with 100
Area 1 (NSSA)
Malt
Ale
10.10.130.0/24
PBR
.1
.2
ge - 0/0/0.1141
ge - 0/0/0.1141
OSPF backbone (Area 0)
Default route injected for connectivity to AS external (EIGRP) destinations
10.10.131.0/24
Stout
.1
.2
ge - 0/0/0.2131
ge - 0/0/0.2131
Barley
Lager
Area 2 (NSSA)
Hierarchical OSPF RD
Block routes already tagged 100
Tag remaining (OSPF) with 100
route-map OSPF_EIGRP deny 10
match tag 100
route-map OSPF_EIGRP permit 20
match ip address 3
set tag 100

Figure 6-12. EIGRP-to-OSPF migration plan overview

The Junos OSPF configuration

On the Junos side, things are pretty straightforward, and the OSPF and related policy bits are shown for Ale:

```
[edit]
lab@Ale# show protocols ospf
export static;
area 0.0.0.0 {
    interface ge-0/0/0.69;
    interface ge-0/0/0.1121;
}
area 0.0.0.1 {
    nssa {
        default-lsa default-metric 10;
    }
    interface ge-0/0/0.1141;
}

[edit]
lab@Ale# show policy-options policy-statement static
term 1 {
    from {
        protocol static;
```

```
            route-filter 200.0.1.0/24 exact;
        }
        then accept;
    }
```

The OSPF export policy redistributes the simulated customer static route into OSPF. No route tagging is being performed here, because if tag 100 were added, these routes would be filtered from redistribution into the EIGRP domain. Area 1 is configured as an NSSA, and a default route is configured (via the `default-metric` statement) for use by routers within the NSSA when routing AS external destinations. Recall that all the EIGRP routes will be become AS externals once they are injected into the OSPF domain, making the presence of the default route in stub areas critical for maintaining connectivity. The configuration of Junos router `Stout` is shown for completeness, but there is not much to say, except that its area 2 is compatibly configured as an NSSA:

```
[edit]
lab@stout# show protocols ospf
area 0.0.0.2 {
    nssa;
    interface ge-0/0/0.2131;
}
```

The IOS configuration

The real work is being done on the IOS side because these devices are able to run both the old and the new IGPs.

Before adding the new OSPF process to any of the legacy Cisco routers, you must first verify that they have the capacity to run both IGPs without encountering performance issues. The current best practice is to confirm that CPU and memory use are less than 50% to 60%, respectively. If the router is already running short of resources, adding a new IGP and related redistribution may well push it over the limit. Older routers that are already having trouble keeping up should be replaced or upgraded before proceeding.

The `show memory` and `show processes` command output indicates that Beer-Co's IOS boxes are not heavily taxed, so we are free to proceed:

```
Malt# show mem stat
              Head Total(b)  Used(b)   Free(b) Lowest(b) Largest(b)
Processor 82B00CC0 18493864  6288376  12205488  12000052   11685420
      I/O  3C00000  4194304  2013112   2181192   2174960    2181148
Malt# show processes cpu sorted
CPU utilization for five seconds: 0%/0%; one minute: 0%;
five minutes: 0%
 PID Runtime(ms)  Invoked uSecs   5Sec   1Min   5Min TTY Process
   3       15492     3513  4409  0.31%  0.80%  0.26%   0 Exec
   1           0        2     0  0.00%  0.00%  0.00%   0 Chunk Manager
   2           4     2527     1  0.00%  0.00%  0.00%   0 Load Meter
   4         320     2958   108  0.00%  0.00%  0.00%   0 OSPF Hello
. . . .
```

Having determined sufficient resource capacity, the migration proceeds; the modified portions of Cisco router `Malt` are shown here:

```
router eigrp 100
 redistribute connected
 redistribute static
 redistribute ospf 10 metric 10 100 255 1 1500 route-map OSPF_EIGRP
 network 10.0.0.0
 no auto-summary
!
router ospf 10
 network 192.168.1.0 0.0.0.3 area 0
 redistribute eigrp 100 metric 4 route-map EIGRP_OSPF subnets
 redistribute static metric 3 route-map EIGRP_OSPF subnets
 redistribute connected tag 100 subnets metric 2
!
access-list 3 permit any
!
route-map OSPF_EIGRP deny 10
 match tag 100
!
route-map OSPF_EIGRP permit 20
 match ip address 3
 set tag 100
!
route-map EIGRP_OSPF deny 10
 match tag 100
!
route-map EIGRP_OSPF permit 20
 match ip address 3
 set tag 100
```

The modified portions of the IOS configuration are highlighted to help to call out the delta. The EIGRP process was instructed to redistribute routes from the OSPF process identified as "10," setting the EIGRP bandwidth, delay, reliability, loading, and MTU values to 10, 100, 255, 1, and 1500, respectively. The redistribution is controlled by the logic in the route map named `OSPF_EIGRP`.

The entire OSPF process is new and was added to integrate with the new Juniper router-based backbone. Because connected routes could not be filtered through the existing `EIGRP_OSPF` route map, tagging for the connected routes is configured directly on the distribute line.

In contrast, both static and EIGRP routes are being redistributed through the control of the common `EIGRP_OSPF` route map. The `subnet` keyword inverts the default behavior of redistributing only classful networks. Lastly, you'll see that OSPF area 0 is configured to run on the link connecting `Malt` to `Ale`.

Both route maps make use of an initial deny term for any route with a tag value of 100. Remaining routes are then matched against the match-all IP access list 3, with the result being the addition of tag value 100. When combined, the operation of the two route maps serves to ensure that a route is never redistributed back into the IGP from where it originated, which should prevent loop formation.

> You use Junos routing policy to combine the various effects of IOS's `distribute`, `distribute-list`, `ACL`, and `route-map` functions. For example, here is a policy example that functions to reject and tag routes, much as the `EIGRP_OSPF` route map does, albeit for RIP and OSPF given the lack of EIGRP support. The `RIP_to_OSPF` policy is applied to the OSPF protocol as an export policy to redistribute only untagged RIP routes into OSPF, at which time a tag value of 100 is added:

```
[edit policy-options]
regress@plato# show policy-statement RIP_to_OSPF
term 1 {
    from tag 100;
    then reject;
}
term 2 {
    from protocol rip;
    then {
        tag 100;
        accept;
    }
}

[edit policy-options]
regress@plato# show policy-statement RIP_to_OSPF | display set
set policy-options policy-statement RIP_to_OSPF term 1 from tag 100
set policy-options policy-statement RIP_to_OSPF term 1 then reject
set policy-options policy-statement RIP_to_OSPF term 2 from protocol rip
set policy-options policy-statement RIP_to_OSPF term 2 then tag 100
set policy-options policy-statement RIP_to_OSPF term 2 then accept
```

To better understand how the tagging works, refer back to Figure 6-12 and then consider an EIGRP (or connected, or static) route *x* that originates in the EIGRP domain and is evaluated for redistribution into OSPF. According to the `EIGRP_OSPF` route map, the first action is to deny any route with the tag value 100. Because route *x* originates within EIGRP, it has no tag and therefore the route falls to the next term. Action 20 adds tag 100 to the route and sends it into OSPF. Route *x*, which is now an OSPF Type 5 LSA, is then flooded into the OSPF RD, where it arrives at Cisco router `Barley`. In most cases, `Barley` will already have a more preferred EIGRP route to this destination (recall that it originated in EIGRP to begin with), but if not, it will install the OSPF route to *x*, as learned from `Malt`'s OSPF advertisement.

Now `Barley`'s OSPF process considers OSPF route *x* for redistribution into EIGRP. Fortunately, the first term in its `OSPF_EIGRP` route map denies any routes with tag 100. This action serves to prevent route *x* from being sent back into its originating EIGRP IGP. Any routes that originate in the OSPF domain, regardless of whether they are internal or AS external, arrive at `Barley` with no tag. This permits the redistribution of these routes into the EIGRP process, after they have been tagged. This tag will in turn keep router `Malt` from sending the route back into the OSPF domain.

What about route preferences? Referring back to Figure 6-11, you can see the default preferences for the route sources used in this example. At first glance, it seems that we want both `Malt` and `Barley` to prefer all OSPF routes regardless of whether they are internal or external. This is to ensure that both Cisco routers forward directly into the OSPF cloud when routing to OSPF originated routes, rather than backhauling over the EIGRP backbone because they prefer a redistributed EIGRP version of the same route. This is fortunate here because the OSPF routes redistributed into EIGRP are considered EIGRP externals, and the default distance for these routes is 170, making them less preferred than the native OSPF copy with a default distance of 110.

The default settings mean that the EIGRP domain will always prefer a learned OSPF route over the same copy in the (redistributed) external EIGRP form. The Junos boxes have only one IGP, so there is no need to alter any preference there, of course. Time will tell whether we need to revisit this thinking...

Confirm EIGRP/OSPF Mutual Route Redistribution

With all routers configured, confirm proper redistribution and forwarding. Begin at Cisco router `Malt`, where the IP route table is displayed:

```
Malt# show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

O E2 200.0.200.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O IA 200.10.4.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O IA 200.10.5.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O E2 200.0.1.0/24 [110/0] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O IA 200.10.1.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O E2 200.0.2.0/24 [110/0] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
O IA 200.10.2.0/24 [110/3] via 192.168.1.2, 00:05:09, FastEthernet0/1.69
S    200.0.100.0/24 is directly connected, Null0
O IA 200.10.3.0/24 [110/3] via 192.168.1.2, 00:05:10, FastEthernet0/1.69
     10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
D       10.10.128.200/32 [90/2297856] via 10.1.254.2, 03:10:02, Serial0/0
O       10.10.129.0/24 [110/2] via 192.168.1.2, 00:05:10, FastEthernet0/1.69
O       10.10.128.1/32 [110/1] via 192.168.1.2, 00:05:10, FastEthernet0/1.69
O IA    10.10.130.0/24 [110/2] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
O       10.10.128.2/32 [110/2] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
O IA    10.10.131.0/24 [110/3] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
O IA    10.20.128.4/32 [110/3] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
O IA    10.20.128.3/32 [110/2] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
C       10.10.128.100/32 is directly connected, Loopback0
C       10.1.254.0/24 is directly connected, Serial0/0
```

```
C       10.1.254.2/32 is directly connected, Serial0/0
     192.168.1.0/30 is subnetted, 1 subnets
C       192.168.1.0 is directly connected, FastEthernet0/1.69
     192.168.2.0/30 is subnetted, 1 subnets
O       192.168.2.0 [110/3] via 192.168.1.2, 00:05:14, FastEthernet0/1.69
```

From a quick look, it seems that all the routes are there: PBR's five 200.10.*x*/24 routes as network summaries (interarea), the simulated customer routes from Ale and Lager as AS externals, and their loopback/OSPF interface routes appearing as OSPF internals (intraarea). It certainly appears that these routes are preferred in their OSPF form, despite their being redistributed into EIGRP at Barley, which is desired behavior for optimal routing between the EIGRP and OSPF domains. Note how Barley's loopback 0 address (10.10.128.200) is displayed as an EIGRP learned internal route with a distance of 90.

To confirm that the OSPF routes are really being redistributed into EIGRP (IOS displays only the active route), the EIGRP topology table for one of PBR's 200.0.1.0/24 routes is shown here:

```
Malt# **show ip eigrp topology 200.0.1.0**
IP-EIGRP (AS 100): Topology entry for 200.0.1.0/24
  State is Passive, Query origin flag is 1, 1 Successor(s), FD is
256025600
  Routing Descriptor Blocks:
  192.168.1.2, from Redistributed, Send flag is 0x0
      Composite metric is (256025600/0), Route is External
      Vector metric:
        Minimum bandwidth is 10 Kbit
        Total delay is 1000 microseconds
        Reliability is 255/255
        Load is 1/255
        Minimum MTU is 1500
        Hop count is 0
      External data:
        Originating router is 10.10.28.100 (this system)
        AS number of route is 10
        External protocol is OSPF, external metric is 0
        Administrator tag is 100 (0x00000064)
```

The route's presence is confirmed in the EIGRP topology table, and the tag value of 100 proves that the OSPF_EIGRP route map is working.

Troubleshoot a preference issue

Overall, the output from the show ip route command at Malt is what you want to see. There is one problem, however, with respect to the simulated customer route owned by Barley: the display shows that Malt prefers the OSPF external version of the 200.0.200/24 route because the EIGRP external distance is higher (less preferred) than OSPF's (as noted previously, this is part of the migration plan). This occurs *only* for the simulated customer routes because EIGRP is set to run on the serial and loopback interfaces as a result of the network 10.0.0.0 statement. These routes are therefore considered *internal* to the EIGRP process and they have a distance of 90. In contrast, the simulated customer static route is *redistributed* into EIGRP, making it an EIGRP external. This situation results in an extra hop when `Malt` tries to reach `Barley`'s customer network, and vice versa:

```
Malt# trace 200.0.200.1
Type escape sequence to abort.
Tracing the route to 200.0.200.1

  1 192.168.1.2 4 msec 8 msec 8 msec
  2 10.10.129.2 8 msec 8 msec 8 msec
  3 192.168.2.1 12 msec 8 msec 12 msec
4 192.168.2.1 !H  !H  *
```

Rethinking the default preferences, it was correct to assert that *all* OSPF routes would be preferred over EIGRP externals, which for the majority of our routes is exactly what is desired. The redistributed statics are causing issues with this plan, however. Changing OSPF external preferences may fix the issue with the problematic static routes, but will then create problems for the other OSPF routes that are now doing what they should be doing.

Some possible solutions include running EIGRP passively on the related customer interface so that the route is advertised as an EIGRP internal. This solution requires an actual interface (or loopback instance), and these statics were used to reduce gear requirements in the first place. Still, no new gear is needed for an IOS loopback 1 interface. Or, you could define a static route, but this represents administrative work and may lead to a black hole if the legacy EIGRP backbone fails. Using a qualified/recursive static should result in traffic falling back to the learned OSPF version should the static route's next hop become unreachable, but this would need to be tested to make sure of failover behavior. Yet another solution would be to simply tolerate the inefficient routing, given that connectivity is still provided and the condition should be transient as the EIGRP network is phased out. Being a purist, you opt to alter the IOS configurations to add a new loopback instance that will run EIGRP on behalf of the simulated customer network. Such changes are shown here:

```
!
interface Loopback1
 ip address 200.0.100.1 255.255.255.0
!
. . .
router eigrp 100
 redistribute connected
 redistribute static
 redistribute ospf 10 metric 10 100 255 1 1500 route-map OSPF_EIGRP
 network 10.0.0.0
network 200.0.100.0
passive-interface Loopback1
 no auto-summary
```

A new loopback instance has been defined to represent the simulated customer network that previously was represented by a static route. The static route has also been removed (not shown), and the EIGRP process is configured to run passively on the loopback 1 interface. The passive declaration ensures that CPU cycles are not wasted on the EIGRP neighbor discovery that is doomed to fail, given the lonely neighborhood that is loopback 1. And yes, loopback 0 should be set to be passive for the same reasons, but that is saved for another day. After similar changes are made at `Barley`, the active EIGRP routes are displayed and the previous traceroute is repeated:

```
Malt# showip route eigrp
D    200.0.200.0/24 [90/2297856] via 10.1.254.2, 00:11:42, Serial0/0
     10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
D       10.10.128.200/32 [90/2297856] via 10.1.254.2, 04:24:16,
Serial0/0
Malt# traceroute 200.0.200.1

Type escape sequence to abort.
Tracing the route to 200.0.200.1

1 10.1.254.2 16 msec 12 msec *
```

Excellent, just what you wanted to see. Before moving on, traceroutes to a few other destinations in the OSPF domain are executed for added confirmation. Note that the simulated customer network routes at `Ale` and `Lager` are set to discard, so you should expect no reply from them:

```
Malt# trace 10.20.128.3

Type escape sequence to abort.
Tracing the route to 10.20.128.3

  1 192.168.1.2 4 msec 4 msec 12 msec
  2 10.20.128.3 4 msec 8 msec 8 msec
Malt# trace 200.10.5.1
Type escape sequence to abort.
Tracing the route to 200.10.5.1

  1 192.168.1.2 8 msec 8 msec 8 msec
  2 200.10.5.1 4 msec 20 msec 100 msec
```

The traceroutes to the loopback address and OSPF area 1 routes on `PBR` are successful and are observed to take a reasonable forwarding path. Similar results are observed at `Barley`:

```
Barley# trace 200.10.2.1

Type escape sequence to abort.
Tracing the route to 200.10.2.1

  1 192.168.2.2 20 msec 4 msec 12 msec
  2 10.10.129.1 4 msec 28 msec 12 msec
  3 200.10.2.1 8 msec 8 msec 8 msec
```

Let's temporarily down the OSPF adjacency at `Malt` (traffic will be rerouted through `Barley`) to confirm that `Malt` falls back to the EIGRP versions of the OSPF domain's routes and actually begins to forward through `Barley`:

```
Malt(config)# interface fastEthernet 0/1
Malt(config-if)# sh
Malt(config-if)# ^Z
. . .
```

After a few moments, the route table is again displayed at `Malt`:

```
Malt# show ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

D    200.0.200.0/24 [90/2297856] via 10.1.254.2, 00:31:34, Serial0/0
D EX 200.10.4.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.10.5.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.0.1.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.10.1.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.0.2.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
D EX 200.10.2.0/24 [170/256537600] via 10.1.254.2, 00:00:36, Serial0/0
C    200.0.100.0/24 is directly connected, Loopback1
D EX 200.10.3.0/24 [170/256537600] via 10.1.254.2, 00:00:37, Serial0/0
     10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
D       10.10.128.200/32 [90/2297856] via 10.1.254.2, 04:44:10, Serial0/0
D EX    10.10.129.0/24 [170/256537600] via 10.1.254.2, 00:00:37, Serial0/0
D EX    10.10.128.1/32 [170/256537600] via 10.1.254.2, 00:00:37, Serial0/0
D EX    10.10.130.0/24 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
D EX    10.10.128.2/32 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
D EX    10.10.131.0/24 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
D EX    10.20.128.4/32 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
D EX    10.20.128.3/32 [170/256537600] via 10.1.254.2, 00:00:39, Serial0/0
C       10.10.128.100/32 is directly connected, Loopback0
C       10.1.254.0/24 is directly connected, Serial0/0
C       10.1.254.2/32 is directly connected, Serial0/0
     192.168.1.0/30 is subnetted, 1 subnets
D EX    192.168.1.0 [170/256537600] via 10.1.254.2, 00:00:34, Serial0/0
     192.168.2.0/30 is subnetted, 1 subnets
D EX    192.168.2.0 [170/2172416] via 10.1.254.2, 00:00:40, Serial0/0
```

The display confirms that the EIGRP versions of the redistributed OSPF routes are now active. A traceroute confirms the expected forwarding path, given the down `fa 0/0` interface at `Malt`:

```
Malt# traceroute 200.10.5.1
Type escape sequence to abort.
Tracing the route to 200.10.5.1

  1 10.1.254.2 12 msec 12 msec 12 msec
  2 192.168.2.2 20 msec 16 msec 20 msec
  3 10.10.129.1 116 msec 24 msec 20 msec
  4 200.10.5.1 48 msec 28 msec 36 msec
Malt#
```

`Malt`'s `fa 0/1` interface is returned to operation and the OSPF adjacency is allowed to reform. You should then inspect the route table to ensure that the network state has returned to the initial state. Issues with route redistribution/preference are often timing-dependent, and you may find that after a failure the network does not return to the desired state. Here, expect to find that the OSPF versions of the routes are again preferred over the EIGRP version:

```
Malt#
*Mar  1 06:02:24.202: %OSPF-5-ADJCHG: Process 10, Nbr 10.10.128.1 on FastEthernet0/1.
69 from LOADING to FULL, Loading Done
Malt#
Malt# show ip route eigrp
D    200.0.200.0/24 [90/2297856] via 10.1.254.2, 00:36:14, Serial0/0
     10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
D       10.10.128.200/32 [90/2297856] via 10.1.254.2, 04:48:48, Serial0/0
Malt#
```

The display confirms that the native OSPF routes are again active, as they are preferred over redistributed EIGRP copies. This validates that the network is able to fail over, and then switch back to a steady state. Connectivity between the two RDs has already been demonstrated, so let's conclude our IGP migration verification with some selective captures in the OSPF domain, starting by examining the "large" external LSA database now on backbone routers:

```
[edit]
lab@Ale# run show ospf database extern
    OSPF AS SCOPE link state database
 Type       ID              Adv Rtr         Seq       Age  Opt  Cksum  Len
Extern  10.1.254.0     10.10.28.100 0x8000000b   850  0x20 0xe0c4  36
Extern  10.1.254.0     10.10.28.200 0x8000000b   783  0x20 0x86ba  36
Extern  10.1.254.1     10.10.28.200 0x8000000b   783  0x20 0x7cc3  36
Extern  10.1.254.2     10.10.28.100 0x8000000b   850  0x20 0xccd6  36
Extern  10.10.128.100 10.10.28.100 0x80000009  1607  0x20 0xfbbc  36
Extern  10.10.128.100 10.10.28.200 0x80000009  1531  0x20 0xb59c  36
Extern  10.10.128.200 10.10.28.100 0x80000009  1607  0x20 0x242e  36
Extern  10.10.128.200 10.10.28.200 0x80000009  1531  0x20 0xb53a  36
Extern *200.0.1.0      10.10.128.1   0x80000005  2101  0x22 0x87c7  36
Extern  200.0.2.0      10.10.128.2   0x80000005  2427  0x22 0x76d6  36
Extern  200.0.100.0    10.10.28.100 0x8000000d   592  0x20 0xdda2  36
Extern  200.0.100.0    10.10.28.200 0x80000002   526  0x20 0xad77  36
Extern  200.0.200.0    10.10.28.100 0x80000002   351  0x20 0xb76d  36
Extern  200.0.200.0    10.10.28.200 0x80000002   526  0x20 0x4979  36
```

Well, it seems that *large* truly is a subjective term. However, more than 10 Type 5 LSAs are in the backbone area's database, and considering the small scope of the EIGRP network in this lab example, it's safe to say that a large enterprise could easily generate hundreds if not thousands of these AS external LSAs:

```
[edit]
lab@Ale# run show ospf database extern detail | match tag
  Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
```

```
    Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 4, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 4, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 0, fwd addr 0.0.0.0, tag 0.0.0.0
    Type 2, TOS 0x0, metric 0, fwd addr 0.0.0.0, tag 0.0.0.0
    Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 4, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 4, fwd addr 0.0.0.0, tag 0.0.0.100
    Type 2, TOS 0x0, metric 2, fwd addr 0.0.0.0, tag 0.0.0.100
```

Next, the CLI's matching function, combined with the `detail` switch, allows confirmation that most of these externals originated in the EIGRP domain, given that the majority are sporting a tag with an EIGRP process number.

The new OSPF network was designed to be hierarchical to promote scaling. To take this a step further, let's also deploy NSSAs to reduce the processing demands on non-backbone routers. Internal routers within a stub area do not see any AS external LSAs, which in this type of a migration can substantially reduce their load. Confirm this fact at router PBR:

```
[edit]
lab@PBR# run show ospf database

    OSPF link state database, Area 0.0.0.1
 Type       ID             Adv Rtr        Seq      Age  Opt  Cksum  Len
Router   10.10.128.1  10.10.128.1  0x8000000c  273  0x20 0xac79  48
Router  *10.20.128.3  10.20.128.3  0x80000008  928  0x20 0x6124 108
Network *10.10.130.2  10.20.128.3  0x80000007  928  0x20 0x7b49  32
Summary  10.10.128.2  10.10.128.1  0x80000008 2223  0x20 0xda30  28
Summary  10.10.129.0  10.10.128.1  0x80000008 2073  0x20 0xe328  28
Summary  10.10.131.0  10.10.128.1  0x80000008 1773  0x20 0xd731  28
Summary  10.20.128.4  10.10.128.1  0x80000007 1473  0x20 0x5aa4  28
Summary  192.168.1.0  10.10.128.1  0x8000000b  625  0x20 0x9a9c  28
Summary  192.168.2.0  10.10.128.1  0x80000006  573  0x20 0xa396  28
NSSA     0.0.0.0      10.10.128.1  0x80000008  423  0x20 0xa1ea  36
NSSA     200.0.1.0    10.10.128.1  0x80000005 2373  0x20 0x89c5  36
```

Note the absence of Type 4 and Type 5 LSAs, and the presence of the default route, which provides the internal stub area routers with a route to external destinations:

```
[edit]
lab@PBR# run show route 200.0.200.4

inet.0: 23 destinations, 23 routes (23 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 04:26:43, metric 11, tag 0
                    > to 10.10.130.1 via ge-0/0/0.1141
```

This last display confirms the use of the default route for AS external destinations by the internal NSSA router PBR.

With initial connectivity confirmed, the EIGRP-to-OSPF migration can proceed through a phased movement of legacy EIGRP segments to the new OSPF backbone. Alternatively, the EIGRP domain can be shrunk back by increasing the scope of the OSPF domain and moving the EIGRP redistribution points until there is no EIGRP left.

EIGRP-to-OSPF Migration Summary

This section demonstrated how you can integrate a new OSPF backbone into an existing EIGRP infrastructure, while maintaining loop-free connectivity through careful use of route filtering. Filtering is needed to ensure that those routes are redistributed only once. The example used route tags to simplify filtering. Address-based filters can also work, especially if the two IGP domains have distinct numbering that can easily be summarized.

Mutual route redistribution is always a bit tricky, and careful thought should be leveled against any migration plan to try to head off potential issues stemming from protocol preferences or incomplete route filtering. In this example, the interaction of OSPF and EIGRP external preferences created a problem for static routes redistributed into EIGRP. Although connectivity was maintained and no loops were formed, the condition resulted in suboptimal forwarding for some destinations. The specifics of this example allowed the creation of a new loopback interface, which then ran a passive instance of EIGRP to stand in for the static route, yielding optimal connectivity for all destinations in the test bed.

Conclusion

The IGP is a critical component in any enterprise network. The IGP functions to provide optimal connectivity to interior destinations in the face of changing network conditions. To perform this function, the IGP must balance the opposing forces of rapid convergence against instability and routing loops. A well-designed and implemented IGP can easily spell the difference between a high-performing network and an ongoing litany of trouble tickets and support calls.

Historically, enterprise networks needed to support multiple routed protocols, and the dominance of Cisco Systems in these early years resulted in widespread deployment of its proprietary IGRP and EIGRP IGP solutions. Since that time, most enterprise networks have completed a migration to an all-IP routing infrastructure. Simply stated, the world seems to have settled on the mantra “IP over everything, and everything over IP.” Although EIGRP does a good job at routing IP, its closed nature, coupled with its lack of routing hierarchy and MPLS TE support, cast serious concerns over its future high-performance enterprise networks.

Over the years, several tried and proven strategies have been developed to ease the pain and disruption that often accompany IGP migration. Whether an enterprise chooses to deploy Junos or not, these migration techniques can get your legacy network weaned off of EIGRP and onto an open standard such as OSPF.

Juniper Networks routers support all standardized IGPs, and their implementation has been successfully battle tested in the planet's largest service provider networks. The same OSPF code running in the multiterabit iron of the Juniper Networks flagship T4000 core router can also be found purring away in the smallest enterprise-targeted Juniper devices. Although historically designed for service provider networks, Juniper Networks continues to evolve its IGP implementation to meet the needs of both its service provider and enterprise customers.

Exam Topics

We covered the following Enterprise Exam Topics in this chapter:

- The role and function of an IGP
- Operational characteristics of RIP, RIPv2, OSPF, and IGRP/EIGRP
- RIP and OSPF configuration on Juniper Networks routers
- Operational analyses of RIP and OSPF on Juniper Networks routers
- The overlay, redistribution, and integrated IGP migration models

Chapter Review Questions

1. Which of the following defines *split horizon*?
   A. Sending routes out the interface they were learned from
   B. Sending routes out the interface they were learned from with infinite metric
   C. Holding a recently unreachable route in the table for a fixed time to allow other routers to be notified
   D. Not sending routes out the interface they were learned from
2. When you configure RIP on a Juniper Networks router, how do you specify what interfaces the protocol should operate on?
   A. You use a network statement with a network mask
   B. You use a network statement with a wildcard mask
   C. You specify interface names and logical units explicitly as part of RIP neighbor configuration
   D. You use routing policy
   E. None of the above

3. What command displays the RIP routes a Juniper Networks router is sending out to a given interface?
   A. This is not possible given the LS nature of RIP
   B. `show route protocol rip`
   C. `show route advertising-protocol rip` *`<neighbor>`*
   D. `show route receiving-protocol rip` *`<neighbor>`*
4. Which type of router generates a Type 2 LSA?
   A. Internal
   B. ABR
   C. ASBR
   D. DR
5. Which is true regarding a stub area with `no-summaries`?
   A. The area uses a default to reach interarea destinations
   B. The area imports external routes as Type 7 LSAs
   C. The area does not receive Type 3 summary LSAs from the backbone
   D. The area has no OSPF routers in it
6. When you add a new OSPF router to a LAN, what factor(s) determine whether it will become the DR?
   A. Its priority setting
   B. The RID
   C. Whether any other routers are already operating on that LAN
   D. All of the above
7. What determines which route will be active when a given prefix is learned by multiple routing protocols?
   A. The lowest metric
   B. The path with the fewest hops
   C. The protocol with the highest numerical preference is chosen
   D. The protocol with the lowest numerical preference is chosen
8. Which syntax at an ABR would suppress individual summaries for routes in the 10.0/16 block in area 1 while replacing them with a single summary?
   A.
   ```
   [edit protocols ospf area 0.0.0.1]
   set area-range 10.0/16 restrict
   ```
   B.
   ```
   [edit protocols ospf area 0.0.0.0]
   set area-range 10.0/16
   ```

C.
```
[edit protocols ospf area 0.0.0.1]
set area-range 10.0/16
```
D. This is not possible; LSAs cannot be filtered without breaking LS protocol operation

9. Which is true regarding the overlay migration model?
   A. You first set the legacy IGP to be less preferred than the new IGP
   B. You first set the new IGP to be less preferred than the legacy IGP
   C. Route redistribution is needed to maintain connectivity through the migration
   D. A new backbone is needed
10. What is the primary mechanism for loop prevention in the redistribution model?
   A. A common LSDB ensures a loop-free topology
   B. Strict controls that ensure routes are not redistributed back to their originating IGP
   C. Setting the new IGP to be more preferred than the legacy IGP
   D. A careful mapping of metrics between originating and receiving IGPs
11. What types of authentication are supported in Junos for OSPF?
   A. Simple password
   B. MD5 checksum
   C. Hitless key chain of MD5 keys/checksums
   D. All of the above
12. Which configuration will inject a default route into stub area 1?

A.
```
area 0.0.0.1 {
stub default-metric 10 no-summaries;
area-range 10.0.0.0/16 restrict;
}
```
B.
```
area 0.0.0.0 {
stub default-metric 10;
}
```
C.
```
area 0.0.0.1 {
stub no-summaries;
area-range 10.0.0.0/16 restrict;
}
```
D.
```
area 0.0.0.1 {
stub default-metric;
area-range 10.0.0.0/16 restrict;
}
```

Chapter Review Answers

1. Answer: D. Split horizon rules prevent a router from readvertising routing information back out the same interface it was learned from; poisoned reverse alters this behavior to permit such updates as long as they have an infinite metric.
2. Answer: C. You specify RIP-enabled interfaces by name and unit number, under the `[edit protocols rip group` *`<name>`* `neighbor]` hierarchy.
3. Answer: C. The **`show route advertising protocol`** *`<protocol>`* **`<neighbor>`** command is used to display the route the local router is sending out an interface to a neighbor for RIP/BGP, respectively. The **`receiving-protocol`** form of this command shows the routes being learned over an interface.
4. Answer: D. Only designated routers, which are elected only on multiaccess networks, generate Type 2 network summary LSAs. This LSA type is used to report the list of OSPF neighbors (including the DR itself) attached to the multiaccess segment.
5. Answer: C. A stub area with `no-summaries` does not receive summary LSAs from the backbone. It relies on an injected default route to reach interarea and AS external destinations.
6. Answer: D. All of the factors listed influence whether a given router can become the DR. Recall that DR election is not revertive. A router's ID and priority come into play only during an active DR election.
7. Answer: D. The protocol with the numerically lowest preference (or administrative distance) is considered more "reliable" and is chosen as the source of the active route.
8. Answer: C. Your goal is to filter from area 1 into area 0, so the `area-range` statement needs to be applied to area 1. The restrict keyword should not be used here as it will also filter on the summary, in effect converting from a match type of `longer` to one of `orlonger`. The goal is to permit the summary, which makes answer A false.
9. Answer: B. To avoid disruption, the legacy protocol must operate until all aspects of the new IGP have been put in place and confirmed. The new IGP has to be less preferred than the original until you are ready to actually make the switchover.
10. Answer: B. You must diligently use filtering mechanisms to ensure that routes are never redistributed back into the IGP from where they originated, or else loops will likely form.
11. Answer: D. For OSPF, Junos supports simple passwords, MD5, and a key chain of MD5 secrets. RIP does not support key chain authentication as of the Junos 8.3 release.
12. Answer: A. Junos will generate a default route only when a metric value is specified using the `default-metric` command.

CHAPTER 7

Border Gateway Protocol and Enterprise Routing Policy

This chapter reviews the Border Gateway Protocol (BGP) version 4 operation and key attributes to accommodate a detailed discussion of BGP enterprise applications. BGP is all about the *control* of routing information *between* autonomous systems (ASs). Emphasis is placed on the use of routing policy to facilitate load balancing and common enterprise applications of inbound and outbound routing requirements when customers are dual-homed to different service providers. The topics covered include:

- BGP overview and enterprise applications
- External BGP (EBGP) peering with asymmetric load balancing
- BGP policy for the enterprise
- BGP dual-homing scenario with route reflection and outbound policy
- Implementation of a dual-homed inbound policy by manipulating BGP attributes

Juniper Networks routers offer extensive feature support for BGP. In fact, the list of supported standards is too long to be valuable here. Consult the BGP overview in the Junos documentation to confirm the list of supported RFCs and drafts for your particular Junos software release.

What Is BGP?

BGP is an interdomain routing protocol, which means it operates between networks that are under different administrative control—making BGP an Exterior Gateway Protocol (EGP) that operates between ASs. An AS is defined as a group of IP networks operated by one or more network operators that has a single, clearly defined routing policy.

BGP is a path-vector routing protocol that relies on the uniqueness of AS path numbers for loop prevention. Rather than advertising a simple vector (prefix), as in the case of the Routing Information Protocol (RIP), BGP's reachability information is a prefix with associated attributes that describe the *path* to that prefix. The rich set of supported attributes in turn allows for an equally rich set of policy actions.

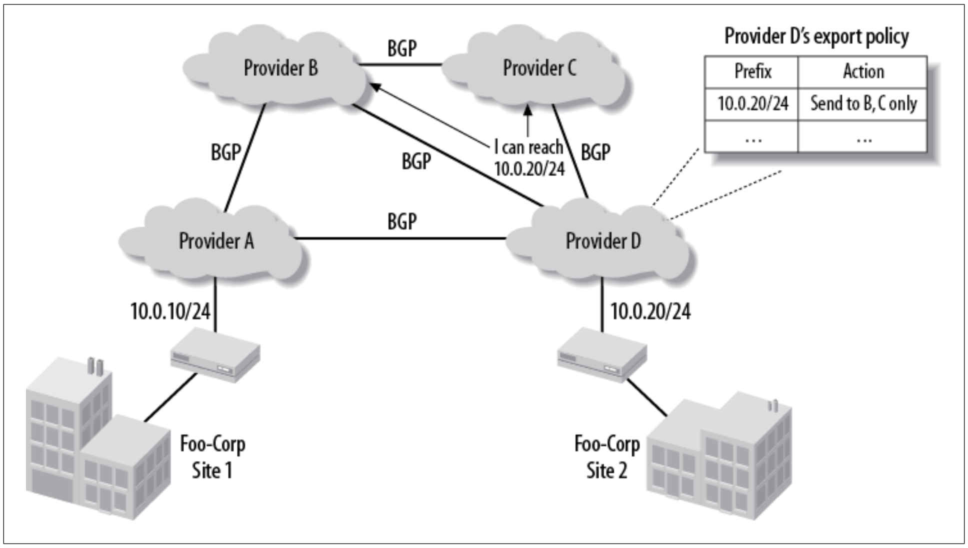
BGP is somewhat unique in that it uses a reliable Transmission Control Protocol (TCP)-based transport for its control and update messages. Reliable transport means there is no need for periodic route updates, which is really, really good, considering that a full BGP table typically comprises more than 350,000 routes! BGP does generate periodic keepalive traffic in the absence of route update activity to ensure that the underlying TCP transport is still functional.

BGP version 4 has been in use for more than two decades, with the current version (BGP 4) originally defined in RFC 1654 back in 1994. This RFC was obsoleted by RFC 1771, which in turn was obsoleted by the current specification, RFC 4271. The fact that BGP still enjoys a growing deployment base, with no replacement looming on the horizon, is a testament to the architects' forward-thinking design. BGP is based on the use of parameter type, parameter length, and parameter value tuples (sometimes called *tag length values*, or TLVs). It is these TLVs that provide the inherent extensibility without the need for significant protocol changes. You want IPv6 address family support? Simple; just define a new network layer reachability information (NLRI) attribute. You need route reflection? No problem; add some new attributes to communicate cluster and originator ID information. Meanwhile, the basic operation and protocol mechanisms remain unaltered and, in many cases, backward-compatible.

Inter-AS Routing

In several regards, you can think of BGP as the antithesis of an Interior Gateway Protocol (IGP). For example, an IGP functions *within* an AS and strives to *promote* connectivity, whereas a BGP operates *between* ASs and tends to *limit* connectivity. That last point may require a bit more clarification. An IGP normally actively seeks to discover routing peers (neighbor discovery). Once the neighbors are found, routes are exchanged and connectivity is promoted by virtue of always seeking the best path between endpoints. BGP, on the other hand, has to be explicitly told which neighbors to peer with, and then the use of administrative policy is used to filter and modify routing information to select the "best" route that meets the network operator's defined policy. The word *best* is quoted here because when routing between ASs, the concept of what constitutes a best path is cloudy at best. For example, a company may choose to filter large portions of BGP connectivity from best path consideration, based solely on a local policy that does not allow the use of a specific competitor's backbone. Exactly why such a policy is in place is not the question, although many good answers spring to mind, including potential concerns of corporate espionage. The point here is that with BGP, you are normally as concerned about restriction/ignoring routing information as you are about receiving it in the first place. The IGP is focused on getting you there, whereas BGP is more concerned with *how* you get there.

Figure 7-1 illustrates a simple interdomain routing scenario, where each AS is represented by a cloud. The cloud is, of course, the universal symbol for "don't ask, don't tell." This is to say that specifics of each AS are left to the administrators of that network and are generally not known outside of that scope. It might be possible for a transit network to deploy an avian-based transport technology, as per RFC 1149*; as long as they meet their service level agreements (SLAs), the details of how they manage to pull it off are typically not a matter of concern.



Prefix	Action
10.0.20/24	Send to B, C only
...	...

Figure 7-1. Interdomain routing with BGP

BGP operates on the links that tie these networks together, in effect serving as the *public face* of each network. The BGP speakers in each AS advertise network reachability to the ASs they are configured to peer with, under the confines of their specific export policy. In like fashion, each BGP speaker filters received information through its respective import policy before placing what remains into its route table for consideration for the active route selection process. Figure 7-1 shows that Provider D's policy prevents the advertisement of the 10.0.20/24 prefix from Site 2 to Provider A. Provider A will have to receive the Site 2 prefix from Provider B. As a result, the two customer sites will be forwarding over additional AS hops to reach each other. This point helps to demonstrate that for BGP, connectivity is as much a matter of politics as it is performance.

BGP Route Attributes

BGP advertises route information called next layer reachability information (NLRI), along with various attributes that describe the path to that prefix. The terms *NLRI*,

* RFC 1149 is one of the more notorious "less than serious" RFCs, as indicated by its April 1 publication date.

route, and *prefix* are synonymous and are used interchangeably in this chapter. This section describes key BGP path attributes. Policy discussions later in this chapter require that you understand what these attributes do and how you work with them to achieve your routing goals.

All BGP route attributes fall into one of the following categories based on whether all BGP speakers are expected to understand the attribute and whether the attribute has local-AS or end-to-end scope:

Well-known mandatory
: A well-known mandatory attribute must be supported by all BGP speakers and must be present in all BGP updates that contain an NLRI.

Well-known discretionary
: A well-known discretionary attribute must be supported by all BGP speakers and may or may not be present in a given NLRI update.

Optional transitive
: An optional transitive attribute is an optional attribute that may not be understood by all speakers and is expected to transit the local AS, even if it is not understood by the local speaker.

Optional nontransitive
: An optional nontransitive attribute is an optional attribute that may not be understood by all speakers and does not transit the local AS—that is, it is not readvertised to another, remote AS.

Common BGP path attributes include:

Next hop
: The next hop is a mandatory attribute that carries the IP address of a BGP speaker (or a third party when permitted) to identify where packets should be forwarded when using the associated route. The next hop is changed by default for EBGP and is unchanged for Internal BGP (IBGP); however, this default behavior can be altered with policy.

Local preference
: Local preference is a well-known discretionary attribute used to influence BGP path selection with regard to the desired egress point for traffic from within an AS. Traffic flows toward the peer advertising the highest (most preferred) local preference. Local preference is present only in IBGP updates (nontransitive); this attribute is not advertised to EBGP peers.

AS path
: The mandatory attribute AS path lists the AS numbers that will be crossed when forwarding to the associated NLRI. The AS path attribute is used for loop prevention and influences path selection in accordance with the motto "the fewer ASs in a path, the better." Each AS adds its AS number to the front of the current AS sequence when generating *EBGP* updates; the lack of updated AS path information

in IBGP updates is why IBGP speakers are not permitted to readvertise routes learned from IBGP back to other IBGP speakers. By default, BGP discards any route advertisement that contains its local AS number in the AS path, because this indicates that the route has already passed through the local AS once; that is, a loop has formed.

Origin
: The origin code is a well-known, mandatory attribute that identifies the original source of a route as being learned from an IGP, EGP, or unknown source. In route selection, a BGP speaker will prefer IGP to EGP, and EGP to unknown. Origin is present in all route updates and is subject to modification with policy (transitive).

Multiple exit discriminator
: The multiple exit discriminator (MED) attribute is an optional, nontransitive attribute, which means that some BGP speakers may not understand or use MED. MED is added on updates sent over EBGP links, and is then advertised by IBGP within the receiving AS to influence its outbound routing. However, the MED attribute does not transit beyond the AS into which it was originally advertised—BGP speakers in upstream ASs either receive no MED or receive a new MED value created by that peering AS.

  MED functions like a conventional routing metric in that speakers prefer the route with the lowest MED when all preceding decision points are equal. The MED advertised by the originating AS to an adjacent AS provides a clue to the adjacent AS regarding what links should be used for *egress* from the neighbor AS back toward the originating AS, and therefore what links are used as *ingress* to the local AS. Stated differently, the MED is used by the local AS to influence the routing decisions in an adjacent AS for traffic that is inbound to the local AS. When absent, Junos software assumes an MED value of 0, which is the most preferred setting. In contrast, the absence of a local preference is assumed to be a value of 100.

Community
: The community attribute allows for the arbitrary grouping of routes that share one or more characteristics via the addition of a common community tag value. The community tags can be used for a variety of purposes, such as route filtering and attribute modification. For example, all routes learned from customers may be assigned the community value of 65000:100. When this community is seen on a route, the local policy will set a more preferred local preference. As another example, consider the well-known community *no-export*. When attached to a route, this community tells the adjacent AS that the associated route should not be readvertised to any remote ASs.

BGP Path Selection

A BGP speaker that is presented with two or more updates, specifying the same prefix, performs a route selection process to select the best BGP path for that prefix. Once the best path is selected, the route is installed in the route table, where it may become active if the same prefix is not being learned by a protocol with a better global preference. The Junos software BGP path selection process consists of the following decision steps:

1. Can the BGP next hop be resolved?
2. Prefer the path with the highest local preference value.
3. Prefer the path with the shortest AS-path length.
4. Prefer the path with the lowest origin value.
5. Prefer the path with the lowest MED value.
6. Prefer the path learned using EBGP over paths learned using IBGP.
7. Prefer paths with the lowest IGP metric:
   a. Examine route tables `inet.0` and `inet.3` for the BGP next hop, and then install the physical next hop(s) for the route with the better preference.
   b. For preference ties, install the physical next hop(s) found in `inet.3`.
   c. For preference ties within the same route table, install the physical next hop(s) where the greater number of equal-cost paths exists.
8. Prefer paths with the shortest cluster length.
9. Prefer routes from the peer with the lowest router ID (RID), unless multipath is enabled:
   a. For external routes from different ASs, do not alter the active route based on the lowest RID to prevent MED oscillation.
10. Prefer routes from the peer with the lowest peer ID (BGP peering address), unless multipath is enabled.

Configuring the multipath option deactivates the last two decision points, which are normally used as tiebreakers. When multipath is enabled, all paths that are equal up to step 9 are installed in the route table. Multipath supports EBGP and IBGP, but it is normally associated with EBGP sessions because IBGP will often achieve its load-balancing functionality through the underlying IGP when equal cost paths to the IBGP speaker exist. Use multipath for IBGP when two or more IBGP speakers advertise the same prefix and you wish to install both speakers as viable next hops.

Figure 7-2 demonstrates the BGP path selection process at work.

Here, NLRI 10.0.20/24 is originated into BGP by AS 65000. Note that when advertised to ASs 65010 and 65069, this NLRI is associated with an AS path attribute that consists of a single AS and has an origin value of "I" indicating IGP learned. This could be a default value for redistribution of static routes into BGP or the result of policy setting. The NLRI is then readvertised into AS 65069 by AS 65010. Initially, routers R1 and R2 prefer their local copy of this path, so both R1 and R2 select it as active and advertise the NLRI to all IBGP peers, which means that R3 receives two updates for the same path. In this example policy, R2 causes the route to be sent into IBGP with a modified

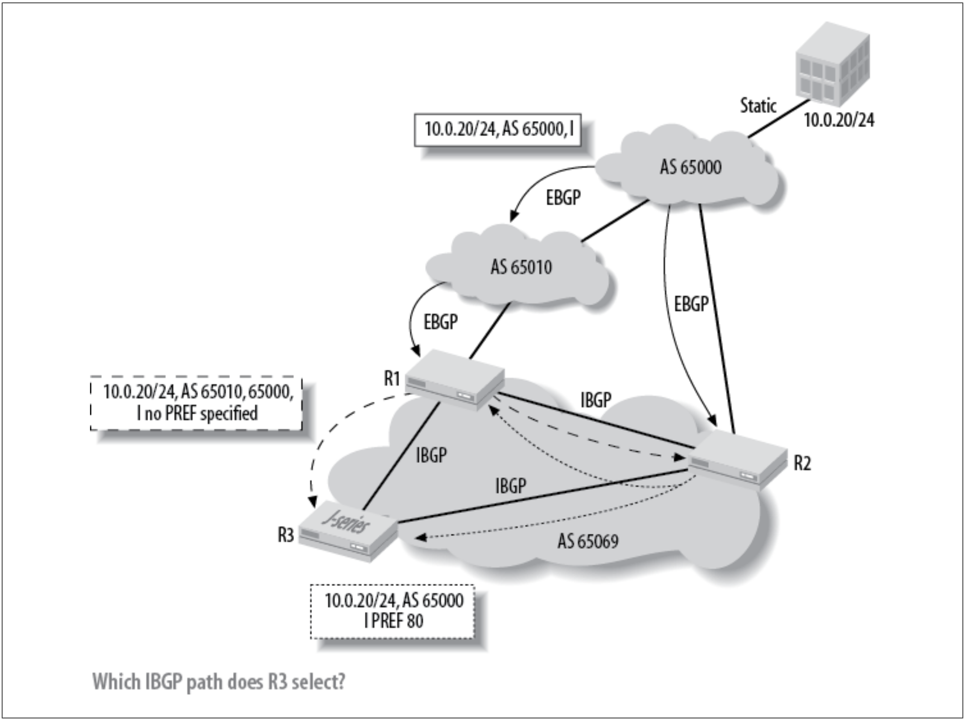

10.0.20/24, AS 65000, I
Static
10.0.20/24
AS 65000
EBGP
AS 65010
EBGP
EBGP
R1
IBGP
10.0.20/24, AS 65010, 65000, I no PREF specified
IBGP
R2
IBGP
R3
J-series
AS 65069
10.0.20/24, AS 65000 I PREF 80
Which IBGP path does R3 select?

Figure 7-2. BGP path selection

local preference value of 80. Note that the route received from AS 65010 has an AS sequence one AS longer than the route sent to R2 directly from AS 65000.

Running through the path selection process steps listed previously, it's safe to assume that R3 will make a decision early in the process, preferring the copy of the route with a default local preference of 100. Had both local preference values been the same, the selection criterion would now become the shortest AS path length, resulting in R3 forwarding through R2. Note that R1 and R2 will also send their 10.0.20/24 updates to each other. This means that R2 prefers the path through R1, and therefore now sends another update to R1 and R3, withdrawing its earlier IBGP update for 10.0.20/24. The example also helps to demonstrate how local preference is used to influence the egress point in the local AS.

Junos software is designed to display all valid BGP paths, and even includes the reason why a given path was not selected. This greatly simplifies the network administrator's job when the goal is to make a currently inactive path the active path; policy can be applied to alter the criterion that leads to the original path being preferred. Here's the output from a `show route detail` command, to illustrate this point:

```
user@host> show route 10.0.20/24 detail
inet.0: 52 destinations, 94 routes (52 active, 0 holddown, 0 hidden)
10.0.20.0/24 (3 entries, 1 announced)
```

```
                *BGP    Preference: 170/-201
                        Source: 192.168.32.1
                        Next hop: 10.222.28.2 via ge-0/0/0.0, selected
                        Protocol next hop: 192.168.32.1 Indirect next hop:
        858b4e0 73
                        State: <Active Int Ext>
                        Local AS: 65069 Peer AS: 65069
                        Age: 18:57      Metric2: 3
                        Task: BGP_65432.192.168.32.1+1042
                        AS path: 65000 65010 I
                        Localpref: 100
                        Router ID: 192.168.32.1
                 BGP    Preference: 170/-101
                        Source: 10.222.29.2
                        Next hop: 10.222.29.2 via ge-0/1/0.0, selected
                        State: <Ext>
                        Inactive reason: Local Preference
                        Local AS: 65069 Peer AS: 65069
                        . . .
                        Localpref: 80
```

From the sample output, it is quite clear that because of the local preference comparison, the path through 192.168.32.1 is preferred. Knowing that this BGP route was not chosen because of the local preference value makes it a relatively simple task to change the selection of the path through 192.168.32.1 by setting its preference to be higher than 100.

Internal and External BGP

We have already used the terms *Internal BGP* and *External BGP* (IBGP/EBGP) a few times leading up to this point. It's time to explore what this terminology signifies. For the most part, BGP operation is the same when operating internally to an AS versus externally to a remote AS, but Table 7-1 summarizes the key differences.

Table 7-1. IBGP and EBGP

Characteristic/attribute	IBGP	EBGP
Local AS added to AS path	No	Yes
Next hop overwritten	No	Yes
New MED added	No; the MED received on an EBGP link can be advertised via IBGP within the local AS	Yes
Local preference	Yes	No
Peering address	Normally loopback, recursive lookup provided by IGP, Time to Live (TTL) = 64	Normally peers directly to interface address, no recursion or IGP needed, TTL = 1
Update received from EBGP, is sent to	All IBGP peers	Other EBGP peers
Update received from IBGP, is sent to	No IBGP peers	All EBGP peers

Although the differences may seem trivial, they can have a significant impact. For example, because IBGP updates do not alter the AS path attribute, loops become a concern, and this leads to the restriction that IBGP speakers cannot readvertise an IBGP update to other IBGP speakers, which leads to the requirement that IBGP speakers should be fully meshed (see the next section for alternatives).

The next hop-handling differences often lead to IBGP routes that are hidden because the receiver cannot resolve the associated BGP next hop. By default, the next hop identifies the EBGP speaker in the adjoining AS, and often the IGP will not carry this route, thereby leading to an unreachable next hop. An IBGP export policy that overwrites the BGP next hop, typically to the IBGP peering address (next-hop self), is normally used to resolve this issue (no pun intended).

The MED attribute is normally added only when a route is advertised over an EBGP peering, and its absence may be interpreted as the lowest or highest possible value, depending upon implementation—Juniper assumes the lowest value, which is 0. In contrast, local preference is present only in IBGP updates, and by standard is assumed to be 100 when absent. When received from an EBGP peer, the MED value can be advertised to other speakers within that AS using IBGP.

The peering differences are significant for several reasons. EBGP normally peers to a neighbor using an address on the directly connected link between the routers. As a result, no route recursion is needed to resolve the BGP peering address to a next hop forwarding address, given that they are one and the same. This means that an IGP, to include static routing, is normally *not* required to support EBGP peering. It also means that loss of the directly connected network/peering interface results in loss of the EBGP session. For security reasons, the TTL for EBGP sessions is set to 1 by default, which prevents attempts to peer from a remote link. This behavior is altered by configuring multihop on the EBGP session. Lastly, a `local-address` (referred to as *update-source* in IOS) is normally *not* used for an EBGP session, because by default, it is sourced from the same directly connected network interface that the two BGP routers are peering over; therefore, the source and destination addresses for the BGP session will be from the same, directly connected subnet.

IBGP, in contrast, is normally configured to peer between the loopback addresses of the routers. This provides resiliency from the failure of individual networks or interfaces. IBGP inherently supports multihop, which is good because IBGP neighbors can be located anywhere with the AS and often do not share a link. A recursive route lookup is needed to resolve the loopback peering address to an IP forwarding next hop, and thus this service is normally provided by the network's underlying IGP. When defining a BGP loopback peering session, you need to correctly match the source address used by the local peer to ensure that it matches the session definition at the remote peer. Recall that by default, the router will source traffic from its egress interface, which will not be the loopback interface, and this can make the incoming connection request appear to come from an undefined peer.

Scaling IBGP with Route Reflection

The previous sections touched on the fact that IBGP speakers should be fully meshed because of the restrictions that IBGP has on readvertising updates to other IBGP speakers. When BGP was first envisioned more than 20 years ago, conventional wisdom was that the global Internet would consist of only a few ASs, and that each AS would have a few BGP speakers, and that these speakers would be dealing with a few hundred routes. Recall also that the VP of IBM once announced the worldwide market for mainframes to be around 10 units! Maintaining a full IBGP mesh among a few routers is trivial, but doing so among hundreds of routers is nearly impossible.

Given the modern reality of transit provider networks needing to run IBGP on virtually every router in their AS, and that there may be hundreds of these routers, you can quickly conclude that maintaining a full mesh of IBGP sessions quickly becomes unmanageable. The formula to compute the number of sessions required for a full mesh is $v \times (v - 1)/2$, where v is the number of BGP speakers. Using the formula, we see that for 10 IBGP speakers, a total of 45 IBGP sessions are needed ($10 \times (9)/2 = 45$). Increase the number of speakers by a mere 50%—to 15—and the number of sessions required increases geometrically to 105! It's clear that the full-mesh model simply does not scale; soon routers would exhaust all their control plane resources just maintaining all their BGP sessions. A solution was needed, and route reflection, as currently defined in RFC 4456, provides a remarkably elegant solution to what could have been a significant protocol shortcoming. Figure 7-3 shows a small IBGP cloud before and after route reflection is added.

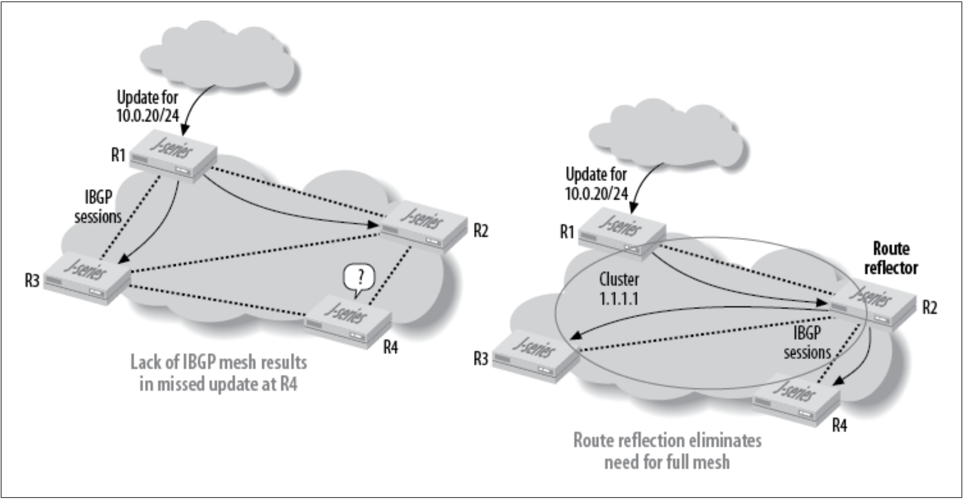


Figure 7-3. BGP route reflection

Note that in the first example, an IBGP session is missing, resulting in a less than full mesh, which in turn leads to holes in the BGP topology. In the second example, however, R2 has been configured to perform reflection, using but a single command to assign a cluster ID. The only change made to clients R1, R3, and R4 is the removal of their now unneeded IBGP sessions.

Route reflection adds two new attributes to IBGP updates to address concerns about BGP loops that would otherwise occur, given that IBGP updates do not modify the AS path. These attributes are added by the route reflector when it first touches a client's route. Configuration of reflection is performed only on the route reflector itself; no configuration changes are needed for a route reflector client, other than perhaps to decommission unneeded IBGP peering definitions to other clients in the same cluster.

The cluster list attribute identifies the route reflection clusters that the route has visited, whereas the originator ID attribute identifies the route's original source. These attributes are processed by route reflectors to prevent loops by ensuring that IBGP updates are echoed only once to each reflector client and nonreflector client. Simply put, a cluster's reflector will not readvertise an IBGP update into cluster ID *n*, when cluster ID *n* is already present in the cluster list attribute. The reflector also uses the originator ID attribute to ensure that updates are never sent back to the client that originated the route. Note that the route reflector first performs the best path selection process on all updates and reflects only the paths it chooses as best.

You typically want the forwarding topology to differ from the reflection topology, which is to say that packets can be forwarded directly between two BGP speakers, despite their learning each other's routes through a reflector. If the IGP's shortest path does not lead through the reflector, the packets should not flow through the reflector. Care must be taken with any next hop self-policy applied to a reflector to ensure that it does not rewrite the next hop on IBGP routes that it is reflecting—doing so will force extra hops on packets that now need to cross the reflector. A next hop self-policy is often applied to IBGP updates to rewrite the BGP next hop of EBGP learned routes with the peering address of the local speaker. This prevents problems with internal speakers not being able to resolve the next hop originally received in the EBGP update, which is set to the remote EBGP speaker's peering address and normally not altered in IBGP updates.

Route reflection and redundancy

Reflection can represent a single point of failure, making it common to add redundancy by deploying multiple reflectors. Normally, each reflector IBGP peers with each client in the cluster, and the two route reflectors are then joined via a nonclient IBGP session. There always seems to be endless debate in such designs as to whether each reflector should be assigned the same or a unique cluster ID. Figure 7-4 illustrates the two design alternatives.

In most cases, a design using unique cluster IDs—which technically results in two route reflector clusters, each having one reflector—is considered the best approach for maintaining connectivity in the event of failures. This is because the reflectors do not see

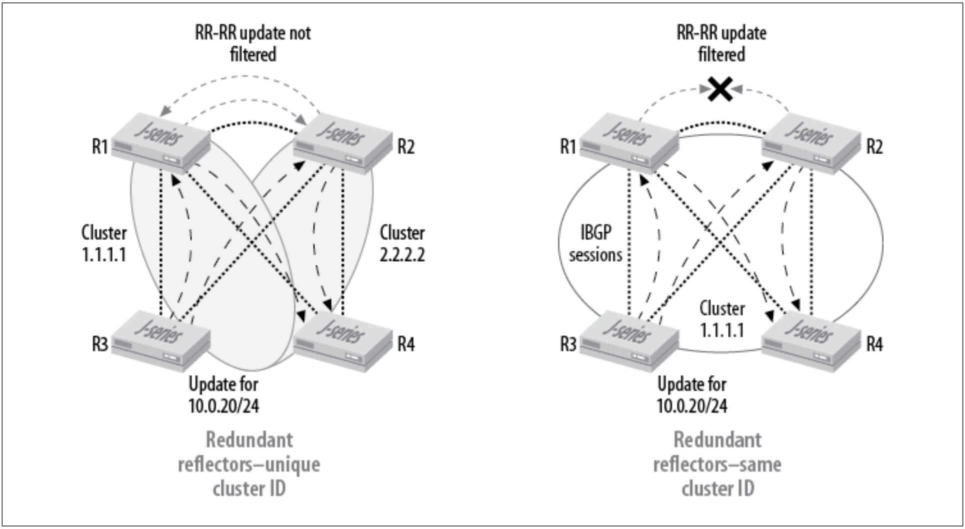


Figure 7-4. Route reflection redundancy

their own cluster ID in the updates they send each other via the route reflector–route reflector IBGP session, and therefore the reflectors will learn of both their intracluster and intercluster paths, resulting in a more complete BGP table at the reflectors. For example, if the R3-R1 IBGP session should fail, R1 is still able to reach R3 via the path learned from R2 in cluster 2.2.2.2. The dual-cluster approach does have the drawback of increased BGP route state at the reflectors, prompting some to prefer the shared cluster ID model.

We discussed the main drawback to the shared cluster ID approach earlier—namely, the potential for client-to-reflector session loss and the resultant lack of connectivity. However, if we assume loopback-based peering, there is actually little risk to the shared cluster model. This is because it's extremely unlikely that a client-to-reflector IBGP session will be lost while the client is still able to maintain connectivity to the rest of the network. You should use unique cluster IDs if you're using interface-based peering so as to provide tolerance for failure of individual interfaces.

Scaling IBGP: Confederations

A BGP confederation effectively divides a large AS into smaller, mini ASs known as *member ASs*. Within each member AS, you normally find a full IBGP mesh, but route reflectors can also be deployed as part of a confederation solution. It's normal to see member ASs assigned AS numbers from the private numbering space because member AS numbers are not seen external to the AS confederation anyway. Because the number of routers within each sub-AS is relatively small, maintaining a full IBGP mesh is manageable. To the outside world, all these confederation shenanigans are hidden, and the entire AS confederation is represented by a single AS number.

Confederation use is rare in enterprise networks, and we will not explore the subject here other than to mention that Juniper routers offer full support for BGP confederations. For more information on BGP confederations, consult Junos software documentation or RFC 5065, “Autonomous System Confederations for BGP.”

BGP and the Enterprise

The preceding section provided a targeted review of BGP’s operational characteristics and scaling approaches. BGP is normally associated with Internet service provider (ISP) networks that offer transit services for Internet traffic. This section focuses on how BGP can be applied to meet the routing needs of enterprise networks.

When Should an Enterprise Run BGP?

BGP is a sophisticated routing protocol that can help to optimize an enterprise’s routing, but that doesn’t mean all enterprise networks will see a benefit from its deployment. An enterprise decision to run BGP normally hinges on the benefits that can be gained by making intelligent outgoing routing decisions and by using BGP attributes in an attempt to influence how upstream networks route toward your network to help control which links are used for ingress traffic. The common factor to both of these scenarios is a network with at least two external connections—such a network is considered to be *dual-homed*. Enterprise networks with a single attachment to a service provider will normally not benefit by running BGP and should simply use a static default route. When dual-attached to the same provider, two static defaults can be used to achieve some measure of outbound load balancing.

A word about AS numbers

Although likely obvious by now, we must state that to run BGP you must first have an AS number. Like IP addresses, there are both public and private AS number pools. Public AS numbers are assigned by a Regional Internet Registry—for example, ARIN for the Americas, Caribbean, and sub-Saharan Africa, APNIC for Asia Pacific, or RIPE for Europe, the Middle East, and Northern Africa.

Historically, the ASN space was limited by the use of a 2-byte value, which permitted a maximum of 65,535 ASs. Support of 4-byte coding for ASNs, which can provide more than 4 billion unique ASNs, is defined in RFC 4893 and is supported in Junos software.

An enterprise should expect to justify its need to the Regional Internet Registry when applying for a public ASN. Requirements vary, but normally you qualify for a public ASN only when your network is multihomed and has a single, clearly defined routing policy that is different from its providers’ routing policies. This brings up a key point about BGP, policy, and dual homing. When you are attached to a single upstream provider, from the perspective of the rest of the world your policy must, by definition, match that of your provider. This is because only one external view of that enterprise’s routes is being made available, and this view is based on your provider's policy. BGP can still be used when connected to a single upstream provider, but in these cases, you will often configure the routers with an ASN from the private AS space. The provider will then strip the private ASN and replace it with its ASN when announcing these routes to other networks. The private ASN space, which is technically allocated to the IANA itself, ranges from 64,512 to 65,534, inclusive. These numbers are often used to number subconfederations within a confederated AS.

ASN Portability

An organization may obtain its ASN directly from a regional numbering authority or as part of its service agreement with a local provider, which in this case functions as a Local Internet Registry (LIR) by delegating ASNs (and address blocks) from its assigned pool. In most cases, ASNs obtained from an LIR will not be portable if you later decide to move to a new provider. This situation is similar to nonportable IP address blocks, which stay with the provider should you choose to obtain service elsewhere. Although AS renumbering is certainly less work than IP renumbering, both can be disruptive and time-consuming—careful thought should be given to the potential need for ASN portability when planning your BGP deployment.

Dual-homed: Single versus multiple providers

Being dual-homed is a great way to improve performance and reliability. But do all dual-homed environments warrant use of BGP? In most cases, this is a function of whether the enterprise is dual-homed to the same or to different upstream providers. Figure 7-5 shows the two types of dual-homing arrangements. Note that both models support multiple attachments to the same ISP, whether for reasons of redundancy or added capacity. In fact, the simplest form of the dual-homed single-provider/dual-provider model is to use a single router with dual links. Relying on a single device for all external connectivity suffers obvious reliability concerns, and it is assumed rare for all but the smallest of enterprise networks. Every rule has exceptions, and here the exception is when a clustered arrangement of SRXs is used to interface to the provider. In this case, the simplicity of the single device is coupled with the reliability of a multirouter design.

Running BGP is normally overkill when you are dual-homed to the same provider, especially when the parallel connections are in close geographic proximity. This is because you are pretty much at the mercy of your provider's policy, and BGP cannot do much to alter the way traffic enters or exits your network—your global view of the Internet must match that of your provider because it is the only view you receive. An enterprise with this type of connectivity is often well served with a simple static default route. Load balancing can occur in one of two ways. For a single router with dual attachments, the load balancing occurs at that router, using the underlying IGP (static) to map prefixes or flows to one of the two links. This router is in turn configured to

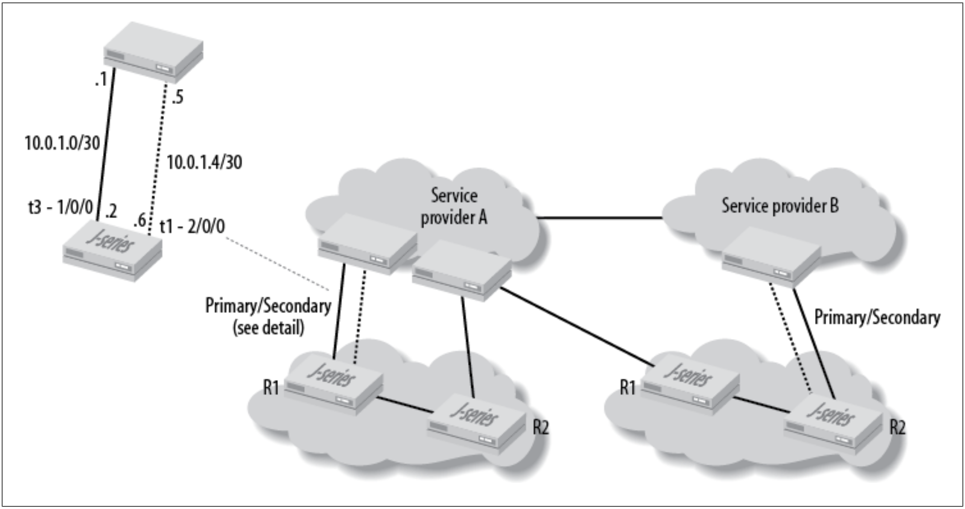


Figure 7-5. BGP dual homing

advertise a default route into the IGP to attract nonlocal traffic. When dual routers are used, each with a single provider uplink, it's common to see each router generate and advertise a default route into the IGP, while they in turn each have a static default pointing toward that router's provider uplink.

Asymmetric Link Speed Support

The use of asymmetric link speeds for redundant attachment to the same provider is common in both models. When running BGP, the bandwidth community can be used to provide unequal cost load balancing proportionate to the link speed. In contrast, static routing over asymmetric links is typically done by directing all traffic over the high-speed link until it becomes unavailable, at which point the traffic is switched to the lower-speed secondary. In Junos software, this is accomplished with a static route along with a *qualified next hop*. A qualified next hop is a list of next hops with varying preferences/metrics that are used in order of their preference, based on the ability to resolve the associated next hop. The following code snippet shows how a dual-homed customer could configure all traffic to egress on a high-speed T3 link, unless the T3 interface/next hop becomes unavailable, at which point the traffic will switch to the qualified next hop with the next most preferred (next lowest) preference:

```
[edit routing-options static]
ruser@router# show
route 0.0.0.0/0 {
    qualified-next-hop 10.0.1.1 {
        preference 20;
        interface t3-1/0/0.0;
    }
    qualified-next-hop 10.0.1.5 {
        preference 30;
        interface t1-2/0/0.0;
    }
}
```

Which Routers Should Run IBGP?

Great! You've made it this far, which shows that you still feel your network either justifies use of BGP, or simply needs a puppy. From this point forward, this chapter assumes a network that is dual-homed to multiple providers, as is your desire for fine-grained control over how traffic enters and exits your network. Having reached this determination, the next logical question is, "Where should I configure BGP?" Knowing where to run EBGP is pretty straightforward; you must configure EBGP on the routers that peer to other ASs. The real question is where do you have to run IBGP, and this is a very, very good question indeed.

First, consider that most service provider networks run *both* an IGP and an IBGP on *all* of their core routers.[†]

Service providers need to run BGP on all their routers to ensure that the Internet core remains a default free routing zone, and because no service provider in its right mind would (intentionally) try to redistribute a full BGP table into its IGP. For the first point, any transit network that does not carry full Internet routing, and therefore relies on some type of default route, will be prone to loops. If the network is not running BGP on all transit routers, and there is no default route, the implication is that the IGP is in fact carrying a full Internet route table. Even the best implemented IGPs are not intended to carry hundreds of thousands of external routes, making such a design implausible given the sheer size of Internet route tables.

It's interesting to note that Junos software does not have the concept of IGP-BGP synchronization, making a `no synchronization` configuration statement unnecessary. In IOS, the BGP process expects the IGP to have a copy of each route before that route can be advertised by BGP, unless, of course, you have turned off synchronization. This is why disabling synchronization is the first step in almost any IOS configuration. Consider this one less command to get BGP up and running on a Juniper!

By running BGP on all its routers, a service provider does not rely on a default route, and it can mercifully spare its IGP an ignoble meltdown. By running both protocols, the IGP is left to do what it does best: providing connectivity between the loopback interfaces used for IBGP peering, while BGP routes keep the transit traffic from looping about and also provide needed administrative policy controls.

† The notable exception here is the "BGP free core," typically based on Multiprotocol Label Switching (MPLS) to avoid the need for full routing state in the core.

No Transit Services

Service provider networks are richly interconnected to the outside world, and they are optimized for making money by transporting traffic that neither originates on nor terminates in their networks. This is, after all, what makes them *transit* service providers. In contrast, an enterprise network is concerned with the transport of its own traffic, albeit sometimes needing to venture offsite to obtain required information. By not providing transit services, an enterprise can avoid running IBGP on every router. When possible, the network should be designed so that the BGP speakers are geographically localized, thus minimizing the portions of the network that need to run BGP. Figure 7-6 provides a sample topology to illustrate this concept.

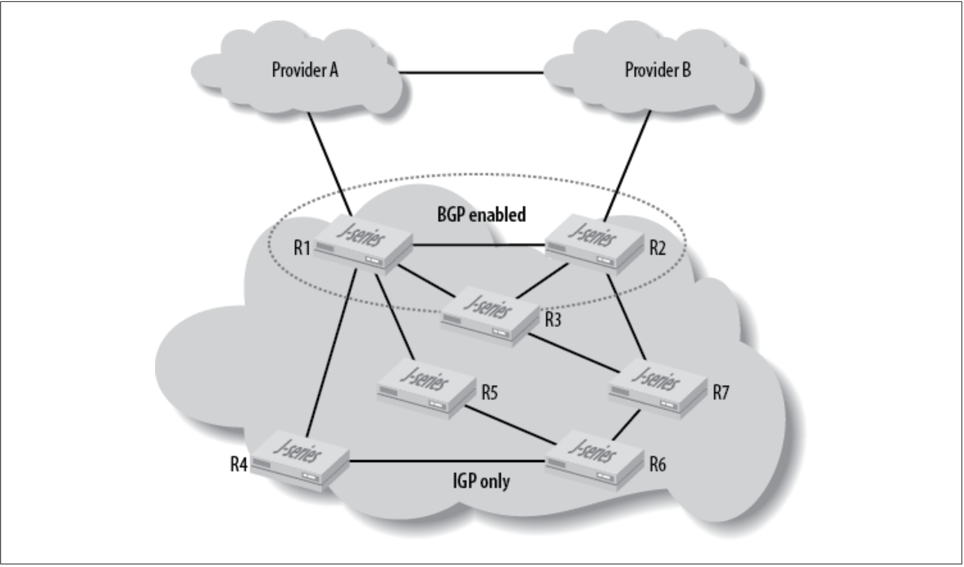


Figure 7-6. Which routers need to run IBGP?

The figure shows a network topology that runs BGP for its own connectivity, not for providing transit/connectivity services to other networks. The BGP speakers have been positioned near the network's edge and in geographic proximity, in an effort to constrain the scope of routers that need to run BGP. Routers R1 through R3 are BGP-enabled and speak EBGP to their attached service providers and IBGP among themselves. BGP is needed between these routers because Internet-destined traffic originating within the enterprise can arrive at any of these, and the consistent BGP tables ensure that traffic egresses the network according to local policy, even if some additional hops across the backbone are needed to reach the desired egress point.

A default route is generated by two of the IBGP speakers and is injected into the IGP to provide the non-BGP-speaking routers with external connectivity. The use of a generated route, as opposed to a simple static route, allows the withdrawal of an advertised default when the BGP speaker has problems with its EBGP session—the generated route is made active by the presence of learned EBGP routes. Internal routers simply select the remaining default route that is metrically closest to maintain their external connectivity.

The Impact of Accepting Specifics Versus a Default from Your Provider

The need to run IBGP on routers that do not speak EBGP is normally a function of whether the enterprise's import policy accepts only a default route or is configured to accept specific routes. In the latter case, you will need to run BGP on any routers that are used to interconnect your EBGP/IBGP-speaking nodes to prevent routing loops. Figure 7-7 provides an example of how inconstant routing knowledge can lead to a routing loop. The inconsistency arises from forwarding state that is known to the BGP speakers only while other routers rely on a default route. If all routers accepted only a default or the same set of specifics, this condition would not arise.

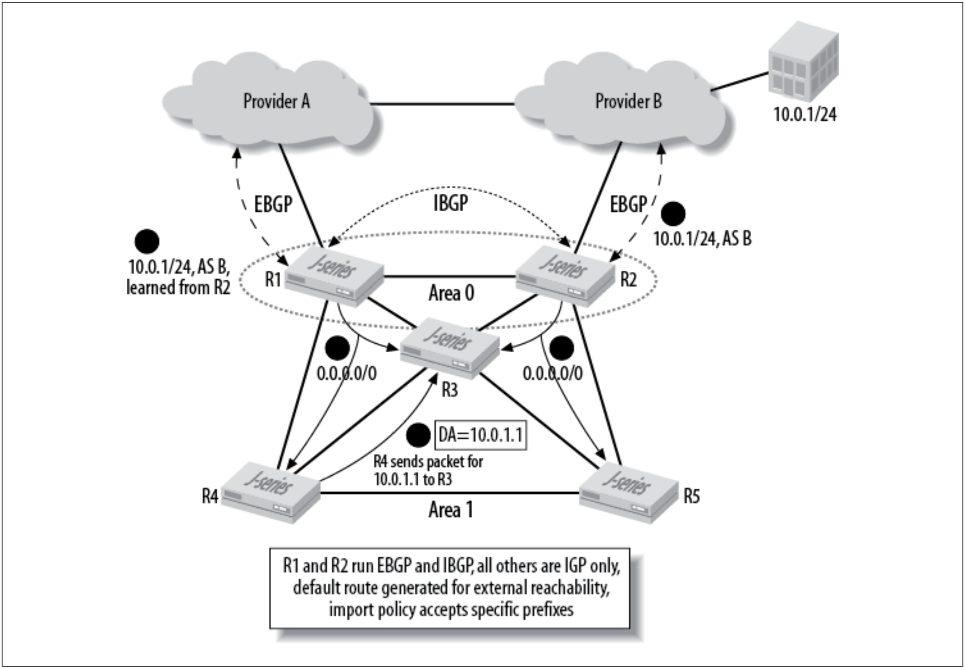

Provider A
Provider B
10.0.1/24
EBGP
IBGP
EBGP
10.0.1/24, AS B
10.0.1/24, AS B, learned from R2
R1
R2
Area 0
R3
0.0.0.0/0
0.0.0.0/0
DA=10.0.1.1
R4 sends packet for 10.0.1.1 to R3
R4
R5
Area 1
R1 and R2 run EBGP and IBGP, all others are IGP only, default route generated for external reachability, import policy accepts specific prefixes

Figure 7-7. Routing loop from lack of BGP routing knowledge

In this example, routers R1 and R2 are running EBGP with import policies that accept specific routes. Both routers IBGP-peer to each other. All other routers are running an IGP only. Things begin at step 1 in Figure 7-7, where both R1 and R2 generate a default route that is injected into Open Shortest Path First (OSPF). Step 2 shows Provider B advertising the 10.0.1/24 prefix, which is accepted by R2, given its import policy that accepts specifics and rejects the default route. R2 advertises this route to R1 over the IBGP session at step 3. R1 installs this route as active in this example because the same route learned from ISP A will have a longer AS path length.

Things begin to go wrong at step 4 in Figure 7-7, when R4 decides to avail itself of the default route to forward a packet to destination 10.0.1.1. In this example, R4 sends the packet to R3, but sending it directly to R1 would not change things in the long run. Recall that R3 is not running BGP and is therefore relying on the default route to reach this destination, as did R4. If R3 decides to forward to the default it learned from R2, everything is all right. But there is a 50% chance that it will decide to forward to the default route it learns from R1. As a BGP speaker, R1 has specific routing information for this prefix, which it learned over its IBGP session to R2. R1's routing decision determines that the packet should be forwarded toward the protocol next hop advertised by R2, that is, R2's loopback address. The result of R1's recursive route lookup on R2's loopback address may be the decision to forward the packet over the R1-R2 link or over the set of R1-R2-R3 links, as determined by IGP metrics. If R1 forwards the packet back to R3, a loop is formed, given that R3 has already handled this packet and decided to send it to R1.

Two solutions present themselves:

Enable IBGP on R3
: If you enable IBGP on R3, and then fully mesh the IBGP speakers, R3 would have never used the default route to forward this packet and would have sent it directly to R2 for dispatch into AS B.

Reject specifics
: If the import policy at R1 and R2 is altered to accept only a default, this route could be redistributed into the IGP. The EBGP learned version of the default route will remain active at both R1 and R2, even if the BGP speakers readvertise the default route to each other, owing to the route selection step that prefers EBGP learned over IBGP learned routes. Now, when a packet addressed to 10.0.1.1 arrives at R1, it longest-matches against the default route learned from Provider A and is not sent back to either R2 or R3, so no loops form.

Although the second solution prevents a routing loop, sending to ISP A is probably not the optimal way for this enterprise to reach prefix 10.0.1.0/24. This helps to illustrate why accepting specific routes, and then running IBGP among the routers that can be used to transit between EBGP speakers, is generally the optimal way for an enterprise to deploy BGP.

Summary of Enterprise BGP Requirements

To summarize, an enterprise should consider running EBGP when it is multihomed, to take advantage of the optimal routing and routing controls provided by BGP. The enterprise should run IBGP on any router that runs EBGP, and it must carefully consider what other routers should be IBGP-enabled. Recall that IBGP requires a full mesh or the use of route reflection/confederations for proper operation. Because BGP is not redistributed into your IGP, failing to run IBGP on all routers will result in those routers not having a complete view of BGP reachability. Normally, a generated default route is injected into the IGP to accommodate external routing for the non-BGP speakers. Remember that BGP will need to be enabled on routers that are expected to provide transit service *between* your EBGP speakers when the enterprise policy is to accept specific routes from your service providers to prevent against routing loops. Rejecting specifics and accepting only a default route lessens this requirement, as described earlier.

This section gave a comprehensive review of BGP and its key capabilities and operational characteristics. We also discussed how BGP can benefit an enterprise by helping to make optimized outbound routing decisions, and when all goes to plan, to also help influence your peer's outbound decisions to effect better control of how traffic arrives at your network's boundaries.

You may consider taking a brief break before diving into the next section. Some of the hands-on scenarios are a bit lengthy because of the numerous inclusions of actual router output, which are added to ensure that the reader is able to follow the details of the case study.

BGP Deployment: Asymmetric Load Balancing

Having made it through the protocol overview and enterprise application section, it is now time to apply your knowledge of BGP and Junos software to the first of three practical BGP deployment scenarios.

The first scenario begins when the CIO at Beer-Co seizes upon the organization's newfound appreciation for all things BGP by applying for a public ASN and detailing a BGP deployment plan that ultimately involves dual-homing to multiple providers. BGP deployment will occur in a phased approach, and you have been selected to head up phase 1: establishment of the initial BGP peering and related policy to Botnet in AS 34.

The deployment goals for initial BGP peering with Botnet are as follows:

- Establish EBGP interface-based peering to Botnet/AS 34.
- Use import policy to reject all but the default route that originates within Botnet/AS 34.
- Use export policy to advertise a single aggregate route that represents Beer-Co's internal prefixes.
- Use a static route to direct traffic to the backup link *only* in the event of BGP session disruption, and to ensure that traffic switches back to the primary upon service restoration.

- Redistribute a default route to provide external reachability for internal Beer-Co routers.

Figure 7-8 details the current Beer-Co internal topology and the newly activated access links to Botnet.

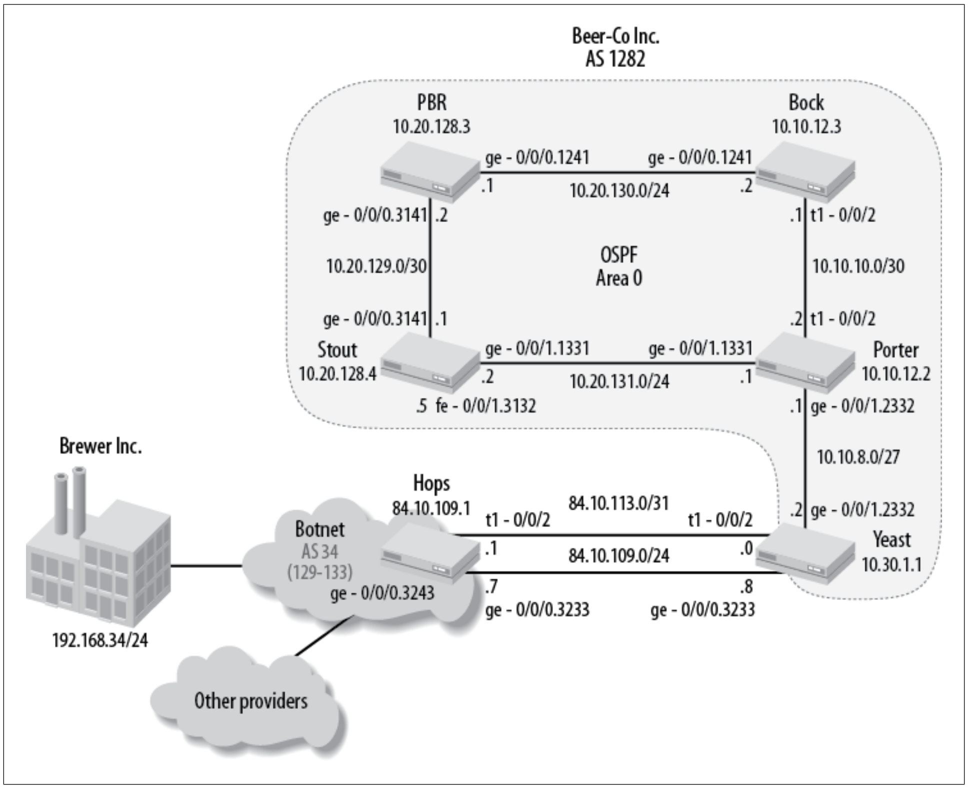


Figure 7-8. Beer-Co to Botnet peering

Figure 7-8 shows that Botnet is attached to other service providers, and to a particular customer, Brewer Inc., which has been assigned a 192.168.34.0/24 address block. The numbers enclosed within parentheses represent the range of route prefixes that Botnet is expected to advertise. In this example, these routes are instantiated as locally defined static routes, complete with associated AS numbers and origin code. This technique helps to simulate the learning, and subsequent readvertisement, of BGP routes between Botnet and its BGP peers. The customer route shown for provider Brewer, which is 192.168.34.0/24 in this case, is set to a reject next hop so that reachability can be confirmed, even when the customer site does not exist. Note that you expect to receive an Internet Control Message Protocol (ICMP) destination unreachable message due to the reject-style next hop, but this error message serves to validate reachability for our purposes.

Note also that Beer-Co has redundant links to Botnet. The huge disparity in link speed (1 Gbps versus 1.5 Mbps) drives the decision to use the faster link as a primary with the second link used only in the event of problems on the primary interface or a related BGP peering session. Care must be taken to ensure that the static route used to direct traffic over the secondary link is *less preferred* than any BGP routes learned from AS 34, which is not the default behavior, as a static route is more preferred than any dynamically learned one. A mistake here could easily mean paying for a 1 Gbps pipe while throughput is limited to a paltry 1.544 Mbps!

Validate Baseline Operation

Configuration gets underway at router `Yeast` with the definition of a generated static route. Recall that a generated route differs from an aggregated route in that the former has a forwarding next hop determined by the most preferred contributing route. In contrast, an aggregate route can only point to a discard or reject next hop. The generated route is redistributed into OSPF to provide connectivity to Internet destinations for Beer-Co's internal routers.

The OSPF configuration for area 0 is preexisting, and all routers have a similar configuration—the OSPF stanza at `Porter` is displayed, along with its adjacency status:

```
lab@Porter> show configuration protocols ospf
area 0.0.0.0 {
    interface ge-0/0/1.1331;
    interface ge-0/0/1.2332;
    interface t1-2/0/2.0;
}
lab@Porter> show ospf neighbor
  Address          Interface        State      ID            Pri  Dead
10.20.131.2      ge-0/0/1.1331    Full     10.20.128.4     128    33
10.10.8.2        ge-0/0/1.2332    Full     10.30.1.1       128    36
10.10.10.1       t1-2/0/2.0       Full     10.10.12.3      128    32
```

The single-area OSPF configuration at `Porter` matches the topology in Figure 7-8, and the router has all three expected OSPF adjacencies: one each to routers `Stout`, `Yeast`, and `Bock`. The routes being learned by OSPF are displayed and piped through the command-line interface's (CLI's) `match` function to show only those routes with a /32 network mask. These routes represent the loopback addresses assigned to each router (they are the only /32 IP addresses assigned), and therefore provide a quick sanity check of internal reachability:

```
lab@Porter> show route protocol ospf | match /32
10.10.12.3/32      *[OSPF/10] 00:05:54, metric 3
10.20.128.3/32     *[OSPF/10] 00:05:54, metric 2
10.20.128.4/32     *[OSPF/10] 00:23:46, metric 1
10.30.1.1/32       *[OSPF/10] 00:22:18, metric 1
224.0.0.5/32       *[OSPF/10] 01:03:03, metric 1
```

The output confirms a route to the loopback addresses of `Stout`, `Yeast`, `PBR`, and `Bock`. The metric values associated with each route seem reasonable in this topology. The default scaling factor of 100 Mbps assigns a Gigabit Ethernet interface a cost of 1, which results in avoidance of the T1 link between Bock and Porter. Porter therefore sees an OSPF cost of 3 to reach the loopback interface of Bock via Stout and PBR. Next, the route to Brewer Inc. is displayed:

```
lab@Porter> show route 192.168.34.0

lab@Porter>
```

The output confirms that Porter cannot route to the 192.168.34/24 route associated with Brewer Inc., which also confirms the lack of a default route in area 0. As a final verification step, reachability is confirmed to the EBGP peering addresses on both the primary and secondary links between Botnet and Yeast:

```
lab@Yeast> ping 84.10.113.1 count 1
PING 84.10.113.1 (84.10.113.1): 56 data bytes
64 bytes from 84.10.113.1: icmp_seq=0 ttl=64 time=26.887 ms

--- 84.10.113.1 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 26.887/26.887/26.887/0.000 ms

lab@Yeast> ping 84.10.109.7 count 1
PING 84.10.109.7 (84.10.109.7): 56 data bytes
64 bytes from 84.10.109.7: icmp_seq=0 ttl=64 time=12.255 ms

--- 84.10.109.7 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 12.255/12.255/12.255/0.000 ms
```

Configure Generated Route

Configure a generated default route that uses policy to constrain the set of contributing routes to the direct route associated with the backup peering link to Botnet. The premise here is that in normal operation, Yeast will have two default routes: one learned through BGP that points to the primary Botnet peering, and a second, generated default route pointing to the secondary peering. Route preference adjustments are made to ensure that the BGP route will be preferred when available. Loss of the BGP session results in the generated static route becoming active. Either way, an OSPF export policy redistributes the default route, be it learned or generated, into OSPF. The default route is withdrawn only in the event that Yeast loses its BGP session at the same time as its t1-2/0/2 interface goes down, in which case the decision to forego guaranteed diverse routing for the primary and secondary circuits may come into question.

The configuration starts with the static route and, at this stage, is quite straightforward. By beginning with the generated default, you have a chance to test failover to secondary link behavior before the primary link is brought up. It's always a good idea to periodically confirm operation of backup links during a maintenance window, rather than waiting until your primary fails. The generated route portion of Yeast's configuration is displayed:

```
[edit]
lab@Yeast# show routing-options generate
route 0.0.0.0/0 policy gen_default;

[edit]
lab@Yeast# show policy-options policy-statement gen_default
term 1 {
    from {
        protocol direct;
        route-filter 84.10.113.0/31 exact;
    }
    then accept;
}
term 2 {
    then reject;
}
```

The configuration results in the generation of a 0/0 route that, when matched, will forward over the next hop assigned to the preferred contributing route. Here, the set of possible contributors is constrained by the policy named `gen_default`, which matches only on the 84.10.113.0/31 route assigned to the `t1-2/0/2` interface. The policy's second term guarantees that no other route can contribute by rejecting all remaining routes and sources. Operation of the generated route is verified:

```
[edit]
lab@Yeast# run show route protocol aggregate detail
inet.0: 17 destinations, 17 routes (17 active, 0 holddown, 0 hidden)
0.0.0.0/0 (1 entry, 1 announced)
        *Aggregate Preference: 130
                Next-hop reference count: 2
                Next hop: via t1-2/0/2.0, selected
                State: <Active Int Ext>
                Age: 10:07
                Task: Aggregate
                Announcement bits (1): 0-KRT
                AS path: I
                                Flags: Generate Depth: 0      Active
                Contributing Routes (1):
                        84.10.113.0/31 proto Direct
```

The highlighted portions of the output confirm that all is working to plan with the generated route. A default route is present, it is currently active (there is no BGP learned version yet), and traffic matching this route will be directed out the `t1-2/0/2` interface. Further, the expected number of contributing routes, 1, is shown, and that route matches the direct route for the secondary peering. Note that the route is considered to be of the type `aggregate`, and that the preference for this route is 130. Thinking ahead, you'll recall that this route ultimately needs to be less preferred than any BGP learned version, and that the default preference for BGP is 170. The generated route's preference is set to be just higher than BGP's, so it will be less preferred when a BGP learned version becomes available:

```
[edit]
lab@Yeast# set routing-options generate route 0.0.0.0/0 preference 175
```

The T1 interface is briefly brought down, and the `show route` command is repeated to validate that the generated route's fate tracks that of the `t1-2/0/2` interface:

```
[edit]
lab@Yeast# set interfaces t1-2/0/2 disable

[edit]
lab@Yeast# commit
commit complete

[edit]
lab@Yeast# run show route protocol aggregate detail

inet.0: 16 destinations, 16 routes (15 active, 0 holddown, 1 hidden)
```

The command output does not display any active aggregate routes. The highlight calls out that one route, of an as-yet-unknown type, is hidden, however. To display a hidden route, add the `hidden` switch. Here, the display confirms that the hidden route is, in fact, the generated default—the route is now hidden because of a lack of contributors:

```
[edit]
lab@Yeast# run show route protocol aggregate detail hidden
inet.0: 16 destinations, 16 routes (15 active, 0 holddown, 1 hidden)
0.0.0.0/0 (1 entry, 0 announced)
         Aggregate
                Next hop type: Reject
                Next-hop reference count: 3
                State: <Hidden Int Ext>
                Age: 1:19:04
                Task: Aggregate
                AS path: I
                            Flags: Generate Depth: 0       Inactive
```

The change is rolled back and committed (not shown) at `Yeast` to ensure that the `t1-2/0/2` interface is no longer disabled. Next, a policy is written to redistribute a default route from any protocol source. The `ospf_default` policy is applied to the OSPF protocol as `export`:

```
[edit]
lab@Yeast# show policy-options policy-statement ospf_default
term 1 {
    from {
        route-filter 0.0.0.0/0 exact;
    }
    then accept;
}

[edit]
lab@Yeast# show protocols ospf export
export ospf_default;
```

The `ospf_default` policy is written to be protocol-agnostic, because the goal is to have an active default route stemming from *either* BGP or the aggregate protocol sources. If you prefer a tight ship, you could always add a logical OR match condition for the two protocols, aggregate and bgp. After committing the changes, an OSPF learned default route is confirmed in area 0 at router PBR:

```
lab@PBR> show route 192.168.34.0

inet.0: 20 destinations, 20 routes (20 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 00:03:04, metric 0, tag 0
                    > to 10.20.129.1 via ge-0/0/0.3141
```

Great! As planned, the longest match for the 192.168.34/24 route to Brewer Inc. at PBR is now the OSPF learned default route. A traceroute verifies connectivity to Botnet customers from within Beer-Co. The traceroute has an auspicious beginning, but it soon degrades to timeouts:

```
lab@PBR> traceroute 192.168.34.1 no-resolve
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte
packets
 1  10.20.129.1  14.345 ms  9.916 ms  8.099 ms
 2  10.20.131.1  11.864 ms  30.002 ms  20.016 ms
 3  10.10.8.2  9.901 ms  29.991 ms  9.984 ms
 4  * * *
5  *^C
lab@PBR>
```

The traceroute result shows the expected routing path through Beer-Co's intranet—from PBR to Stout, and then to Porter—and it makes it as far as the 10.10.8.2 address assigned to Yeast's ge-0/0/1.2332 interface. This makes it seem like there's a problem on the Porter–Yeast link, except that previous observations showed that the OSPF adjacency was stable. To narrow down the issue, a ping is generated from Yeast, but this time it is sourced from the router's loopback interface. This is an important point because it will reveal any potential routing issues that may impact Botnet's ability to route back into Beer-Co's 10/8 address block:

```
lab@Yeast> ping 84.10.113.1 count 1
PING 84.10.113.1 (84.10.113.1): 56 data bytes
64 bytes from 84.10.113.1: icmp_seq=0 ttl=64 time=16.750 ms

--- 84.10.113.1 ping statistics ---
1 packets transmitted, 1 packets received, 0% packet loss
round-trip min/avg/max/stddev = 16.750/16.750/16.750/0.000 ms

lab@Yeast> ping 84.10.113.1 count 1 source 10.30.1.1
PING 84.10.113.1 (84.10.113.1): 56 data bytes

--- 84.10.113.1 ping statistics ---
1 packets transmitted, 0 packets received, 100% packet loss
```

Eureka! The default ping, as sourced from the shared direct connection, succeeds, whereas the loopback sourced ping fails. This demonstrates a routing problem within Botnet. It is not uncommon to encounter difficulties such as this. After a few phone calls, you are assured that everything is (now) in order with the newly installed static route back to your network; it seems that confusion stemmed from Botnet's misunderstanding that BGP would be used to advertise an aggregate for your network, and it shall—once it's up and running, that is. The traceroute is repeated, and its successful completion indicates that you are ready to move on to BGP configuration:

```
lab@PBR> traceroute 192.168.34.1 no-resolve
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte
packets
 1  10.20.129.1  14.807 ms  9.827 ms  9.949 ms
 2  10.20.131.1  19.967 ms  40.010 ms  13.579 ms
 3  10.10.8.2  16.439 ms  10.131 ms  9.777 ms
 4  84.10.113.1  39.727 ms !N  40.154 ms !N  17.789 ms !N
```

Recall that in this lab, you expect an ICMP unreachable error message for the final hop because a static route pointing to a reject next hop is used within Botnet to simulate the Brewer Inc. network.

Configure Initial BGP Peering

With the backup link and its associated static routing/generated route confirmed, you'll move on to the task of configuring BGP. In addition to the BGP session, you also need to create an aggregate route representing Beer-Co's internal reachability, along with the export policy needed to advertise it into EBGP. The aggregate route is critical because it enables remote ASs to route toward Beer-Co. An import policy that rejects all but a Botnet-originated default route is also needed. In most cases, you will want to write and apply policy before the BGP session is actually activated to guard against unwanted side effects that stem from receiving or advertising undesired routes, or worse yet, before hitting a platform scaling limit that leads to an unpredictable operation.

We must emphasize that enterprise routing platforms are not always capable of handling a full BGP table, especially when the same platform is also taxed with value-added services such as stateful firewalls, Network Address Translation (NAT), virtual private network (VPN) tunnels, and so on. Exceeding platform scaling limits can result in control plane instability and possible forwarding plane impact. Care should be exercised to factor the effects of route table size, the number of routing peers, the impact of enabled services, and internal resource consumption for managing interfaces (IFDs/IFLs) and Address Resolution Protocol (ARP) tables before adding a new protocol or service to any production router. When in doubt, simulation testing should be performed. When simulation is not possible, you should closely monitor device operation and resource usage as new peers and services are activated to prevent operational problems caused by resource exhaustion.

As of this writing, Juniper Networks recommends that J-series routers expected to handle a full BGP route table, in conjunction with services being enabled, have 1 GB of memory. The J2320 platform serving the role of `Yeast` in this network is equipped with the full complement of DRAM. This setup and the limited number of routes in our network afford the liberty of adding the import policy *after* the EBGP session is established. This method is adopted here to help demonstrate the effects of import policy using a before-and-after approach.

We've already stated this, but we will say it one more time. It is highly recommended that you write and apply *both* your export and import policies *before* you attempt to establish any EBGP peerings. Failing to do this could result in router meltdown due to excessive BGP table size or the potential for unwanted routing exchange/forwarding behavior. The Junos software candidate configuration and commit functionality makes it easy to build and apply a policy before any of the changes take effect at commit time.

The BGP configuration begins at `Yeast` with configuration of the local router's ASN. The ASN is configured under the `[edit routing-options]` hierarchy, rather than within the BGP stanza, where you may expect to find it when you are familiar with the IOS way of configuring BGP:

```
[edit]
lab@Yeast# edit routing-options

[edit routing-options]
lab@Yeast# set autonomous-system 1282
```

You next define a BGP group to house the 84.10.109.7 neighbor associated with the Botnet peering. At a minimum, you must create the group, declare the group type as internal or external, specify the peer, and in the case of an external group, specify the ASN associated with the peer. The resulting BGP stanza is displayed along with the `set` commands that created it:

```
[edit protocols bgp]
lab@Yeast# show
group as_34 {
    type external;
    peer-as 34;
    neighbor 84.10.109.7;
}

[edit protocols bgp]
lab@Yeast# show | display set
set protocols bgp group as_34 type external
set protocols bgp group as_34 peer-as 34
set protocols bgp group as_34 neighbor 84.10.109.7
```

To better evaluate the impact of adding EBGP to `Yeast`, the current memory and CPU usage is examined before the changes are committed:

```
[edit protocols bgp]
lab@Yeast# run show task memory summary
Memory InUse: 6439 kB [1%] Max: 6762 kB [1%]

[edit protocols bgp]
lab@Yeast# run show chassis routing-engine
Routing Engine status:
    Temperature                22 degrees C / 71 degrees F
    CPU temperature            24 degrees C / 75 degrees F
    Total memory             1024 MB Max   584 MB used ( 57 percent)
      Control plane memory    594 MB Max   279 MB used ( 47 percent)
      Data plane memory       430 MB Max   310 MB used ( 72 percent)
    CPU utilization:
      User                      0 percent
      Real-time threads        17 percent
      Kernel                    0 percent
      Idle                     83 percent
    Model                         RE-J2320-2000
    Serial ID                     AABY9625
    Start time                    2010-12-20 21:31:28 UTC
    Uptime                        21 days, 5 hours, 1 minute, 56 seconds
    Last reboot reason            0x1:power cycle/failure
    Load averages:                1 minute   5 minute  15 minute
                                     1.30       0.46       0.17
```

The output from the `show task memory` command displays memory usage from the perspective of `rpd`, the routing daemon. In this case, it's rather low, indicating that `rpd` is having an easy time. The `show chassis routing-engine` command output shows that the Routing Engine's (RE's) CPU is largely idle.

With the pre-BGP resource snapshot in place, the new BGP configuration is committed at `Yeast`. After a few moments, BGP session status is determined with a `show bgp summary` command:

```
[edit protocols bgp]
lab@Yeast# commit and-quit
commit complete
Exiting configuration mode

lab@Yeast> show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table  Tot Paths  Act Paths Suppressed  History Damp State   Pending
inet.0         0          0          0        0          0         0
Peer       AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
84.10.109.7       34          0        0       0      0   11 Active
```

The command output shows that `Yeast` is actively trying to establish its BGP session to peer 84.10.109.7. This is a good sign, but it's not as good as an established session. A status of *idle*, for example, indicates that the router cannot even begin to initiate a session, likely because of no route to the peering address. BGP will retry its connection every 30 seconds or so, making patience a virtue here. About a minute later, the status is again displayed:

```
lab@Yeast> show bgp summary
Groups: 1 Peers: 1 Down peers: 0
Table  Tot Paths  Act Paths Suppressed  History Damp State   Pending
inet.0       434        434          0        0          0         0
Peer       AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|# Active/
Received/Damped...
```

```
84.10.109.7          34        285          7        0        0   2:25
801/801/0          0/0/0
```

The output confirms BGP session establishment—the highlighted display indicates that a total of 801 routes have been learned from the 84.10.109.7 peering, and that all of the received routes have been selected as active. It also notes the total number of routes learned from this peer and the number of routes currently damped, respectively. In this example, Botnet has advertised a total of 801 routes, all of which are currently active at `Yeast`.

> As of this writing, a full BGP feed is approximately 350,000 routes. Obviously, the BGP table used in this lab is a bit smaller. The goal here is to have enough routes to simulate a real BGP experience, without the hassle of obtaining a live feed.

You can view details for the peering session with a `show bgp neighbor` command. The display includes any negotiated options, session hold time, supported NLRI queued messages, and so on:

```
lab@Yeast> show bgp neighbor
Peer: 84.10.109.7+179 AS 34    Local: 84.10.109.8+2333 AS 1282
  Type: External    State: Established    Flags: <ImportEval Sync>
  Last State: OpenConfirm   Last Event: RecvKeepAlive
  Last Error: None
  Options: <Preference PeerAS Refresh>
  Holdtime: 90 Preference: 170
  Number of flaps: 0
  Peer ID: 84.10.109.1    Local ID: 10.30.1.1    Active Holdtime: 90
  Keepalive Interval: 30         Peer index: 0
  Local Interface: ge-0/0/0.3233
  NLRI advertised by peer: inet-unicast
  NLRI for this session: inet-unicast
  Peer supports Refresh capability (2)
  Table inet.0 Bit: 10000
    RIB State: BGP restart is complete
    Send state: in sync
    Active prefixes:              801
    Received prefixes:            801
    Suppressed due to damping:    0
    Advertised prefixes:          0
  Last traffic (seconds): Received 8    Sent 8    Checked 8
  Input messages:  Total 296   Updates 280  Refreshes 0   Octets 15175
  Output messages: Total 18    Updates 0    Refreshes 0   Octets 368
  Output Queue[0]: 0
```

Here the output shows that the EBGP session to Botnet is in the established state, that it supports IPv4 unicast NLRI, that the session has negotiated the BGP refresh option, and that the hold time is 90 seconds, which leads to a 30-second keepalive timer. The refresh option allows a BGP speaker to request that its peer resend previously advertised routing information. This is useful when a change in import policy may result in acceptance of a route that was previously denied. Without refresh, the BGP session would have to be bounced to force the peer to resend routes. Recall that BGP uses TCP transport, so there is, in theory, no reason for a BGP speaker to ever readvertise routing information that it has already sent.

The receipt of valid BGP routing is confirmed by displaying BGP routes in the route table:

```
lab@Yeast> show route protocol bgp detail

inet.0: 818 destinations, 819 routes (818 active, 0 holddown, 0 hidden)
0.0.0.0/0 (2 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 1602
                Source: 84.10.109.7
                Next hop: 84.10.109.7 via ge-0/0/0.3233, selected
                State: <Active Ext>
                Local AS:  1282 Peer AS:    34
                Age: 2:26:23
                Task: BGP_34.84.10.109.7+179
                Announcement bits (2): 0-KRT 3-OSPFv2
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1

129.1.0.0/16 (1 entry, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 1602
                Source: 84.10.109.7
                Next hop: 84.10.109.7 via ge-0/0/0.3233, selected
                State: <Active Ext>
                Local AS:  1282 Peer AS:    34
                Age: 9:04
                Task: BGP_34.84.10.109.7+179
                Announcement bits (1): 0-KRT
                AS path: 34 11537 3112 3112 I
                Localpref: 100
                Router ID: 84.10.109.1
. . .
```

The display confirms many active BGP routes at `Yeast`. The highlights call out key route attributes such as the AS path, the origin of the route, the forwarding next hop, and local/remote ASNs. This example shows that a default route is advertised, and the AS path, by virtue of the single entry for 34, confirms that this route originates within AS 34. In contrast, the route to 129.1/16 indicates an origin in AS 3112, and subsequent transversal of ASs 11537 and 34 (Botnet), before arriving at Beer-Co. Note that these routes have an *assumed* local preference of 100 as per BGP standards. A local preference value attribute is not attached to any of these routes because this attribute is not supported on EBGP links.

The announcement bits for the 0/0 BGP route indicate that it is being redistributed into OSPF. Because only active routes are subject to export policy, this implies that the BGP version of the default route must be preferred over the generated one. This is easily confirmed:

```
lab@Yeast> show route 0.0.0.0/0

inet.0: 818 destinations, 801 routes (818 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both
0.0.0.0/0          *[BGP/170] 00:26:28, localpref 100
                      AS path: 34 I
                    > to 84.10.109.7 via ge-0/0/0.3233
                    [Aggregate/175] 16:56:59
                    > via t1-2/0/2.0
```

The display shows that the BGP default is active with a preference of 170, and the highlights show that traffic matching this default route will be forwarded over the high-speed BGP peering link. Should the BGP session malfunction, `Yeast` will lose the BGP version of the default and fall back to the generated copy, which in turn forwards traffic over the secondary T1 link.

To confirm what routes are being received, or sent, to a specific BGP peer, use the `show route-advertising protocol` or `show route receive-protocol` command:

```
lab@Yeast> show route receive-protocol bgp 84.10.109.7

inet.0: 818 destinations, 801 routes (818 active, 0 holddown, 0 hidden)
  Prefix          Nexthop       MED    Lclpref  AS path
* 0.0.0.0/0       84.10.109.7                   34 I
* 129.1.0.0/16    84.10.109.7                   34 11537 3112 3112 I
* 129.2.0.0/16    84.10.109.7                   34 11537 10886 27 I
* 129.7.0.0/16    84.10.109.7                   34 11537 4557 7276 I
* 129.7.0.0/17    84.10.109.7                   34 11537 4557 7276 I
* 129.7.128.0/19  84.10.109.7                   34 11537 4557 7276 I
* 129.7.160.0/19  84.10.109.7                   34 11537 4557 7276 I
* 129.7.192.0/19  84.10.109.7                   34 11537 4557 7276 I
* 129.7.224.0/19  84.10.109.7                   34 11537 4557 7276 I
* 129.8.0.0/16    84.10.109.7                   34 11537 2153 2152
11422 2150 I
---(more)---[abort]

lab@Yeast> show route advertising-protocol bgp 84.10.109.7

lab@Yeast>
```

The `show route receive-protocol bgp 84.10.109.7` command confirms the receipt of prefixes from neighbor 84.10.109.7. You can add the `detail` or `extensive` switch to see additional information. In contrast, the `show route advertising-protocol bgp 84.10.109.7` command confirms that no routing information is being sent back to Botnet. This is expected, given that recent Junos software releases no longer echo received BGP routes back to their source, and because the default BGP export policy is to advertise active BGP routes. Here, all the active BGP routes were learned from neighbor 84.10.109.7; hence, there is nothing for `Yeast` to advertise back.

Readers familiar with the IOS display format for BGP routes may appreciate the terse switch:

```
lab@Yeast> show route protocol bgp terse

inet.0: 818 destinations, 801 routes (818 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

A Destination      P Prf Metric 1  Metric 2  Next hop      AS path
* 0.0.0.0/0        B 170       100          >84.10.109.7   34 I
* 129.1.0.0/16     B 170       100          >84.10.109.7   34 11537 3112 3112 I
* 129.2.0.0/16     B 170       100          >84.10.109.7   34 11537 10886 27 I
* 129.7.0.0/16     B 170       100          >84.10.109.7   34 11537 4557 7276 I
* 129.7.0.0/17     B 170       100          >84.10.109.7   34 11537 4557 7276 I
* 129.7.128.0/19   B 170       100          >84.10.109.7   34 11537 4557 7276 I
* 129.7.160.0/19   B 170       100          >84.10.109.7   34 11537 4557 7276 I
* 129.7.192.0/19   B 170       100          >84.10.109.7   34 11537 4557 7276 I
* 129.7.224.0/19   B 170       100          >84.10.109.7   34 11537 4557 7276 I
* 129.8.0.0/16     B 170       100          >84.10.109.7   34 11537 2153 2152 11422
2150 I
* 129.10.0.0/16    B 170       100          >84.10.109.7   34 11537 10578 156 I
* 129.11.0.0/16    B 170       100          >84.10.109.7   34 11537 20965 786 I
. . .
```

In the preceding display, the local preference is shown under the Metric 1 column. Before moving on, you gauge the effects of running BGP by again analyzing resource utilization at Yeast:

```
lab@Yeast> show task memory summary
Memory InUse: 6517 kB [1%] Max: 6762 kB [1%]

lab@Yeast> show chassis routing-engine
Routing Engine status:
    Temperature                 31 degrees C / 87 degrees F
    CPU temperature             32 degrees C / 89 degrees F
    Total memory              1024 MB Max   584 MB used ( 57 percent)
      Control plane memory     594 MB Max   279 MB used ( 47 percent)
      Data plane memory        430 MB Max   310 MB used ( 72 percent)
    CPU utilization:
      User                       0 percent
      Real-time threads         18 percent
      Kernel                     0 percent
      Idle                      82 percent
    Model                          RE-J2320-2000
    Serial ID                      AABY9625
    Start time                     2010-12-20 21:31:28 UTC
    Uptime                         21 days, 5 hours, 21 minutes, 16 seconds
    Last reboot reason             0x1:power cycle/failure
    Load averages:                 1 minute   5 minute  15 minute
                                       0.10       0.15       0.02
```

The output confirms very little change to resource consumption. However, we must stress that you are dealing with a very small number of peers (1) and a very limited set of routes (800 or so), and that these routes are stable, resulting in very little ongoing BGP process churn.

Configure Initial BGP Policy

The initial BGP peering session is confirmed operational. To complete this task, you now create and apply both BGP import and export policy. The former is to reject all received BGP routes except a default route that originates in AS 34. The latter needs to advertise a single 10/8 aggregate to represent the internal connectivity of Beer-Co. An import policy is created and displayed at Yeast:

```
[edit]
lab@Yeast# show policy-options policy-statement as_34_import
term 1 {
    from {
        protocol bgp;
        as-path 34_originate;
        route-filter 0.0.0.0/0 exact;
    }
    then accept;
}
term 2 {
    from protocol bgp;
    then reject;
}

[edit]
lab@Yeast# show policy-options as-path 34_originate
"^34$";

[edit]
lab@Yeast# show protocols bgp group as_34 import
import as_34_import;
```

The as_34_import policy matches on a specific route (0/0) and route source (BGP), and forces the associated AS path to match the AS regular expressions defined in 34_originate. The AS path regular expression functions to guarantee that only a default route that originates in AS 34 will be accepted—all routes originating within AS 34 will have an AS path list that starts and ends with 34; the associated regex uses the ^ and $, respectively, to force AS 34 to be the first and last AS number in the list. The as_34_import policy is applied to the as_34 BGP group at import, and the results are confirmed:

```
[edit]
lab@Yeast: run show route protocol bgp
inet.0: 818 destinations, 819 routes (18 active, 0 holddown, 800 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[BGP/170] 02:34:36, localpref 100
                      AS path: 34 I
                    > to 84.10.109.7 via ge-0/0/0.3233
```

The output confirms that only the default route is accepted and installed into the route table, resulting in some 800 routes being hidden.

Generally speaking, the output of the `show route receive-protocol` command displays routing information as received, before import policy is applied. The exception to this rule is route filtering, which occurs *before* the `show route receive-protocol` command output is compiled. This means that if your import policy is set to remove a given community, you can expect to see the community (that is to be removed) in the `show route receive-protocol` output, but not when the route is installed into the route table, because your import policy will have taken effect and will have removed the specified community. In contrast, if your import policy uses `route-filter` syntax to reject routes, these routes will not be observed in either the route table or the output of a `show route receive-protocol` command. This condition is demonstrated here, where only the 0/0 default that is accepted by import policy route filtering is displayed:

```
lab@Yeast> show route receive-protocol bgp 84.10.109.7

inet.0: 818 destinations, 819 routes (18 active, 0 holddown, 800 hidden)
  Prefix                  Nexthop              MED     Lclpref    AS path
* 0.0.0.0/0               84.10.109.7                  34 I
```

Add the `hidden` keyword to display received routes that are hidden, perhaps due to route filtering actions.

Your export policy requires that you define a 10/8 aggregate, and then advertise this aggregate into BGP. At this time, it's assumed that Botnet is routing back into your AS using its static route that points to the slow-speed T1 interface, making this a critical step for proper operation. In theory, it has configured its network to prefer a BGP learned version of the 10/8 route, which results in use of the high-speed link for inbound traffic once you advertise the route through BGP. Here are the aggregate route definition and BGP export policy:

```
[edit]
lab@Yeast# show routing-options aggregate
route 10.0.0.0/8;

[edit]
lab@Yeast# show policy-options policy-statement as_34_export
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then accept;
}

[edit]
lab@Yeast# show protocols bgp group as_34 export
export as_34_export;
```

After committing the change, the aggregate route is confirmed active and advertised to Botnet via EBGP:

```
lab@Yeast> show route protocol aggregate

inet.0: 801 destinations, 451 routes (18 active, 0 holddown, 432 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          [Aggregate/175] 17:57:54
                   > via t1-2/0/2.0
10.0.0.0/8        *[Aggregate/130] 00:00:13
                     Reject

lab@Yeast> show route advertising-protocol bgp 84.10.109.7

inet.0: 801 destinations, 451 routes (18 active, 0 holddown, 432 hidden)
  Prefix                  Nexthop          MED     Lclpref    AS path
* 10.0.0.0/8              Self                                I
```

The 10/8 aggregate route is active, which is good given that only active routes can be redistributed through policy. Note that unlike the generated route, the aggregate route has a nonforwarding next hop, which happens to be the default reject-style next hop in this case. Traffic routed into Beer-Co should normally match a more specific route (OSPF or direct) and be forwarded toward that destination. If not, the traffic is shunted to reject, and an ICMP error message is generated reporting an unreachable destination. The `show route advertising-protocol` command confirms that a single route, the 10/8 aggregate, is advertised to Botnet.

For final verification, the previous traceroute is repeated at `PBR`:

```
lab@PBR> traceroute 192.168.34.1 no-resolve
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte packets
 1  10.20.129.1  53.267 ms  13.506 ms  10.634 ms
 2  10.20.131.1  9.955 ms  9.985 ms  9.996 ms
 3  10.10.8.2  9.977 ms  10.042 ms  10.034 ms
 4  84.10.109.7  15.349 ms !N  24.503 ms !N  19.968 ms !N
```

The traceroute again succeeds, but this time the final hop is 84.10.109.7; this confirms that the high-speed primary interface is now used to forward traffic into AS 34. This completes the initial BGP peering scenario.

Use BGP for Asymmetric Load Balancing

While congratulating you on the fine work, the CIO of Beer-Co respectfully suggests that you find a way to use the secondary link also. After all, 1.544 Mbps is nothing to sneeze at, and paying for a backup circuit that will never see any use except during a primary outage can be painful.

The most direct solution to this problem is to bring up a second EBGP session to Botnet and simply enable BGP multipath. The multipath option removes the tiebreakers from the active route decision process, thereby allowing otherwise equal-cost BGP routes learned from multiple sources to be installed into the forwarding table. Once multiple next hops are installed in the forwarding table, a specific forwarding next hop is selected by the default Junos software per-prefix load-balancing algorithm. This process hashes against a packet's source and destination addresses to deterministically map the prefix paring onto one of the available next hops. Per-prefix mapping works best when the hash function is presented with a large number of prefixes, such as might occur on an Internet peering exchange, and it serves to prevent packet reordering among pairs of communicating nodes.

An enterprise network will normally want to alter the default behavior to evoke a "per-packet" load-balancing algorithm. *Per-packet* is quoted here because its use is a misnomer that stems from the historic behavior of the original Internet Processor ASIC. In reality, current Juniper Networks routers support per-prefix (default) and *per-flow* load balancing. The latter involves hashing against various L3 and L4 headers, including portions of the source address, destination address, transport protocol, incoming interface, and application ports. The effect is that now individual *flows* are hashed to a specific next hop, resulting in a more even distribution across available next hops, especially when routing between fewer source and destination pairs. With per-packet load balancing, packets comprising a communication stream between two endpoints may be resequenced, but packets within individual flows maintain correct sequencing.

Whether you opt for per-prefix or per-packet load balancing, the extreme asymmetry of the Botnet access links presents a technical challenge. Either way, the prefixes/flows that are mapped to the T1 link will exhibit degraded performance when compared to those flows that map to the GE access link, and worse yet, with heavy traffic loads, any attempt at 50/50 load balancing is likely to result in total saturation of the T1 link and session disruption stemming from packet loss.

Fortunately, the Juniper BGP implementation supports the notion of a bandwidth community. This extended community encodes the bandwidth of a given next hop, and when combined with multipath, the load-balancing algorithm will distribute flows across the set of next hops proportional to their relative bandwidths. Put another way, if you have a 10 Mbps and a 1 Mbps next hop, on average nine flows will map to the high-speed next hop for every one that uses the low speed.

As of this writing, use of BGP bandwidth community is supported only with per-packet load balancing.

The current configuration task is divided into two parts:

- Configure a second EBGP peering session, enable multipath, and define an import policy to tag routes with a bandwidth community that reflects link speed.
- Enable per-packet (really per-flow) load balancing for optimal distribution of traffic.

You start with the definition of the second EBGP peering session at `Yeast`. Though not shown here, the generated default route is removed from the configuration because it is no longer needed. Recall that you now expect two default routes, both learned from BGP, with proportionate load balancing when both routes are active:

```
 [edit]
lab@Yeast# show protocols bgp
group as_34 {
    type external;
    import as_34_import;
    export as_34_export;
    peer-as 34;
    neighbor 84.10.109.7;
    neighbor 84.10.113.1;
}
```

The new session shares the same group-level import and export policy, which results in accepting only a default route and the advertisement of only the 10/8 aggregate. After a minute or so, you confirm successful establishment of the second Botnet peering session:

```
[edit]
lab@Yeast# run show bgp summary
Groups: 1 Peers: 2 Down peers: 0
Table  Tot Paths  Act Paths Suppressed    History Damp State  Pending
inet.0      1602          1          0          0          0        0
Peer            AS      InPkt  OutPkt  OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
84.10.109.7    34        824     329     0       0     2:42:55 1/801/0
0/0/0
84.10.113.1    34        462       3     0       0           6 0/801/ 0
0/0/0
```

The display confirms establishment of the second peering session. Of special interest is the fact that 801 routes have been learned over each session, and only one of these routes is active, for only one of the sessions. Recall that the goal here is to receive an active default route from each peering. For additional details, we display the default route:

```
[edit]
lab@Yeast# run show route protocol bgp detail

inet.0: 818 destinations, 1619 routes (18 active, 0 holddown, 1600
hidden)
0.0.0.0/0 (2 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 802
                Source: 84.10.109.7
                Next hop: 84.10.109.7 via ge-0/0/0.3233, selected
                State: <Active Ext>
                Local AS:  1282 Peer AS:    34
                Age: 2:46:39
                Task: BGP_34.84.10.109.7+179
                Announcement bits (2): 0-KRT 3-OSPFv2
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1
         BGP     Preference: 170/-101
                Next-hop reference count: 801
                Source: 84.10.113.1
                Next hop: 84.10.113.1 via t1-2/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Update source
                Local AS:  1282 Peer AS:    34
                Age: 3:50
                Task: BGP_34.84.10.113.1+179
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1
```

The display shows that each BGP peer is advertising the 0/0 route, and it confirms that only one version of the route is active. This active route is learned through peer 84.10.109.7, and as such, the route shows a single forwarding next hop of `ge-0/0/0.3233`. There is no hope of any load balancing until both of the next hops for both BGP routes are installed into the forwarding table. The problem here is called out by the `update source` inactive reason. According to documentation, this indicates that a route was not selected because of characteristics associated with the source, which means either the RID or the BGP peering address. These last two steps in the active route selection process exist to break ties, which is exactly what has happened here. Because both peering sessions terminate on the same router (`Hops`), the RID is the same, and therefore the route learned from the numerically lowest peering address is selected. To disable the tiebreaking rules and allow use of multiple otherwise equal-cost BGP routes, you must enable multipath:

```
[edit]
lab@Yeast# set protocols bgp group as_34 multipath

[edit]
lab@Yeast# commit
commit complete
```

The change is confirmed by the presence of both the 84.10.109.7 *and* 84.10.113.1 BGP next hops in the `show route` display:

```
[edit]
lab@Yeast# run show route protocol bgp detail
inet.0: 818 destinations, 1619 routes (18 active, 0 holddown, 1600
hidden) 0.0.0.0/0 (2 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 1
                Source: 84.10.109.7
                Next hop: 84.10.109.7 via ge-0/0/0.3233, selected
                Next hop: 84.10.113.1 via t1-2/0/2.0
                State: <Active Ext>
                Local AS:  1282 Peer AS:    34
                Age: 2:54:43
                Task: BGP_34.84.10.109.7+179
                Announcement bits (2): 0-KRT 3-OSPFv2
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1
         BGP    Preference: 170/-101
                Next-hop reference count: 801
                Source: 84.10.113.1
                Next hop: 84.10.113.1 via t1-2/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Update source
                Local AS:  1282 Peer AS:    34
                Age: 11:54
                Task: BGP_34.84.10.113.1+179
                AS path: 34 I
                Localpref: 100
                Router ID: 84.10.109.1
```

The display still shows that only one route is active, but without the tiebreakers in effect, the next hops associated with both routes have been installed for use, thereby enabling load balancing. Your next goal is to adjust the `as_34_import` policy to tag routes with a bandwidth community, based on the peering from where they are learned. You start by defining the two extended bandwidth communities. The format of this community is `bandwidth:asn:bandwidth_value`, where the bandwidth is entered in bytes per second. The actual values entered are not as important as having the correct ratio because it is the ratio that actually determines the percentage of flows/prefixes mapped to each next hop:

```
[edit policy-options]
lab@Yeast# show community bw_slow
members bandwidth:1282:193000;

[edit policy-options]
lab@Yeast# show community bw_fast
members bandwidth:1282:12500000000;
```

The `bw_slow` and `bw_fast` communities are set to reflect the byte-per-second rates of a T1 and Gigabit Ethernet interface, respectively. The ratio of the two is approximately .0001544, meaning that for every 100000 prefixes/flows, you expect to see 1.5 of them mapped to the T1. In the Juniper implementation, the flow count is rounded up, giving us an expected spread of 2 flows mapped to the T1 for every 98000 mapped to the Gigabit Ethernet. The existing `as_34_import` policy is rewritten, and the modified policy is displayed:

```
[edit]
lab@Yeast# show policy-options policy-statement as_34_import
term slow_peer {
    from {
        protocol bgp;
        neighbor 84.10.113.1;
        as-path 34_originate;
        route-filter 0.0.0.0/0 exact;
    }
    then {
        community add bw_slow;
        accept;
    }
}
term fast_peer {
    from {
        protocol bgp;
        neighbor 84.10.109.7;
        as-path 34_originate;
        route-filter 0.0.0.0/0 exact;
    }
    then {
        community add bw_fast;
        accept;
    }
}
term reject-all {
    then reject;
}
```

The new `as_34_import` policy makes use of a `from neighbor` match condition to tag the matching route with the identified bandwidth community. In theory, this can also be done as part of an export policy within Botnet, but this puts reliance on the administration of the remote AS, which may involve delays and the potential for billing and mistakes. Expected operation is verified by once again displaying details about the active BGP route:

```
[edit policy-options]
lab@Yeast# run show route protocol bgp detail

inet.0: 818 destinations, 1619 routes (18 active, 0 holddown, 1600
hidden) 0.0.0.0/0 (2 entries, 1 announced)
      *BGP    Preference: 170/-101
              Next-hop reference count: 1
              Source: 84.10.109.7
              Next hop: 84.10.109.7 via ge-0/0/0.3233 balance 99%
              Next hop: 84.10.113.1 via t1-2/0/2.0 balance 1%, selected
              State: <Active Ext>
              Local AS:  1282 Peer AS:    34
              Age: 3:48:08
              Task: BGP_34.84.10.109.7+179
              Announcement bits (2): 0-KRT 3-OSPFv2
              AS path: 34 I
              Communities: bandwidth:1287:12500000
              Localpref: 100
              Router ID: 84.10.109.1
       BGP    Preference: 170/-101
              Next-hop reference count: 801
              Source: 84.10.113.1
              Next hop: 84.10.113.1 via t1-2/0/2.0, selected
              State: <NotBest Ext>
              Inactive reason: Update source
              Local AS:  1282 Peer AS:    34
              Age: 1:05:19
              Task: BGP_34.84.10.113.1+179
              AS path: 34 I
              Communities: bandwidth:1287:193000
```

```
                Localpref: 100
                Router ID: 84.10.109.1
```

The highlights in the show route output confirm that balancing now occurs in proportion to link speed, as required. To complete this task, a per-packet load-balancing policy must be placed into effect at Yeast. A policy named lb_per_packet is created, and it is applied to the main routing instance's forwarding table:

```
[edit]
lab@Yeast# show policy-options policy-statement lb_per_packet
then {
    load-balance per-packet;
    accept;
}

[edit]
lab@Yeast# show routing-options forwarding-table
export lb_per_packet;
```

The lb_per_packet policy matches on all possible routes and effectively converts the system from per-prefix to per-flow load balancing. The effect of your work is confirmed back on router PBR, where traceroutes are performed. The test traffic is sourced from various IP addresses owned by PBR in an attempt to trigger the per-flow hashing function to use both next hops. Note that by enabling per-flow load balancing, fewer bits are made available for hashing against the source address/destination address pair. The result is that without a wide degree of source address/destination address variance, there is a good chance that all test traffic will hash to the same next hop. To accurately test Juniper per-prefix or per-flow load balancing, a large number of flows should be generated, preferably from multiple traffic sources. Put another way, as the number of flows/prefixes increases, so too does the likelihood of observing ideal balancing among the set of available next hops. Bearing this in mind, the bw_slow community is temporarily set to equal bw_fast so that we can expect a 50/50 load-balancing split. This will increase the chances of observing load balancing at play with the limited number of flows available in the lab setup:

```
lab@PBR> traceroute 192.168.34.1 no-resolve source 10.20.129.2
traceroute to 192.168.34.1 (192.168.34.1) from 10.20.129.2, 30 hops
max, 40 byte packets
 1  10.20.129.1  14.553 ms  9.782 ms  8.084 ms
 2  10.20.131.1  21.914 ms  9.935 ms  9.988 ms
 3  10.10.8.2  10.081 ms  19.865 ms  10.002 ms
 4  84.10.113.1  15.697 ms !N  14.286 ms !N  18.954 ms !N
```

The final hop of the traceroute to Brewer Inc.'s 192.168.34.1 route is the 84.10.113.1 address associated with the low-speed Botnet peering link. In this example, test traffic is explicitly sourced from the 10.20.129.2 address on the PBR–Stout link, which happens to be the same IP address that the packet would normally take. Next, a different flow is created by generating an ICMP echo packet from the same source address, but to a different host address (.100), on the 192.168.34.0/24 subnet. The goal here is to try and trigger a different flow hashing result by altering some of the bits used in the flow hashing algorithm. Here, we change both the protocol (ICMP versus UDP) and some of the bits in the addresses' host ID:

```
lab@PBR> ping 192.168.34.100 rapid count 1 source 10.20.129.2
PING 192.168.34.100 (192.168.34.100): 56 data bytes
36 bytes from 84.10.109.7: Destination Net Unreachable
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 0054 5e00   0 0000  3d  01 b186 10.20.129.2  192.168.34.100
.
--- 192.168.34.100 ping statistics ---
1 packets transmitted, 0 packets received, 100% packet loss
```

The destination unreachable error message generated by 84.10.109.7 proves that the ICMP test packet was forwarded over the high-speed Botnet peering link. Satisfied that per-flow load balancing is working, you restore the `bw_slow` community to its previous value and take a well-deserved break:

```
[edit]
lab@Yeast# rollback 1
load complete

[edit]
lab@Yeast# show | compare
[edit policy-options community bw_slow]
-   members bandwidth:1287:12500000000;
+   members bandwidth:1287:193000;

[edit]
lab@Yeast# commit
commit complete
```

Initial BGP Peering Summary

This section showed you an example of how to configure and verify basic EBGP peering using Junos software. We also showed the use of routing policy to filter received routes and to control the routes that you advertise, along with the redistribution of a BGP-learned default route into your IGP to provide external reachability for non-BGP speakers within your AS. You also saw how to use a static route with an altered global preference (a concept known as a *floating static route* in IOS speak) to back up a BGP peering, and how the BGP bandwidth community is used to provide asymmetric load balancing based on link speed.

The next section explores typical enterprise applications of BGP routing policy, which in turn prepares you for the increasingly complicated BGP deployment scenarios that follow later in this chapter. Now is a good time to take a break, perhaps to think back over the points covered in this section or just to clear your mind for the outbound and inbound policy discussions in the next section.

Enterprise Routing Policy

You have now been exposed to various applications of Junos software routing policy, here and in earlier chapters. We discussed the operational theory of routing policy in detail in Chapter 5. In summary, import routing policy is responsible for placing routes into the route table, possibly with modified attributes, and export policy is responsible for placing copies of routes into outgoing routing protocol updates, again possibly with modified attributes. The complexity of an organization's policy is typically tied directly to the degree of its interconnectivity requirements. An enterprise that is single-homed needs very little policy; in most cases, such an attachment does not even warrant use of BGP!

This section focuses on applying Junos software routing policy to meet the needs of an enterprise that is dual-homed to different providers.

Inbound and Outbound Routing Policies

In a majority of cases, a dual-homed enterprise network will have distinctly different inbound and outbound policies. Your inbound policy is intended to control how traffic enters your AS from other networks, whereas your outbound policy dictates how traffic leaves your AS to enter other networks. You use specific instances of export and import policy to facilitate your organization's inbound and outbound policy goals.

Achieving your inbound policy goals can be difficult, or even impossible, given that you do not have direct control over the outbound policies of the networks that you peer with. In the end, each network operator has complete control of its local outbound policy, so at best your inbound policy can influence its policy decisions only within the limits that are permitted by that network's outbound policy. In some cases, achieving your inbound policy goals may require selecting ISPs that are willing to work with your needs—this is a political, not a technical, issue. In contrast, you have complete control over your outbound policy. Simply put, it's your network, and you can configure it to do whatever you want in this regard.

As with most network design considerations, each network must carefully weigh its policy desires against the potential costs, measured in increased administrative/support burdens, potential economic impacts, performance considerations, equipment capabilities, and so on. The network then must decide on a set of policies that best balance all of the factors involved.

Common Policy Design Criteria

Although the specifics always vary, many common elements drive most policy decisions:

Topology-driven

A topology-driven policy is based on the physical connectivity of your network and is typically concerned with locating the lowest-cost (lowest-metric) path for traffic. In many cases, a topology-driven policy will use IGP metrics to locate the best egress point, and in turn will send the IGP metric as the MED in EBGP updates. Recall that MED is like a true metric, in that lower values are preferred. If your peer honors MEDs in its decision process, this should result in traffic entering your AS at the point that is metrically closest to the actual destination. You can set the MED in BGP policy using the `metric` keyword. Support for automatically tracking the IGP metric is also provided.

The topology-driven model is the easiest to implement because in most cases, you leave all attributes unmodified and simply rely on the route selection algorithm to select the best route, which will normally be the shortest path (the fewest number of ASs, best origin, lowest MED, and lowest IGP metric).

Primary/secondary

A primary/secondary policy is based on the preferential use of a primary access link. Motivations for a primary/secondary model tend to be performance-driven, but can also factor in economic, reliability, or security concerns. The last factor, security, is often overlooked. Knowing that all your traffic leaves and enters on the same set of links greatly simplifies deployment of stateful firewalls and NAT devices. This is because state instantiated by the transmission of traffic is readily available to match against the return traffic. Sending traffic out of one device, and having the response handled at a different access point by a different device, makes stateful services quite complex.

In a *strict* primary/secondary model, no traffic should use the secondary links unless the primary link becomes unavailable. In contrast, in a *loose* model, some traffic, perhaps based on topology considerations, is allowed to use the secondary, even when the primary is operating. Your design should also factor the desire to revert back to a primary after service is restored. A revertive design switches back to the primary, but this behavior can cause issues when chronic problems plague the primary link. This is because ongoing disruption occurs each time traffic is redirected to and from the bouncing primary circuit. Here, a nonrevertive policy that promotes stability over other factors such as cost, or raw bandwidth, would be preferred.

Using equal capacity links in conjunction with a strict primary/secondary model provides the highest degree of redundancy because either link can handle the offered load with equal performance. With the loose variation, usable bandwidth can be the sum of both link capacities; therefore, the failure of either link reduces overall capacity and may impact performance. This is also true of a strict model that uses asymmetric link speeds to save on bandwidth costs.

Load-sharing

A load-sharing policy attempts to maximize use of all available resources by spreading traffic over the set of available access points. This is typically performed on a per-prefix basis, where some set of routes is mapped to one link while another set is mapped to a different link. In a failure scenario, traffic from affected links is switched to the next most preferred operational link.

A word on outbound/inbound versus export/import policy

Before moving on, it's worth noting that there is somewhat of a reverse relationship between your inbound/outbound policy and the type of Junos software routing policy that is applied to your EBGP session. For example, you will normally use *export* policy when you wish to instantiate an *inbound* policy to control how other networks route traffic into your AS. Likewise, you normally use *import* policy to adjust attributes in received routes that in turn affect your *outbound* policy—for example, setting local preference on routes as they are received from an EBGP peer.

If that were not confusing enough, you will likely find that in many cases, you can achieve the same effect using either an import or an export policy. For example, local preference can be set at reception from an EBGP peer using an import policy or when sending the route to other IBGP speakers using an export policy. In fact, you may use an import to set an attribute to some local value, and then use an export to send a modified value to other peers. Wherever possible, you should take a consistent approach to help minimize support burdens and overall network complexity.

Know your ISP's policy

Because your BGP speakers are expected to interact with those under the control of your ISP, it pays to be familiar with your ISP's general policies. For example, many ISPs set route attributes within their network, based on the receipt of certain communities attached by their customers. As another example, consider that there is no point in advertising a prefix with a /32 network mask if your ISP's policy is not to accept any routes with a prefix length longer than /28.

Most providers use local preference to prefer routes from their customers over those learned from their peers, filter route updates based on prefix lengths, and filter updates received from their customers to ensure that they are not acting as transit peers. Providers often post their policies on public websites where the information can be used to comparison shop when seeking service.

Enterprise Policy Summary

This section broke down the seemingly daunting task of BGP and policy into the categories of inbound and outbound policies, which helps to make things more manageable. In most cases, an enterprise will need to be dual-homed to take full advantage of the power of BGP and Junos software routing policy. Remembering that you use *export* policy to affect your *inbound* routing goals, and use *import* policy for your *outbound* goals, helps to eliminate a lot of potential confusion.

By default, BGP settles on a topology-based model, but in many cases you will want to alter this behavior based on your organization's needs and desires. You have direct control over your own network's output routing, making that part of the equation straightforward. Effectively establishing a desired inbound policy means you have managed to influence the outbound action of routers in a remote network, which are not under your direct control. That is the mark of a true BGP policy guru.

In the next section, you will begin to apply complex enterprise routing policies, right after you multihome the network by adding a new EBGP peering and deploy a route-reflected IBGP topology within Beer-Co.

Multihome Beer-Co

Beer-Co's initial BGP peering with Botnet in AS 34 is operating successfully, and it's time to bring up a second EBGP session to Borgnet in AS 420. When multihomed to dual providers, the true benefit of BGP and its policy controls can be fully realized. Figure 7-9 provides the new BGP peering topology and illustrates how Borgnet connects to service provider Darknet in AS 666, which is also peered with Botnet. It seems that things could get quite interesting here.

The figure shows key details of each AS. These include the EBGP peering router's name, its loopback address, and the set of routes that originate within that AS and the customer routes associated with that network. The figure calls out three particular customer prefixes within Borgnet, Darknet, and Botnet, which are assigned to customers Cap-co Inc., Bottles Inc., and Brewer Inc., respectively. The 192.168.*xx*/24 prefixes associated with these extranet partners demonstrate the effects of inbound and outbound policy actions in the following sections.

In this scenario, Beer-Co's IGP consists of an area 0 backbone with two stub areas. Area border routers (ABRs) `PBR` and `Stout` originate an OSPF default route into their respective stub areas.

The design goals for the new BGP peering arrangement are as follows:

- Deploy new import policy at routers `Yeast` and `PBR` to accept only routes that originate in the peering AS, including a default route generated by both providers.
- Establish the new EBGP peering session between `PBR` and `Wheat` and advertise a 10/8 aggregate.
- Configure loopback-based IBGP peering on a minimal set of routers as needed for loop-free transport within Beer-Co.
- Use route reflection to reduce the total number of IBGP sessions and ensure no single point of failure.

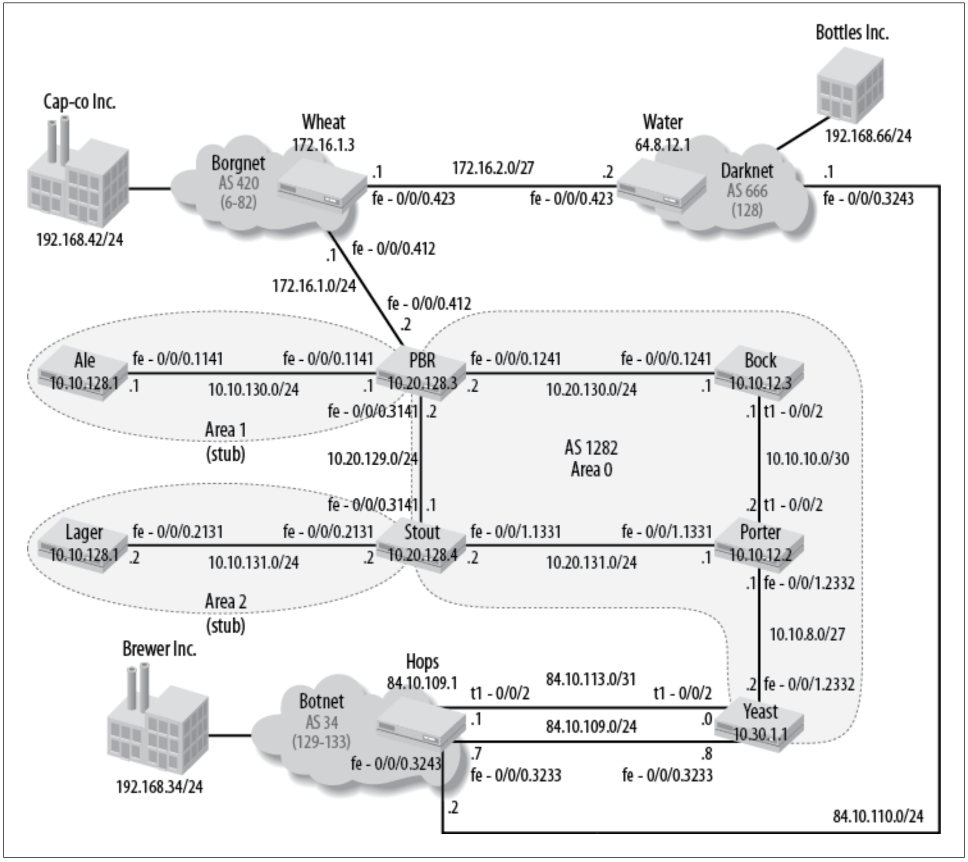


Figure 7-9. Beer-Co goes multihomed with a connection to Borgnet

- Establish an outbound policy that prefers each peer's customer routes, with all other destinations using the Borgnet link as a revertive primary.

The result of the initial BGP multihoming task is a (default) topology-driven inbound policy and a hybrid outbound policy that combines elements of the topology-driven and primary models. Route filtering and route reflection are used to minimize BGP processing demand on routers with limited memory.

To help put these requirements into a functional perspective, the expected behavior is summarized as follows:

- EBGP speakers accept only peer customer routes (customer routes).
- When sending to customer routes, forward directly to the AS that owns that route when the related peering session is operational.
- When sending to other BGP destinations, all BGP speakers use the default route associated with the primary peering to Borgnet.

- Routers in stub areas use a default to reach the closest ABR, at which point BGP forwarding takes effect.
- The failure of any access link should not sever communications; upon restoration, traffic should again adhere to the loose primary outbound policy.

Implement Beer-Co's Outbound Policy

Configuration begins by creating the import policy at PBR that accepts only those routes that originate within Borgnet. The intention is to protect the relatively small access router from the potentially harmful effects associated with the receipt of a full BGP route table from Wheat. Similar policy actions will also be performed at Yeast. The effect is a topology-driven outbound routing model for the routes owned by each peering AS, and the use of the metrically closest default route for destinations that originate outside of these ASs; for example, the 128/8 and 192.168.66/24 routes that are originated by the nonadjacent AS Darknet.

This type of BGP import policy normally uses an AS path regular expression because it greatly simplifies the matching criteria against the numerous route prefixes that could originate within a given AS. In this example, the routes owned by Borgnet are shown as being in the range of 6–82, making a route filter feasible. However, you also need to consider its internal/direct routes, in this case the 172.16.1.3 loopback address of Wheat. When really tight control is needed, you can always combine the effects of route filters and AS path regular expressions. The import policy created for PBR uses an AS path regular expression to only accept routes with one or more instances of ASN 420. The regular expression is written in this manner to accommodate the potential of AS path prepending within Borgnet. This way, even if there are 10 instances of ASN 420 in the prefix, the route is still considered to have originated within that specific AS. PBR's import policy is displayed:

```
[edit policy-options]
lab@PBR# show
policy-statement as_420_import {
    term 1 {
        from {
            protocol bgp;
            as-path as_420_originate;
        }
        then accept;
    }
    term 2 {
        then reject;
    }
}
as-path as_420_originate "^420+$";
```

The first term of the as_420_import policy accepts routes from BGP with an AS path matching the named expression as_420_originate. The second term defeats the default BGP import policy, which is to accept all (sane) BGP routes. The AS path regular expression uses the ^ and $ anchors to force a match against the start and end of the AS path attribute, respectively. The + multiplier indicates that the proceeding pattern (420) must appear at least once, but can appear multiple times. The combined effect is a match against any AS path attribute that begins and ends with the value 420, which may contain zero or more repetitions of that same value. The `as_34_import` policy at `Yeast` is modified to accept all BGP routes originating in AS 34:

```
[edit]
lab@Yeast# show policy-options policy-statement as_34_import
term slow_peer {
    from {
        protocol bgp;
        neighbor 84.10.113.1;
        as-path 34_originate;
    }
    then {
        community add bw_slow;
        accept;
    }
}
term fast_peer {
    from {
        protocol bgp;
        neighbor 84.10.109.7;
        as-path 34_originate;
    }
    then {
        community add bw_fast;
        accept;
    }
}
term reject-all {
    then reject;
}
[edit]
lab@Yeast# show policy-options as-path
34_originate "^34+$";
```

The route filter was removed, so now, rather than accepting only a default route, `Yeast` accepts all routes that originate in AS 34. The as-path also was updated to allow multiple occurrences of AS 34.

EBGP Peering to AS 420

With the import policy defined, you need a BGP stanza with which to apply it. The EBGP peering definition at `PBR` is pretty straightforward:

```
[edit]
lab@PBR# show protocols bgp
group as_420 {
    type external;
    import as_420_import;
    neighbor 172.16.1.1 {
        peer-as 420;
    }
}
```

The newly created `as_420_import` policy has been applied as import. The commit failure offers a friendly reminder that, for BGP to operate, a local ASN is required. This is quickly remedied:

```
[edit]
lab@PBR# commit
[edit protocols]
  'bgp'
    Error in neighbor 172.16.1.1 of group as_420:
must define local autonomous system when enabling BGP
error: configuration check-out failed

[edit]
lab@PBR# set routing-options autonomous-system 1282

[edit]
lab@PBR# commit
commit complete
```

BGP session status is verified with a `show bgp summary` command:

```
[edit]
lab@PBR# run show bgp summary
Groups: 1 Peers: 1 Down peers: 0
Table    Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0        806        123          0         0          0        0
Peer         AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
172.16.1.1    420    356        257       0       0     2:06:57
123/806/00/0/0
```

The EBGP session to Borgnet is established, as confirmed by the `x/x/x` field that summarizes active routes, received routes, and damped routes, respectively. This display also begins to validate the `as_420_import` policy, in that only 123 of the 806 routes received are active. The presence of hidden routes, ostensibly due to filtering, is confirmed:

```
[edit]
lab@PBR# run show route hidden detail

inet.0: 825 destinations, 826 routes (143 active, 0 holddown, 682 hidden)
64.8.12.1/32 (1 entry, 0 announced)
         BGP                 /-101
                Next-hop reference count: 929
                Source: 172.16.1.1
                Next hop: 172.16.1.1 via ge-0/0/0.412, selected
                State: <Hidden Ext>
                Local AS:  1282 Peer AS:   420
                Age: 2:19:43
                Task: BGP_420.172.16.1.1+1530
                AS path: 420 666 I
                Localpref: 100
                Router ID: 172.16.1.3

128.3.0.0/16 (1 entry, 0 announced)
         BGP                 /-101
                Next-hop reference count: 929
                Source: 172.16.1.1
                Next hop: 17^C[abort]
---(more)---
. . .
```

The summary portion of the `show route hidden detail` command confirms both a large number of hidden routes (682) and that the hidden route displayed has an AS path that *does not* indicate origin in AS 420. This shows that the route is hidden due to your AS path-based import filtering. The CLI's AS path regular expression filter is used for final confirmation:

```
[edit]
lab@PBR# run show route aspath-regex ^420+$ | match path
                      AS path: 420 I
                      AS path: 420 I
                      AS path: 420 I
                      AS path: 420 I
                      AS path: 420 I
. . .
[edit]
lab@PBR# run show route aspath-regex ^420+$ | match path | countCount: 124 lines
```

The regex-filtered `show route` display verifies that all matching routes have an AS path consisting of only AS 420. The CLI's `count` function is then used to confirm that `PBR` has received a total of 124 routes from Borgnet that pass the `as_420_import` policy. One of these should be a default route that is used to reach BGP destinations that do not originate in either AS 34 or AS 420:

```
[edit]
lab@PBR# run show route

inet.0: 825 destinations, 826 routes (143 active, 0 holddown, 682 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/150] 02:24:20, metric 0, tag 0
                    > to 10.20.130.1 via ge-0/0/0.1241
                    [BGP/170] 00:28:13, localpref 100
                      AS path: 420 I
                    > to 172.16.1.1 via ge-0/0/0.412
```

The `show route` display at `PBR` confirms the receipt of a BGP default route but shows a potential problem as well; `PBR` also receives the default route redistributed into OSPF by `Yeast`, and it prefers the OSPF version due to global preference (known as administrative distance in IOS land).

The goal of your hybrid topological/primary outbound routing policy is to have routers forward to peer customer routes using a topology model that hands traffic directly to the AS that owns those routes, while a default route is used to reach filtered BGP destinations over the primary Borgnet peering. To meet the requirements, this default route should always direct traffic over the Borgnet link when it is operational. Therefore, in normal operation, all routers must prefer the default route advertised by `PBR` over any copy advertised by `Yeast`.

In the current setup, a BGP learned default route from AS 34 is being redistributed into OSPF at router `Yeast`. Recall that this was necessary because up until now, `Yeast` was the only BGP speaker in Beer-Co. Given that you are now, or soon will be, deploying IBGP among a set of Beer-Co's internal routers, the need to redistribute the default into OSPF can be revisited. The stub area routers already rely on an OSPF default generated by each area's ABR, so this discussion centers on what is done for routers `PBR`, `Bock`, `Stout`, `Porter`, and `Yeast`. Figure 7-10 details the plan of action for IBGP deployment on Beer-Co's backbone.

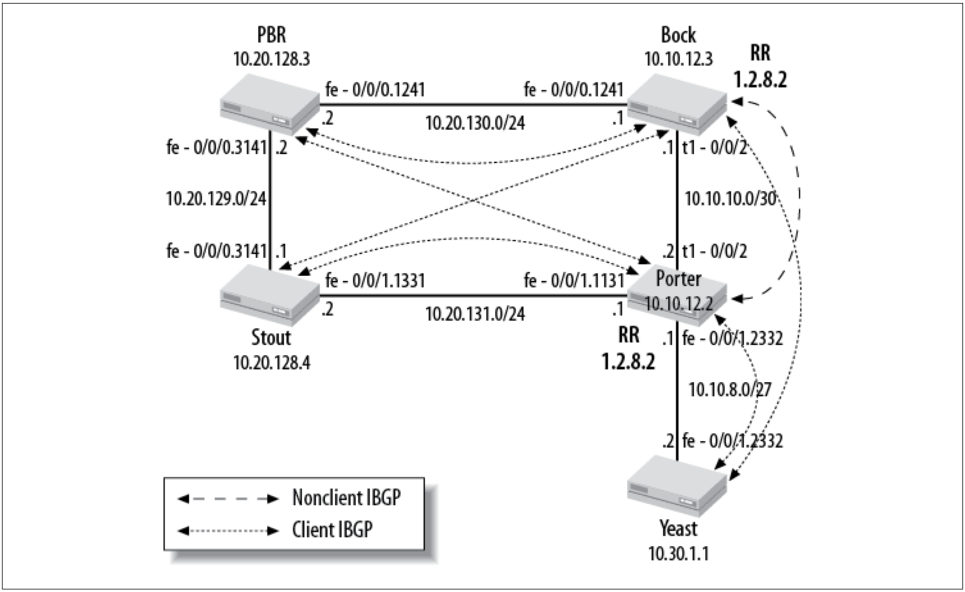


Figure 7-10. Beer-Co IBGP deployment details

Figure 7-10 shows that all OSPF area 0 routers will be configured to run IBGP. Recall from an earlier discussion that deciding which routers need to run IBGP is a function of whether your import policy accepts only a default, and whether intermediate routers are in the forwarding path between EBGP speakers. Also recall that an EBGP speaker should always be enabled for IBGP unless there is only one BGP speaker in your network. Because your EBGP speakers are accepting only specific prefixes, IBGP should be enabled on any router that can forward traffic between the speakers. In this example, that means `Stout`, `Bock`, and `Porter` must support IBGP. Because the backbone routers will run BGP, they can learn the default route through BGP; this means that redistribution of the BGP default into OSPF is no longer necessary. With this understanding, the `ospf_default` export policy is removed at `Yeast`:

```
[edit]
lab@Yeast# delete policy-options policy-statement ospf_default

[edit]
lab@Yeast# delete protocols ospf export
```

The effect of this change is confirmed at `PBR`, where now only the BGP version of the default route is present and is therefore made active:

```
[edit]
lab@PBR# run show route

inet.0: 827 destinations, 827 routes (145 active, 0 holddown, 682 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[BGP/170] 17:26:08, localpref 100
                      AS path: 420 I
                    > to 172.16.1.1 via ge-0/0/0.412
```

Export Beer-Co Aggregate to Borgnet

The requirements state that `PBR` should advertise a single 10/8 aggregate to its EBGP peers representing Beer-Co's internal connectivity. The same approach used at `Yeast` is brought to bear here. Specifically, an aggregate route is defined and policy is created to export it to `Wheat` in AS 420:

```
[edit]
lab@PBR# show routing-options aggregate
route 10.0.0.0/8;
lab@PBR# show policy-options policy-statement as_420_export
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then accept;
}

[edit]
lab@PBR# show protocols bgp group as_420 export
export as_420_export;
```

Validation of the `as_420_export` policy is straightforward:

```
[edit]
lab@PBR# run show route advertising-protocol bgp 172.16.1.1

inet.0: 827 destinations, 827 routes (145 active, 0 holddown, 682 hidden)
  Prefix                  Nexthop              MED     Lclpref    AS path
* 10.0.0.0/8              Self                                    I
```

Although not shown, a similar state of EBGP learned and advertised routes is also confirmed to exist at router Yeast, except that is has learned the 129–133 and 192.168.34/24 customer routes from AS 34. This completes the EBGP peering and initial import policy phases of the BGP multihoming scenario. It is time to add IBGP to the network.

Monitor system load

Before adding EBGP to Yeast, system resources were analyzed using the `show chassis routing-engine` and `show task memory` commands. Now that EBGP has been added, it is a good idea to reexamine resource usage. If the router is having a hard time maintaining its current EBGP load for whatever reason, obviously the addition of IBGP sessions will not help matters. The hidden `set task accounting` command is used to get a better feel for how much burden BGP itself is adding to the router.

Hidden commands are hidden because Juniper Networks support engineers feel inappropriate use can cause operational problems. As a general rule, you should never issue hidden commands on a production network router unless a support engineer has instructed you to do so.

This command displays the resource consumption of the various components of the routing daemon (`rpd`) and is hidden because it requires the router's resources to run, which could make a bad situation worse. Because there is no reason to believe that any of Beer-Co's routers are actually running short on resources, task accounting is enabled (note that there is no CLI auto-completion, hence the term *hidden*). After a few moments, the results are displayed, and task accounting is turned back off. Task accounting should be enabled only when needed, and then only long enough to get the information desired. Also note that `set task accounting on` is an operational mode command:

```
lab@PBR> set task accounting on
Task accounting enabled.

lab@PBR>
```

After a few moments, the results are displayed:

```
lab@PBR> show task accounting
Task accounting is enabled.

Task                         Started User Time System Time Longest Run
Scheduler                        425     0.004       0.007       0.000
LMP Client                        75     0.001       0.002       0.000
Memory                             6     0.000       0.000       0.000
OSPFv2 I/O./var/run/ppmd_        120     0.001       0.002       0.000
BGP RT Background                 32     0.000       0.000       0.000
OSPFv2                           100     0.000       0.001       0.000
BFD I/O./var/run/bfdd_con         29     0.000       0.000       0.000
BGP_420.172.16.1.1+1530           38     0.000       0.001       0.000
```

```
    KRT                              12     0.000       0.000       0.000
    Redirect                          2     0.000       0.000       0.000
    MGMT_Listen./var/run/rpd_         2     0.000       0.000       0.000
    SNMP Subagent./var/run/sn         3     0.000       0.000       0.000
```

The output indicates that the EBGP peering at PBR is not consuming appreciable system resources. Note that instability and resulting route flaps (repeated route withdrawals and readvertisement) could change this situation. BGP route damping is used to buffer the effects of flapping routes when needed. In operation, once an unstable prefix is damped, subsequent updates/withdrawals are ignored for a specified period to preserve the local router's control plane resources.

Task accounting is again disabled to prevent unnecessary resource usage:

```
lab@PBR> set task accounting off
Task accounting disabled.
```

IBGP Peering Within AS 1282

Referring back to Figure 7-10 and the scenario's design requirements, it's obvious that you need to configure IBGP on the backbone routers. Route reflection is used to minimize the total number of IBGP sessions required. Dual route reflectors are deployed for redundancy, in this case using the same cluster ID. The use of loopback-based IBGP peering means that the potential for session disruption to one reflector, but not the other, is virtually nonexistent, making the lack of cluster 1.2.8.2 updates over the route reflector-route reflector IBGP session a nonissue. Using the same cluster ID on both reflectors reduces the BGP routing information base (RIB) size on the reflectors because they filter updates received from each other that contain the shared cluster ID. Note that the two route reflectors peer to each other as nonclients. The same cluster ID value is configured on both reflectors. In this example, the cluster ID is based on Beer-Co's ASN 1282.

For the SRXs and the J-series routers, BGP route reflection is a value-added service that requires separate licensing. Route reflection will not operate without the Advanced BGP feature license. You obtain feature licenses from the distributor that sold you the router. Without the license, the BGP connection will not pass the idle state on the route reflector. This is a change for Juniper. Until a short time ago, the license enforcement was only a warning in the configuration, but today the licensed features do not operate.

Configuration of route reflection begins with creation of the route reflector–route reflector IBGP peering session on Porter:

```
[edit]
lab@Porter# set routing-options autonomous-system 1282

[edit]
lab@Porter# edit protocols bgp group 1282_rr
```

```
[edit protocols bgp group 1282_rr]
lab@Porter# set type internal neighbor 10.10.12.3

[edit protocols bgp group 1282_rr]
lab@Porter# set local-address 10.20.12.2

[edit protocols bgp group 1282_rr]
lab@Porter# top show routing-options
autonomous-system 1282;

[edit protocols bgp group 1282_rr]
lab@Porter# show
type internal;
local-address 10.20.12.2;
neighbor 10.10.12.3;
```

With definition of the local system's ASN under the `routing-options` stanza complete, you create a BGP group called `1282_rr`; this group is designated as an `internal` group, making the configuration of a `peer-as` unnecessary. The highlights show how a loopback-based peering session is defined through specification of the neighbor's loopback address in conjunction with a `local-address` statement representing the local loopback address. The use of the `local-address` statement is crucial for proper loopback peering. Omitting the `local-address`, which is known as `update-source` in IOS, results in a session that is sourced from whatever interface the session is routed over. Because the remote router is configured to peer with a loopback address, the incoming session, which is now sourced from a physical interface's IP, appears unexpected, and peering is refused. Generally speaking, you can omit the `local-address` from one end, as both ends try to form a connection by default, but best practices for loopback peering call for both ends to be configured symmetrically.

A similar configuration is added to `Bock`:

```
[edit protocols bgp group 1282_rr]
lab@Bock# show
type internal;
local-address 10.10.12.3;
neighbor 10.10.12.2;
```

After a minute or two, the reflector-to-reflector IBGP session status is verified:

```
[edit]
lab@Porter# run show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table    Tot Paths  Act Paths Suppressed  History Damp State   Pending
inet.0          0          0          0        0          0         0
Peer        AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.3   1282       0       0       0       0        4:35 Idle
```

Things do not look good at `Porter`. The `Idle` state implies that the BGP session cannot even be routed, let alone established. A glance at `Bock` shows an `Active` state, meaning that the router is at least able to route its TCP session toward its peer and is therefore actively trying to establish a TCP connection:

```
[edit protocols bgp group 1282_rr]
lab@Bock# run show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table   Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0          0          0          0          0        0        0
Peer         AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.2   1282       0          8       0       0      2:33 Active
```

Troubleshoot an IBGP peering problem

Attention is focused at `Porter` because its BGP session status is the lesser/worse of the two. Because loopback-based peering requires an IGP to resolve the forwarding next hop used to reach the session's target loopback address, it's reasonable to begin fault isolation with the IGP infrastructure. The first step is to confirm whether `Porter` has a route to `Bock`'s loopback address:

```
[edit]
lab@Porter# run show route 10.10.12.3

inet.0: 20 destinations, 21 routes (20 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.12.3/32      *[OSPF/10] 02:24:59, metric 3
                    > to 10.20.131.2 via ge-0/0/1.1331
```

The output confirms that `Porter` has an OSPF learned route to `Bock`'s loopback address. A traceroute is performed *between* the IBGP peering addresses. This is achieved by sourcing the traceroute from `Porter`'s loopback address, as highlighted:

```
[edit]
lab@Porter# run traceroute 10.10.12.3 source 10.10.12.2
traceroute to 10.10.12.3 (10.10.12.3) from 10.10.12.2, 30 hops max,
40 byte packets
 1  10.20.131.2 (10.20.131.2)  12.790 ms  14.714 ms  5.128 ms
 2  10.20.129.2 (10.20.129.2)  24.976 ms  9.342 ms  9.845 ms
 3  10.10.12.3 (10.10.12.3)  10.103 ms  27.564 ms  31.800 ms
```

The traceroute succeeds, and in so doing vindicates the IGP as the source of the IBGP peering problem. From a loopback-based IBGP perspective, all that is required of the IGP is a route between loopback addresses, and clearly that part is working here. The next step is to add BGP protocol tracing to see whether that sheds any light. Tracing is added to `Porter`, and the trace file is monitored in real time using the `monitor start` command:

```
[edit protocols bgp]
lab@Porter# show traceoptions
file bgp_trace;
flag open detail;
```

```
[edit protocols bgp]
lab@Porter# commit
commit complete

[edit protocols bgp]
lab@Porter# run monitor start bgp_trace
```

BGP trace output is observed after a minute or so; use the `clear bgp neighbor` *`<peer address>`* command to help expedite activity when you are impatient:

```
*** bgp_trace ***
Sep  1 01:49:02.088247
Sep  1 01:49:02.088247 BGP RECV 10.10.12.3+1601 -> 10.10.12.2+179
Sep  1 01:49:02.088335 BGP RECV message type 1 (Open) length 45
Sep  1 01:49:02.088423 BGP RECV version 4 as 1282 holdtime 90 id
10.10.12.3 parmlen 16
Sep  1 01:49:02.088447 BGP RECV MP capability AFI=1, SAFI=1
Sep  1 01:49:02.088460 BGP RECV Refresh capability, code=128
Sep  1 01:49:02.088469 BGP RECV Refresh capability, code=2
Sep  1 01:49:02.088508
Sep  1 01:49:02.088508 BGP SEND 10.10.12.2+179 -> 10.10.12.3+1601
Sep  1 01:49:02.088537 BGP SEND message type 1 (Open) length 29
Sep  1 01:49:02.088552 BGP SEND version 4 as 1282 holdtime 90 id
10.10.12.2 parmlen 0
Sep  1 01:49:02.088566
Sep  1 01:49:02.088566 BGP SEND 10.10.12.2+179 -> 10.10.12.3+1601
Sep  1 01:49:02.088583 BGP SEND message type 3 (Notification) length 21
Sep  1 01:49:02.088689 BGP SEND Notification code 2 (Open Message
Error) subcode 5 (authentication failure)
Sep  1 01:49:02.089581 bgp_pp_recv: NOTIFICATION sent to 10.10.12.3+1601
proto): code 2 (Opelist
monitor start "bgp_trace" (Last changed Sep  1 01:49:02)
(Message Error) subcode 5(authentication failure), Reason: no group
for 10.10.12.3+1601 (proto) from AS 1282 found (peer idled), dropping
him
```

The highlights call out key aspects of the trace. Things begin when `Porter` receives a BGP session open from `Bock`. Note that this session is correctly sourced between the loopback addresses associated with routers `Bock` and `Porter.` `Porter` responds with a notification message that reports an authentication failure. In the BGP context, this type of message means that an unknown peer has tried to establish a peering session. BGP normally communicates only with explicitly configured peers (unless you add the `allow` *`<prefix>`* keyword). The last highlight is telling—the local system reports that this peer does not belong to any configured groups. The lack of `Porter`-initiated BGP session requests is expected here; recall that its connection is in the idle state, which means that it cannot begin to form a session, so there would be nothing to trace.

The IBGP configuration is examined with extra scrutiny, because you are sure that `Porter` has peer 10.10.12.3 configured in the `1282_rr` group:

```
[edit protocols bgp]
lab@Porter#
*** monitor and syslog output disabled, press ESC-Q to enable ***
```

```
[edit protocols bgp]
lab@Porter# show
traceoptions {
    file bgp_trace;
    flag open detail;
}
group 1282_rr {
    type internal;
    local-address 10.20.12.2;
    neighbor 10.10.12.3;
}
```

The IBGP configuration problem at `Porter` jumps out and slaps you in the head, emitting a d'oh-like sound that echoes between your ears. The `local-address` statement incorrectly specifies a nonexistent address. This accounts for the local state of idle because the router cannot create a packet with a spoofed address! This effectively puts the `1282_rr` group into an idle state, which in turn leads to the authentication failure for the session initiated by `Bock`. The tracing configuration is removed, the mistake is corrected, and session status is confirmed to be operational a short time later:

```
[edit protocols bgp]
lab@Porter# delete traceoptions

[edit protocols bgp]
lab@Porter# set group 1282_rr local-address 10.10.12.2

[edit protocols bgp]
lab@Porter# run show bgp summary
Groups: 1 Peers: 1 Down peers: 0
Table  Tot Paths  Act Paths Suppressed    History Damp State    Pending
inet.0         0          0          0          0          0          0
Peer            AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.3  1282          5          6       0       0       1:52 0/0/0
0/0/0
```

Configure route reflection

The configuration for cluster 1.2.8.2 is now added to each reflector. Here is `Bock`'s `1282_clients` group:

```
[edit protocols bgp group 1282_clients]
lab@Bock# show
type internal;
local-address 10.10.12.3;
cluster 1.2.8.2;
neighbor 10.20.128.3;
neighbor 10.20.128.4;
neighbor 10.30.1.1
```

The `1282_rr_clients` group is similar to the previously created `1282_rr` group, except for the inclusion of a cluster ID, which makes the local router a route reflector for all peers in that group. All three client loopback addresses are configured, making them clients for cluster 1.2.8.2. A similar configuration is added to Porter.

A note on next-hop self and route reflectors is in order here. It is common to have an IBGP export policy on EBGP speakers that sets the advertised next hop to the IBGP speaker's peering address to eliminate issues with other routes not being able to resolve the EBGP next hop originally advertised by the remote AS. Applying such a policy for routes that are reflected among clients can easily result in suboptimal forwarding, as traffic will be forced to transit the reflector. In most cases, you want the reflection topology to be independent of the forwarding topology, and leaving the next hop unchanged on reflected routes achieves this goal.

IBGP configuration at routers PBR, Stout, and Yeast is similar. Each router gets an IBGP group that defines loopback peering to each reflector. The use of redundant route refection doubles the total number of IBGP sessions needed for this network, bringing the total to 13. This is still far fewer than the 20 sessions needed to form a full mesh among five routers if reflection were not used. Here is the configuration of client Stout:

```
[edit protocols bgp group 1282_clients]
lab@stout# top show routing-options
autonomous-system 1282;

[edit protocols bgp group 1282_clients]
lab@stout# show
type internal;
local-address 10.20.128.4;
neighbor 10.10.12.3;
neighbor 10.10.12.2;
```

After the new 1282_clients peer group is added to client routers PBR, Stout, and Yeast, IBGP session status is confirmed at client Stout:

```
[edit protocols bgp group 1282_clients]
lab@stout# run show bgp summary
Groups: 1 Peers: 2 Down peers: 0
Table  Tot Paths  Act Paths Suppressed  History Damp State    Pending
inet.0          0          0          0        0          0          0
Peer          AS      InPkt     OutPkt  OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.2    1282    13  14        0       0      6:19 0/0/0    0/0/0
10.10.12.3    1282    20  22        0       0      9:57 0/0/0    0/0/0

[edit protocols bgp group 1282_clients]
lab@stout# run show route protocol bgp

inet.0: 20 destinations, 20 routes (20 active, 0 holddown, 0 hidden)
```

The output is a bit of a mixed bag of results. On the one hand, both IBGP sessions are established to the reflectors; on the other hand, no routes are being learned over either session. Oddly, a `show route advertising-protocol bgp` command at `PBR` confirms that it is readvertising its EBGP learned routes to reflector `Bock`:

```
[edit protocols bgp group 1282_clients]
lab@PBR# run show route advertising-protocol bgp 10.10.12.2

inet.0: 827 destinations, 827 routes (145 active, 0 holddown, 682 hidden)
  Prefix                  Nexthop              MED     Lclpref    AS path
* 0.0.0.0/0               172.16.1.1                   100        420 I
* 6.1.0.0/16              172.16.1.1                   100        420 I
* 6.2.0.0/22              172.16.1.1                   100        420 I
. . . .
```

If `PBR` is advertising routes to the reflector, why are these routes not being reflected to the cluster's clients?

Troubleshoot BGP next hop reachability

Attention shifts to the reflectors, since the missing routes were last observed being sent to them, while nothing is seen coming back from them. The `show route receive-protocol bgp` command output on reflector `Bock` implies that *no* routes are being received, which is not possible, given that `PBR`'s output shows it advertised routes to `Bock`, and the underlying TCP transport guarantees delivery!

```
[edit protocols bgp group 1282_clients]
lab@Bock# run show route receive-protocol bgp 10.20.128.3

inet.0: 825 destinations, 950 routes (19 active, 0 holddown, 930 hidden)
```

The presence of hidden routes is noted, so you investigate by adding the `hidden` switch:

```
[edit protocols bgp group 1282_clients]
lab@Bock# run show route receive-protocol bgp 10.20.128.3 hidden

inet.0: 825 destinations, 950 routes (19 active, 0 holddown, 930 hidden)
  Prefix                 Nexthop              MED     Lclpref    AS path
  0.0.0.0/0              172.16.1.1                   100        420 I
  6.1.0.0/16             172.16.1.1                   100        420 I
. . .
```

The output confirms that the BGP routes advertised by `PBR` are in fact hidden at `Bock`. This explains the lack of reflection to other clients, because active routes only are subject to advertisement. The `extensive` switch is added to get as much detail as possible, but the output does not contain any additional information:

```
[edit protocols bgp group 1282_clients]
lab@Bock# ...protocol bgp 10.20.128.3 hidden extensive

inet.0: 825 destinations, 950 routes (19 active, 0 holddown, 930 hidden)
  0.0.0.0/0 (2 entries, 0 announced)
     Nexthop: 172.16.1.1
     Localpref: 100
     AS path: 420 I
. . .
```

The limited set of information displayed does include the route's associated BGP next hop, which here represents the address assigned to Wheat for use on its EBGP peering to PBR. Recalling that the BGP route selection process begins with a decision as to whether the next hop is reachable, you display the route to 172.16.1.1 at Bock:

```
[edit protocols bgp group 1282_clients]
lab@Bock# run show route 172.16.1.1
```

The output, or more correctly the lack thereof, confirms that the issue is one of BGP next hop reachability. The `show route resolution unresolved detail` command is used to confirm this fact:

```
[edit protocols bgp group 1282_clients]
lab@Bock# run show route resolution unresolved detail
Tree Index 1
133.3.0.0/16
        Protocol Nexthop: 84.10.109.7
        Indirect nexthop: 0 -
132.252.0.0/16
        Protocol Nexthop: 84.10.109.7
        Indirect nexthop: 0 -
. . . .
```

The display confirms that route reflector Bock is unable to resolve the EBGP next hop attached to the routes it learns from Yeast. There are several common solutions to this classic problem. Recall that by default, the BGP next hop is updated only on EBGP links. You could alter this behavior with a `next-hop self` policy on the EBGP speakers, which is then applied as an IBGP *export* policy to update the next hop of each route as it is readvertised to other IBGP speakers.

Never apply a `next-hop self` policy as import for an EBGP session because the resulting routes appear to be looped and are hidden.

Another way to fix the unreachable next hop is to advertise the EBGP peering subnet into your IGP. You should do this by running a passive IGP instance on your EBGP peering links. The passive mode guarantees that an adjacency cannot form to the remote AS, which could be very, very bad (IGPs lack policy controls for interdomain routing, and combining two large IGPs into a single, larger one may push routers beyond their limits).

An IBGP export to affect `next-hop self` behavior solves the problem. The changes made to PBR's configuration are also placed into effect at Yeast:

```
[edit]
lab@PBR# show policy-options policy-statement next_hop_self
term 1 {
    from protocol bgp;
    then {
        next-hop self;
        }
    }

[edit]
lab@PBR# show protocols bgp group 1282_clients export
export next_hop_self;
```

The BGP summary display back at `Stout` confirms that route reflection is working:

```
[edit protocols bgp group 1282_clients]
lab@stout# run show bgp summary
Groups: 1 Peers: 2 Down peers: 0
Table  Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0      1612        806          0         0          0        0
Peer            AS    InPkt    OutPkt   OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
10.10.12.2   1282     163        84      0       0     41:18 806/806/0
0/0/0
10.10.12.3   1282     259         92      0       0     44:56 0/806/0
0/0/0
```

The highlights show that `Stout` is receiving the same number of BGP routes from both reflectors, which is expected. Recall that BGP tiebreaking rules prefer routes learned from the router with the lowest RID, which is `Porter` in this case. You could enable multipath for IBGP to install both copies of the routes into the forwarding table. However, in this example, it does not buy anything, as both copies point to the same forwarding next hop address. We will rely on the IGP to perform load balancing if there are multiple equal cost paths. Details for the customer route to Brewer Inc. are displayed to confirm various attributes for the route, including why the copy learned from `Porter` is preferred:

```
[edit protocols bgp group 1282_clients]
lab@stout# run show route 192.168.34.0 detail

inet.0: 826 destinations, 1632 routes (826 active, 0 holddown, 0 hidden)
192.168.34.0/24 (2 entries, 1 announced)
        *BGP    Preference: 170/-121
                Next-hop reference count: 2732
                Source: 10.10.12.2
                Next hop: 10.20.131.1 via ge-0/0/1.1331, selected
                Protocol next hop: 10.30.1.1
                Indirect next hop: 8791128 262144
                State: <Active Int Ext>
                Local AS:  1282 Peer AS:  1282
                Age: 30         Metric2: 2
                Task: BGP_1282.10.10.12.2+179
                Announcement bits (2): 0-KRT 4-Resolve tree 1
                AS path: 34 I (Originator) Cluster list:  1.2.8.2
                AS path:  Originator ID: 10.30.1.1
                Communities: bandwidth:1287:12500000
                Localpref: 120
                Router ID: 10.10.12.2
         BGP    Preference: 170/-121
                Next-hop reference count: 2732
                Source: 10.10.12.3
                Next hop: 10.20.131.1 via ge-0/0/1.1331, selected
                Protocol next hop: 10.30.1.1
                Indirect next hop: 8791128 262144
                State: <NotBest Int Ext>
                Inactive reason: Router ID
                Local AS:  1282 Peer AS:  1282
                Age: 4:29       Metric2: 2
                Task: BGP_1282.10.10.12.3+179
                AS path: 34 I (Originator) Cluster list:  1.2.8.2
                AS path:  Originator ID: 10.30.1.1
                Communities: bandwidth:1287:12500000
                Localpref: 120
                Router ID: 10.10.12.3
```

Confirm Outbound Policy Operation

The EBGP and IBGP peering is established within your network, and route reflection is confirmed operational. The verification of your output policy is performed at IBGP speaker `Stout`. Recall that `Ale` and `Lager` use the OSPF default to forward packets to their respective ABRs, which in turn now have BGP routing state and are expected to make the correct outbound forwarding decision.

Things start with traceroutes to customer networks in peering ASs Borgnet and Botnet:

```
lab@stout> traceroute 192.168.42.1
traceroute to 192.168.42.1 (192.168.42.1), 30 hops max, 40 byte packets
 1  10.20.129.2 (10.20.129.2)  6.360 ms  59.843 ms  15.233 ms
 2  172.16.1.1 (172.16.1.1)  10.191 ms !N  8.985 ms !N  10.114 ms !N

lab@stout> traceroute 192.168.34.1
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte packets
 1  10.20.131.1 (10.20.131.1)  40.976 ms  34.719 ms  2.141 ms
 2  10.10.8.2 (10.10.8.2)  10.009 ms  18.695 ms  8.191 ms
 3  84.10.109.7 (84.10.109.7)  32.183 ms !N  19.530 ms !N  19.790 ms !N
```

The results match the topological aspects of Beer-Co's outbound policy—`Stout` is using the specific routes it has learned from the EBGP peering routers to forward directly to the peer AS that owns the customer route. The point being stressed here is that this aspect of outbound policy is a side effect of the route filtering performed at the EBGP-speaking routers. `Yeast`, for example, filters the copy of Cap-Co's 192.168.42/24 route when it is readvertised from Botnet because that route did not originate within AS 34. This means that although there are two copies of customer route 192.168.42/24, both copies identify the *same* BGP next hop, which is `PBR` in this example. There are two copies of this route because of the redundant route reflector design. Refer back to the previous `show route` display for full details. The following (filtered) display calls out that both copies of the 192.168.42/24 route point to the same BGP egress point, despite being learned from two different reflectors:

```
lab@stout> show route 192.168.42.0 detail | match next
                Next-hop reference count: 496
                Next hop: 10.20.129.2 via ge-0/0/0.3141, selected
                Protocol next hop: 10.20.128.3
                Indirect next hop: 8791000 262142
                Next-hop reference count: 496
                Next hop: 10.20.129.2 via ge-0/0/0.3141, selected
                Protocol next hop: 10.20.128.3
                Indirect next hop: 8791000 262142
```

Things are not so perfect when it comes to destinations that are filtered by both EBGP speakers—for example, the 192.168.66/24 Bottle Inc. route. Because the BGP speakers are relying on a learned default route, which has equal specificity for all such filtered destinations, special steps are required to meet the stated outbound policy to avoid a tiebreaker situation between the otherwise equal-cost versions of the default route. Recall that in this example, all IBGP speakers should prefer the default route learned through `PBR` and use the one learned from `Yeast` only when the `PBR` session is disrupted.

The route to Bottle Inc. is shown at `Stout`:

```
lab@stout> show route 192.168.66.0 detail

inet.0: 577 destinations, 1134 routes (577 active, 0 holddown, 0 hidden)
0.0.0.0/0 (2 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 499
                Source: 10.10.12.3
                Next hop: 10.20.129.2 via ge-0/0/0.3141, selected
                Protocol next hop: 10.20.128.3
                Indirect next hop: 8791000 262142
                State: <Active Int Ext>
                Local AS:  1282 Peer AS:  1282
                Age: 1:15       Metric2: 1
                Task: BGP_1282.10.10.12.3+179
                Announcement bits (2): 0-KRT 4-Resolve tree 1
                AS path: 420 I (Originator) Cluster list:  1.2.8.2
                AS path:  Originator ID: 10.20.128.3
                Localpref: 100
                Router ID: 10.10.12.3
         BGP    Preference: 170/-101
                Next-hop reference count: 1729
                Source: 10.10.12.2
                Next hop: 10.20.131.1 via ge-0/0/1.1331, selected
                Protocol next hop: 10.30.1.1
                Indirect next hop: 8791128 262144
                State: <Int Ext>
                Inactive reason: IGP metric
                Local AS:  1282 Peer AS:  1282
                Age: 1:15       Metric2: 2
                Task: BGP_1282.10.10.12.2+179
                AS path: 34 I (Originator) Cluster list:  1.2.8.2
                AS path:  Originator ID: 10.30.1.1
                Communities: bandwidth:1287:12500000
                Localpref: 100
                Router ID: 10.10.12.2
```

The output confirms that Stout relies on a BGP learned default to reach destinations in nonadjacent ASs. The highlights show that Stout has learned of two copies of the default, one reflected by Bock that originates at PBR and the other via Porter, which originated at Yeast. In this example, the failure to adjust BGP attributes has left route selection to the default algorithm, which here selects the lowest metric IGP path, given that all other factors up to that decision step are the same. Your goal is to ensure that all IBGP speakers prefer the default advertised by PBR—this is not the case, so additional policy action is needed to meet the design requirements. The most direct way to alter which BGP routes are preferred by IBGP speakers is to adjust local preference:

```
lab@PBR# show protocols bgp group 1282_clients export
export [ next_hop_self prefer_Borgnet_transit ];

[edit]
lab@PBR# show policy-options policy-statement prefer_Borgnet_transit
term 1 {
    from {
        protocol bgp;
        route-filter 0.0.0.0/0 exact;
    }
    then {
        local-preference 110;
    }
}
```

After committing the change, the result is confirmed back at Stout:

```
lab@stout> show route 192.168.66.0

inet.0: 577 destinations, 1134 routes (577 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[BGP/170] 00:02:47, localpref 110, from 10.10.12.2
                      AS path: 420 I
                    > to 10.20.129.2 via ge-0/0/0.3141
                    [BGP/170] 00:02:47, localpref 110, from 10.10.12.3
                      AS path: 420 I
                    > to 10.20.129.2 via ge-0/0/0.3141
```

Why Only Two Copies of the Default?

You may be wondering why a router such as Stout is not receiving four copies of the BGP default route. Given that it receives two copies of the 192.168.42/24 route that is advertised *only* by PBR, you might expect twice as many copies for a route that is sent by *both* PBR and Yeast. The answer lies in the active route selection process performed by the reflectors. Each reflector readvertises only routes that are locally active. Because each reflector learns of route 192.168.42/24 from a single source (PBR), each reflector installs the route as active and both reflect it to their clients. In contrast, the default route is learned by each reflector from both PBR and Yeast, and each reflector chooses the copy it considers best, reflecting only that copy to its clients.

As a result, if the current network were to lose one of its EBGP speakers, there would *still* be two copies of the default route at each client. The difference is that now both copies will be the same route, as advertised by the remaining EBGP speaker. The same result occurs if the local preference of one default route is altered, causing it to be preferred by both reflectors.

There are still two copies of the default route, one learned from each reflector, but now both copies identify PBR as the protocol next hop. Therefore, using either version results in a forwarding path that directs traffic to nonadjacent ASs over the Borgnet peering. Both reflectors now prefer the route advertised by PBR because of its higher preference value. A traceroute is performed to confirm a normal forwarding path, and then the EBGP session at PBR is cleared to confirm fallback to Botnet:

```
lab@stout> traceroute 192.168.66.1
traceroute to 192.168.66.1 (192.168.66.1), 30 hops max, 40 byte packets
 1  10.20.129.2 (10.20.129.2)  9.087 ms  8.966 ms  29.973 ms
 2  172.16.1.1 (172.16.1.1)  9.289 ms  9.886 ms  9.868 ms
 3  172.16.2.2 (172.16.2.2)  30.022 ms !N  15.394 ms !N  23.853 ms !N
```

The EBGP session is clear at PBR:

```
[edit]
lab@PBR# run clear bgp neighbor 172.16.1.1
Cleared 1 connections
```

And now the traceroute takes the secondary path via Botnet:

```
lab@stout> traceroute 192.168.66.1
traceroute to 192.168.66.1 (192.168.66.1), 30 hops max, 40 byte packets
 1  10.20.131.1 (10.20.131.1)  39.481 ms  18.973 ms  20.043 ms
 2  10.10.8.2 (10.10.8.2)  159.897 ms  199.206 ms  10.097 ms
 3  84.10.109.7 (84.10.109.7)  39.908 ms  19.261 ms  13.438 ms
 4  84.10.110.1 (84.10.110.1)  16.441 ms !N  44.843 ms !N  34.459 ms !N
```

After a few minutes, PBR's EBGP session should be reestablished, making its default once again preferred, causing transit traffic to switch back (revertive behavior) to the Borgnet peering:

```
lab@stout> traceroute 192.168.66.1
traceroute to 192.168.66.1 (192.168.66.1), 30 hops max, 40 byte packets
 1  10.20.129.2 (10.20.129.2)  9.980 ms  8.803 ms  9.848 ms
 2  172.16.1.1  (172.16.1.1)  20.031 ms  29.300 ms  19.929 ms
 3  172.16.2.2 (172.16.2.2)  9.851 ms !N  9.394 ms !N  29.928 ms !N
```

The final verification is performed at stub router Lager, which has no BGP routes and uses the stub area default to reach its ABR:

```
lab@Lager> show route protocol bgp

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
```

No BGP routes are present because Lager is not running BGP:

```
lab@Lager> show route 192.168.66.0
```

```
inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[OSPF/10] 05:19:25, metric 11
                    > to 10.10.131.2 via ge-0/0/0.2131

lab@Lager> show route 192.168.34.0

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both
0.0.0.0/0          *[OSPF/10] 05:19:30, metric 11
                    > to 10.10.131.2 via ge-0/0/0.2131
```

Lager uses the OSPF default to reach all AS external destinations:

```
lab@Lager> traceroute 192.168.34.1
traceroute to 192.168.34.1 (192.168.34.1), 30 hops max, 40 byte packets
 1  10.10.131.2 (10.10.131.2)  10.507 ms  10.555 ms  9.706 ms
 2  10.20.131.1 (10.20.131.1)  17.896 ms  21.192 ms  20.007 ms
 3  10.10.8.2 (10.10.8.2)  39.897 ms  19.354 ms  20.043 ms
 4  84.10.109.7 (84.10.109.7)  19.780 ms !N  19.619 ms !N  19.887 ms !N

lab@Lager> traceroute 192.168.42.1
traceroute to 192.168.42.1 (192.168.42.1), 30 hops max, 40 byte packets
 1  10.10.131.2 (10.10.131.2)  8.841 ms  8.663 ms  9.940 ms
 2  10.20.129.2 (10.20.129.2)  19.825 ms  9.554 ms  9.726 ms
 3  172.16.1.1 (172.16.1.1)  9.979 ms !N  9.345 ms !N  10.121 ms !N

lab@Lager> traceroute 192.168.66.1
traceroute to 192.168.66.1 (192.168.66.1), 30 hops max, 40 byte packets
 1  10.10.131.2 (10.10.131.2)  8.731 ms  8.681 ms  10.097 ms
 2  10.20.129.2 (10.20.129.2)  19.732 ms  9.801 ms  9.650 ms
 3  172.16.1.1 (172.16.1.1)  9.872 ms  9.606 ms  9.856 ms
 4  172.16.2.2 (172.16.2.2)  39.847 ms !N  19.351 ms !N  29.992 ms !N
```

Lager forwards all external traffic to its ABR. The ABR (PBR in this case) then uses its BGP knowledge to make an optimal forwarding decision that adheres to Beer-Co's outbound routing policy. This completes the multihomed outbound routing policy scenario.

Dual-Homing and Outbound Policy Summary

In this section, you added a second EBGP peering and deployed IBGP on the necessary subset of routers within the Beer-Co network. A redundant route reflection topology was used to minimize the number of IBGP peerings while eliminating single points of failure.

With multihoming in place, you implemented an outbound policy that was a hybrid of the topology driven and strict primary/secondary models. This was achieved via an import policy that accepted only a subset of the routes advertised by your external BGP peers. This filtering allows an optimal routing decision for the specific routes that are accepted, while significantly reducing hardware requirements associated with handling full BGP feeds. The use of local preference ensured that a specific BGP learned default route is used for all other destinations, which in turn provided the strict primary/secondary (with revertive behavior) aspect of the sample outbound policy.

The next section builds upon this foundation by delving into the mechanics of implementing a typical inbound policy by manipulating BGP path attributes through the use of BGP export policy.

Inbound Policy

Referring back to Figure 7-9, it strikes you that the Beer-Co network has come a long way in recent weeks. The network has migrated from being single-homed to one provider to being multihomed to multiple providers, and you have successfully implemented a hybrid outbound policy based on a topology-driven model for peers and a primary/secondary model for transit. With these aspects of BGP operation in check, attention is focused on your company's inbound policy goals.

The use of stateful firewalls and NAT at the EBGP egress points greatly benefits from symmetric routing. By this, we mean that if a packet is routed to Destination X out of router `PBR`, ideally the response traffic will return along the same path to ingress back on router `PBR`. The symmetric routing paths tend to produce symmetric performance, which can be reason enough when asymmetric peering links are present, but the real goal here is to ensure that response traffic correctly matches against the dynamic state created when the outbound request was processed by the border router's stateful firewall.

The design goals for inbound policy indicate they should mirror your outbound policy—namely, that peers should route directly into your AS while transit traffic should arrive via the peering with Borgnet when available. In the previous section, local preference made steering traffic toward the desired EBGP speaker/egress point a straightforward matter. But as previously stated, it's generally quite easy to control how traffic flows within your *own* network. The real art and finesse of BGP policy comes to bear when the goal is to influence traffic flow in a remote network that is not under your direct control. The Beer-Co inbound policy should provide the following behavior:

- Topological policy for peers, which should route directly into Beer-Co when the peering session is up
- Revertive primary/secondary traffic for nonadjacent ASs, which should ingress at `PBR` when that peering session is up

Table 7-2 summarizes the BGP attributes that can impact the policy/routing actions of a remote network. As a rule, attributes that are evaluated sooner in the path selection process are more likely to have an impact than those that are evaluated later. For example, altering local preference, which is evaluated at step 2 of 10, is likely to have some impact, whereas changing origin code, which is evaluated at step 4 of 10, is less likely to change a peer's forwarding behavior. The table uses parentheses to identify at which step of the 10-step decision process a given attribute is evaluated. Refer back to "BGP Path Selection" on page 253 for details on these steps.

Table 7-2. BGP attributes that influence speakers in other networks

Attribute	Mechanism	Scope/caveat
AS path	AS path prepending impacts AS path selection criteria (step 3 of 10).	Global, in that once added, ASNs cannot be removed from the AS path list.
Origin	Altering origin impacts path selection criteria (step 4 of 10).	Global, but can be overwritten by intervening networks.
MED	Altering MED impacts MED selection criteria (step 5 of 10).	Adjacent AS only; MEDs are nontransitive. Generally, useful only for influencing link selection when all links terminate at the same adjacent AS.
Communities	Tagged routes are treated to some pre-agreed action, such as altered local preference.	Generally adjacent AS only. Many network operators strip all community tags upon ingress to their network, and again at egress.

It warrants restating that in all cases, the receiving ASs' policy can thwart even the most skilled attempts at controlling their outbound routing. For example, they can set a higher local preference, which means that AS path length is never even considered, which in turn negates any AS path prepending action you may perform in the hope of altering their path selection. This is why a detailed understanding of each peer AS's policies, and a good working relationship with their administrators, is always beneficial.

The most difficult aspect of the desired inbound policy is the need to influence the routing actions of Darknet, which does not peer directly with your AS. The goal is to make Darknet prefer the 10/8 aggregate it learns through Borgnet such that it uses the advertisement learned from Botnet only when the former is unavailable.

Using MED is out of the question here because the MED, being nontransitive, does not transit the networks you peer with. Also, `PBR` has a single attachment to Borgnet, so there is no use for MED there. MED could be used on the `Yeast`/Botnet peering to help steer ingress traffic over the high-speed link, but this is not the current focus. Communities are likely not an option because you are not a Darknet customer, and it's quite likely that they do not take action on communities attached to noncustomer routes; besides, communities may be stripped when the routes are exchanged between Borgnet and Darknet.

Before settling on a solution, it's noted that both of Beer-Co's BGP peers have a published policy regarding the use of customer routes with specific community tags. This policy results in a modified local preference setting within that peer's network. Table 7-3 provides the community-to-local preference mappings.

Table 7-3. Peer AS community-to-local preference mappings

Community value	Modified local preference
ASN:110	110
ASN:100	100
ASN:90	90
ASN:80	80

After careful consideration, it appears that the main problem in achieving the desired inbound behavior lies with the route selection algorithm in nonadjacent AS Darknet. Because you do not peer directly with this AS, the use of MED, and likely communities, is out. This narrows your choice to AS path prepending as the primary mechanism for influencing path selection within AS 666.

Figure 7-11 shows the state of affairs with regard to path selection for the 10/8 prefix in router `Darknet`.

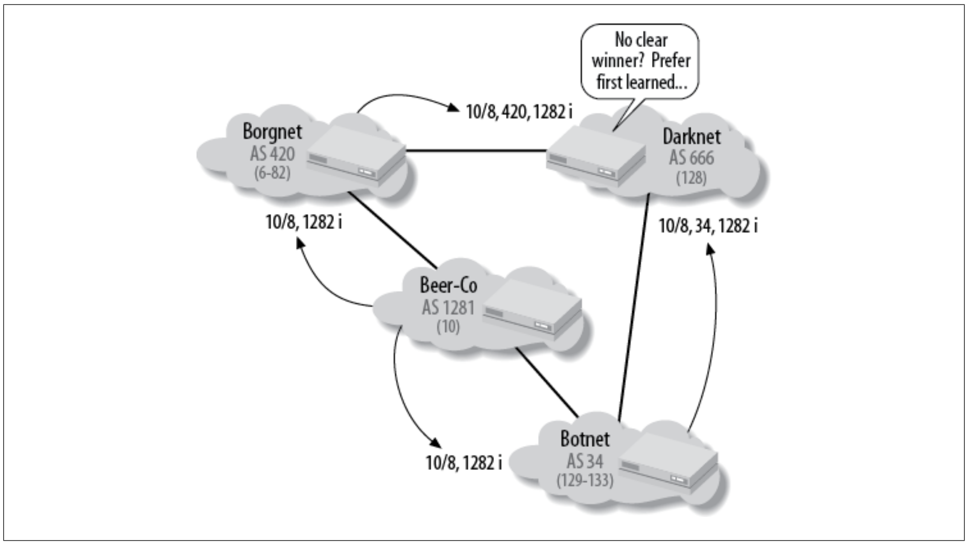


Figure 7-11. 10/8 route selection in Darknet

The figure shows that Darknet receives BGP updates for Beer-Co's 10/8 aggregate from both AS 420 and AS 34. Because all attributes are equal in this example, including the AS path length, the active path selected at `Water` is determined by which advertisement is learned first. To demonstrate, the 10/8 route is displayed at `Water`:

```
[edit]
lab@Water# run show route 10/8 detail

inet.0: 812 destinations, 1324 routes (812 active, 0 holddown, 0 hidden)
10.0.0.0/8 (2 entries, 1 announced)
```

```
            *BGP    Preference: 170/-101
                    Next-hop reference count: 946
                    Source: 84.10.110.2
                    Next hop: 84.10.110.2 via ge-0/0/0.3243, selected
                    State: <Active Ext>
                    Local AS:   666 Peer AS:    34
                    Age: 41:35
                    Task: BGP_34.84.10.110.2+4664
                    Announcement bits (2): 0-KRT 1-BGP RT Background
                    AS path: 34 1282 I Aggregator: 1282 10.30.1.1
                    Localpref: 100
                    Router ID: 84.10.109.1
             BGP    Preference: 170/-101
                    Next-hop reference count: 682
                    Source: 172.16.2.1
                    Next hop: 172.16.2.1 via ge-0/0/0.423, selected
                    State: <Ext>
                    Inactive reason: Active preferred
                    Local AS:   666 Peer AS:   420
                    Age: 39:41
                    Task: BGP_420.172.16.2.1+179
                    AS path: 420 1282 I Aggregator: 1282 10.20.128.3
                    Localpref: 100
                    Router ID: 172.16.1.3
```

The output shows that `Water` installed the path through AS 34 as the active path, and that the desired primary path is currently not preferred, simply because it was not learned first. Recall that for an EBGP learned route, step 9 of the active route selection process, which normally prefers the lower RID, is not performed due to MED oscillation issues. Instead, EBGP learned routes eliminate steps 9 and 10 to simply prefer the route that is learned first. Because this condition is timing-dependent, if something happens to the 10/8 advertisement from Botnet, the situation is reversed:

```
[edit]
lab@hops# run clear bgp neighbor 84.10.110.1
Cleared 1 connections
```

After waiting for the Botnet/Darknet EBGP peering to reform, the path to 10/8 is again displayed at `Water`:

```
[edit]
lab@Water# run show route 10/8

inet.0: 812 destinations, 1370 routes (812 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.0.0.0/8         *[BGP/170] 00:43:43, localpref 100
                      AS path: 420 1282 I
                    > to 172.16.2.1 via ge-0/0/0.423
                    [BGP/170] 00:00:29, localpref 100
                      AS path: 34 1282 I
                    > to 84.10.110.2 via ge-0/0/0.3243
```

The display confirms that the tiebreaking action of prefer first-learned is not going to reliably produce the desired inbound policy; nor would relying on the RID/peering address tiebreakers, for that matter. This looks like a classic example of how AS path prepending can help to steer path selection by remote networks—in this case, one that you do not even peer with. If the export policy at `Yeast` is altered to add an extra instance of the local AS number, the AS path length selection criterion should result in the path through AS 420 always being preferred by Darknet routers when available.

AS Path Prepend to Influence Nonadjacent AS Path Selection

Previous analysis of the policy showed that increasing the AS path length for the 10/8 prefix that Darknet learns from Botnet should result in the desired behavior of nonadjacent ASs routing to your network using Botnet as the primary transit AS.

The existing `as_34_export` policy is displayed at `Yeast`:

```
[edit]
lab@Yeast# show policy-options policy-statement as_34_export
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then accept;
}
```

The `as_34_export` policy is modified to add *two* extra instances of ASN 1282 to the 10/8 update—based on Figure 7-11, it appears that only one instance is required, but extra padding should help to ensure that Darknet prefers the path through Borgnet and provides an additional safety margin to accommodate the potential for topology changes between Borgnet and Darknet. Such a routing change might result in transit through additional ASs and a corresponding increase in the AS path length over the preferred path:

```
[edit policy-options policy-statement as_34_export]
lab@Yeast# show
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then {
        as-path-prepend "1282 1282";
        accept;
    }
}
```

The effects are examined from the perspective of router `Water` in the Darknet AS:

```
[edit]
lab@Water# run show route 10/8 detail
```

```
inet.0: 812 destinations, 1370 routes (812 active, 0 holddown, 0 hidden)
10.0.0.0/8 (2 entries, 1 announced)
        *BGP    Preference: 170/-101
                Next-hop reference count: 684
                Source: 172.16.2.1
                Next hop: 172.16.2.1 via ge-0/0/0.423, selected
                State: <Active Ext>
                Local AS:   666 Peer AS:   420
                Age: 53:05
                Task: BGP_420.172.16.2.1+179
                Announcement bits (2): 0-KRT 1-BGP RT Background
                AS path: 420 1282 I Aggregator: 1282 10.20.128.3
                Localpref: 100
                Router ID: 172.16.1.3
         BGP    Preference: 170/-101
                Next-hop reference count: 990
                Source: 84.10.110.2
                Next hop: 84.10.110.2 via ge-0/0/0.3243, selected
                State: <Ext>
                Inactive reason: AS path
                Local AS:   666 Peer AS:    34
                Age: 59
                Task: BGP_34.84.10.110.2+4730
                AS path: 34 1282 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 84.10.109.1
```

The output confirms that chance has been removed from the path selection process for the 10/8 prefix at Water. The longer AS path in the 10/8 prefix learned from the Botnet AS ensures that AS 666 always prefers to route through Borgnet to reach Beer-Co, unless that path is withdrawn (due to problems with the PBR–Wheat peering), at which point it falls back to the Botnet path.

To the casual observer, Beer-Co has met its inbound policy goals, all with a single-line addition to an existing export policy to affect AS path prepending. BGP policy is not really that hard, it would seem. Before heading out the door, you decide to confirm failover behavior. This begins by deactivating the secondary EBGP session to confirm that all traffic arrives at the Borgnet peering:

```
[edit]
lab@Yeast# deactivate protocols bgp group as_34

[edit]
lab@Yeast# commit
```

Traceroutes are now performed from routers *within* the adjacent and nonadjacent ASs. In most cases, you will need to inspect each AS's routing view, perhaps through a looking glass service, to confirm their forwarding paths.

What Is a Looking Glass?

A looking glass is basically a publicly accessible route server that allows you to view Internet routing, from the perspective of that particular route server. You use a looking glass to see the effects of that network's import policy and active route selection process, by displaying which BGP paths it has installed as active. You can also gauge the relative stability of a prefix, from the view of that looking glass, by examining how long a route has been known. The following example makes use of an AT&T looking glass, telnet to route-server.ip.att.net, to display its view of the route to Juniper Networks:

```
------------- route-server.ip.att.net ---------------
User Access Verification Username: rviews
route-server> sho ip rou juniper.net
Routing entry for 207.17.136.0/22, supernet
  Known via "bgp 65000", distance 20, metric 0
  Tag 7018, type external
  Last update from 12.123.1.236 2w3d ago
  Routing Descriptor Blocks:
  * 12.123.1.236, from 12.123.1.236, 2w3d ago
      Route metric is 0, traffic share count is 1
      AS Hops 3
      Route tag 7018
route-server> sho ip bgp 207.17.136.0/22
BGP routing table entry for 207.17.136.0/22, version 181930
Paths: (18 available, best #13, table Default-IP-Routing-Table)
  Not advertised to any peer
  7018 2914 14203, (received & used)
    12.123.29.249 from 12.123.29.249 (12.123.29.249)
      Origin IGP, localpref 100, valid, external
      Community: 7018:5000 7018:33051
. . .
```

The output suggests that AT&T has learned this route from 18 different speakers, that the prefix is stable (given that the last update was more than two weeks ago), and that the AS path to reach this prefix from within AT&T is 7018 (AT&T WorldNet), 2914 (Verio), and finally, 14203 (Juniper Networks itself).

Do

All routers in the test network advertise their loopbacks (or an encompassing aggregate route) into BGP. All traceroutes are conducted between loopback addresses because full connectivity is expected among the prefixes used for loopback addressing:

```
[edit]
lab@Wheat# run traceroute 10.10.12.2 source 172.16.1.3
traceroute to 10.10.12.2 (10.10.12.2), 30 hops max, 40 byte packets
 1  172.16.1.2 (172.16.1.2)  17.316 ms  10.118 ms  21.751 ms
 2  10.20.129.1 (10.20.129.1)  12.798 ms  9.507 ms  9.711 ms
 3  10.10.12.2 (10.10.12.2)  16.981 ms  22.462 ms  19.689 ms
```

The traceroute to `Porter`'s loopback address succeeds from within AS 420:

```
[edit]
lab@Water# run traceroute 10.10.12.2 source 64.8.12.1
traceroute to 10.10.12.2 (10.10.12.2), 30 hops max, 40 byte packets
 1  172.16.2.1 (172.16.2.1)  106.100 ms  17.772 ms  10.472 ms
 2  172.16.1.2 (172.16.1.2)  9.423 ms  9.373 ms  9.842 ms
 3  10.20.129.1 (10.20.129.1)  20.042 ms  39.411 ms  19.786 ms
 4  10.10.12.2 (10.10.12.2)  10.109 ms  9.390 ms  94.337 ms
```

The traceroute to `Porter`'s loopback address succeeds from within AS 66:

```
[edit]
lab@hops# run traceroute 10.10.12.2 source 84.10.109.1
traceroute to 10.10.12.2 (10.10.12.2) from 84.10.109.1, 30 hops max, 40 byte packets
 1  84.10.110.1  45.013 ms  125.144 ms  25.062 ms
 2  172.16.2.1  8.442 ms  19.978 ms  9.940 ms
 3  172.16.1.2  30.019 ms  9.885 ms  9.849 ms
 4  10.20.129.1  16.135 ms  10.130 ms  13.433 ms
 5  10.10.12.2  15.628 ms  24.492 ms  16.888 ms
```

And finally, the traceroute to `Porter`'s loopback address succeeds from within AS 34. So far so good, so the EBGP peering session to AS 34 is reactivated. After waiting for the EBGP session to Botnet to re-form, the traceroutes are repeated:

```
[edit]
lab@Wheat# run traceroute 10.10.12.2 source 172.16.1.3
traceroute to 10.10.12.2 (10.10.12.2), 30 hops max, 40 byte packets
 1  172.16.1.2 (172.16.1.2)  9.914 ms  8.950 ms  9.571 ms
 2  10.20.129.1 (10.20.129.1)  19.977 ms  19.534 ms  19.824 ms
 3  10.10.12.2 (10.10.12.2)  9.886 ms  9.498 ms  9.848 ms

lab@Water> traceroute 10.10.12.2 source 64.8.12.1
traceroute to 10.10.12.2 (10.10.12.2), 30 hops max, 40 byte packets
 1  172.16.2.1 (172.16.2.1)  19.317 ms  12.022 ms  16.594 ms
 2  172.16.1.2 (172.16.1.2)  9.889 ms  9.364 ms  10.281 ms
 3  10.20.129.1 (10.20.129.1)  19.596 ms  19.528 ms  7.891 ms
 4  10.10.12.2 (10.10.12.2)  21.967 ms  49.523 ms  9.720 ms
```

The results from Borgnet and Darknet are as before, and both are as expected. Things are not ideal from the perspective for Botnet, however:

```
[edit]
lab@hops# run traceroute 10.10.12.2 source 84.10.109.1
traceroute to 10.10.12.2 (10.10.12.2) from 84.10.109.1, 30 hops max, 40 byte packets
 1  84.10.110.1 (84.10.110.1)  8.589 ms  8.666 ms  10.118 ms
 2  172.16.2.1 (172.16.2.1)  29.935 ms  19.230 ms  20.005 ms
 3  172.16.1.2 (172.16.1.2)  20.021 ms  19.588 ms  19.710 ms
 4  10.20.129.1 (10.20.129.1)  9.916 ms  9.298 ms  10.128 ms
 5  10.10.12.2 (10.10.12.2)  21.422 ms  17.796 ms  14.098 ms
```

The traceroute from Botnet clearly shows that the traffic is failing to arrive at the peering exchange for that AS, resulting in extra AS hops as the traffic is directed over the primary path. This is a violation of the desired inbound policy. Displaying the route to 10/8 at Botnet confirms the problem and sheds lights on its cause:

```
[edit]
lab@hops# run show route 10/8 detail

inet.0: 817 destinations, 1069 routes (817 active, 0 holddown, 0 hidden)
10.0.0.0/8 (3 entries, 1 announced)
        *BGP    Preference: 170/-101
```

```
                Next-hop reference count: 750
                Source: 84.10.110.1
                Next hop: 84.10.110.1 via ge-0/0/0.3243, selected
                State: <Active Ext>
                Local AS:    34 Peer AS:   666
                Age: 43:41
                Task: BGP_666.84.10.110.1+179
                Announcement bits (2): 0-KRT 2-BGP RT Background
                AS path: 666 420 1282 I Aggregator: 1282 10.20.128.3
                Localpref: 100
                Router ID: 64.8.12.1
         BGP    Preference: 170/-101
                Next-hop reference count: 126
                Source: 84.10.109.8
                Next hop: 84.10.109.8 via ge-0/0/0.3233, selected
                State: <Ext>
                Inactive reason: Active preferred
                Local AS:    34 Peer AS:  1282
                Age: 4:36
                Task: BGP_1282.84.10.109.8+2957
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 10.30.1.1
         BGP    Preference: 170/-101
                Next-hop reference count: 126
                Source: 84.10.113.0
                Next hop: 84.10.113.0 via t1-2/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Not Best in its group
                Local AS:    34 Peer AS:  1282
                Age: 4:32
                Task: BGP_1282.84.10.113.0+3127
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 10.30.1.1
```

IP internetworks are complicated systems, and with any such systems, making a change in one place can have unexpected consequences somewhere else. Before you added AS path prepending, both peer ASs had no problems preferring Beer-Co's 10/8 aggregate as learned directly from Beer-Co. This was because an AS path length of 1 is very hard to beat. The use of AS path prepending, in an attempt to make Darknet prefer the path through the Borgnet AS, has inadvertently altered the path selection in peer AS 34.

Even worse is that this situation results in path selection that is tied to the order in which routes are learned. Timing-related route selection issues are difficult to troubleshoot because administrative actions on one front—say, attribute modification—may trigger a change in the order that routes are learned. This can easily lead to an incorrect belief that policy changes are behind the altered path selection, when in reality things may change back at the next outage. Fortunately, there is a straightforward solution to this problem: community tags.

Use Communities to Influence Peer AS

Referring back to Table 7-3, notice that you can affect the local preference value within your peer ASs by attaching a specific community to your route updates. Because local preference is evaluated before AS path length, altering the local preference of the 10/8 route within AS 34 should be just the ticket. This change ensures that AS 34 always prefers the 10/8 learned directly from the Beer-Co peering regardless of the related AS path length.

Your changes begin with the definition of named communities. In this example, you need to set the 10/8 local preference to a value higher than 100, which is the default. Here, multiple communities are defined, but only the 110 community definition is required and used:

```
[edit]
lab@Yeast# show policy-options
. . .
community 100 members 1282:100;
community 110 members 1282:110;
community 70 members 1282:70;
community 80 members 1282:80;
community 90 members 1282:90;
community bw_fast members bandwidth:1287:12500000000;
community bw_slow members bandwidth:1287:193000;
as-path 34_originate "^34$";
as-path 34_trans "^34.+$";
```

The existing `as_34_export` policy is altered to add the appropriate community, which is `110` in this example:

```
[edit policy-options policy-statement as_34_export]
lab@Yeast# show
term 1 {
    from {
        protocol aggregate;
        route-filter 10.0.0.0/8 exact;
    }
    then {
        community add 110;
        as-path-prepend "1282 1282";
        accept;
    }
}
```

The results are confirmed at router `Hops` in AS 34:

```
[edit]
lab@hops# run show route 10/8 detail

inet.0: 817 destinations, 1069 routes (817 active, 0 holddown, 0 hidden)
10.0.0.0/8 (3 entries, 1 announced)
        *BGP    Preference: 170/-111
                Next-hop reference count: 2
                Source: 84.10.109.8
                Next hop: 84.10.109.8 via ge-0/0/0.3233
                Next hop: 84.10.113.0 via t1-2/0/2.0, selected
                State: <Active Ext>
                Local AS:    34 Peer AS:  1282
                Age: 12
                Task: BGP_1282.84.10.109.8+2957
                Announcement bits (2): 0-KRT 2-BGP RT Background
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                **Communities: 1282:110**
                **Localpref: 110**
                Router ID: 10.30.1.1
         BGP    Preference: 170/-111
                Next-hop reference count: 126
                Source: 84.10.113.0
                Next hop: 84.10.113.0 via t1-2/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Update source
                Local AS:    34 Peer AS:  1282
                Age: 12
                Task: BGP_1282.84.10.113.0+3127
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Communities: 1282:110
                Localpref: 110
                Router ID: 10.30.1.1
         BGP    Preference: 170/-101
                Next-hop reference count: 749
                Source: 84.10.110.1
                Next hop: 84.10.110.1 via ge-0/0/0.3243, selected
                State: <Ext>
                **Inactive reason: Local Preference**
                Local AS:    34 Peer AS:   666
                Age: 1:11:39
                Task: BGP_666.84.10.110.1+179
                **AS path: 666 420 1282** I Aggregator: 1282 10.20.128.3
                Localpref: 100
                Router ID: 64.8.12.1
```

Excellent! AS 34 now prefers the route learned directly from Beer-Co, and it still has a valid alternate path in the event of BGP session disruption to Beer-Co. The primary peering link is now deactivated to verify failover to the secondary and reversion back to the primary upon restoration:

```
[edit]
lab@PBR# **deactivate protocols bgp group as_420**
```

Traceroutes are now performed from adjacent and nonadjacent ASs:

```
[edit]
lab@Wheat# **run traceroute 10.10.12.2 source 172.16.1.3**
traceroute to 10.10.12.2 (10.10.12.2) from 172.16.1.3, 30 hops max, 40 byte packets
 1  172.16.2.2 (172.16.2.2)  8.411 ms  8.980 ms  9.840 ms
 2  84.10.110.2 (84.10.110.2)  20.057 ms  29.367 ms  9.886 ms
 3  84.10.113.0 (84.10.113.0)  19.999 ms  39.343 ms  20.021 ms
 4  10.10.12.2 (10.10.12.2)  13.796 ms  15.536 ms  19.873 ms

lab@Water> **traceroute 10.10.12.2 source 64.8.12.1**
```

```
traceroute to 10.10.12.2 (10.10.12.2) from 64.8.12.1, 30 hops max, 40 byte packets
 1  84.10.110.2 (84.10.110.2)  30.620 ms  21.427 ms  19.623 ms
 2  84.10.113.0 (84.10.113.0)  30.052 ms  16.285 ms  12.970 ms
 3  10.10.12.2 (10.10.12.2)  20.066 ms  35.912 ms  13.312 ms

[edit]
lab@hops# run traceroute 10.10.12.2 source 84.10.109.1
traceroute to 10.10.12.2 (10.10.12.2) from 84.10.109.1, 30 hops max, 40 byte packets
 1  84.10.113.0 (84.10.113.0)  8.924 ms  28.830 ms  9.856 ms
 2  10.10.12.2 (10.10.12.2)  9.846 ms  9.697 ms  9.795 ms
```

The results prove continued connectivity for both adjacent and nonadjacent ASs, with all traffic now arriving at the only functional peering exchange. The desired failover behavior is working. The Borgnet peering session is now reactivated to test the revertive behavior:

```
[edit]
lab@PBR# rollback 1
load complete
```

After session establishment, traceroutes are again performed to verify revertive primary behavior. Recall that the goal is to have peers route directly into AS 1282 while nonadjacent ASs route toward the Borgnet peering to ingress at PBR:

```
[edit]
lab@Wheat# run traceroute 10.10.12.2 source 172.16.1.3
traceroute to 10.10.12.2 (10.10.12.2) from 172.16.1.3, 30 hops max, 40 byte packets
 1  172.16.1.2 (172.16.1.2)  19.252 ms  12.858 ms  16.050 ms
 2  10.20.129.1 (10.20.129.1)  9.900 ms  9.498 ms  9.686 ms
 3  10.10.12.2 (10.10.12.2)  19.985 ms  19.611 ms  19.615 ms

lab@Water> traceroute 10.10.12.2 source 64.8.12.1
traceroute to 10.10.12.2 (10.10.12.2) from 64.8.12.1, 30 hops max, 40 byte packets
 1  172.16.2.1 (172.16.2.1)  9.220 ms  8.755 ms  29.928 ms
 2  172.16.1.2 (172.16.1.2)  9.844 ms  9.609 ms  9.873 ms
 3  10.20.129.1 (10.20.129.1)  29.962 ms  19.311 ms  20.003 ms
 4  10.10.12.2 (10.10.12.2)  9.862 ms  29.366 ms  29.967 ms

[edit]
lab@hops# run traceroute 10.10.12.2 source 84.10.109.1
traceroute to 10.10.12.2 (10.10.12.2) from 84.10.109.1, 30 hops max, 40 byte packets
 1  84.10.113.0 (84.10.113.0)  9.691 ms  8.756 ms  9.864 ms
 2  10.10.12.2 (10.10.12.2)  19.969 ms  29.445 ms  9.859 ms
```

The results confirm desired inbound policy behavior, thereby concluding the EBGP multihomed enterprise routing scenario. For completeness, the complete protocols and policy stanzas for EBGP routers PBR and Yeast, reflector Porter, and client Stout are shown.

Here is router PBR's configuration:

```
[edit]
lab@PBR# show policy-options | no-more
policy-statement as_420_export {
    term 1 {
        from {
            protocol aggregate;
            route-filter 10.0.0.0/8 exact;
        }
        then accept;
    }
}
policy-statement as_420_import {
    term 1 {
        from {
            protocol bgp;
            as-path as_420_originate;
        }
        then accept;
    }
    term 2 {
        then reject;
    }
}
policy-statement next_hop_self {
    term 1 {
        from protocol bgp;
        then {
            next-hop self;
        }
    }
}
policy-statement prefer_Borgnet_transit {
    term 1 {
        from {
            protocol bgp;
            route-filter 0.0.0.0/0 exact;
        }
        then {
            local-preference 110;
        }
    }
}
as-path as_420_originate "^420+$";

[edit]
lab@PBR# show protocols
bgp {
    group as_420 {
        type external;
        import as_420_import;
        export as_420_export;
        neighbor 172.16.1.1 {
            peer-as 420;
        }
    }
    group 1282_clients {
        type internal;
        local-address 10.20.128.3;
        export [ next_hop_self prefer_Borgnet_transit ];
        neighbor 10.10.12.3;
        neighbor 10.10.12.2;
    }
}
ospf {
    area 0.0.0.0 {
        interface ge-0/0/0.3141;
        interface ge-0/0/0.1241;
    }
    area 0.0.0.1 {
        stub default-metric 10;
        interface ge-0/0/0.1141;
    }
}
```

Here is router `Yeast`'s configuration:

```
[edit]
lab@Yeast# show policy-options | no-more
policy-statement as_34_export {
    term 1 {
        from {
            protocol aggregate;
            route-filter 10.0.0.0/8 exact;
        }
        then {
            community add 110;
            as-path-prepend "1282 1282";
            accept;
        }
    }
}
policy-statement as_34_import {
    term slow_peer {
        from {
            protocol bgp;
            neighbor 84.10.113.1;
        }
        then {
            community add bw_slow;
        }
    }
    term fast_peer {
        from {
            protocol bgp;
            neighbor 84.10.109.7;
        }
        then {
            community add bw_fast;
        }
    }
}
policy-statement as_34_originate {
    term 1 {
        from {
            protocol bgp;
```

```
                as-path 34_originate;
            }
            then accept;
        }
        term 2 {
            then reject;
        }
    }
    policy-statement lb_per_packet {
        then {
            load-balance per-packet;
            accept;
        }
    }
    policy-statement next_hop_self {
        term 1 {
            from protocol bgp;
            then {
                next-hop self;
            }
        }
    }
    community 100 members 1282:100;
    community 110 members 1282:110;
    community 70 members 1282:70;
    community 80 members 1282:80;
    community 90 members 1282:90;
    community bw_fast members bandwidth:1287:12500000000;
    community bw_slow members bandwidth:1287:193000;
    as-path 34_originate "^34$";
    as-path 34_trans "^34.+$";

    [edit]
    lab@Yeast# show protocols | no-more
    bgp {
        group as_34 {
            type external;
            import [ as_34_import as_34_originate ];
            export as_34_export;
            peer-as 34;
            multipath;
            neighbor 84.10.109.7;
            neighbor 84.10.113.1;
        }
        group 1282_clients {
            type internal;
            local-address 10.30.1.1;
            export next_hop_self;
            neighbor 10.10.12.3;
            neighbor 10.10.12.2;
        }
    }
    ospf {
        area 0.0.0.0 {
            interface ge-0/0/1.2332;
        }
    }
```

Here is route reflector Porter's configuration:

```
    [edit]
    lab@Porter# show policy-options

    [edit]
    lab@Porter# show protocols | no-more
    bgp {
        group 1282_rr {
            type internal;
            local-address 10.10.12.2;
            neighbor 10.10.12.3;
        }
        group 1282_clients {
            type internal;
            local-address 10.10.12.2;
            cluster 1.2.8.2;
            neighbor 10.20.128.4;
            neighbor 10.20.128.3;
            neighbor 10.30.1.1;
        }
    }
    ospf {
        area 0.0.0.0 {
            interface ge-0/0/1.1331;
            interface ge-0/0/1.2332;
            interface t1-2/0/2.0;
        }
    }
```

Here is client Stout's configuration:

```
    [edit]
    lab@stout# show policy-options
    [edit]
    lab@stout# show protocols | no-more
    bgp {
        group 1282_clients {
            type internal;
            local-address 10.20.128.4;
            neighbor 10.10.12.3;
            neighbor 10.10.12.2;
        }
    }
    ospf {
        area 0.0.0.0 {
            interface ge-0/0/0.3141;
            interface ge-0/0/1.1331;
        }
        area 0.0.0.2 {
            stub default-metric 10;
            interface ge-0/0/0.2131;
        }
    }
```

BGP Inbound Policy Summary

This section demonstrated ways in which a dual-homed enterprise can manipulate BGP path attributes to achieve a desired inbound policy goal. The example demonstrated the need for both AS path manipulation and the use of BGP communities, which worked together to influence the routing decisions of both adjacent and nonadjacent ASs.

Conclusion

BGP can have a dramatic impact on the operation of an enterprise network when the network is multihomed, and even more so when it is multihomed to multiple providers. BGP itself is not a very complex protocol, but the myriad ways in which its attributes are acted upon, and the cascading effects of advertising only what the local speaker considers the best route, often lead to an unanticipated result. To the uninitiated, this often leads to confusion and what might seem to be unpredictable behavior. Junos software provides a complete set of diagnostic tools, from the CLI's operational mode displays to the extensive protocol tracing, which makes most BGP problems easy to diagnose. For example, the way the software displays *why* a given BGP path was not selected makes changing the results for that BGP decision step a straightforward matter; that is, whatever attribute caused the route to lose should be modified.

EBGP and IBGP are similar, but they have key differences in the way they are typically configured and in how they operate. This chapter detailed those differences and demonstrated typical EBGP physical peering and IBGP loopback-based peering. Because IBGP does not rewrite the next hop, you will often need a next hop self-policy or some other method of advertising the external EBGP peering address into your IGP.

Bringing up BGP peerings is really just the start of the process. BGP is all about policy and administrative control over route exchanges, and therefore forwarding paths. Outbound policy controls how your network chooses to reach destinations and is relatively easy to implement as you control all aspects of your own network's operation. Inbound policy is far trickier, because here you are attempting to impact decisions made in remote ASs, over which you have no direct control. A detailed understanding of the BGP attributes that reach into, and beyond, other networks increases the probability that remote networks will bend to your will, resulting in ingress traffic patterns that optimize those factors that matter most within your organization.

The large size of BGP tables means that careful consideration should be leveled as to which routers need to run the protocol and on the import policy that determines which prefixes are accepted. The careful application of policy can easily reduce a BGP table from more than 230,000 routes to a more manageable set that can be distributed among lower-end routers. A partial table can be used to make intelligent routing decisions that optimize network resources and performance. When a full BGP table is not feasible, some form of a default route is used to balance the remaining prefixes or to direct the network traffic to a primary egress point as local policy dictates.

Route reflection is often used to reduce the burden of maintaining a full IBGP mess among a network's IBGP speakers, and when combined with route filtering, it allows the deployment of BGP on even the smallest of enterprise routers.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Explain the use of BGP.
- Differentiate between IBGP and EBGP sessions.
- Policies to control route advertisement.
- Miscellaneous BGP configuration options.
- Load-balancing BGP routes.
- ISP multihoming scenarios.
- Configure an IBGP route reflection topology.
- Configure EBGP sessions.
- Identify BGP attributes that can be modified using policies.
- Implement a BGP policy for routing traffic over multiple ISP connections.

Chapter Review Questions

1. What BGP attribute guards against loops?
   A. MED
   B. Barring an IBGP speaker from resending IBGP updates
   C. Cluster ID
   D. AS path
2. What BGP attribute is most likely to influence egress from your AS?
   A. AS path
   B. Local preference
   C. MED
   D. Cluster length
   E. None of the above

3. What BGP attribute is mostly likely to influence a remote AS that you do not peer with?
   A. This is not possible given the local scope of BGP
   B. AS path
   C. MED
   D. Local preference
4. Which of the following correctly describes how IBGP differs from EBGP?
   A. IBGP peers to the interface address while EBGP peers to loopbacks
   B. IBGP updates do not alter the next hop attribute
   C. EBGP updates do not alter the next hop
   D. EBGP requires a full mesh
5. When export policy is specified at the global, group, and neighbor levels, which policy is executed?
   A. Only the least specific, which is global export
   B. Only the most specific, which is neighbor-level export
   C. All three are chained, and the global, group, and neighbor policies are executed
   D. None of the above; export can be defined only at the group level
6. When you issue a `show bgp summary` command, what is indicated by the Active state?
   A. The router is actively trying to form the BGP session; you should wait
   B. The session is established and active; you are done
   C. The router is unable to even route the session; you should suspect a routing problem
   D. At least one route has been received and made active
7. What command displays the routes you are receiving from a BGP peer?
   A. `show route advertising-protocol bgp`
   B. `show route receive-protocol bgp`
   C. `show route protocol bgp`
   D. `show ip route bgp`
8. Which type of Junos software policy is normally applied at an EBGP speaker to achieve an organization's *outbound* policy?
   A. Export policy
   B. Import policy
   C. Inbound policy
   D. Outbound policy

9. When implementing loopback-based peering, what is the purpose of the `local-address` statement?
   A. It ensures that the router sources the connection from its loopback address
   B. It ensures that the router sources the connection from the interface closest to the session target
   C. It eliminates the need for recursive route lookup in EBGP peering
   D. It eliminates the need for recursive route lookup in IBGP peering
10. Which of the following is/are true regarding route reflection on a J-series router?
   A. A license is required for support, not operation
   B. A single command is needed on the reflector
   C. New attributes are needed to prevent route looping
   D. Reflectors can hide parts of the topology because they reflect only their choice of best route
   E. All of the above
11. When configuring BGP in the Junos operating system, where is the local router's AS defined?
   A. At the `[edit protocols bgp]` hierarchy
   B. At the `[edit routing-options]` hierarchy
   C. At the `[edit protocols bgp group]` hierarchy
   D. At the `[edit protocols bgp group` *`<group name>`* `neighbor]` hierarchy
12. In the following display, why is the route learned from 84.10.109.8 not active?

```
inet.0: 817 destinations, 1069 routes (817 active, 0 holddown, 0 hidden)
10.0.0.0/8 (3 entries, 1 announced)
      *BGP    Preference: 170/-101
              Next-hop reference count: 750
              Source: 84.10.110.1
              Next hop: 84.10.110.1 via ge-0/0/0.3243, selected
              State: <Active Ext>
              Local AS:    34 Peer AS:   666
              Age: 43:41
              Task: BGP_666.84.10.110.1+179
              Announcement bits (2): 0-KRT 2-BGP RT Background
              AS path: 666 420 1282 I Aggregator: 1282 10.20.128.3
              Localpref: 100
              Router ID: 64.8.12.1
       BGP    Preference: 170/-101
              Next-hop reference count: 126
              Source: 84.10.109.8
              Next hop: 84.10.109.8 via ge-0/0/0.3233, selected
              State: <Ext>
              Inactive reason: Active preferred
              Local AS:    34 Peer AS:  1282
              Age: 4:36
              Task: BGP_1282.84.10.109.8+2957
```

```
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 10.30.1.1
         BGP    Preference: 170/-101
                Next-hop reference count: 126
                Source: 84.10.113.0
                Next hop: 84.10.113.0 via t1-2/0/2.0, selected
                State: <NotBest Ext>
                Inactive reason: Not Best in its group
                Local AS:    34 Peer AS:  1282
                Age: 4:32
                Task: BGP_1282.84.10.113.0+3127
                AS path: 1282 1282 1282 I Aggregator: 1282 10.30.1.1
                Localpref: 100
                Router ID: 10.30.1.1
```

A. When all else is equal, an EBGP speaker prefers the first route learned

B. When all else is equal, an IBGP speaker prefers the first route learned

C. When all else is equal, the router prefers the route with best preference

D. The AS path is shorter

Chapter Review Answers

1. Answer: D. The AS path attribute records each AS that a route update has passed through, and is updated on EBGP links. A BGP speaker discards received updates that contain the local ASN in the AS path.
2. Answer: B. The local preference attribute is evaluated early in the BGP decision process, before AS path, MED, origin, and so on.
3. Answer: B. The AS path attribute has global significance; once a value has been added, no other speaker can remove that ASN from the list because this would break BGP's loop prevention. The AS path is considered early in the selection process, and so has a good chance of impacting forwarding decisions in remote ASs. MED does not transit the peer AS, local preference is not supported on EBGP links, and communities can be stripped.
4. Answer: B. The next hop is unchanged on IBGP updates, but it is rewritten on EBGP links. EBGP does not require a full mesh, because the AS path is updated on EBGP links.
5. Answer: B. Junos applies only the most specific policy applications, and a neighbor level is more specific than a group level, which is more specific than a global level. If you need a particular neighbor to execute what you consider a global, group, and neighbor policy, all three must be changed at the neighbor level.
6. Answer: A. The Idle state indicates an inability to route the session, and an established session is displayed with an `x/x/x`, for active, received, and damped routes, respectively.

7. Answer: B. The `show route protocol bgp` command shows all routes learned via BGP, not those from a given neighbor.
8. Answer: B. By filtering and setting attributes in received routes, you most directly impact how your network in turn sends to external destinations. Export policy is normally used to influence peers in the remote AS to affect your inbound policy goals.
9. Answer: A. Loopback-based peering requires that the router source the connection from its loopback interface to match the definition at the remote peer. A recursive route lookup is always required for a loopback-based peering because the remote router's loopback address can never be direct, and therefore must be resolved to a direct forwarding next hop via an IGP, to include a static route.
10. Answer: E. All of the options listed are true.
11. Answer: B. The local router's autonomous number is configured under routing options. The peer AS number is configured at the group or neighbor level for EBGP groups.
12. Answer: A. The RID and peering address tiebreakers are replaced by first-learned for EBGP learned routes only. In this example, all three routes have the same local preference, global preference, and AS path length.

CHAPTER 8

Access Security

This chapter discusses the techniques of securing the router via different types of access security. *Access security* is a broad term that includes the creation of users with various authorization levels or allowing access to particular services or networks. Also included in *access security* is verifying that the router has not been compromised and is performing as you expected. The topics covered include:

- Security concepts
- Securing access to the router
- Firewall filters and policers
- Spoof prevention
- Router monitoring

Security Concepts

Everybody wants to have a secure network, but providing that security is often a very complex and difficult process due to the multiple levels that need to be examined. For example, it does not do much good if you provide very detailed filters and access privileges on a router, when the physical access is an unlocked door in a wiring closet at a remote location. Security must not be an afterthought; it must be designed literally from the ground up, from physical access to the network to filters that allow only certain types of traffic. When implementing security at any layer, design toward the security concepts that are displayed in Figure 8-1: integrity, availability, and confidentiality. These concepts will help to build the network's circle of trust.

The first concept of security design is to ensure the *integrity* of the data. In other words, the data should not be altered in any way without purpose. This includes data that could be modified by unauthorized personnel, but does not exclude data manipulation by authorized personnel. Many network breaches are sourced from an "insider," someone who either works or did work for the company. This could be a disgruntled employee who decides to wreak havoc on the network because he never received his new

Integrity
Availability
Confidentiality

Figure 8-1. Security circle of trust

office stapler! Also, data integrity implies that the data is consistent across internal and external access—that is, a user should not have the experience of making changes to a device from home only to discover that those changes were never propagated to the network.

The next concept is *availability*, which is *access* to reliable and consistent data. You can divide availability into two parts: data that needs to be accessible and the network elements to reach that system. This requires elements such as system redundancy, along with Out-of-Band (OoB) network access to routers and switches. For example, a router that is under a denial of service (DoS) attack may prevent remote access from one location; however, is there another way to reach the router to thwart the attack? Design your network with the correct security tools; and most important, and often overlooked, make sure the tools actually work before disaster strikes. In other words, what good does it do to have protection in place if you cannot log in to the system to implement your tools or monitor and troubleshoot the devices? In recent years, horrible events such as terrorist attacks, earthquakes, and tsunamis have reopened many people's eyes to the importance of availability and redundancy.

Lastly is the *confidentiality* of the data; this means ensuring that unauthorized disclosure has not been unintentionally or intentionally given. In the modern age of thumb drives, smartphones, and PCs, the ability to access information has never been greater, and so are the security vulnerabilities. How many times have users left themselves logged in at a cybercafé somewhere? It takes just a few seconds for an evil network engineer lurking in the shadows to notice the open PC, expand a router session that has been left open, delete the configuration, and walk away, ecstatic.

Are you getting scared yet? We hope so. A security expert without any fear is a very naïve one! Security must take a multiphase and dynamic approach; you will make mistakes, but the objective is to learn from those mistakes, use the tools available to you, and make the necessary corrections so that you avoid those mistakes later. Always remember: security is a process and not an event! As Homer said, "Even a fool may be wise after the event." As we examine each topic in the remaining chapters, remember to think of the security circle of trust and where each feature fits and enables your security to be a circle without holes.

Summary of Security Concepts

Most people find the security concepts presented here to be somewhat common sense. The issue is that humans are inherently lazy, and security by its very definition tends to get in the way of our need to access information. The need for connectivity often overshadows the need to secure those communications, until the damage is done and it is too late to plug the holes. Always keep these security principles in mind when designing a new network or hardening an existing one.

The next section details ways to secure access to the router itself, which is a critical aspect of an overall security plan.

Securing Access to the Router

The goal of this chapter is to secure the network in Figure 8-2, which consists of three routers—`Ale`, `PBR`, and `Bock`—that are running Open Shortest Path First (OSPF) as the Interior Gateway Protocol (IGP). `PBR` connects to multiple Internet service providers (ISPs) via the Border Gateway Protocol (BGP). Various types of traffic are sent and received from the two ISPs, including web browsing, email, and a variety of remote accounting and engineering applications. The first step will be to secure access to `Ale`, `PBR`, and `Bock` so that only authorized users have access to each router.

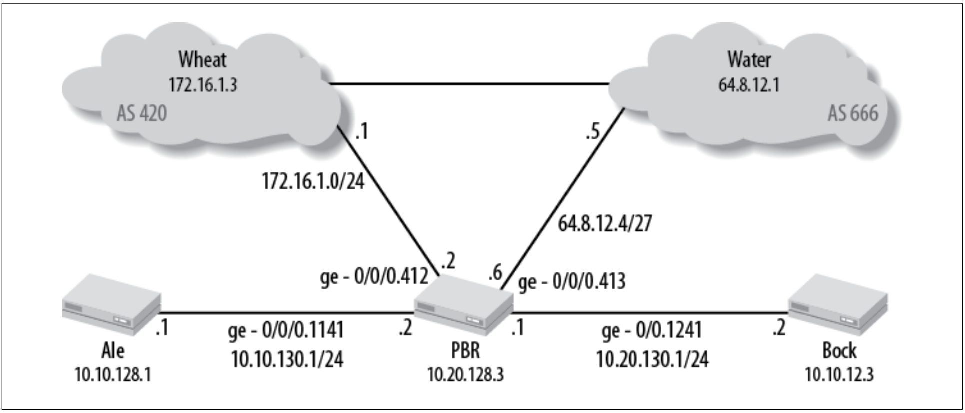


Figure 8-2. Network topology

User Authentication

There are two types of users on a Junos-based device—a nonroot user and a root user, both of which must be secured. Recall that user root is the only user who is predefined by default, accessible only via the console port without any default password. You must set a root password before the router will allow you to commit the configuration. To set up a root password, issue the `root-authentication` keyword under the `[edit system]` level:

```
lab@Bock# set system root-authentication ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration
                       data
+ apply-groups-except  Don't inherit configuration data from these
                       groups
  encrypted-password   Encrypted password string
  load-key-file        File (URL) containing one or more ssh keys
  plain-text-password  Prompt for plain text password (autoencrypted)
> ssh-dsa              Secure shell (ssh) DSA public key string
> ssh-rsa              Secure shell (ssh) RSA public key string
```

Remember that user `root` is very powerful. When logged in as `root`, you are placed directly into the kernel in the form of a BSD shell! As a result, `root` can log in only via SSH or the console port, by default.

The password can either be a plain-text password that will be encrypted automatically in the configuration, an SSH key, or an encrypted string for copying and pasting to other routers. In this case, a password of `Bia&abi55a` is supplied (but not shown in the interface):

```
lab@Bock# set system root-authentication plain-text-password
New password:
Retype new password:
```

When issuing a plain text password, Junos has some default requirements for password length and content. The password must be between six and 128 characters and must contain one change of case or special character. You can modify these defaults under `[edit system password]`.

Once the password is set on `Bock`, it automatically becomes encrypted:

```
lab@Bock# show system root-authentication
encrypted-password "$1$iOLTVCdC$2jViYwTCG.kET399/uF/yO";
## SECRET-DATA
```

The encrypted string is now copied to other routers (`PBR` and `Ale`) without needing knowledge of the actual password:

```
[edit system root-authentication]
lab@PBR# load merge terminal relative
[Type ^D at a new line to end input]
encrypted-password "$1$iOLTVCdC$2jViYwTCG.kET399/uF/yO";
## SECRET-DATA
load complete
```

```
[edit system root-authentication]
lab@PBR# show
encrypted-password "$1$iOLTVCdC$2jViYwTCG.kET399/uF/yO";
## SECRET-DATA
```

Next, nonroot users are configured. These users can be defined with local user passwords and permissions, or an external server such as RADIUS or TACACS could be used. In either case, three items need to be configured for the user:

- Username
- Permissions
- Password

A user or user template must always be configured on the router, but the permissions and password could be configured on an external server. To illustrate the possible options, this scenario has the following six requirements:

1. Define two local users, `doug` and `harry`, and provide them with maximum access.
2. A group will be created for the NOC group consisting of 15 engineers. Each NOC engineer will have his own username, but will share the same permissions of read-only commands and maintenance commands for troubleshooting.
3. A group will be created for the design engineer group, consisting of three engineers. This group will have full access to all command-line interface (CLI) commands, except for the `restart` and `request` commands.
4. All users will be authenticated using a RADIUS server with a shared secret of "brianbosworth."
5. Authorization is defined on the local router.
6. If the RADIUS server is down, only `harry` and `doug` may log in to the router.

One user that is not explored in this case study is the remote user. This is a user that could be created for use on the router if the authenticated user does not exist on the local router or if the authenticated user's record in the authentication server specifies a local user. You can think of this as a default fallback account.

Each user defined must be associated with a login class, which assigns the permissions for a user. The login class can be one of the four default classes listed in Table 8-1, or a custom-defined class.

Table 8-1. Predefined Junos user classes

Class	Permissions
`superuser` or `super-user`	All
`read-only`	View
`operator`	Clear, Network, Reset, Trace, View
`unauthorized`	None

Users `harry` and `doug` require maximum access, so it makes sense to use a predefined Junos software class called `super-user`. Here we show the step-by-step process for `harry` only, as user `doug` has identical steps:

```
lab@Ale# edit system login user harry

[edit system login user harry]
set class super-user authentication plain-text-password
New password:
Retype new password:

[edit system login user harry]
lab@Ale# show
    class super-user;
    authentication {
        encrypted-password "$1$oOspqmHP$jlxUulOcAgPq3j88/7WQP/";
        ## SECRET-DATA
    }
```

For brevity and sanity, the configuration examples show one router, but the reader should assume that the configuration is copied to all routers in the network.

Next, a group of 15 NOC engineers are defined. Since configuring 15 local users will be a pain to manage and tiresome to type, we will use a *user template*. A user template allows multiple users defined on the RADIUS server with unique passwords to be grouped to a single local Juniper user. Since a predefined class will not satisfy the authorization level for the NOC engineers of read-only and maintenance commands, we will define a custom class:

```
[edit system login]
lab@Ale# set class ops permissions [view maintenance trace]
```

Refer to the access-privilege technical documentation to see each command that is allowed for every permission setting.

Next, we assign the user ops the new class, also called ops:

```
[edit system login]
lab@Ale# set user ops class ops

[edit system login]
lab@Ale# show class ops
permissions [ trace view maintenance ];
lab@Ale# show user ops
uid 2000;
class ops;
```

The RADIUS server will then have 15 users defined that all map to the same Juniper-local user of ops. For example, the configuration for 2 of the 15 users using a RADIUS server would be similar to the following:

```
bruiser   Auth-Type = Local, Password = "iamaDog"
        Service-Type = Login-User,
        Juniper-Local-User-Name = "ops"

josh     Auth-Type = Local, Password = "plumper1"
        Service-Type = Login-User,
        Juniper-Local-User-Name = "ops"
```

The design engineer group requirement will also use a template but will make use of special allow and deny commands that we can also define in a class. If the permission bits that are set are too broad, we can deny individual commands within the permission settings. (And vice versa; if we need an additional command or set of commands that go beyond the permission setting, we can allow them.) These allow and deny statements could be a single command or a group of commands using regular expressions. They are also separated in allow or deny operational mode commands or configuration mode:

```
[edit system login]
lab@Ale# set class design ?
Possible completions:
  allow-commands       Regular expression for commands to allow explicitly
  allow-configuration  Regular expression for configure to allow explicitly
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  deny-commands        Regular expression for commands to deny explicitly
  deny-configuration   Regular expression for configure to deny explicitly
  idle-timeout         Maximum idle time before logout (minutes)
  login-alarms         Display system alarms when logging in
  login-tip            Display tip when logging in
+ permissions          Set of permitted operation categories
```

The design engineer's class will have the permission bits set to all, and all commands that start with *r* (request and restart) will be disallowed:

```
[edit system login]
lab@Ale# set class design permissions all
[edit system login]
lab@Ale# set class design deny-commands "^r.*$"

lab@Ale# set user design class design
```

Regular expressions are beyond the scope of the book, but here is a list of common operators:

`.`
: Any character

`*`
: Zero or more characters

`^`
: Start of string to which the regex is applied

`$`
: End of string to which the regex is applied

`?`
: Zero or one character

As mentioned, we can define users locally on the router or on an external server such as RADIUS or TACACS. In this chapter's case study, we specified a RADIUS server earlier, in requirement 4. The RADIUS server's IP address and secret password are configured:

```
[edit system]
design@Ale# set radius-server 10.20.130.5 secret brianbosworth
```

For the system to use the RADIUS server, we must configure the `authentication-order` statement. This indicates which order of authentication method should be used, with the default being the local router database only. In this section of our case study, we must decide between the following configuration choices:

1. `authentication-order [radius password]`
2. `authentication-order [radius]`

In either configuration, the local database will be consulted if the RADIUS server is down, so the difference between the two options is evident when the RADIUS server returns a reject. This reject could be caused by a mistyped password or a username that is not defined in the RADIUS server. In option 1, the RADIUS server returns the reject and the local database will be consulted. Option 2 consults the local database only if the RADIUS server is unresponsive; processing stops if the server returns a `reject` message. The requirements state that the RADIUS server should always be used when available (as specified in option 1). If the RADIUS server is not available, users `doug` and `harry` will be allowed to log in using the local database since they are the only users with locally defined passwords on the router. These users are also defined on the RADIUS server:

```
doug    Auth-Type = Local, Password = "superbowlshuffle5"
        Service-Type = Login-User
```

Here is a complete system login configuration that meets all six of the criteria specified earlier:

```
[edit system]
design@Ale# show
host-name Ale;
authentication-order radius password;
ports {
    console type vt100;
}
root-authentication {
    encrypted-password "$1$85xXcov4$fLHtgMlqxRSg24z08Kbe81"; ##
    SECRET-DATA
}
radius-server {
    10.20.130.5 secret "$9$KdgW87db24aUcydsg4Dj69A0RSWLN24ZNd.5TFAt";
    ## SECRET-DATA
}
login {
    class design {
        permissions all;
        deny-commands "^r.*$";
    }
    class ops {
        permissions [ trace view maintenance ];
    }
    user design {
        uid 2004;
        class design;

    user harry {
        uid 2001;
        class super-user;
        authentication {
            encrypted-password "$1$oOspqmHP$jlxUulOcAgPq3j88/7WQP/";
            ## SECRET-DATA
        }
    }
    user doug {
        uid 2003;
        class superuser;
        authentication {
            encrypted-password "$1$ocs3AXkS$JdlQW7z4ZIJblfFZD.fqH/";
            ## SECRET-DATA
        }
    }
    user ops {
        uid 2000;
        class ops;
    }
}
services {
    ftp;
    ssh;
    telnet;
}
syslog {
    user * {
        any emergency;
    }
    file messages {
        any notice;
        authorization info;
    }
    file config-changes {
        change-log any;
    }
}
```

Lastly, to verify that the user has the correct permissions, log in to the router and issue a `show cli authorization` command:

```
    design@Ale> show cli authorization
    Current user: 'design      ' class 'design'
    Permissions:
        admin       --Can view user accounts
        admin-control--Can modify user accounts
        clear       --Can clear learned network information
        configure   --Can enter configuration mode
        control     --Can modify any configuration
        edit        --Can edit full files
        field       --Special for field (debug) support
        floppy      --Can read and write from the floppy
        interface   --Can view interface configuration
        interface-control--Can modify interface configuration
        network     --Can access the network
        reset       --Can reset/restart interfaces and daemons
        routing     --Can view routing configuration
        routing-control--Can modify routing configuration
        shell       --Can start a local shell
        snmp        --Can view SNMP configuration
        snmp-control--Can modify SNMP configuration
        system      --Can view system configuration
        system-control--Can modify system configuration
        trace       --Can view trace file settings
        trace-control--Can modify trace file settings
        view        --Can view current values and statistics
        maintenance --Can become the super-user
        firewall    --Can view firewall configuration
        firewall-control--Can modify firewall configuration
        secret      --Can view secret configuration
        secret-control--Can modify secret configuration
        rollback    --Can rollback to previous configurations
        security    --Can view security configuration
        security-control--Can modify security configuration
        access      --Can view access configuration
        access-control--Can modify access configuration
        view-configuration--Can view all configuration (not including
        secrets)
    Individual command authorization:
        Allow regular expression: none
        Deny regular expression: ^r.*$
        Allow configuration regular expression: none
        Deny configuration regular expression: none
```

Remote Access

After the users are configured on the router, we must decide what kind of remote access will be provided to the router, as all methods are disabled by default. Here are the possible options:

Dynamic Host Configuration Protocol (DHCP)
: Provides dynamic IP assignment from a pool of addresses to clients attached to the interface (not available on M-series routers). This option is most often used for the auto-installation feature.

Finger
: A protocol to get information about a user logged in to the router. This protocol is no longer used on a large scale and should never be enabled on the router:

```
% finger lab@10.20.128.3
[10.20.128.3]
Login: lab                          Name:
Directory: /var/home/lab            Shell: /usr/sbin/cli
On since Mon Sep 24 00:31 (UTC) on ttyd0, idle 0:01
No Mail.
No Plan.
%
```

FTP
: Provides file transfer services. Although FTP is a widely used protocol, it transfers files in plain text, which can lead to security issues. When possible, you should use secure copy (SCP).

Rlogin
: The Remote login protocol, which allows remote login to the CLI. This Unix utility has several security flaws and was used only in private environments. This utility is enabled by a hidden command on the router and should never be enabled on the router.

A *hidden command* is a command that does not show up when you use `?` in the CLI and does not autocomplete with the Space bar. One of the most famous hidden commands in Junos software is `show version and haiku`. Try it yourself if you want to read some really bad poetry!

SSH
: Allows for two devices to communicate over an encrypted tunnel. This ensures not only availability, but also data integrity and confidentiality. When SSH is enabled, this automatically enables SCP.

Telnet
: A common protocol to remotely manage a system developed in 1969. Telnet transits all data in clear text, so you should use SSH when possible.

Web management
: Enables the use of the jweb web GUI on the router for management and configuration. These can be either encrypted or unencrypted Hypertext Transfer Protocol (HTTP) connections.

Junoscript server
: Enables the router to receive commands from a Junoscript server via clear text or Secure Sockets Layer (SSL) connections.

Netconf
: The Network Configuration protocol, which is defined in RFC 4741 and uses XML for configuration and messages. Netconf is the Internet Engineering Task Force (IETF) standard created as a replacement for the Simple Network Management Protocol (SNMP) and is based on Junoscript. Netconf SSH is needed when the device is going to be controlled by Juniper's Network and Security Manager (NSM).

The most secure methods of remote access on the router will be SSH and transferring files using SCP. To enable any service, simply set it under the `[edit system services]` directory:

```
[edit system services]
lab@Ale# set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration
                       data
+ apply-groups-except  Don't inherit configuration data from these
                       groups
> dhcp                 Configure DHCP server
> finger               Allow finger requests from remote systems
> ftp                  Allow FTP file transfers
> netconf              Allow NETCONF connections
> service-deployment   Configuration for Service Deployment (SDXD)
                       management application
> ssh                  Allow ssh access
> telnet               Allow telnet login
> web-management       Web management configuration
> xnm-clear-text       Allow clear text-based Junoscript connections
> xnm-ssl              Allow SSL-based Junoscript connections
```

Each service will have a variety of options, such as setting a maximum number of connections, rate-limiting the inbound connections, and choosing a certain protocol version:

```
lab@Ale# set system services ssh ?
Possible completions:
   <[Enter]>            Execute this command
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  connection-limit     Maximum number of allowed connections (1..250)
+ protocol-version     Specify ssh protocol versions supported
  rate-limit           Maximum number of connections per minute
                      (1..250)
  root-login           Configure root access via ssh
  |                    Pipe through a command
```

XML Tags

Junoscript is a tool you can use to configure and manage the router. Every Junos output and configuration contains XML tags that can be referenced by a Junoscript client. Here is an example of a configuration and an operational command that displays the XML tags for each field:

```
lab@PBR> show system users | display xml
<rpc-reply xmlns:junos="http://xml.juniper.net/junos/10.4R1/junos">
    <system-users-information xmlns="http://xml.juniper.net/junos/
    10.4R1/junos">
        <uptime-information>
            <date-time junos:seconds="1293056770">8:54AM</date-time>
            <up-time junos:seconds="207372">2 days,  9:36</up-time>
            <active-user-count junos:format="1 user">1</active-user-
            count>
            <load-average-1>0.06</load-average-1>
            <load-average-5>0.02</load-average-5>
            <load-average-15>0.00</load-average-15>
            <user-table>
                <user-entry>
                    <user>lab</user>
                    <tty>d0</tty>
                    <from>-</from>
                    <login-time junos:seconds="1190593874">Mon12AM</login-time>
                    <idle-time junos:seconds="0">-</idle-time>
                    <command>-cli (cli)</command>
                </user-entry>
            </user-table>
        </uptime-information>
    </system-users-information>
    <cli>
        <banner></banner>
    </cli>
</rpc-reply>

lab@PBR> show configuration routing-options | display xml
<rpc-reply xmlns:junos="http://xml.juniper.net/junos/10.4R1/junos">
    <configuration>
            <routing-options>
                <static>
            <route>
                        <name>10.10.128.1/32</name>
                        <next-hop>10.10.111.1</next-hop>
                    </route>
                </static>
            </routing-options>
    </configuration>
    <cli>
        <banner></banner>
    </cli>
```

In this case, SSH is enabled on the router using the default parameters of 150 connection attempts and 75 active sessions per minute:

```
[edit]
lab@Ale# set system services ssh
```

`Bock` then initiates a session to `Ale`. The first connection will need to establish the RSA fingerprint for authentication:

```
lab@Bock> ssh 10.10.128.1
The authenticity of host '10.10.128.1 (10.10.128.1)' can't be
established.
RSA key fingerprint is 5d:f5:51:91:51:0e:ff:54:0c:f4:0a:07:51:3b:70:3a.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added '10.10.128.1' (RSA) to the list of known
hosts.
lab@10.10.128.1's password:
--- Junos 10.4R1.9 built 2010-12-08 09:22:36 UTC
lab@Ale> exit

Connection to 10.10.128.1 closed.
```

However, once `Ale` is added to the list of known hosts, future sessions do not require reverification:

```
lab@Bock> ssh 10.10.128.1
lab@10.10.128.1's password:
--- Junos 10.4R1.9 built 2010-12-08 09:22:36 UTC
lab@Ale>
```

When SSH is enabled on the router, it also automatically enables SCP to initiate secure file exchanges. You can upload or download files using variations of the `file copy` command. In this case, `PBR` transfers a file called *test* to `Ale.` `PBR` must add `Ale` into its good hosts file:

```
lab@PBR> file copy test lab@10.10.128.1:test.txt
The authenticity of host '10.10.128.1 (10.10.128.1)' can't be
established.
RSA key fingerprint is 5d:f5:51:91:51:0e:ff:54:0c:f4:0a:07:51:3b:70:3a.
Are you sure you want to continue connecting (yes/no)? yes
Warning: Permanently added '10.10.128.1' (RSA) to the list of
known hosts.
lab@10.10.128.1's password:
test                                  100% 9480     9.3KB/s   00:00
```

After `Ale` is learned as a host, future transfers will pass the authentication check because both `Ale` and `PBR` know each other as trusted hosts:

```
lab@PBR> file copy test2 lab@10.10.128.1:test2.txt
lab@10.10.128.1's password:
test                                  100% 9480     9.3KB/s   00:00
```

Summary of Access Security

Routers are the very fabric of any IP-based network, making it critical that access be limited to only those users that are authorized to access the system, and only for those tasks they are authorized to perform. Junos software provides a variety of tools, ranging from local and remote authentication and authorization to secure access and file transfer protocols, which make it easy to secure the router from unauthorized access and many forms of DoS attacks.

The next section details packet-based (stateless) firewall filtering and policing capabilities, which are another critical aspect of a total security solution.

Firewall Filters

To protect the router, you can deploy packet filters to allow only certain traffic into the router's control plane (Routing Engine [RE]). These filters have different names on each router OS, but they still operate in the same stateless manner. On a Cisco device, these filters are called *access lists*, and on a Juniper router, they are called *firewall filters*. These filters look similar to the policy we discussed in Chapter 5; however, filters operate on the actual data-forwarding plane. Table 8-2 provides a comparison of the two features.

Table 8-2. Firewall filters versus routing policies

Feature	Firewall filter	Routing policy
Operates in...	Forwarding plane	Control plane
Match keyword	`from`	`from`
Action keyword	`then`	`then`
Match attributes	Packet fields	Route attributes
Default action	Discard	Depends on default policy
Applied to...	Interfaces	Routing protocols/tables
Named terms required	Yes	No
Chains allowed	Yes	Yes
Absence of `from` statement	Match all	Match all

Firewall filter syntax takes a human-friendly, intuitive form:

```
firewall {
    family inet {
        filter filter-1 {
            term term-1 {
                from {
                    protocol tcp;
                    destination-port telnet;
                }
                then {
                    accept;
                }
            }
        }
    }
}
```

This filter matches on Telnet traffic and accepts the packets. As observed, the syntax is very similar to a routing policy with the match conditions in the `from` term and the actions specified in a `then` term.

Filter Processing

Similar to a policy, a filter is made up of multiple terms, and each term is examined in the order listed. If there is a match in a term and there is a terminating action, no other term is examined (see Figure 8-3). Terminating actions are:

`accept`
: Allows the packet through the filter

`discard`
: Silently discards the packet

`reject`
: Discards the packet with an Internet Control Message Protocol (ICMP) error message (the default is administratively prohibited)

Action modifier
: Any action modifier, such as `log`, `count`, `syslog`, and so on

> The presence of an action modifier such as `count` without an explicit `accept`, `discard`, or `reject` will result in a default action of `accept`. If the desired action is to discard or reject the packet, it must be explicitly configured.

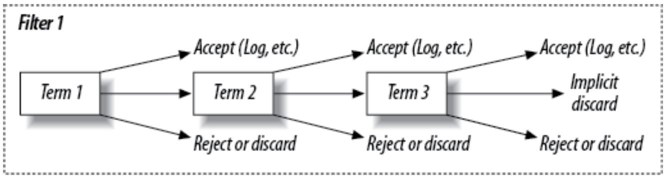


Figure 8-3. Filter processing

If the packet does not match any terms in the filter, it is discarded.

You also can apply multiple filters to the interface in the form of a filter list, and in this case it operates in the same fashion down the filter list until there is a terminating action. If no match occurred in the filter list, the packet is discarded (see Figure 8-4).

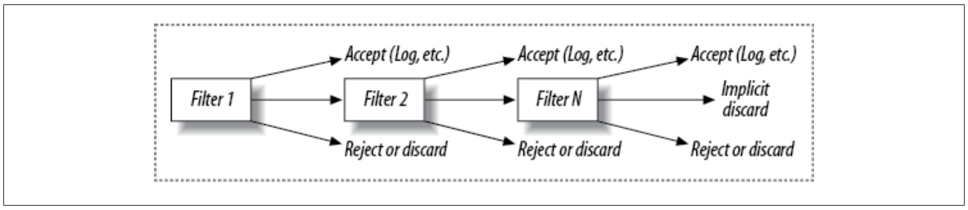


Figure 8-4. Filter chaining

Filter Match Conditions

When examining the possible match conditions, the general rule of thumb is that if it is a field in the IP, Transmission Control Protocol (TCP), User Datagram Protocol (UDP), or ICMP header, it is probably a potential match:

```
lab@PBR# set firewall family inet filter foo term 1 from ?
Possible completions:
> address                Match IP source or destination address
+ apply-groups              Groups from which to inherit configuration
                            data
+ apply-groups-except       Don't inherit configuration data from these
                            groups
> destination-address    Match IP destination address
+ destination-port          Match TCP/UDP destination port
+ destination-port-except  Do not match TCP/UDP destination port
  destination-prefix-list  Match IP destination prefixes in named
                             list
+ dscp                   Match Differentiated Services (DiffServ) code
                         point
+ dscp-except            Do not match Differentiated Services (DiffServ)
                         code point
+ esp-spi                Match IPSec ESP SPI value
+ esp-spi-except         Do not match IPSec ESP SPI value
  first-fragment         Match if packet is the first fragment
+ forwarding-class       Match forwarding class
+ forwarding-class-except  Do not match forwarding class
  fragment-flags         Match fragment flags
+ fragment-offset        Match fragment offset
+ fragment-offset-except  Do not match fragment offset
+ icmp-code              Match ICMP message code
+ icmp-code-except       Do not match ICMP message code
+ icmp-type              Match ICMP message type
+ icmp-type-except       Do not match ICMP message type
> interface              Match interface name
+ interface-group        Match interface group
+ interface-group-except  Do not match interface group
> interface-set          Match interface in set
+ ip-options             Match IP options
+ ip-options-except    Do not match IP options
  is-fragment          Match if packet is a fragment
+ packet-length        Match packet length
+ packet-length-except  Do not match packet length
+ port                 Match TCP/UDP source or destination port
+ port-except          Do not match TCP/UDP source or destination
                       port
+ precedence           Match IP precedence value
+ precedence-except    Do not match IP precedence value
> prefix-list          Match IP source or destination prefixes in
                       named list
+ protocol             Match IP protocol type
+ protocol-except      Do not match IP protocol type
  service-filter-hit   Match if service-filter-hit is set
> source-address       Match IP source address
+ source-port          Match TCP/UDP source port
+ source-port-except   Do not match TCP/UDP source port
> source-prefix-list   Match IP source prefixes in named list
  tcp-established      Match packet of an established TCP connection
  tcp-flags            Match TCP flags
  tcp-initial          Match initial packet of a TCP connection
+ ttl                  Match IP ttl type
+ ttl-except           Do not match IP ttl type
```

The match conditions fall into three general categories: numeric, address, and bit field matches (see Table 8-3).

Table 8-3. General match conditions

Numeric matches	Address matches	Bit fields
Protocol fields	Source address	IP options
Port numbers	Destination address	TCP flags
Class of service (CoS) fields	Source-prefix lists	IP fragmentation
ICMP type codes	Destination-prefix lists	Time to Live (TTL)

A term can have zero or many match conditions specified. The absence of a `from` statement creates a match all condition, whereas multiple match conditions are treated as a logical AND or OR depending on common versus uncommon match conditions. A common match is treated as a logical OR, which the router will group together in square brackets. The filter example matches on TCP or UDP packets:

```
filter example {
    term common {
        from {
            protocol [ tcp udp ];
        }
    }
}
```

An uncommon match is treated as a logical AND. You can combine these logical ANDs and ORs in the same term with limitless possibilities. Adding to the example, the following filter matches on TCP or UDP packets and port 123:

```
filter example {
    term common {
        from {
            protocol [ tcp udp ];
            port 123;
        }
    }
}
```

Also, numeric matches such as port or protocol values can either take the numeric match or the more user-friendly keywords. For example, the first term and second term of the filter called `same` are equivalent, but the second term is written in a more efficient and user-friendly method:

```
firewall {
    filter same {
        term numbers {
            from {
                protocol 6;
                port 23;
            }
            then accept;
        }
        term user-friendly {
            from {
                protocol tcp;
                port telnet;
            }
            then accept;
        }
    }
}
```

Bit field matching such as IP options and TCP flags also support numeric values or more user-friendly terms. In these cases, the numeric support must be written in hex format, so a TCP flag match for SYN packets could be written with the keyword `syn` or the value 0x2. No reason to break out the hex converter—make life easy and use the keywords!

Can your mother read this?

When writing a filter, always try to adhere to the KISS (Keep It Short and Simple) method. An individual security element may not be that difficult, but when combined with other security functions as a whole, it can contribute to a large web of complexity. In other words, try to create a filter that the average network engineer can understand without compromising any security. A great start to reach this goal is to use the alpha names for protocol, port numbers, and bit fields instead of the actual numerical values.

Additionally, Junos has even more to offer, using text synonyms to map common bit mappings. These allow the casual reader to quickly understand a filter at a glance and avoid panicked and hysterical research to find what service maps to a numerical value (see Table 8-4).

Table 8-4. Text synonyms

Text synonym	Match equivalent	Common use
`first-fragment`	Offset = 0, MF = 1	Match on the first fragment of a packet for counting and logging.
`is-fragment`	Offset does not equal zero	Protect from fragmented DoS attacks.
`tcp-established`	ACK or RST	Allow only established TCP sessions over an interface. This option does not implicitly check that the protocol is TCP. Use the TCP match condition.
`tcp-initial`	SYN and not ACK	Allow sessions to be initiated either inbound or outbound.

Filter Actions

Besides the terminating actions that we already discussed (`accept`, `discard`, and `reject`), other action modifiers are commonly used. These include:

`count` *`<counter name>`*
: Counts the total number of packets and bytes that match a term. You can view counters with the `show firewall` command.

`log`
: Records the packet header information and stores the information in memory on the router, which limits the size to approximately 400 entries and clears upon a router reboot. To view the log, issue a `show firewall log` command.

`syslog`
: Records the packet header information and stores the log into a file or sends it to a syslog server. The syslog facility of the firewall will allow any local file to be created for this information.

`policer`
: Rate-limits traffic based on bandwidth and burst size limits (discussed later in this chapter).

`forwarding-class`
: Sends packets to a forwarding class, which maps to a queue.

`sample`
: Creates cflowd export records.

`next term`
: Allows packets to match a term and then move on to the next term listed. Since the presence of any action modifier implies an `accept`, this action allows packets to pass through to the next term. This is often deployed when all packets need to be counted before being rejected farther in the chain.

Applying a Filter

The final step after writing the filter is to actually apply it to the interface. You can apply filters to either transit or nontransit traffic. To apply a filter to transit traffic, apply the filter to any Packet Forwarding Engine (PFE) interface as either an input or an output filter or as part of a list of filters. Filters are applied on a logical unit basis:

```
lab@hops# set interfaces ge-0/0/0 unit 0 family inet filter ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  group                Group to which interface belon
  input                Name of filter applied to received packets
+ input-list           List of filter modules applied to received packets
  output               Name of filter applied to transmitted packets
+ output-list          List of filter modules applied to transmitted packets
```

You can apply a single filter with the `input` or `output` command, or a list with `input-list` or `output-list`, so why the option for both? Historically in Junos, only a single filter could be applied per direction per unit, but in later code the concept of a list was created. It is recommended that even if just a single filter is being applied to an interface, to use the `list` command. This adds flexibility in adding more filters to the chain at a later time.

To protect traffic to the router itself (local traffic), you can apply a filter or filter-list to the loopback interface (see Figure 8-5). Local traffic is any packet that is destined to the router itself, such as routing protocols, ICMP, SSH, and other management protocols.

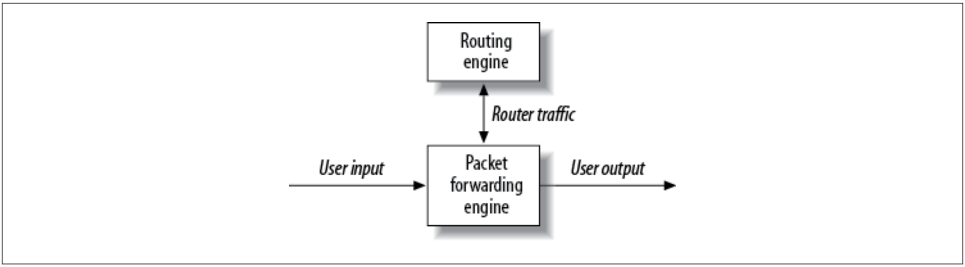


Figure 8-5. Transit versus loopback filters

Case Study: Transit Filters

It is common to see a filter applied to the router's connection to the Internet. Before sitting down to begin typing away on the router, always write down the goals of the filter. In this case study, all outbound traffic from the network to the Internet is allowed while some traffic from the Internet will be filtered. The goals here are as follows:

- TCP connections are only allowed to be initiated outbound to the Internet, except to access a local web server.
- No fragmented ICMP or UDP packets should be allowed.
- TCP fragments are allowed.
- UDP packets should be allowed inbound for traceroutes and return traffic for outbound UDP connections.
- Ping and traceroute are allowed outbound.
- Traceroute is allowed inbound.

First create a prefix list for the internal subnets, which in this case are as follows:

```
10.10.128/22
10.20.128/22
10.10.12/22
[edit]
lab@PBR# set policy-options prefix-list internal-subnets 10.10.128/22

[edit]
lab@PBR# set policy-options prefix-list internal-subnets 10.20.128/22

[edit]
lab@PBR# set policy-options prefix-list internal-subnets 10.20.12/22

lab@PBR# show policy-options prefix-list internal-subnets
10.10.128.0/22;
10.10.12.0/22;
10.20.128.0/22;
```

Now the filter called `internet-in` will be examined with each term explained to match the five goals stated at the beginning of this case study. First, we define our first term to allow established TCP sessions inbound, which are destined for internal subnets. The keyword `tcp-established` allows only packets with a TCP flag of `ack` or `rst`. As a result of the implicit deny all at the end of the filter list, this term will also accomplish task 1, allowing only outbound TCP sessions. Also, the `fragment-offset` keyword allows for unfragmented packets or first packet fragments to be received as only the first fragmented packet has the headers needed for the check:

```
lab@PBR# show firewall family inet
filter internet-in {
    term allow-established-tcp-sessions {
        from {
            destination-prefix-list {
                internal-subnets;
            }
            fragment-offset 0;
            tcp-established;
            protocol tcp;
        }
        then accept;
    }
```

Next, TCP connections are allowed to the web server at 10.20.12.9, using port numbers https (443) and 8080. Port 80 connections are not allowed toward this web server to add an additional layer of security:

```
        term allow-webserver-connections {
            from {
                destination-address {
                    10.20.12.9/32;
                }
                protocol tcp;
                destination-port [  https 8080 ];
            }
            then accept;
        }
```

UDP and ICMP fragments are denied as these types of packets are normally used in popular DoS attacks. The `fragment-offset` command is matching on all ICMP and UDP fragments, excluding the first packet. If the first fragment also were to be dropped, the `is-fragment` and `first-fragment` would be used and two terms would have been required:

```
    term deny-udp-icmp-frags {
            from {
                fragment-offset 1-8191;
                protocol [ icmp udp ];
            }
            then {
                discard;
            }
        }
```

TCP fragments are allowed, however. Recall that the `is-fragment` keyword matches on all fragments except the first fragment, which was matched in the first term of the filter:

```
        term allow-tcp-frags {
            from {
                is-fragment;
                protocol tcp;
            }
            then {
                accept;
            }
        }
```

Next, incoming UDP packets are allowed to internal subnets that are not fragments. This is to allow return traffic for outbound UDP sessions as well as inbound traceroute packets that use UDP inbound:

```
        term allow-udp {
            from {
                destination-prefix-list {
                    internal-subnets;
                }
                protocol udp;
            }
            then accept;
        }
```

Lastly, ping and traceroute are allowed outbound. Since this is an input filter, the return traffic is actually being allowed in for both ping (echo replies) and traceroute (time exceed messages). Additionally, unreachable messages are allowed in for any possible outbound error responses:

```
        term allow-some-icmp-outbound {
            from {
                destination-prefix-list {
                    internal-subnets;
                }
                protocol icmp;
                icmp-type [ echo-reply time-exceeded unreachable ];
            }
            then accept;
        }
    }
```

The filter is applied to both WAN interfaces on router `PBR` as the input list of one to allow for filter additions at a later date:

```
    lab@PBR# show interfaces
    ge-0/0/0 {
        vlan-tagging;
        unit 412 {
            description PBR-to-Wheat;
            vlan-id 412;
            family inet {
                filter {
                    input-list internet-in;
                }
                address 172.16.1.2/24;
            }
        }
        unit 413 {
            description PBR-to-Water;
            vlan-id 413;
            family inet {
                filter {
                    input-list internet-in;            }
                address 64.8.12.6/27;
```

Case Study: Loopback Filters

Next, traffic destined to the router itself needs to be secured. The goals of this case study are to allow:

- OSPF traffic
- BGP traffic from configured peers only
- SSH from internal subnets

- Virtual Router Redundancy Protocol (VRRP) packets
- Ping and traceroute
- Domain Name System (DNS) replies
- SNMP and Network Time Protocol (NTP)

First, define a prefix list for the internal subnets in your network:

```
lab@PBR# show policy-options
prefix-list internal-subnets {
    10.10.128.0/22;
    10.10.12.0/22;
    10.20.128.0/22;
}
```

Since BGP traffic should be from configured peers only, the `apply-path` command is used to avoid any IP change issues or neighbor additions that may happen in the future. The `apply-path` allows configuration elements to be matched when the `prefix-list` is applied by using regular expressions. In this case, this will create a list of BGP peers for every BGP group configured because of the match all * regular expression:

```
prefix-list bgp-configured-peers {
    apply-path "protocols bgp group <*> neighbor <*>";
}
```

The `filter protect-router` is created with the first term allowing SSH traffic to *and* from the router because of the `port` command, which matches on either the source or destination port:

```
    filter protect-router {
        term allow-ssh {
            from {
                source-prefix-list {
                    internal-subnets;
                }
                protocol tcp;
                port ssh;
            }
            then accept;
        }
```

Create a term to allow for OSPF packets:

```
        term allow-ospf {
            from {
                protocol ospf;
            }
            then accept;
        }
```

Then take advantage of the prefix list that was previously created to allow only the configured BGP peer's traffic:

```
        term allow-bgp {
            from {
                source-prefix-list {
                    bgp-configured-peers;
                }
                protocol tcp;
                port bgp;
            }
           then accept;
        }
```

Allow VRRP traffic:

```
        term allow-vrrp {
            from {
                protocol vrrp;
            }
            then accept;
        }
```

Don’t forget about DNS replies. Since these are stateless, filter the return traffic so that DNS resolution is allowed in:

```
        term dns-replies {
            from {
                protocol udp;
                source-port 53;
            }
            then accept;
        }
```

SNMP is allowed:

```
        term snmp {
            from {
                protocol udp;
                port [ snmp snmptrap ];
            }
            then accept;
        }
```

Also allowed are UDP packets with a TTL of 1 for traceroute to operate:

```
        term traceroute {
            from {
                protocol udp;
                ttl 1;
            }
            then accept;
        }
```

Allow pings, traceroutes, and error messages:

```
        term allow-icmp {
            from {
                protocol icmp;
                icmp-type [ echo-request echo-reply time-exceeded
                unreachable ];
            }
```

```
                then accept;
            }
```

NTP is also allowed:

```
            term allow-ntp {
                from {
                    prefix-list {
                        internal-subnets;
                    }
                    protocol udp;
                    port ntp;
                }
                then accept;
            }
```

Lastly, there is a term that denies all other traffic (which is the default) but allows this traffic to be counted as well as logged to a syslog file:

```
            term match-denied {
                then {
                    count bad-packets;
                    syslog;
                    discard;
                }
            }
        }
    }
```

The filter is then applied to the loopback interface as an input filter. Even though it is just a single filter, it is added as a list for future expansion:

```
    lab@PBR# set interface lo0.0 family inet filter input-list protect-router
```

This is a good point to dust off the `commit confirmed` to make sure the filter does not break the current network or, worse yet, lock you out of the router:

```
    [edit]
    lab@PBR# commit confirmed
    commit confirmed will be automatically rolled back in 10 minutes unless
    confirmed
    commit complete
    # commit confirmed will be rolled back in 10 minutes
    [edit]
    lab@PBR# commit
    commit complete
```

Be very aware when working on remote devices and lo0 filters. In the preceding example, after the `commit confirmed` was entered, connectivity was verified and a second commit issued. If there are routing protocols in use (e.g., OSPF, BGP), the keepalive timers could take over a minute to expire. It is prudent to wait a couple of minutes prior to issuing the second commit to verify that the protocols do not time out.

Policers

To rate-limit traffic entering an interface, you can deploy a *policer*. The policers that are implemented in the Juniper router are token-based and use the IP packet to limit based on bandwidth and bursts. The bandwidth is measured as the average number of bits in over a one-second interval (see Figure 8-6). The burst size is the number of bytes that can exceed the bandwidth constraints.

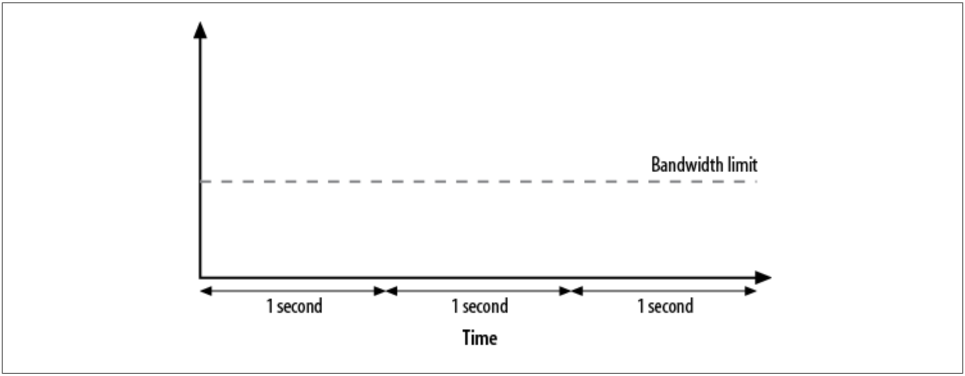


Figure 8-6. Bandwidth limit

The burst size is what implements the policer's "token"-based behavior. The burst size will set the initial and maximum sizes of a bucket in bytes (tokens) that would be accessed each time data needs to be sent. As a packet is sent, the bucket bytes (tokens) are removed from the bucket. If there are not enough tokens to send the packet, the packet will be policed. The bucket is then replenished at the bandwidth rate.

In Figure 8-7, a packet that bursts above the bandwidth limit is nonetheless sent, as there are enough tokens in the bucket. After the packet is sent, the tokens are decreased based on the packet size.

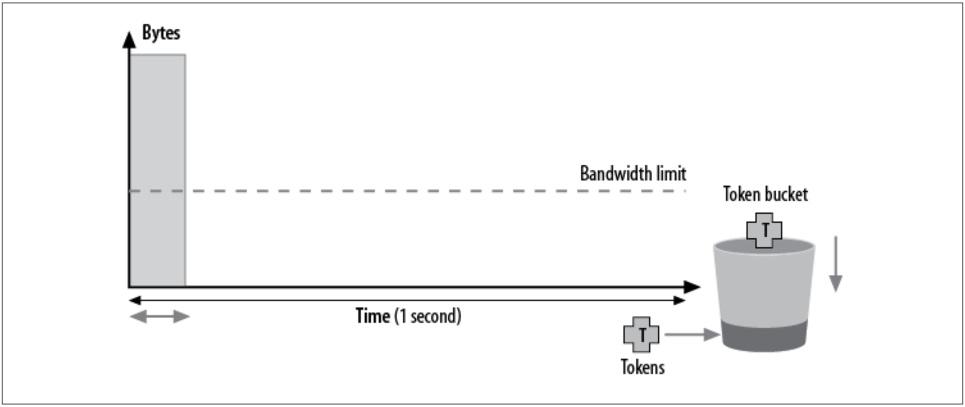


Figure 8-7. Initial burst

Then, some time later, another packet needs to be sent that is also above the bandwidth limit. Since there are no longer enough tokens left in the bucket, the packet is policed (see Figure 8-8).

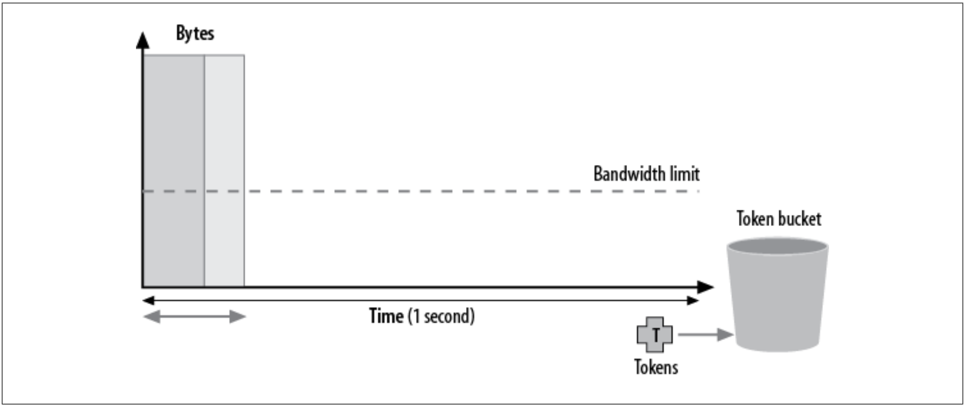


Figure 8-8. Empty token bucket

As time goes by, the bucket will replenish at a rate equal to the bandwidth limit. When a new packet arrives, it can be sent, as tokens are now available in the bucket. This process continues over a one-second interval, and the result is a rate equal to the bandwidth limit (see Figure 8-9).

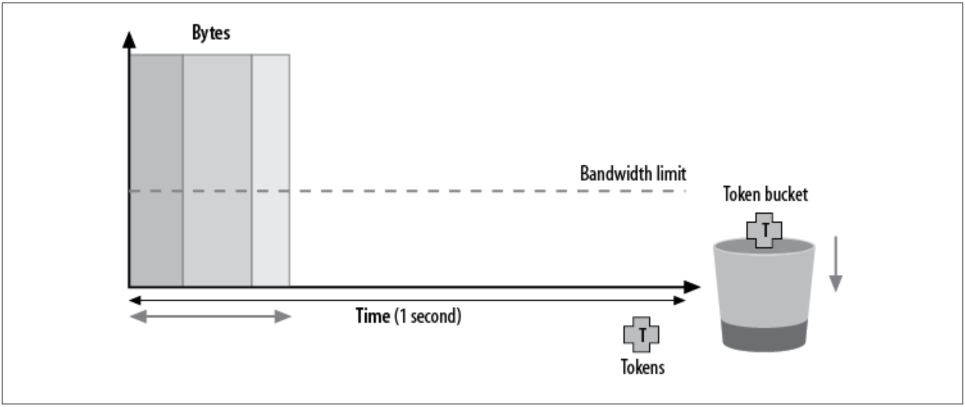


Figure 8-9. Token bucket replenishing

Burst-size limit mystery

The setting of the burst size has always seemed to be a mystery for many operators. Set this value too low, and potentially all packets will be policed. Set the value too high, and no packets will be policed. The rule of thumb is that the burst size should never be lower than 10 times the maximum transmission unit (MTU). The recommended value is to set the amount of traffic that can be sent over the interface in five milliseconds. So, if your interface is a Gigabit Ethernet interface, the minimum is 15,000 bytes (10 × 1,500), and the recommended value would be 625,000 bytes (125,000 bytes/ms × 5).

Policer actions

Once the policer limits have been configured, you must choose the action taken if a packet exceeds the policer. Two types of policing are available: *soft* policing and *hard* policing. Hard policing specifies that the packet will be dropped if it exceeds the policer's traffic profile. Soft policing simply marks the packet or reclassifies the packet, which could change the probability of the packet being dropped at the egress interface during times of congestion. Soft policing is implemented by either setting the packet loss priority (PLP) setting on the packet or by placing the packet into a different forwarding class. We will examine these concepts further in Chapter 11.

Configuring and applying policers

Policers are configured under the `[edit firewall]` level. The policer will be named and then the burst size will be applied in bytes/second, the bandwidth limit in bits/second, or the percentage of interface bandwidth set along with the policer action. For example:

```
policer simple {
    if-exceeding {
        bandwidth-limit 50m;
        burst-size-limit 15k;
    }
    then discard;
}
```

Once you have configured the policer, you must apply it to an interface. You can do this in one of two ways: either by applying the policer directly underneath the interface or by referencing the policer name in the firewall filter. If you apply the policer directly to the interface, no match conditions can be used. If you reference the policer in a filter, specific types of traffic can be policed as the entire toolkit of filter actions is allowed. You can apply both an interface policer and a policer in a filter at the same time. In this case, a kind of hierarchical policing is used as interface policers are evaluated before input filters and after output filters. Figure 8-10 shows policer processing.

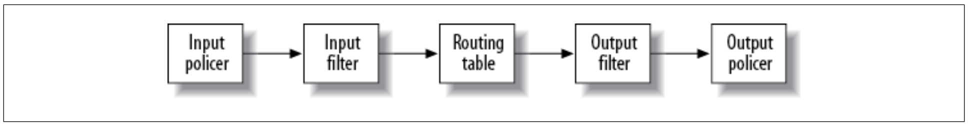


Figure 8-10. Policer processing

Since you can apply the same filter to multiple interfaces, you can apply the same policer to multiple interfaces. In this case, the aggregate bandwidth of all the interfaces is examined before any policing parameters. To avoid this behavior and create a separate instance for each interface, include the `interface-specific` command in the filter. This will create unique policers and counters for each interface to which the filter is applied.

Policer example

In this section, we will examine a very simple two-level policer that:

- Limits virtual LAN (VLAN) 1241 to 1 MB with a burst size of 5,000 bytes
- Limits FTP to 10% of the bandwidth and ICMP to 500,000 bits per second

First, the policers are defined under the firewall level:

```
lab@Bock# show firewall
policer total-int {
    if-exceeding {
        bandwidth-limit 1m;
        burst-size-limit 5k;
    }
    then discard;
}
policer limit-ftp {
    if-exceeding {
        bandwidth-percent 10;
        burst-size-limit 625k;
    }
    then discard;
}
policer police-icmp {
    if-exceeding {
        bandwidth-limit 500k;
        burst-size-limit 62500;
    }
    then discard;
}
```

Then a filter is created to match on FTP and ICMP traffic to limit each application to certain thresholds. The `interface-specific` keyword is used to create a unique instance of the filter if applied to multiple interfaces. This is required if a policer is referenced that uses bandwidth percentage such as the `limit-ftp` policer:

```
firewall {
    family inet {
        filter police-traffic {
            interface-specific;
            term police-ftp {
                from {
                    protocol tcp;
                    port [ ftp ftp-data ];
                }
                then policer limit-ftp;
            }
            term police-icmp {
                from {
                    protocol icmp;
                }
                then policer police-icmp;
            }
            term catch-all {
                then accept;
            }
        }
    }
}
```

Apply the filter and policer to the interface:

```
lab@Bock# show interfaces ge-0/0/0
vlan-tagging;
unit 1241 {
    description Bock-to-PBR;
    vlan-id 1241;
    family inet {
        filter {
            input-list police-traffic;
        }
        policer {
            input total-int;
        }
        address 10.20.130.1/24;
    }
}
```

To verify whether the policer is applied, issue a `show interfaces policers` command:

```
lab@Bock>show interfaces policers
Interface       Admin Link Proto Input Policer       Output Policer
ge-0/0/0        up    up
ge-0/0/0.1241   up    up   inet  total-int-ge-0/0/0.1241-inet-i
gr-0/0/0        up    up
ip-0/0/0        up    up
ls-0/0/0        up    up
lt-0/0/0        up    up
mt-0/0/0        up    up
pd-0/0/0        up    up
pe-0/0/0        up    up
sp-0/0/0        up    up
...
```

To examine whether packets are exceeding the traffic parameters, view the policer counters. For interface policers, you can see packet counts with the `show policer` command:

```
lab@Bock> show policer total-int-ge-0/0/0.1241-inet-i
Policers:
```

```
Name                                                Packets
total-int-ge-0/0/0.1241-inet-i                            5
```

Policers that are referenced in a firewall filter automatically get counters created for them based on the policer name, interface applied, and direction. You can view these in the same command as normal counters for filters, with the `show firewall` command:

```
lab@Bock> show firewall
Filter: ge-0/0/0.1241-i
Policers:
Name                                                Packets
police-icmp-police-icmp-ge-0/0/0.1241-i                   0
limit-ftp-police-ftp-ge-0/0/0.1241-i                      0
Filter: _  _default_bpdu_filter_  _
Filter: police-traffic
Policers:
Name                                                Packets
police-icmp-police-icmp                                   0
limit-ftp-police-ftp                                      0
```

A difficulty is determining how much traffic the policer is allowing to ascertain if the exceeding parameters are too large or too small. You can do this using the policer counters, interface statistics, and a little math. First, determine the byte-per-packet size the policer sees by dividing the bytes by the number of packets as seen by the policer counter. Then, multiply the egress rate in packets per second by the per-packet size and 8 bits to get the bytes per second.

For example, say the policer counter claimed 1,406,950 bytes and 18,494 packets exceeded the policer. This would calculate to an average per-packet size of 76 bytes (1,406,950/18,494). Then, via the `show interfaces` command, the interface rate would be determined to be 203 packets per second (pps). So, 203 pps multiplied by 76 bytes divided by a packet time of 8 bits per second will provide a bytes-per-second rate of 123,424, which should be close to the configured bandwidth rate.

Summary of Firewall Filters and Policers

Stateless firewall filters offer the advantage of high-speed processing, which allows you to maintain local control plane and transit security at near-wire-rate speeds. The easy-to-read and intuitive nature of Junos filter and policer syntax makes it easy to create, deploy, monitor, and modify filters.

You may also consider the use of stateful firewall filtering, which provides for enhanced packet and application layer processing, using the techniques covered in Chapter 12 and Appendix A. The flexibility of Junos software allows you to choose which solution is best for a specific set of needs and, when desired, to use both types of filtering for an optimal security and performance solution.

The next section details ways in which Junos can help to prevent the use of bogus source addressing, which is a common occurrence in a distributed DoS (DDoS) attack.

Spoof Prevention (uRPF)

Many distributed DoS attacks take advantage of address "spoofing" by randomly selecting an address in the source field of IP packets. In some attacks, this source address is deterministic to the target network under attack. In other words, this address will be taken out of the network's address block to create attacks on other internal machines generating ICMP error messages or other traffic back to the spoofed addresses. You can protect yourself from these types of attacks by applying ingress filtering at the edge of your network, which denies incoming packets with addresses out of the network's address block. This filtering has traditionally been solved with an inbound packet filter.

Referring back to the topology in Figure 8-2, note that three internal address blocks are assigned to `PBR`, `Ale`, and `Bock`'s network:

    10.10.128/22
    10.20.128/22
    10.10.12/22

So, a simple filter would deny any addresses from those address blocks coming from the WAN connection off `PBR`:

```
[edit firewall]
lab@PBR# show
family inet {
    filter spoof-prevention {
        term my-addresses {
            from {
                source-address {
                    10.10.128.0/22;
                    10.20.128.0/22;
                    10.10.12.0/22;
                }
            }
            then {
                count spoofs;
                log;
                discard;
            }
        }
        term allow-rest {
            then count no-spoof;
        }
    }
}
```

Apply the firewall filter as an input filter on `ge-0/0/0.412` and `ge-0/0/0.413`:

```
lab@PBR# show interfaces ge-0/0/0
vlan-tagging;
unit 412 {
    description PBR-to-Wheat;
    vlan-id 412;
    family inet {
        filter {
            input-list spoof-prevention;
        }
        address 172.16.1.2/24;
    }
}
unit 413 {
    description PBR-to-Water;
    vlan-id 413;
    family inet {
        filter {
            input-list spoof-prevention;
        }
        address 64.8.12.6/27;
    }
}
```

After applying the filter, we can see that spoofed addresses are being properly denied over PBR's `ge-0/00.413` interface, as shown in the firewall log:

```
lab@PBR> show firewall log
Log :
Time      Filter    Action Interface     Protocol Src Addr       Dest Addr
01:39:18  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:17  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:16  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:15  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:14  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:13  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:12  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:11  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:10  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
01:39:09  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
```

The problem with ingress firewall filters is that you must update them manually when an address block or network changes. A more dynamic method that has been developed to prevent spoofing is called *unicast Reverse Path Forwarding* (uRPF). RPF is a mechanism that is used in multicast networks to avoid looping based on the source IP address (the reverse path), not the destination IP address. In essence, the source IP address is compared against the route table to see whether it was learned over that interface. If the packet was received via the incoming interface on which it was learned, it is accepted; if not, the packet will be dropped.

This concept has now been extended to Unicast packets for spoof prevention to create dynamic filters based on the route table. The mechanism will remain the same, in that the source IP address will need to be "verified" for incoming packets. Unicast RPF can operate on one of two modes:

Strict
: The incoming packet must be received on the interface that would be used to forward traffic to the source IP address. Strict mode is the default.

Loose
: The incoming packet's source address must be in the route table.

Strict mode provides a reliable, simple, fast, and cheap filter at the edge of any network. The configuration to enable strict mode is quite simple; just add the `rpf-check` command under the proper interface:

```
lab@PBR# show interfaces ge-0/0/0
vlan-tagging;
unit 412 {
    description PBR-to-Wheat;
    vlan-id 412;
    family inet {
        rpf-check;
        address 172.16.1.2/24;
    }
}
unit 413 {
    description PBR-to-Water;
    vlan-id 413;
    family inet {
        rpf-check;
        address 64.8.12.6/27;
    }
}
```

Verify that uRPF is enabled by looking for the `uRPF` flag in the interface:

```
[edit]
lab@PBR# run show interfaces ge-0/0/0.413 | match uRPF
      Flags: uRPF
```

The packets that fail the RPF check are automatically counted on the interface:

```
[edit]
lab@PBR# run show interfaces ge-0/0/0.413 extensive | match RPF
      Flags: uRPF
      RPF Failures: Packets: 8, Bytes: 672
```

Strict mode is the preferred solution when possible, but it does run into some problems under certain scenarios. In particular, it assumes symmetrical traffic flows. In the case of a BGP multihoming environment or redundant IGP paths, this may not always be the case.

> Remember that the default load balancing for a Juniper router is to choose a single next hop to install in the forwarding table per destination.

PBR is multihomed to two ISPs (see Figure 8-11) and receives the same set of routes from each; however, only the route received from autonomous system (AS) 666 is active:

```
lab@PBR# run show bgp summary
Groups: 2 Peers: 2 Down peers: 0
```

```
Table          Tot Paths  Act Paths Suppressed    History Damp State    Pending
inet.0               497        249          0          0          0          0
Peer                   AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn
State|#Active/Received/Damped...
64.8.12.5             666       1239       1114       0       0     9:15:56 248/248/0
0/0/0
172.16.1.1            420       1354       1238       0       0     9:15:26 0/248/0
0/0/0
```

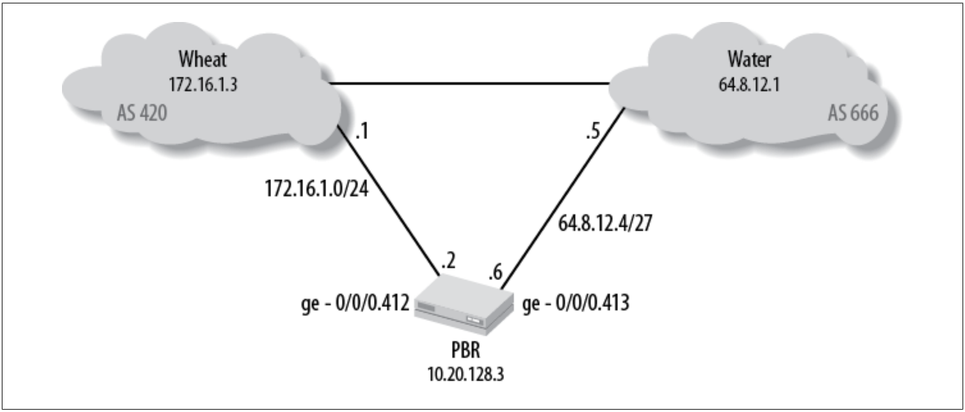


Figure 8-11. Multihoming

This means that any traffic received from AS 420 that is an inactive route will fail the RPF check. An example is the 128.3/16 address block:

```
[edit]
lab@PBR# run show route 128.3.3.4

inet.0: 264 destinations, 513 routes (264 active, 0 holddown, 1 hidden)
+ = Active Route, - = Last Active, * = Both

128.3.0.0/16       *[BGP/170] 09:20:20, localpref 100
                      AS path: 666 11537 293 16 I
                    > to 64.8.12.5 via ge-0/0/0.413
                    [BGP/170] 09:19:50, localpref 100
                      AS path: 420 666 11537 293 16 I
                    > to 172.16.1.1 via ge-0/0/0.412
```

Since Junos performs uRPF against active paths only, in order to allow for multihoming or asymmetric traffic flows you can configure a feature called *feasible paths*. This knob allows every possible path in the route table to be considered, including active and inactive paths. You enable this global command for the entire router under the `[edit routing-options]` stanza:

```
lab@PBR# show routing-options
aggregate {
    route 10.10.128.0/22;
    route 10.20.128.0/22;
    route 10.10.12.3/32;
}
autonomous-system 1282;
forwarding-table {
    unicast-reverse-path feasible-paths;
}
```

Loose RPF provides less security, as it verifies only that the route is in the route table and does not check which interface it points to. This is more of a route presence check than an actual verification of the reverse path. The only benefit would be for *route martians*, or packets that are not currently being routed. One such example could be a private RFC 1918 address if only publicly routable addresses are used in the network. Since loose mode sacrifices directionality, it is not a recommended approach to spoof prevention and has limited scope.

Another problem with loose mode occurs when a default route is present in the table. In this case, every packet would pass the check and thus uRPF checks would be negated. Strict mode with a default route will still verify that the packet entered on the interface to which the default route points.

To enable loose mode on an interface, specify the `loose` command after turning on uRPF:

```
lab@PBR# set interfaces ge-0/0/0.412 family inet rpf-check mode loose
```

Other filters could still be applied to the interface when uRPF mode is enabled; in this case, the input filter is examined first, and the uRPF checks process only the traffic that passes this filter. Because of this processing, it is hard to perform a log action for packets that failed the RPF filter. In this instance, you can configure a *fail* filter. A fail filter is performed after the RPF check and on all traffic that has failed the RPF check (see Figure 8-12).

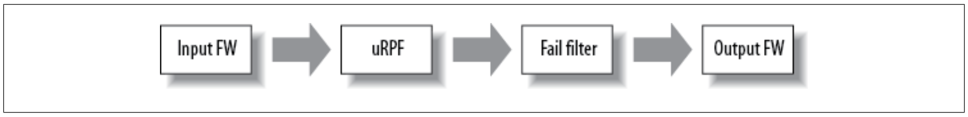


Figure 8-12. Firewall filter and uRPF relationship

You can use a fail filter to:

- Allow traffic that would normally fail an RPF check, such as DHCP on a LAN interface
- Allow traffic that would normally fail an RPF check to be accepted and counted
- Allow failed traffic to be processed by a filter modifier such as counting or logging

An example of the first filter could be DHCP requests that would always fail an RPF check:

```
filter rpf-dhcp {
            term dhcp {
                from {
                    source-address {
                        0.0.0.0/32;
                    }
                    destination-address {
                        255.255.255.255/32;
                    }
                }
                then accept;
            }
        }
    }
```

If traffic that fails the RPF check should be further examined, you also can use a fail filter. The following filter would be able to log all packets that are failing the RPF check:

```
filter match-spoofs {
    term 1 {
        then {
            log;
            discard;
        }
    }
}
```

Apply the fail filter to the interface:

```
[edit interfaced ge-0/0/0]
lab@PBR# show
unit 413 {
    description PBR-to-Water;
    vlan-id 413;
    family inet {
        rpf-check fail-filter match-spoofs;
        address 64.8.12.6/27;
    }
}
```

View the packets that are failing uRPF by examining the firewall log:

```
lab@PBR# run show firewall log
Log :
Time      Filter    Action Interface     Protocol Src Addr       Dest Addr
02:23:59  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
02:23:58  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
02:23:57  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
02:23:56  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
02:23:55  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
02:23:54  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
02:23:53  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
02:23:52  pfe       D      ge-0/0/0.413  ICMP     10.10.12.3     10.20.128.3
```

Summary of Spoof Prevention

Current best practices suggest that all source addresses should be validated as close to the ingress point of traffic as is possible. Historically, the added processing led to poor forwarding performance due to a lack of processing resources. This often resulted in a total lack of address enforcement, and the resulting ease in which DDoS attacks can be successfully launched.

The unique design of Junos software allows you to enable spoof prevention features while still maintaining a high level of forwarding performance.

The next section details ways that Junos can help monitor the router to actively and proactively determine the presence of attacks.

Monitoring the Router

Once the access configuration is in place, you should monitor the router for health and analysis. The two primary methods of remote monitoring are via SNMP and syslog (system logging). SNMP is a way to gather statistics and other event information off the router, whereas syslog is used to gather various log messages off the router. To validate these types of messages, you should use proper time and date stamping, which is often implemented by using NTP.

Syslog

Syslog was originally developed as a method to send information for the sendmail application in BSD, but it was so useful that it was extended to other applications and operating systems. Essentially, syslog is a standard way to send log messages across an IP network.

Syslog describes the actual transport mechanism used to send these messages and is often used to describe the actual application that is sending them. Originally, it was an "industry" standard and was not attached to an informational RFC until 2001, with RFC 5424, "The BSD Syslog Protocol."

Syslog messages are sent over UDP with a destination port of 514. The IP transport mechanism is defined and not the actual syslog content. It is left to the discretion of the application or system coder to create an informative message to the receiver. The message always contains a message severity level and a facility level. The *facility level* can be defined as the type of message that is being sent, and the *severity level* indicates the message's importance. Table 8-5 defines the severity levels.

Table 8-5. Syslog severity levels

Numerical code	Severity
0	Emergency: system is unusable
1	Alert: action must be taken immediately
2	Critical: critical conditions
3	Error: error conditions
4	Warning: warning conditions
5	Notice: normal but significant condition
6	Informational: informational messages
7	Debug: debug-level messages

Table 8-6 lists the facility levels that are available in Junos.

Table 8-6. Syslog facility levels

Facility	Description
Any	All facilities (all messages)
Authorization	Authentication and authorization attempts
Change-Log	Changes to the configuration
Conflict-Log	Specified configuration is invalid on the routing platform type
Daemon	Actions performed or errors encountered by system processes
DFC	Events related to dynamic flow capture
Firewall	Packet filtering actions performed by a firewall filter
FTP	Actions performed or errors encountered by the FTP process
Interactive commands	Commands executed by the user interface
Kernel	Actions performed or errors encountered by the Junos kernel
PFE	Actions performed or errors encountered by the Packet Forwarding Engine
User	Actions performed or errors encountered by user-space processes

The default system log is called “messages”; you can view it with the `show log messages` command:

```
lab@PBR> show log messages
Nov 20 06:00:00 PBR newsyslog[2858]: logfile turned over due to size>128K
Nov 21 09:47:59  PBR login: LOGIN_PAM_AUTHENTICATION_ERROR: PAM authentication error
 for user lab
Nov 21 09:47:59  PBR login: LOGIN_FAILED: Login failed for user lab from host
Nov 21 09:48:03  PBR login: LOGIN_INFORMATION: User lab logged in from host [unknown]
 on device ttyd0
Nov 21 09:48:06  PBR mgd[2978]: UI_DBASE_LOGIN_EVENT: User 'lab' entering
 configuration mode
Nov 21 09:54:36  PBR mgd[2978]: UI_DBASE_LOGOUT_EVENT: User 'lab' exiting
```

```
 configuration mode
Nov 21 09:54:55  PBR mgd[2978]: UI_REBOOT_EVENT: System rebooted by 'lab'
Nov 21 09:55:09  PBR /kernel: KERNEL_MEMORY_CRITICAL: System low on free memory,
 notifying init (#1).
Nov 21 09:55:09  PBR rpd[2800]: Received low-memory signal: no job active, 34 free
 pages
Nov 21 09:55:09  PBR rpd[2800]: Processing low memory signal
Nov 21 09:55:49  PBR shutdown: reboot by lab:
Nov 21 09:55:49  PBR init: watchdog (PID 2768) terminate signal sent
Nov 21 09:55:49  PBR init: chassis-control (PID 2770) terminate signal sent
Nov 21 09:55:49  PBR init: alarm-control (PID 2771) terminate signal sent
Nov 21 09:55:49  PBR craftd[2772]: craftd_user_conn_shutdown: socket 8, errno = 0
Nov 21 09:55:49  PBR init: craft-control (PID 2772) terminate signal sent
Nov 21 09:55:49  PBR snmpd[2811]: SNMPD_CLOSE_SA_IPC: ipc_free_local: closed IPC
 socket /var/run/craft
Nov 21 09:55:49  PBR init: management (PID 2773) terminate signal sent
Nov 21 09:55:49  PBR init: inet-process (PID 2775) terminate signal sent
Nov 21 09:55:49  PBR init: syslogd (PID 2682) terminate signal sent
Nov 21 09:55:49  PBR init: ecc-error-logging (PID 2779) terminate signal sent
Nov 21 09:55:49  PBR init: forwarding (PID 2780) terminate signal sent
Nov 21 09:55:49  PBR init: usb-control (PID 2781) terminate signal sent
Nov 21 09:55:49  PBR init: mib-process (PID 2799) terminate signal sent
Nov 21 09:55:49  PBR snmpd[2811]: SNMPD_CLOSE_SA_IPC: ipc_free_local: closed IPC
 socket /var/run/mib2d
Nov 21 09:55:49  PBR init: routing (PID 2800) terminate signal sent
Nov 21 09:55:49  PBR rpd[2800]: RPD_SIGNAL_TERMINATE: first termination signal
 received
Nov 21 09:55:49  PBR init: l2-learning (PID 2801) terminate signal sent
Nov 21 09:55:49  PBR init: vrrp (PID 2802) terminate signal sent
Nov 21 09:55:49  PBR snmpd[2811]: SNMPD_CLOSE_SA_IPC: ipc_free_local: closed IPC
 socket /var/run/vrrpd
Nov 21 09:55:49  PBR rpd[2800]: RPD_OSPF_NBRDOWN: OSPF neighbor 10.20.130.1
 (ge-0/0/0.1241) state changed from Full to Down due to KillNbr
 (event reason: interface went down)
Nov 21 09:55:49  PBR init: sampling (PID 2803) terminate signal sent
Nov 21 09:55:49  PBR init: class-of-service (PID 2804) terminate signal se
```

Many of the syslog messages will have headers specified in uppercase letters that you can input into the help command specifying which facility the message was logged on, the severity level, a description, and a recommended action. Looking at the log entry for November 21, one such header is noted as `RPD_OSPF_NBRDOWN`:

```
Nov 21 09:55:49  PBR rpd[2800]: RPD_OSPF_NBRDOWN: OSPF neighbor 10.20.130.1
 (ge-0/0/0.1241) state changed from Full to Down due to KillNbr
 (event reason: interface went down)
```

You can examine this message using the `help syslog` command, which indicates that an OSPF neighbor went down due to an event:

```
lab@PBR> help syslog RPD_OSPF_NBRDOWN
Name:          RPD_OSPF_NBRDOWN
Message:       OSPF neighbor <neighbor> (<interface>) state changed from
               <old-state> to <new-state> due to <event> (event reason:
               <event-reason>)
Help:          OSPF neighbor adjacency was terminated
```

```
Description:   An OSPF adjacency with the indicated neighboring router was
               terminated. The local router no longer exchanges routing
               information with, or directs traffic to, the neighboring router.
Type:          Event: This message reports an event, not an error
Severity:      notice
```

You can create custom logs by specifying a filename, facility, message facility, and location to send the message. The message can either be stored in a local file, sent to a syslog server, sent to the console, or sent to a user or group of users when logged in to the router.

The factory default configuration enables three system logs: two logs that are sent to a file, and one log that is sent to any user that is logged in. Although the default system log receives all information as specified with the any keyword, you can create other files for easier log parsing:

```
syslog {
    user * {
        any emergency;
    }
    file messages {
        any any;
        authorization info;
    }
    file interactive-commands {
        interactive-commands any;
    }
}
```

Case study: Syslog

To avoid having to specify every syslog option available, let's examine a realistic example with specific goals. The goals are as follows:

- Increase the default size of the *messages* file to 1 MB and the number of archives to 15.
- Send all messages to a syslog server with a domain name of syslog.tacoshopsf.com.
- Ensure that all messages sent to the syslog server are in the same format as the Cisco routers in your network.
- Create a syslog file to log all firewall filter log information.

Each syslog file that is created on a Juniper Networks router is stored in the file directory *var/log* and is given a size of 128 KB on a J-series router or SRX and 1 MB on an M-series router. When the file is full, the file is cleared, an archive is created of the old data, and the file is written to again. For example, once 128 KB of data is written into the *messages* file, that file will be cleared and the information will be moved into a *message.0* file. When the *messages* file is filled up again, the old data is archived into *messages.0* and the old *messages.0* now becomes *messages.1*. This will continue for 10 archives until the data is written. In the case study, you should increase the default number of archives to 15 and the file size to 1 MB. You can do this with the following archive configuration:

```
[edit system syslog]
lab@PBR# set file messages archive files 15 size 1M

[edit system syslog]
lab@PBR# show file messages
any notice;
authorization info;
archive size 1m files 15;
```

Next, syslog messages need to be sent to a syslog server:

```
[edit system syslog]
lab@PBR# set host syslog.underdogssf.com any any
```

The default Junos message does not send the priority (facility value and severity) of the syslog message, which could cause issues when trying to parse the output at the receiver. Cisco routers by default do send this priority field; to ensure that both vendors send the same message format, configure the `explicit-priority` keyword:

```
[edit system syslog]
lab@PBR# set host syslog.tacoshopsf.com explicit-priority
```

Lastly, a new syslog file is created to log firewall entries:

```
[edit system syslog]
lab@PBR# set file fw-log firewall info
```

Here is the complete stanza:

```
[edit system syslog]
lab@PBR# show
user * {
    any emergency;
}
host syslog.underdogssf.com {
    any any;
    explicit-priority;
}
file messages {
    any notice;
    authorization info;
    archive size 1m files 15;
}
file interactive-commands {
    interactive-commands any;

}
file fw-log {
    firewall info;
}
```

SNMP

SNMP is a standard protocol used for a network management station to receive information for the router (or agent; see Figure 8-13). The manager can poll the router for router health information such as memory utilization, link status, or firewall filter statistics in the form of a GET command. The router can also send event information to the network manager without polling, in a process called a *TRAP*.

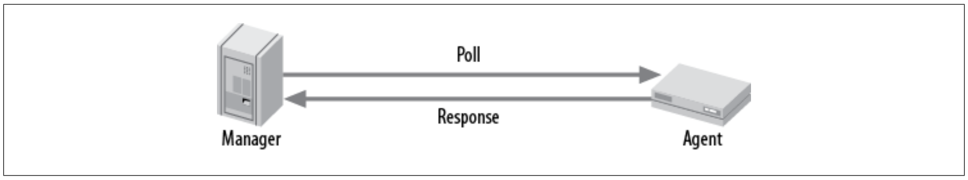


Figure 8-13. SNMP concept

The data structure that is used to carry information is called a Management Information Base (MIB). An MIB has a structure in the format of a tree that defines groups of objects into related sets. These MIBs are identified by an Object Identifier (OID), which names the object. The leaf of the OID contains the actual managed objects. MIBs are defined into two categories: standard and enterprise-specific. Standard MIBs are defined by the IETF in various RFCs, whereas enterprise-specific MIBs are defined by the vendor and must be compiled into the management station. Here is an example of MIB data taken from a network manager:

```
SNMPv2-MIB::sysDescr.0 = STRING: M120 - Okemos, MI
SNMPv2-MIB::sysObjectID.0 = OID: JUNIPER-MIB::jnxProductNameM120
SNMPv2-MIB::sysUpTime.0 = Timeticks: (80461526) 9 days, 7:30:15.26
SNMPv2-MIB::sysContact.0 = STRING: Doug Marschke - x8675309
SNMPv2-MIB::sysName.0 = STRING: PBR-3
SNMPv2-MIB::sysLocation.0 = STRING: Okemis, MI USA - Rack 4
SNMPv2-MIB::sysServices.0 = INTEGER: 4
```

To configure SNMP on a Juniper router, you must specify a community string on the router. This acts as a password to verify incoming SNMP information on the management station:

```
[edit snmp]
lab@PBR# set community sample

[edit snmp]
lab@PBR# show
community sample;
```

Juniper Networks routers support SNMP v1, SNMP v2, and SNMP v3.

With this basic configuration, SNMP GETs can be received on any interface from any management statement. It is recommended that access is restricted to particular interfaces and clients:

```
lab@PBR# show
interface ge-0/0/0.1141;
community sample {
    clients {
        10.10.12.4/32;
        0.0.0.0/0 restrict;
    }
}
```

Also, the router may want to initiate some information in the form of TRAPs. TRAPs are sent to a specified list of targets and are defined by categories. Possible categories include:

Authentication
User login authentication failures

Chassis
Chassis and environmental notifications

Configuration
Notification of configuration changes

Link
Link status changes

Remote operations
Remote operation notifications

Rmon-alarm
Events for RMON alarms

Routing
Routing protocol information such as neighbor status changes

Services
Events for additional Junos services such as Network Address Translation (NAT) and stateful firewall

Sonet-alarm
A variety of SONET alarms such as loss of light, BER defects, and so on

Start-up
Warm and cold boots

VRRP events
VRRP events such as mastership changes

In the following example, a TRAP group called `health` is added to the SNMP configuration that sends chassis and link TRAPs to station 10.10.12.4:

```
lab@PBR# show
interface ge-0/0/0.1141;
```

```
community sample {
    clients {
        10.10.12.4/32;
        0.0.0.0/0 restrict;
    }
}
trap-group health {
    categories {
        chassis;
        link;
    }
    targets {
        10.10.12.4;
    }
}
```

By default, both SNMP v1 and v2 TRAPs are sent. You can overwrite this by specifying a version under the TRAP group.

It may also be useful to walk down the MIB tree to verify information in the MIB and for troubleshooting purposes. To perform an SNMP walk on the router, issue the `show snmp mib <object>` command. In this case, the system MIB is examined on the router:

```
lab@PBR> show snmp mib walk system
sysDescr.0    = Juniper Networks, Inc. jsr2320 internet router, kernel
Junos 10.4R1.90 #0: 2010-04-16 07:17:53 UTC builder@ormonth.juniper.net:/volume/build/
junos/10.4/release/10.4R1.9/
    obj-i386/bsd/sys/compile/JSR Build date: 2010-12-08 06:50:00 UTC Copyright (c) 1
sysObjectID.0 = jnxProductNameJ2320
sysUpTime.0   = 332346
sysContact.0
sysName.0     = Lager
sysLocation.0
sysServices.0 = 4
```

NTP

When examining logs, it is essential to ensure that the proper date and time are recorded for each event. You can set the time and date manually on each router using the `set date` command:

```
lab@PBR> set date ?
Possible completions:
  <time>  New date and time (YYYYMMDDhhmm.ss)
  ntp     Set system date and time using Network Time Protocol servers
```

However, since many devices are likely to be managed at once, each with slightly different clock speeds and drift, it is virtually impossible to keep all the clocks on every device synchronized. NTP was developed for the purpose of clock synchronization. NTP works in one of three modes:

Client
: A client has a one-way synchronization with a server.

Symmetric active
: There is equal peer synchronization with each other's local clock.

Broadcast
: The server sends periodic broadcast messages on shared media, and clients listen to these messages for synchronization.

NTP uses a concept of *clock strata* to define the distance from the clock reference and the accuracy. A stratum 0 clock is the reference clock (such as an atomic clock), and each level of peering relationship decreases in accuracy and stratum level (see Figure 8-14).

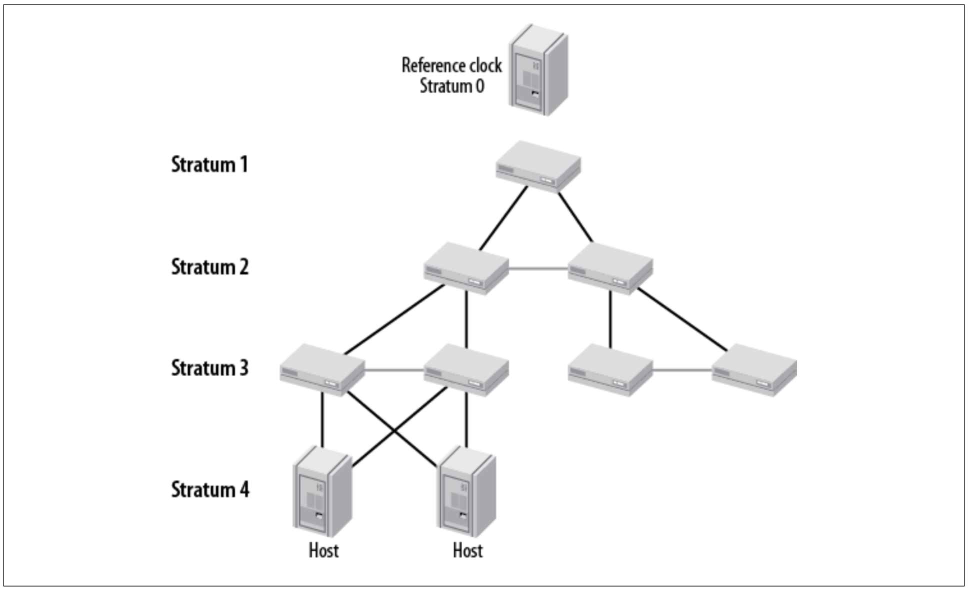


Figure 8-14. NTP stratum levels

All NTP configurations are set under `[edit system ntp]`. In the following configuration, `Bock` is configured in client mode with a server of 10.20.130.5. Also, a boot server is configured to allow the initial clock setting to be set at boot time:

```
lab@Bock> show configuration system ntp
boot-server 10.20.130.5;
server 10.20.130.5;
```

If a router is configured for NTP and the clocks are more than 128 seconds apart, the synchronization process will fail. In the past, to recover from that scenario, the operator either rebooted the device with the boot server configuration or set the date manually within 128 seconds. Junos software now allows you to synchronize the device by simply issuing the `set date ntp` command and avoiding a reboot:

```
lab@Bock> set date ntp 10.20.130.5
10 Feb 13:50:21 ntpdate[794]: step time server 10.20.130.5 offset 0.000163 sec
```

To verify that NTP has worked correctly, issue the `show ntp associations` command and look for the * next to the remote IP:

```
lab@Bock> show ntp associations
     remote     refid   st t when poll reach  delay   offset  jitter
====================================================================
*10.20.130.5  LOCAL(0)  11 u   10   64   17   0.491   12.991  10.140
```

Check the correct time:

```
lab@Bock> show system uptime
Current time: 2010-12-22 03:53:35 UTC
System booted: 2010-11-20 04:58:58 UTC (1d 22:54 ago)
Protocols started: 2010-11-20 04:59:24 UTC (1d 22:54 ago)
Last configured: 2010-11-22 03:40:02 UTC (00:13:33 ago) by lab
 3:53AM  up 1 day, 22:55, 1 user, load averages: 0.19, 0.10, 0.03
```

You also can change the time zone in the router by issuing a `set system time-zone` command:

```
lab@Bock# set system time-zone ?
Possible completions:
  <time-zone>         Time zone name or POSIX-compliant time zone string
  Africa/Abidjan
  Africa/Accra
  Africa/Addis_Ababa
  Africa/Algiers
  Africa/Asmera
---(more 5%)---[abort]
```

Is NTP Really Working?

The `show ntp associations` command is often a source of mass confusion and terror for operators, as there is no distinct "broken field." The synchronization process will be indicated by interpreting the delay and offset fields, as well as by noting the presence or absence of a * character.

Here is an example of an association that has failed. Notice the space in front of the 10.20.130.5 as well as the zeros in the delay and offset fields. This is an indication that no messages have been sent at all!

```
lab@Bock> show ntp associations
    remote       refid   st t when poll reach   delay   offset  jitter
=====================================================================
10.20.130.5 0.0.0.0      0 u   12   64    0    0.000    0.000 4000.00
```

In comparison, here is another association that failed; however, notice that there are values in the delay and offset fields. These indicate that NTP messages have been exchanged but synchronization has not been achieved, as no * has been displayed next to the remote peer. The large offset is usually an indication that the clocks are too far apart (above the 128-second threshold):

```
lab@Bock> show ntp associations
    remote    refid  st t when poll reach   delay   offset  jitter
==================================================================
10.20.130.5 LOCAL(0)    11 u   25   64   37  0.492  2542804 4000.00
```

After issuing a `set date ntp` command, the clocks synchronize without having to reboot the router. Note the more sane offset value and the presence of the illustrious star next to the remote peer address:

```
lab@Bock> show ntp associations
     remote      refid  st t when poll reach   delay   offset  jitter
=====================================================================
*10.20.130.5  LOCAL(0)    11 u   10   64   17   0.491   12.991  10.140

3:53AM  up 1 day, 22:55, 1 user, load averages: 0.19, 0.10, 0.03
```

Since NTP uses a step process to synchronize the clocks after issuing the `set date ntp` command, the association could still appear to be broken. This is normal for NTP, so just sit back, enjoy a drink, and after three to five minutes, everything should be working as normal.

Summary of Router Monitoring

Many types of attacks and network abuse leave telltale signs, if the operator only takes the time to look for them. The Unix underpinnings of Junos software offer full syslogging capabilities, which when synchronized to other routers via the NTP protocols can provide invaluable forensics when problems are being investigated. Using SNMP to remotely monitor network operations to include the receipt of asynchronous TRAPs reporting anomalous conditions provides an excellent way to adopt a more proactive stance toward securing your network.

Conclusion

When the router is deployed in the network, you must secure it properly to protect your network, investments, and hard work. The first step is to configure the proper users with access privileges. Depending on the number of users, the local router or an external server database may be used to hold this information, or an external server.

Once the users are in place, you need to deploy packet filters to protect the router. These filters may be very elaborate or quite simple depending on your security policies. Also, you may need to rate-limit some applications in your network using policers.

It also does not do much good to have a secure router if you can't gather router health and other statistical information from it. Therefore, you also should deploy standard protocols such as SNMP, syslog, and NTP to achieve these management goals.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- List the various user authentication methods.
- Describe the uses of login classes.
- Describe authentication order.
- Describe system logging.
- Identify the configuration of a stateless packet filter.
- Secure the router by applying packet filters to protect the Routing Engine.
- Evaluate the result of a given stateless packet filter.
- Configure SNMP.
- Customize class templates with varying permissions and commands.
- Configure and operate the Network Time Protocol.

Chapter Review Questions

1. What is the default password on the router?
   A. Juniper
   B. Cisco
   C. There is no password
   D. Enable
2. Which predefined login class allows the user to have access rights to any login command?
   A. Privileged
   B. Super-user
   C. Privileged exec
   D. Power-user
3. What is the default action at the end of a firewall filter chain?
   A. Discard
   B. Reject
   C. Accept
   D. Do nothing
4. Which interface would you apply to a filter to protect the router's local traffic?
   A. `fxp1`
   B. `fxp0`
   C. `manage`

   D. `lo0`

5. Which command is used to view all firewall filter counters, including counters automatically created in policers?
   A. `show counters`
   B. `show policer`
   C. `show interfaces filters counters`
   D. `show firewall`
6. Which two features can you use to protect your network against spoofed IP addresses? (Choose two.)
   A. Firewall filters
   B. Spoof routes
   C. Unicast reverse path forwarding
   D. Secondary addresses
7. Which three parameters are specified in a policer? (Choose three.)
   A. Bandwidth limit
   B. Policer action
   C. Bucket level
   D. Burst size
   E. Leak rate
8. Choose two possible reasons for using a fail filter using uRPF. (Choose two.)
   A. Allow packets to pass through RPF
   B. Log packets that fail RPF
   C. Implement NAT
   D. Send traffic through a tunnel
9. Which syslog facility logs all CLI commands?
   A. `cli-commands`
   B. `accounting`
   C. `change-log`
   D. `interactive-commands`
10. In which directory are all logfiles stored?
    A. */var/home/user*
    B. */log*
    C. */var/home/log*
    D. */var/log*
    E. */syslog*

11. Which feature of SNMP v2 acts as a password to authenticate SNMP messages?
    A. MIBs
    B. Communities
    C. OID
    D. TRAPs
12. Which command allows NTP synchronization without a router reboot?
    A. `set system ntp`
    B. `request system time update`
    C. `set date ntp`
    D. `set ntp boot-server`

Chapter Review Answers

1. Answer: C. There is no default password on a Juniper router in the factory default configuration. A single user, `root`, will be configured with no password.
2. Answer: B. The class of `superuser` allows users to issue any command that they desire on the router. The other options listed are not supported classes.
3. Answer: A. At the end of a filter chain, if a packet has not matched any other term, it will be discarded. Special care must always be taken when writing a filter to allow traffic that would otherwise be denied by the final implicit discard at the end of the filter.
4. Answer D. If a filter is applied to the loopback interface, any traffic local to the router can be protected, including routing protocol, ICMP, and FTP traffic.
5. Answer: D. You can use the `show firewall` command to view counters defined in any firewall filter. Also, any policer that is referenced in a filter will have a counter automatically created and viewed by this command. The `show policer` command will only show the counter for policers applied directly to the interface.
6. Answer: A, C. Both firewall filters and Unicast RPF will help to avoid packets with spoofed IP addresses. Unicast RPF could provide for more dynamic and automatic filtering.
7. Answer: A, B, D. Policers must specify bandwidth and burst size limit. Also, once a packet hits one of the limits, an action to either hard- or soft-police must be specified.
8. Answer: A, B. A fail filter matches on packets that fail the RPF check. You could use this to accept packets such as DHCP, which would always fail an RPF check, or to count or log packets that have passed an RPF check.
9. Answer: D. The facility `interactive-commands` will log any commands that were typed via any user interface method, including the CLI.

10. Answer: D. This is the directory for all syslog and trace-options files.
11. Answer: B. A community will act as a password for SNMP messages. This community value is sent in clear text on the wire, which could easily be captured. The next version of SNMP corrects this issue.
12. Answer: C. If the NTP server is reachable, `set date ntp` will restart the NTP update process without having to reboot the router, thus eliminating the need for a `boot-server` configuration statement.

CHAPTER 9

Junos Layer 2 Services

Once the routing aspect of a network has been deployed, you'll want additional services to be added to fit your network requirements. In the past, a separate device would have performed these types of services, but in modern networking these tasks have been moved to the router itself. *Service* is a broad term that can include tasks that are performed at Layer 2 (such as link bonding) or at Layer 3 (such as Network Address Translation [NAT]). We will examine the Layer 2 services in this chapter.

Because many of these services require intensive packet processing on the router, you may have to install additional hardware to avoid any degradation in packet forwarding and throughput. Although this may seem to be a slight nuisance at first, it does solve the problem of increased services causing decreased throughput, as is observed in most other router implementations.

The service topics covered in this chapter include:

- Junos services
- Layer 2 services
- Additional service options

The information covered in this chapter is based on services that are implemented via ASP on the M7i, a DSP on the MX series, or on the J-series or SRX through its emulation of ASP functionality.

Junos Services

A Junos software service consists of a variety of Layer 2 services, including:

- Multilink Point-to-Point Protocol (MLPPP)
- Multilink Frame Relay (MLFR)
- Compressed Real-Time Transport Protocol (CRTP)
- Multiclass MLPPP

- Aggregated Ethernet (AE)
- Ethernet Switching
- Stateful firewall
- NAT
- Intrusion detection service (IDS)
- IPSec
- Layer 2 Tunneling Protocol (L2TP)
- Active monitoring (cflowd)
- Tunnel services (Generic Routing Encapsulation [GRE], IP-IP, Physical Interface Module [PIM] register encapsulation)
- Data link switching (DLSw)

In an M-series router, enabling these services will require an additional piece of hardware: a Physical Interface Card (PIC) for packet processing. A J-series router or SRX Services Gateway supports most of the features in the preceding list and performs the packet processing within the software, so no special hardware is necessary. Depending on the type of service required and the size of the service, different PICs can be used. The current offerings include:

Link Services PIC
: Provides simultaneous support for three separate capabilities: enhanced multilink bundling, tunneling, and link fragmentation and interleaving (LFI) on larger M-series routers.

Encryption Services PIC
: Provides IPSec encryption for IPSec tunnels.

Monitoring Services III PIC
: Provides J-Flow accounting at high speeds and across millions of flows, using standards-based cflowd v5 and v8 records for the larger M-series and T-series routers.

Tunnel Services PIC
: Provides tunnel services such as GRE, IP-IP, IPv6 in IPv4, and multicast tunnels.

Adaptive Services PIC (ASP)
: The ASP is EOL, but still supported in the M7i. The FIPS version is still operational for Layer 2 and 3 services.

Multiservices 100 PIC
: Internal module that supports all services (for the M7i only). Can support up to 2,000 service sets.

Adaptive Services Module (ASM)
: The ASM is EOL, but still supported in the M7i.

Which PIC to Use?

Deciding which PIC to use is a delicate balance of feature set versus price. For example, if all you require are IPSec tunnels (which can be provided on an Encryption Services PIC 1), you may not need to use the more expensive Multiservices PIC. However, you should also consider your need for future services. So, if you require NAT, you would have to use an ASP, or a Multiservices PIC since the Multiservices PIC will do both NAT and IPSec; ideally this should be your first choice.

The most common implementation of services will use an MX, J-series, or SRX without additional hardware, an ASM in an M7i, or a Monitoring Services PIC in other M-series routers. Table 9-1 lists the performance and scaling values for these deployments.

Table 9-1. Service scaling number

Feature	Multiservices 100	ASP	ASM
Throughput	920 Mbps	800 Mbps	256 Mbps
Service sets	2,000	2,000	500
Flows	1.6 million	1 million	400,000
MLPPP links	2,048	2,044	2,044
MLPPP bundles	1,023	255	255
IPSec throughput	950 Mbps	640 Mbps	200 Mbps
IPSec tunnels	5,000	2,048	512

In addition to scaling differences in the various PICs and platforms, there are some minor configuration differences when referencing the interface names for Layer 2 service, as shown in Table 9-2.

Table 9-2. Service interface naming

Service interface	ASM	ASP	Multiservice	Multilink service	SRX/J-series
Layer 2	`lsq`	`lsq`	`lsq`	`ml`	`ls`

In Junos 10.0, the interface used for Multilink functionality has been moved from the `ls-0/0/0` interface to the `lsq-0/0/0` interface for SRXs and J-series routers. The configuration examples shown are all `lsq` interfaces, except for configurations that do not support the `lsq` interface; in those cases, the older `ls` interface is used.

Layer 2 Services

Layer 2 services are essentially the services that are enabled on a physical interface such as LFI (FRF.12), MLFR (FRF.15), user-to-network interface (UNI) NNI (FRF.16), MLPPP, and multiclass MLPPP.

Multilink PPP

MLPPP (RFC 1990) allows the router to combine multiple links together into one large logical bundle (as shown in Figure 9-1). This was originally created to bond multiple Integrated Services Digital Network (ISDN) bearer signals together, but it is now used for any two systems with multiple links between them. Multilink is negotiated during the initial Link Control Protocol (LCP) option negotiation. When configuring MLPPP on a Juniper router, you can combine into one bundle any eight PPP links of the *same* type on the chassis. To configure MLPPP, first create a logical bundle link:

```
lsq-0/0/0 {
    unit 0 {
        encapsulation multilink-ppp;
        family inet {
            address 166.8.67.30/30;
        }
    }
}
```

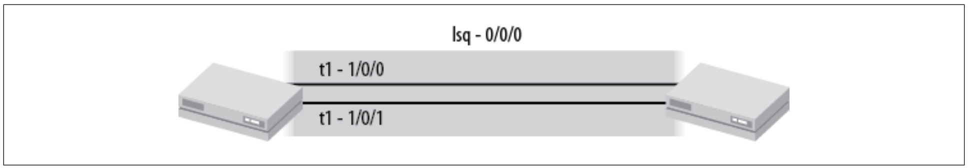


Figure 9-1. MLPPP bundle

Next, configure the physical interfaces to link the newly created link service interface. In the following example, interfaces `t1-1/0/0` and `t1-1/0/1` are linked to the logical bundle unit 0 on the `lsq-0/0/0` interface:

```
t1-1/0/0 {
    unit 0 {
        family mlppp {
            bundle lsq-0/0/0.0;
        }
    }
}
t1-2/0/1 {
    unit 0 {
        family mlppp {
            bundle lsq-0/0/0.0;
        }
        }
    }
```

When there are multiple links in your bundle, packets above the minimum maximum transmission unit/maximum received reconstructed unit (MTU/MRRU) size of all links in the bundle will be fragmented on a packet-by-packet basis across all the physical links. MRRU is similar to an interface MTU except that it applies only to multilink bundles. To avoid out-of-order issues, a sequence number is added to each packet. The receiving end will then reassemble the fragments into the full packet size. The advantage of this approach is that the high-bandwidth flows are able to use the full capacity of all the egress links. The disadvantage of this per-packet approach is that smaller packets may have to "wait" for larger packets to be transmitted.

For example, imagine you have low delay-sensitive data packets traversing with a size of 1,250 bytes and high delay-sensitive voice traffic with a size of 64 bytes. If the data packet arrives first on a link and the voice packet arrives second, the voice packet will have to wait until the data packet is done before it can be sent. On low-speed interfaces with a high serialization delay, this could greatly affect the high delay-sensitive traffic. To solve this problem, you can configure LFI. For link services IQ interfaces (lsq), the LFI statement is not valid. Instead, you can enable LFI by configuring fragmentation maps.

The first step is to fragment the larger-size packets to allow the router to balance the fragments across multiple links, thus reducing the time it takes to transmit the packet:

```
root@P1R1# set interfaces ls-0/0/0 unit 0 fragment-threshold ?
Possible completions:
  <fragment-threshold>  Fragmentation threshold (64..16320 bytes)
[edit]
root@P1R1# set interfaces ls-0/0/0 unit 0 fragment-threshold  128
```

Now that the larger packets are fragmented, we want to place the nonfragmented packets on the link with the fragmented packets. Otherwise, the voice traffic will have to wait for *all* fragments to transmit before being sent. To turn on this behavior, configure the `interleave-fragments` command underneath the bundle configuration:

```
root@P1R1# set interfaces ls-0/0/0 unit 0 interleave-fragments
```

It is also recommended when LFI is turned on that the member links turn on traffic shaping to reduce jitter. Configure the shaping rate to be equal to the combined physical interface bandwidth for the constituent links. To apply shaping rates to interfaces, you must enable `per-unit scheduling` in the interfaces.

Since each egress link may not have the same delay, the packets that are not fragmented and are part of the same traffic flow may arrive out of order at the far end. To avoid this scenario (which will increase delay and jitter), each flow should take the same egress link.

By default, the Junos operating system chooses a single link for each unfragmented Transmission Control Protocol/User Datagram Protocol (TCP/UDP) flow over MLPPP links using a hash algorithm, based on the source and destination addresses, source and destination port numbers, and protocol field. This default behavior ensures that flows stay on the correct link and arrive in the correct order at the far end.

The final issue to think about is to enable the voice traffic to have a higher priority and thus be transmitted before the data traffic. Although we will discuss class of service (CoS) in a later chapter, we will provide a high-level discussion here.

To ensure that voice traffic is transmitted first, place it into a higher-priority queue. For CRTP traffic, this mapping occurs automatically, whereas for other traffic, it will have to be configured. Note that the J-series and M-series differ on this mapping. In a J-series router, high-priority traffic, including CRTP, should *only* be mapped to queue 2 on an MLPPP link. When the router maps traffic to constituent links, traffic from queue 2 of the bundle interface will be mapped to queue 2 on the constituent links, whereas traffic from all other queues on the bundle interface will be mapped to a default queue of 0 (as shown in Figure 9-2). Traffic that is placed into other queues on the bundle interface and that is mapped into queue 0 on a constituent link will be serviced according to the relative priority. In other words, if traffic on the bundle interface is placed into queue 1 with a medium-high priority and into queue 4 with a medium-low priority, queue 1 will be scheduled first and will be placed into the constituent link's queue 0 first. In an M-series router using multiclass MLPPP, other queues besides queue 0 and queue 2 could be utilized.

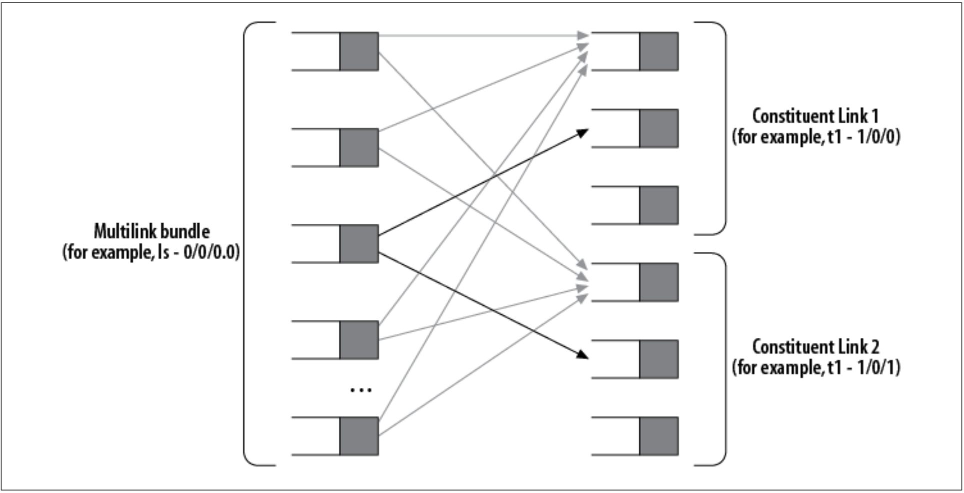

Multilink bundle
(for example, ls - 0/0/0.0)
...
Constituent Link 1
(for example, t1 - 1/0/0)
Constituent Link 2
(for example, t1 - 1/0/1)

Figure 9-2. J-series queuing and LFI

Multiclass MLPPP

Sometimes when using LFI, fragments from different classes cannot be interleaved. This means that all fragments from a single packet must be sent before any fragments from another packet can be sent. Using LFI, nonfragmented packets can be interleaved with fragmented packets to reduce the latency of the nonfragmented packets. The nonfragmented packets can also be placed into a different queue to be transmitted first, which basically enables two classes of packets: *fragmented* and *nonfragmented*. This model extends to scenarios in which the delay-sensitive traffic comprises the nonfragmented packets, but fails if there is high-priority fragmented traffic that must take precedence over the nonfragmented traffic. In this case, it would make sense to be able to assign a higher priority for some fragmented traffic over nonfragmented traffic by placing some fragmented traffic into a higher-priority queue. This mapping of fragments to different queues is referred to as Multiclass Multilink PPP (MCML).

MCML is supported only on PICs with link services intelligent queuing (LSQ) interface support—that is, ASPs, ASMs, and Multiservices PICs. It is not supported on a J-series router.

Also, when using classic LFI on MLPPP, packets that are nonfragmented will be balanced across a link on a per-flow basis. This can lead to the *hot link* scenario where a single flow will always take the same link and will not fully utilize the full-bundle bandwidth. MCML can help with this problem by allowing packets that are not fragmented to be load-balanced across multiple links.

Lastly, MCML can be used if you simply need more than two CoSs for either fragmented or nonfragmented packets. In general, MCML needs to be deployed if any of these criteria has to be met:

- Some fragmented traffic needs to be transmitted before nonfragmented traffic.
- Nonfragmented traffic needs to be balanced across multiple links.
- More than two queues (0 and 2) are required.

To configure MCML, you should configure a fragmentation map where a fragmentation threshold is configured and a multilink class is assigned the forwarding class. The other option is to disable fragmentation on a per-forwarding class basis using the `no-fragmentation` command. If the `no-fragmentation` command is used, the `fragment-threshold` and `multilink-class` statements cannot be configured:

```
[edit class-of-service fragmentation-maps sample forwarding-class
expedited-forwarding]
lab@PBR# set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  fragment-threshold   Fragmentation threshold (64..9192 bytes)
```

```
    multilink-class        Multilink-Class assigned to this FC (0..7)
    no-fragmentation       Don't allow fragmentation
```

Lastly, the fragmentation map must be tied to the bundle interface under the `class-of-service` stanza:

```
class-of-service {
    interfaces {
        lsq-0/3/0 {
            unit 1 {
                fragmentation-map sample;
            }
        }
    }
}
```

CRTP

On lower-speed interfaces, serialization and queuing delay can be a factor for delays of sensitive traffic. *Serialization delay* is the time it takes to move the packet out the network interface, and it depends on the clock rate and the size of the packet. For instance, for a 512-byte packet on a T1, the serialization delay would be:

```
(512 * 8)bits/1,544,000 bits/sec = 2.65 ms
```

Queuing delay is the time it takes for the packet to be buffered in the router when other packets are being transmitted. This delay is variable but is related to the serialization delay, as each packet has to wait for the previous packet to be sent before it can be transmitted. So, if the buffer is three packets deep, the delay to transmit the 512-byte packet is not 2.65 ms, but perhaps 8 ms to 19 ms.

The most common type of delay for sensitive traffic is voice traffic, which is often transported using the Real-Time Transport Protocol (RTP). RTP is simply a standard packet format to transport voice or video over an IP network, usually using UDP ports in the range of 384–32,767. It produces a header of 40 bytes: 12 bytes for RTP, 8 bytes for UDP, and 20 bytes for IP.

One quick way to reduce serialization and, potentially, queuing delay is to reduce the packet size. When using RTP, you can compress the entire IP/UDP/RTP header to a 2- or 4-byte header. As explained earlier in this chapter, this is referred to as Compressed RTP (CRTP) and is standardized in RFC 2508.

Juniper Networks routers can compress RTP traffic in MLPPP bundles. SRXs and J-series routers can also compress RTP traffic on standard PPP interfaces.

All CRTP voice traffic is automatically placed into queue 2 on SRXs and J-series routers.

To enable CRTP on any interface, configure the compression parameters on the link services interface. The router maps which traffic to compress by either matching on a range of UDP port numbers or matching on the queue on which the packet was placed. You can configure both conditions, and the router treats the match as a logical OR. In the following example, a standard PPP interface is using CRTP with a port range of 384–32,767:

```
lsq-0/0/0 {
    unit 0 {
        compression {
            rtp {
                port minimum 384 maximum 32767;
            }
        }
        family inet {
            address 10.10.10.1/30;
        }
    }
}
```

You can then map the physical interface to the link services compression interface:

```
t1-2/0/2 {
    description Bock-to-porter;
    unit 0 {
        compression-device lsq-0/0/0.0;
    }
}
```

If you are using CRTP with MLPPP, simply add the compression configuration to the existing bundle.

To verify that CRTP is working, use the `show services crtp` command:

```
lab@Bock# run show services crtp ?
Possible completions:
  <[Enter]>            Execute this command
  extensive            Show CRTP extensive output
  flows                Show CRTP flow table entries
  interface            Name of link services interface
  |                    Pipe through a command
```

Use the `show services crtp extensive` command to verify correct configuration as well as track statistics for packets exiting the interface:

```
[edit]
lab@Bock# run show services crtp extensive
Interface: lsq-0/0/0.0
  Port minimum: 384, Port maximum: 32767
  Maximum UDP compressed sessions: 256
  CRTP maximum period: 256, CRTP maximum time: 5
  Compression ratio: 0, Decompression ratio: 0, Discards: 0
```

```
CRTP stats                       Receive         Transmit
Sessions                               0                0
IP bytes                               0                0
Compressed bytes                       0                0
CRTP packets                           0                0
CUDP/CNTCP packets                     0                0
Full header packets                    0                0
Context state packets                  0                0
IP packets                             0                0
Compressed packets                     0                0
```

Multilink Frame Relay

Similar to bonding multiple PPP sessions together, a router can also bond multiple Frame Relay circuits together. These will have the same fragmentation and interleaving characteristics as previously discussed with MLPPP. One bonding standard is FRF.15, which allows the router to bind multiple Frame Relay data-link connection identifiers (DLCIs) together into a single logical interface, as shown in Figure 9-3. The DLCIs could be on the same physical interface or on multiple physical interfaces, but the aggregate bandwidth cannot be greater than a DS3. The advantage of FRF.15 is that the provider does not have any knowledge that link bonding has occurred, but the disadvantage is that the each MLFR bundle can communicate with only a single endpoint.

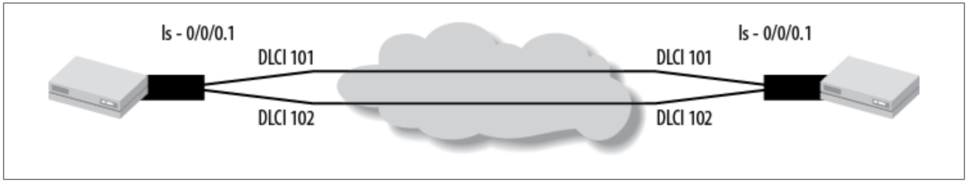


Figure 9-3. FRF.15

FRF.15 on J-series routers is supported only on T1/E1 interfaces, as of Junos 8.0R2.

To configure FRF.15, first create a logical unit with the bundle IP address on the link services interface and specify the desire for FRF.15 with `encapsulation multilink-frame-relay-end-to-end`:

```
lsq-0/0/0 {
    unit 1 {
        encapsulation multilink-frame-relay-end-to-end;
        family inet {
            address 84.10.113.1/31;
        }
        }
    }
```

Then bond the local DLCIs' values together to the newly created bundle interface. In this case, the DLCIs were on the same physical interface but could have also been on different physical interfaces:

```
[edit interfaces t1-2/0/2]
lab@Yeast# show
description Yeast-to-hops2;
encapsulation frame-relay;
unit 101 {
    dlci 101;
    family mlfr-end-to-end {
        bundle lsq-0/0/0.1;
    }
}
unit 102 {
    dlci 102;
    family mlfr-end-to-end {
        bundle lsq-0/0/0.1;
    }
}
```

Verify that the links are bonded by viewing the bundle interface:

```
lab@hops# run show interfaces lsq-0/0/0.1
  Logical interface lsq-0/0/0.1 (Index 70) (SNMP ifIndex 37)
    Flags: Point-To-Point SNMP-Traps 0x4000 Encapsulation: Multilink-FR
    Bandwidth: 3072kbps
    Statistics        Frames        fps         Bytes          bps
    Bundle:
      Fragments:
        Input :           71          0          5030            0
        Output:            3          0           264            0
      Packets:
        Input :           71          0          4604            0
        Output:            3          0           270            0
    Link:
      t1-2/0/2.101
        Input :           36          0          2540            0
        Output:            2          0           176            0
      t1-2/0/2.102
        Input :           35          0          2490            0
        Output:            1          0            88            0
    Protocol inet, MTU: 1500
      Flags: None
      Addresses, Flags: Is-Preferred Is-Primary
        Destination: 84.10.113.0/31, Local: 84.10.113.1
```

Another type of Frame Relay bonding is called FRF.16, which allows the router to take multiple physical connections from the provider and tie them into a single logical connection, as shown in Figure 9-4. Once this connection is bonded together, one or more DLCIs could be configured over this single logical connection. This allows for incremental and increased bandwidth Frame Relay connections, while also allowing the

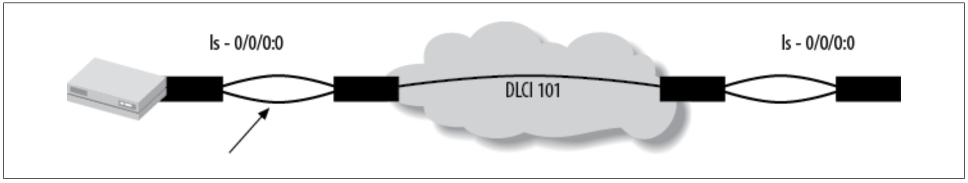


Figure 9-4. FRF.16

provider to combine each bundle into multiple high-speed bundles in the network. The advantage over FRF.15 is that a different endpoint in each bundle is supported, but the disadvantage is that the provider is no longer transparent to bundling.

To configure FRF.16 on a Juniper router, the link services interface is configured and *channelized*. A channel is designated, but the colon (`:`) represents the FRF.16 logical bundle. You can configure a single DLCI or multiple DLCIs to different endpoints in this bundle.

First, to create a channelized bundle interface, set the `mlfr-unu-nni-bundles` statement under `[edit chassis]`. Channels start counting at zero, so the following configuration will create an `lsq-/0/0/0:0`:

```
chassis {
    fpc 0 {
        pic 0 {
            mlfr-uni-nni-bundles 1;
        }
   }
```

Here is a bundle specified as channel 1 with one DLCI specified:

```
lsq-0/0/0:0{
    encapsulation multilink-frame-relay-uni-nni;
    unit 0 {
        dlci 101;
        family inet {
            address 101.88.77.1/30;
        }
    }
 }
```

A last point to understand in MLFR is that the physical interfaces, such as those with two Juniper T1s, will need to be bonded together to the logical bundle `lsq-0/0/0:0` interface:

```
t1-2/0/2 {
    encapsulation multilink-frame-relay-uni-nni;
    unit 0 {
        family mlfr-uni-nni {
            bundle lsq-0/0/0:0
        }
    }
}

t1-2/1/2 {
    encapsulation multilink-frame-relay-uni-nni;
    unit 0 {
        family mlfr-uni-nni {
            bundle lsq-0/0/0:0
        }
    }
}
```

GRE

Here we examine the configuration of a generic routing encapsulation (GRE) tunnel:

```
    gr-0/0/0 {
        unit 0 {
            tunnel {
                source 10.20.1.38;
                destination 172.66.13.1;
            }
            family inet
        }
    }
```

Although various PICs will allow a GRE tunnel to be created on an M-series router, using an ASP, a Multiservices PIC, or a J-series router can enable a few additional features, namely key numbers (ASP, Monitoring Services only), fragmentation, and tunnel MTU.

Although GRE tunnels are supported on an M-series router using an ASP in Layer 2 or Layer 3 mode, fragmentation and GRE keys are supported only in Layer 3 mode.

The first feature is taken from RFC 2890 and is called "Key and Sequence Number Extensions to GRE." This RFC adds two more optional fields that can be carried in the GRE header: a *key field* and a *sequence number field*. The key field is inserted by the sender and is matched at the receiver to identify fields. If the key fields do not match, the packet is dropped. Currently, only the ASP and Monitoring Services PIC support this feature, and only one key is allowed per source and destination pair. To enable this feature, manually configure a key value under the logical unit:

```
    lab@Cider set interfaces gr-0/0/0 unit 0 tunnel key 123
```

A concern when configuring any type of tunnel is making sure the maximum payload is no larger than the MTU across the entire path. By default, the `gr` interface has an unlimited physical MTU and a protocol MTU that is equivalent to the MTU of the next hop interface toward the tunnel destination. So, when an IP packet arrives at the ingress router, the GRE header is added, with the do-not-fragment bit set, and the IP packet is sent to the egress router. If a transit router had a smaller MTU than the ingress router, the packet would be dropped.

A few tools in the router can solve this issue. For example, use path MTU discovery to determine the MTUs that are along the path. In the current Junos release, path discovery is enabled by default. The following example shows that the maximum IP protocol MTU can be 726:

```
 [edit]
lab@Water# run show interfaces gr-0/0/0.0 extensive | match mtu
  Type: GRE, Link-level type: GRE, MTU: Unlimited, Speed: 800mbps
    Protocol inet, MTU: 726, Generation: 141, Route table: 0
```

A problem can arise when traffic is coming into the router with an MTU that is too large and the do-not-fragment bit is set. If you must send traffic with the do-not-fragment bit over the tunnel, you can override the sender's wishes by having the router clear the do-not-fragment bit. In the following example, router `Wheat` is trying to send traffic over the GRE tunnel that is too large, and `Water` is sending an Internet Control Message Protocol (ICMP) error message indicating that the packet is being dropped:

```
[edit]
root@Wheat# run ping 5.5.5.5 size 700 do-not-fragment
PING 5.5.5.5 (5.5.5.5): 700 data bytes
36 bytes from 1.1.1.2: frag needed and DF set (MTU 726)
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 02d8 3274   2 0000  40  01 f9a5 1.1.1.1  5.5.5.5

36 bytes from 1.1.1.2: frag needed and DF set (MTU 726)
Vr HL TOS  Len   ID Flg  off TTL Pro  cks      Src      Dst
 4  5  00 02d8 3275   2 0000  40^C
--- 5.5.5.5 ping statistics ---
2 packets transmitted, 0 packets received, 100% packet loss
```

On an SRX or J-series router or with the ASP, ASM, or Monitoring Services PIC, you can enable a `clear-dont-fragment` command, which allows for ingress fragmentation as well as clearing the do-not-fragment bit on all packets that transmit the tunnel. Note, however, that although the original packets have the do-not-fragment bit cleared, the GRE packets still have the `DF` bit set. This command is set on `Water`:

```
[edit]
lab@Water# set interfaces gr-0/0/0 unit 0 clear-dont-fragment-bit

[edit]
lab@Water# commit
[edit interfaces gr-0/0/0]
  'unit 0'
    gr-0/0/0.0: Must configure INET family MTU
error: configuration check-out failed
```

To use this command, you must also set the MTU value so that the ingress router knows which size packets to begin fragmenting. This MTU value should be the smallest value along the entire path of the GRE tunnel:

```
lab@Water# set interfaces gr-0/0/0 unit 0 family inet mtu 726
```

Verify correct operation by reissuing the `ping` command from router `Wheat`:

```
[edit]
root@Wheat# run ping 5.5.5.5 size 1400 do-not-fragment
PING 5.5.5.5 (5.5.5.5): 700 data bytes
1408 bytes from 5.5.5.5: icmp_seq=0 ttl=63 time=18.449 ms
1408 bytes from 5.5.5.5: icmp_seq=1 ttl=63 time=120.600 ms
1408 bytes from 5.5.5.5: icmp_seq=2 ttl=63 time=30.325 ms
^C
```

Ethernet Aggregation

In Chapter 2, we explored the uses of Ethernet link aggregation in the enterprise, and here we examine the configurations that are used to implement this capability.

Link aggregation groups (LAGs), based on IEEE 802.3ad, allow you to aggregate physical interface links on a device to increase bandwidth and link availability. The Link Aggregation Control Protocol (LACP), a subcomponent of IEEE 802.3ad, provides additional functionality for LAGs. The configuration for Ethernet link aggregation is comprised of three parts.

The first is to configure the number of aggregation interfaces that will be found on the chassis:

```
lab@Water# set chassis aggregated-devices ethernet device-count 2
```

The use of LACP failure modes and priorities are also set at the chassis stanza. In this case we have set the system priority to determine the master of the link and defined the link protection as nonrevertive. This setting will reduce the number of times that the link will switch over:

```
lab@Water# set chassis aggregated-devices ethernet lacp system-priority 1
lab@Water# set chassis aggregated-devices ethernet lacp link-protection non-revertive
```

The second step in the configuration is the definition of the aggregated interface. The interface type is an aeX interface. The addressing and link options are set on the interface. The options consist of the minimum number of links that are required to keep the ae interface operational (the default is 1), the definition of the speed of the aggregated link, and LACP options. Here you set the interface link speed to 1 Gbps and give the interface an address. A similar configuration is established at the far end:

```
lab@Water# set interfaces ae0 aggregated-ether-options ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> ethernet-switch-profile  Ethernet virtual LAN/media access control-level options
  flow-control         Enable flow control
> lacp                 Link Aggregation Control Protocol configuration
  link-protection      Enable link protection mode
  link-speed           Link speed of individual interface that joins the AE
  loopback             Enable loopback
  minimum-links        Minimum number of aggregated links (1..8)
  no-flow-control      Don't enable flow control
  no-link-protection   Don't enable link protection mode
  no-loopback          Don't enable loopback
  no-source-filtering  Don't enable source address filtering
> source-address-filter  Source address filters
  source-filtering     Enable source address filtering
lab@Water# set interfaces ae0 aggregated-ether-options link-speed 1g
lab@Water# set interfaces ae0 unit 0 family inet address 10.10.10.1.30
```

After the ae interface is set, the third step is to configure the physical interfaces that comprise the links of the aggregate. Here you add two gigabit Ethernet interfaces to the LAG:

```
lab@Water# set interfaces ge-0/0/2 gigether-options 802.3ad ae0
lab@Water# set interfaces ge-0/0/3 gigether-options 802.3ad ae0
```

You can also configure the physical interfaces for LACP roles (active or passive, the latter being the default).

The uses of LAGs are restricted based on the type of service used and the device type. These restrictions are changing with each release of the Junos operating system. Consult the release notes to determine the restrictions for your devices and code releases.

Once committed, the interface becomes active, and a ping to the far end shows that traffic is passing on both links of the aggregate. In this case, the ping traffic left on one link and arrived back on the other:

```
lab@Water# run show interfaces ae0.0 extensive
 Logical interface ae0.0 (Index 72) (SNMP ifIndex 155) (Generation 149)
   Flags: SNMP-Traps 0x4000 Encapsulation: ENET2
   Bandwidth: 0
   Statistics        Packets        pps         Bytes          bps
   Bundle:
       Input :             6          0           504            0
       Output:             9          0           770            0
   Link:
     ge-0/0/2.0
       Input :             0          0             0            0
       Output:             9          0           770            0
     ge-0/0/3.0
       Input :             6          0           504            0
       Output:             0          0             0            0
```

Switching Services

The SRXs and J-series routers allow you to configure interfaces to operate in Layer 2 mode. This provides an Ethernet switching capability for certain interfaces on the router, thereby reducing the need for additional switching equipment. The switching capabilities are restricted to Universal PIMs (uPIMs) on the J-series routers and to the built-in ports on the branch office SRX models (the SRX650 requires an XPIM). The

PIMs perform the switching operation, and the routing engine performs the routing operations.

You can set the PIMs to router mode (default), or to either a normal switch mode or an enhanced switched mode. In the enhanced switch mode, the module switches or routes the traffic depending on the destination MAC address. The built-in ports do not support the enhanced switching mode.

The switch ports support LLDP and LLDP-MED for device identification and various VLAN tagging options. The configuration of these protocols is covered in detail in *Junos Enterprise Switching* (O'Reilly).

Considering that our lab equipment does not have uPIMs, the following configuration example is borrowed from a J6350 with a uPIM in FPC slot 1:

```
lab@Water# show chassis
chassis {
    fpc 1 {
        pic 0 {
            ethernet {
                pic-mode switching;
            }
        }
    }
}
lab@Water# show interface ge-1/0/0

ge-1/0/0 {
        gratuitous-arp-reply;
        switch-options {
            switch-port 0 {
                auto-negotiation;
            }
            switch-port 1 {
                no-auto-negotiation;
                link-mode full-duplex;
                speed 100m;
            }
            switch-port 2 {
                no-auto-negotiation;
                link-mode full-duplex;
                speed 100m;
            }
            switch-port 3 {
                no-auto-negotiation;
                link-mode full-duplex;
                speed 100m;
            }
            ...
            }
        }
    }
```

Additional Service Options

You can enable many other services that are not as common but could play a large role in your network. We will briefly discuss these services here, but you should consult the router or PIC documentation at *http://www.juniper.net/techpubs* for more detailed configuration information.

Layer 2 Tunneling Protocol (L2TP)

L2TP is a tunneling protocol that tunnels PPP packets across a network, acting like a Layer 2 data link tunneling protocol. L2TP headers and payload are actually sent in a UDP datagram, so maybe people claim it to be a Layer 5 or Layer 4.5 protocol. Each endpoint of the tunnel has its own designation, one being an LNS and the other an LT2P Access Concentrator (LAC). A Juniper Networks router can act as an LNS.

Only M7i and M10i routers support LT2P.

Real-Time Performance Monitoring (RPM)

RPM is a feature for tracking and monitoring your network by sending network *probes* to other devices. These probes could be ICMP, UDP, or TCP[*] depending on the configuration. You can use these probes to measure packet round-trip times, jitter, delay, and packet (probe) loss. You also can use RPM to verify the path toward Border Gateway Protocol (BGP) neighbors.

RPM does not require an ASP or Multiservices PIC, unless you are configuring RPM timestamping, which was released in Junos 8.1 for the sender and in Junos 8.3 for the responder.

You can configure probes with a variety of parameters, such as the type or contents of the probe. Also, you can set thresholds to trigger syslog messages and Simple Network Management Protocol (SNMP) TRAPs. In the following example, router `PBR` has a probe to send an ICMP ping to `Porter` at 10.10.12.2. Seven probes should be sent every three seconds:

```
[edit services rpm]
lab@PBR# show
     probe foo {
    test Porter {
        probe-type icmp-ping;
```

[*] UDP and TCP probes require a Juniper server.

```
            target address 10.10.12.2;
            probe-count 7;
            probe-interval 3;
        }
    }
```

To verify that probes are being sent and data is being received, you can examine SNMP Management Information Bases (MIBs) or use the local router sending the probes by issuing `show services rpm` commands. The first command, `history-results`, should show the time at which the probes are sent and the round-trip length of the probe:

```
lab@PBR# run show services rpm history-results
    Owner, Test          Probe received              Round trip time
    foo, Porter          Wed Aug  8 07:02:54 2010         46097 usec
    foo, Porter          Wed Aug  8 07:07:41 2010         33662 usec
    foo, Porter          Wed Aug  8 07:07:44 2010         20133 usec
    foo, Porter          Wed Aug  8 07:07:47 2010         20112 usec
    foo, Porter          Wed Aug  8 07:07:50 2010         20112 usec
    foo, Porter          Wed Aug  8 07:07:53 2010         20104 usec
    foo, Porter          Wed Aug  8 07:07:56 2010         20092 usec
    foo, Porter          Wed Aug  8 07:07:59 2010         20104 usec
```

Verify the actual probe results by issuing a `show services rpm probe-results` command:

```
[edit services rpm]
lab@PBR# run show services rpm probe-results
   Owner: foo, Test: Porter
   Target address: 10.10.12.2, Probe type: icmp-ping, Test size: 7 probes
   Probe results:
     Response received, Wed Aug  8 07:07:59 2010
     Rtt: 20104 usec
   Results over current test:
     Probes sent: 7, Probes received: 7, Loss percentage: 0
     Measurement: Round trip time
       Minimum: 20092 usec, Maximum: 33662 usec, Average: 22046 usec,
       Jitter: 13570 usec, Stddev: 4742 usec
   Results over last test:
     Probes sent: 7, Probes received: 7, Loss percentage: 0
     Test completed on Wed Aug  8 07:07:59 2010
     Measurement: Round trip time
       Minimum: 20092 usec, Maximum: 33662 usec, Average: 22046 usec,
       Jitter: 13570 usec, Stddev: 4742 usec
   Results over all tests:
     Probes sent: 7, Probes received: 7, Loss percentage: 0
     Measurement: Round trip time
       Minimum: 20092 usec, Maximum: 33662 usec, Average: 22046 usec,
       Jitter: 13570 usec, Stddev: 4742 usec
```

You also can examine the paths to configured BGP peers by sending probes to configured peers. Once RPM is configured, probes will be sent to neighbors configured for BGP automatically. In this example, router `PBR` has one BGP neighbor to router `Porter`. The probes will be ICMP pings with five probes sent at an interval of one second. They will be 255 bytes with ICMP data of hex 0123456789. The test will run every 60 seconds:

```
[edit services rpm]
lab@PBR# show
bgp {
    probe-type icmp-ping;
    probe-count 5;
    probe-interval 1;
    test-interval 60;
    history-size 10;
    data-size 255;
    data-fill 0123456789;
}
```

As previously mentioned, you can retrieve the results via `show services rpm` commands or via SNMP in MIBs such as the following:

- `pingResultsTable`
- `jnxPingResultsTable`
- `jnxPingProbeHistoryTable`
- `pingProbeHistoryTable`

The following, final example details the `show services rpm probe-results` for PBR's BGP peer:

```
[edit services rpm]
lab@PBR# run show services rpm probe-results
   Owner: Rpm-Bgp-Owner, Test: Rpm-Bgp-Test-0
   Target address: 10.10.12.2, Source address: 10.20.128.3,
   Probe type: icmp-ping, Test size: 5 probes
   Probe results:
     Response received, Wed Aug  8 07:20:37 2010
     Rtt: 20135 usec
   Results over current test:
     Probes sent: 5, Probes received: 5, Loss percentage: 0
     Measurement: Round trip time
       Minimum: 20102 usec, Maximum: 69744 usec, Average: 30049 usec,
       Jitter: 49642 usec, Stddev: 19847 usec
   Results over last test:
     Probes sent: 5, Probes received: 5, Loss percentage: 0
     Test completed on Wed Aug  8 07:20:37 2010
     Measurement: Round trip time
       Minimum: 20102 usec, Maximum: 69744 usec, Average: 30049 usec,
       Jitter: 49642 usec, Stddev: 19847 usec
   Results over all tests:
     Probes sent: 10, Probes received: 10, Loss percentage: 0
     Measurement: Round trip time
       Minimum: 20102 usec, Maximum: 69744 usec, Average: 25119 usec,
       Jitter: 49642 usec, Stddev: 14875 usec
```

Data Link Switching (DLSw)

DLSw is a protocol that offers IP routing support for unroutable, legacy protocols such as System Network Architecture (SNA) and NETBUI/NetBIOS. Once configured, the routers set up connections with their local end systems, as well as with other peer routers, and the traffic flow from one end system to another is transparent, meaning the presence of the routed IP network is not known to the end stations. When DLSw is configured, TCP sessions are established between peer routers and capabilities are negotiated. Then a circuit is established between the end system and the router.

DLSw is supported only on J-series routers.

For example, in the SNA example shown in Figure 9-5, the sequence would be as follows:

1. An SNA device sends out an explorer frame looking for Mainframe 1.
2. The router receives this frame and sends a `canureach` frame to its peer DLSw routers.
3. The remote routers forward the `canureach` message to their attached Mainframes.
4. Mainframe 1 sends an `icanreach` response to its local router, which in turn forwards the frame toward the DLSw peers.
5. After the frames have been exchanged, a circuit is established between the SNA devices and the local routers, as well as between the peer routers.

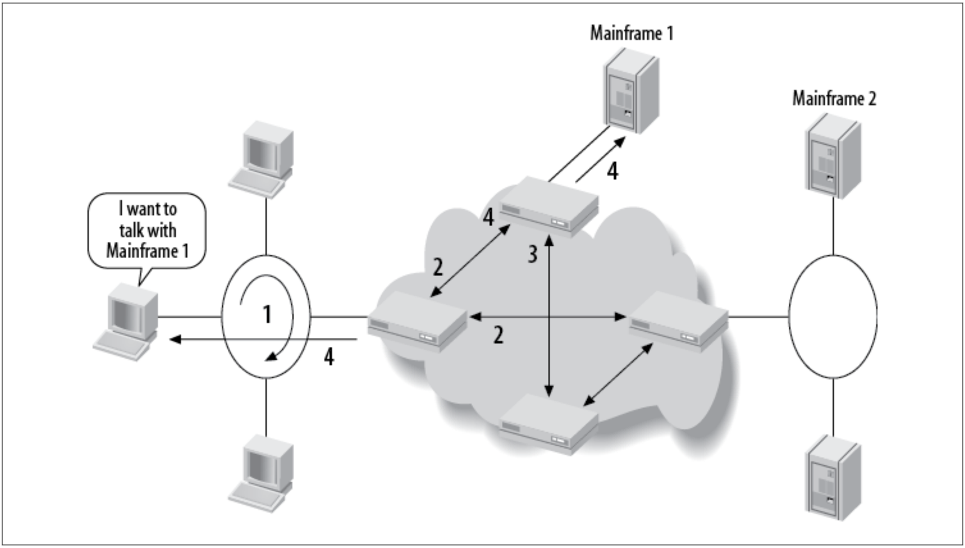


Figure 9-5. DLSw example flow

Flow Monitoring

Juniper Networks routers give you the ability to take monitored traffic flows and export this data in cflowd format or direct the flows in their native format to different packet analyzers. You can also encrypt the flows when sending them.

One common type of monitoring that you can perform is called *active monitoring*, whereby the router takes the inbound traffic, extracts the flow into a cflowd format, and sends the cflowd record of the matched traffic to a flow collector device, as shown in Figure 9-6. The original packet is usually forwarded toward the destination, but other options do exist, including *discard accounting*, whereby the cflowd record is sent to the flow collector and the original packet is discarded, or *port mirroring*, whereby the entire packet is copied and sent to an additional interface and the original packet is forwarded on to its intended destination.

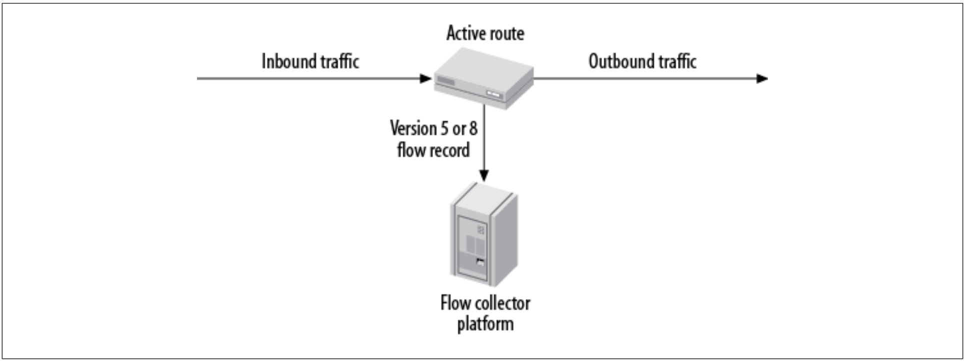


Figure 9-6. Active flow monitoring

There are some restrictions on how many actions can be performed on a network flow in the router:

- Sampling (cflowd) to a collector *or* port mirroring at one time
- Forwarding the original packet *or* discard accounting at one time

And only certain combinations of configurations are allowed on the *same* set of traffic:

- Port mirroring and forwarding
- Port mirroring and discard accounting
- Sampling and forwarding
- Sampling and discard accounting

Sampling (cflowd) and port mirroring can be performed at the same time only if they are on different sets of traffic. Sampling and mirroring are not supported on the SRX-series gateways.

Tunnel Services

We have already discussed a variety of different tunnels, and even more can be configured. You can use these tunnels for external connections or for connections with the same router. Any tunnel that is created will get an internal interface created for it. These interfaces are as follows:

`ip`
: For configuring an IP-IP tunnel that encapsulates one IP packet inside another. This type of tunnel is often seen in mobile environments where the endpoint address changes, and is migrated to different networks. This could also be useful in tunneling IPv6 packets over an IPv4 network.

`lt`
: Creates internal tunnel connections between different logical routers or VRs in the same chassis. In a J-series router, you also can use this interface to implement CoS on DLSw and RPM.

`mt`
: Used to create multicast tunnels. These tunnels are automatically created when running multicast in a Layer 3 BGP/Multiprotocol Label Switching (MPLS) VPN.

`pd`
: Used to de-encapsulate PIM register messages sent from a designated router to a rendezvous point (RP) in a multicast network.

`pe`
: Used to encapsulate PIM register messages sent from a designated router to an RP in a multicast network.

`vt`
: Used to loop a packet through the Packet Forwarding Engine (PFE) as an additional instance. This is normally used in a VPN environment to concurrently perform both an MPLS lookup and an IP lookup. This is supported only on M/T-series routers and not on J-series routers.

Conclusion

Junos software offers a vast number of Layer 2 services that you can run on your network. Not all of these services will likely be running on your network at the same time, but often you'll use them for the features and security they offer. This chapter examined the configuration of those services, and how to deploy them on a single-service feature basis.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Configure MLPPP.
- Configure Layer 2 services to optimize voice traffic.
- Aggregated Ethernet.
- Layer 2 switching services.

Chapter Review Questions

1. Which type of service allows for multiple physical interfaces running Frame Relay to be bonded together into a single logical bundle?
   A. MLPPP
   B. FRF.15
   C. FRF.12
   D. FRF.16
2. True or False: All Layer 2 services will always use the `ls-` interface.
3. Which CLI command displays the number of allowed aggregated Ethernet interfaces?
   A. `show configuration chassis`
   B. `show interface ae`
   C. `show chassis hardware`
   D. `show layer 2 services`
4. What type of load balancing is used across MLPPP links for fragmented traffic?
   A. Per packet
   B. Per flow
   C. Per fragment
   D. Per port
5. If fragmentation is turned on for MLPPP, what type of load balancing would occur for unfragmented packets?
   A. Per packet
   B. Per flow
   C. Per fragment
   D. Per port

6. Which feature will help to lower latency of voice traffic on a point-to-point link?
   A. CHAP
   B. Codecs
   C. RTP
   D. CRTP
7. Interfaces of a uPIM can be configured into which three modes?
   A. Routing
   B. Switching
   C. Enhanced switching
   D. Enhanced routing
8. Which type of service PIC can be integrated on an M7i?
   A. ASM
   B. ASP
   C. Monitoring Services
   D. Hardware acceleration
9. How is traffic chosen to be compressed when configuring CRTP? (Choose two.)
   A. IP address
   B. Port numbers
   C. Packet size
   D. Queue

Chapter Review Answers

1. Answer: D. FRF.16 allows bonding of physical interfaces together, whereas FRF.15 bonds multiple DLCIs together.
2. Answer: False. Some PICs will use an `lsq` interface, and others will use an `ls` interface. `lsq` allows for more CoS features than `ls`.
3. Answer: A. In Junos software, you configure the total number of aggregate interfaces in the chassis stanza.
4. Answer: C. When MLPPP is enabled, packets will be sent down each link on a per-fragment basis. Since each packet fragment will have an MLPPP header with a sequence number, order will be maintained by the end device.
5. Answer: B. If fragmentation does not occur on an MLPPP link, the packets are balanced over a flow (source IP, destination IP, protocol, etc.). Since nonfragmented packets will not contain an MLPPP header, per flow is the only way to maintain packet order.

6. Answer: D. Compressed RTP decreases the header size to a few bytes, which reduces serialization and queuing delay.
7. Answer: A, B, C. The uPIM module on J-series routers and the XPIM on the SRX650 can be configured to operate in router, switch, or enhanced switch modes of operation.
8. Answer: A. You can integrate ASM into an M7i router only. For other M-series routers, you must install a physical PIC into a slot.
9. Answer: B, D. Traffic can be classified for RTP compressed based on port numbers or based on which queue a packet was placed into. If both match conditions are configured, a packet will be compressed if either condition is met.

CHAPTER 10

Class of Service

This chapter details class of service (CoS) capabilities while also demonstrating typical CoS configuration and verification steps under the Junos operating system. A detailed comparison between the ASIC-based and the software-based platform is provided to clarify their operational differences, which is a common source of confusion given that they have so many similarities. The topics covered include:

- What IP CoS is and why it is needed
- IP differentiated services primer
- CoS capabilities
- DiffServ-based CoS deployment and verification
- J-series virtual channels

Juniper Networks routers offer extensive support for IP CoS. As of this writing, the list of supported standards includes:

- RFC 2474, “Definition of the Differentiated Services Field in the IPv4 and IPv6 Headers”
- RFC 2597, “Assured Forwarding PHB Group”
- RFC 3246, “An Expedited Forwarding PHB”
- RFC 2698, “A Two Rate Three Color Marker”

What Is IP CoS, and Why Do I Need It?

Simply put, CoS provides a mechanism by which certain packets are afforded preferred treatment in an effort to provide the associated application with a level of performance required for proper operation. Although the preceding sentence seems simple enough, it implies support for several capabilities that must work together within each node—and in a *consistent* manner network-wide—for an IP CoS deployment to be successful.

Why IP Networks Need CoS

IP networks are based on the principle of statistical multiplexing (stat MUX), which is a resource-sharing technique that allocates resources on an as-needed basis. A stat MUX provides efficiency gains by playing the odds that a given application or user will not be active at its peak rate 100% of the time. By allocating bandwidth resources only when needed, a large number of bursty applications can be supported over a network with an aggregate capacity that is significantly less than the potential aggregate rate of its user base.

To make all this work, some degree of buffering is needed to accommodate the occasional synchronized bursts. Because no network has infinite buffers, flow control (typically supported by a virtual circuit [VC] technology) or simple discard in the case of datagram operation (connectionless) is needed during chronic periods of congestion. Throwing more buffers at the problem only changes the symptom from one of discard to one of delay and delay variance, which is known as *jitter*. Although non-real-time applications such as an order-entry system can tolerate loss and lengthy/variable delays, the user will generally have a degraded experience and productivity can suffer. More demanding real-time applications such as Voice over IP rapidly become unusable when loss and delay/jitter are not kept within relatively stringent bounds.

IP networks are based on statistical multiplexing, and there is an increasing trend to converge all communications, be it data, voice, video, real-time simulation, and so on over a single IP infrastructure to maximize return on investment and economy of scale. Saving money always looks good on paper, but these gains quickly disappear if the result is unproductive, angered workers who can no longer perform their jobs due to intermittent application performance.

Historically, network technologies were circuit-based and were designed to support toll-quality voice. Although there is little to find sexy in "toll-quality voice," these telephone network architects did not realize that what they had built into their network would become the panacea of IP network quality of service (QoS)—namely, a service that provides (once connected) minimal and *fixed* delays, freedom from congestion, guaranteed bandwidth, in-sequence delivery, and low loss. All these elements had to be added to the IP network to handle the services that were designed to be carried on the telephone network. Legacy circuit-switched networks are not without their drawbacks, and all indications are that the future of voice, data, and video transport will be packet- rather than circuit-based.

Overbuilding an IP network with excess bandwidth is a viable way to ensure that all applications work properly, even during periods of peak usage or network outages. The fact that costs associated with bandwidth are constantly dropping, and new ways are always being found to drive existing fiber to increasingly higher rates, allows the "overbuild it and they will be happy" network design philosophy to pass the giggle test, which is to say that there are cases where adding bandwidth is more expedient, and potentially less costly, than deploying an IP CoS solution. This is especially true if existing IP infrastructure requires hardware upgrades to support CoS, which is often the case with legacy gear that may be struggling in the basic IP routing role and that does not have the capability or resources to provide additional CoS processing.

When simply throwing bandwidth at the problem is not seen as feasible, due to either economic impact or equipment limitations, deploying IP CoS is the key to successfully converging services and applications onto an IP-based infrastructure.

Although there are CoS processing variances across the product line, all current Juniper Networks routing platforms provide IP CoS capabilities you can deploy in a production network without impacting basic IP packet forwarding performance.

Circuit-switching inefficiencies

Although legacy circuit-switched networks offered some mighty fine CoS, circuit-switched technologies are inefficient or poorly suited as a convergent technology in numerous areas. The root cause of this inefficiency is the lack of statistical multiplexing in circuit-switched networks, which prevents the sharing of resources during naturally occurring idle periods in communication streams. The issues with circuit switching and network efficiency are outlined in the following list, and they hold true whether using an analog or newer digital (ISDN) type of circuit switch:

Blocking during congestion
: Establishment of new circuits is blocked when the network reaches capacity through a call admission control (CAC) function (fast busy). This behavior helps to preserve the CoS of existing users, but lack of priority/preemption capabilities means that routine calls can lock out new users, even when their communication needs are high priority.

Dedicated resources
: Allocating guaranteed bandwidth in fixed chunks (64 Kbps DSO) is inefficient, even for voice, given that most communication is bursty—the simple fact that voice communication is inherently bursty, that it is half-duplex, and that speech waveforms are predictable and consist of idle periods is behind most speech compression algorithms.

Fixed bandwidth allocation
: The fixed allocation of bandwidth can be too coarse, given that it is based on multiples of a 3 KHz voice band coded into a 64 Kbps channel with standard Pulse Code Modulation (PCM). For some applications, this is too much bandwidth, and for others, it is not enough. Bonding multiple voice channels together to form a higher-speed link is possible, but you are still forced to deal with complete channels—one channel may not be enough and two might be too much.

Poor survivability
: In most cases, the failure of any link or node along a circuit-switched connection's path results in the loss of that connection. The user normally has to reestablish his connection to resume communications, which can take time. Furthermore,

because of blocking, perhaps due to diminished capacity after equipment failure, the call may not succeed.

To date, most IP networks are not CoS-enabled. This is because the historic application of IP as an internetworking protocol for LAN and WAN interconnection simply did not warrant the added complexity, both in equipment design and in the network-wide configuration needed for a working CoS solution. In fact, with some early (non-Juniper) router architectures, enabling CoS services consumed so many resources that forwarding performance was actually *better* with CoS disabled.

In other cases, when some level of performance was actually required, engineers simply overbuilt the network from a capacity and bandwidth perspective. The simple truth is that all of the world's most sophisticated CoS processing does no good for a packet that encounters a router with relatively empty queues anyway; CoS matters only when link utilization begins to exceed 80%; otherwise, packets are dispatched virtually as soon as they arrive, as there is no appreciable queue fill in such conditions. Put differently, enabling CoS on an underutilized network is akin to buying a low-emissions vehicle just so that you can use a carpool lane, and then finding your commute is at 2:00 a.m., when the roadways are empty anyway.

Even though bandwidth prices continue to trend downward while the raw forwarding rates of routers continue to rise, there are practical limits to the "overbuild and they will be happy" philosophy of network design. In addition, the increasing trend toward the use of IP as a mission-critical infrastructure supporting many, if not all, of an enterprise's data, voice, and automation/manufacturing needs makes the prioritization of critical traffic a prudent decision. In the most basic sense, consider the outbreak of a fire that significantly reduces your network's capacity. With the "overbuild it" safeguard now up in smoke (pun intended), you reach for the last unmelted IP phone handset to summon emergency help. This is not the time that you should have to ask yourself whether you feel lucky; with IP CoS, you *know* that your critical voice signaling and related media packets will be the first to be routed, assuming, of course, that any routing is still possible.

The use of IP-based statistical multiplexing combined with a sound CoS deployment provides the best of all worlds—the efficiency gains of statistical multiplexing and easily extended IP-based signaling protocols that provide CAC (RFC 2205, "RSVP") and/or preemption and priority (RFC 4542, "Implementing an Emergency Telecommunications Service (ETS) for Real-Time Services in the Internet Protocol Suite"), combined with the ability to support virtually all known application types over a single, future-proof network infrastructure.*

* Although the future of IP may well rest with IPv6, version 4 has shown a remarkable degree of resiliency and has quietly supported the world's internetworking needs while rival after rival has come and gone, leaving only obsolete recommendations in their wake. There are numerous migration strategies to move from IPv4 to IPv6, and the CoS models are the same, which allows direct application of this material to an IPv6 infrastructure when needed.

CoS Terms and Concepts

This section defines common IP network CoS terms and operational concepts in the context of Junos software, and the terminology used in the Internet QoS working group's survey titled "Network QoS Needs of Advanced Internet Applications." The reader is encouraged to consult this document for a detailed description of application-specific characteristics and typical CoS needs; the focus here is strictly on those QoS parameters and concepts associated with IP layer network operation and packet handling.

It should also be noted that the actual measurement of IP performance, including the effects of CoS, is defined in RFC 2544, "Benchmarking Methodology for Network Interconnect Devices."

This section explores the following terms and concepts:

- Network QoS parameters
- Classification
- Packet marking
- Forwarding classes, queues, and schedulers
- Congestion management
- Policing and shaping
- Typical CoS processing stages in a Juniper router

Network QoS parameters

In common vernacular, the terms *CoS* and *QoS* are used interchangeably. To help keep things clear, this chapter reserves the term *QoS* for individual network parameters such as delay or loss probability, and uses *CoS* to describe the combined effect of applying specific QoS parameters to a packet stream, which should result in a service differentiation among the supported traffic classes in your network.

By way of analogy, consider commercial aviation and the typical coach versus first-class traveling experience. First, if there were no differences between these service classes, the airline would have a hard time charging so much more for a first-class seat. It can be said that the service associated with these classes of travel is in turn a function of various QoS parameters, such as the maximum time to get a drink after being seated (delay), the likelihood of having your luggage make it to your destination (loss), and being treated to proper flatware and real food, as opposed to the experience of using a plastic spork (a combined spoon/fork) to choke down a bag lunch. The combined effects of these airline-based QoS parameters yield a particular CoS, and each such service class is differentiated so as to leave little ambiguity as to which class one happens to be traveling in at any given time.

To get maximum benefit of network QoS, the user's application should be QoS-aware so that it can request the appropriate resources during CAC (when supported) and correctly mark its traffic to ensure that it maps to the desired service class or classes. The network also has to offer CoS on an edge-to-edge basis, meaning all network elements have to support CoS. If the application is not QoS-aware, the network edge device must step in to provide a capability to correctly identify QoS traffic and ensure that it is handled with the proper CoS in the network. It is simpler, less error prone, and requires less configuration to have the applications QoS-aware.

The primary network QoS parameters are defined as follows:

Bandwidth
: Bandwidth is a measure of each link's information-carrying capacity. It is limited by the lesser of the bandwidth supported by each link crossed between two endpoints.

Delay
: Delay is a measure of the time taken to move a packet from one point to another. End-to-end delay is a cumulative function of serialization delays, propagation delays, and any queuing delays (buffering) that the packet may experience.

Delay variation (jitter)
: Delay variation, often called jitter, is a measure of the variance in transfer delays between packets that make up a stream. Jitter is significant to real-time applications because the receiver must dimension its jitter buffer based on maximum jitter, which adds delays for all packets and causes eventual loss when jitter values exceed buffer capacity.

Loss
: Loss measures the percentage of packets not delivered. Loss can stem from transmission errors or discard stemming from congestion in packet-based networks.

Loss pattern
: The loss pattern defines the nature of a loss event as either bursty (short duration) or chronic, which is sometimes called a *dribble error*.

Classification

Classification is the act of associating received packets with a defined forwarding class, which in turn maps to a queue. Classification is a critical aspect of IP CoS, in that the underlying principle of CoS is to enforce different forwarding behavior on one packet versus another, based on the associated set of QoS parameters defined for each forwarding class. Errors in classification result in incorrect handling of the associated packet stream, which may negate CoS benefits by treating all traffic the same or by causing congestion in one or more forwarding classes, which in turn leads to loss and delay-related problems for that forwarding class. Figure 10-1 shows how incoming packets are subjected to a classifier function that in turn maps each packet to a defined forwarding class.

At egress, the forwarding class is used to link the packet to the correct output queue/scheduler profile. Classification can be a resource drain on a router, because it adds

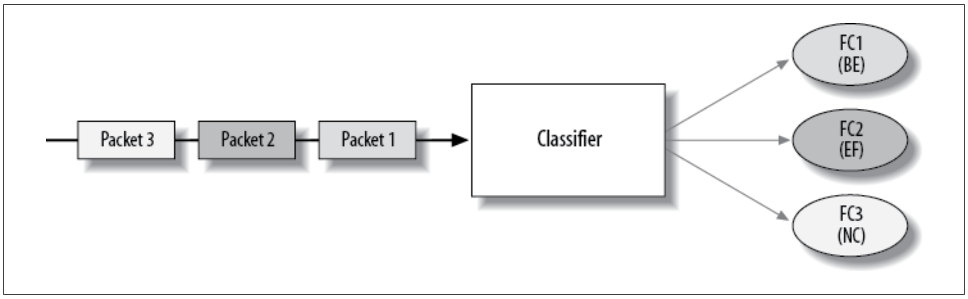


Figure 10-1. Classification

processing steps to each received packet. Modern IP routers support two types of classification to help mitigate resource consumption concerns:

Multifield classification
: Multifield classifiers are the most flexible and therefore the most computationally burdensome type of classifier. As the name suggests, a multifield classifier is based on matches against multiple fields with the IP packet, including source and destination addresses, protocol type, ports, and so on.

Behavior aggregate (BA)
: A BA classifier uses a fixed field in the packet header to make classification decisions. This is highly efficient because of the fixed position, length, and meaning of the bits used in the BA classification field. Classifications based on IP precedence or Differentiated Services code points (DSCPs) are examples of BA classification.

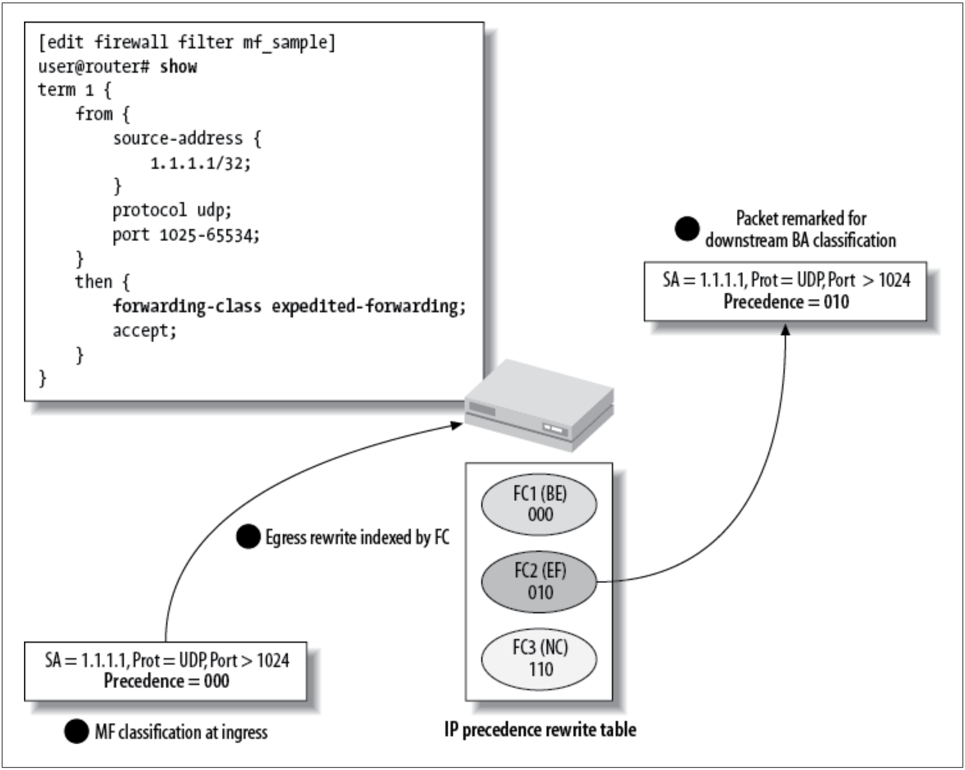
Normally you deploy multifield classifiers at the network's edges, as close to the traffic source as possible—that is, in the access layer. Once correctly classified, the packets are typically remarked to permit the more efficient BA type of classification in the aggregation and core layers. Juniper routers use firewall filters to perform multifield classification and support various types of BA classifiers, as detailed in "BA classification capabilities" on page 447. The highly efficient manner in which Junos software firewall filters are compiled and optimized allows large-scale use of multifield classification without incurring a significant reduction in forwarding capacity. With that said, you should use BA type classification wherever possible to keep things streamlined.

Loss priority. Many CoS models expect that loss will be lower in some classes than in others, or that loss will be lower for traffic within a class when it conforms to the class's associated rate limit, versus a higher loss probability for nonconformant traffic. Technologies such as ATM and Frame Relay achieve this functionality with the cell loss priority (CLP) and discard-eligible (DE) bits, respectively.

The IP packet header does not have a mechanism for signaling a packet's loss priority. As a result, the loss priority status for an IP packet is an internal flag that is set based on classification or policing actions. Once a packet is flagged at ingress as having a low or high loss priority, other nodes are expected to make the same determination—policing is done at the edge, and the resultant loss status should not be altered once set. This is normally accomplished by rewriting the BA field. Downstream nodes then use the altered BA value during classification to determine that packet's loss priority.

Packet marking/rewriting

Once mapped to a forwarding class, a packet can be subjected to one or more rewrite rules. Rewrite rules are used to mark the packet to facilitate BA classification in downstream nodes. Figure 10-2 shows packet marking in action.



```
[edit firewall filter mf_sample]
user@router# show
term 1 {
    from {
        source-address {
            1.1.1.1/32;
        }
        protocol udp;
        port 1025-65534;
    }
    then {
        forwarding-class expedited-forwarding;
        accept;
    }
}
```

Packet remarked for downstream BA classification
SA = 1.1.1.1, Prot = UDP, Port > 1024 Precedence = 010
Egress rewrite indexed by FC
FC1 (BE) 000
FC2 (EF) 010
FC3 (NC) 110
SA = 1.1.1.1, Prot = UDP, Port > 1024 Precedence = 000
MF classification at ingress
IP precedence rewrite table

Figure 10-2. Packet marking

Step 1 of Figure 10-2 shows an incoming packet with a default IP precedence field that is subjected to a multifield classifier. In this example, the packet matches against the source address, protocol, and port range criteria associated with the Expedited Forwarding (EF) class, which results in a mapping to forwarding class 2. At egress, the packet is subjected to an IP precedence rewrite rule that is indexed according to each packet's assigned forwarding class and drop priority. In this example, packets belonging to forwarding class 2 (EF) have their IP precedence field rewritten to a binary 010—the altered IP precedence field can now be used for BA-based classification in downstream nodes (steps 2 and 3, respectively). Though not shown, the packet's local packet loss priority (PLP) can also be factored into a rewrite pattern that enabled downstream nodes, which typically do not perform policing actions, to make the same discard priority determination.

Generally speaking, you cannot rely upon user applications to correctly mark the BA fields of their traffic streams; doing so can easily lead to service abuse by savvy users who know how to change their operating system's protocol stack to alter the default marking of their packets. The current best practice is to perform multifield classification and remarking to the appropriate forwarding class at the networked edges to ensure that BA tags used in the core meet your organization's acceptable use CoS policy. If desired, you can rewrite the BA field to a default value at network egress, perhaps to meet the receiving application's expectations or simply to hide the markings used for classification in the core.

Forwarding classes, queues, and schedulers

It's been established that packet classification results in the mapping of each packet to a forwarding class. So, what is a forwarding class? In Juniper parlance, a forwarding class essentially maps to a queue. Typically, there is a one-to-one mapping of forwarding class to queue number, but a many-to-one mapping is also possible. For example, the default CoS configuration defines only two forwarding classes—Best Effort (BE) and Network Control (NC)—and the default IP precedence classifier maps the eight possible precedence values into these two forwarding classes (queues) in a 6:1 and 2:1 ratio, respectively. Forwarding classes are referenced by symbolic names, which you can redefine if desired. Table 10-1 shows the default mappings.

Table 10-1. Default forwarding class names and queue mappings

Forwarding class	Symbolic name	Queue number
0	Best-effort	0
1	Expedited-forwarding	1
2	Assured-forwarding	2
3	Network-control	3

In IP DiffServ terminology, a forwarding class maps to a *DS behavior aggregate*, or in the newer terminology, an *ordered aggregate*. The term *ordered* here refers to the fact that packets classified as part of the same micro-flow should not be resequenced, and therefore the associated BA is expected to preserve sequencing. These terms describe the externally visible behavior of a DiffServ-compliant node for a given BA, which is a stream of packets with the same DSCP marking crossing a link in a particular direction. Stating this differently, and in English, a forwarding class is a stream of packets that, as a result of classification, are placed into the same egress queue and are therefore serviced by a common set of dequeuing parameters, resulting in consistent, and therefore predictable, handling of packets within that node.

Schedulers. Packets placed into an egress queue are serviced by a scheduler. The scheduler algorithm determines how often a queue is serviced, and in which order, based on an associated priority and transmit rate percentage. Packet scheduling combined with rate limiting and policing are an important aspect of IP CoS because together they provide the necessary isolation between forwarding classes. This isolation ensures that one misbehaving or nonconformant forwarding class does not degrade the service of other (compliant) forwarding classes.

The scheduler essentially controls how packets are dequeued for transmission, and it is therefore a critical component of the Junos software CoS model. Figure 10-3 illustrates the high-level operation of a scheduler.

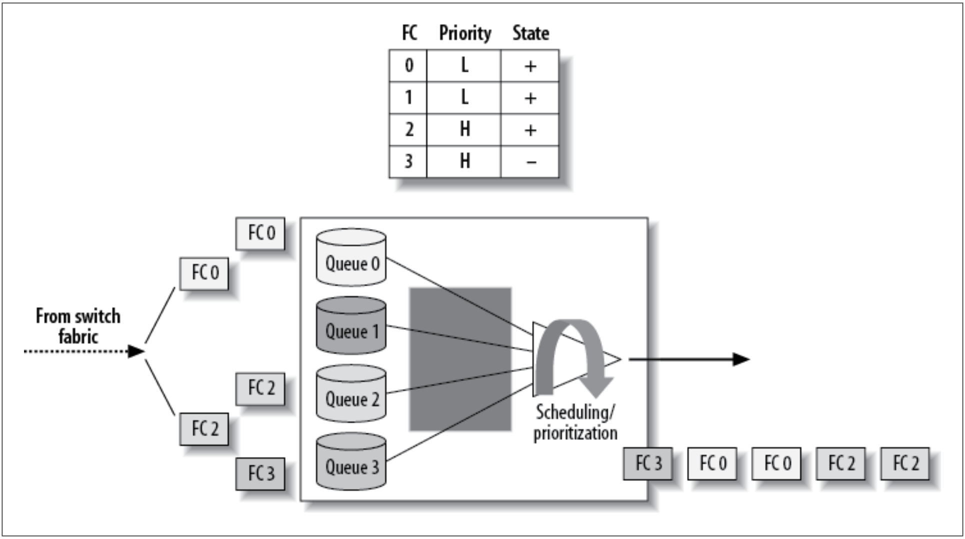


Figure 10-3. Scheduler operation

Figure 10-3 shows how packet notifications arriving from the switch fabric are placed into notification queues, based on their ingress classification. Recall that in the Juniper architecture, the packets themselves are placed into shared memory once, and only a notification that points to the packet's shared memory address is actually queued on the egress Flexible PIC Concentrator/Physical Interface Card (FPC/PIC). The scheduler selects the next packet to dequeue based on a function of transmission credit and associated priority.

The basic algorithm is to service all high-priority queues with positive credit before moving on to service low-priority queues with positive credit. When no queues with positive credit remain, the scheduler divides any remaining bandwidth among those nonempty queues, typically using a simple round-robin algorithm (this can vary by platform, as detailed in "Scheduling and queuing" on page 455). The net result is that all queues are guaranteed to receive at least their configured transmission rate, and high-priority queues will exhibit less delay because the associated queue is serviced before low-priority queues as long as it remains within its configured transmit rate.

Figure 10-3 shows the scheduler state for each forwarding class as either positive (+) or negative (–) and also indicates the associated priority setting. In this example, queue 3 is set to high priority, but it is currently in negative credit—this means the queue has sent more traffic than its configured transmit percentage and must now wait to accumulate credit to go positive again. Queue 1 has no packets pending, so it is skipped—a work-conserving scheduler does not service empty queues. The result is that the high-priority queue (#2) with positive credit is serviced first, which results in the dequeuing of its two packets. Because there are no remaining high-priority queues with positive credit and pending notifications, the low-priority queues can be serviced, and queue 0, having pending traffic and positive credit, is serviced next.

Queue 0 is emptied after its two packets are serviced, leaving only queue 3 with traffic pending. Unless this queue is rate-limited, it will be serviced, despite its negative credit status, as long as no positive credit queues become active. However, servicing a queue with negative credit results in an increase in the queue's negative credit, up to some maximum value, which, while allowing a queue to send more than its configured transmit rate, ensures that other queues will be the first to be serviced as soon as they have a notification pending.

Congestion management

Statistically multiplexed networks are subject to congestion. This can be chronic as a function of design or transient due to equipment or circuit failures or because of synchronized bursts from users. In any of these events, a method is needed to deal with congestion gracefully, and in a manner that is fair to all users. Because datagram networks do not support flow control, discard is the only mechanism a router has to prevent total buffer meltdown during a congestion event.

Modern IP routers implement some form of Active Queue Management (AQM), which is intended to optimize discard actions to obtain maximum benefit and to ensure fairness. AQM for IP networks is defined in RFC 2309, "Recommendations on Queue Management and Congestion Avoidance in the Internet."

Put simply, when a queue is filling faster than it can be emptied, a router has two choices as to where to drop. It can wait until the queue can hold no more, and then simply drop all packets as they arrive (which is called *tail dropping*). Or it can detect incipient congestion and *proactively* begin to drop packets based on a probability function that is in turn tied to average queue depth. The latter technique is known as *random early detection (RED)* and has many advantages over simple tail dropping.

Tail dropping can allow hyperactive applications to lock out less busy users, and it tends to result in queues operating at near capacity. A queue is really useful only when it is able to absorb packet burst, and any queue, no matter how large, that is near its fill capacity becomes useless for absorbing burst (it's already full), and therefore serves only to add delay. RED acts before the queue is full, and works on the principle that Transmission Control Protocol (TCP) sources assume that lost segments stem from congestion, and lower their window advertisements as a result. This ultimately results in less traffic from the related TCP source.

RED seeks to maintain an average queue fill by taking more aggressive drop actions as the queue fill increases. Using the queue's average fill level allows tolerance for receiving packet burst, because discards are probable only when the *average* queue level rises above configured thresholds. RED begins to perform tail drops once the queue reaches 100% full, in which case no new notifications can be queued and they are dropped upon receipt. The random nature of RED discards avoids the potential of queue lockout of certain users, as can occur with simple tail drops. In fact, because RED makes a discard decision upon receipt of each packet, the busiest users experience the most RED-induced drops, which is more than fair.

Figure 10-4 shows a sample RED configuration block and a graphical depiction of the resultant profile.

```
user@router# show class-of-service
drop profiles {
    segmented-style-profile {
        fill-level 25 drop-probability 25;
        fill-level 50 drop-probability 50;
        fill-level 75 drop-probability 75;
        fill-level 95 drop-probability 100;
    }
}
```

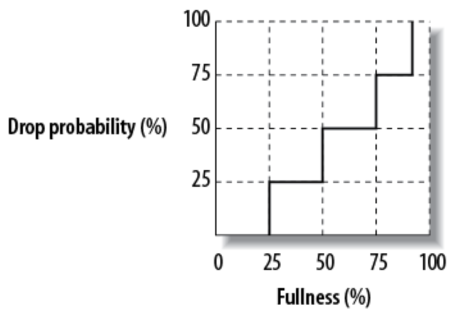


Figure 10-4. RED configuration and profile

Weighted RED. Weighted RED (WRED) is simply a RED algorithm that maintains different drop probability profiles based upon traffic type. In the Juniper implementation, you can index one of as many as four RED profiles, based on traffic type of TCP versus User Datagram Protocol (UDP) with a loss priority of high or low. The result is a weighting of RED drop actions, based on traffic type.

Policing and shaping

Packet-based networks are capable of interconnecting devices and links that operate at variable speeds. Packet buffers are critical when supporting mixed-link speeds because they provide an elastic coupling between the high- and low-speed links. As noted previously, a packet buffer is most useful when it operates at a low fill level. Any packet network that constantly operates near buffer capacity should be redesigned, because a full buffer has lost its ability to provide additional buffering and leads only to increased delays.

The inherent support of mismatched device and link speeds, combined with the many-to-one nature of datagram networks, can result in a chronic condition in which more traffic arrives at a device than can be transmitted downstream. If left unchecked, this condition can lead to indiscriminate tail dropping—WRED tends to have little effect on UDP-based applications, so cannot be relied on to prevent congestion.

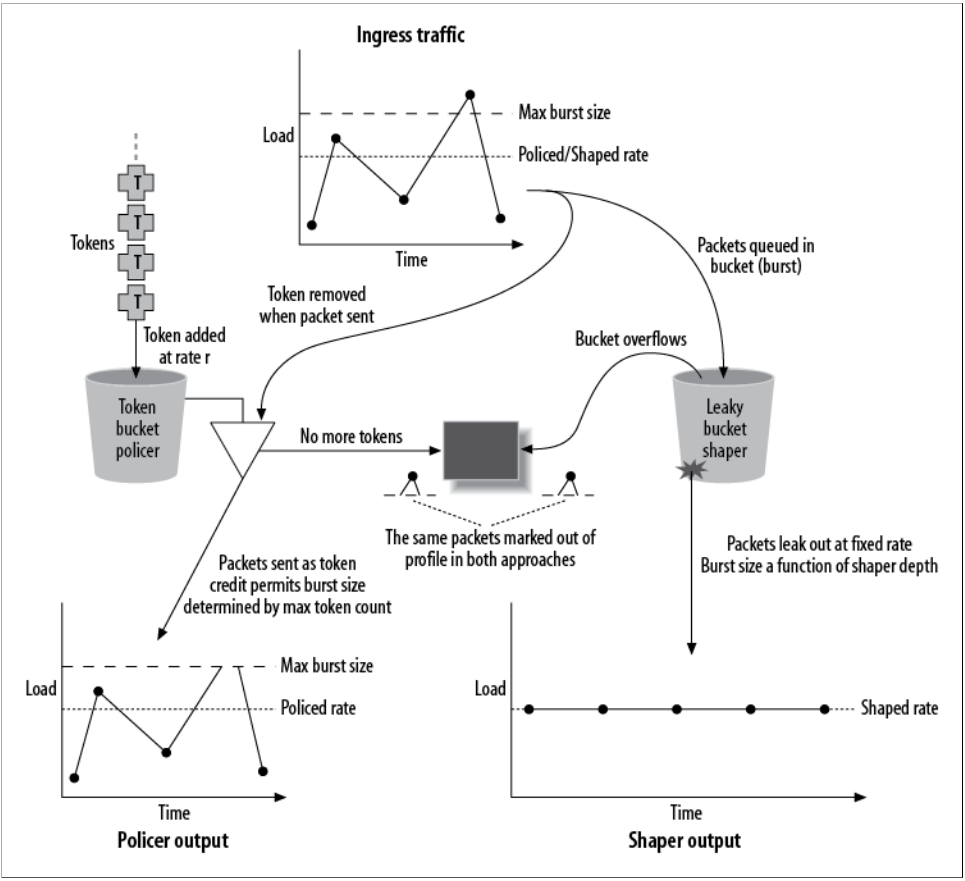
To resolve this type of problem, a mechanism is needed to limit, or *cap*, the amount of traffic that a device is able to send. Such a mechanism is called *policing* or *rate limiting*, and serves to limit the overall amount of traffic that can be sent over a given unit of time by placing limits on maximum packet rate and burst size.

Isolation is needed to preserve CoS. Isolation between forwarding classes is a critical aspect of IP CoS. Class-based isolation is provided by the scheduler via its priority and transmit weight settings. However, isolation between classes is not sufficient to ensure fair service for users that share the same class. Although policing can be used on a forwarding class basis, it's commonly used at the individual device, or even at a micro-flow level, to limit the amount of traffic that is accepted into the network. Policing provides the necessary isolation between users or applications in the same forwarding class to prevent one user from dominating the resources associated with that class.

Policing versus shaping. Users are often confused about the differences between policing and shaping. Figure 10-5 shows the operational differences.

The lefthand side of Figure 10-5 shows a typical token-rate-based policer. The size of the token bucket limits the total number of tokens that can accumulate, which in turn limits the maximum burst size. The rate at which new tokens are added limits the average transmission rate. Policers do not smooth traffic bursts, and they either mark or discard traffic that exceeds the configured burst size or average rate of token accumulation. A policer does not buffer the actual user traffic, and therefore does not add appreciable delays.

On the righthand side of the figure, the same input traffic is subjected to a leaky bucket-based shaper. The shaper buffers the actual user data (not tokens, as in the case of a policer), and the related output is spread over time to eliminate bursts—the shaper smoothes the peaks and valleys by buffering traffic and letting it leak out at a specified rate. The upside to shaping is that packet-buffering requirements are reduced in



Ingress traffic
Load
Max burst size
Policed/Shaped rate
Time
Tokens
T
Token added at rate r
Token removed when packet sent
Packets queued in bucket (burst)
Bucket overflows
Token bucket policer
No more tokens
Leaky bucket shaper
The same packets marked out of profile in both approaches
Packets sent as token credit permits burst size determined by max token count
Packets leak out at fixed rate Burst size a function of shaper depth
Load
Max burst size
Policed rate
Time
Policer output
Load
Shaped rate
Time
Shaper output

Figure 10-5. Policing versus shaping

downstream nodes, given the lack of bursting. The downside is the need for buffering within the shaper, which adds delay and cost.

Generally speaking, on a macro level there is no difference in the amount of traffic transmitted (or marked/discarded) by a policer versus a shaper when they are configured with compatible parameters. At increasingly smaller time scales, the difference is manifest by the absence, or presence, of clumped packets (bursts) that instantaneously exceed the configured average rate. As long as downstream devices are not operating near buffer capacity, policing is generally preferred to shaping, given that it is less complex and less costly (buffers are not free), and it does not induce any additional buffering delays. Stated differently, you perform shaping at an upstream device to *condition* traffic only when needed to meet the requirements of an attached device with limited buffering capabilities. If the downstream device is not buffer/capacity-challenged, it's far more efficient to quickly move traffic from point A to point B by sending bursts rather than artificially delaying each subsequent packet to eliminate clumping (bursts).

Summary of CoS processing steps

Figure 10-6 provides a big-picture view of the CoS processing stages associated with Juniper routers. Although useful in its own right, because of its detailed depiction of Junos CoS capabilities, the intent here is to tie the various terms and concepts discussed in this section into a single example to show how the various CoS process stages work together.

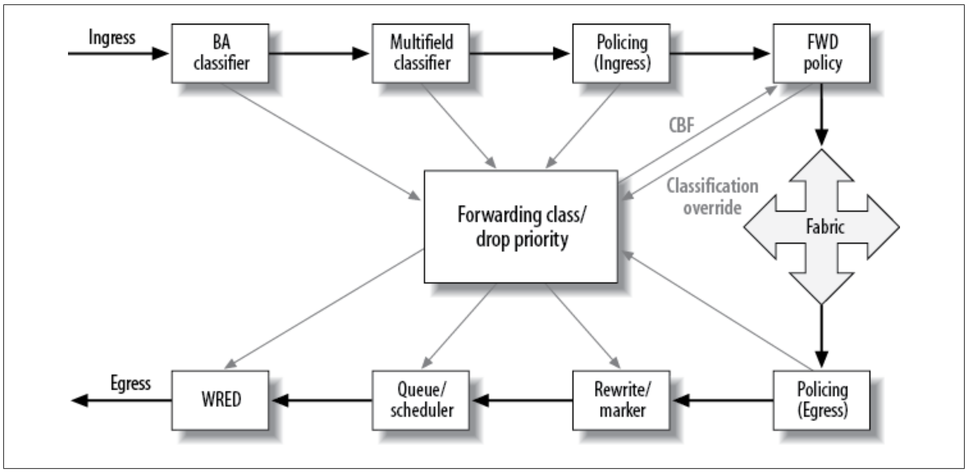


Figure 10-6. Big-picture CoS walkthrough

The discussion begins with a packet arriving at the ingress interface. The operation and general capabilities of each CoS stage encountered as a packet travels from ingress to egress are described as follows:

Ingress CoS processing

BA classification
: Packets arriving at the router are first subjected to the BA classification stage. This stage sets the forwarding class and packet loss priority (PLP) using any of the supported BA classifier types, including IP precedence, DiffServ DSCP, IEEE 802.1P, and so on.

Multifield classification
: The next processing stage is multifield classification. Here a firewall filter can be defined to match against numerous packet fields, incoming interfaces, and so on, in order to set the forwarding class or PLP or to override the values set during previous BA classification.

Ingress policing
: When desired, a firewall or interface-level policer can be applied to limit matching traffic, by discard, by reclassification, or by marking excess traffic with a loss priority of high. This means that in the event of congestion, a RED profile can be used to more aggressively drop PLP high traffic.

Forwarding policy

The last ingress processing stage is forwarding policy. This policy can alter the existing forwarding class or PLP setting, and it can be used to select a forwarding next hop based on a forwarding class, a feature called Class-Based Forwarding (CBF).

Egress CoS processing

Egress policing

After encountering the switching fabric, a packet begins its journey toward the selected egress interface. The first egress CoS processing state is output policing, which is again based on either a firewall or an interface-level policer. Once again, excess traffic can be discarded or marked with a loss priority for later discard in the event of congestion.

Rewrite marker

The rewrite marker stage allows you to alter one, or in some cases multiple, packet fields, as the packet is transmitted to downstream nodes. Normally, you rewrite packet fields to accommodate downstream BA-based classification. Rewrite markers are indexed by protocol family and by forwarding class—for example, writing a 001 pattern into the precedence field of all `family inet` packets that are classified as BE.

Queuing and scheduling

The queuing stage involves placing packet notifications into the corresponding forwarding class queue, where they are serviced by a scheduler that factors priority and configured weight to determine when a packet should be dequeued from a given queue.

RED/congestion control

The final CoS processing stage involves a WRED drop decision, based on protocol, loss priority, and average queue fill level. Recall that RED tends to operate at the head of the queue, and a RED decision is made against each packet selected for transmission by the scheduler stage.

At this stage, it should be clear that Juniper Networks enterprise routers offer a rich set of IP CoS capabilities that provide numerous points where a packet can be touched for CoS actions or manipulations. In most cases, a single router would not be configured to use all of these capabilities at the same time, but the Juniper design means that all CoS features can be deployed with minimal impact to the control and forwarding planes. As a point of fact, the default out-of-the-box configuration includes IP CoS, albeit in a relatively simplified manner. Details regarding the default CoS configuration are provided in "Junos Software CoS Defaults" on page 470.

A scalable CoS design strives to distribute the load—for example, by placing the relatively computationally intensive multifield classification function at the edges of the access layer only. Once classified, packets can be remarked to accommodate streamlined BA-based classification in the core and distribution layers, where packet rates tend to be higher and more cycles need to be dedicated to forwarding traffic, rather than on complex classification tasks.

Figure 10-7 illustrates the CoS divide and conquer approach. It shows the CoS-enabled subset of the Beer-Co network, which has been divided into access and distribution/core layers. Generally speaking, CoS functionality is most complex at the edges of your network. This is because the network's edge has to deal with individual devices/microflows, whereas the core acts on traffic aggregates. Core devices are normally not burdened with CPU-intensive operations such as multifield classification, thus allowing these devices to focus their actions on actual packet forwarding. By policing at the network's edge, you throttle each user/application at ingress, making additional policing within the distribution and core layers unnecessary. Policing aggregate stream rates in the core is possible, but it has the serious drawback of allowing one or more hyperactive users to dominate the resources of that forwarding class. By performing rate limiting and related discard at the edges, as traffic initially ingresses the network, you can fairly limit all users to their assigned rate; when combined with a properly dimensioned core, additional policing actions are unnecessary.

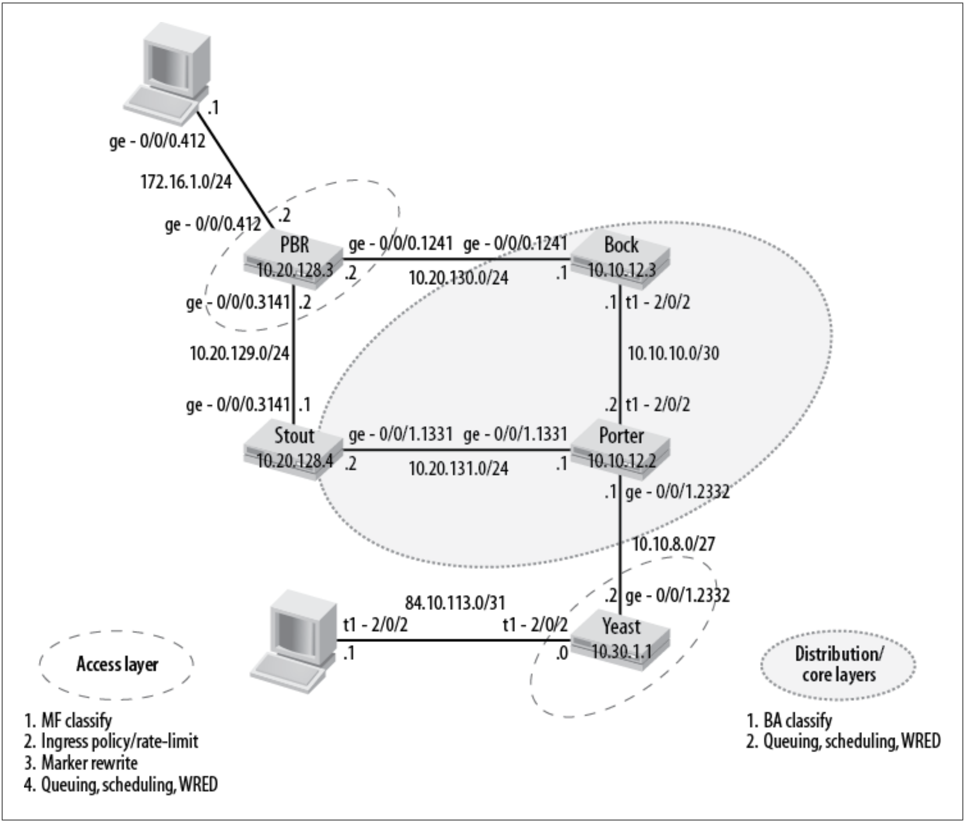


Figure 10-7. The CoS divide and conquer approach

The core CoS functionality of classification and resulting queuing/congestion control is performed by all nodes in the network to provide the consistent node-by-node, and therefore end-to-end, packet-handling behavior needed for a successful IP CoS deployment.

IP CoS Summary

This section described IP CoS and why it's becoming increasingly important with the trends toward IP convergence. We defined basic network CoS/QoS terminology, and we walked through the typical CoS processing stages of a modern IP router.

Although likely not too earth shattering, there was a fair bit of information to digest here. You might consider taking a brief break before diving into the next section, which provides a primer on IP Differentiated Services (DiffServ).

IP Differentiated Services

Over the years, there have been several false starts to a standardized IP CoS solution. This section summarizes the history of IP CoS, and it provides a primer on the current solution known as IP Differentiated Services (DiffServ).

The original use of IP networks was to support robust communications in the face of battlefield conditions, an application to which datagram (connectionless) operation is well suited. This discussion is tempered with the knowledge that the concept of integrating services over IP internetworks was not considered by the protocol's architects, and wide-scale adoption of IP CoS has yet to occur. However, recent advancements in router platforms have enabled the high-bandwidth forwarding rates required to make IP-based convergence a commercial reality. With high-capacity forwarding in place, the final piece of the IP CoS puzzle is the intelligent handling of packets to effectively prioritize certain packets during times of reduced capacity or link congestion.

IP ToS

RFC 791 is the original RFC specification of the Internet Protocol (IP) and was published in 1981. The RFC defined an 8-bit field in the IP header as a Type of Service (ToS) field. Figure 10-8 shows the IP header and details the structure of the ToS field itself.

The original IP ToS field is structured into a 3-bit precedence field, a 3-bit ToS indication field, and two reserved bits. The ToS bits were intended to provide a clue to the router as to which type of link metric (e.g., delay, throughput, or reliability) should be considered when handling the packet. This capability presumes a ToS-capable routing protocol, one that builds a routing information base (RIB) based on specific link metrics. Such a protocol has never seen use in commercial networks (Open Shortest Path First [OSPF] has this capability, but it never saw actual deployment).

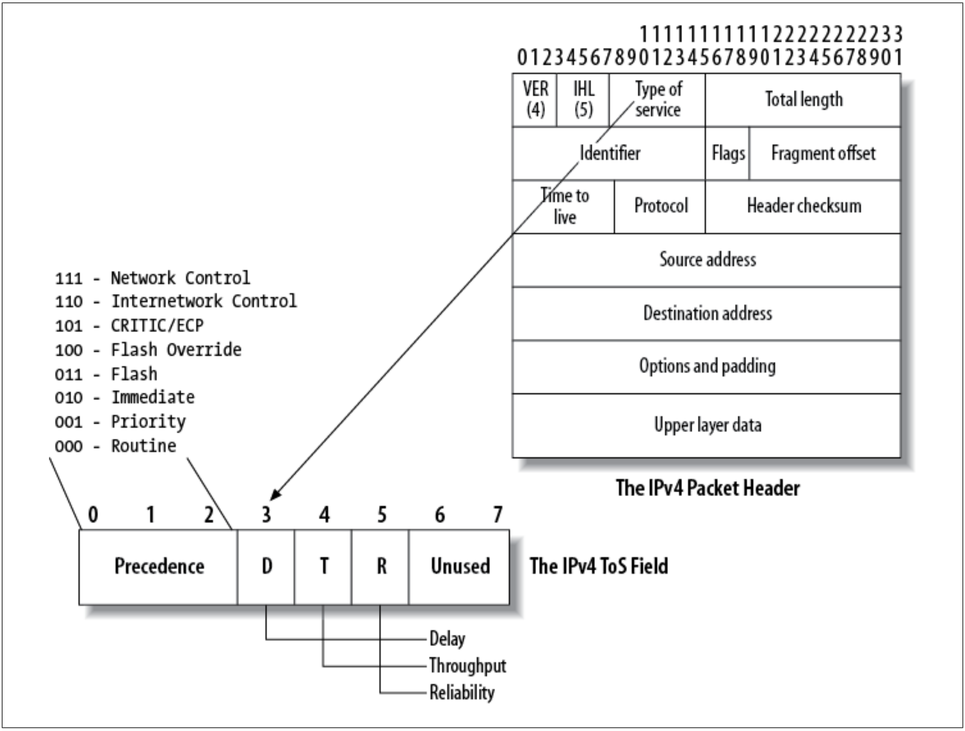


Figure 10-8. The IP ToS byte

Lack of ToS-capable Interior Gateway Protocols (IGPs) meant that the ToS bits have gone historically unused by routers. Many applications set these bits; for example, Telnet often sets the D bit to indicate low delay, but routers generally take no specific action upon any ToS combinations.

With bits 6 and 7 reserved, this left only the precedence field, which at 3 bits in length is able to code eight possible precedence levels (2^3). IP precedence is supposed to influence packet loss—generally speaking, each increase from the default value, which is 0, was expected to result in a reduced probability for discard. Unlike the ToS bits, IP precedence processing has been supported in routers for some time, but usually in a rather coarse, binary manner that results in two discard probabilities—a low probability for precedence values 6 and 7, which are associated with NC, and a higher probability for all other levels. In the Juniper implementation, the default behavior results in a maximum of four drop probabilities, two for non-NC classes and two for the NC class, based on a WRED profile set to act differently on high- versus low-loss probability traffic.

Most routing protocol stacks do in fact set the precedence bits of their control packets, as shown in the following `monitor traffic` sample, which explains how Junos transmits an OSPF packet:

```
[edit]
lab@Bock#run monitor traffic interface ge-0/0/1.100 detail
Listening on ge-0/0/1.100, capture size 96 bytes
. . .
02:12:44.430326 Out IP (tos 0xc0, ttl   1, id 3867, offset 0, flags
[none], proto: OSPF (89), length: 68) 10.10.11.3 > 224.0.0.5: OSPFv2,=
Hello, length: 48
        Router-ID: 10.10.12.1, Backbone Area, Authentication Type:
none (0)
        Options: [External] [|ospf]
```

The hexadecimal value shown for the ToS field (`0xc0`) breaks down to a binary 1100 0000, which in turn codes IP precedence level 6 with the D, T, and R ToS bits cleared (not set). The default Juniper behavior is to classify based on IP precedence, such that NC messages are placed into queue 3, which is the default queue for the NC class, as shown here:

```
lab@PBR>edit class-of-service

[edit class-of-service]
Show classifier type inet-precedence name ipprec-compatibility | match network-control
  110                  network-control                      low
  111                  network-control                      high
```

A breakdown of IP precedence to binary, along with the decimal equivalent, is provided. This can be useful when testing CoS using utilities such as ping or traceroute, because when you include the **tos** switch, the resultant values are specified in *decimal*, not binary or hexadecimal. Note that only IP ToS bits are supported with the CLI tos switch—you cannot specify a DSCP value. Table 10-2 provides a complete breakdown of IP precedence to binary and the resultant decimal equivalents.

Table 10-2. IP ToS to binary and decimal equivalents

Precedence	Binary	Powers of 10	Decimal
Precedence 7	1110 00xx	128+64+32+0+0+0+x+x	224
Precedence 6	1100 00xx	128+64+0+0+0+0+x+x	192
Precedence 5	1010 00xx	128+0+32+0+0+0+x+x	160
Precedence 4	1000 00xx	128+0+0+0+0+0+x+x	128
Precedence 3	0110 00xx	0+64+32+0+0+0+x+x	96
Precedence 2	0100 00xx	0+64+0+0+0+0+x+x	64
Precedence 1	0010 00xx	0+0+32+0+0+0+x+x	32
Precedence 0	0000 00xx	0+0+0+0+0+0+x+x	0

Enter IP Integrated Services

Recognizing an increasing need for functional IP CoS, the Internet Engineering Task Force (IETF) began work on an Integrated Services (IS, or IntServ) model that was first published in 1994 in RFC 1633, “Integrated Services in the Internet Architecture: An

Overview." The authors felt that simple packet classification and scheduling was not enough to guarantee real-time services over the Internet, and specifically felt that some form of admission control and resultant resource reservation was needed. Figure 10-9 shows the IntServ concept.

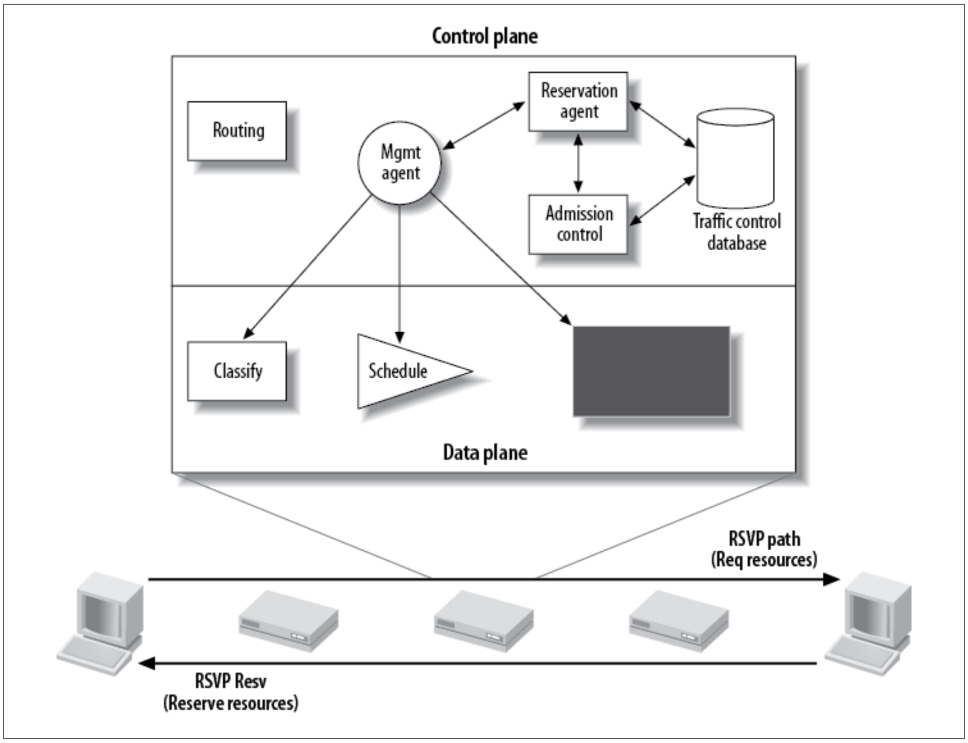


Figure 10-9. IP Integrated Services

The added functionality needed to support IntServ is shown in the upper-right portion of the router's control plane in Figure 10-9—specifically, the addition of the CAC and the reservation control entities, along with the related resource reservation database and related hooks into the router's management plane.

Put simply, the IntServ plan was to include the Resource Reservation Protocol (RSVP), as defined in RFC 2205, in routers and hosts, adding what amounts to a *call establishment* phase (for non-BE traffic). Here, the user specifically requests resources from the network, while also characterizing the nature of the related traffic with parameters such as average and peak rates, maximum transmission unit (MTU), and so on.

Each network node then either accepts or rejects the reservation request based on its local CAC function, which is run against that node's current resource availability. When all nodes along the path accept the reservation, soft state is established for the duration of the reservation and is used to create the data plane state needed to support the new reservations. Specifically, a classifier is instantiated to match traffic belonging to that reservation using the details contained in the RSVP traffic information. The reservation is torn down when it is no longer needed. This results in removal of the related data plane state and the freeing of allocated resources to accommodate the next reservation request. When a node is encountered that cannot meet the reservation's requirements, the session fails with the appropriate reason given—in theory, the user application will either keep trying, give up, or reduce its resource request to improve its chances of success.

Although all this sounds great, many practical issues resulted in little to no real deployment of IntServ. Ironically, the RSVP signaling protocol has seen significant commercial success as a Multiprotocol Label Switching (MPLS) signaling protocol within service provider networks, rather than in its original QoS signaling role.

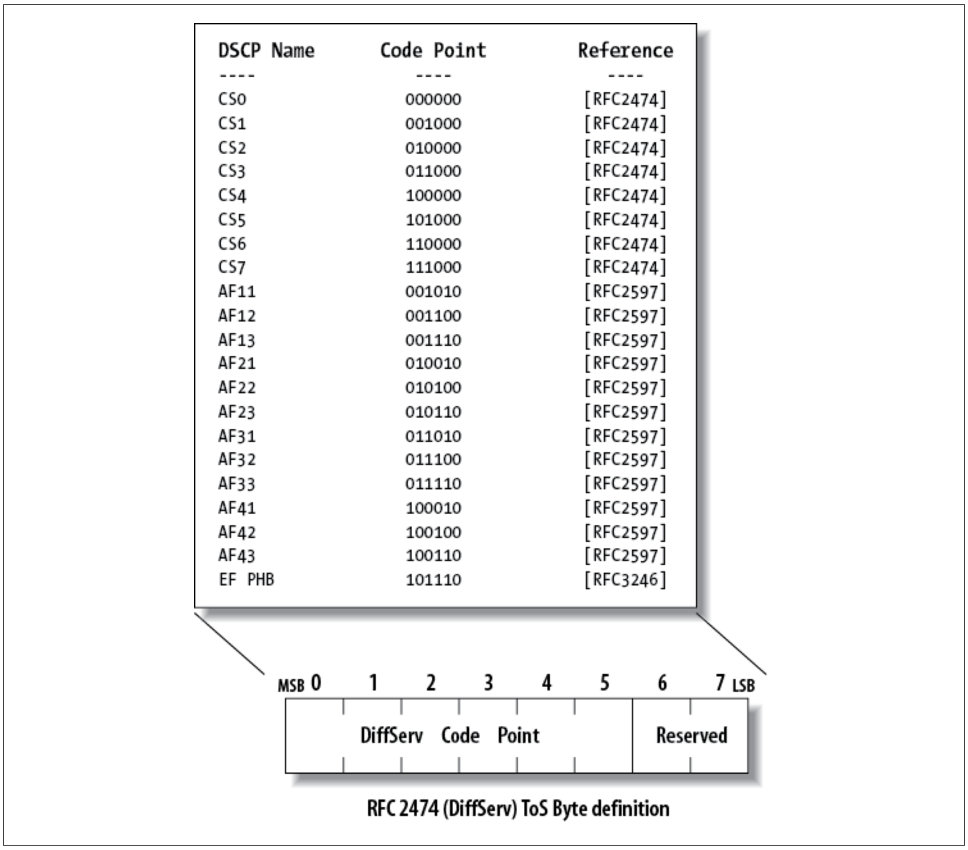
IntServ results in network blocking when the network approaches capacity, meaning that no new reservations can be placed. Although not a problem for those users lucky enough to already hold a reservation, the total absence of (integrated) service for the remaining users was seen by many as a serious violation of the historical Internet paradigm of providing the same level of (degraded) service to all users in the same class. With IntServ, users at the *same* service level can be locked out by existing reservations, and the real rub is that this is true even when those existing reservations are not transporting traffic due to bursty sources. Many still have a hostile view toward the idea of blocking users in the control plane (putting aside the scaling issues of a control plane that has to interact on an end-user micro-flow basis), when at that very moment the data plane may well be idle, leading to wasted resources.

The commercial failure of IntServ prompted the development of a data-plane-only solution known as Differentiated Services.

IP Differentiated Services

IP Differentiated Services (DiffServ) was originally defined in RFCs 2474 and 2475 in 1998. Since that time, several RFCs have updated the original definition of the DSCP. RFC 3168 added explicit congestion notification (ECN) support, and RFC 3260 clarified the terminology to support MPLS traffic engineering, but the essence of the original DiffServ architecture remains.

DiffServ is scalable because it is a data-plane-only solution; there is no signaling component to DiffServ. DiffServ redefines the original IP ToS byte to support a 6-bit field, which, as noted previously, is called the DiffServ code point (DSCP). This provides for up to 64 levels of BA classification. Figure 10-10 shows the DiffServ definition of the IP ToS field. Related RFCs define the current set of per-hop behaviors (PHBs), which are described later, and essentially define the externally visible handling characteristics associated with a given forwarding class, or BA in DiffServ terminology.



DSCP Name	Code Point	Reference
----	----	----
CS0	000000	[RFC2474]
CS1	001000	[RFC2474]
CS2	010000	[RFC2474]
CS3	011000	[RFC2474]
CS4	100000	[RFC2474]
CS5	101000	[RFC2474]
CS6	110000	[RFC2474]
CS7	111000	[RFC2474]
AF11	001010	[RFC2597]
AF12	001100	[RFC2597]
AF13	001110	[RFC2597]
AF21	010010	[RFC2597]
AF22	010100	[RFC2597]
AF23	010110	[RFC2597]
AF31	011010	[RFC2597]
AF32	011100	[RFC2597]
AF33	011110	[RFC2597]
AF41	100010	[RFC2597]
AF42	100100	[RFC2597]
AF43	100110	[RFC2597]
EF PHB	101110	[RFC3246]

Figure 10-10. The DiffServ code point

Figure 10-10 also shows a table of the recommended DSCP mappings, most of which have yet to be defined. The Class Selector (CS) code points are designed to mimic the functionality of IP precedence, and they provide backward compatibility for non-DiffServ-aware routers, assuming any still exist. All of the CS code points have zeros where the original ToS definition placed the Delay, Throughput, and Reliability (DTR) flags. The 6-bit DSCP field leaves the original two least-significant bits (LSBs) of the original IP ToS field untouched, where they can be used for ECN signaling as per RFC 3168, "The Addition of Explicit Congestion Notification (ECN) to IP."

DiffServ Terminology

This section defines key DiffServ terms and operational concepts. Refer to Figure 10-11 to match the terms to their functional location in a DiffServ network.

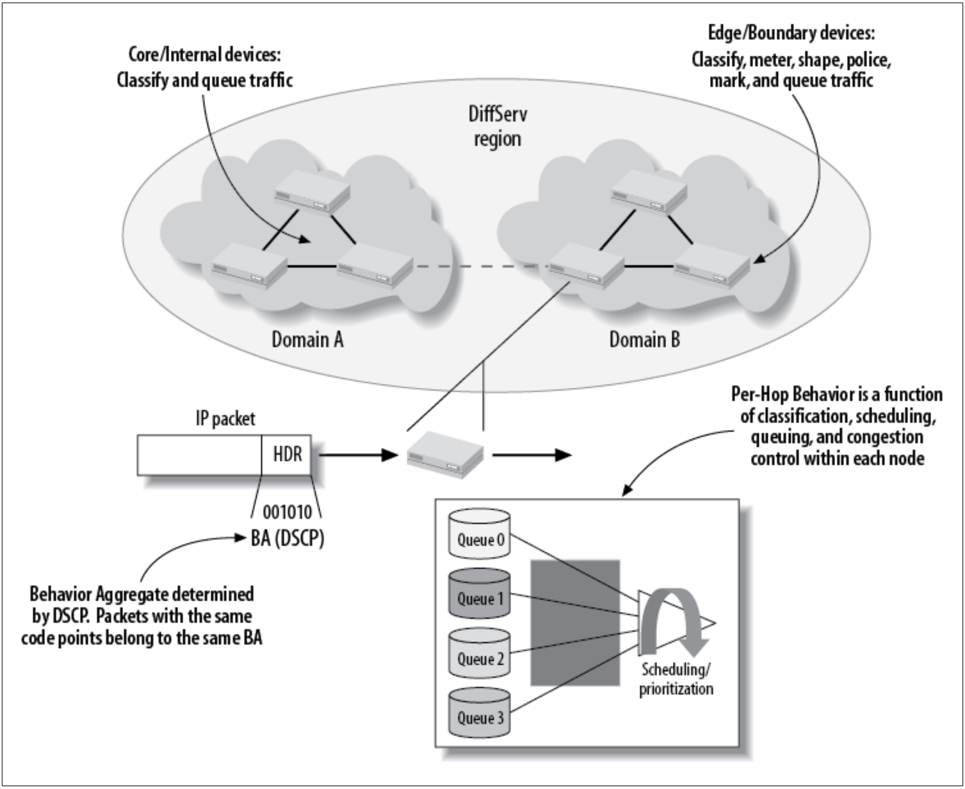

Core/Internal devices:
Classify and queue traffic
Edge/Boundary devices:
Classify, meter, shape, police, mark, and queue traffic
DiffServ region
Domain A
Domain B
IP packet
HDR
001010
BA (DSCP)
Behavior Aggregate determined by DSCP. Packets with the same code points belong to the same BA
Per-Hop Behavior is a function of classification, scheduling, queuing, and congestion control within each node
Queue 0
Queue 1
Queue 2
Queue 3
Scheduling/ prioritization

Figure 10-11. DiffServ terminology and concepts

BA
: This is a classification based on DSCP packets with a common DSCP belonging to the same BA.

DiffServ field
: This is the original IPv4 ToS byte. DSCPs occupy the six most significant bits of the DS field.

PHB
: This is the externally visible forwarding treatment associated with a given BA. Within a DiffServ domain, the set of PHBs should be consistent across all nodes, resulting in a consistent end-to-end handling of traffic.

PHB group
: This is a set of one or more PHBs that can only be meaningfully specified and implemented simultaneously, due to a common constraint applying to all PHBs in the set, such as a queue servicing or queue management policy. Currently, the only standardized group behavior relates to the Assured Forwarding (AF) PHB.

DiffServ domain

This is a contiguous collection of nodes under a common policy with a common set of PHBs:

- Edge/boundary devices classify, meter, shape, police, mark, and queue traffic.
- Core devices classify and queue traffic.

DiffServ region

This is a contiguous set of interconnected DiffServ domains.

DiffServ PHBs

Currently, four PHBs are standardized within DiffServ: the default PHB, CS, EF PHBs, and the AF PHB group:

The default PHB

The default PHB must be present in each DiffServ-compliant node, and it defines a BE delivery service. Any packets that are not explicitly classified into one of the other PHBs are considered to belong to the default group. Although the default group should not be starved, BE is generally serviced only after all other active PHBs have been given their share of bandwidth.

The CS PHB

The CS PHB is designed to subsume the historic drop behavior associated with the original IP precedence field definition. The PHB behavior set for the CS PHB is left somewhat vague, in keeping with the fact that IP precedence was used only to control drop probability and not to provide any delay, delay jitter, or minimum through guarantees. To be compliant, a DiffServ node supporting the CS PHB must demonstrate at least two different forwarding behaviors, and a packet with a CS value of 000xxx should be dropped in preference of a packet with a CS code point of 111xxx. Put simply, there are no throughput or delay guarantees in the CS PHB, and at a minimum, a node is expected to favor CS code points mapping to IP precedence 6 and 7 over all other CS values from a drop perspective.

The EF PHB

The EF PHB is associated with a low-latency, low-jitter, low-loss, end-to-end service. This type of service is suitable for circuit emulation, or the support of voice, video, or other real-time services. EF support is not mandated, but when offered, the EF PHB requires two independent functions: that each node is configured with a minimum departure rate that is independent of the activity levels of other PHBs within that node, and that the EF BA be conditioned through policing or shaping to ensure that the EF arrival rate at any node is always less than that node's configured minimum departure rate. The first behavior is defined within the EF PHB itself, and the second is a function of general traffic conditioning.

The AF PHB

The AF PHB is a family of PHBs, called a *PHB group*, which is used to classify packets into various drop precedence levels. The drop precedence assigned to a packet determines the relative importance of a packet within the AF class and generally also indicates whether that packet was within, or above, some guaranteed rate. Packets within the associated AF PHB group's minimum rate have the lowest drop probability and are expected to be delivered, whereas packets above the minimum rate have an increasing probability of loss.

The AF PHB can be used to implement a multitiered model consisting of three classes—bronze, silver, and gold—and is associated with loss-sensitive, nonreal-time applications. A minimal AF PHB implementation is required to recognize all three drop priorities within each supported AF group, but it has to offer only a minimum two-drop precedence within each AF group.

Recommended/default DHCPs. Each administrator of a DiffServ region is free to choose the specific DSCPs that map to supported PHBs. It's critical that any such mapping be consistent across all nodes in the DiffServ domain/region. Packet remarking can be used to map between two regions that are part of the same domain, but this process is prone to error. The various IETF documents describing DiffServ PHBs provide recommended DSCP mappings, which were shown in Figure 10-10.

DiffServ Summary

This section provided a brief history of IP CoS, from the original ToS definition to the not-quite-successful IntServ model on up to the current approach known as IP Differentiated Services. The data-plane-centric approach defined in DiffServ provides a scalable solution that is known to work.

DiffServ is based on the principle of isolation between forwarding classes (BAs) and a consistent classification and resultant per-hop behavior across the routers in a DiffServ domain, such that predictable end-to-end CoS can be provided.

The next section provides a detailed description of Junos CoS capabilities and their differences. There is a lot to cover, so perhaps another break is in order before you dive back in.

CoS Capabilities

With a thorough grounding in IP CoS concepts and terminology now under your belt, it's time to get down to the particular CoS capabilities of Juniper's enterprise routing products.

Although all Juniper routers run pretty much the same Junos software, the design of the router does lead to some operational differences and capabilities. Fortunately, the vast majority of CoS functionality is shared between all the platforms, and this section is structured accordingly—the common capabilities are covered first, followed by details regarding any specific exceptions or differences.

The discussion of CoS capabilities and default settings is presented in the context of the CoS packet processing steps available for transit traffic. This is done to provide structure and to reinforce your understanding of CoS processing stages within a Juniper router. You should refer back to Figure 10-6 as each CoS processing stage is discussed.

You configure CoS at the `[edit class-of-service]` hierarchy, which has quite a few options under it. The primary CoS configuration options are displayed:

```
[edit]
lab@Bock#edit class-of-service
[edit class-of-service]
lab@Bock# set ?
Possible completions:
> adaptive-shapers     Define the list of trigger types and associated rates
+ apply-groups            Groups from which to inherit configuration data
+ apply-groups-except     Don't inherit configuration data from these groups
> classifiers          Classify incoming packets based on code point value
> code-point-aliases   Mapping of code point aliases to bit strings
> drop-profiles        Random Early Drop (RED) data point map
> forwarding-classes   One or more mappings of forwarding class to queue number
> forwarding-policy    Class-of-service forwarding policy
> fragmentation-maps   Mapping of forwarding class to fragmentation options
> interfaces           Apply class-of-service options to interfaces
> loss-priority-maps   Map loss priority of incoming packets based on code point value
> rewrite-rules        Write code point value of outgoing packets
> scheduler-maps       Mapping of forwarding classes to packet schedulers
> schedulers           Packet schedulers
> traceoptions         Trace options for class-of-service process
> virtual-channel-groups  Define list of virtual channel groups
> virtual-channels     Define the list of virtual channels
```

Input Processing

Input processing stages include BA classification, multifield classification, policing, and forwarding policy actions. Each is discussed separately.

BA classification capabilities

The BA classification stage supports classification based on the following Layer 3 and Layer 2 fields:

- DSCP (Layer 3, 64 levels in updated ToS byte)
- IP precedence (Layer 3, eight levels in ToS byte)
- MPLS EXP (Layer 2, eight levels via experimental [EXP] bits in MPLS tag)
- IEEE 802.1p (Layer 2, eight priority levels in 802.1Q virtual LAN [VLAN] tag)

If you apply an IEEE 802.1p to a logical interface, you cannot apply any other classifier types to other logical interfaces on the same PIC port if you are using older PICs on the M-series routers. Some combinations of BA classifiers simply make no sense and are mutually exclusive; for example, you cannot apply both an IP precedence and a DSCP classifier to the same logical interface at the same time. You configure a BA classifier at the [edit class-of-service classifiers] hierarchy:

```
[edit class-of-service classifiers]
lab@Bock#set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> dscp                 Differentiated Services code point classifier
> dscp-ipv6            Differentiated Services code point classifier IPv6
> exp                  MPLS EXP classifier
> ieee-802.1           IEEE-802.1 classifier
> ieee-802.1ad         IEEE-802.1ad (DEI) classifier
> inet-precedence      IPv4 precedence classifier
```

The following example shows a user-defined IP precedence type classifier named test, with a defined code point that maps to the BE forwarding class with a low-loss priority:

```
[edit class-of-service classifiers inet-precedence test]
lab@Bock#show
forwarding-class best-effort {
    loss-priority low code-points 000;
}
```

When desired, you can populate a classifier table with default values, which is useful when your goal is to modify only some code points. The best practice is to always have complete classification tables, even when all possible code point values are not expected. Even though unmatched code points map to the BE class by default, explicitly stating this with a complete code point mapping can reduce confusion down the road:

```
[edit class-of-service classifiers inet-precedence test]
lab@Bock#set import ?
Possible completions:
  <import>             Include this classifier in this definition
  default              Default classifier for this code point type
  test
[edit class-of-service classifiers inet-precedence test]
lab@Bock# set import default

[edit class-of-service classifiers inet-precedence ]
lab@Bock# show import default;
forwarding-class best-effort {
    loss-priority low code-points 000;
```

The BA classifier is placed into service when you apply it to one or more logical interfaces:

```
[edit class-of-service interfaces]
lab@Bock#set ge-0/0/0 unit 0 classifiers inet-precedence test

[edit class-of-service interfaces]
lab@Bock# show
ge-0/0/0 {
    unit 0 {
        classifiers {
            inet-precedence test;
        }
    }
}
```

Note that a BA classifier is applied to an interface at the `[edit class-of-service interfaces <interface-name> unit <unit-number>]` hierarchy, whereas multifield classifiers are applied to an interface at the `[edit interfaces <interface-name> unit <unit-number>]` hierarchy. Keep this distinction in mind to avoid confusion down the road.

On MX platforms, a forwarding class can be assigned directly to the logical interface without the use of a classifier `set class-of-service interface <interface-name> unit <unit-number> forwarding-class <class>` command.

Multifield classification

In the Juniper architecture, multifield classification is implemented via firewall filters, using a variety of Layer 2 or Layer 3 match criteria. We discuss general firewall filter configuration and capabilities in Chapter 8.

Suffice it to say that you use a filter to perform multifield classification by associating a set of match criteria with a `then forwarding-class` action. To activate multifield classification, the filter is applied as an input filter on an ingress interface. Because BA classification is always performed first, you can always apply a multifield classifier in combination with any BA classifier. In case of conflict, the forwarding class associated with the BA match is overwritten by the multifield classifier's choice of forwarding class.

This example shows a simple multifield classifier that classifies a specific UDP protocol and port combination to the BE class with high-loss priority, while all other traffic is classified as BE with the default low-loss priority:

```
[edit firewall filter mf_class]
lab@Bock#show
term udp_port_5555 {
    from {
        protocol udp;
        port 5555;
    }
    then {
        loss-priority high;
        forwarding-class best-effort;
        accept;
    }
}
term default {
    then {
        loss-priority low;
        forwarding-class best-effort;
```

```
            accept;
        }
    }
```

Another form of filter that can be used for classification is the simple filter. Simple filters are restricted to specific hardware, are input filters, support IPv4 fields only, and always have an implied accept action. They are configured at the `edit firewall family inet simple-filter` stanza. An example simple filter is:

```
[edit firewall family inet simple-filter test1]
lab@Bock#show
term 1 {
    from {
      source-address {
         10.10.0.0/16;
      }
      protocol {
         tcp;
      }
    }
then loss-priority low;
```

Policing

Policers are generally considered to be part of the Junos software firewall architecture, in that you normally link to a policer as a result of a firewall filter match. Juniper also supports policers that are applied directly to protocol families, on a per-logical-interface basis. From a CoS perspective, interface-level policers are really useful only when you classify based on the incoming interface—that is, all traffic received on interface *`<name>`* is forwarding class *`x`*, which is a somewhat corner case, given that most interfaces are assumed to carry a mix of forwarding classes.

Ingress policing is a key component of the traffic conditioning that is needed in the DiffServ model to ensure independence between forwarding classes and the associated PHBs, and between users in the same class. You should deploy policing on the network's edges, as close to the traffic sources as possible. The goal is to limit the aggregate rate of all non-BE traffic to constrain it to a value less than the aggregate rate of the transmission resources associated with all non-BE classes. This ensures that the non-BE PHBs can be met locally and by subsequent core nodes, which generally are not burdened by any CoS-related policing.

Where possible, you should police on a per-class basis for *each* user—Junos software features such as highly scalable firewall filters, combined with ease-of-use features such as per-prefix counting and policing, generally make such a fine-grained level of policing practical. This policing ensures that a few dominant users are not able to monopolize all the resources of a given forwarding class by providing per-user isolation within the same class.

Traffic that exceeds the policer's profile can be discarded, reclassified into a different class, or marked for increased discard probability by altering the internal PLP. The latter approach provides a minimum level of service with the potential for increased delivery during periods of low network utilization. In contrast, immediate discard caps the user at ingress, which helps to prevent network congestion from occurring in the first place.

Here is an example of a firewall filter that both classifies and polices on a per-forwarding class basis:

```
[edit firewall]
lab@Bock#show
policer EF_policer {
    if-exceeding {
        bandwidth-limit 128k;
        burst-size-limit 2k;
    }
    then discard;
}
filter mf_class_and_police {
    interface-specific;
    term EF_classify {
        from {
            protocol udp;
            port 6000-6100;
        }
        then {
            policer EF_policer;
            forwarding-class expedited-forwarding;
        }
    }
    term other {
        then forwarding-class best-effort;
    }
}
```

In this example, UDP packets with a matching port range (either source or destination ports) are directed to a policer named `EF_policer`. Traffic within the policer profile is handed back to the calling term, where it's classified as EF and accepted. In this case, any excess traffic is summarily dropped. The final term in the filter classifies all remaining traffic as BE, which is not policed in this example.

It may seem odd that the EF class is policed—with a rather draconian discard action, no less—while the BE class, which appears to be less important, is left to run unchecked. The reason for this seemingly backward policer application is due to the related scheduling priority, which for the EF class is often strict, or strict-high, and can lead to the starvation of lower-priority forwarding classes when there is an abundance of this traffic. Ingress policing with associated discard ensures an aggregate limit on the EF class, which prevents this problem. Ironically, it's relatively safe to accept all the BE traffic users care to generate, because BE is generally assigned a low priority (other classes cannot be starved) and a low transmit percentage (so that it does not significantly impact other classes), thus excess BE is sent only when one or more of the other forwarding classes are not using their full bandwidth allocation anyway.

The addition of the `interface-specific` statement allows the same filter to be applied to multiple interfaces, with each such application resulting in instantiation of a unique policer instance. The end result is that each interface to which this filter is applied will be limited to a maximum average EF rate of 128 Kbps. The aggregate EF class rate becomes a simple function of policer rate multiplied by the number of interfaces to which the filter is applied. Note that omitting the `interface-specific` statement and applying the same filter to multiple interfaces results in a shared policer, which in this example would cap the aggregate EF class rate to 128 Kbps.

CoS policy

CoS policy is used in one of two ways: to provide CBF or to perform classification override. CBF allows you to specify one or more next hops based on a packet CoS classification. CBF is not demonstrated in this chapter, but a good configuration example is provided in the user manual, located at *http://www.juniper.net/techpubs/en_US/junos10.4/information-products/pathway-pages/cos/index.html*.

Classification override does just what its name implies. This capability can be useful when performing CoS-related testing, or it can mitigate negative impacts that can result from an upstream device that is suspected of generating improperly marked traffic. The configuration example performs an override of any previous classification including overriding any loss-priority setting, and it resets all matching traffic to the BE class:

```
[edit]
lab@Bock#show policy-options
policy-statement AF_override {
    term 1 {
        from interface ge-0/0/0.0;
        then class reset_to_be;
    }
    term 2 {
        then accept;
    }
}
```

The `AF_override` policy is used to identify what traffic is subjected to classification override; in this example, all traffic received over interface `ge-0/0/0` is marked as belonging to a CoS-related policy class named `reset_to_be`:

```
[edit]
lab@Bock#show class-of-service
forwarding-policy {
    class reset_to_be {
        classification-override {
            forwarding-class best-effort;
        }
    }
}
[edit]
lab@Bock# show routing-options forwarding-table
export AF_override;
```

A `forwarding-policy` is created at the `[edit class-of-service]` hierarchy that identifies the policy class that is subject to classification override. In this example, packets marked as belonging to the `reset_to_be` policy class have their initial classification, whatever that might be, reset to the BE class. The forwarding policy must be applied at the `[edit routing-options forwarding-table export]` hierarchy to take effect. Such a policy configuration might temporarily work around issues with an upstream device that incorrectly marks all traffic as EF, resulting in EF class congestion and violation of the related service level agreements (SLAs). The group managing the upstream device will quickly find the motivation needed to correct the configuration error when its users begin to complain about poor performance stemming from suddenly getting nothing but BE treatment.

Output Processing

Output CoS processing stages include egress policing, rewrite marking, queuing/scheduling, and active queue management through RED-based congestion control.

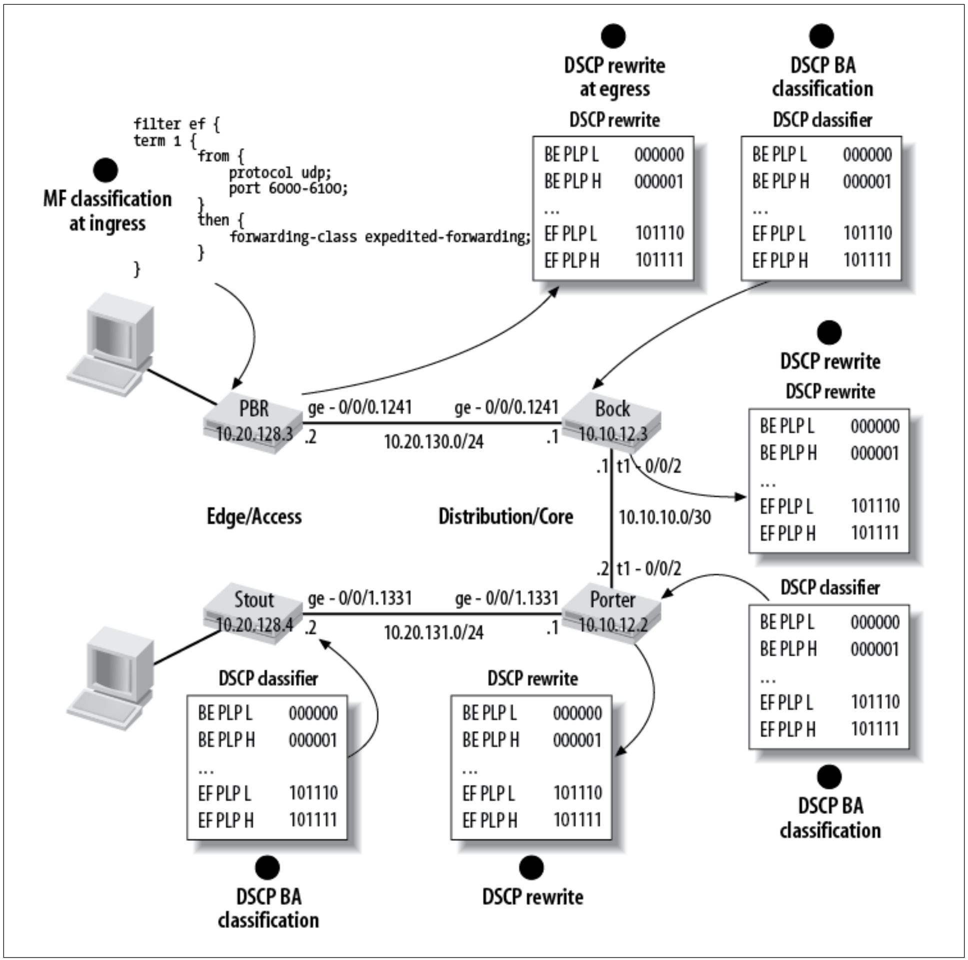
Egress policing

Policers are, well, policers, and there is really nothing unique about an output policer versus an input one, other than the simple fact that the policing action now occurs after the route lookup, rather than before. To an external observer, there is no difference between the use of input versus output policers. Consider an input policer, unless you must police based on the result of route lookup—that is, based on the forwarding next hop.

Rewrite marking

The rewrite marking stage is a critical component of a scalable CoS design because it's one-half of the BA classification story. For scalability, multifield classification should be used only at the network's access layer, where the function can be distributed among the largest set of routers with the smallest average packet forwarding requirements. Packet rates near the core typically dictate the more efficient BA type classification; Juniper routers are capable of wire-rate BA classification in all scenarios, whereas heavy use of firewall filters can degrade forwarding performance.

You should think of your input BA classifiers as a mirror image of the corresponding rewrite marker. This is to say that for each entry in a given BA table, there should be a corresponding entry in the associated rewrite marker table, and that entry is normally set to the same value—this ensures that the node downstream makes the same classification decision as did the local node. The consistent classification at each node between endpoints is a critical component of the DiffServ model, which presumes a consistent PHB among all nodes in a DS region. Figure 10-12 shows the interaction between multifield classification, marker rewrite, and resultant BA classification.



```
filter ef {
term 1 {
        from {
            protocol udp;
            port 6000-6100;
        }
        then {
            forwarding-class expedited-forwarding;
        }
}
```

BE PLP L	000000
BE PLP H	000001
...	
EF PLP L	101110
EF PLP H	101111

Figure 10-12. Multifield at the edge, BA in the core

The sequence numbers in Figure 10-12 take you from initial ingress processing (where a multifield classification is used at step 1), on to step 2 (where the ingress node uses a DSCP rewrite table to write a specific DSCP pattern, based on its ingress classification). In this example, we assume EF with low PLP, so the packet's DSCP field is written to binary 101110. At step 3, the downstream node (which is in the distribution or core layer) performs *only* DSCP-based BA classification. Note that Bock's DSCP classifier entry for the EF class with low PLP matches the same value as that used in PBR's DSCP rewrite table. The result, shown in steps 4–7, is a consistent classification, and therefore there is a resulting consistency in the PHB across each node in the path.

The configuration example shown creates an IP precedence rewrite marker table that matches the example provided in the section "BA classification capabilities" on page 447:

```
[edit class-of-service rewrite-rules inet-precedence test]
lab@Bock#show
import default;
forwarding-class best-effort {
    loss-priority low code-point 000;
}
```

As in the case of BA classifiers, a rewrite table can be fully populated by importing any entries not explicitly defined by the user from the default set associated with that classifier type.

Scheduling and queuing

The scheduling stage determines when a given queue is serviced, in which order, and how much traffic can be drained at each servicing. Schedulers and queues are closely linked in the Juniper architecture. When you configure a scheduler, you can also control certain queue parameters such as maximum queue depth, and you also link that queue to one or more WRED profiles. You typically alter a queue's default size, which is based on the associated transmit weight, to control delay—larger buffer sizes favor less loss at the cost of increased latency.

Scheduling discipline. Juniper routing platforms implement a modified deficit round-robin (MDRR) scheduler. Because different transmit weights can be assigned to each queue, the algorithm is technically a modified weighted deficit round-robin (MWDRR) approach.

Scheduling is one area where the CoS implementation significantly differs between models. The basic scheduling behavior is described here, along with general scheduling capabilities and concepts. "Differences Between Junos CoS" on page 463 specifically calls out where the platforms differ in scheduling behavior.

MDRR extends the basic deficit round-robin (DRR) mechanism by adding support for a priority queue that exhibits minimal delay. The deficit part of the algorithm's name stems from the allowance of a small amount of negative credit in an attempt to keep queues empty. The resultant negative balance from one servicing interval is carried over to the next quantum's credit allocation, keeping the average dequeuing rate near the configured transmit value.

An MDRR scheduler is defined by four variables:

Buffer size
: This is the delay buffer for the queue that allows it to accommodate traffic bursts. You can configure a buffer size as a percentage of the output interface's total buffer capacity or as a temporal value from 1 to 200,000 microseconds, which simply represents buffer size as a function of delay, rather than bytes.

The quantum
: The quantum is the number of credits added to a queue every unit of time and is a function of the queue's transmit weighting. In Juniper's implementation, a quan-

tum is added 5,000 times per second (or once every 200 microseconds). The queue's transmit rate specifies the amount of bandwidth allocated to the queue and can be set based on bits per second or as a percentage of egress interface bandwidth. By default, a queue can be serviced when in negative credit, as long as no other queues have traffic pending. When desired, you can rate-limit a queue to its configured transmit rate with inclusion of the `exact` keyword.

Priority

The priority can be low, medium-low, medium-high, high, or strict-high, and it determines the sequence in which queues are serviced. The scheduler services high-priority queues with positive credit before it addresses any low-priority queues.

A strict-high priority queue is a special case of high priority, where the effective transmit weight is set to equal egress interface capacity. This means that a strict-high queue can never go negative, and therefore is serviced before any low-priority queue anytime it has traffic waiting. The result is a type of low-latency queuing (LLQ). Care should be used when a queue is set to strict-high to ensure that the queue does not starve low-priority traffic; a strict-high queue does not support shaping via the `exact` keyword. Normally, though, ingress policing/rate limiting is used to control the aggregate rate of traffic that can be placed into the strict-high queue. When you have two or more queues set to high priority (two high, or one high and one strict-high), the MDRR scheduler simply round-robins between them until they both go negative, or until the queue is empty in the case of strict-high, at which time the low-priority queues can be serviced.

Deficit counter

MDRR uses the deficit counter to determine whether a queue has enough credits to transmit a packet. It is initialized to the queue's quantum, which is a function of its transmit rate, and it is the number of credits that are added to the queue every quantum.

The Juniper implementation of MDRR scheduling supports a basic deficit weighted round-robin (DWRR) scheduling discipline, or a combination of strict-priority queuing (SPQ) and DWRR scheduling when a strict high-priority queue is configured.

Scheduler configuration. You configure the scheduling and queuing stage by first defining a scheduler for each forwarding class used in your network. Schedulers are defined at the `[edit class-of-service schedulers]` hierarchy, and they indicate a forwarding class's priority, transmit weight, and buffer size:

```
[edit class-of-service]
lab@Bock#show schedulers
be_sched {
    transmit-rate percent 30;
    priority low;
    drop-profile-map loss-priority high protocol any drop-profile be_high_drop;
    drop-profile-map loss-priority low protocol any drop-profile be_low_drop;
}
ef_sched {
    buffer-size temporal 50k;
    transmit-rate percent 60 exact;
    priority high;
    drop-profile-map loss-priority high protocol any drop-profile ef_high_drop;
    drop-profile-map loss-priority low protocol any drop-profile ef_low_drop;
}
nc_sched {
    transmit-rate percent 10;
    priority low;
    drop-profile-map loss-priority high protocol any drop-profile nc_high_drop;
    drop-profile-map loss-priority low protocol any drop-profile nc_low_drop;
}
```

This example supports three forwarding classes—BE, EF, and NC—and each forwarding class's scheduler block is associated with a priority and a transmit rate. Priority support takes the form of strict-high, high, medium-high, medium-low, and low.

The differences in scheduler priorities and behavior between Juniper routers are discussed in "Differences Between Junos CoS" on page 463. For example, although all platforms support a `strict-priority` scheduler setting, the effect is platform-dependent and significantly different.

The transmit rate can be entered as a percentage of interface bandwidth or as an absolute value. You can rate-limit (sometimes called *shape*) a queue with the `exact` keyword, which prevents a queue from getting any unused bandwidth, effectively capping the queue at its configured rate.

Other options for the transmit rate are a specified rate or the remainder of the bandwidth. Some combinations are not allowed; for example, you cannot set both the remainder and the exact keywords.

In this example, the EF scheduler is set to high priority and is rate-limited to 60% of the interface speed, even when all other schedulers are idle, through the addition of the `exact` keyword. Using `exact` is a common method of providing the necessary forwarding class isolation when a high-priority queue is defined, because it caps the total amount of EF that can leave each interface to which the scheduler is applied. Rate-limiting helps to ensure that the aggregate rate of EF traffic arriving at downstream nodes is not excessive, whereas ingress policing should limit the arriving EF to an aggregate rate that is less than the EF scheduler's transmit rate to ensure that the local node meets the associated PHB.

With the configuration shown, each of the three forwarding classes are guaranteed to get at least their configured transmit percentage. The EF class is limited to no more than 60%, while during idle periods both the BE and NC classes can use 100% of egress bandwidth. When it has traffic pending, the high-priority EF queue is serviced as soon as possible—that is, as soon as the BE or NC packet currently being serviced has been completely dequeued.

Assuming a somewhat worst-case T1 link speed (1.544 Mbps) and a default MTU of 1,504 bytes, the longest time the EF queue should have to wait to be serviced is only about 7.7 milliseconds ($1/1.544^6 \times (1504 \times 8)$). With higher speeds (or smaller packets), the servicing delay becomes increasingly smaller. Given that the typical rule of thumb for the one-way delay budget of a Voice over IP application is 150 milliseconds, this PHB can accommodate numerous hops before voice quality begins to suffer.

The preceding example would not commit until the drop profiles are defined for these schedules. Drop profiles are covered later in this chapter.

Delay Buffer Size

Notifications for packets pending transmission are stored in a delay bandwidth buffer that is sized according to the interface's speed and the platform's maximum delay buffer time. The routers support at least 100,000 microseconds (or 100 milliseconds) of delay buffer time.

When using low-speed interfaces, such as DSOs within a channelized T1/E1, you may want to enable large buffer support. With the `q-pic-large-buffer` knob in conjunction with supported hardware, you can increase delay buffer time to as much as 4 million microseconds (four seconds). The larger delay buffer can be useful on slow-speed interfaces due to the resultant increase in serialization delay, which is a function of link speed and MTU.

In this example, the delay buffer size for the BE and NC classes is left at the default `remainder` setting. This means that each is allocated a percentage of the 100-millisecond delay buffer based on its configured transmit weighting, and is allowed to grow into any unallocated buffer space, such as can occur when the sum of configured weights does not add up to 100%.

The formula to compute the actual delay buffer size is:

interface speed (bps) × delay buffer size (microseconds) = delay buffer size (bytes)

If we assume a J-series platform with a 100 Mbps Fast Ethernet interface in this example, the total scheduler delay buffer size is $100^6 \times 100^{-3}$ = 1.25 MB. By default, the BE and NC classes are assigned 30% and 10% of the scheduler's delay buffer, respectively.

In contrast, the EF queue has its buffer set to permit no more than 50,000 microseconds (50 milliseconds). When using a temporal setting, the maximum delay buffer size is computed by multiplying the interface speed by the configured temporal value.

Because the EF class has been assigned 60% of the transmit bandwidth, the default behavior would allocate 60% (60,000 microseconds) of delay buffer; by reducing the size of the delay buffer, as shown in the case of the EF class, you keep the higher transmit percentage while forcing a smaller buffer size. Setting a delay buffer that is smaller than the default results in a trade-off between the resultant increased probabilities of congestion-related loss versus a reduction in maximum delay and delay variance (jitter).

The scheduler block for each forwarding class also references WRED drop profiles, which provide active queue management to control congestion. Generally, you will have a different WRED profile for each forwarding class—for example, one aggressive profile that begins to drop at a lower fill, with a greater drop probability for the BE class, and another that waits until a higher queue fill before less-aggressive drops begin for the NC class. We will discuss drop profiles in "Congestion control" on page 460.

For each scheduler, you can configure the buffer size as either a percentage of the total buffer, as the remaining buffer available, or to a temporal value. The percentage is a percentage of the total buffer for the interface. The remainder is the buffer percentage that is not assigned to other queues. For example, if you assign 30% of the delay buffer to queue 0, allow queue 3 to keep the default allotment of 5%, and assign the remainder to queue 5, then queue 5 uses approximately 65% of the delay buffer. For the temporal setting, the queuing algorithm starts dropping packets when it queues more than the number of bytes computed by the temporal value multiplied by the interface speed.

Scheduler Maps

Once you have defined your schedulers, you must link them to one or more egress interfaces using a `scheduler-map`. Scheduler maps are defined at the `[edit class-of-service scheduler-maps]` hierarchy:

```
[edit class-of-service]
lab@Bock# show scheduler-maps
three_FC_sched {
    forwarding-class best-effort scheduler be_sched;
    forwarding-class expedited-forwarding scheduler ef_sched;
    forwarding-class network-control scheduler nc_sched;
}
```

Applying a `scheduler-map` to an interface places the related set of schedulers and drop profiles into effect:

```
[edit class-of-service]
lab@Bock# show interfaces
ge-0/0/0 {
    scheduler-map three_FC_sched;
}
```

Defining scheduler blocks that are based on a transmit percentage rather than an absolute value, such as in this example, makes it possible to apply the same `scheduler-map` to all interfaces without worrying whether the sum of the transmit rates exceeds interface capacity, which results in a committed, but effectively ignored, CoS configuration that can be a real pleasure to debug. An example of this condition is shown for `Bock`, whose T1 interface cannot handle the 1 Gbps required when the rate is substituted for the same numeric value, but in Mbps!

```
lab@Bock# show class-of-service schedulers ef_sched
transmit-rate 35m exact;
buffer-size temporal 30k;
priority high;

[edit]
lab@Bock# run monitor start log messages
monitor start "messages" (Last changed Oct 29 05:21:00)

[edit]
lab@Bock# commit
Oct 30 05:39:11  Bock mgd[2982]: UI_COMMIT: User 'lab' performed commit: no comment
Oct 30 05:39:15  Bock cosd[1071]: COSD_TX_QUEUE_RATES_TOO_HIGH: Unable to apply
scheduler map af-sched to interface t1-2/0/0: sum of scheduler transmission rates
exceeds interface shaping or transmission rate
. . .
```

A word on per-unit scheduling

By default, when you apply a scheduler to an interface, it takes effect at the port, or interface device (`ifd`) level. This is fine when the port in question is configured with a single logical interface (`ifl`), such as would be the case when running Cisco High-Level Data Link Control (HDLC) or the Point-to-Point Protocol (PPP). However, when the interface is partitioned into multiple logical units—for example, as the result of adding VLAN tagging—you need to apply a per-unit scheduler. A per-unit scheduler provides fine-grained queuing by creating a set of queues and an associated scheduler for each logical interface. Per-unit scheduling is a function of the hardware, and some older PICs do not support this feature.

You configure per-unit scheduling by adding the `per-unit-scheduler` statement at the interface level. Because some hardware combinations do not support fine-grained queuing, you should monitor the *messages* log when committing a per-unit scheduling configuration to make sure the configuration is compatible with installed hardware:

```
[edit interfaces ge-0/0/0]
lab@Bock# show
per-unit-scheduler;
vlan-tagging;
unit 0 {
    vlan-id 1241;
    family inet {
        address 10.20.130.1/30;
    }
}
```

Congestion control

The final CoS processing stage in the output direction is the WRED congestion control function. We described the reasoning behind active queue management previously—we'll reiterate that the general goal is to avoid the indiscriminate tail drops that occur when a queue reaches capacity, by sensing a queue that is beginning to fill and then randomly discarding packets from the head of the queue. The chance of actual discard rises from the first fill level and discard probability point until it reaches 100% at 100% fill. Configuring a discard profile with a fill/discard probability of 100/100 effectively disables RED on that queue. This is the default setting.

Configure WRED drop profiles

You configure a WRED drop profile at the `[edit class-of-service drop-profiles]` hierarchy. RED drop profiles are placed into effect on an egress interface via application of a `scheduler-map`. Recall that, as shown earlier, the `scheduler-map` references a set of schedulers, and each scheduler definition links to one or more drop profiles. It is an indirect process, to be sure, but it quickly begins to make sense once you have seen it in action.

Here are some examples of drop profiles, as referenced in the preceding `scheduler-map` example:

```
[edit class-of-service drop-profiles]
lab@Bock# show
be_high_drop {
    fill-level 40 drop-probability 0;
    fill-level 50 drop-probability 10;
    fill-level 70 drop-probability 20;
}
be_low_drop {
    fill-level 70 drop-probability 0;
    fill-level 80 drop-probability 10;
}
ef_high_drop {
    fill-level 80 drop-probability 0;
    fill-level 85 drop-probability 10;
}
ef_low_drop {
    fill-level 90 drop-probability 0;
    fill-level 95 drop-probability 30;
}
nc_high_drop {
    fill-level 40 drop-probability 0;
    fill-level 50 drop-probability 10;
    fill-level 70 drop-probability 20;
}
nc_low_drop {
    fill-level 70 drop-probability 0;
    fill-level 80 drop-probability 10;
}
```

In this example, the drop profiles for the BE and NC classes are configured the same, so technically a single-drop profile could be shared between these two classes. It's a best practice to have per-class profiles because ongoing CoS tuning may determine that a particular class will perform better with a slightly tweaked RED threshold setting.

Both the BE and NC queues begin to drop 10% of high-loss priority packets once the respective queues average a 50% fill level. You can specify as many as 64 discrete points between the 0% and 100% loss points, or use the `interpolate` option to have all 64 points automatically calculated around any user-supplied thresholds. In this example, only three points are specified. At 50% fill, 10% of PLP 1 BE and NC traffic is dropped; when the queue fill crosses 70%, the next discard threshold is activated and 20% of the packets are discarded. The 20% discard rate is maintained during an average queue fill of 70% to 99%. At 100% fill, tail drop begins, as the queue can no longer hold incoming notifications. The weighted aspect of the RED algorithm is shown with the configuration of a less-aggressive drop profile for BE/NC traffic with a low-loss priority.

A similar approach is taken for the EF class, except it uses a less aggressive profile for both loss priorities, with discards starting at 80% and 90% fill for high- and low-loss priorities, respectively. Some CoS deployments disable RED (100/100) for real-time classes such as EF because these sources are normally UDP-based and do not react to loss in the same way that TCP-based applications do. Some platforms support WRED profiles based on TCP versus UDP, in addition to loss priority, which allows you to adopt a less aggressive RED profile for those application types that do not react to RED drop anyway. Other platforms support WRED indexing based on loss priority only. The examples shown are from a J-series, which forces the protocol to `any`.

Here's the `be_high` drop profile:

```
[edit]
lab@Bock# run show class-of-service drop-profile be_high_drop
Drop profile: be_high_drop, Type: discrete, Index: 27549
  Fill level    Drop probability
          40                   0
          50                  10
          70                  20
```

To provide contrast, the `be_high` profile is altered to use `interpolate`, which fills in all 64 points between 0% and 100% loss, as constrained by any user-specified fill/drop probability points:

```
edit]
lab@Bock# show class-of-service drop-profiles be_high_drop
interpolate {
    fill-level [ 40 50 70 ];
    drop-probability [ 0 10 20 ];
}
[edit]
lab@Bock# run show class-of-service drop-profile be_high_drop
Drop profile: be_high_drop, Type: interpolated, Index: 27549
  Fill level    Drop probability
           0                   0
           1                   0
           2                   0
           4                   0
           5                   0
              . . .
```

```
        38                  0
        40                  0
        42                  2
        44                  4
        45                  5
        46                  6
        48                  8
        49                  9
        51                 10
        52                 11
        54                 12
            . . .
        78                 41
        80                 46
        82                 52
        84                 57
        85                 60
            . . .
        99                 97
       100                100
```

Differences Between Junos CoS

The preceding section detailed the general CoS capabilities across all Junos-based routing platforms. This section calls out areas where the CoS capabilities differ. With so many similarities, the differences are easy to lose track of, but no matter how similar, they can have a pronounced operational impact if you do not understand and design for them.

Table 10-3 summarizes the differences between CoS behavior on various Juniper enterprise routers. Note that the oJ-Series column also includes the SRX210, SRX240, and SRX650 gateways; the M-Series is both the M7i and the M10i; and the MX-Edge routers include all models. The SRX3000s and SRX5000 gateways have special considerations that are beyond the scope of this book. Please refer to *Junos Security* (O'Reilly) for additional information on these devices.

Table 10-3. Enterprise router CoS behavior and capabilities

Feature	SRX and J- Series	M-Series (FPCs)	M-Series (enhanced FPCs)	MX-Edge routers
Schedulers	Priority	Weight	Weight	Weight
Classifiers	64	1	8	32
Forwarding classes	8	4	4	16
Queues	8	4	8	8
Loss priorities	4	2	4	4
dscp	Yes	No	Yes	Yes
dscp-ipv6	Yes	No	Yes	Yes
ieee-802.1p	Yes	No	Yes	Yes

Feature	SRX and J- Series	M-Series (FPCs)	M-Series (enhanced FPCs)	MX-Edge routers
Schedulers	**Priority**	**Weight**	**Weight**	**Weight**
inet-precedence	Yes	Yes	Yes	Yes
mpls-exp	Yes	Yes	Yes	Yes
Loss priorities based on the Frame Relay discard eligible (DE) bit	Yes	No	No	No
Drop profiles				
Maximum	32	2	16	64
Per queue	Yes	No	Yes	Yes
Per loss priority	Yes	Yes	Yes	Yes
Per Transmission Control Protocol (TCP) bit	Yes	No	Yes	No
Per protocol	No	Yes	Yes	No
Policing				
Adaptive shaping for Frame Relay traffic	Yes	No	No	No
Traffic policing	Yes	Yes	Yes	Yes
Virtual channels	Yes	No	No	No
Queuing priority	Yes	No	Yes	Yes
Per-queue output statistics	Yes	No	Yes	Yes
Rewrite markers	**64**	**No maximum**	**No maximum**	**32**
dscp	Yes	No	Yes	Yes
dscp-ipv6	Yes	No	Yes	Yes
frame-relay-de	Yes	No	No	No
inet-precedence	Yes	Yes	Yes	Yes
mpls-exp	Yes	Yes	Yes	Yes

Table 10-3 details the operational differences between the product lines. We will examine a few functional differences in detail in the following sections.

Per-unit scheduling

As mentioned earlier, the older M-series platforms do not support per-unit scheduling unless the platform is equipped with an IQ-style PIC, in which case the actual queuing is moved from the chassis level onto the PIC itself when you enable per-unit scheduling.

The other platforms support fine-grained, per-unit scheduling on all interfaces.

In addition to logical unit-based queuing, per-unit scheduling also enables use of the `shaping-rate` command at the logical unit level to shape output traffic on all interfaces.

Weight- versus priority-based scheduling

One of the most pronounced differences is the way in which the MDRR algorithm is implemented. The differences are so pronounced that you will typically find that an existing scheduler configuration cannot be copied to another model and receive the same CoS operation!

The weight-based scheduler. On ASIC-based routers, the MDRR scheduler is based on guaranteed transmit weight with any leftover (unused) bandwidth divided on a prioritized, round-robin basis, which empties high-priority queues in negative credit before moving on to low-priority queues with negative credit. As an example, Figure 10-13 illustrates the operational characteristics of the M-series scheduler implementation.

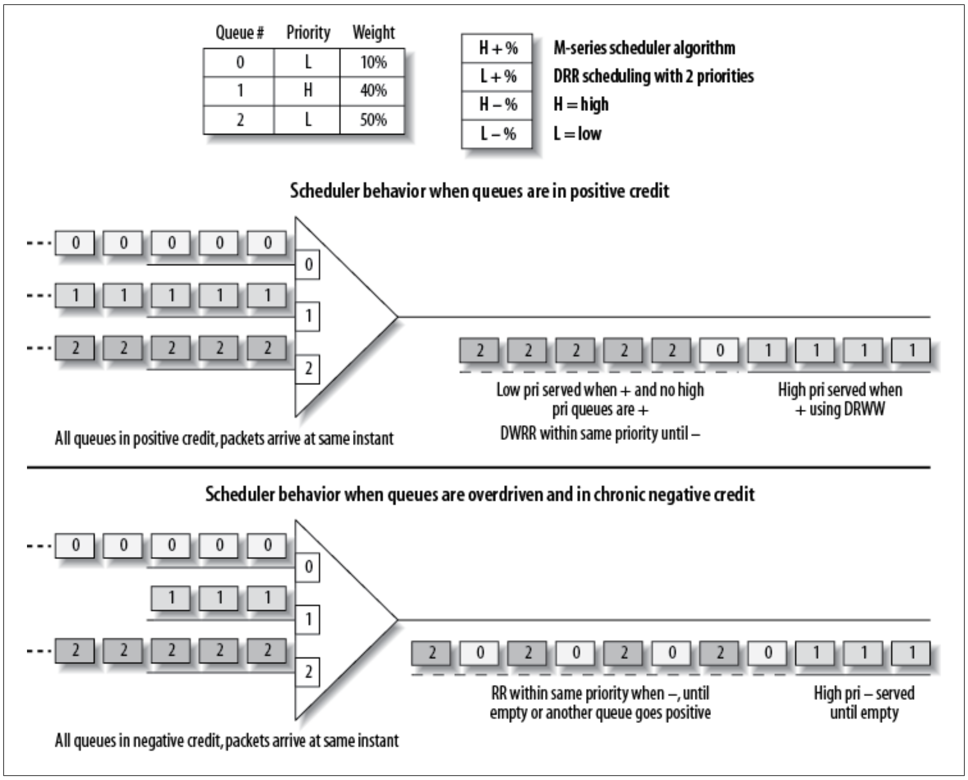

Queue # Priority Weight
0 L 10%
1 H 40%
2 L 50%
H + %
L + %
H – %
L – %
M-series scheduler algorithm
DRR scheduling with 2 priorities
H = high
L = low
Scheduler behavior when queues are in positive credit
All queues in positive credit, packets arrive at same instant
Low pri served when + and no high pri queues are +
DWRR within same priority until –
High pri served when + using DRWW
Scheduler behavior when queues are overdriven and in chronic negative credit
All queues in negative credit, packets arrive at same instant
RR within same priority when –, until empty or another queue goes positive
High pri – served until empty

Figure 10-13. The weight-based scheduler

Figure 10-13 shows a scheduler configuration supporting two priorities and three forwarding classes/queues. The scheduler first services all high-priority queues with positive credit, and then moves on to service low-priority queues with positive credit. Once all queues have been given at least their assigned weights, the queues go negative and the scheduler begins to allocate unused bandwidth. Because the dispatch of unused bandwidth is affected by numerous factors, including the number of priorities, number of queues, and average packet size, it is safe to say that the algorithm for the allocation of unused bandwidth among negative credit queues is, practically speaking, nondeterministic. This does not mean the process is random, just that it is extremely difficult to predict how much extra bandwidth a given queue will end up getting.

The top half of the figure shows the scheduler's DWRR operation when queues are in positive credit. The scheduler services the high-priority queue until its transmit weight is satisfied, resulting in four forwarding class 2 packets, or 40% utilization in this example. Once the priority queue is in negative credit, the scheduler moves on to the low-priority level, which has two queues in this example. The scheduler services both of the low-priority queues according to their weight, resulting in one FC0 and five FC2 packets being transmitted.

The lower half of Figure 10-13 continues the example by showing scheduler behavior among queues with negative credit. The leftover bandwidth is not allocated according to configured weight, but rather using a priority-based round-robin approach that empties one packet per queue, first emptying all high-priority queues and then moving on to round-robin between negative low-priority queues.

This approach can lead to some unexpected results, especially when queues are chronically overdriven and therefore tend to remain in negative credit, and when the average packet size differs within each queue. The lack of granularity in the per-packet round-robin handling of negative queues tends to favor the queue with the larger packet size. This can be most pronounced when that queue is also given the lowest weight, because it will be able to send the same number of packets as other negative queues at the same priority level. When combined with a larger packet size, such a queue winds up getting a larger percentage of the leftover bandwidth than you might first assume.

On the ASIC-based systems, the `strict-high` priority is the same as high priority—the `strict-high` setting simply provides that queue with a 100% transmit weight, thus ensuring that it is always in positive credit and able to send. You cannot rate-limit a `strict-high` queue with the `exact` keyword because it always gets 100% of the interface transmit weight, and you can include only one `strict-high` queue in a given `scheduler-map`.

The priority-based scheduler. The other scheduler implementation is based on strict priority. In this context, the word *strict* means that each priority level at value *n* is considered a higher priority than level *n* – 1, and that the scheduler always services higher-priority queues before lower-priority queues, even if the higher-priority queue is negative while the lower-priority queue is in positive credit. This is a critical point, so it's restated differently, a few times:

- WRR/configured weight is honored only for queues at the same priority level.
- A high-priority queue can starve all other priorities unless it is rate-limited. The same goes for medium-high and medium, medium-low and low, and so on down the priority chain.

The `strict-high` setting is an actual priority level, making it, pardon the pun, *higher* than high. The `strict-high` setting is specifically offered to back up the LLQ feature.

The `strict-high` queue cannot be rate-limited with the `exact` keyword. Instead, a policer is used to mark traffic above a configured limit as excess. Excess LLQ traffic is permitted only when all other queues have been emptied, meaning there is no interface congestion. The result is a queue that is always serviced as soon as possible, whenever it has traffic pending (the highest of all priorities, and only one `strict-high` queue is permitted per scheduler map), with a guarantee of at least the configured rate, while still permitting excess LLQ traffic when no other queues are congested.

The strict high-priority queuing feature allows you to configure traffic policing that prevents lower-priority queues from being starved. The strict-priority queue does not override a lower-priority queue when an output (egress) policer is defined to limit the traffic that the strict queue can service.

If these differences were not enough to confuse the innocent, the priority-based scheduler differs from the weight-based by honoring configured weight when servicing negative credit queues at the same priority. As a side effect, you can configure shaping within a policy-based scheduler. This `shaping-rate` can be less than the default 100%, but more than the configured transmit rate, which shapes the queue's output to the specified value while allowing limited used of unused bandwidth, as determined by the differences between the transmit and shaping rates.

Figure 10-14 shows the priority-based scheduler behavior.

The upper portion of Figure 10-14 shows the priority-based scheduling behavior, which results in the complete emptying of all queues at priority *n* before it moves to the next set of queues at priority *n* – 1. The configured transmit rate is significant only between classes at the *same* priority level. In this case, the higher-priority traffic associated with queue 1 is shown starving the two lower-priority queues. To resolve this issue, you need to either rate-limit the high-priority traffic or assign all queues to the same priority level.

The lower half of Figure 10-14 shows how the priority-based scheduler honors weight among negative credit queues at the same priority. Since no additional priority packets are pending in this example, the scheduler continues to serve the low-priority queues according to their weight, rather than using a simple round-robin scheme, as is the case with the M-series.

Although it's likely obvious, we are nonetheless explicitly stating here that, because of the differences in scheduler behavior, you cannot simply copy an existing M-series CoS configuration over to a J-series and just expect it to work the same way. Successful

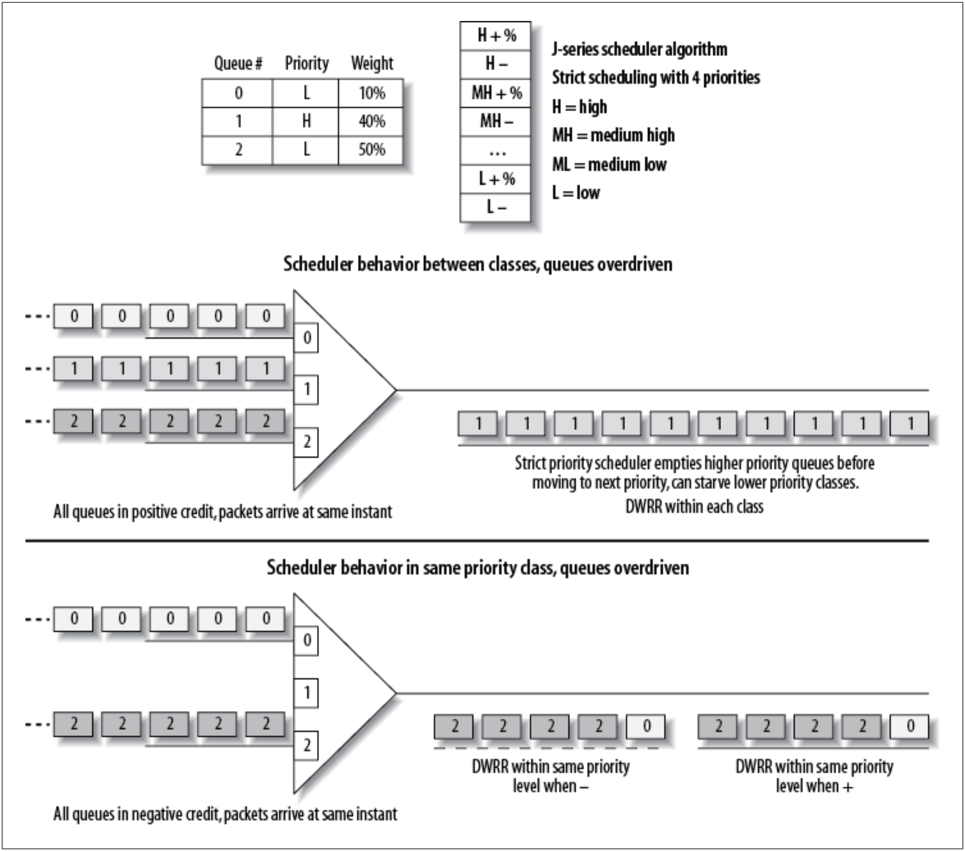
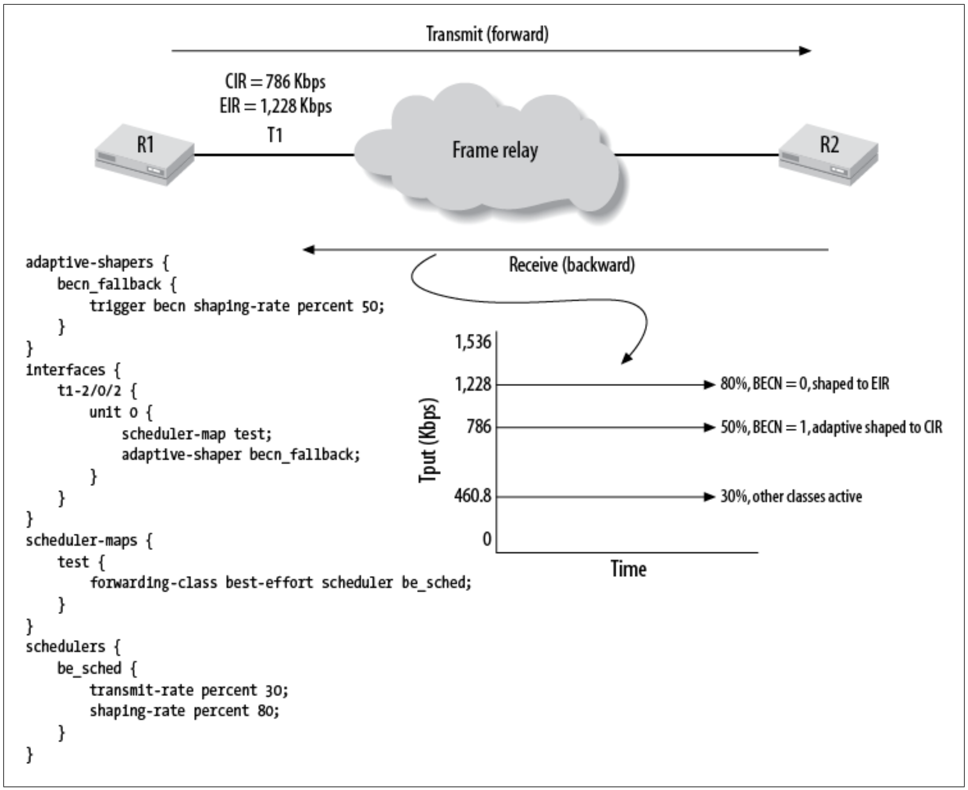

Queue #
Priority
Weight
0
L
10%
1
H
40%
2
L
50%
H + %
H –
MH + %
MH –
...
L + %
L –
J-series scheduler algorithm
Strict scheduling with 4 priorities
H = high
MH = medium high
ML = medium low
L = low
Scheduler behavior between classes, queues overdriven
All queues in positive credit, packets arrive at same instant
Strict priority scheduler empties higher priority queues before moving to next priority, can starve lower priority classes.
DWRR within each class
Scheduler behavior in same priority class, queues overdriven
All queues in negative credit, packets arrive at same instant
DWRR within same priority level when –
DWRR within same priority level when +

Figure 10-14. The priority-based scheduler

translation between the two scheduler models requires a complete understanding of the operational differences. The upcoming lab scenario provides an example of both a weight-based and a priority-based scheduler that meet the same requirements, and therefore provide similar operational behavior.

Virtual channels

SRXs and J-series routers support the notion of a virtual channel, which in the context of CoS is not a logical connection such as an ATM permanent virtual circuit (PVC), but instead a grouping of logical channels that share a common scheduler. We provide a virtual channel configuration example in "Virtual channels" on page 468, so a detailed discussion is held until that time. For now, it is sufficient to say that virtual channels are designed to accommodate Frame Relay hub and spoke topologies by allowing a central site with a high-speed attachment the ability to schedule traffic into each DLCI based on some maximum rate, which is typically matched to the remote site's access rate.



```
adaptive-shapers {
    becn_fallback {
        trigger becn shaping-rate percent 50;
    }
}
interfaces {
    t1-2/0/2 {
        unit 0 {
            scheduler-map test;
            adaptive-shaper becn_fallback;
        }
    }
}
scheduler-maps {
    test {
        forwarding-class best-effort scheduler be_sched;
    }
}
schedulers {
    be_sched {
        transmit-rate percent 30;
        shaping-rate percent 80;
    }
}
```

Figure 10-15. Adaptive shaping in response to network congestion

Adaptive shaping. Adaptive shaping is an SRX and J-series specific feature that allows the use of two output shapers, based on the current congestion state of a Frame Relay network. Figure 10-15 shows the adaptive shaping feature in action.

Figure 10-15 shows a pair of routers connected via Frame Relay. R1 is attached via a T1 interface and has a committed information rate (CIR) of 50% of T1 capacity, or 778 Kbps. The Frame service offers an extended burst through the excess information rate (EIR). EIR is not guaranteed, especially when the network experiences congestion, which is indicated in the forward direction by the receipt of frames with a set FECN bit, and in the backward direction with a set backward explicit congestion notification (BECN) bit.

The shaper for the BE class is set to 30% of the interface bandwidth. It is guaranteed only 30% of capacity, which equates to the 460.8 Kbps of throughput in this case. When other classes are not active, the BE class can burst to its shaped rate of 80%. The shaped rate matches the EIR parameter, which is good, because traffic in excess of the EIR can be discarded upon ingress by the network—the shaping configuration prevents immediate discard by limiting how much unused bandwidth the BE class can use. The maximum (EIR) rate is shown in the top throughput line and represents 80% of a T1's usable throughput.

An adaptive shaper is also configured and applied to the T1 interface. The adaptive shaper takes effect when the last frame received (assuming there is transmit traffic from R2 to R1) has a set BECN bit. When activated, the adaptive shaper enforces the CIR to prevent congestion-related discards within the network. When a frame is received with a cleared BECN bit, the adaptive shaper is removed and R1 is again able to send at the EIR, assuming that no other classes are active.

Junos Software CoS Defaults

Junos software comes with a set of default CoS settings that are designed to ensure that both transit and control plane traffic is properly classified and forwarded. The default CoS setting supports two forwarding classes (BE and NC) and implements an IP precedence-style BA classifier that maps network control into queue 3 while all other traffic is placed into queue 0 as BE. A scheduler is placed into effect on all interfaces that allocates 95% of the bandwidth to queue 0 and the remaining 5% to queue 3. Both of the queues are low priority, which guarantees no starvation in either platform.

A default WRED profile with a single loss point is placed into effect. The 100% drop at 100% fill setting effectively disables WRED.

No IP packet rewrite is performed with a default CoS configuration. Packets are sent with the same markers as when they were received.

Four forwarding classes, but only two queues

The default CoS configuration defines four forwarding classes: BE, EF, AF, and NC, which are mapped to queues 0, 1, 2, and 3, respectively. However, as noted earlier, there is no default IP classification that will result in any traffic being mapped to either the AF or the EF class. This is good, because as also noted earlier, no scheduling resources are allocated to queue 1 or 2 in a default CoS configuration. It's worth noting that the default MPLS EXP classifier table is capable of directing traffic into all four queues, but MPLS is not being deployed in this lab. Some very interesting and difficult-to-solve problems occur if you begin to classify AF or EF traffic without first defining and applying schedulers for those classes. Doing so typically results in intermittent communications (some small trickle credit is given to 0% queues to prevent total starvation) for the AF/EF classes; this intermittency is tied to the loading levels of the BE and NC queues, given that when there is no BE or NC traffic, more AF/EF can be sent, despite the 0% default weighting.

BA and rewrite marker templates

Junos creates a complete set of BA classifier and rewrite marker tables for each supported protocol family and type, but most of these tables are not used in a default CoS configuration. For example, there is both a default IP precedence (two actually) and a default DSCP classifier and rewrite table. You can view default and custom tables with the `show class-of-service classifier` or `show class-of-service rewrite-rule` command.

The default values in the various BA classifier and rewrite tables are chosen to represent the most common/standardized usage. In many cases, you will be able to simply apply the default tables. Because you cannot alter the default tables, it is suggested that you always create custom tables, even if they end up containing the same values as the default table. This does not involve much work, as you can copy the contents of the default tables into a customer table, and in the future, you will be able to alter the customer tables as requirements change.

In a default configuration, input BA classification is performed by the `ipprec-compatibility` table and IP rewrite is in effect, meaning the ToS marking of packets at egress match those at ingress. The only rewrite table in effect in a default configuration is for MPLS using the `exp-default` table.

CoS Summary

This section detailed the many common CoS capabilities of the Juniper router platforms, and it highlighted the few areas where their operation or capabilities differ. Despite these differences, the use of a common code base and CLI, combined with relatively consistent CoS handling, means that the same set of commands are used to configure and monitor CoS operation.

The next section applies the knowledge gained thus far in a practical CoS deployment and verification scenario. Despite the fact that the lab sections are such fun, you should consider taking another break to think about the material covered to this point and to review any areas with which you are not comfortable.

DiffServ CoS Deployment and Verification

It was a long time getting here, but you have arrived, and you are now ready to rush headlong into a Junos software-based CoS configuration and verification lab. Figure 10-16 provides the network topology for the IP DiffServ CoS deployment scenario.

There are a few things to note in Figure 10-16. The test topology is somewhat simplified, and the test bed lacks the external test equipment needed to accurately measure and verify data plane performance. The first issue is not really a problem, because a workable CoS configuration is somewhat repetitive, basically involving the need to put the same configuration bits, consistently, in lots of places. As such, any network with a clearly marked edge and distribution/core devices services is a workable model with which to demonstrate CoS configuration and operational verification.

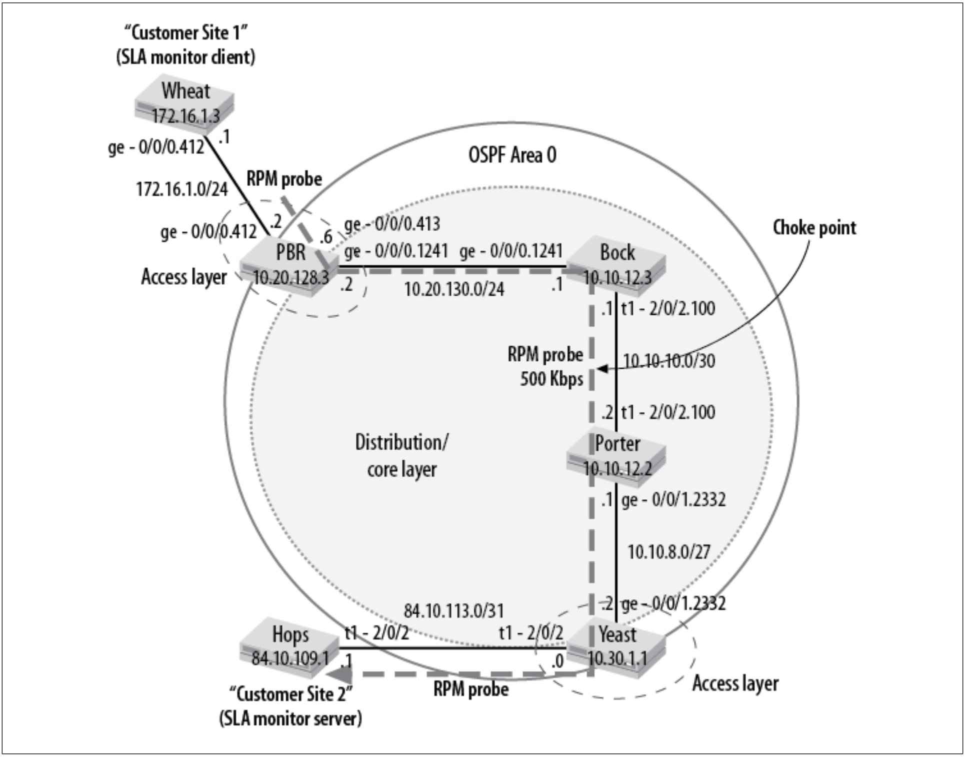


Figure 10-16. DiffServ CoS deployment topology

The subset of routers selected for the CoS topology was chosen in large part because of the (relatively) low-speed T1 interface interconnecting `Bock` and `Porter`. We noted previously that CoS matters only when link utilization begins to approach 80%. Obviously, with a given offered load, a slower link will exhibit higher utilization than a faster one—considering the lack of external traffic generators, it will be hard enough to congest a T1 link, let alone a 1 Gbps Ethernet. In fact, to help stack the odds against a successful CoS demonstration, the T1 link between `Bock` and `Porter` is shaped to 500 Kbps. Although considerably less than the full T1 rate of 1536 Kbps, the shaped rate still qualifies as a broadband connection, which maintains a fair degree of realism.

Why Not Test CoS with Control-Plane-Generated Traffic?

The only true way to measure the impact of any CoS configuration is through data plane stimulation using a *reputable* external traffic generator. We stress the term *reputable* here because any device that is used to diagnose problems that might relate to a few extra milliseconds of queuing delay has to be spot-on accurate and believable; otherwise, you are likely to find that folks blame unexpected results on the test methodology and tools rather than on the router's CoS performance. Software-based traffic generators exist, and they are certainly better than trying to generate test traffic from a router's control plane, but a real router tester, one that is hardware-based, can easily cost tens of thousands of dollars.

The Juniper Networks architecture separates the control and data planes, and various rate-limiting and prioritization functions within the PFE and routing engine conspire against any attempt to generate either large volumes of traffic or test traffic with a high degree of time-based accuracy. To expand, internal RE-based rate limits control how much traffic the RE can generate using rapid or flood pings. The PFE also has a rate limit as to how many such Internet Control Message Protocol (ICMP) echo request packets it will even try to pass up to the host RE. If that were not enough, handling ICMP messages is considered a low priority within Junos software. Given the choice of replying to a ping or processing a Border Gateway Protocol (BGP) route update, a Juniper router always chooses the latter. This is not to say that the router will not reply to the ping; quite the opposite—it most certainly will reply, but only when it's good and ready. Although exceedingly reasonable, this behavior results in significant variance in ping response, even in a network that is largely idle in the control plane and is transporting very little data.

Putting issues with time-based inaccuracies aside for the moment, the Junos software control plane simply does not generate enough traffic to congest most modern network links. With no congestion, there is no way to consistently demonstrate any benefit to a CoS configuration.

Consider the output taken between `PBR` and `Bock`, when the *only* traffic in the network is periodic OSPF hellos and the ICMP test traffic itself:

```
[edit]
lab@PBR# run traceroute 10.10.12.3
traceroute to 10.10.12.3 (10.10.12.3), 30 hops max, 40 byte packets
 1  10.10.12.3 (10.10.12.3)  10.519 ms  4.800 ms  6.902 ms
```

The traceroute confirms that the direct 1 Gbps link is used between `PBR` and `Bock`, yet notice the large variance in ping response times, which is normal and expected given the Juniper design:

```
[edit]
lab@PBR# run ping 10.10.12.3 count 20
PING 10.10.12.3 (10.10.12.3): 56 data bytes
64 bytes from 10.10.12.3: icmp_seq=0 ttl=64 time=2.926 ms
64 bytes from 10.10.12.3: icmp_seq=1 ttl=64 time=2.153 ms
64 bytes from 10.10.12.3: icmp_seq=2 ttl=64 time=2.137 ms
64 bytes from 10.10.12.3: icmp_seq=3 ttl=64 time=2.147 ms
64 bytes from 10.10.12.3: icmp_seq=4 ttl=64 time=3.969 ms
64 bytes from 10.10.12.3: icmp_seq=5 ttl=64 time=2.152 ms
. . .
64 bytes from 10.10.12.3: icmp_seq=8 ttl=64 time=1.947 ms
64 bytes from 10.10.12.3: icmp_seq=9 ttl=64 time=3.993 ms
64 bytes from 10.10.12.3: icmp_seq=10 ttl=64 time=3.989 ms
64 bytes from 10.10.12.3: icmp_seq=11 ttl=64 time=2.147 ms
64 bytes from 10.10.12.3: icmp_seq=12 ttl=64 time=2.136 ms
64 bytes from 10.10.12.3: icmp_seq=13 ttl=64 time=1.909 ms
```

```
64 bytes from 10.10.12.3: icmp_seq=14 ttl=64 time=2.137 ms

--- 10.10.12.3 ping statistics ---
20 packets transmitted, 20 packets received, 0% packet loss
round-trip min/avg/max/stddev = 9.868/16.122/69.799/14.835 ms
```

The highlighted entries show the degree of response time variance considered par for the course in the Juniper design. Clearly, trying to validate CoS using rapid pings is simply not workable in Junos software, because you will not be able to generate enough traffic to reliably congest most links. Also, the test results will be all over the map, whether or not your CoS configuration is working, simply because the endpoints generating the test traffic treat it as a low-priority process, thereby breaking the CoS chain at its first link.

Cannot control classification of locally generated traffic

Generally speaking, unless you are running Junos software Release 8.5 or later, you have virtually no control over what egress queue locally generated traffic is placed into. The basic issue here is that when the RE injects traffic into the PFE, it bypasses ingress multifield and BA classification and simply does what it feels is best.

For example, a BGP transmission is normally placed into the BE queue (0), unless it is a retransmission, in which case it goes into the NC queue (3). As another example, you can generate a ping with any arbitrary ToS pattern, but this ping will be locally classified as BE and placed into queue 0. Downstream nodes can be expected to correctly recognize the packet's ToS field, because they see the traffic as transit.

The inability to apply your transit CoS actions to locally generated traffic is yet another reason why you cannot test a local node's PHB with traffic sourced or received by that same node.

Starting on Junos Release 8.5 M-series and MX edge routers, the outbound queue assignments for routing-engine-generated traffic can be modified from their defaults. The use of the class-of-service host-outbound-traffic commands allows an administrator to change the default handling of outgoing traffic from the routing engine. This allows the use of queues other than 0 and 3 on the outgoing interfaces. The changes are global in nature, and the queues must be configured on the interfaces to have an effect on the traffic.

Enter resource performance monitoring

Juniper routers support an SLA monitoring feature that uses Real-Time Performance Monitoring (RPM) probes to measure performance, and if desired, to generate Simple Network Management Protocol (SNMP) alarms when performance falls below a configurable threshold. In the initial implementation, the RPM daemon ran as a user process in the RE—unfortunately, this resulted in inaccuracies when the RE CPU happened to be busy doing something else. Routers can move the timestamp function into the real-time thread for significantly improved accuracy (M10i routers require an Adaptive

Services PIC [ASP]). The use of hardware timestamps does not cause the actual generation or processing of the RPM probes to be any more accurate, as the RE will still schedule the processing as it sees fit, but when the RE does get around to looking at the probe, the timestamp, already added at the hardware layer, allows for accurate performance measurements.

Although not nearly as definitive as a *real* traffic generator, the RPM service automatically tracks loss and summarizes one-way and round-trip delays, including jitter measurements, which beats the heck out of using pings and a pad of paper. Also, because the RPM service is instantiated on a pair of routers that are *external* to the CoS test bed, maximum accuracy can be expected. By *external*, we mean that `Wheat` and `Hops` simulate attached CE devices and are not taxed with any packet forwarding (other than the locally generated RP probes themselves) or any other processing task that could lead to large variances in RPM test probe results—these routers are not running *any* other services, are not running any routing protocols, and are not involved in the FTP transfer used to produce congestion. In this lab topology, `Wheat` and `Hops` function strictly as SLA monitoring devices—which is actually a realistic scenario, as some service providers deploy routers in just such a capacity.

Configure DiffServ-Based CoS

Refer back to Figure 10-16 for the topology details of the IP DiffServ CoS scenario. You can assume that the network infrastructure is already configured with the interface addressing and single-area OSPF topology shown. A passive OSPF instance is enabled on the customer-facing interfaces at `PBR` and `Yeast` in order to provide reachability between their respective interface addresses. Your goal is to enable CoS in accordance with these criteria:

1. Perform the following multifield classification:
   - Classify ICMP timestamp messages received over customer-facing interfaces as EF to support RPM-based SLA monitoring for the EF class.
   - Classify Telnet traffic received over customer-facing interfaces as bronze (BR).
   - Classify OSPF in the core as NC.
   - Classify all other traffic as BE.
2. Perform DSCP-based BA classification at all other nodes, supporting the following forwarding classes and queue assignments:
   - BE, mapped to queue 0
   - EF, mapped to queue 1
   - BR, mapped to queue 2
   - NC, mapped to queue 3
3. Shape traffic on the Frame Relay link to 500 Kbps, in accordance with a 0 CIR service terminating in a 500 Kbps switch port.

4. Define and apply the following scheduler policy:
    - Provide BE at least 50% and allow use of excess bandwidth. Configure a PLP = 0 RED profile with 5% drop probability at 50%, and 20% drop probability at 80%, and a PLP = 1 RED profile with 20% drop probability at 50%, and 70% drop probability at 80%.
    - Limit BR to 10%; accept up to 1 Mbps/200 KB burst of BR from customers. Excess traffic must be treated as BE with high PLP by all nodes.
    - Provide EF at least 35% and ensure that it's serviced quickly to support low-latency applications. Traffic must not experience more than 30 milliseconds of buffering per hop.
    - Provide NC with at least 5% and ensure that it cannot be starved. The NC class must be able to use excess bandwidth.

At first glance, the long list of CoS requirements may seem daunting, but when tackled in small parts, the overall task becomes much easier to manage. CoS-related configurations tend to have a lot of common elements, which allows you to save time by configuring one node and then using that configuration as a template to bootstrap the configuration of the remaining routers.

Because the default CoS configuration offers scheduling support for the BE and NC classes only, it's a good idea to get much of the CoS infrastructure up and running before you apply any classification that could result in traffic being mapped into queues other than 0 and 3. This avoids potential disruption resulting from traffic being assigned to a queue with no scheduling resources assigned.

This scenario calls for the use of DSCP classification. Previous sections detailed how the original IP precedence functionality is subsumed by the CS code point grouping. The default DSCP rewrite and classifier tables support the CS DSCPs. This means you can use the default IP precedence classifier at the network's edges while the rest of CoS is configured, including the DSCP BA classification and rewrite in the distribution and core layers. Stated differently, the goal is to enable CoS for all four forwarding classes, while maintaining the pre-CoS classification of only two forwarding classes in an attempt to minimize disruptions stemming from a network with partial CoS configuration. When all nodes are CoS-aware, MF classification is activated at the edge to enable use of all four forwarding classes.

Multifield classification and policing (task 1)

The first set of CoS functions to be configured are the multifield classifiers used at the edges to perform initial classification actions on the traffic received from customers. This is accomplished with firewall filters, which also provide a hook into the policing needed for the EF class in this example. Because the customer devices do not run any routing protocol, there is no need to support NC classification at ingress. If NC support is needed, it's a good idea to define explicit multifield classifier support, because the results of ingress BA classification can be overwritten by a multifield classifier, which could lead to NC being placed into the BE queue.

A multifield classifier and associated policer meeting the requirements of this example are configured at PBR:

```
lab@PBR# show
policer police_bronze {
    if-exceeding {
        bandwidth-limit 1m;
        burst-size-limit 200k;
    }
    then {
        loss-priority high;
        forwarding-class best-effort;
    }
}
filter mf_classify {
    term classify_ef {
        from {
            protocol icmp;
            icmp-type [ timestamp timestamp-reply ];
        }
        then {
            count ef_in;
            forwarding-class expedited-forwarding;
            accept;
        }
    }
    term classify_bronze {
        from {
            protocol tcp;
            port telnet;
        }
        then {
            policer police_bronze;
            count bronze_in;
            forwarding-class bronze;
        }
    }
    term else_be {
        then {
            forwarding-class best-effort;
            accept;
        }
    }
}
```

The `classify_ef` term matches on ICMP timestamp-related messages, which are then classified as EF. This term supports the ICMP-based RPM probe request that is generated at `Wheat`, along with the probe replies generated at `Hops`. The `classify_bronze` term performs a similar function for matching Telnet traffic, except it also evokes a policer to limit traffic in this class. The associated `bronze_policer` is set with a traffic profile in accordance with the provided criteria for rate and burst size. Conforming traffic is handed back to the calling `classify_bronze` term, where it is classified as BR, while out-of-profile traffic is classified as BE with a high-loss priority. Both the EF- and BR-related terms evoke a counter action that can be used later when confirming that CoS handling and classification are working as expected. The final term matches on everything else for classification into the BE bin.

Although not shown, the same multifield classifier and policer configuration is also added to `Yeast`. Also, for reasons cited earlier, the multifield classifier is not yet placed into effect given that resources have not yet been defined for the EF or BR class.

BA classification and rewriting (task 2)

With multifield classification ready to be placed into effect, you move on to create the DSCP-based BA tables used by distribution and core layer devices for efficient packet classification. This example creates custom tables that are then populated with the defaults. This ensures full table population, which is a good housekeeping practice, given the required behavior of dispatching unmatched traffic into the BE queue. Note that unlike the default IP precedence classifier (which is actually in effect by default), the default DSCP tables support four forwarding classes: BE, AF, EF, and NC. This example replaces the AF class with a custom-defined class called `bronze` (BR). Once you define a forwarding class called BR and map it to queue 2, the classification and rewrite tables automatically associate any code point mapping to that queue as belonging to the BR class.

The default DSCP table entries do not support a high- and low-loss priority for BE traffic. To convey an ingress setting of PLP to other nodes, as required in this case study, you need to define an entry for BE traffic with high-loss priority. It is customary to use the least significant bit of a given BA field to denote loss priority, which is the approach taken here, such that the binary pattern 000000 is interpreted as BE with a low-loss priority, and binary 000001 indicates BE with a high-loss priority. Note how each entry in a BA classification should have a matching entry in the related rewrite table for consistent handling in downstream nodes.

The custom forwarding class definition and BA classification/rewrite configuration is shown at `Bock`:

```
[edit class-of-service]
lab@Bock# show forwarding-classes
queue 2 bronze;

[edit class-of-service]
lab@PBR# show classifiers
dscp dscp_classify {
    import default;
    forwarding-class best-effort {
        loss-priority high code-points 000001;
    }
}
```

```
[edit class-of-service]
lab@PBR# show rewrite-rules
dscp dscp_rewrite {
    import default;
    forwarding-class best-effort {
        loss-priority high code-point 000001;
    }
}
```

The `forwarding-classes` statement is used to define a new forwarding class alias called `bronze`, and to bind that alias to a queue number. In this case, only one nondefault forwarding class alias is needed, and it is correctly mapped to queue 2; in a default configuration, this queue number is associated with the AF alias.

The user-defined DSCP BA classifier and rewrite tables are assigned names that denote their function and are initially populated with the code point defaults. A single modified entry is added to support the conveyance of loss priority for the BE class to downstream nodes.

The custom forwarding class definition and DSCP classification/rewrite tables are placed into effect on all noncustomer-facing interfaces at all nodes. There is no harm in applying these tables to the customer-facing interfaces, but there isn't much gain either. The multifield classification that will be used at the edge makes any BA classifier superfluous, given that the `mf_classify` filter is written to classify *all* traffic that is received and overrides the results of any BA classification anyway. A rewrite marker at the customer edge is generally used only when you wish to reset packet markings to some agreed upon default, or to help obfuscate the markings that are significant in the core, which could be used as ammunition in a CoS-centered denial of service (DoS) attack. In this example, packets are handed to the egress customer device, with whatever marking they were received with on the core-facing interface.

Here is the application of the user-defined DSCP classifier and rewrite tables, again at `Bock`:

```
[edit class-of-service]
lab@Bock# show interfaces
ge-0/0/0 {
    unit 1241 {
        classifiers {
            dscp dscp_classify;
        }
        rewrite-rules {
            dscp dscp_rewrite;
        }
    }
}
t1-2/0/2 {
    unit 100 {
        classifiers {
            dscp dscp_classify;
        }
        rewrite-rules {
            dscp dscp_rewrite;
        }
    }
}
```

At this stage, the custom forwarding class definition and DSCP BA configuration is replicated to all nodes. The DSCP classifier and rewrite tables are then applied on all interfaces in the CoS topology, with the exception of the customer-facing interfaces, which do not use a BA classifier or rewrite table.

Completing the aforementioned steps at all routers has accomplished a large portion of the needed CoS configuration. To recap, you now have a multifield classifier with policing on the network's edges (not yet activated, however), you have defined a custom forwarding class call `bronze`, and you created and applied custom DSCP classifiers and rewrite rules to support loss priority for the BE class on all noncustomer-facing interfaces.

The DSCP tables currently use default values for any entry not explicitly specified by the user because the `import default` statement is included. The default code points inherently support the IP precedence-based classification that is still in effect at the network's edges. The use of the default IP precedence classifier, combined with the inherent compatibility of IP precedence via the CS DSCPs, results in all traffic being classified into either the BE or the NC class at ingress, just as it was before you began the CoS configuration. Importantly, the ingress classification is maintained end to end even though downstream devices classify based on DSCP. It's noted again that the default scheduler configuration, which is still in effect, allocates resources only to the BE and NC classes, meaning that actions to this point should have had no operational effect on the network. It could be said that for the average core node, the only changes are a newly defined but still unused forwarding class and the use of DSCP rather than default IP precedence ingress classification. However, the compatibility between the precedence and DSCP tables means that the packets are classified into BE or NC with both the original and modified configurations.

CoS shaping (task 3)

Shaping, which reduces the maximum speed of an interface to some lesser value, is useful for a variety of reasons. You can rate-limit an interface using a policer, but this is problematic from a CoS perspective because the CoS components do not see the policed rate, but rather the rate of the interface itself. As a result, policing a 1 Gbps interface to 1 Mbps, and then configuring a scheduler with a 1% transmit rate, leads the scheduler to allocate 1% of 1 Gbps, not the policed rate of 1 Mbps. Shaping performed at the `[edit class-of-service]` hierarchy works around this issue, but is supported on only M-series routers when using IQ/IQ2 PICs. J-series routers support shaping on all interfaces because of their built-in support for per-unit scheduling.

In this example, `Bock` and `Porter` are interconnected via a Frame Relay service provisioned with a 0 CIR, which terminates in a 500 Kbps port. Traffic sent in excess of the port speed results in immediate discard, so the T1 interfaces at `Bock` and `Porter` are shaped to a 500 Kbps rate. Later, when you apply a scheduler to these interfaces, the scheduler will allocate resources based on the *shaped* rate of 500 Kbps rather than the 1.536 Mbps physical rate. What follows are the Frame Relay interface configuration and related CoS shaping settings for `Bock`:

```
[edit]
lab@Bock# show interfaces t1-2/0/2
description Bock-to-porter;
per-unit-scheduler;
dce;
encapsulation frame-relay;
unit 100 {
    dlci 100;
    family inet {
        address 10.10.10.1/30;
    }
}

[edit]
lab@Bock# show class-of-service interfaces t1-2/0/2
unit 100 {
    shaping-rate 500k;
    classifiers {
        dscp dscp_classify;
    }
    rewrite-rules {
        dscp dscp_rewrite;
    }
}
```

The code highlights show the `per-unit-scheduler` statement, which is specified at the interface device level to back up the `shaping-rate` configuration at the `[edit class-of-service interfaces interface-name unit unit-number]` hierarchy. Also highlighted is the related Frame Relay configuration; in this case, `Bock` is set to a data circuit-terminating equipment (DCE) device to enable use of ANSI Annex D link integrity (keepalive) and PVC status polling from (default) data terminal equipment (DTE) `Porter`.

With shaping in place, the only CoS functionality yet to be configured is the scheduler definition and application to CoS-enabled interfaces.

Scheduler definition and application (task 4)

Up until this stage, the CoS configuration examples and steps shown are the same whether you are dealing with any platform. The differences in scheduler behavior between platforms demand careful consideration—you will generally need different scheduler configurations for a priority-based versus a weight-based to produce similar scheduling effects.

The scheduling requirements of this scenario were decided upon in equal parts because they are typical and because they help to demonstrate the differences in scheduling behavior. Table 10-4 summarizes the scheduling requirements.

Table 10-4. Summary of scheduling behavior for the DiffServ scenario

Class	Guaranteed rate	Priority; AQM; buffer	Excess bandwidth
BE	50%	Low; WRED based on PLP; N/A	Yes
BR	10%	Low; N/A; N/A	No/Yes, ingress policing sets excess as BE with PLP = 1
EF	35%	High; N/A; 30 msec	No
NC	5%	High; N/A; N/A	Yes

Weight-based scheduler definition. Table 10-4 shows that two priority levels are required to help expedite EF and NC traffic over BR and BE, and also details each queue's settings with regard to transmit weight, AQM (WRED)–enabled, buffer size restriction, and ability to use leftover bandwidth above its configured weight.

The following output shows a weight-based scheduler definition that meets all of the specified requirements:

```
[edit class-of-service]
lab@M-Series# show schedulers
be_sched {
    transmit-rate percent 50;
    priority low;
}
ef_sched {
    transmit-rate percent 35 exact;
    priority high;
    buffer-size temporal 30k;
}
nc_sched {
    transmit-rate percent 5;
    priority high;
}
bronze_sched {
    transmit-rate percent 10 exact;
    priority low;
}
```

The EF class does not require use of excess bandwidth and is rate-limited through the use of the `exact` keyword. This limits EF traffic to its configured weight, which helps to ensure that the class is not oversubscribed in downstream nodes. Because both the EF and NC classes are set to high priority, you can guarantee that neither can starve the other. By not specifying `strict-high`, you also ensure no starvation among low-priority queues should the nonpoliced NC class become overactive. This is because the weight-based scheduler round-robins between high-priority queues until their transmit weight has been satisfied, and then moves on to service low-priority queues with positive credit.

The EF scheduler has its buffer depth manually set to 30 milliseconds of delay bandwidth (30,000 microseconds). This queue's relative high transmit weight combined with its high priority means it should maintain a low fill level anyway. The reduced buffer size and rate limiting leads to drops in the EF queue during periods of excessive EF traffic, even when all other classes are idle. In most cases, trying to accept overflow EF traffic—for example, by reclassifying the excess into another class or by configuring ever-larger buffer depths—results in more harm than good. This is because although you may reduce the overall number of EF drops, the resultant increase in delay and delay variance is often more disruptive to a real-time application than the outright loss such actions aimed to prevent. Worse yet, troubleshooting this type of problem is difficult when compared to the relatively straightforward task of correlating service complaints to excessive EF queue drops.

You cannot use the `exact` keyword for NC scheduling because of the requirement that it be able to use any excess bandwidth. Without some form of policing/rate limiting, it is possible that excess NC traffic could capitalize on all unused bandwidth, preventing both the BE and BR classes from being able to send traffic above their configured weights. Although it's easy enough to police NC traffic, this is seen as unnecessary here because:

- There is no requirement that the BE and BR classes must actually get excess bandwidth, just that they should be able to use it when it's available. Because M-series scheduling is not strict-priority-based, you need to worry about having high-priority queues affecting a low-priority queue's ability to get at least its configured weight.
- You are not accepting any NC traffic from customer/end devices, which means the only source of NC traffic is within the network, and you trust your network not to launch an NC-based DoS attack. The only source of NC in this network is OSPF, which unlike a full BGP table feed, does not generate appreciable volumes of NC. This is especially true for a small- to medium-scale network that is mostly stable.

The BR scheduler is also shaped to its transmit rate via the `exact` keyword; recall that ingress policing classifies excess BR as BE, so the BR class gets its excess bandwidth indirectly via the BE class.

Priority-based scheduler definition. Here is an example of a priority-based scheduler, found on J-Series routers, that closely approximates the weight-based example just described:

```
be_sched {
    transmit-rate percent 50;
    priority low;
}
ef_sched {
    transmit-rate percent 35 exact;
    priority high;
    buffer-size temporal 30k;
}
nc_sched {
    transmit-rate percent 5;
    shaping-rate percent 20;
    priority high;
}
bronze_sched {
    transmit-rate percent 10 exact;
    priority medium-high;
}
```

Because of the strict priority-base nature scheduler, your first concern should be how to ensure that higher-priority classes do not prevent lower-priority classes from at least getting their configured weight. This is accomplished in a number of ways.

First the EF and NC classes are set to the same priority, which is the highest priority configured. This ensures that the EF and NC classes cannot be starved, and that they cannot starve each other. The EF class is again capped to its configured weight using `exact`. In this example, the NC class is *shaped*, rather than rate-limited, allowing it to use up to 20% of interface bandwidth.

Although not able to send at line rate, technically this meets the requirement given because the NC class is able to use excess bandwidth beyond its configured weight. This behavior differs from the weight-based scheduler example, where the NC class could use up to 100% of available bandwidth when no other classes are active, but again, the behavior still meets all criteria specified.

Second, the shaped rate of 20% for the NC class, combined with the maximum 35% rate for the EF class, accounts for only 55% of transmit bandwidth. This leaves a guarantee that at least 45% of the bandwidth remains for use by the BE and BR classes. The BR class is serviced after the high-priority queues have reached their limits, but before the BE class due to its higher priority setting. Because the BR class is limited to a maximum of 10%, you can guarantee that the BE class will get at least 35% of interface bandwidth, using the following formula:

BE avail% = 100 – (EF max + NC max + BR max)
BE avail% = 100 – (35 + 20 + 10)
BE avail% = 100 – 65

The net result of all this interaction is that the BE class is *actually* guaranteed to get 35% of transmit bandwidth, despite its configured 50% weight. However, this reduction in BE capacity occurs *only* during periods of excessive NC activity, an event that should be both rare and transient. Besides, any negative impacts of the design are relegated to the BE class where folks are used to being treated poorly, so who will complain?

An Alternative Priority-Based Scheduler Approach

Although not demonstrated here, you can more closely approximate weight-based scheduler behavior by defining additional forwarding classes that are used to support overflow traffic from higher-priority classes and that are serviced only when no other *real* class has traffic pending. This approach is quite workable on the routers, given the support of eight queues/forwarding classes.

Here is an example of the alternative scheduler approach:

```
be_sched {
    transmit-rate percent 49;
    priority low;
}
ef_sched {
    transmit-rate percent 35 exact;
    priority high;
    buffer-size temporal 30k;
}
nc_sched {
    transmit-rate percent 5 exact;
    priority high;
}
bronze_sched {
    transmit-rate percent 10 exact;
    priority medium-high;
}
nc_overflow_sched {
    transmit-rate percent 1;
    priority low;
}
```

Note that the scheduler now supports five classes. The new forwarding class is defined as `nc_overflow`, and the related scheduler is assigned a low priority, as well as a minimal transmit rate designed to minimize impact on the BE class. The NC scheduler is now configured with an exact transmit rate of 5%. The support of excess NC is now backed up by a policer (not shown) that limits NC to 5% of the interface speed, which for Gigabit Ethernet would be 50 Mbps.

To configure a policer that is based on a percentage of interface bandwidth, you must add the `interface-specific` keyword to the firewall filter that calls the policer.

Traffic exceeding the policer profile is classified as `nc_overflow`. Because the `nc-overflow` and BE classes are assigned the same priority, you ensure that excessive amounts of BE traffic cannot starve the NC overflow queue. This is a matter of choice here, as the requirements do not mandate that the NC class *always* be able to send more than its weight, just that it be able to when excess bandwidth is available.

With the alternative configuration, the NC class gets a guaranteed 5% as NC, and an additional 1% BE transmit rate, and can burst up to 100% when no other classes are active (95% of which will be treated as BE). At the same time, the BE class is now guaranteed to get at least 49% when all other classes are active and can burst to line rate when they are not. This configuration meets all requirements, and offers the additional benefit of allowing the NC scheduler to operate at 100% when other classes are idle.

Define RED Profiles

To complete the definition of the BE scheduler, you must define two drop profiles—one for PLP 0 and another for PLP 1 traffic—and link them to the `be_sched` scheduler. The drop profiles are shown, and the BE scheduler is updated to incorporate them. The same WRED configuration applies to any Juniper routers because the requirements do not expect drop behavior that is tied to TCP versus UDP, which is not supported on some models. This is an example of WRED because two drop profiles are defined; in this case, the weighting is toward the internal loss-priority status of each packet in the BE queue:

```
[edit class-of-service]
lab@PBR# show drop-profiles
be_low_plp {
    fill-level 50 drop-probability 5;
    fill-level 80 drop-probability 50;
}
be_high_plp {
    fill-level 50 drop-probability 50;
    fill-level 80 drop-probability 70;
}

[edit class-of-service]
lab@PBR# show schedulers be_sched
transmit-rate percent 50;
priority low;
drop-profile-map loss-priority low protocol any drop-profile be_low_plp;
drop-profile-map loss-priority high protocol any drop-profile be_high_plp;
```

The remaining forwarding classes use the default RED profile, which effectively disables RED given that the only drop point specified is 100% drop at 100% fill.

Scheduler application

The priority-based version of the scheduler definition is used in this example, in keeping with the J-series makeup of the enterprise routing lab. You apply a scheduler to an interface through a `scheduler-map` statement. Here is a working scheduler map and its application to all CoS-enabled interfaces, shown at node `PBR`:

```
[edit class-of-service]
lab@PBR# show scheduler-maps
er_cos_scheduler {
    forwarding-class best-effort scheduler be_sched;
    forwarding-class expedited-forwarding scheduler ef_sched;
    forwarding-class network-control scheduler nc_sched;
    forwarding-class bronze scheduler bronze_sched;
}
```

```
[edit class-of-service]
lab@PBR# show interfaces
ge-0/0/0 {
    unit 412 {
        scheduler-map er_cos_scheduler;
    }
    unit 1241 {
        scheduler-map er_cos_scheduler;
        classifiers {
            dscp dscp_classify;
        }
        rewrite-rules {
            dscp dscp_rewrite;
        }
    }
}
```

The `scheduler-map` links each defined forwarding class to a scheduling policy. When applied to an interface, a scheduler is instantiated according to the combined policy of the statements in the `scheduler-map`. Note that in this example the use of VLAN tagging warrants the need for per-unit scheduling, which enables scheduling at the logical interface—that is, at the VLAN level. By default, a per-unit scheduler assumes the full physical interface bandwidth, unless it is shaped to a lesser value. The scheduler map shown will fail to commit unless `per-unit-scheduling` is also set at the `[edit interfaces interface-name]` hierarchy, as shown:

```
[edit]
lab@PBR# show interfaces ge-0/0/0
per-unit-scheduler;
vlan-tagging;
unit 412 {
    description PBR-to-Wheat;
    vlan-id 412;
    family inet {
        address 172.16.1.2/24;
    }
}
unit 1241 {
    description PBR-to-Bock;
    vlan-id 1241;
    family inet {
        address 10.20.130.2/24;
    }
}
```

Activate multifield classification

Now that all forwarding classes have been defined with scheduling resources and you have a consistent BA classification scheme deployed throughout the network, it is safe to activate the previously defined multifield classification filter at edge nodes `PBR` and `Yeast`. The filter and related policer were defined in a previous step; all that is left now is to apply the filter in the input direction on all customer-facing interfaces:

```
[edit]
lab@PBR# show interfaces ge-0/0/0 unit 412
description PBR-to-Bock;
vlan-id 412;
family inet {
    filter {
        input mf_classify;
    }
    address 172.16.1.2/24;
}
```

The complete configuration

The various parts of the CoS configuration have been shown and discussed individually. Here is the complete CoS configuration at ingress node PBR, to give you a better perspective of the big picture:

```
[edit]
lab@PBR# show class-of-service | no-more
classifiers {
    dscp dscp_classify {
        import default;
        forwarding-class best-effort {
            loss-priority high code-points 000001;
        }
    }
}
drop-profiles {
    be_low_plp {
        fill-level 50 drop-probability 5;
        fill-level 80 drop-probability 50;
    }
    be_high_plp {
        fill-level 50 drop-probability 50;
        fill-level 80 drop-probability 70;
    }
}
forwarding-classes {
    queue 2 bronze;
}
interfaces {
    ge-0/0/0 {
        unit 412 {
            scheduler-map er_cos_scheduler;
        }
        unit 1241 {
            scheduler-map er_cos_scheduler;
            classifiers {
                dscp dscp_classify;
            }
            rewrite-rules {
                dscp dscp_rewrite;
            }
        }
    }
```

```
}
rewrite-rules {
    dscp dscp_rewrite {
        import default;
        forwarding-class best-effort {
            loss-priority high code-points 000001;
        }
    }
}
scheduler-maps {
    er_cos_scheduler {
        forwarding-class best-effort scheduler be_sched;
        forwarding-class expedited-forwarding scheduler ef_sched;
        forwarding-class network-control scheduler nc_sched;
        forwarding-class bronze scheduler bronze_sched;
    }
}
schedulers {
    be_sched {
        transmit-rate percent 50;
        priority low;
        drop-profile-map loss-priority low protocol any drop-profile be_low_plp;
        drop-profile-map loss-priority high protocol any drop-profile be_high_plp;
    }
    ef_sched {
        transmit-rate percent 35 exact;
        buffer-size temporal 30k;
        priority high;
    }
    nc_sched {
        transmit-rate percent 5;
        shaping-rate percent 20;
        priority high;
    }
    bronze_sched {
        transmit-rate percent 10 exact;
        priority medium-high;
    }
}

[edit]
lab@PBR# show interfaces ge-0/0/0per-unit-scheduler;
vlan-tagging;
unit 412 {
    description PBR-to-Wheat;
    vlan-id 412;
    family inet {
        filter {
            input mf_classify;
        }
        address 172.16.1.2/24;
    }
}
unit 1241 {
    description PBR-to-Bock;
```

```
        vlan-id 1241;
        family inet {
            address 10.20.130.2/24;
        }
    }

    [edit]
    lab@PBR# show firewall
    policer police_bronze {
        if-exceeding {
            bandwidth-limit 1m;
            burst-size-limit 200k;
        }
        then {
            loss-priority high;
            forwarding-class best-effort;
        }
    }
    filter mf_classify {
        term classify_ef {
            from {
                protocol icmp;
                icmp-type [ timestamp timestamp-reply ];
            }
            then {
                count ef_in;
                forwarding-class expedited-forwarding;
                accept;
            }
        }
        term classify_bronze {
            from {
                protocol tcp;
                port telnet;
            }
            then {
                policer police_bronze;
                count bronze_in;
                forwarding-class bronze;
            }
        }
        term else_be {
            then {
                forwarding-class best-effort;
                accept;
            }
        }
    }
```

Most of the CoS configuration is common to all nodes, with the exception of interface names and the presence of multifield versus BA classification at customer-facing interfaces. Recall that T1 interface shaping is also in effect at nodes `Bock` and `Porter`. The `t1-2/0/2` CoS configuration is displayed to show the shaping configuration, and the interface is set for DSCP-based BA classification and DSCP rewrite:

```
[edit]
lab@Bock# show class-of-service interfaces t1-2/0/2
unit 100 {
    scheduler-map er_cos_scheduler;
    shaping-rate 500k;
    classifiers {
        dscp dscp_classify;
    }
    rewrite-rules {
        dscp dscp_rewrite;
    }
}
```

Verify DiffServ-Based CoS

With the routers configured, it's time to verify that all this CoS mumbo jumbo actually amounts to a hill of beans, and better yet, happy end users.

Whenever you feel that a CoS-related configuration is not doing what you expected, it is a good idea to monitor the system's messages and cosd logfiles while you perform a commit. Some misconfigurations (or a configuration that requires some bit of missing hardware to function correctly) often pass the commit check while generating a log message, indicating that some aspect of the configuration is being ignored and for what reason.

A number of operational mode commands display CoS configuration, and more important, operational status. Most you can access with the show class-of-service command:

```
lab@PBR> show class-of-service ?
Possible completions:
  <[Enter]>      Execute this command
  adaptive-shaper      Show trigger types and associated rate for adaptive shaper
  classifier           Show mapping of code point to forwarding class/loss priority
  code-point-aliases   Show mapping of symbolic name to code point bit pattern
  drop-profile         Show interpolated data points of named drop profile
  forwarding-class     Show mapping of forwarding class names to queue numbers
  forwarding-table     Show forwarding table information
  fragmentation-map    Show mapping of forwarding classes to fragmentation options
  interface            Show mapping of CoS objects to interfaces
  loss-priority-map    Show mapping of code point to loss priority
  rewrite-rule         Show mapping of forwarding class/loss priority to code point
  scheduler-map        Show mapping of forwarding classes to schedulers
  traffic-control-profile  Show traffic control profiles
  virtual-channel      Show virtual channel names
  virtual-channel-group  Show virtual channel group information
```

To save space, we will call upon the various commands when actually needed to verify CoS in the test network; we will cover the virtual channel and adaptive shaper-related commands in the next section.

You will also find that general firewall and the `show interface queue` commands come in particularly handy when checking CoS behavior—the former because firewall filters are used for multifield classification and to help debug CoS through match and count operations, and the latter because the resultant per-queue packet and drop counts provide critical information needed to verify classification-general queuing behavior. The `show interface queue` command is hardware dependent and might not be available on some routers.

Also note that you have the relative luxury of a test bed that, aside from OSPF, is completely quiescent unless stimulated in some way by user traffic, which is under your control. This makes it quite easy to confirm packet classification and general queuing behavior and to test the overall effects of CoS. This luxury is rarely afforded on a production network, and it is why it is always a good idea to stage a new CoS rollout in a proof-of-concept test bed where it is easy to validate and debug the results.

Confirm general CoS configuration

Things start at edge node PBR, where confirmation of the required forwarding classes is performed:

```
lab@PBR> show class-of-service forwarding-class
Forwarding class                       ID             Queue  Policing Priority
  best-effort                           0                 0           normal
  expedited-forwarding                  1                 1           normal
  bronze                                2                 2           normal
  network-control                       3                 3           normal
```

All four forwarding classes are present, including the custom `bronze` class. Good. You next verify CoS-related interface parameters for the core-facing Gigabit Ethernet interface at PBR with the `show class-of-service interface` command:

```
lab@PBR> show class-of-service interface ge-0/0/0.1241
  Logical interface: ge-0/0/0.1241, Index: 70
    Object              Name                 Type        Index
    Scheduler-map       er_cos_scheduler     Output      21207
    Rewrite             dscp_rewrite         dscp        26780
    Classifier          dscp_classify        dscp        25819
```

The output confirms that the `er_cos_scheduler` map is in effect, and shows that the custom `dscp_classify` classifier and `dscp_rewrite` rewrite tables have been applied. The index numbers are used internally when referencing the various tables or scheduler map instances. The makeup of the `er_cos_scheduler` is now confirmed:

```
lab@PBR> show class-of-service scheduler-map er_cos_scheduler
Scheduler map: er_cos_scheduler, Index: 21207

  Scheduler: be_sched, Forwarding class: best-effort, Index: 54989
    Transmit rate: 50 percent, Rate Limit: none, Buffer size: remainder,
    Priority: low
    Excess Priority: unspecified
    Drop profiles:
      Loss priority    Protocol    Index    Name
      Low             any          45889    be_low_plp
      Medium low      any              1    <default-drop-profile>
      Medium high     any              1    <default-drop-profile>
      High            any          14464    be_high_plp

  Scheduler: ef_sched, Forwarding class: expedited-forwarding, Index: 5877
    Transmit rate: 35 percent, Rate Limit: exact, Buffer size: 30000 us,
    Priority: high
    Excess Priority: unspecified
    Drop profiles:
      Loss priority   Protocol    Index    Name
      Low             any             1    <default-drop-profile>
      Medium low      any             1    <default-drop-profile>
      Medium high     any             1    <default-drop-profile>
      High            any             1    <default-drop-profile>

  Scheduler: bronze_sched, Forwarding class: bronze, Index: 26824
    Transmit rate: 10 percent, Rate Limit: exact, Buffer size: remainder,
    Priority: medium-high
    Excess Priority: unspecified
    Drop profiles:
      Loss priority   Protocol    Index    Name
      Low             any             1    <default-drop-profile>
      Medium low      any             1    <default-drop-profile>
      Medium high     any             1    <default-drop-profile>
      High            any             1    <default-drop-profile>

  Scheduler: nc_sched, Forwarding class: network-control, Index: 22188
    Transmit rate: 5 percent, Rate Limit: none, Buffer size: remainder,
    Priority: high
    Excess Priority: unspecified
    Shaping rate: 20 percent,
    Drop profiles:
      Loss priority   Protocol    Index    Name
      Low             any             1    <default-drop-profile>
      Medium low      any             1    <default-drop-profile>
      Medium high     any             1    <default-drop-profile>
      High            any             1    <default-drop-profile>
```

The output of the `show class-of-service scheduler-map` command contains a lot of gold. The various highlights call out key differences in the scheduler behavior for each forwarding class. For example, the BE class is associated with the two RED drop profiles that are indexed against packet loss priority. All other forwarding classes link to the default RED profile. The EF scheduler's high priority is called out, as is the time-based constraint on its buffer size.

The BR scheduler is called out for its `medium-high` priority, and its rate-limiting through use of `exact`. Excess traffic in this BR class is reclassified as high-loss BE, affording this class an indirect way of getting unused bandwidth. The NC scheduler has a 20% shaping rate, which caps that queue at 20% of the transmit bandwidth, even when all other forwarding classes are idle.

It's critical to note that in this example, the only mechanism that prevents higher-priority schedulers from starving lower-priority schedulers is the rate limiting achieved through use of either the `exact` or the `shaping-rate` keyword. As an alternative, you could also use a firewall-based policer to provide the isolation needed between traffic classes for a successful DiffServ deployment.

The RED profiles associated with the BE class are displayed:

```
ab@PBR> show class-of-service drop-profile
Drop profile: <default-drop-profile>, Type: discrete, Index: 1
  Fill level    Drop probability
         100                 100
Drop profile: be_high_plp, Type: discrete, Index: 14464
  Fill level    Drop probability
          50                  50
          80                  70
Drop profile: be_low_plp, Type: discrete, Index: 45889
  Fill level    Drop probability
          50                   5
          80                  50
```

The output confirms the 100%/100% setting for the default drop profile, and the two custom RED profiles reflect the required drop points, which differ for high versus low-loss priority BE traffic. You now confirm the DSCP BA and rewrite tables. For brevity's sake, we show only a portion of the classification table:

```
lab@PBR>show class-of-service classifier type dscp name dscp_classify
Classifier: dscp_classify, Code point type: dscp, Index: 25819
  Code point         Forwarding class                  Loss priority
  000000             best-effort                       low
  000001             best-effort                       high
  000010             best-effort                       low
  000011             best-effort                       low
. . .
```

The highlighted code calls out the custom portion of the table, which defines a high-loss priority BE class code point. With the basic components of CoS configuration confirmed, it's time to move on to confirm data plane behavior.

Verifying Control and Data Plane Consistency

Most of the operational-mode CoS commands shown in this chapter have a forwarding table counterpart. Generally speaking, the output of control plane versus data plane forwarding table-related commands should agree. In some cases, a configuration may be rejected, and as a result the changes are not pushed into the forwarding table. When troubleshooting a CoS problem, it's always a good idea to look for CoS-related log messages when you commit, and to confirm that the forwarding table state matches the configuration and related control plane displays. The following code sample taken from `PBR` shows that the forwarding table's view of the DSCP rewrite function does in fact match the configuration:

```
[edit]
lab@PBR# run show class-of-service forwarding-table rewrite-rule
Rewrite table index: 26780, # entries: 4, Table type: DSCP
FC#  Low bits  State    High bits  State    Medium     State    Medium     State
                                            Low bits            High bits
0   000000   Enabled   000001    Enabled
1   101110   Enabled   101110    Enabled
2   001010   Enabled   001100    Enabled
3   110000   Enabled   111000    Enabled
```

The output confirms that packets placed into queue 0, the BE queue, will have their DSCP rewritten to binary 000000 when classified as low loss, or 000001 when classified as high loss. The default DSCP classifier supports loss priority for the AF (now called `bronze`) and NC classes. User customization was required for BE loss priority support. The default settings for queue 1 (EF) result in the same marker regardless of PLP status.

Confirm classification and queuing

Displayed here for reference is the RPM-related configuration for the SLA monitoring client `Wheat`. We will display and analyze the actual RPM probe status later in this section:

```
[edit]
lab@Wheat# show services
rpm {
    probe test_cos {
        test icmp_timestamp_cos {
            probe-type icmp-ping-timestamp;
            target address 84.10.109.7;
            probe-count 2;
            probe-interval 1;
            test-interval 1;
            history-size 15;
            data-size 574;
            hardware-timestamp;
        }
    }
    probe-limit 100;
}
```

The RPM configuration defines a test called `icmp_timestamp_cos` that is owned by the `test_cos` entity. The target address specifies `Hops`'s `ge-0/0/0.3233` interface address. Various other parameters are specified to control probe frequency, test count, and test repetition rate. In this case, we expect to see one probe generated each second, with two such probes constituting a test group and a new test beginning one second later. The service is configured to retain 15 history samples, which given these settings, represents approximately 15 seconds' worth of performance data.

The SLA probe routers support timestamping within the real-time forwarding thread, which is enabled with the `hardware-timestamp` keyword. This significantly decouples general control plane activity from the processing of the probe message timestamps, thereby offering significantly improved accuracy.

No specific configuration is needed at the probe server because ICMP messages are replied to by default; the use of a TCP or UDP test probe requires a server configuration to ensure that a matching process is created to listen for incoming probe requests.

Multifield classification. CoS is configured in the test network in a symmetric, bidirectional manner. Still, it sometimes helps to think in a simplex manner when verifying CoS. Once proper behavior is verified in the `Wheat-to-Hops` direction, you simply perform the same steps, but now in the opposite direction, to obtain full confirmation of CoS operation.

You begin confirmation of multifield classification at `PBR` because `Wheat` is the source of EF test probes. To ensure a clean slate, you clear all firewall and interface counters at `PBR`, and the interface counters at all other nodes; here are the commands issued on `PBR`:

```
lab@PBR> clear firewall all

lab@PBR> clear interfaces statistics all
```

After a few moments, you display the firewall counters associated with the `mf_classify` filter:

```
lab@PBR> show firewall filter mf_classify
Filter: mf_classify
Counters:
Name                                               Bytes      Packets
ef_in                                              56488           92
bronze_in                                              0            0
Policers:
Name                                             Packets
police_bronze-classify_bronze                          0
```

The firewall counter and related policer output is a good indication that `PBR` is correctly classifying EF traffic. The presence of ICMP test probes is registering as EF traffic, and the lack of a Telnet session keeps the `bronze` class at zero. The `police_bronze` policer, which is called from the `classify_bronze` term, has a 0 count, indicating that no out-of-profile BR traffic has been reclassified as BE. Given that there is currently no traffic in the BR class, this too is in keeping with expectations.

To test the BR classification, a Telnet session is opened and subsequently closed, between `Wheat` and `Hops`:

```
lab@Wheat# run telnet 84.10.109.7
Trying 84.10.109.7...
Connected to 84.10.109.7.
Escape character is '^]'.

hops (ttyp0)

login: lab
Password:

--- Junos 10.4R1.9built 2010-10-13 04:50:17 UTC
```

```
lab@hops> exit

Connection closed by foreign host.

[edit]
```

Correct multifield classification for the BR class is confirmed by redisplaying the counters associated with the multifield classifier:

```
lab@PBR> show firewall | match bronze
bronze_in                                       1986    35
police_bronze-classify_bronze                      0
```

The `bronze_in` counter correctly reflects the generated Telnet traffic, which confirms multifield classification for BR traffic.

BA classification. There is no firewall counter for the BE class in this example. To verify correct BE classification, and for that matter, general BA classification among all nodes in the forwarding path between `Wheat` and `Hops`, you examine egress queue statistics using the `show interfaces queue` command. In this example, the command is run on the customer-facing interface of egress node `Yeast`. Observing the expected queue statistics here goes a long way toward confirming that network-wide BA classification is working correctly.

Before looking at the queue stats, we stimulate the BE class with some regular (not timestamp related) pings from `Wheat` to `Hops`. Recall that except for the background OSPF, this network is otherwise completely idle, which makes it easier to correlate test traffic to queuing statistics:

```
[edit]
lab@Wheat# run ping 84.10.109.7 rapid count 10
PING 84.10.109.7 (84.10.109.7): 56 data bytes
!!!!!!!!!!
--- 84.10.109.7 ping statistics ---
10 packets transmitted, 10 packets received, 0% packet loss
round-trip min/avg/max/stddev = 9.972/20.469/32.392/7.602 ms
```

Here are the egress queuing statistics for the customer-facing interface at router `Yeast`:

```
lab@Yeast# run show interfaces queue ge-0/0/0.3233
  Logical interface ge-0/0/0.3233 (Index 69) (SNMP ifIndex 41)
Forwarding classes: 8 supported, 4 in use
Egress queues: 8 supported, 4 in use
Burst size: 0
Queue: 0, Forwarding classes: best-effort
  Queued:
   Packets             :                    10            0 pps
    Bytes              :                  1020            0 bps
  Transmitted:
    Packets            :                   10             0 pps
    Bytes              :                 1020             0 bps
    Tail-dropped packets :                  0             0 pps
    RED-dropped packets  :                  0             0 pps
     Low               :                    0             0 pps
```

```
      Medium-low         :                     0              0 pps
      Medium-high        :                     0              0 pps
      High               :                     0              0 pps
     RED-dropped bytes   :                     0              0 bps
      Low                :                     0              0 bps
      Medium-low         :                     0              0 bps
      Medium-high        :                     0              0 bps
      High               :                     0              0 bps
Queue: 1, Forwarding classes: expedited-forwarding
  Queued:
    Packets              :                   130              0 pps
    Bytes                :                 82160           5000 bps
  Transmitted:
    Packets              :                   130              0 pps
    Bytes                :                 82160           5000 bps
    Tail-dropped packets :                     0              0 pps
    RED-dropped packets  :                     0              0 pps
     Low                 :                     0              0 pps
     Medium-low          :                     0              0 pps
     Medium-high         :                     0              0 pps
     High                :                     0              0 pps
    RED-dropped bytes    :                     0              0 bps
     Low                 :                     0              0 bps
     Medium-low          :                     0              0 bps
     Medium-high         :                     0              0 bps
     High                :                     0              0 bps
Queue: 2, Forwarding classes: bronze
  Queued:
    Packets              :                    36              0 pps
    Bytes                :                  2686              0 bps
  Transmitted:
    Packets              :                    36              0 pps
    Bytes                :                  2686              0 bps
    Tail-dropped packets :                     0              0 pps
    RED-dropped packets  :                     0              0 pps
     Low                 :                     0              0 pps
     Medium-low          :                     0              0 pps
     Medium-high         :                     0              0 pps
     High                :                     0              0 pps
    RED-dropped bytes    :                     0              0 bps
     Low                 :                     0              0 bps
     Medium-low          :                     0              0 bps
     Medium-high         :                     0              0 bps
     High                :                     0              0 bps
Queue: 3, Forwarding classes: network-control
  Queued:
    Packets              :                     0              0 pps
    Bytes                :                     0              0 bps
  Transmitted:
    Packets              :                     0              0 pps
    Bytes                :                     0              0 bps
    Tail-dropped packets :                     0              0 pps
    RED-dropped packets  :                     0              0 pps
     Low                 :                     0              0 pps
     Medium-low          :                     0              0 pps
     Medium-high         :                    0               0 pps
     High                :                    0               0 pps
    RED-dropped bytes    :                    0               0 bps
     Low                 :                    0               0 bps
     Medium-low          :                    0               0 bps
     Medium-high         :                    0               0 bps
     High                :                    0               0 bps
```

The display is long, but mostly repetitive in that the same information is repeated for each defined forwarding class. The command output displays the number of bytes/packets queued and transmitted—any differences in these counts indicate some type of drop. Tail and RED-induced drops are each counted, allowing you to determine the nature of any drops that happen to occur.

The sample output shows that no drops have occurred, and it reflects that the 10 ordinary ICMP packets (non-timestamp-related) were classified as BE, that ongoing traffic is being tallied as EF (the RPM probes), and that 36 BR packets have been classified (the Telnet session). The NC queue is shown at zero, which is expected given that OSPF is not actively sending hellos on the `Hops`–facing interface. These results show that initial multifield classification at the edge is correctly conveyed among all nodes in the path via BA classification.

Confirm that all this CoS stuff actually does something

To this point the various operational mode commands have returned expected results, which imply that CoS is correctly configured and is up and doing its thing. But how can you really prove the benefit, especially when lacking external packet generation equipment?

The use of highly accurate RPM timestamp probes, combined with the relatively low-speed link (the 500 Kbps [shaped] between `Bock` and `Porter`), should allow a repeatable demonstration of IP CoS benefits.

No CoS benchmark

You begin by obtaining a no CoS network baseline. Later, when CoS is reenabled, the before and after results allow you to accurately gauge what effects CoS has in the current test bed. You remove CoS by stripping down the `class-of-service` stanza at `Bock` and `Porter` to leave only the 500 Kbps shaping rate. Remember, a CoS chain is only as strong as the weakest link, so removing CoS-aware packet handling at the 500 Kbps choke point should fatally weaken the entire chain. This actually provides an interesting demonstration of how a consistent PHB in *all nodes* is critical to overall CoS success—a single misconfigured router can ruin CoS performance on an end-to-end basis.

The modified CoS configuration is displayed at `Bock`:

```
[edit]
lab@Bock# show class-of-service
interfaces {
    t1-2/0/2 {
        unit 100 {
            shaping-rate 500k;
        }
    }
}
```

Meanwhile, back at `Wheat`, connectivity is confirmed and the RPM service is temporarily deactivated to ensure that a fresh history is created:

```
[edit]
lab@Wheat# run ping 84.10.109.7 rapid count 10
PING 84.10.109.7 (84.10.109.7): 56 data bytes
!!!!!!!!!!
--- 84.10.109.7 ping statistics ---
10 packets transmitted, 10 packets received, 0% packet loss
round-trip min/avg/max/stddev = 9.884/22.581/39.944/9.170 ms

[edit]
lab@Wheat# deactivate services

[edit]
lab@Wheat# commit
```

An FTP transfer is started between `Porter` and `Bock`. Once the transfer begins, the RPM service is activated at `Wheat`:

```
[edit]
lab@Porter# run ftp 10.10.12.3
Connected to 10.10.12.3.
220 Bock FTP server (Version 6.00LS) ready.
Name (10.10.12.3:lab): lab
331 Password required for lab.
Password:
230 User lab logged in.
Remote system type is UNIX.
Using binary mode to transfer files.
ftp> mget ju*
mget junos-jseries-10.0R2.8-domestic.tgz? y
200 PORT command successful.
150 Opening BINARY mode data connection for 'junos-jseries-10.0R2.8-domestic.tgz'
 (38563456 bytes).
0%  44888      14:19 ETA
```

With the transfer underway, the RPM service is reactivated:

```
[edit]
lab@Wheat# activate services

[edit]
lab@Wheat# commit
```

The probes are allowed to run for 15 to 30 seconds to get some statistical accuracy. The RPM history is displayed at `Wheat`:

```
[edit]
lab@Wheat# run show services rpm history-results
  Owner, Test                 Probe received          Round trip time
```

```
test_cos, icmp_timestamp_cos Mon Oct 29 00:58:53 2010   266417 usec
test_cos, icmp_timestamp_cos Mon Oct 29 00:58:54 2010   265010 usec
test_cos, icmp_timestamp_cos Mon Oct 29 00:58:55 2010   237000 usec
. . .
test_cos, icmp_timestamp_cos Mon Oct 29 00:59:08 2010   268167 usec
test_cos, icmp_timestamp_cos Mon Oct 29 00:59:09 2010   171237 usec
```

The display confirms some pretty long round-trip times, some as long as 265 milliseconds. Given that the one-way target delay for Voice over IP is only 150 milliseconds, it's safe to say there is no joy for IP telephony users in the current network.

You can display details about each probe, along with an average for all completed tests, using the `show services rpm probe-results` command:

```
[edit]
lab@Wheat# run show services rpm probe-results
    Owner: test_cos, Test: icmp_timestamp_cos
    Target address: 84.10.109.7, Probe type: icmp-ping-timestamp,
    Test size: 2 probes
    Probe results:
      Response received, Mon Oct 29 00:59:17 2010,
      Client and server hardware timestamps
      Rtt: 300236 usec, Round trip jitter: 283526 usec,
      Round trip interarrival jitter: 95059 usec
    Results over current test:
      Probes sent: 1, Probes received: 0, Loss percentage: 100
    . . .
    Results over all tests:
        Probes sent: 53, Probes received: 49, Loss percentage: 7
      Measurement: Round trip time
        Samples: 49, Minimum: 16710 usec, Maximum: 300236 usec,
        Average: 199529 usec, Peak to peak: 283526 usec, Stddev: 81768 usec
      Measurement: Positive round trip jitter
        Samples: 25, Minimum: 421 usec, Maximum: 283526 usec,
        Average: 82333 usec, Peak to peak: 283105 usec, Stddev: 75539 usec
      Measurement: Negative round trip jitter
        Samples: 23, Minimum: 1407 usec, Maximum: 280411 usec,
        Average: 88507 usec, Peak to peak: 279004 usec, Stddev: 71908 usec
```

The highlights call out that some probes are being lost, and that the average round-trip delay is more than 199 milliseconds. Note that average one-way jitter is rather large at some 82 milliseconds.

The CoS benchmark

OK, drum roll, please...a lot of work has led up to this point, and now it is time for the CoS rubber to meet the road, as it were. You restore the CoS configuration at `Bock` and `Porter`, and again deactivate the RPM service at `Wheat` to reset for a new test.

A new FTP session is started between `Porter` and `Bock`:

```
[edit]
lab@Porter# run ftp 10.10.12.3
Connected to 10.10.12.3.
220 Bock FTP server (Version 6.00LS) ready.
```

```
. . .
mget junos-jseries-10.0R2.8-domestic.tgz? y
200 PORT command successful.
150 Opening BINARY mode data connection for 'junos-jseries-10.0R2.8-domestic.tgz'
 (38563456 bytes).
  0%  31856       40:12 ETA
```

With the new FTP session underway, the RPM service is again activated at `Wheat`:

```
[edit]
lab@Wheat# activate services

[edit]
lab@Wheat# commit
```

As before, we again wait 30 seconds or so to allow some RPM statistics to accumulate. After a long 30 seconds, the results are displayed:

```
[edit]
lab@Wheat# run show services rpm history-results
  Owner, Test                 Probe received         Round trip time
  test_cos, icmp_timestamp_cos Mon Oct 29 01:08:52 2010   17236 usec
  test_cos, icmp_timestamp_cos Mon Oct 29 01:08:53 2010   20896 usec
  . . .
  test_cos, icmp_timestamp_cos Mon Oct 29 01:09:06 2010   17769 usec
  test_cos, icmp_timestamp_cos Mon Oct 29 01:09:07 2010   18294 usec
  test_cos, icmp_timestamp_cos Mon Oct 29 01:09:08 2010   19068 usec
```

Well, the history results are far, far better than observed in the no-CoS benchmark. The round-trip delays now average only 18 milliseconds, as opposed to the 200+ result observed with no CoS. Once again, probe details are displayed:

```
[edit]
lab@Wheat# run show services rpm probe-results
    Owner: test_cos, Test: icmp_timestamp_cos
    Target address: 84.10.109.7, Probe type: icmp-ping-timestamp,
    Test size: 2 probes
    Probe results:
      Response received, Mon Oct 29 01:09:12 2010,
      Client and server hardware timestamps
      Rtt: 24557 usec, Round trip jitter: -13326 usec,
      Round trip interarrival jitter: 8125 usec
    Results over current test:
      Probes sent: 2, Probes received: 2, Loss percentage: 0
      Measurement: Round trip time
        Samples: 2, Minimum: 24557 usec, Maximum: 37883 usec,
        Average: 31220 usec, Peak to peak: 13326 usec, Stddev: 6663 usec
    . . .
    Results over all tests:
      Probes sent: 58, Probes received: 58, Loss percentage: 0
      Measurement: Round trip time
        Samples: 58, Minimum: 16455 usec, Maximum: 44654 usec,
        Average: 22455
 usec, Peak to peak: 28199 usec, Stddev: 7167 usec
      Measurement: Positive round trip jitter
       Samples: 28, Minimum: 506 usec, Maximum: 26628 usec, Average: 8293 usec,
        Peak to peak: 26122 usec, Stddev: 8134 usec
      Measurement: Negative round trip jitter
        Samples: 29, Minimum: 7 usec, Maximum: 25318 usec, Average: 7781 usec,
        Peak to peak: 25311 usec, Stddev: 6889 usec
```

The probe details confirm that CoS has made a dramatic impact on network performance, at least when congestion is present and you are a member of the EF class! The average round-trip time is 22 milliseconds and the average one-way jitter is now only 8 milliseconds. A quick look at `Bock`'s T1 interface stats confirms that all drops are confined to the BE class, and that the drops stem from the low-loss priority RED profile:

```
lab@Bock# run show interfaces queue t1-2/0/2.100
   Logical interface t1-2/0/2.100 (Index 69) (SNMP ifIndex 39)
Forwarding classes: 8 supported, 8 in use
Egress queues: 8 supported, 8 in use
Burst size: 0
Queue: 0, Forwarding classes: best-effort
  Queued:
    Packets              :                 32519              0 pps
    Bytes                :              48570458              0 bps
  Transmitted:
    Packets   :                            30047              0 pps
    Bytes                :              44852756              0 bps
    Tail-dropped packets :                     0              0 pps
    RED-dropped packets  :                  2472              0 pps
     Low                 :                  2472              0 pps
     Medium-low          :                     0              0 pps
     Medium-high         :                     0              0 pps
     High                                      0              0 pps
```

Note that the total queued versus transmitted packet counters for the BE class differ by the same number as displayed under RED drops. This confirms that RED is kicking in when the BE queue begins to fill. The lack of tail drops implies that the TCP-based FTP source correctly sensed the loss as an indication of congestion, and began to slow down the rate of traffic by reducing the window size.

Comparing pre- and post-CoS results leaves little doubt that Junos software CoS works. The only question that remains is "Why are you still here reading this, when you should be adding CoS to your network now?"

DiffServ Deployment Summary

This section demonstrated how Juniper Networks routers are configured to provide end-to-end CoS based on the DiffServ model. This involves the use of multifield classification at the network's edges and custom BA classification in the core to convey loss priority for the BE class.

The scenario also demonstrated three different approaches to scheduling, two of which were based on the priority-based schedules and one on the weight-based scheduler.

We demonstrated the use of shaping, policing, and rate limiting to preserve class isolation, as well as the operational mode commands that allow you to confirm proper CoS behavior and operation. We proved that the Junos software CoS solution works through the use of external LSA monitoring probes that show a clear benefit to the CoS configuration when link congestion occurred.

The next section details specific CoS capabilities that are designed to enhance interworking with Frame Relay. You should make sure you are comfortable with the configuration and confirmation examples used in this section before proceeding.

Adaptive Shapers and Virtual Channels

This section focuses on SRX and J-series specific CoS capabilities that are designed to work with Frame Relay. The virtual channel and adaptive shaping features help to optimize Frame Relay–based transport. Note that currently you cannot combine the functionality of an adaptive shaper with that of a virtual channel.

Configure Adaptive Shaping

Recall that `Bock` and `Porter` are connected via a 0 CIR Frame Relay service terminating in a 500 Kbps port. With the newly added DiffServ-based CoS infrastructure now in place, the idea of a 0 CIR service has been revisited. The result is a decision to pay extra for a guaranteed CIR of 256 Kbps, with the ability to burst to port speed via an EIR of 244 Kbps (CIR + EIR = port speed).

Simply configuring a scheduler or shaper that allows the router to send at maximum speed, all the time, is problematic because during network congestion only the CIR traffic is guaranteed for delivery. Ideally, you want to send at the EIR rate *only* when the network is not congested, and then fall back to the CIR when congestion is detected, in an effort to ensure that congestion-induced discards do not negate your CoS SLAs. This capability is exactly what adaptive shaping provides.

The configurations at `Bock` and `Porter` are updated to support adaptive shaping. The modified configuration at `Bock` is shown:

```
[edit class-of-service]
lab@Bock# show adaptive-shapers
becn_shaper {
    trigger becn shaping-rate 256k;
}

[edit class-of-service]
lab@Bock# show interfaces t1-2/0/2
unit 100 {
    scheduler-map er_cos_scheduler;
    adaptive-shaper becn_shaper;
    shaping-rate 500k;
    classifiers {
        dscp dscp_classify;
    }
    rewrite-rules {
        dscp dscp_rewrite;
    }
}
```

The changes to the configuration are highlighted, and they show the definition of an adaptive shaper called `becn_shaper`. The adaptive shaper is set to trigger on receipt of a set BECN bit, at which point the scheduler begins to shape to 256 Kbps. This rate matches the service's CIR, which prevents discards and the resulting impact to your CoS SLA. When the last frame received has a cleared BECN, the interface begins to schedule back into the 500 Kbps rate.

Here, use the `show class-of-service interface` and `show class-of-service adaptive-shaper` commands to verify adaptive shaping:

```
[edit class-of-service]
lab@Bock# run show class-of-service adaptive-shaper
Adaptive shaper: becn_shaper, Index: 44416
  Trigger type    Shaping rate
        BECN        256000 bps

[edit class-of-service]
lab@Bock# run show class-of-service interface t1-2/0/2.100
  Logical interface: t1-2/0/2.100, Index: 69
    Shaping rate: 500000
    Object                  Name                    Type       Index
    Scheduler-map           er_cos_scheduler        Output     21207
    Adaptive-shaper         becn_shaper                        44416
    Rewrite                 dscp_rewrite            dscp       26780
    Classifier              dscp_classify           dscp       25819
```

The displays confirm that the adaptive shaper is correctly programmed and placed into effect on `Bock`'s Frame Relay interface.

Virtual Channels

Virtual channels are used to ensure that a central site with a high bandwidth connection does not overrun remote sites that access the network at slower rates. Figure 10-17 illustrates a typical hub and spoke Frame Relay topology. The headquarters site has a significantly higher access rate when compared to the branch office spokes.

The key point of Figure 10-17 is that the central site terminates at a T1 switch port in the service provider's network, while the remote sites are terminated at significantly lower speeds. In a Frame Relay service, the absolute limit on data transfer rate is the logical port speed, which can be lower than the transmission link's physical bit rate; for example, Site 1 is using a Fractional T1 (FT1) circuit to access the provider, but pays for only 128 Kbps of port speed and can use only 128 Kbps of the T1's capacity. Regardless of CIR rate or the state of network congestion, Site 1 and Site 2 are physically limited to the reception of no more that 128/256 Kbps of traffic, respectively.

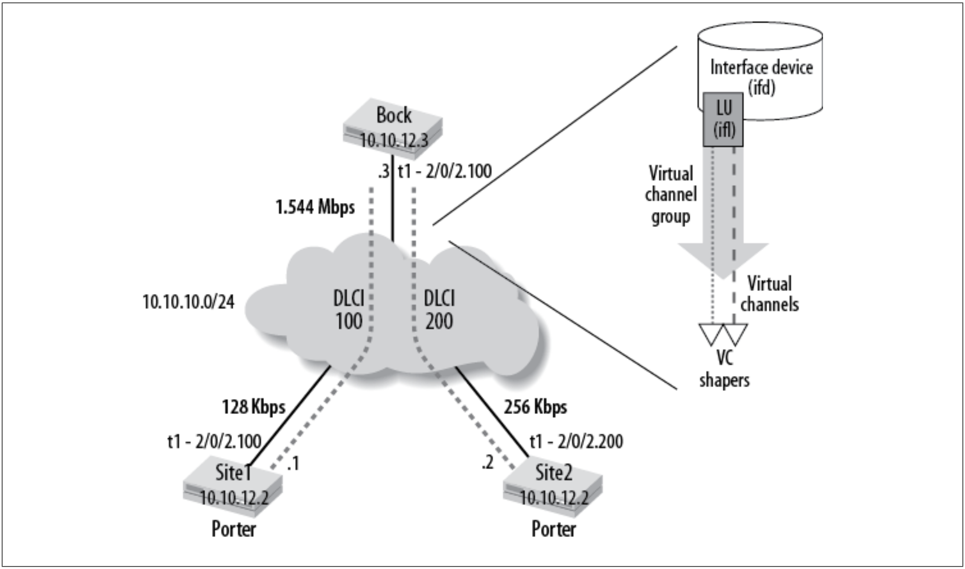


Figure 10-17. J-series virtual channels

The problem, if not already obvious, is that the central site can easily burst to full T1 rates, and if these bursts are of any appreciable duration, there will be massive loss due to buffer overflow in the network. This causes TCP-based sources to sense congestion and throttle back. If not corrected, this can lead to an ongoing boom/bust cycle as the sources ramp up, sense loss, and then ramp back down, resulting in diminished throughput and higher latency due to buffering within the network. This is more than a simple issue of not knowing each virtual channel's CIR, as the topology shown in Figure 10-17 may well be based on a 0 CIR service. The issue is simply one of mismatched port speed over a network that does offer extensive buffering.

A virtual channel group is a collection of virtual channels that are applied to a logical interface. Each virtual channel within the group has its own queues and `scheduler-map`, and each can be shaped to a rate that is less than the physical interface speed. In some cases, you may choose to shape a virtual channel based on CIR, but in most cases the shaping rate is set to the lesser of the two port speeds. When not shaped, each virtual channel can burst to full interface speed, and when multiple unshaped virtual channels are active, they each get a round-robin fair share of the total physical interface bandwidth. There is no priority scheduling between virtual channels.

Firewall filters are used to direct traffic to the correct virtual channel based on some match condition—for example, the destination address. Unmatched traffic is sent to a default virtual channel. This requires that one virtual channel be designated as the default within each virtual channel group.

Configure virtual channels

The lack of Frame Relay switching results in the need to use `Porter` twice—once as Site 1 using DLCI 100 and again as Site 2 with DLCI 200. This is why Figure 10-17 shows the same `lo0` address for both Sites 1 and 2. Because there is no virtual channel configuration at remote sites, this example focuses on `Bock`, the central site router. In this example, we do not bother with a virtual router (VR) instance for the second connection from `Porter` to `Bock`; instead, a new logical unit is added to the `t1-2/0/2` interface with a unique host ID, and the original IP address is reassigned under unit 100 to match the addressing shown in Figure 10-17:

```
[edit]
lab@Porter# show interfaces t1-2/0/2
description Porter-to-Bock;
per-unit-scheduler;
encapsulation frame-relay;
unit 100 {
    dlci 100;
    family inet {
        address 10.10.10.1/24;
    }
}
unit 200 {
    dlci 200;
    family inet {
        address 10.10.10.2/24;
    }
}
```

The addressing results in a duplicate subnet shared between units 100 and 200, but this is not a problem here:

```
[edit]
lab@Porter# run show ospf neighbor
  Address          Interface         State      ID             Pri  Dead
10.10.8.2        ge-0/0/1.2332     Full       10.30.1.1      128    31
10.10.10.1       t1-2/0/2.100      Full       10.10.12.3     128    31
10.10.10.1       t1-2/0/2.200      Full       10.10.12.3     128    30

[edit]
lab@Porter# run show route 10.10.10/24

inet.0: 14 destinations, 16 routes (14 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.10.0/24      *[Direct/0] 00:01:46
                    > via t1-2/0/2.200
                    [Direct/0] 00:01:46
                    > via t1-2/0/2.100
                    [OSPF/10] 00:01:45, metric 65
                    > via t1-2/0/2.100
10.10.10.1/32      *[OSPF/10] 00:01:45, metric 65
                    > via t1-2/0/2.200
                      via t1-2/0/2.100
```

```
10.10.10.2/32      *[Local/0] 00:01:46
                      Local via t1-2/0/2.100
10.10.10.3/32      *[Local/0] 00:01:46
                      Local via t1-2/0/2.200
```

The result is OSPF adjacencies over both the 100 and 200 logical units and two equal cost routes to `Bock`'s IP address. Things are more interesting at `Bock`, where a multipoint Frame Relay interface is defined to create the logical connectivity shown in Figure 10-17:

```
[edit]
lab@Bock# show interfaces t1-2/0/2
description Bock-to-porter;
per-unit-scheduler;
dce;
encapsulation frame-relay;
unit 100 {
    multipoint;
    family inet {
        address 10.10.10.3/24 {
            multipoint-destination 10.10.10.1 dlci 100;
            multipoint-destination 10.10.10.2 dlci 200;
        }
    }
}
```

The modified configuration maps two locally defined DLCIs on the same logical interface to each associated IP address; DLCI 100 leads to Site 1's 10.10.10.1 address and DLCI 200 maps to the address of Site 2 and the 10.10.10.2 address. Per-unit scheduling must be enabled on the physical interface to support scheduling into each virtual channel.

At first glance, the `show route` command at `Bock` indicates that all traffic for the 10.10.10/24 subnet will use the same link, as indicated by the absence of logical unit 200:

```
[edit]
lab@Bock# run show route 10.10.10.2

inet.0: 12 destinations, 13 routes (12 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.10.10.0/24      *[Direct/0] 00:13:24
                    > via t1-2/0/2.100
                    [OSPF/10] 00:13:12, metric 130
                    > to 10.10.10.2 via t1-2/0/2.100
```

The route to 10.10.10.2 seems to indicate that `Bock` plans to use the wrong DLCI, given that DLCI 200 maps to Site 2, not Site 3. The forwarding table, however, correctly reflects the correct IP-to-DLCI mapping as configured under the multipoint Frame Relay interface:

```
[edit]
lab@Bock# run show route forwarding-table destination 10.10.10.1
```

```
Routing table: inet
Internet:
Destination      Type RtRef Next hop     Type Index NhRef Netif
10.10.10.1/32    dest     0 dlci: 100    ucst   334     5 t1-2/0/2.100

[edit]
lab@Bock# run show route forwarding-table destination 10.10.10.2
Routing table: inet
Internet:
Destination      Type RtRef Next hop     Type Index NhRef Netif
10.10.10.2/32     dest     0 dlci: 200   ucst   336     1 t1-2/0/2.100
```

With the Frame Relay aspects confirmed, you move on to the virtual channel configuration:

```
[edit class-of-service]
lab@Bock# show virtual-channels
site1_default;
site2;
```

Two virtual channels are defined, one for each remote site. Here, Site 1 is set as the default virtual channel. Traffic that is routed out the logical interface to which the virtual channel group is applied will default to the virtual channel for Site 1, unless directed via a firewall filter to Site 2. The virtual channel group configuration is displayed:

```
[edit class-of-service]
lab@Bock# show virtual-channel-groups

er_vc_group {
    site1_default {
        scheduler-map er_cos_scheduler;
        shaping-rate 128k;
        default;
    }
    site2 {
        scheduler-map er_cos_scheduler;
        shaping-rate 256k;
    }
}
```

A virtual channel group configuration links multiple virtual channel definitions together for application to a logical interface. Here, the `er_vc_group` configuration links the `site1` and `site2` definitions, much like a `scheduler-map` links multiple scheduler policies. When applied to a logical interface, eight queues are created for each virtual channel associated with the group, and a `scheduler-map` is used to control scheduling into each set of per-virtual-channel queues. This example shapes each virtual channel to the remote site's port speed, but if desired, some virtual channels can be left unshaped to allow bursting up to physical interface speed.

The virtual channel group is applied to an interface, at the logical unit level. You will not be able to commit the configuration unless you remove any adaptive shaping, shaping, or `scheduler-map` configuration on the same logical unit:

```
[edit class-of-service]
lab@Bock# show interfaces t1-2/0/2
unit 100 {
    virtual-channel-group er_vc_group;
    classifiers {
        dscp dscp_classify;
    }
    rewrite-rules {
        dscp dscp_rewrite;
    }
}
```

The final step in the virtual channel configuration is the definition of the filter that directs traffic to the correct virtual channel, where it is in turn shaped according to the remote site's port speed. Recall that one virtual channel in each group must be designated the default virtual channel, which means it's used when no explicit virtual channel mapping is found. A working virtual channel mapping filter is shown at `Bock`:

```
[edit]
lab@Bock# show firewall
filter er_vc_select {
    term select_site2 {
        from {
            destination-address {
                10.10.10.2/32;
            }
        }
        then {
            virtual-channel site2;
            accept;
        }
    }
    term default_to_site1 {
        then {
            virtual-channel site1_default;
            accept;
        }
    }
}
```

Do

The `er_vc_select` filter matches on packets addressed to Site 2 and directs them to the scheduler/shaper associated with the `site2` virtual channel. Any traffic not matched by the `select_site2` term is matched by the `default_to_site1` term, which results in a mapping to the default virtual channel. The `er_vc_select` filter is placed into service in the output direction:

```
[edit]
lab@Bock# show interfaces t1-2/0/2 unit 100 family inet filter
output er_vc_select;
```

To confirm that your virtual channel configuration is active on a given interface, use the `show class-of-service interface` command:

```
[edit]
lab@Bock# run show class-of-service interface t1-2/0/2.100
```

```
    Logical interface: t1-2/0/2.100, Index: 70
    Object                  Name                    Type       Index
    Virtual-channel-group   er_vc_group                        55210
    Rewrite                 dscp_rewrite            dscp       26780
    Classifier              dscp_classify           dscp       25819
```

The `show class-of-service virtual-channel-group` command confirms the details of `er_vc_group`:

```
[edit]
lab@Bock# run show class-of-service virtual-channel-group
   Virtual channel group: er_vc_group, Index: 55210
        Virtual channel: site1_default
                Scheduler map: er_cos_scheduler
                Shaping rate : 128000 bps
        Virtual channel: site2
                Scheduler map: er_cos_scheduler
                Shaping rate : 256000 bps
```

Currently, you cannot obtain per-virtual-channel queuing statistics from the CLI. The output of the `show interfaces queue t1-2/0/2.100` command displays the aggregate packet counts for all virtual channels in effect on the interface.

Adaptive Shaping and Virtual Channel Summary

This section demonstrated the configuration and operational analysis of the SRX- and J-series-specific adaptive shaper and virtual channel features. The former allows dynamic switching between two shapers, one based on the service's CIR and another on the EIR, based on the congestion state of the network, as signaled by received BECN bits. By sending at or below the CIR during periods of network congestion, you avoid loss, and when the congestion clears, you are able to send at the EIR rate with a high probability of delivery, given the lack of congestion.

The virtual channel feature is designed to allow a central site route with a high-speed attachment to shape into individual virtual channels, with each such virtual channel dimensioned according to the remote site's port speed (or CIR). The goal of this feature is to prevent buffer overrun and loss that can occur when a site with a high-speed access rate sends to a remote site that is attached at a much slower speed.

Conclusion

IP CoS is an enabling factor for many value-added services, or a cost-effective convergence onto a single network infrastructure. Even though bandwidth may be relatively cheap and links always seem to get faster, you can still deploy CoS to ensure that you get the most of whatever bandwidth your network has to work with. All Juniper Networks routers support a robust and practical set of CoS capabilities that, given the general design of Juniper products, can be enabled in any production network without concerns of performance degradation or unpredictable behavior.

The future is IP-based, and more and more services are being adapted to IP transport each day. By deploying an effective CoS solution early, you gain a competitive advantage, now and in the future, because you will find you can confidently roll out new and ever-more-demanding applications, knowing that your network will make the most of its resources to deliver the goods that matter most.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Describe the uses of CoS.
- Explain CoS processing on Junos routers.
- Identify the ways traffic can be classified.
- Explain the purpose of BAs.
- Explain the use of policers.
- Describe how traffic is mapped to queues.
- Configure the mapping of forwarding classes to queues.
- Explain the role of a scheduler.
- Configure a scheduler to service queues based on a CoS design.
- Monitor a CoS implementation.
- Configure BA and multifield classification.
- Congestion management and avoidance.
- Code point rewriting.
- Rate-limiting with shaping, policing, or both.
- Adaptive shapers and virtual channels.

Chapter Review Questions

1. Which IP CoS approach requires signaling to reserve resources?
   A. IP ToS
   B. IntServ
   C. DiffServ
   D. ATM
2. In the DiffServ architecture, what is a BA?
   A. A sequence of packets with a shared marking, crossing a given link
   B. The collective behavior of all nodes in the domain

C. The act of aggregating multiple reservations into a single, larger one, for scalability

D. None of the above

3. How do you convey packet loss priority to a downstream node?

   A. By implementing the same multifield classifiers as used originally at the ingress

   B. This is not possible because the IP header does not support a loss-priority flag

   C. You must reclassify all packets with high loss priority into a forwarding class reserved for that purpose

   D. Use a BA rewrite table with a matching BA classifier

4. Which of the following is true?

   A. On the J-series, strict-high and high are the same priority

   B. On the M-series, strict-high is a separate priority

   C. You must use the `exact` option with a strict-high queue to prevent starvation

   D. Policing should be used when strict-high is set, especially on the J-series

5. What is the purpose of the `shaping-rate` statement in the following code snippet?

```
test_sched {
     transmit-rate percent 5;
     shaping-rate percent 20;
     priority high;
 }
```

   A. It ensures that this queue cannot starve other queues of their configured weight

   B. It limits how much traffic this queue can send, even when all other queues are idle

   C. It shapes the traffic allowed by the transmit rate so that at least 20% of the packets are not clumped

   D. This is used in adaptive shaping, in order to set the maximum transmit rate when the network is not congested

6. When committing a CoS configuration, you notice the following log message. What does it mean?

```
Oct 30 05:39:15  Bock cosd[1071]: COSD_TX_QUEUE_RATES_TOO_HIGH: Unable to apply
scheduler map af-sched to interface t1-2/0/0: sum of scheduler transmission
rates exceeds interface shaping or transmission rate
```

   A. There is a problem in the configuration and the default settings are in effect

   B. There is a problem in the configuration, causing it to fail commit

   C. There is a problem in the configuration; the software adapts the configuration to meet the underlying capability

   D. The error indicates that the sum of the assigned weights in the `scheduler-map` did not equal 100%

7. Consider the CoS configuration at PBR in the DiffServ scenario, as shown in Figure 10-16, and select the best option:
   A. Each logical interface on ge-0/0/0 can send up to 1 G
   B. When both logical interfaces are active, each gets only 50 Mbps
   C. Both A and B
   D. None of the above
8. Refer to the output provided and select the best answer:

   ```
   [edit class-of-service drop-profiles test]
   lab@PBR# show
   fill-level 50 drop-probability 0;
   fill-level 70 drop-probability 10;
   fill-level 80 drop-probability 20;
   fill-level 90 drop-probability 30;
   ```

   A. Between 70% and 80% fill, there is 10% drop probability
   B. Between 75% and 80% fill, there is 15% drop probability
   C. Between 70% and 80% fill, there is 10% drop probability for PLP = 1
   D. Between 70% and 80% fill, there is 10% drop probability for PLP = 0
9. Which of the following is true?
   A. BA overrides multifield classification
   B. Multifield overrides BA classification
   C. You cannot combine BA and multifield classification; a packet is classified only once
   D. You should perform BA and multifield classification on all nodes for consistency
10. How can the PLP status be set?
   A. With multifield classification
   B. With BA classification
   C. With a policer
   D. Using policy
   E. All of the above

Chapter Review Answers

1. Answer: B. Only the Integrated Services (IntServ) model made use of control plane signaling for resource allocation.
2. Answer: A. In the DiffServ model, a BA is a collection of packets with a shared code point. It is expected that each node will have the same PHB for a given BA, and therefore end-to-end performance can be modeled.

3. Answer: D. Although you could use multifield classification everywhere, this approach does not scale. Use a BA classifier and associated rewrite to convey PLP status between nodes.
4. Answer: D. Because strict-high is given 100% of transmit weight, it should be used with a policer to ensure that other classes are not starved, especially on the J-series, where strict-high is an actual priority. You cannot use `exact` with a strict-high queue, but on the J-series you can use the shaping rate to cap total usage. However, a policer is preferred, as this allows excess bandwidth only when other queues are empty.
5. Answer: B. Supported on the J-series only, the `shaping-rate` limits the total amount of bandwidth available to the queue, regardless of activity in other queues. This in itself does not prevent starvation of lesser-priority queues, but it can help.
6. Answer: A. Many CoS configuration errors allow a commit, but they generate a log warning indicating that the configured values can be programmed. This means the default values are in effect.
7. Answer: C. Unless you shape at the logical interface level, each IFL can send up to line rate, and when multiple IFLs are active, they share available bandwidth. This is another benefit to using schedulers based on transmit percentage, rather than absolute values. The latter would result in one IFL getting all the bandwidth while the other receives a default scheduler configuration with 95%/5% assigned to queue 0 and 3, respectively.
8. Answer: A. The profile defines a 10% drop probability for fill levels between 70% and 80%. You cannot tell from the drop profile itself whether it affects PLP 0 or 1 (or UDP versus TCP), because the function of WRED against some criteria is performed via a `scheduler-map`, which was not shown.
9. Answer: B. Multifield overrides BA classification and generally is used only at network edges.
10. Answer: E. All of the methods listed can impact the PLP status of a given packet.

CHAPTER 11

IP Multicast in the Enterprise

This chapter explores typical enterprise deployment scenarios for IPv4 multicast. Focus is placed on the design and configuration of a scalable, fault-tolerant, multicast infrastructure using the Junos operating system. Operational analysis and fault isolation are also demonstrated. The topics covered include:

- Multicast terminology and concepts
- Multicast protocols: group management and routing
- Protocol Independent Multicast (PIM) sparse mode using static rendezvous points (RPs)
- PIM sparse mode with bootstrap-based RP election
- PIM and Multicast Source Discovery Protocol (MSDP)-based Anycast-RP

Juniper Networks routers offer extensive support for IPv4 multicast. Consult the multicast overview in the Junos documentation to confirm the list of supported RFC and drafts for your software release.

What Is Multicast?

Multicast defines the concept of a one-to-many communications stream. To a casual observer, multicast is similar to broadcast in that a single copy of a packet can be received by multiple nodes—however, multicast is not dependent on an underlying multiaccess medium. It can operate network-wide (unlike broadcast traffic that is not forwarded by routers), and is associated with protocols that attempt to automatically tune the network to eliminate unnecessary transport and delivery of multicast traffic.

Routers use multicast routing protocols to control the forwarding of multicast traffic to prevent loops and avoid inefficiencies associated with having multiple copies of a given packet transmitted over the same link multiple times. Multicast group membership protocols are used by hosts to express interest in one or more multicast groups—multicast traffic is not forwarded over an interface with attached hosts unless at least one host has explicitly requested the receipt of multicast traffic.

When all goes to plan, the presence of multicast traffic is noted only by those nodes that have expressed interest in that particular stream, which is in marked contrast to a link-level broadcast that forces reception of the packet by all nodes on that link. In summary, broadcast is one-to-all with a link-level scope, whereas multicast is one-to-many, network-wide, but only when there is express interest in receiving multicast.

The sources and destinations of multicast content are generally hosts, not routers. The role of a multicast router entails locating multicast sources, replicating packets for transmission over multiple interfaces, preventing routing loops, and connecting interested destinations with the proper source, all while keeping the flow of unwanted packets to a minimum.

Multicast Applications

There are numerous applications for IP multicast. In many cases, a given application is capable of operating in either unicast or multicast mode, depending on user settings and overall scaling needs. Network applications that can function with unicast but are better suited for multicast include collaborative groupware, teleconferencing, and distributed applications such as multiplayer gaming or virtual reality. Any IP network concerned with reducing network resource consumption for one-to-many or many-to-many applications, to include multimedia streams with multiple receivers such as IP-TV, benefits from multicast.

Multicast-enabled networks and applications provide significant scaling benefits. When unicast is employed by an Internet radio or news ticker service, for example, each recipient requires a *separate* traffic session. The processing load at the server and network bandwidth consumed increase linearly as each new receiver attaches to the server. This is extremely inefficient, whether dealing with the global scale of the Internet or a modest enterprise-scale network.

In a broadcast model, the source needs to generate only a single stream using a broadcast destination address. Ignoring for the moment that the link-level scope of broadcast makes this model unusable in a routed network, a broadcast model is extremely inefficient because it consumes maximum bandwidth and places the burden of packet rejection on each host.

Multicast provides the most efficient and effective solution for most one-to-many or many-to-many applications, with none of the drawbacks and all of the advantages of the unicast or broadcast model. With multicast, a single multicast packet stream finds its way to every interested receiver, and replication is performed in a distributed manner within each router as needed, allowing large-scale deployment because no one device is forced to replicate or handle all traffic associated with the application. With IP multicast, a sending host generates a single IP packet stream, whether there is one receiver or 1 million receivers, and links that connect to subnets consisting of entirely uninterested receivers carry no multicast traffic at all.

Locating content

Once you have enabled multicast in your network, the first question becomes "What new services and applications can I enable with it, and how will users know?" In other words, for maximum benefit, there needs to be a TV Guide–like function available to the end user. The Session Directory tool (known as SDR) is an end-user application that uses multicast protocols to locate and list available sessions in the network. Figure 11-1 shows the user interface for the SDR application.

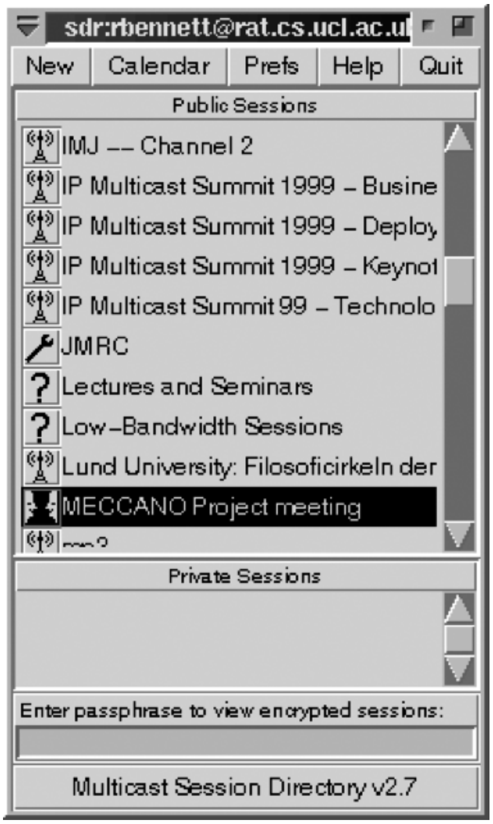

sdr:rbennett@rat.cs.ucl.ac.u
New
Calendar
Prefs
Help
Quit
Public Sessions
IMJ -- Channel 2
IP Multicast Summit 1999 – Busine
IP Multicast Summit 1999 – Deploy
IP Multicast Summit 1999 – Keynot
IP Multicast Summit 99 – Technolo
JMRC
Lectures and Seminars
Low-Bandwidth Sessions
Lund University: Filosoficirkeln der
MECCANO Project meeting
Private Sessions
Enter passphrase to view encrypted sessions:
Multicast Session Directory v2.7

Figure 11-1. The Session Directory tool

The transport protocol used by the Session Directory tool is the Session Announcement Protocol (SAP). SAP messages are transmitted to the well-known multicast group address of 224.2.127.254, and they contain descriptions of currently available sessions formatted using the Session Description Protocol (SDP). You can download the SDR application and get additional information at *http://www-mice.cs.ucl.ac.uk/multimedia/software/sdr/*.

Multicast Terminology and Concepts

To the uninitiated, multicast can seem to be a jumble of confusing terms and concepts. It helps to keep in mind that multicast is largely state-driven, which is to say that things may or may not happen, based on the presence or absence or some other event. For example, a join message is generated when a router wishes to receive multicast traffic for a given group. As a result of this join, a multicast distribution tree is instantiated, or modified, which adds the interface on which the join was received in the outgoing interface list (OIL) for that group. After some period of time, lack of continued join activity results in this state timing out, the removal of the interface from the OIL, and the cessation of multicast forwarding for that group over that interface. This “now you see it, now you don’t” aspect of multicast often leads to confusion, at least when compared to the more or less steady-state nature of unicast routing protocols. In Open Shortest Path First (OSPF), the absence or presence of a route is not a function of an actual desire or need to use the route. In contrast, a multicast “route” is actually a dynamic entry that is based on the presence of an active sender and, to some degree, the presence of at least one interested receiver.

Routing turned upside down

If the dynamic state of multicast is not reason enough for confusion, consider that multicast forwarding is actually a type of reverse routing. Unicast routing is based on longest-matching against the packet’s destination address, with the overall goal being the forwarding of a packet toward its destination. In contrast, multicast forwarding is performed based on the *source* address, with the goal being the forwarding of the packet *away* from the source, as opposed to toward any particular destination. This behavior is known as reverse path forwarding (RPF) and is detailed in a later section.

Multicast terms

The reader should be familiar with the following terms and concepts before delving any further into multicast. Refer to Figure 11-2 to see how the terms relate to an IP multicast network.

Figure 11-2 looks complicated, so let’s tackle each part individually:

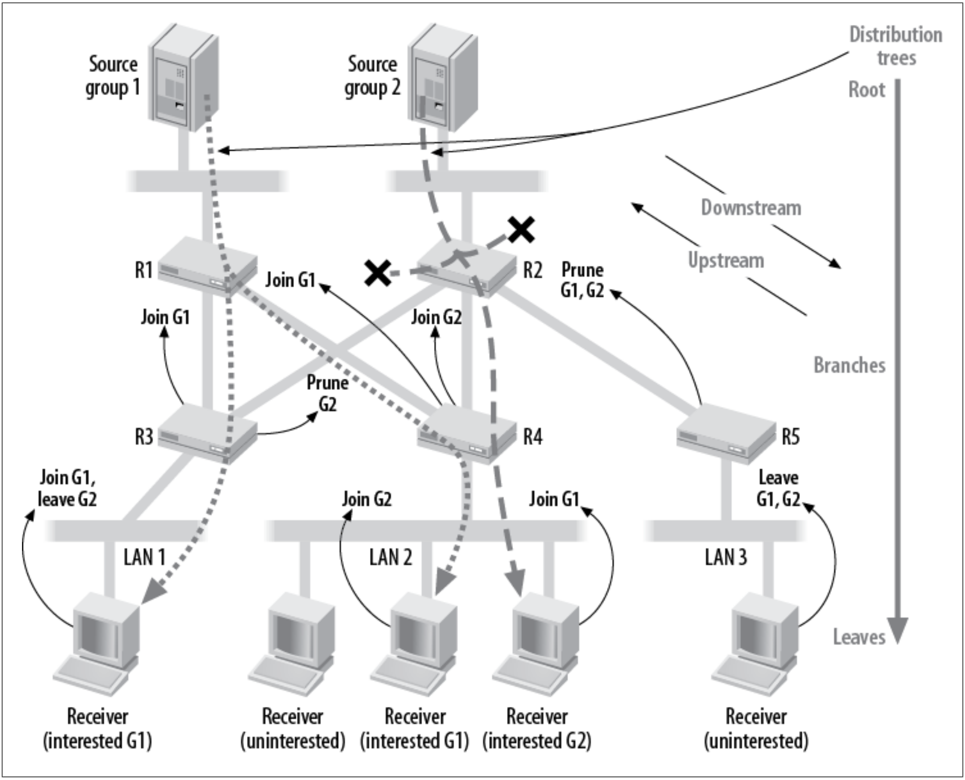


Figure 11-2. Multicast terms

Multicast sources

The multicast sources for groups 1 and 2 are shown at the top of Figure 11-2. A multicast source is the entity that generates a stream of packets addressed to one or more multicast groups. The set of addresses from 224.0.0.0 to 239.255.255.255 (224/4) are reserved for IP multicast use. Any device that sends one or more packets to a destination address in this range is a multicast sender. No multicast-specific routing or group management protocol is required by a multicast sender; in fact, the sender does not even need to be able to receive multicast traffic. The sender is the root of a shortest-path tree (SPT).

Multicast receivers

Several multicast receivers are shown at the bottom of Figure 11-2. The receivers form the leaves of a multicast distribution tree. Multicast receivers run the Internet Group Management Protocol (IGMP), to inform attached routers what multicast groups they are interested in. A node becomes a leaf on the distribution tree when it joins a given group. A branch is pruned from the multicast tree when no interested hosts remain; that is, when all of its leaves have fallen off. This condition is shown for LAN 3, where the sole receiver has indicated a desire to leave both multicast groups. Note how the group management protocol's leave messages become a multicast routing protocol prune message, assuming that the first hop router has no other interested receivers (leaves) for the related branch. (Oh, the fun of the terminology: a leaf sends a leave messages to be pruned from the tree, so in the plural, leaves sends leaves to leave a broadcast session.)

Multicast protocols

Multicast protocols control the flow of multicast traffic between sources and receivers. For now, it's sufficient to note that receivers use a group management protocol to inform their routers which groups they are interested in; receivers are not aware of the actual multicast topology. Routers run a group management protocol to communicate with attached receivers, and a multicast routing protocol when communicating with other multicast-aware routers. A multicast routing protocol such as PIM is significantly more complex than the group management protocols used by receivers, and it is responsible for ensuring loop-free forwarding and management of the distribution tree based on the absence or presence of interested receivers.

Upstream/downstream

Many operations in multicast are directionally oriented. The multicast tree is rooted at each source and terminates at the various receivers. Traffic flows downstream, along the distribution tree, from the source to each receiver. In contrast, control messages that establish a prune/join state are sent upstream, in the direction of the receiver to the source. Figure 11-2 shows the multicast traffic from groups 1 and 2 flowing downstream toward interested receivers while the related control messages flow upstream.

Distribution trees, branches, and leaves (oh, my)

A distribution tree is the interconnection of nodes that lie between a sender and interested receivers. Figure 11-2 shows two senders, and each is associated with its own distribution tree. In our example the tree is rooted at the sender. Later in the chapter, we will discuss the concepts of shared trees, where a rendezvous point (RP) becomes the root of the tree. The example in the figure consists of two SPTs. Traffic flows downstream on the tree while control messages flow upstream to influence multicast flow. Between the root and each leaf lies one or more branches. A router must replicate packets to each branch that leads to a leaf, noting, however, that the same effort is required whether there is one or 1,000 leaves on that branch. A leaf is a multicast receiver with interest in a given group. A branch is pruned from the tree when it has no remaining leaves. The figure shows R3 and R5 pruning branches from the tree in response to the receipt of leave messages that indicate no remaining leaves.

Dense and sparse modes

There are two primary strategies when it comes to forming the initial distribution tree. There is the *flood first*, *prune later* philosophy known as dense mode, and there is the *prune first and flood only when asked for* method known as sparse mode. Stated differently, dense mode is like a push model that assumes that all receivers want all multicast, and sparse mode functions in a client pull manner, where it is assumed that most receivers do not want any multicast. In both methods, the distribution tree is ultimately pruned of any leafless branches, but in the former, the expiration of state results in resumed dense mode flooding, whereas in the latter, an expiration of join state results in a return to the default pruned mode. Generally speaking, older multicast routing protocols such as the Distance Vector Multicast Routing Protocol (DVMRP) support only dense mode, whereas newer protocols such as PIM support both modes. In some cases, the same protocol can operate in a *sparse-dense* mode, whereby certain groups are handled in dense fashion while others are treated as sparse. Dense mode operation is best suited for use over LANs because its flood-first nature tends to consume more bandwidth. On the upside, dense mode does not require the complexities of an RP. Recall that in dense mode, any active source results in flooding down all branches, which are then pruned if not needed; this means that routers have no problems learning about active sources and groups. In contrast, sparse mode operation creates somewhat of a chicken-before-the-egg problem, in that a router must send an explicit join before it can receive traffic for a given group, but before it can send the join it has to know which groups and sources are active! This problem is resolved with the introduction of a shared tree and an RP, which we will detail in a subsequent section.

Additional multicast building blocks

This section discusses IP multicast concepts that are independent of any specific multicast routing protocol or mode of operation. Understanding these concepts prepares the reader for the upcoming IP multicast configuration and operational mode analysis examples.

Multicast addressing. Multicast uses the Class D IP address range, from 224.0.0.0 to 239.255.255.255. In modern vernacular, the concept of classful addresses has lost favor, so addresses in this range are commonly referred to as simply *multicast addresses*. A multicast address can be used only as the destination address of an IP packet—the source address must always be of the unicast form. A multicast address normally has a /32 prefix length, although other prefix lengths are allowed. Recall that a multicast address represents a logical grouping of devices rather than a physical collection of devices. Multicast addresses can still be described in terms of prefix length using traditional notation. For example, the entire multicast address range can be written as 224/8. The base address 224.0.0.0 is reserved and cannot be assigned to any group, addresses in the 224.0.0.1–224.0.0.255 range are reserved for local wire use, and the 239.0.0.0–239.255.255.255 range is reserved for administratively scoped addresses.

Internet numbering authorities normally do not allocate multicast addresses to their customers. This is because multicast addresses are concerned more with content than with a given physical device. Receivers do not require a multicast address, but they need to know the multicast address associated with the multicast content they are interested in. Multicast sources need an assigned multicast address only to produce the content, not to identify their place in the network. Every source, receiver, and numbered router interface still needs an ordinary, unicast IP address.

Many applications have been assigned a range of multicast addresses, either by the Internet Engineering Task Force (IETF) or by the applications' developers. Although statically assigned multicast addressing is certainly possible, in most cases you can simply use the application's defaults. Table 11-1 shows some application-to-multicast address mappings, as defined by the Internet Assigned Numbers Authority (IANA) at *http://www.iana.org/assignments/multicast-addresses*.

Table 11-1. IANA application-to-multicast address mappings (select examples)

Address	Application
224.2.0.0–224.2.127.253	Multimedia conference calls
224.4.0.0–224.4.0.254	London Stock Exchange
224.0.1.141	Dynamic Host Configuration Protocol (DHCP) servers
224.0.1.39	cisco-rp-announce

Mapping IP Multicast to Link Layer Multicast

On multiaccess networks such as LANs, using the broadcast address to forward IP multicast results in disruption to all nodes on that LAN segment, whether they are interested in multicast or not. Using a unicast address negates the one-to-many efficiency benefit of multicast. The solution is to map a Layer 3 IP multicast address, which is 32 bits in length, into a corresponding 48-bit media access control (MAC) layer multicast address. Figure 11-3 shows a sample of this mapping.

Given the different address lengths, a direct 1:1 mapping between Layer 2 and Layer 3 addresses is not possible. One-half of the IANA-owned block of Ethernet MAC addresses, the first 24 bits starting with 0x 01:00:5E, are reserved for multicast, yielding the usable range of 0100.5e00.0000–0100.5e7f.ffff inclusive. This allocation results in a 24-bit field, but because the first bit is always set to 0, only 23 bits remain to be populated with the IP multicast address. The mapping process strips the 4-bit class D identifier as well as the 5 high-order bits from the group ID, which leaves 23 bits remaining to be mapped into the multicast MAC address. Because 5 high-order bits are stripped from the group ID, there is a resulting loss of granularity in the Layer 3 to Layer 2 address mapping resulting in 32(2^5) different group addresses mapping to the same multicast MAC address, as shown at the bottom of Figure 11-3.

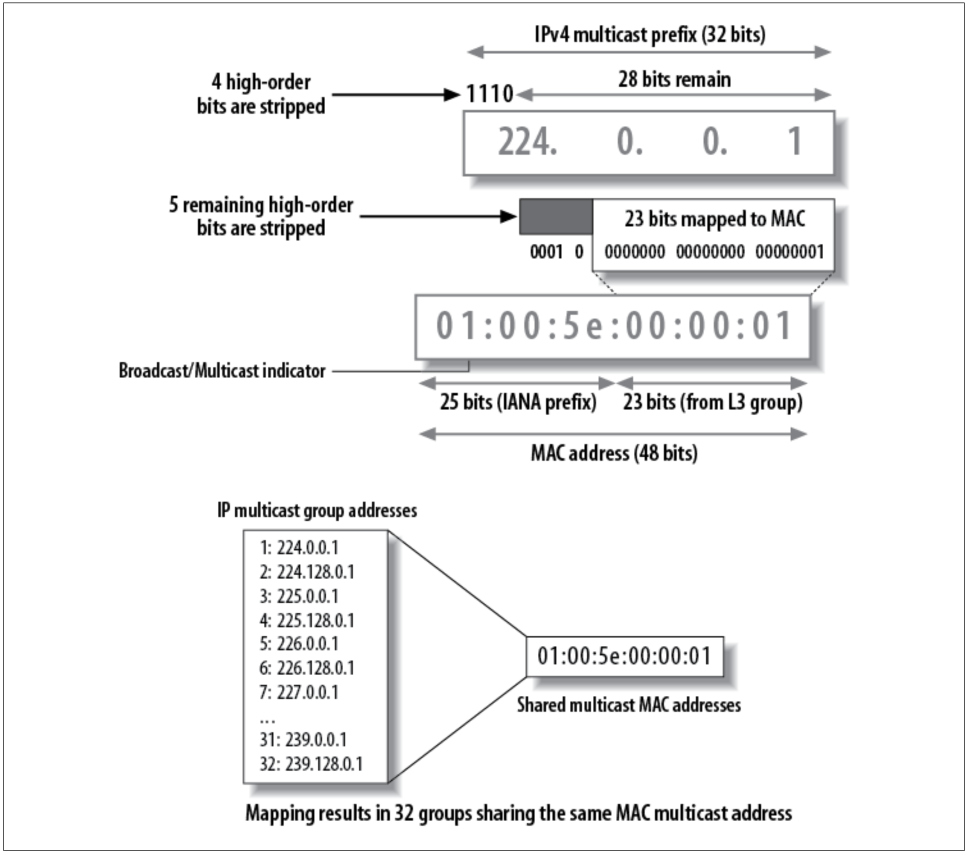


Figure 11-3. Layer 3 to Layer 2 multicast mapping

In a Layer 2 network, the sharing of a MAC address among as many as 32 IP multicast groups results in a loss of efficiency, because traffic sent to one multicast group will be received by all hosts using the same shared MAC layer multicast address, even though they do not subscribe to that particular group. Wherever possible, you should be careful when selecting IP multicast addresses to ensure that they map to a unique MAC layer multicast address; otherwise, host systems will have to expend cycles receiving, and then discarding, multicast traffic for groups that have no local applications listening.

Multicast addressing and administrative scoping

Multicast addresses are categorized according to their scope. Scoping is designed to limit the extent to which a multicast packet can travel. Scoping is used for both performance and administrative reasons. Table 11-2 details currently defined IPv4 multicast address scopes.

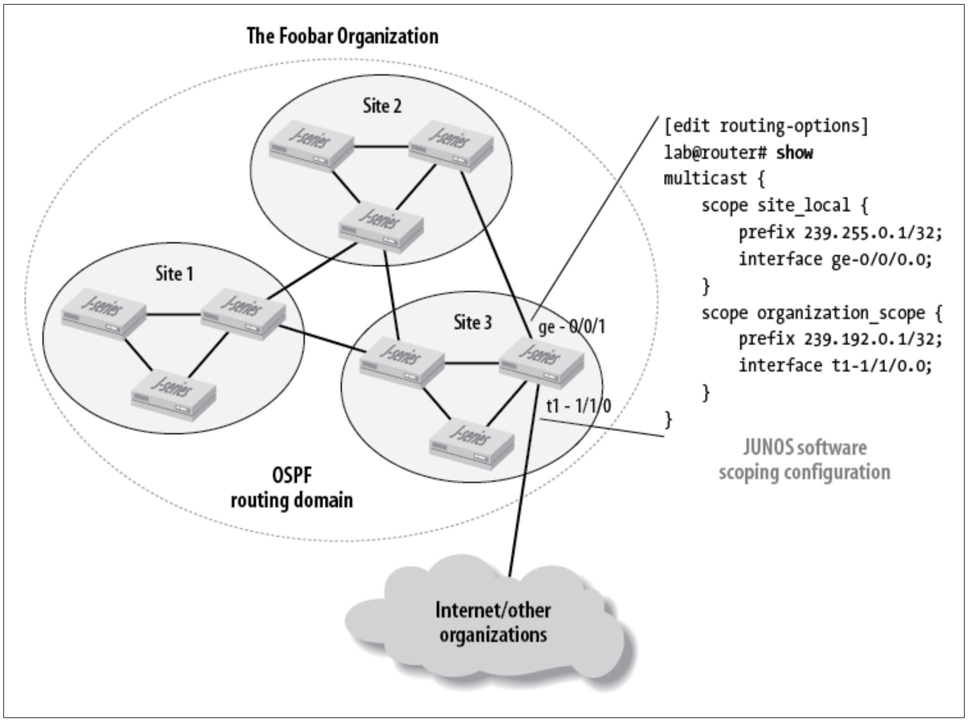
Table 11-2. IPv4 multicast address scopes

Address	Scope	Comment
224.0.0.0/24	Link local	Confined to a single link, often used for unicast routing protocols; allows same multicast address on each link
239.0.0.0–239.255.255.255	Administratively scoped	Further subdivided into site-local (239.255.0.0/16) and organizational (239.192.0.0/14) scopes
224.0.1.0–238.255.255.255	Global	Addresses with global scope, of which several static assignments exist: • 224.1.0.0-224.1.255.255: shared tree multicast groups • 224.2.0.0-224.2.127.253: multimedia conference calls • 224.2.127.254: SAPv1 announcements • 224.2.127.255: SAPv0 announcements • 224.2.128.0-224.2.255.255: SAP dynamic assignments • 224.252.0.0-224.255.255.255: DIS transient groups (RFC2365) • 232.0.0.0-232.255.255.255: VMTP transient groups (RFC1045)

Modern IP networks use address-based scoping rather than IP Time to Live (TTL)–based scoping. This is because TTL-based techniques are prone to problems in terms of being able to accurately predict TTL values network-wide, especially in the face of changes in forwarding topology during failover scenarios. Addresses in the link-local scope cannot be forwarded beyond the boundaries of a single link. These addresses tend to be used by unicast routing protocols such as Routing Information Protocol version 2 (RIPv2) and OSPF. The administratively scoped address range is broken into site-local and organizational boundaries. An enterprise might consist of a single site, the exact definition of which is left to the administrators of the routing domain, or it may consist of multiple sites. Generally, the organizational scope is defined as the extent of a routing domain. Administrators configure site or global scoping on the appropriate interfaces to block related traffic from leaving that interface. Figure 11-4 illustrates a scoping example.

The approach shown in Figure 11-4 is address-based, but Junos also supports scoping based on a `scope-policy`. Unlike address scoping, which is applied per interface, a `scope-policy` applies to all interfaces, and you cannot use it in conjunction with interface-level scoping. You confirm address scoping using the **`show multicast scope`** command. The remaining IP multicast address space is considered to have a global scope. Some addresses within the global range are statically assigned by the IANA, as shown in Table 11-2.

It is common to see scoping used to block the multicast addresses associated with the auto-RP discovery mechanism (224.0.1.39 and 224.0.1.40) at administrative



```
[edit routing-options]
lab@router# show
multicast {
    scope site_local {
        prefix 239.255.0.1/32;
        interface ge-0/0/0.0;
    }
    scope organization_scope {
        prefix 239.192.0.1/32;
        interface t1-1/1/0.0;
    }
}
```

Figure 11-4. Multicast scoping

boundaries to prevent the use of the local domain's RP by routers outside of local administrative control.

> You cannot use scoping to block RP discovery via the bootstrap protocol because the bootstrap mechanism operates hop by hop and uses the 224.0.0.13 ALL-PIM-Routers multicast address, which, if scoped, would break other aspects of PIM operation. Normally, bootstrap messages are "scoped" by configuring interdomain interfaces to run PIMv1, which does not support bootstrap, or through definition of bootstrap import/export policy that blocks reception or transmission of bootstrap router (BSR) messages, respectively.

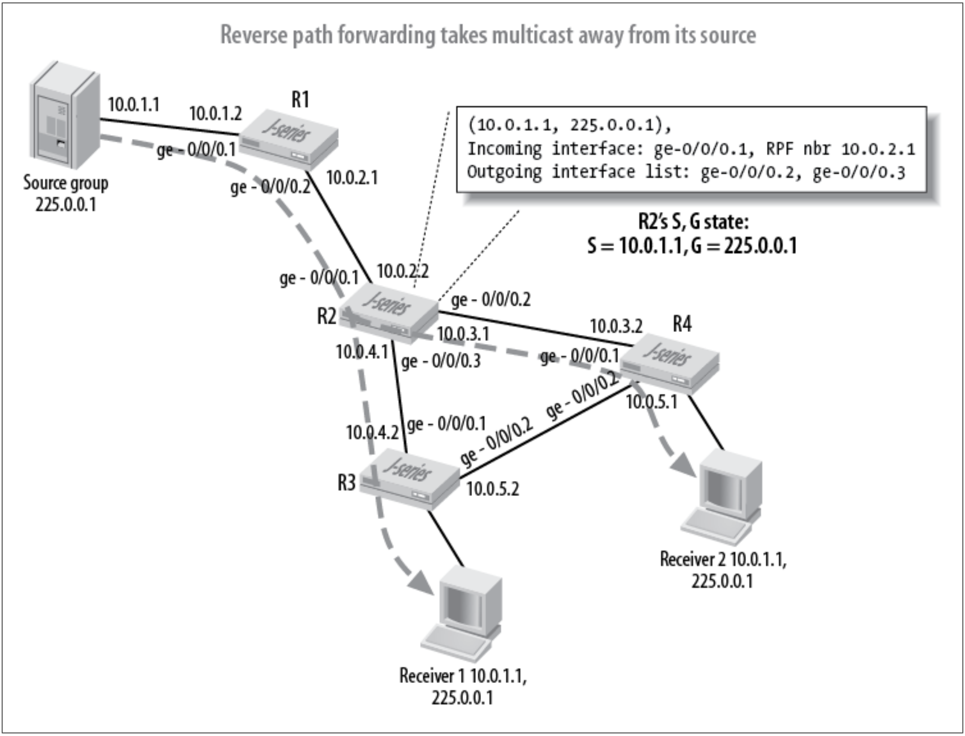
Interface lists

Multicast routers maintain state to determine which multicast packets should be forwarded, and over which interfaces copies of a packet should be sent. Part of this state is in the form of incoming and outgoing interface lists (IILs/OILs) for each active multicast source in the network. Maintaining accurate interface lists is critical for loop avoidance.

Loops in any IP network are a bad thing. A multicast loop can be particularly nasty given the replication action of routers, which serves to provide an amplification effect for any looping packets.

The interface that lies on the shortest path *back* to the source is the upstream (incoming) interface, and packets are never allowed to be forwarded *toward* the multicast source. All remaining interfaces could become a downstream (outgoing) interface, depending upon join state.

A router with multicast forwarding state for a particular multicast group is “switched on” for that group’s content. Interfaces on the router’s outgoing interface list send copies of the group’s packets received on the IIL for that group. Figure 11-5 shows this condition.



```
(10.0.1.1, 225.0.0.1),
Incoming interface: ge-0/0/0.1, RPF nbr 10.0.2.1
Outgoing interface list: ge-0/0/0.2, ge-0/0/0.3
```

Figure 11-5. Interface lists

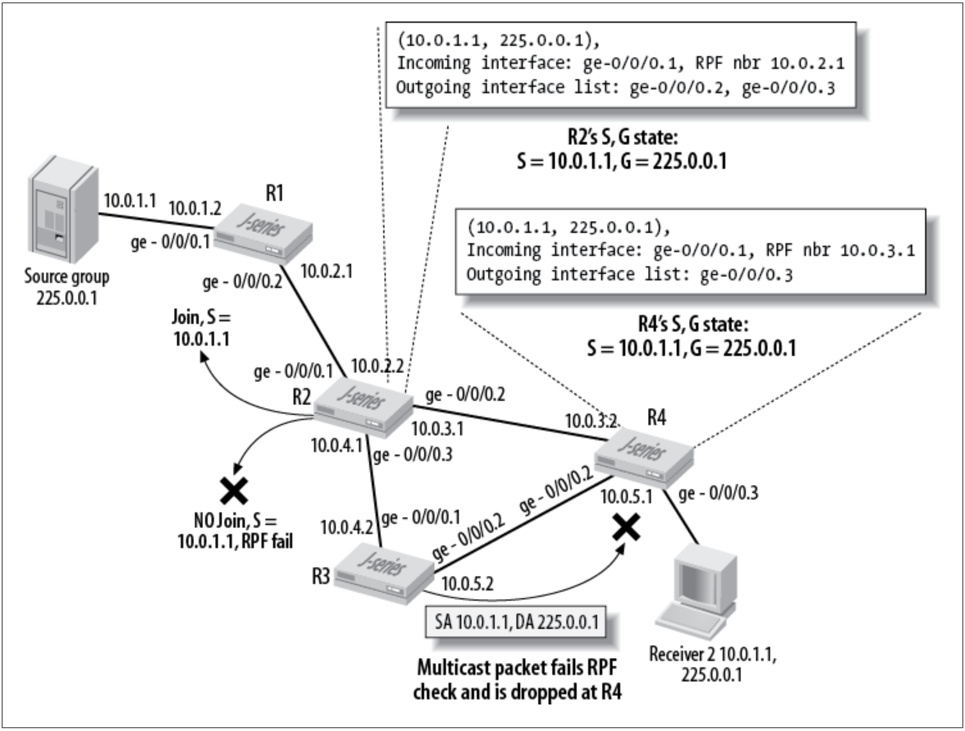
The router state that controls multicast forwarding is referred to as (S,G) or (*,G). In (S,G), the *S* refers to the unicast IP address of the source for the multicast traffic, and the *G* refers to the particular multicast group IP address for which S is the source. All multicast packets sent from this source have S as the source address and G as the destination address. The asterisk (*) in the (*,G) notation is a wildcard indicating that the state applies to any multicast source sending to group G. So, if two sources are originating content for multicast group 224.1.1.2, a router could use (*, 224.1.1.2) to represent the state of a router forwarding traffic from both sources to members of that group, as is done in the case of a shared tree.

An incoming and outgoing interface list is maintained for each active source to group tuple. When you consider that group membership is itself often dynamic, and that this volatility leads to a need for ongoing maintenance of the related interface list, it becomes clear that a router handling large numbers of multicast groups can consume significant control plane resources maintaining multicast forwarding state. All Juniper Networks router architectures are well suited to hardware/real-time thread-based multicast replication and can forward multicast at the same (near-line-rate) performance level as unicast. A typical control plane scaling guideline for a router with 1 GB of memory is no more than 120,000 PIM entries [sum of (*,G) and (S,G)], 1,000 PIM neighbors, and 1,000 dynamic IGMP groups per interface.

Reverse path forwarding

Conventional routing is based on a longest match against the destination address of a packet. The unicast route table is maintained by unicast routing protocols such as the Routing Information Protocol (RIP) and OSPF, and it is used when forwarding unicast packets toward their destinations. As noted previously, multicast is like routing turned upside down, in that now the router actually forwards packets *away* from the source, based on the source rather than the destination address. A multicast router's forwarding state is thus organized based on a *reverse path* paradigm. As noted earlier, this process is known as reverse path forwarding (RPF) and is shown in Figure 11-6.

An RPF check simply makes sure that a packet arrives on the same interface that would be used for egress by the local router when routing *back* to that multicast source using the Interior Gateway Protocol's (IGP's) shortest path—in effect, a multicast packet is routed twice, once based on the source address and, if that passes, again based on the group address, this time against the outgoing interface list for that group. It's important to note that RPF checks occur both in the control plane when processing joins, and in the data plane when deciding whether a packet should be forwarded. Multicast packets that fail the RPF check are dropped because the incoming interface is not on the shortest path back to the source. Figure 11-6 shows how router R4 drops a multicast packet from source 10.0.1.1 when it is received on an interface that would not be used when routing a unicast packet to address 10.0.1.1. The figure also shows that routers generate joins over the RPF interface back to the source.


```
(10.0.1.1, 225.0.0.1),
Incoming interface: ge-0/0/0.1, RPF nbr 10.0.2.1
Outgoing interface list: ge-0/0/0.2, ge-0/0/0.3
```

```
(10.0.1.1, 225.0.0.1),
Incoming interface: ge-0/0/0.1, RPF nbr 10.0.3.1
Outgoing interface list: ge-0/0/0.3
```

Figure 11-6. The multicast RPF check

In some cases, the multicast routing protocol maintains its own RPF table, which is used specifically for the purpose of forwarding multicast. DVMRP is an example of such a protocol. PIM, on the other hand, makes use of the existing unicast route table to perform its RPF checks. This capability is why PIM is considered to be *protocol-independent*; it can use any route source for its RPF checks, including static, IGP, and even Border Gateway Protocol (BGP) routes. Junos supports extensions to unicast routing protocols to accommodate the building of a separate RPF table. Examples include the Multiprotocol Border Gateway Protocol (MBGP) and multitopology routing in Intermediate System–to–Intermediate System (IS-IS), or M-IS-IS.

Using the main unicast route table for RPF checks provides simplicity; using a dedicated route table for RPF checks allows a network administrator to set up separate paths and routing policies for unicast and multicast traffic. This allows the multicast network to function more independently of the unicast network.

Distribution trees

Previous discussions have indicated that multicast traffic is distributed via a tree that is rooted at the source and branches as needed to pick up all interested leaves. Several different types of distribution trees exist, and in many cases multiple tree types are used (over time) for the same multicast stream.

Shortest-path tree (SPT). SPT is a distribution tree that is rooted at the source. This is sometimes called a *source tree*. An SPT is formed by sending the appropriate join messages over the RPF path to the desired source. Figure 11-7 shows this process.

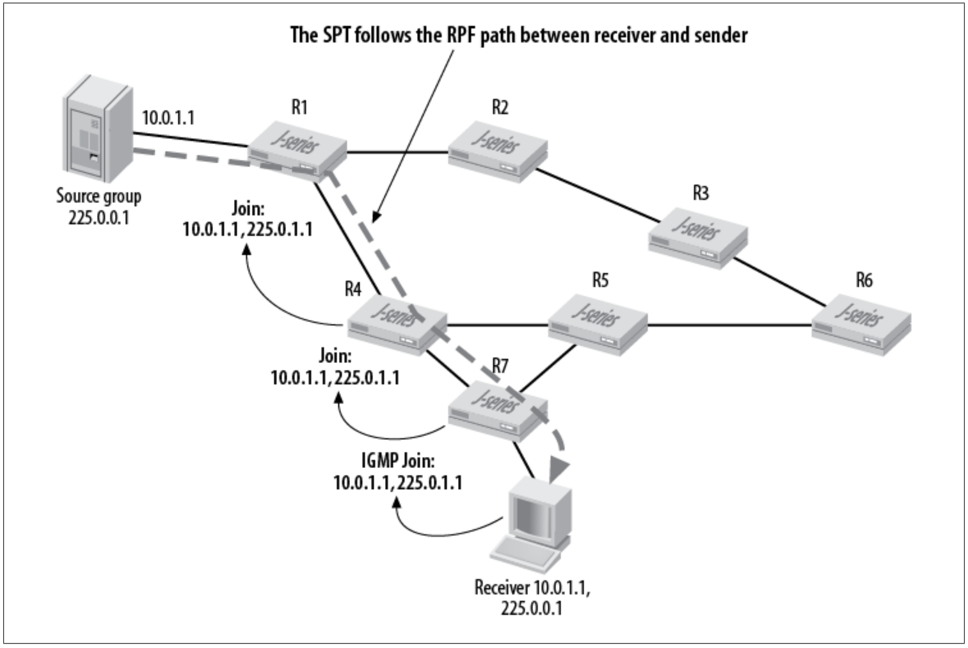

The SPT follows the RPF path between receiver and sender
10.0.1.1
R1
R2
R3
R4
R5
R6
R7
Source group 225.0.0.1
Join: 10.0.1.1,225.0.1.1
Join: 10.0.1.1,225.0.1.1
IGMP Join: 10.0.1.1,225.0.1.1
Receiver 10.0.1.1, 225.0.0.1

Figure 11-7. An SPT

Things begin when the receiver sends an IGMP join for source 10.0.1.1 and group 225.0.0.1. R7, the first hop (and, in this case, designated) router, generates the appropriate join message out the RPF interface for that source. This is referred to as an (S,G) join, because in this case both S and G are known. Router R4 receives the (S,G) join, which triggers the addition of the receiving interface to its OIL for the 10.0.1.1, 225.0.0.1 tuple. R4 now performs its own RPF check on the source address, and as a result R4 sends its (S,G) join message out its RPF interface for 10.0.1.1, causing reception of the (S,G) join at R1. The process stops when the join message reaches the router directly connected to the source or when it reaches a router that already has multicast forwarding state for this (S,G) tuple. The key point is that RPF handling of (S,G) join messages results in an SPT.

Shared trees and RPs. A shared multicast tree is rooted at an intermediate router, rather than at a specific source. The use of a shared tree can offer the benefit of less overall state, in that a single (*,G) entry can now represent state for numerous sources that may be sending to this group. In the most common multicast protocol in use today, PIM, the shared tree is short-lived and used only to make initial contact between senders and receivers, however. Once this initial contact is made, an SPT is established and the shared tree is no longer used for that (S,G) tuple. In PIM, the root of the shared tree is the RP, which functions to support sparse mode operation. Recall that in sparse mode, multicast is forwarded only as a result of an explicit join for the related group. Without prior knowledge of which senders are active for what groups, a router cannot generate an (S,G) join toward the source, because the source is not yet known.

Source-specific multicast (SSM) describes a condition in which the receiver has preexisting knowledge of what source it wishes to join. This allows the generation of an SPT without the need for an RP. The use of receiver joins that do not specify a particular source is known as Any Source Multicast (ASM).

In a sparse mode Any Source Multicast (ASM) operation, the router generates an (*,G) join toward the RP, which results in joining a tree that is shared among all senders associated with that group. Figure 11-8 shows this process.

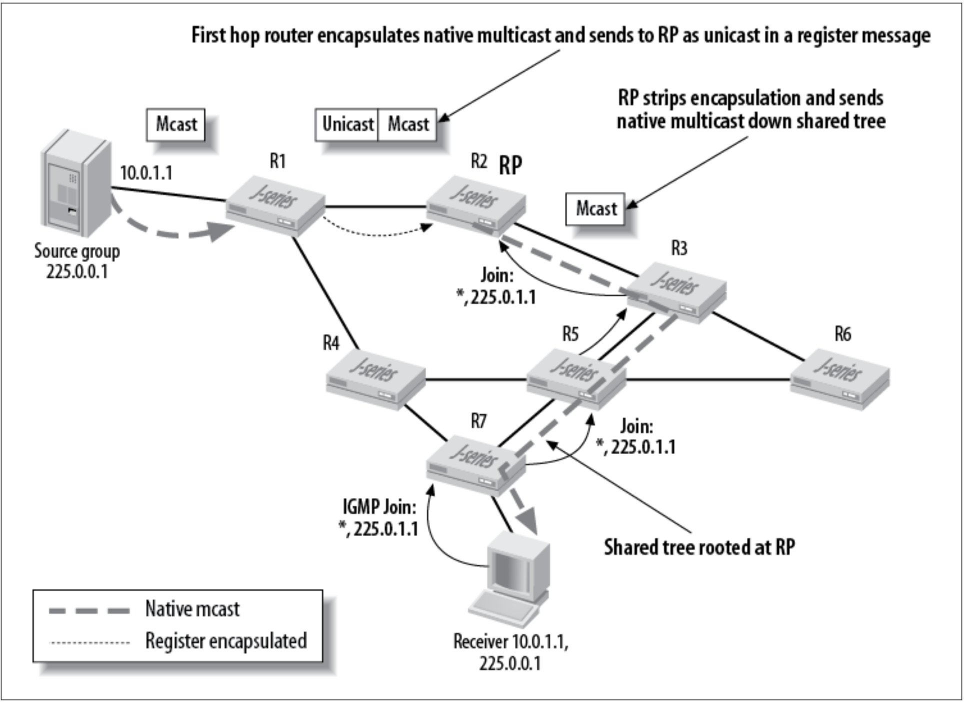

First hop router encapsulates native multicast and sends to RP as unicast in a register message
RP strips encapsulation and sends native multicast down shared tree
Mcast
Unicast
Mcast
Mcast
10.0.1.1
Source group 225.0.0.1
R1
R2 RP
R3
R4
R5
R6
R7
Join: *,225.0.1.1
Join: *,225.0.1.1
IGMP Join: *,225.0.1.1
Shared tree rooted at RP
Receiver 10.0.1.1, 225.0.0.1
Native mcast
Register encapsulated

Figure 11-8. An RP tree

In the example in Figure 11-8, the receiver generates an IGMP join for group 225.0.0.1 that does not specify a particular source; hence, the *any* in the term Any Source Multicast and the use of a wildcard metacharacter to represent the resulting state (*,G). The last hop router, which functions as a designated router, performs an RPF check for the RP that handles this group, and the join is sent toward the RP rather than toward any particular source.

Figure 11-8 calls out how the source generates native multicast to the first hop router, R1 (which also functions as a designated router), which in turn encapsulates the traffic into a unicast datagram addressed to the RP. Upon receipt, the RP strips the register message encapsulation and sends the now native multicast down the shared tree associated with that group.

The purpose of register encapsulation is to eliminate the need for multicast-enabled routers between sources and the RP. The downside is that the first hop routers (those attached directly to multicast sources) and the RP require tunneling hardware/software support. On M-series platforms, this normally requires the presence of a Tunnel Services PIC—note that the M7i has a built-in Tunnel Services PIC whereas the M10i does not. SRXs and J-series platforms perform multicast register message encapsulation in software, using the internal services interface, making additional hardware unnecessary. High-end SRXs and the MXs perform this function natively on the interface cards.

Switching from a shared tree to an SPT. In PIM sparse mode operation, the shared RP tree (RPT) is used only for discovery of active sources. The receipt of traffic on the RPT initiates a switchover to an SPT by the last hop router (the router attached to the receiver), for each active source that is discovered. Once the SPT is formed, the last hop router begins to receive native multicast directly from the source, so an (S,G) prune is sent up the shared tree, toward the RP, to prevent reception of traffic over both the SPT and the RPT for that source. In some PIM implementations, a user-configurable threshold can be set to control when the switch to an SPT is instigated. This capability is designed to prevent cutover to an SPT for short-lived sessions, where the traffic may no longer even be present by the time the SPT is established. In Junos's PIM implementation, you can alter the default behavior of immediately switching to an SPT in favor of *never* switching to an SPT. You can do this with the `spt-threshold infinity` statement, in conjunction with a policy that specifies one or more (S,G) pairs that are subject to the modified behavior. The last hop router will never attempt to switch from the RPT to an SPT for matching (S,G) traffic. This behavior is desired for applications that send very low levels of multicast traffic, where the default behavior could result in undesired oscillation between SPT establishment, a timeout, and a resultant switch back to the RPT.

PIM sparse mode operation requires tunnel services hardware (or software emulation) to perform the register encapsulation and decapsulation functions. J-series platforms can use the internal services interface for this functionality, as can the M7i with its built-in ASM hardware. The M10i requires the installation of tunnel services hardware to support register encapsulation. If your router lacks tunnel services, you can still commit a PIM sparse mode configuration, but things will simply not work if that router is the first hop attached to a source or when it functions as a (remote) RP, as both of these roles require processing of register messages. A Tunnel Services PIC is not required for dense or SSM modes of operation. You can also eliminate the need for register encapsulation and related tunnel PICs with the corner-case scenario of always having the first hop router also function as the RP.

Multicast Terminology Summary

This section defined the key terms and concepts associated with IP multicast. The next section explores multicast routing and group management protocols.

Multicast Protocols

This section describes the operation of group management and multicast routing protocols. We will focus on PIM sparse mode because it's the predominate form of multicast routing protocol in modern IP multicast networks. Simply stated, group management protocols are run by hosts to inform local routers of a host's interest, or lack thereof, in a particular multicast group. Multicast routing protocols are run only on routers and are concerned with RPF checks and the establishment and maintenance of (*,G) and (S,G) forwarding state.

Group Management Protocols

IGMP performs multicast group management and is run on hosts and on routers that attach to host segments. IGMP versions 1, 2, and 3 are currently defined in RFCs 1112, 2236, and 3376, respectively. The basic mechanics of IGMP operation center on hosts generating report messages to inform attached routers what groups the host is interested in, and to inform routers generating query messages to determine whether any active listeners still remain for a particular group.

There are three versions of IGMP—Juniper routers default to version 2, but you can configure them for version 1 or version 3 as needed. Although the various versions of IGMP are backward-compatible, this compatibility is achieved at the cost of having to drop back to the lowest common denominator. For example, if one host is running IGMPv1, any router attached to the LAN running IGMPv2 drops back to IGMPv1 operation, effectively eliminating the advantages of IGMPv2. Where possible, you should ensure that all multicast receivers run the highest version of IGMP that is supported and configured on the routers serving that network segment.

Table 11-3 identifies the key differences among IGMP versions.

Table 11-3. ICMP version comparison

Version	Characteristics	Comment
IGMPv1	Periodic generation of queries to the all-routers multicast address (224.0.0.1); hosts reply with list of interested groups; querier function performed by routing protocol	Join and leave latency stemming from periodic (60-second) nature of queries
IGMPv2	Lowest IP becomes querier for LAN; group-specific query and leave-group message	Routing protocol no longer performs the querier function; improved join/leave latency
IGMPv3	Support for group-source report messages	Supports SSM by allowing receivers to specify (S,G) tuples

Figure 11-9 details key aspects of IGMPv2 report and query behavior.

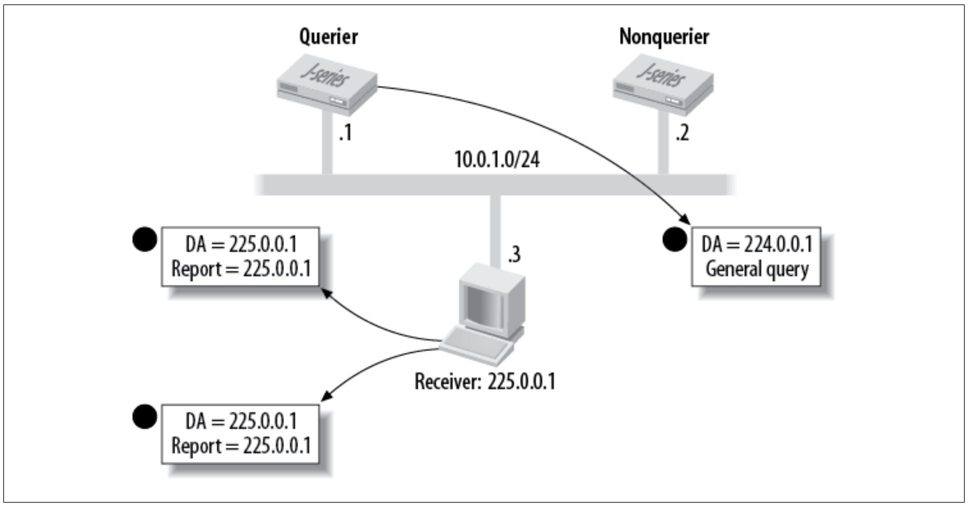


Figure 11-9. IGMPv2 operation

Things begin in Figure 11-9 when the receiver generates an IGMPv2 report, expressing interest in becoming a member of the 225.0.0.1 group. Note that the report is sent to the multicast address equating to the group being joined. Both multicast routers see this report. The router with the lowest IP address is elected the querier and periodically generates general queries to update its knowledge of host-to-group bindings on this LAN, as shown in step 2. All multicast-capable hosts receive the general query, and after a randomized delay, one of the interested hosts will reaffirm the group binding by generating a corresponding report message, which is shown in step 3. Other interested hosts suppress their reports upon seeing a matching report sent by any other node on the segment—the same level of multicast replication and forwarding is needed, be there one or 1,000 interested hosts on a given segment—therefore, only one report is needed to keep the group binding active.

Figure 11-10 goes on to show an IGMPv2 leave process.

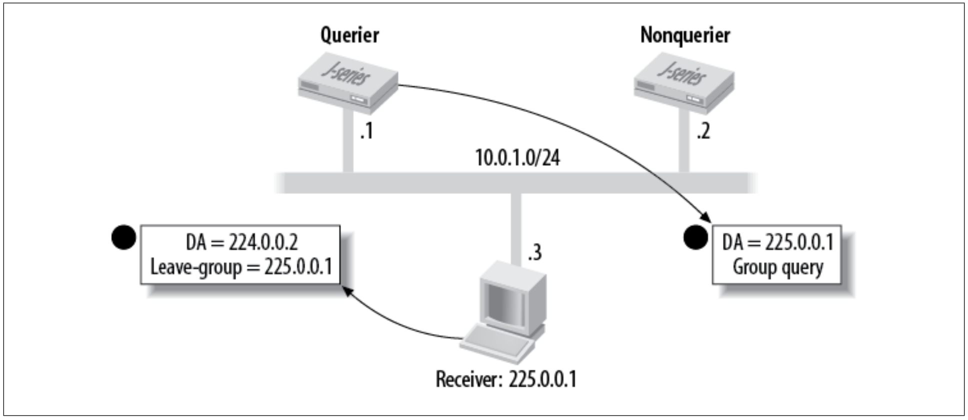


Figure 11-10. IGMPv2 leave process

Later on, the receiving host no longer desires content from group 225.0.0.1. It generates an IGMPv2 group-leave message, which is addressed to 224.0.0.2, the all-routers multicast address. The querier router now generates a group-specific query, which is addressed to the multicast address of the related group, in order to determine whether any interested listeners remain. If so, one will be the first to generate a group report, which keeps the binding active. Otherwise, after a small delay, the group join state is removed from the associated interface. The support of group leaves and general queries can greatly reduce join and leave latency. For example, in IGMPv1, the routing protocol must generate three queries before removing join state—with the default 60-second timer, this equates to 180 seconds of continued multicast delivery after the last interested host has left the group.

IGMPv3

IGMPv3 adds the concept of a source-specific join, which in turn enables source-specific multicast (SSM). The new capability allows a host to filter multicast content by group, as well as by source. With IGMPv1 or IGMPv2, a host simply has no way to express interest in a particular source, and therefore has to receive traffic from all active senders to that group. Because a source-specific join explicitly identifies the desired source, an SPT can be instantiated without the services of an RP. Figure 11-11 shows IGMPv3 SSM operation.

In Figure 11-11, our trusty receiver (which is now IGMPv3-enabled) is told by its multicast application to *subscribe* to the multicast *channel* identified by the tuple

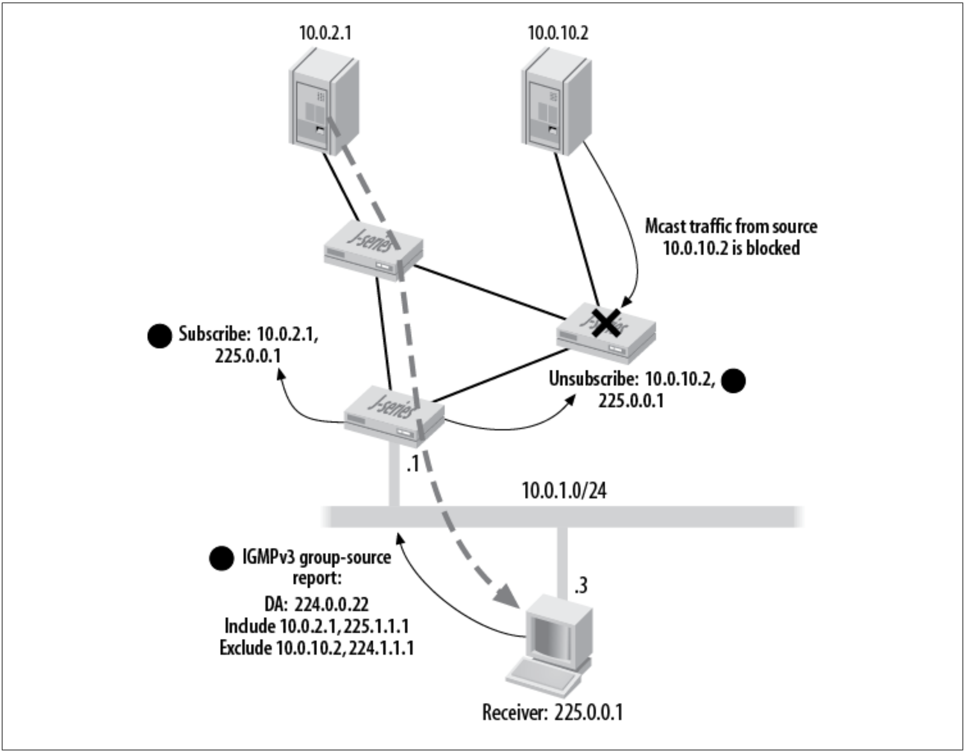

10.0.2.1
10.0.10.2
Mcast traffic from source 10.0.10.2 is blocked
Subscribe: 10.0.2.1, 225.0.0.1
Unsubscribe: 10.0.10.2, 225.0.0.1
.1
10.0.1.0/24
IGMPv3 group-source report:
DA: 224.0.0.22
Include 10.0.2.1, 225.1.1.1
Exclude 10.0.10.2, 224.1.1.1
.3
Receiver: 225.0.0.1

Figure 11-11. IGMPv3 SSM operation

10.0.2.1,225.0.0.1. At the same time, the application instructs the machine to unsubscribe from the 10.0.10.2.225.0.0.1 channel. SSM uses the term *channel* in a manner analogous to the word *group* in ASM. Similarly, the terms *subscribe* and *unsubscribe* describe what in ASM is called *join* and *leave*. Note that the same protocol fields and values are used; the modified terminology simply helps to disambiguate which mode is being discussed, and more correctly describes ASM operation. Subscribing to an (S,G) is somewhat like tuning into a specific media channel when compared to IGMPv2's behavior of drawing traffic from all sources in the group. Note that IGMPv3 group report messages are sent to all IGMPv3-capable multicast routers with a multicast address of 224.0.0.22, rather than to the multicast address of the group specified in the group address of the report message itself, as is done in versions 1 and 2.

The result, shown at step 1, is the receiver generating an IGMPv3 report that specifically lists the sources (and groups) for which content is desired. The same message can also be used to remove any previously subscribed-to sources. The LAN's designated router translates the IGMP report into the appropriate PIM join and prune messages, which in this context are referred to as subscribe and unsubscribe, respectively.

PIM

Several multicast routing protocols are still in use, but by far the most widely deployed is PIM. PIM was designed to avoid the dense-mode scaling issues of DVMRP and the potential performance problems of Core-Based Tree (CBT) at the same time. PIM supports dense mode, sparse mode, and sparse-dense modes of operation, and it has been in production use for several years.

PIM is a rapidly evolving Internet specification. PIM has seen two major revisions to its protocol operation (and packet structure)—PIM version 1 and PIM version 2—three major RFCs (RFC 4601 obsoleted RFC 2362, which in turn obsoleted RFC 2117), and numerous drafts describing major components of PIM. Work continues on PIM in a number of areas, such as bidirectional trees, and the rapid pace of development generates numerous PIM-related Internet drafts.

PIM versions

PIMv1 and PIMv2 can coexist on the same router, but not on the same interface. The main difference between PIMv1 and PIMv2 is the packet format. PIMv1 messages use IGMP packets, whereas PIMv2 has its own IP protocol number (103) and packet structure. All routers connecting to a shared IP subnet must use the same PIM version. Because the difference between PIMv1 and PIMv2 simply involves the message format, not the semantics or message processing rules, a router can easily support a mix of PIMv1- and PIMv2-enabled interfaces.

In this chapter, we are focusing on PIMv2 operating in sparse mode because this represents the most common usage of PIM in modern IP internetworks.

PIM components

The components needed to run PIM vary depending on operational mode. PIM dense mode requires only multicast sources and receivers and a series of interconnected PIM dense mode routers to allow receivers to obtain multicast content.

PIM sparse mode is more complicated because it requires the services of an RP in the network core. The RP is the root of a shared tree and is the point where upstream join messages from interested receivers meet downstream traffic from multicast sources. If there is only one RP in a routing domain, the RP and adjacent links might become congested and form a single point of failure for all multicast traffic. As a result, it is common to see multiple RPs deployed within a multicast network, for both performance and reliability reasons.

You can view PIM SSM as a subset of a special case of PIM sparse mode, and it requires no specialized equipment other than that used for PIM sparse mode (and IGMP version 3). When a host sends an IGMPv3 join for (S,G), the receiving designated router initiates creation of the SPT by sending an (S,G) join to its RPF neighbor for that source.

RP discovery. Having one or more routers configured as RPs is one thing, but how do the various sources and receivers come to learn which routers are acting as RPs, and for which multicast groups? You can take several approaches to propagate knowledge of the routing domain's RPs to client routers. They include:

Static
: The simplest RP discovery mechanism is a static definition of the RP's address and group ranges on each client. This approach does not require any dynamic discovery protocols, but it is prone to reliability issues in the event that the statically defined RP fails, unless Anycast-RP is being used. PIM versions 1 and 2 support static RP assignments.

Auto-RP
: The auto-RP mechanism is a nonstandard approach (developed by Cisco Systems) for the dissemination of RP information. Despite the lack of standards, auto-RP is supported in Junos. The main drawback to auto-RP, aside from its nonstandard status, is the need for dense-mode handling of the two group addresses associated with auto-RP itself. This requirement forces sparse-dense mode operation on the network. The two auto-RP groups are 224.0.1.39 (announce), which is used to learn which routers in the network are possible candidate RPs, and 224.0.1.40 (discovery), which allows PIM routers to learn about the active group-to-RP mapping information. In operation, one or more routers are configured to perform the mapping function, which takes as input the set of candidate RPs learned in discovery messages and generates as output the chosen RP-to-group mappings that all routers should use. Auto-RP does support failover to backup RPs, but auto-RP does not support the ability to load-balance among multiple RPs for the same group range. Auto-RP is supported in PIM versions 1 and 2.

Bootstrap
: The BSR mechanism is the standardized way to dynamically communicate a domain's RP to group address bindings. Unlike auto-RP, BSR does not require any dense-mode flooding. This is because bootstrap messages are propagated hop by hop rather than flooded via multicast, which thereby eliminates the cart-before-the-horse issues of auto-RP needing a working dense-mode multicast infrastructure before an RP can be communicated. The bootstrap mechanism is supported in PIM version 2 only. You can configure multiple candidate BSRs for redundancy—it is common to have the same routers configured as candidate RPs to be set as candidate BSRs also.

  Once the BSR is elected (the router with the highest BSR priority), each candidate RP advertises its configured group ranges. The BSR processes the received advertisements, based in part on factors such as local policy, group range specificity, configured RP priority, and so on. The resulting RP set is communicated to all PIM routers, at which point each router is required to run its own hash to determine the RP for a given group. It is important to note that the hash algorithm ensures that all routers select the same RP-to-group mappings from the information in the domain's RP set, and when multiple candidate RPs are present, the algorithm automatically load-balances between those RPs. Stated differently, if two RPs both announce the default 224/4 range, bootstrap operation results in each RP handling one-half of the active groups. The failure of one RP results in all groups being shifted to the remaining RP—however, at no one time can multiple RPs be active for the same group when using bootstrap.

Anycast-RP
PIM supports the notion of Anycast-RPs, which bypasses the restriction of having one active RP per multicast group. With Anycast-RP, you can deploy multiple RPs for the same group range. Anycast-RP provides redundancy and load balancing, but unlike bootstrap, Anycast-RP can balance traffic from sources within the *same* group. With Anycast-RP, the various RPs share a common unicast IP address, such that clients simply choose the metrically closest route to the shared RP address. In the event of RP failure, the IGP simply reroutes to the next best path to the shared IP address, thus preserving connectivity. For proper operation, is it critical that each Anycast-RP be aware of active sources using other Anycast-RPs. This RP-to-RP communication can be performed using MSDP, as defined in RFC 3446, or using the newer, PIM-only approach defined in RFC 4610. Both methods are supported in Junos.

PIM modes

PIM can operate in dense, sparse, sparse-dense, or SSM mode. Although in this chapter we are emphasizing PIM sparse mode in support of ASM, for completeness we will expand on the various modes here.

Dense mode. PIM dense mode is useful for multicast LAN applications, the main environment for all dense mode protocols. PIM dense mode uses the same flood first, prune later approach associated with DVMRP. The main difference between DVMRP and PIM dense mode is that PIM provides protocol independence and can use the route table populated by any underlying unicast routing protocol to perform RPF checks. PIM dense mode supports the ASM model.

Sparse mode. PIM sparse mode is the most common way to deploy PIM. Sparse mode operation is considerably more complex than dense mode, but sparse mode offers the benefit of bandwidth conservation, which often more than justifies the added complexity. The various configuration examples shown in this chapter are based on PIM sparse mode. The key aspect of sparse mode operation is the need for an RP to serve as a liaison between active senders and any receivers that wish to obtain their content.

A PIM sparse mode router joins the RP-based shared tree upon receipt of an IGMP join from attached receivers. This is known as an (*,G) join because it matches any source sending to that group. If any sources are active for that group, their packets are sent down the shared tree until they reach the last hop router (the router directly attached to the receiver) and are delivered to the receiver(s) on that network segment. Receipt of traffic over the shared tree allows the last hop router to learn the address of active sources, at which point it initiates an SPT by sending an (S,G) over the RPF path toward each source. Once the SPT is established, the last hop router prunes that source from the shared tree by sending an (S,G) prune. This transitional aspect of PIM sparse mode from shared to source-based tree is one of the major attractions of PIM. This feature prevents overloading the RP or surrounding core links, which was the Achilles' heel of the CBT approach—which has yet to see commercial deployment.

PIM sparse mode supports the ASM and SSM models.

Source-specific multicast. The original multicast RFCs specify both many-to-many and one-to-many models. These modes are now known as ASM because ASM supports one or many sources for a multicast group's traffic. However, ASM operation requires that receivers be able to determine the locations of *all* sources for a particular multicast group, no matter where the sources might be located in the network. In ASM, *source discovery* is a critical and complex function within the network.

ASM makes sense in a highly dynamic environment where sources often come and go, as, for example, in a videoconferencing service. However, several promising multicast applications, such as IP-based television, are being brought to commercial realization quickly and efficiently through an assumption that there is a longer-lived single source for some particular content. PIM SSM is simpler than PIM sparse mode because only the one-to-many model is supported. PIM SSM therefore forms a subset of PIM sparse mode. It builds only SPTs, and an RP is no longer necessary, given that the user specifies the source address as part of his IGMPv3 report message.

PIM SSM can coexist with ASM by confining the SSM model to a subset of the IP multicast group address range. The IANA has reserved the address range 232.0.0.0–232.255.255.255 for SSM operation. Junos allows SSM configuration for the entire range of IP multicast addresses (224.0.0.0–239.255.255.255). When a custom SSM range is defined, legacy IP multicast applications cannot receive any traffic for groups in that SSM range, unless the application is modified to support SSM (S,G) channel subscription.

PIM messages

PIM uses a variety of message types to do its job. The reader is encouraged to consult the appropriate RFC for an exhaustive description of each field found in the various PIM messages. Our purpose here is to describe *how* these PIM messages operate to establish SSM operation:

Join/prune
: PIM state is established and withdrawn using join/prune messages. An individual message may contain both join and prune information, join information (a join message) only, or prune information (a prune message) only. A single join/prune message can list multiple senders/groups to join or prune.

Register

Routers connected to a multicast source encapsulate the multicast data stream into unicast packets that are addressed to the RP that serves that group range. A PIM register message contains an encapsulated multicast packet, which can be sent to the RP without the need for multicast transport between the sender and the RP. Once received by the RP, the register encapsulation is stripped and the RP forwards native multicast packets down the shared RPT.

Register stop

The RP may wish to stop receiving the encapsulated multicast traffic from the first hop router, and the register-stop message is used to accomplish this goal. An RP may wish to stop receiving register-encapsulated messages for several reasons:

- The RP has no join state for the group address of the traffic (there are no interested listeners on the RPT).
- The RP may have received a prune message from the network for a group being forwarded along the RPT, perhaps as the result of SPT establishment leaving no interested receivers.
- The RP itself might be receiving the multicast traffic natively from the network along an SPT.

The designated router

PIM defines specific functions for the first and last hop routers, which are known as designated routers. The designated router sends register and join/prune messages on behalf of directly connected senders and receivers, respectively. The designated router may or may not be the same router as the IGMP querier.

On multiaccess networks, a designated router is elected to ensure that packets and PIM control state are not duplicated. In operation, PIM neighbors on a shared LAN periodically send PIM Hello messages to each other. The sender with the highest IP address becomes the designated router for that LAN segment.

PIM assert. PIM supports an assert mechanism that prevents ongoing packet duplication, which can occur when there are parallel paths to a source or the RP. Figure 11-12 shows the PIM assert process in action.

The figure shows three routers, R1–R3, connected to a shared LAN, along with an RP and a source for group 225.0.0.1. The figure also shows the IGP metrics to reach the source, as seen by routers R1 and R2. In this example, both R1 and R2 have added the multicast source to their OIL for their LAN attached interface. As a result, a packet sent from the source is replicated and forwarded by both R1 and R2, resulting in an extra copy of the packet on the LAN segment. To prevent ongoing occurrences, the PIM assert process is started, by which the upstream PIM routers assert their right to be the designated forwarder by sending assert messages to the 224.0.0.13 (ALL-PIM-ROUTERS) group multicast address. Each router places its IGP preference and corresponding metric to the source in its assert message. The router with the best preference,

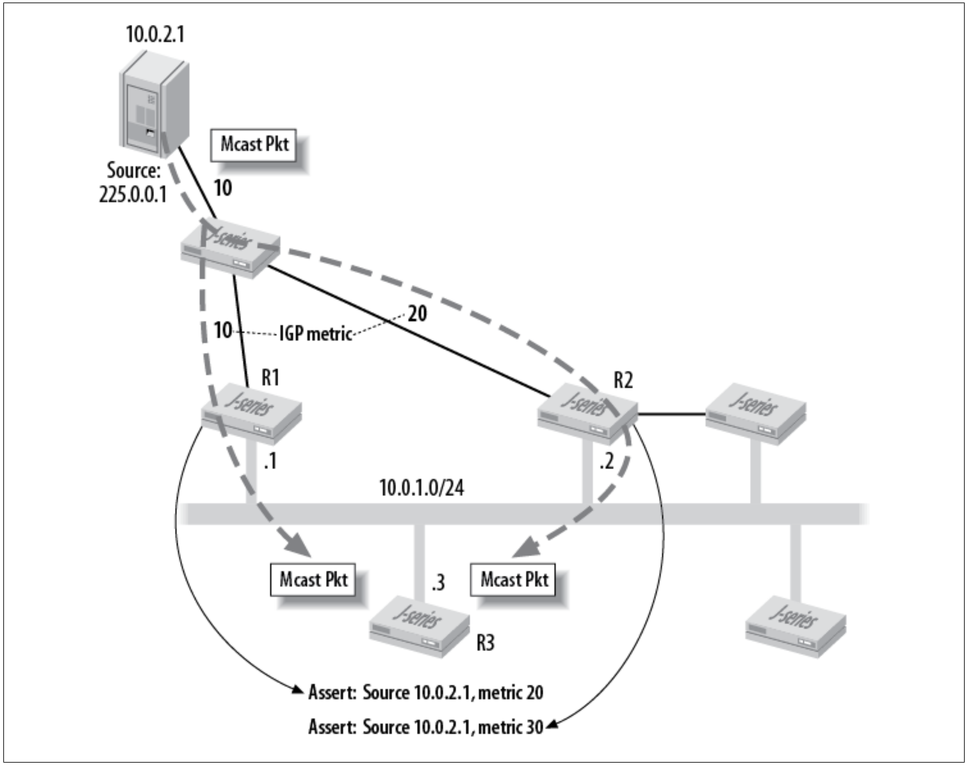


Figure 11-12. The PIM assert process

or lowest metric, wins (metrics are compared only in the event of a preference tie). In the event of a metric tie, the router with the highest IP address wins. Figure 11-12 also shows that R1 has a better metric and therefore becomes the forwarder for the LAN segment. Meanwhile, downstream router R3 has eavesdropped on the assert battle and takes note of the victor because this is the router to which R3 will subsequently send joins for that source.

PIM asserts are also needed for (*,G) entries. This is because the RPT and SPT for a given group may transit a shared media link such as a LAN. In these cases, the assert mechanism determines which of the two trees will carry the packet on the shared links, again to avoid unneeded packet duplication. According to the specifications, an SPT is always preferred over an RPT. When there are multiple paths to the RP through the LAN, the designated router may lose the (*,G) assert process to another router on the LAN. As a result, that router ceases to be the designated router for local receivers on that LAN, and the victor becomes the last hop router and is therefore responsible for sending (*,G) join messages to the RP.

Multicast Protocol Summary

This section detailed the function of group management protocols, which allow routers to determine which interfaces have attached listeners and allow multicast routing protocols that provide for RPF checking and manage join and prune states.

We also discussed the use of shared and source-specific trees, as well as the role of the RP in supporting ASM and SSM.

In the next section, we will put multicast theory to the test with a PIM sparse mode deployment scenario using a static RP.

PIM Sparse Mode: Static RP

At this stage, you should have an extensive grounding in IP multicast theory in general, and in PIM sparse mode operation in particular. This knowledge is soon to bear fruit as you configure and validate the operation of PIM sparse mode using a statically defined RP with Juniper Networks' routers.

The initial PIM sparse mode deployment goals are as follows:

- Configure router `PBR` as an RP for the entire multicast address range.
- Configure all other routers to use `PBR` as the domain's RP without using BSR or auto-RP.
- Configure `Cider` to function as a multicast receiver for group 225.1.1.1.
- Use `Ale` as a multicast source to generate traffic to group 225.1.1.1.
- Verify RPT join and subsequent traffic-driven switches to SPT.

Figure 11-13 details the portion of Beer-Co's network that is to be enabled for multicast support. The figure also highlights key aspects of the IGP routing infrastructure now in place.

Details to note in Figure 11-13 include the following:

- The default OSPF bandwidth scaling factor is in effect with the exception of `PBR`'s end of the `PBR–Lager` link (asymmetric) and the `PBR–Bock` link. The metric for these links has been altered in an effort to favor the `Lager–Stout–Porter` path for communications between `Ale` and `Cider`.
- Router `Ale` is configured to emulate a host sending to a multicast group. `Ale` uses a default route pointing to the virtual IP (VIP) address associated with the `PBR–Lager` Virtual Router Redundancy Protocol (VRRP) group. No routing or multicast protocols are enabled at `Ale`.
- `Cider` is used to simulate a PIM-enabled router with a directly attached multicast receiver.

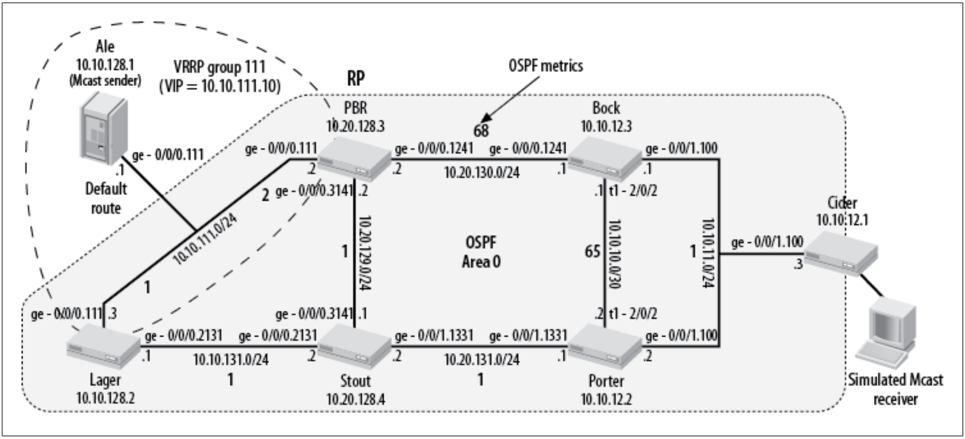


Figure 11-13. Beer-Co's multicast topology

Validate the Baseline IGP Forwarding Path

Before starting any multicast configuration, a quick confirmation of IGP connectivity and the resulting forwarding paths through the network is performed. The use of a default route is confirmed at `Ale`, as is the use of the `Lager`, `Stout`, and `Porter` forwarding paths for communications between `Ale` and `Cider`:

```
[edit]
lab@Ale# **run show route 10.10.12.1**
inet.0: 4 destinations, 4 routes (4 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

  0.0.0.0/0          *[Static/5] 00:00:04
                    > to 10.10.111.10 via ge-0/0/0.111
[edit]
lab@Ale# **run traceroute 10.10.12.1 no-resolve**
traceroute to 10.10.12.1 (10.10.12.1), 30 hops max, 40 byte packets
 1  10.10.111.3  11.837 ms  9.735 ms  10.115 ms
 2  10.10.131.2  19.716 ms  20.203 ms  9.681 ms
 3  10.20.131.1  10.109 ms  10.395 ms  9.298 ms
 4  10.10.12.1  20.214 ms  9.747 ms  19.893 ms
```

Symmetrical forwarding in the return path from `Cider` to `Ale` is also confirmed, as is the use of OSPF routing at `Cider`; recall that unlike `Ale`, which is running no routing protocols, `Cider` simulates a PIM/OSPF-enabled router with an attached receiver:

```
[edit]
lab@Cider# **run traceroute 10.10.128.1 no-resolve**
traceroute to 10.10.128.1 (10.10.128.1), 30 hops max, 40 byte packets
 1  10.10.11.2  9.945 ms  9.711 ms  9.856 ms
 2  10.20.131.2  20.054 ms  39.955 ms  19.863 ms
 3  10.10.131.1  19.854 ms  18.125 ms  31.839 ms
 4  10.10.128.1  19.792 ms  19.949 ms  20.214 ms

[edit]
```

```
lab@Cider# run show route 10.10.128.1

inet.0: 19 destinations, 19 routes (19 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both
10.10.128.1/32     *[OSPF/150]
 00:20:10, metric 0, tag 0
                    > to 10.10.11.2 via ge-0/0/1.100
```

The OSPF route to the loopback address of `Ale` is seen as an OSPF external by router `Cider`. This is because a static route representing `Ale`'s `lo0` address is redistributed into OSPF at routers `PBR` and `Lager`, which is necessary here given that `Ale` does not participate in OSPF routing. The 111 VRRP group shared by `PBR` and `Lager` is configured to make `Lager` the VRRP master when its `ge-0/0/0.111` interface is operational via the `preempt` keyword and a priority of 100—the `accept-data` option is added to permit diagnostic ping testing to the VIP. According to the VRRP RFC, the VIP is allowed to respond only to Address Resolution Protocol (ARP) requests, meaning that unlike Cisco's HSRP, by default you cannot ping the VIP associated with a VRRP group.

`Lager`'s static route, related redistribution policy, and VRRP configuration are shown. `PBR` has a similar configuration, except that its VRRP priority is set to 50:

```
[edit]
lab@Lager# show routing-options
static {
    route 10.10.128.1/32 next-hop 10.10.111.1;
}

[edit]
lab@Lager# show policy-options
policy-statement Ale_lo0 {
    term 1 {
        from {
            protocol static;
            route-filter 10.10.128.1/32 exact;
        }
        then accept;
    }
}

[edit]
lab@Lager# show interfaces ge-0/0/0 unit 111
description Lager_PBR_Ale;
vlan-id 111;
family inet {
    address 10.10.111.3/24 {
        vrrp-group 69 {
            virtual-address 10.10.111.10;
            priority 100;
            preempt;
            accept-data;
        }
    }
}
```

Configure PIM Sparse Mode with Static RP

With the underlying IGP's operation confirmed, you move on to PIM configuration on the routers making up the multicast test bed. In the Junos implementation, enabling PIM on an interface automatically enables IGMPv2, making explicit configuration of IGMP unnecessary unless you need to modify default settings. IGMP is not required on links that connect only routers—hosts use IGMP to inform routers of their group membership. Leaving IGMP enabled on these links does not lead to appreciable resource consumption and ensures that things will work as expected if hosts are added at a later time.

PIM configuration begins at router `PBR` because it's been designated as the RP in the initial multicast topology; without an RP, PIM sparse mode cannot begin to operate. PIM is configured at the `[edit protocols pim]` hierarchy. The configuration options for PIM are displayed:

```
[edit protocols pim]
lab@PBR# set ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
  assert-timeout       Set assert timeout (5..210)
> default-vpn-source   Let all VRFs use master loopback address for mt interface
> dense-groups         Dense mode groups for sparse-dense mode
  disable              Disable PIM
  dr-election-on-p2p   Enable DR election on Point-to-Point Interaces
+ export               PIM sparse export join policy
> family               Local address family
> graceful-restart     Configure graceful restart attributes
+ import               PIM sparse import join policy
> interface            PIM interface options
> join-load-balance    Configure PIM join load balancing
  join-prune-timeout   Set join/prune timeout (210..420)
  no-wildcard-register-stop  Disable sending of wildcard register stop message
> nonstop-routing      Configure PIM nonstop-routing attributes
> rib-group            Routing table group
> rp                   Router's rendezvous point properties
> spt-threshold        Set shortest-path-tree threshold policy
> traceoptions         Trace options for PIM
```

The `assert-timeout` setting determines how often the forwarding router reasserts its right to do so, based on its belief that it has the lowest SPF RPF cost for a given source or RP; the router always generates an assert message when a multicast packet is *received* on an interface that is in the *outgoing* interface list for a given group. Internal rate-limiting of these event-driven assert messages (as with all control plane messaging in Junos) ensures that the network and local processing resources are not overrun in the event of a packet loop or broken multicast forwarding state in an adjacent node.

The `dense-groups` configuration identifies any groups that are flooded in dense mode over interfaces set for sparse-dense mode operation. This setting is used when you operate in sparse mode but you still want dense mode flooding on a group-by-group basis, and it is typically used to support auto-RP's need for dense mode flooding of its announce (224.0.1.39) and discovery (224.0.1.40) messages.

The `graceful-restart` and `nonstop-routing` settings control these features for PIM when they are enabled globally. The `import` and `export` keywords link to one or more policies that allow filtering of join messages, which prevents the resulting (*,G) or (S,G) state, therefore blocking the extent of multicast traffic distribution by preventing installation of related forwarding state in the control plane. In contrast, multicast scoping operates in the *data* plane to provide a similar effect. Generally speaking, the use of scoping is preferred over join filtering because the former scales better, and it prevents the transport of multicast traffic that could result from the use of dense mode flooding or a packet generation tool.

The `spt-threshold` determines whether the local router attempts a switch to an SPT after the first packet (default), or never when set to infinity. The use of multicast distribution tree (MDT) tunnels and routing information base (RIB) groups is beyond the scope of this book. Suffice it to say that MDT tunnels are used to support PIM sparse mode in a Layer 3 virtual private network (VPN) environment, and that use of RIB groups allows a PIM multicast forwarding topology that is independent of the unicast RPF table.

The `interface` keyword allows specification of which interfaces should run PIM, along with interface-level parameters such as PIM version, hello time, and so on. The options available at the `[edit protocols pim interface` *`interface-name`* `]` hierarchy are:

```
[edit protocols pim]
lab@PBR# set interface ge-0/0/0.111 ?
Possible completions:
  <[Enter]>             Execute this command
  accept-remote-source  Accept traffic from remote source
+ apply-groups          Groups from which to inherit configuration data
+ apply-groups-except   Don't inherit configuration data from these groups
> bfd-liveness-detection  Bidirectional Forwarding Detection options
  disable               Disable PIM on this interface
> family                Local address family
  hello-interval        Hello interval (0..255 seconds)
  mode                  Mode of interface
+ neighbor-policy       PIM neighbor policy applied to incoming hello messages
  priority              Hello option DR priority (0..4294967295)
  version               Force PIM version (1..2)
  |                     Pipe through a command
```

Most interface-level options are self-explanatory. The priority setting specified under an interface controls the router's likelihood of being elected the PIM designated router on that network segment; the default setting is 1, making the router least likely to be the designated router. The `mode` keyword determines whether the associated PIM interface operates in sparse, dense, or sparse-dense mode. When an interface is in sparse-dense mode, the list of groups specified with the `dense-groups` keyword is flooded in dense mode, and all other groups are handled as sparse.

You configure a router to be an RP, or to learn about other RPs using either the static, bootstrap, auto-RP, or Anycast-RP mechanism under the [edit protocol pim rp] hierarchy. The configuration options available at this hierarchy are:

```
[edit protocols pim]
lab@PBR# set rp ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> auto-rp              Set auto-RP mode (IPv4 only)
> bootstrap            Bootstrap properties
+ bootstrap-export     Bootstrap export policy (IPv4 only)
+ bootstrap-import     Bootstrap import policy (IPv4 only)
  bootstrap-priority   Eligibility to be the bootstrap router (IPv4 only)
+ dr-register-policy   DR policy applied to outgoing register messages
> embedded-rp          Set embedded-RP mode (IPv6 only)
> local                Router's local RP properties
+ rp-register-policy   RP policy applied to incoming register messages
> static               Configure static PIM RPs
```

As you would expect, the properties that control auto-RP-based RP election are configured under the Auto-RP hierarchy. Auto-RP is not demonstrated here because it has lost favor to BSR-based election for reasons that were cited previously. Several bootstrap-related configuration keywords are used in bootstrap-based RP election—we will skip these knobs for now because we will explore them in a subsequent BSR configuration example.

The dr-register-policy and rp-register-policy keywords link to policy statements that filter register messages sent by the designated router or filter register messages received by the RP, respectively. This feature allows you to control the number of sources that a given RP can know about, and that might be used for performance or security-related reasons. The embedded-rp hierarchy controls the number of embedded RPs, as well as groups that can contain an embedded RP address. Embedded RP is used for interdomain IPv6 multicast and is beyond the scope of this book. Note, however, that IPv4 interdomain multicast is normally associated with MSDP.

Static definition of an RP is performed with the static keyword. A statically configured RP eliminates the need for dynamic RP election, but this simplicity can come at the cost of reduced reliability because routers may continue to use an RP that has ceased functioning. However, the use of a statically defined RP, in conjunction with Anycast-RP, alleviates many of these concerns, and we discuss it in detail in "PIM Sparse Mode with Anycast-RP Summary" on page 590.

Configure PIM on the RP

Local RP characteristics are defined under the [edit protocols pim local] hierarchy, and are used when the local router functions as an RP. Because PBR is the PIM domain's RP in this example, your configuration begins at PBR with the specification of its local

RP properties. The command-line interface's (CLI's) ? function displays the configuration mode set options available at the [edit protocols pim rp local] hierarchy:

```
[edit protocols pim rp local]
lab@PBR# lab@PBR# set ?
Possible completions:
  address               Local RP address (IPv4 only)
+ apply-groups          Groups from which to inherit configuration data
+ apply-groups-except   Don't inherit configuration data from these groups
  disable               Disable this RP (IPv4 only)
> family                Local RP address family
> group-ranges          Group address range for which this router can be an RP
(IPv4 only)
  hold-time             How long neighbor considers this router to be up, in seconds
(IPv4 only)
  priority              Router's priority for becoming an RP (IPv4 only) (0..255)
```

Use the address keyword to define the local RP address for IPv4 operation. Normally, this will be a globally routable address (i.e., a non-127.*x*.*x*.*x* address) assigned to the router's lo0 interface for maximum reliability, given that the virtual nature of a loopback interface tends to make it the last to fail. The family keyword is used to configure an IPv6-based RP under the inet6 family. You may wish to divide the multicast address space among multiple RPs using the group-ranges keyword to help spread processing load or to improve overall robustness by eliminating a potential single point of failure for all multicast groups in the domain.

The configured hold-time value is included in candidate RP messages (sent to a domain's bootstrap router when using BSR), and it determines how long the BSR includes that RP in the candidate RP set before the entry needs to be refreshed by receipt of a new candidate RP advertisement for that same RP. The priority value is used in the hash function that chooses a particular RP for a given group range from the set of candidate RPs. A numerically smaller priority value is preferred—the range is from 0 to 255, with 1 being the default. Note that a setting of 0 indicates that the BSR can override the received RP-to-group mappings in the candidate RP set that it advertises.

Because you are configuring a static RP environment, only the address keyword is of concern in the current configuration. "Configure PIM Sparse Mode with Bootstrap RP" on page 568 demonstrates BSR-based RP election. PBR is configured to use its globally routable loopback address as the domain's RP:

```
[edit protocols pim rp local]
lab@PBR# set address 10.20.128.3
```

The interfaces that should run PIM are configured next; there is no need or benefit to running PIM on the lo0 interface, so transit interfaces only are enabled for PIM. The completed PIM stanza at PBR is displayed:

```
[edit protocols pim]
lab@PBR# show
rp {
    local {
        address 10.20.128.3;
    }
}
interface ge-0/0/0.3141;
interface ge-0/0/0.1241;
interface ge-0/0/0.111;
```

After committing the changes to the local RP, status is confirmed:

```
lab@PBR# run show pim rps
Instance: PIM.master
Address family INET
RP address          Type        Holdtime Timeout Groups Group prefixes
10.20.128.3         static             0    None      0 224.0.0.0/4
```

The output of the `show pim rps` command shows that PBR is functioning as a statically defined RP for the entire multicast address 224/4 group range. You next verify that PIM is enabled on all transit interfaces used in the multicast test bed with a `show pim interfaces` command:

```
[edit protocols pim]
lab@PBR# run show pim interfaces
Instance: PIM.master
Name               Stat Mode     IP V State NbrCnt JoinCnt(sg) JointCnt(*g) DR address
ge-0/0/0.111       Up   Sparse    4 2 DR         0           0            0  10.10.111.2
ge-0/0/0.1241      Up   Sparse    4 2 DR         0           0            0  10.20.130.2
ge-0/0/0.3141      Up   Sparse    4 2 DR         0           0            0  10.20.129.2
pd-0/0/0.32769     Up   Sparse    4 2 P2P        0           0            0
```

The command output confirms that PIM is now running on all three of PBR's network interfaces used in the multicast test bed, and that sparse is the default mode of operation. Because PBR is the first, and so far the only, PIM-enabled router, it has won the designated router election on all of its multiaccess interfaces; a designated router is not required on point-to-point interfaces. The 0 count values indicate that no PIM neighbors have been detected, which is expected until other routers are enabled for PIM, and that no joins have been received, also expected at this point. The `show pim neighbors` command returns an empty list at this time (not shown).

The highlighted code in the output calls out that the router has automatically instantiated a PIM decapsulation (`pd`) interface using the J-series built-in services interface functionality. Recall that in sparse mode, the first hop router encapsulates multicast into a unicast register message (using a PIM encapsulate [`pe`] interface), which is then decapsulated back to native multicast at the RP for distribution down the shared tree. No explicit configuration is needed for these `pd` and `pe` interfaces; they are created automatically when PIM sparse mode is configured and the required tunnel support is present. On some platforms, such as the M10i, you must order and install tunnel hardware to support PIM sparse mode register message encapsulation.

As noted previously, in the Junos OS, enabling PIM automatically enables IGMP on that interface. The output of the `show igmp interface` command confirms that this is the case:

```
lab@PBR# run show igmp interface
Interface: ge-0/0/0.111
    Querier: 10.10.111.2
    State State:         Up Timeout:    None Version:  2 Groups:      2
    Immediate leave: Off
    Promiscuous mode: Off
    Passive: Off
Interface: ge-0/0/0.1241
    Querier: 10.20.130.1
    State:         Up Timeout:    None Version:  2 Groups:      2
    Immediate leave: Off
    Promiscuous mode: Off
    Passive: Off
Interface: ge-0/0/0.3141
    Querier: 10.20.129.1
    State:         Up Timeout:    None Version:  2 Groups:      2
    Immediate leave: Off
    Promiscuous mode: Off
    Passive: Off

Configured Parameters:
IGMP Query Interval: 125.0
IGMP Query Response Interval: 10.0
IGMP Last Member Query Interval: 1.0
IGMP Robustness Count: 2

Derived Parameters:
IGMP Membership Timeout: 260.0
IGMP Other Querier Present Timeout: 255.
```

Configure PIM on remaining routers

With the domain's RP up and running, you move on to add PIM to the remaining routers. Aside from specifying PIM-enabled interfaces, you must also specify the domain's RP explicitly, as this is a static RP scenario. The PIM configuration added to `Stout` is shown. All remaining routers have a similar PIM configuration:

```
[edit protocols pim]
lab@stout#show
rp {
    static {
        address 10.20.128.3;
    }
}
interface ge-0/0/0.2131;
interface ge-0/0/0.3141;
interface ge-0/0/1.1331;
```

The key to this PIM sparse mode configuration is the static definition of the domain's RP, which in this example is `PBR`'s `lo0` address. When desired, you can further define a static RP's group range and PIM version:

```
[edit protocols pim]
lab@stout# set rp static address 10.20.128.3 ?
Possible completions:
  <[Enter]>            Execute this command
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
> **group-ranges**         Group address range of RP
  **version**              PIM version of RP (1..2)
```

In this example, the default version 2 and 224/4 group range are desired, so no further changes are needed. After the changes are committed, you confirm the presence of PIM neighbors at router `Stout`:

```
[edit protocols pim]
lab@stout# run show pim interfaces
Instance: PIM.master

Name             Stat Mode     IP V State NbrCnt JoinCnt(sg) JointCnt(*g) DR address
ge-0/0/0.2131    Up   Sparse    4 2 DR         1           0            0  10.10.131.2
ge-0/0/0.3141    Up   Sparse    4 2 NotDR      1           0            0  10.20.129.2
ge-0/0/1.1331    Up   Sparse    4 2 DR         1           0            0  10.20.131.2
pe-0/0/0.32769   Up   Sparse    4 2 P2P        0
```

The display shows that `Stout` has detected one PIM neighbor on all but its `pe` encapsulation interface, which is expected given this setup. The output also shows that the local router is the designated router for two of its three network interfaces. To display neighbor information, issue a `show pim neighbors` command:

```
lab@stout# run show pim neighbors
Instance: PIM.master
Interface           IP V Mode        Option      Uptime Neighbor addr
ge-0/0/0.2131        4 2             HPLG      00:18:12 10.10.131.1
ge-0/0/0.3141        4 2             HPLG      00:18:12 10.20.129.2
ge-0/0/1.1331        4 2             HPLG      00:18:12 10.20.131.1
```

The display shows the IP address of each detected PIM neighbor, the associated interface, and the supported IP/PIM version. The Mode column is expected to be empty when configured for PIMv2 because v2 supports dense, sparse, and sparse-dense modes. The Option column displays a coded list of each neighbor's supported PIM options. The codes are interpreted as follows:

B
: Bidirectional-capable

H
: Hello option hold time

G
: Generation identifier

P
: Hello option designated router priority

L
: Hello option LAN prune delay

Add the `detail` switch to view the specific timers and parameters associated with each neighbor:

```
[edit protocols pim]
lab@stout# run show pim neighbors detail
Instance: PIM.master
Interface: ge-0/0/0.2131

    Address: 10.10.131.1,       IPv4, PIM v2, Mode: Sparse, sg Join Count: 0tsg
 Join Count: 0
        Hello Option Holdtime: 65535 seconds
        Hello Option DR Priority: 1
        Hello Option Generation ID: 577499317
        Hello Option LAN Prune Delay: delay 500 ms override 2000 ms

    Address: 10.10.131.2,       IPv4, PIM v2, Mode: Sparse
        Hello Option Holdtime: 65535 seconds
        Hello Option DR Priority: 1
        Hello Option Generation ID: 756451044
        Hello Option LAN Prune Delay: delay 500 ms override 2000 ms
```

The PIM neighbor state is as expected at `Stout`. RP information is displayed with the `show pim rps` command:

```
[edit protocols pim]
lab@stout# run show pim rps
Instance: PIM.master
Address family INET
RP address          Type        Holdtime Timeout Groups Group prefixes
10.20.128.3         static             0    None      0 224.0.0.0/4

Address family INET6
```

The output displays the loopback address associated with router `PBR`, which is functioning as the Beer-Co domain's RP. Further, the display confirms that the RP was learned via static configuration (hence, no timeout), and that currently no multicast groups are mapped to this RP, as indicated by the 0 in the Groups column. Given that there are no active groups (or sources, for that matter) in the current network, the lack of any group-to-RP mappings is expected at this time. As further confirmation, PIM join state is displayed at `Stout`:

```
[edit protocols pim]
lab@stout# run show pim join
Instance: PIM.master Family: INET
R = Rendezvous Point Tree, S = Sparse, W = Wildcard

Instance: PIM.master Family: INET6
R = Rendezvous Point Tree, S = Sparse, W = Wildcard
```

The join list is empty, which indicates that no SPT or RPT joins have been instigated by the local router. This display confirms that no groups are currently mapped to the domain's RP. The lack of join state means there should be no multicast forwarding state, which is easily verified with a `show multicast route` command:

```
[edit protocols pim]
lab@stout# run show multicast route
Family: INET

Family: INET6
```

As expected, there are no active multicast routes, which is in keeping with no RPT or SPT join state. At this stage, the PIM network is awaiting an active source and an interested receiver.

Verify RPF

Before you activate any senders or multicast receivers, the RPF state of the current network is analyzed. Recall that multicast forwarding and control plane operations tend to center on the RPF function. An RPF check is, in essence, nothing more than a route lookup on a packet source, and then verification that the packet arrives on the same interface that would be used when routing packets addressed to that source.

Referring back to Figure 11-13, it is restated that IGP metrics are altered to prefer the lower forwarding path consisting of routers `Lager`, `Stout`, and `Porter`. The network's RPF state should reflect the IGP's preferred forwarding path, which is confirmed with a `show multicast rpf` command issued at router `Bock` for the prefix associated with the domain's RP:

```
[edit]
lab@Bock# run show multicast rpf 10.20.128.3
Multicast RPF table: inet.0 , 21 entries
10.20.128.3/32
    Protocol: OSPF
    Interface: ge-0/0/1.100
    Neighbor: 10.10.11.2
```

The output shows that `Bock` expects to receive packets sent from the 10.20.128.3 loopback address of `PBR`, via its `ge-0/0/1.100` interface. Based on this RPF state, any packets from source 10.20.128.3 received on *any other* interface fail the RPF check, resulting in discard. The OSPF route to 10.20.128.3 is displayed at `Bock` to confirm that the shortest path route from `Bock` to `PBR`'s loopback does in fact egress on its `ge-0/0/1.100` interface:

```
[edit]
lab@Bock# run show route 10.20.128.3

inet.0: 21 destinations, 22 routes (21 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both
10.20.128.3/32     *[OSPF/10] 01:18:05, metric 4
                    > to 10.10.11.2 via ge-0/0/1.100
```

Configure the simulated receiver

The test bed used to develop this book did not have external multicast senders or receivers. Although unfortunate from an overall reality perspective, the upside is that their absence forces the use of Junos to simulate their functionality, and these little-known techniques often prove useful when troubleshooting multicast issues because they allow you to isolate potential problems with attached hosts and their multicast applications/protocol stack.

A Word on Multicast Client Options

Multicast is a somewhat dry subject, and it is always nice to use some media content, such as a multiplayer game or cool streaming DVD video, to validate multicast operation and performance. If your test bed contains multicast-capable hosts, we suggest that you investigate programs such as VideoLAN, which supports streaming video over unicast or multicast, on a variety of platforms to include Windows and various flavors of Unix. For more information, see the VideoLAN development website at *http://www.videolan.org*.

Unix platforms can use the *mgen/drec utilities*, which respectively stand for multigenerator and dynamic-receiver. These utilities are available for download at *http://downloads.pf.itd.nrl.navy.mil/mgen/archive/mgen3/*. The command line used to evoke `drec` to function as a receiver for group 225.1.1.1 in this scenario is similar to the example shown, but local interface names will vary:

```
%./drec -b 225.1.1.1 -n 1 -p 5000 -i em1 -S NOW /dev/null
DREC: Version 3.1a3
DREC: Loading event queue ...
DREC: Listening for packets ...
      (Hit <CTRL-C> to stop)
```

As for the command-line switches, the `-b` value specifies the base group address to join, and the `-n` value determines how many groups, starting at the base, are to be joined. The `-p` value specifies a User Datagram Protocol (UDP) port (5000 is the default), and the `-i` switch indicates the local interface that should be joined. The `-S` value determines test start time; test duration can also be specified. Once `drec` is launched, you would expect to see a join for the associated group, and would then fire up mgen with compatible settings to generate multicast traffic to that group. The command example uses the `-t` switch to set the desired TTL and the `-r` switch to set a rate of 10 packets per second:

```
%./ mgen -b 225.0.0.1:5000 -n 1 -i em1 -p 5000 -t 32 -r 10

MGEN: Version 3.1a3
MGEN: Loading event queue ...
MGEN: Seeding random number generator ...
MGEN: Beginning packet generation ...
      (Hit <CTRL-C> to stop)
```

A number of multicast test utilities are available for Windows platforms, but generally speaking, these tend to be somewhat crude when compared to the myriad options supported on Unix systems.

Static IGMP membership

The simplest way to simulate an attached multicast receiver in Junos is to configure a static IGMP join. The problem with a simple static join is that the local router does not join the group, and as such it does not receive any test traffic, which means that without an actual external receiver on the associated interface, there can be no hope of replies to generated multicast test traffic. With no such external receiver in this lab, the only way to confirm multicast forwarding is to monitor interface traffic stats on the receiver interface while trying to correlate the received packet count to the generated multicast test traffic. In a quiescent lab setup, this may be workable, but in any type of production network, there will likely be enough background traffic to make accurate matching of transmitted traffic to received multicast packets all but impossible. The syntax for a static IGMP join is shown, but this approach is not used because a different technique is planned for simulating a multicast receiver at router `Cider`:

```
[edit]
lab@Cider# show protocols igmp
interface ge-0/0/0.0 {
    static {
        group 225.1.1.1;
    }
}
```

Before moving on, it's noted that the lack of multicast hosts means there will be no IGMP activity to monitor in the lab. With the static join in place, you can view IGMP group status to familiarize yourself with the display. Things begin with the clearing of any IGMP membership to ensure that no stale state is displayed:

```
[edit]
lab@Cider# run clear igmp membership
Clearing Group Membership Info for ge-0/0/1.100
Clearing Group Membership Info for ge-0/0/0.0

[edit]
lab@Cider# run show igmp group
Interface: ge-0/0/0.0
    Group: 225.1.1.1
        Source: 0.0.0.0
        Last reported by: Local
        Timeout:       0 Type: Static
Interface: local
    Group: 224.0.0.2
        Source: 0.0.0.0
        Last reported by: Local
        Timeout:       0 Type: Dynamic
    Group: 224.0.0.5
        Source: 0.0.0.0
        Last reported by: Local
        Timeout:       0 Type: Dynamic
    Group: 224.0.0.6
        Source: 0.0.0.0
        Last reported by: Local
        Timeout:       0 Type: Dynamic
```

```
Group: 224.0.0.22
    Source: 0.0.0.0
    Last reported by: Local
    Timeout:       0 Type: Dynamic
```

As noted previously, multicast forwarding is all about dynamic state, and this state can seem to persist for an annoyingly long period of time if it's not cleared out manually. When testing any multicast environment, it is wise to let things cook for at least five minutes in all operational modes to ensure that things are really working the way you expect. Although bogus multicast state will generally not cause any negative impact to the router or network, it can affect communications for several minutes if left to age out using its own means.

The output of the `show igmp membership` command confirms the statically configured membership on interface `ge-0/0/0` for the 225.1.1.1 group. The lack of a specific source address shows that this is an (*,G), or shared tree join. When IGMPv3 is enabled, you can specify a source address when configuring static membership to generate (S,G) state and a resulting SPT. Dynamic entries are associated with a timeout value indicating when the entry will age out if it is not refreshed as a result of a host membership report for that group. The local entries represent multicast addresses associated with local processes that need to listen to multicast traffic. The 225.0.0.5 and 225.0.0.6 addresses represent all OSPF routers and all OSPF designated router groups, 225.0.0.1 is the all hosts group, 225.0.0.2 is the all routers group, and 225.0.0.22 is the multicast group associated with IGMP reports.

Create a listening multicast process

Many multicast applications operate in a simplex fashion, meaning that a reply is not technically needed for the application to work. However, in this lab the goal is to use Internet Control Message Protocol (ICMP) echo packets sent to a multicast group address, with success being determined by the receipt of a unicast reply, because this is the most expedient way to confirm that multicast test traffic is successfully forwarded all the way to the multicast receiver.

You can disable response generation to multicast-targeted pings by including the `no-multicast-echo` statement at the `[edit system]` hierarchy level, in Junos OS releases 8.1 and later. This does not alter behavior for unicast-targeted pings.

The trick to making a Juniper router initiate a PIM join, while also creating a process that listens to the associated group in contrast to a static IGMP join, is to enable the SAP process on the group in question. SAP always operates on the well-known group address 224.2.127.254, using port 9875, but you can configure SAP to operate on other groups (and ports) as well. This is the approach we're taking for the test bed's 225.1.1.1 group.

Active multicast sources transmit SDP messages infrequently, often on the order of minutes. This long delay between messages can cause problems in a PIM sparse mode network. The receipt of the SAP message by the RP causes it to examine its current join state for the 224.2.127.254 multicast group. If no state is enabled, the SAP message is not forwarded into the network. The end result is that the SDP message delay makes it extremely hard to get the SDP messages from the multicast source to the interested clients when operating in sparse mode. To reduce this delay, you can configure a SAP process on each router directly attached to receivers. This causes the router to generate a PIM join for the SAP group address of 224.2.127.254. The router refreshes this join state such that the RP maintains a constant forwarding tree for the SAP group. This allows the infrequent SDP messages to be forwarded to the interested clients and to populate the Session Directory tool. Frankly, it's hard to imagine something this good still being legal.

Before altering the configuration at `Cider`, a `show pim join` command is issued to confirm that no join state currently exists:

```
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Instance: PIM.master Family: INET6
```

`Cider`'s configuration is altered to instantiate a SAP process that will listen on 225.1.1.1, port 5000:

```
[edit protocols]
lab@Cider# show sap
listen 225.1.1.1 port 5000;
```

After the change is committed, PIM join state is again displayed. This time the `extensive` switch is added to view all possible details:

```
[edit protocols]
lab@Cider# run show pim join extensive
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.100
    Upstream neighbor: 10.10.11.2
    Upstream state: Join to RP
    Downstream neighbors:
        Interface: Local
```

```
Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.100
    Upstream neighbor: 10.10.11.2
    Upstream state: Join to RP
    Downstream neighbors:
        Interface: Pseudo-GMP
            ge-0/0/0.0

Instance: PIM.master Family: INET6
R = Rendezvous Point Tree, S = Sparse, W = Wildcard
```

The output indicates that the newly created SAP process has issued an RPT (shared tree or [*,G]) join for both the well-known and user-configured SAP groups. The upstream (incoming) interface is the RPF interface leading toward the domain's RP, and the downstream (outgoing) interface list is empty because this join is the result of a local process rather than a received PIM join or IGMP membership report. The presence of a listening UDP process on both SAP-associated ports is now verified. Here the command makes use of CLI matching and logical OR functionality to make quick work of the task:

```
[edit protocols]
lab@Cider# run show system connections | match "(5000|9875)"
udp4       0      0  *.5000                *.*
udp4       0      0  *.9875                *.*
```

The output confirms the two expected UDP-based listening processes on the well-known and user-specified SAP ports. The lack of data activity on the 225.1.1.1 group results in no cached forwarding state, as evidenced by the lack of a multicast route for the 225.1.1.1 group at transit node `Porter`:

```
[edit]
lab@Porter# run show multicast route
Family: INET

Family: INET6
```

Before generating traffic, the network's RPT join state is again analyzed. Recall that PIM joins are sent using RPF toward the source, and that for an (*,G) join, that source is the RP. Given the metric adjustments in effect in the multicast topology, the RPF path from `Cider` to `PBR` (the RP) should consist of the path `Porter`, `Stout`, `PBR`. The presumed forwarding path is first confirmed:

```
[edit protocols]
lab@Cider# run traceroute 10.20.128.3
traceroute to 10.20.128.3 (10.20.128.3), 30 hops max, 40 byte packets
 1  10.10.11.2 (10.10.11.2)  9.235 ms  8.720 ms  9.706 ms
 2  10.20.131.2 (10.20.131.2)  10.190 ms  9.147 ms  7.321 ms
 3  10.20.128.3 (10.20.128.3)  12.943 ms  38.945 ms  9.847 ms
```

The traceroute results show that the unicast forwarding path from Cider to PBR's loopback address is as anticipated—therefore, an RPT join initiated at Cider should take this same path. Shared tree join state is displayed at Porter:

```
[edit]
lab@Porter# run show pim join 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.1331
```

The RPT join state at Porter is as expected, in that the upstream interface is pointing toward Stout. The join state for 225.1.1.1 is displayed at Stout:

```
[edit]
lab@stout# run show pim join 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/0.3141
```

As expected, RPF forwarding of the shared tree join at Stout results in an upstream interface of ge-0/0/0.3141, which is the metrically closest way for Stout to reach PBR's 10.20.128.3 address.

The current state of the network correctly represents PIM sparse mode state for a receiver interested in a group with no active senders. In the next section, we will generate multicast traffic and examine the impact on network state.

Generate multicast traffic

With the receiver join state and resulting PIM sparse mode RP-rooted shared tree verified, it is time to shake things up by actually generating some multicast traffic! In this example, a Juniper router is used to simulate a multicast source with the ping command, in conjunction with the bypass-routing, ttl, and interface switches. The bypass-routing switch is needed to avoid the fact that the inet.1 table does not have multicast forwarding state for the 225.0.0.1 group; remember, Ale is a router, not a host. Because there is no routing entry to rely on, you must identify the egress interface for the test traffic using the interface switch. By default, locally generated multicast ping traffic uses a TTL of 1, which is done to limit the scope of the traffic to the local link. This is because in a real-world scenario, *numerous* receivers could be listening to the related group, and this in turn can result in significant packet replication and a resulting avalanche of replies. The test bed has only one receiver for the test traffic, making this a nonissue. A TTL value of at least 5 is recommended to ensure that the test traffic can make it all the way from Ale to Cider.

A TTL value of 4 results in the test traffic being handed to `Cider` with a TTL of 1. Although adequate for unicast, in some cases multicast TTL may be decremented upon receipt, which can lead to intermittent replies for packets received with a TTL = 1. By setting the TTL higher than strictly necessary, you guarantee that you will not encounter this issue.

We have spent a lot of effort leading to this point, and several things are about to happen in rapid succession once the sender is fired up; specifically:

- The first hop router, `Lager`, encapsulates the native multicast into a unicast packet sent to 10.20.128.3, the domain's RP.
- The RP decapsulates the traffic based on join state for the associated group, and then sends the native multicast down the shared tree. Given the current join state, the traffic should be sent from the RP to `Stout` and `Porter`, and then to receiver `Cider`.
- The presence of multicast traffic results in the creation of a multicast route in transit routers. This route is placed into the `inet.1` table, and you can think of it as a data-driven forwarding plane reaction to the control plane's join state. Note that without the control plane join, the data plane cannot establish these dynamic multicast forwarding states.
- Upon receipt of traffic from source 10.10.111.1 over the shared tree, router `Cider` initiates an SPT join toward the source. Once the SPT is established, multicast from 10.10.111.1 is transported directly over the SPT. To prevent duplicated packets, the first router in the data path that is on *both* the SPT and RPT (`Stout` in this case) sends an (S,G) prune toward the RP to prevent receipt of packets over both the SPT and the RPT.
- When there are no interested receivers on the RPT, the RP sends a register stop message to the source.
- Once the source is no longer active, the SPT state will eventually age out, resulting in a return to the RPT for group 225.1.1.1.

To help catch some of this behavior, PIM register message tracing is added to `Lager`:

```
[edit protocols pim]
lab@Lager# show traceoptions
file pim;
flag register detail;
```

Multicast pings are now initiated at `Lager`:

```
[edit]
lab@Ale# run ping ttl 5 225.1.1.1 interface ge-0/0/0.111 bypass-routing
PING 225.1.1.1 (225.1.1.1): 56 data bytes
64 bytes from 10.10.11.3: icmp_seq=0 ttl=61 time=16.776 ms
64 bytes from 10.10.11.3: icmp_seq=1 ttl=61 time=20.144 ms
. . .
```

The output confirms that responses are being received from 10.10.11.3, the address of `Cider`'s `ge-0/0/1.100` interface. The presence of replies is a most auspicious beginning, to be sure. Meanwhile, back at `Lager`, the following trace output is observed:

```
Sep 27 00:55:10.983201 PIM SENT 10.10.128.2 -> 10.20.128.3 V2 Register Flags:
0x40000000 Border: 0 Null: 1 Source 10.10.111.1 Group 225.1.1.1  sum 0x43f1 len 28
Sep 27 00:55:10.993582 PIM ge-0/0/0.2131 RECV 10.20.128.3 -> 10.10.128.2 V2
RegisterStop Source 10.10.111.1 Group 225.1.1.1 sum 0x80d1 len 18
```

The trace confirms that, as predicted, the first hop router sent a register message to the RP for source 10.10.111.1 and group 225.1.1.1, and the RP later generated a register stop for this (S,G) pair, thus indicating that no more listeners are present on the shared tree. This is a good indication that the SPT cutover was successful. Next, the resulting (S,G) join state is examined at `Cider`:

```
[edit protocols]
lab@Cider# run show pim join 225.1.1.1 extensive
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.100
    Upstream neighbor: 10.10.11.2
    Upstream state: Join to RP
    Downstream neighbors:
        Interface: Local
Group: 225.1.1.1
    Source: 10.10.111.1
    Flags: sparse,spt
    Upstream interface: ge-0/0/1.100
    Upstream neighbor: 10.10.11.2
    Upstream state: Join to Source
    Keepalive timeout: 355
    Downstream neighbors:
        Interface: Local
```

`Cider`'s display confirms that SPT join state is now also present for the 225.1.1.1 group. `Cider` remains on the RPT via its (*,G) join in case any other sender becomes active for the 225.1.1.1 group—this is an ASM example, after all. The join state at `Stout` also shows an SPT and RPT, but the RPT has been pruned for this (S,G) pair, given the presence of an SPT between the sender and receiver:

```
[edit]
lab@stout# run show pim join 225.1.1.1 extensive
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/0.3141
    Upstream neighbor: 10.20.129.2
```

```
        Upstream state: Join to RP
        Downstream neighbors:
            Interface: ge-0/0/1.1331
                10.20.131.1 State: Join Flags: SRW Timeout: 179

    Group: 225.1.1.1
        Source: 10.10.111.1
        Flags: sparse,spt
        Upstream interface: ge-0/0/0.2131
        Upstream neighbor: 10.10.131.1
        Upstream state: Join to Source, Prune to RP
        Keepalive timeout: 303
        Downstream neighbors:
            Interface: ge-0/0/1.1331
                10.20.131.1 State: Join Flags: S Timeout: 179
```

The join state at Stout is as expected. It too remains on the shared tree for group 225.1.1.1, in case any additional sources become active, and it too has generated an SPT join directly toward the source, as a result of receiving an (S,G) join on its downstream interface, as sent by Porter. The highlights call out the topology difference between the shared and source trees, with the shared tree at Stout pointing toward the RP while the source tree points toward the source. Stout has pruned source 10.10.111.1 from the shared tree, a state that is reflected at the RP:

```
    [edit]
    lab@PBR# run show pim join 225.1.1.1 extensive
    Instance: PIM.master Family: INET

    Group: 225.1.1.1
        Source: *
        RP: 10.20.128.3
        Flags: sparse,rptree,wildcard
        Upstream interface: Local
        Upstream neighbor: Local
        Upstream state: Local RP
        Downstream neighbors:
            Interface: ge-0/0/0.3141
                10.20.129.1 State: Join Flags: SRW Timeout: 156

    Group: 225.1.1.1
        Source: 10.10.111.1
        Flags: sparse,spt
        Upstream interface: ge-0/0/0.111
        Upstream neighbor: Direct
        Upstream state: Local Source, Local RP
        Keepalive timeout: 337
        Downstream neighbors:
            Interface: ge-0/0/0.3141 (pruned)
                10.20.129.1 State: Prune Flags: SR Timeout: 156
```

With the PIM sparse mode control plane looking good, you examine the data plane state as it relates to the (S,G) flow currently active in the network:

```
    [edit]
    lab@stout# run show multicast route detail
```

```
Family: INET

Group: 225.1.1.1
    Source: 10.10.111.1/32
    Upstream interface: ge-0/0/0.2131
    Downstream interface list:
        ge-0/0/1.1331
    Session description: MALLOC
    Statistics: 0 kBps, 1 pps, 1966 packets
    Next-hop ID: 348
    Upstream protocol: PIM
```

The highlights call out the expected upstream and downstream (incoming/outgoing) interfaces. Including the `detail` switch displays current traffic stats for each forwarding cache entry. When a well-known group address is detected, the session description reflects the associated application. In this case, no application is associated with 225.0.0.1, so the display simply indicates that the session belongs to the multicast allocation address space (MALLOC). The next hop ID field is used to tie this route into a forwarding table entry in the Packet Forwarding Engine (PFE). You can display the multicast forwarding table to confirm that this next hop ID is associated with the 10.10.111.1, 225.1.1.1 tuple:

```
[edit]
lab@stout# run show route forwarding-table multicast destination 225.1.1.1
Routing table: inet
Internet:
Destination        Type RtRef Next hop        Type Index NhRef Netif
225.1.1.1.10.10.111.1/64
                   user     0                   mcrt   348     1
```

To actually display what the forwarding table does with the next hop index of 348, you have to access the PFE directly. The following commands are performed for illustrative purposes, and they use unsupported shell commands. Remember: you should use hidden and shell commands only under direct guidance of JTAC:

```
[edit]
lab@stout# run start shell
% su
Password:
root@stout% vty 1

BSD platform (Pentium processor, 84MB memory, 8192KB flash)
```

A shell is started and the user becomes root, because only the root user has access to the `vty` command used to attach to the forwarding devices daemon (fwdd) process. You connect to the software-based PFE, which on a J-series router is called fwdd, by connecting to `tnp` address 1. Once connected to the PFE, information is displayed for the next hop value of 348:

```
FWDD(stout vty)# show nhdb id 348
Nexthop Info:
  ID    Type      Interface     Next Hop Addr Protocol    Encap     MTU
---- ------- -------------  --------------- -------- ---------  ----
 348 MultiRT -               -                  IPv4         -     0
               ge-0/0/1.1331                   IPv4  Ethernet
```

The PFE output confirms that currently, a single outgoing interface is associated with next hop ID 348. A multicast route entry can have numerous next hop interfaces when the topology requires such replication. You now exit out of the `vty` connection and the shell to return to the CLI:

```
FWDD(stout vty)# exit

root@stout% exit
% exit

[edit]
lab@stout#
```

Multicast routes in a forwarding state are placed into the `inet.1` route table. Unlike a learned route, information in `inet.1` is a cache entry that is driven by the actual flow of traffic—the entry ages out a short while after traffic cessation:

```
[edit]
lab@stout# run show route table inet.1 detail

inet.1: 1 destinations, 1 routes (1 active, 0 holddown, 0 hidden)
225.1.1.1.10.10.111.1/64 (1 entry, 1 announced)
        *PIM    Preference: 105
                Next hop type: Multicast (IPv4)
                Next-hop reference count: 2
                State: <Active Int>
                Age: 39:25
                Task: PIM.master
                Announcement bits (1): 0-KRT
                AS path: I
```

The `show multicast usage` command is also handy when you want to determine the number and relative activity level of the various sources in your network:

```
[edit]
lab@stout# run show multicast usage
Group           Sources Packets              Bytes
225.1.1.1       1       2516                 211344


Prefix          /len Groups Packets              Bytes
10.10.111.1     /32  1      2516                 211344
```

Note that multicast usage information is displayed both by group and by (S,G) pairing. Multicast traffic generation is stopped at `Ale`:

```
64 bytes from 10.10.11.3: icmp_seq=7227 ttl=61 time=10.564 ms
^C
--- 225.1.1.1 ping statistics ---
7228 packets transmitted, 7228 packets received, 0% packet loss
round-trip min/avg/max/stddev = 8.079/21.507/201.323/10.705 ms
```

The lack of data plane activity results in aging out of the forwarding state. Because the receiver is still interested in group 225.1.1.1, the control plane join state is refreshed and remains:

```
[edit]
lab@stout# run show multicast route extensive source-prefix 10.10.111.1
Family: INET
Group: 225.1.1.1
    Source: 10.10.111.1/32
    Upstream interface: ge-0/0/0.2131
    Downstream interface list:
        ge-0/0/1.1331
    Session description: MALLOC
    Statistics: 0 kBps, 0 pps, 7306 packets
    Next-hop ID: 348
    Upstream protocol: PIM
    Route state: Active
    Forwarding state: Forwarding
    Cache lifetime/timeout: 171 seconds
    Wrong incoming interface notifications: 1

[edit]
lab@stout# run show pim join extensive 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/0.3141
    Upstream neighbor: 10.20.129.2
    Upstream state: Join to RP
    Downstream neighbors:
        Interface: ge-0/0/1.1331
            10.20.131.1 State: Join Flags: SRW Timeout: 178

Group: 225.1.1.1
    Source: 10.10.111.1
    Flags: sparse,spt
    Upstream interface: ge-0/0/0.2131
    Upstream neighbor: 10.10.131.1
    Upstream state: Join to Source, Prune to RP
    Keepalive timeout: 169
    Downstream neighbors:
        Interface: ge-0/0/1.1331
            10.20.131.1 State: Join Flags: S Timeout: 178
```

After a few minutes, the (S,G) forwarding state is flushed from the network:

```
[edit]
lab@stout#run show multicast route extensive source-prefix 10.10.111.1
Family: INET
```

This result confirms expected PIM sparse mode control and data plane state and delivery of the multicast test traffic to the receiver by the returned echo replies. These results complete the PIM sparse mode with static RP configuration scenario.

PIM Sparse Mode with Static RP Summary

This section demonstrated the configuration and operational verification of a PIM-based IP multicast network that used a statically defined RP. In the next section, we will build on this experience by adding dynamic RP electing using the bootstrap protocol.

Configure PIM Sparse Mode with Bootstrap RP

In this section, we will convert the existing multicast topology from a statically defined RP to a bootstrap learned RP. As part of this conversion, the network is being redesigned to add a second RP for redundancy. The configuration objectives are as follows:

- Remove the static RP definition from all routers.
- Configure `Stout` as a second RP for the 224/4 group range.
- Use bootstrap-based RP election, and make sure that `PBR` is the BSR when operational.
- Ensure that there is no single point of RP/BSR failure in the network.

The new redundancy requirements make it clear that the network will need two RPs and two candidate BSRs. Further, the bootstrap priority will need to be higher (more preferred) at `PBR` to ensure that it is the BSR when operational. Figure 11-14 shows the updated topology.

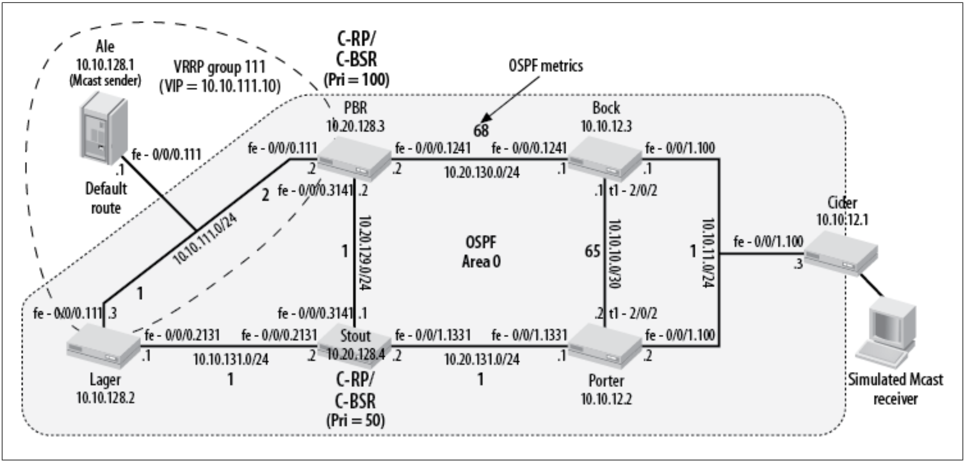


Figure 11-14. Bootstrap RP election

The figure shows that both PBR and Stout are configured to function as candidate RPs and candidate BSRs (C-RP and C-BSR). Although not technically necessary, currently it is a best practice to make the C-RP and C-BSR functionality collocated, given that the loss of either function kills PIM sparse mode operation and negates any benefits associated with distributing C-BSR and C-RP functionality among different nodes. The higher BSR priority setting at PBR results in its election as the domain's BSR when operational; otherwise, Stout steps in to take over.

When both RPs are operational, the BSR advertises a candidate RP set that lists *both* of the domain's RPs. Each PIM router hashes against this set to choose which of the two RPs to use for a specific group range. The hashing function ensures that all routers choose the same candidate RP for the same groups, and that a consecutive set of four groups always map to the same RP. The latter functionality is designed to accommodate applications that use consecutive groups for various elements that make up a single session—for example, an audio channel and the corresponding video stream—by helping to ensure similar latency among the session's component streams.

The static RP definition is removed from routers Lager, Stout, Bock, Porter, and Cider (not shown), and attention is focused on the need to configure candidate BSR functionality at PBR. The configuration is rather straightforward—all that is required is a single statement to enable BSR and assign a priority:

```
[edit protocols pim]
lab@PBR# show
rp {
    bootstrap-priority 100;
    local {
        address 10.20.128.3;
    }
}
interface ge-0/0/0.3141;
interface ge-0/0/0.1241;
interface ge-0/0/0.111;
```

The priority setting of 100 makes PBR a candidate BSR—note that a value of 0 does not disable BSR functionality, but such a setting does make it less likely that candidate PBR will become the BSR. Once a lower priority is set in the soon-to-be-configured Stout, you ensure that PBR is the domain's BSR when operational. In this example, the bootstrap statement is configured directly at the [edit protocols pim rp] hierarchy. The same set of options is available on a per-family basis using the family keyword:

```
[edit protocols pim]
lab@PBR# set rp bootstrap family inet ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these groups
+ export               Bootstrap export policy
+ import               Bootstrap import policy
  priority             Eligibility to be the bootstrap router (0..255)
```

The `import` and `export` keywords link to one or more policy statements that filter bootstrap messages from being received or transmitted, respectively. Normally, you use such policy at the edges of a PIM domain to prevent routers in a remote domain from using the domain's local BSR, and vice versa.

After committing the change, BSR election begins and `PBR` starts a countdown timer intended to reduce thrashing by allowing time for any C-BSR messages to propagate through the domain before a decision is made as to which C-BSR should win to become the BSR. Use the `show pim bootstrap` command to display information about the domain's candidate BSRs:

```
[edit protocols pim]
lab@PBR# commit
commit complete

[edit protocols pim]
lab@PBR# run show pim bootstrap
Instance: PIM.master

BSR              Pri Local address          Pri State      Timeout
None               0 10.20.128.3            100 Candidate       54
None               0 (null)                   0 InEligible       0
```

`PBR` is the only router now configured to be a C-BSR, and therefore it easily wins the election to become the domain's BSR:

```
[edit protocols pim]
lab@PBR# run show pim bootstrap
Instance: PIM.master

BSR                Pri Local address          Pri State      Timeout
10.20.128.3        100 10.20.128.3            100 Elected         37
None                 0 (null)                   0 InEligible       0
```

In the display, each router shows a null entry, as well as an entry for its loopback address and local C-BSR priority. C-BSR information that is learned is displayed on the lefthand side. The output from `PBR` makes it clear that the local router is also the BSR, and that it has a priority of 100.

For proper BSR operation, a candidate BSR must have a routable address assigned to its `lo0` interface. This is true even when a different address, perhaps one assigned to a physical interface, is configured as the BSR address. This requirement stems from an implementation decision that forces C-BSR messages to be sourced from the local router's `lo0` address—C-BSR messages cannot be sent if no `lo0` address is configured or if the only address configured is a 127.*x*.*x*.*x* loopback. You can commit such a configuration, and the result is not particularly easy to troubleshoot, as the symptom is simply a lack of generated C-BSR messages.

A few moments later, proper bootstrap operation is confirmed when all other routers have chosen the same C-BSR, as shown for `Cider`:

```
[edit]
lab@Cider# run show pim bootstrap
Instance: PIM.master

BSR                  Pri Local address           Pri State      Timeout
10.20.128.3          100 10.10.12.1                0 InEligible     112
None                   0 (null)                    0 InEligible       0
```

The `show pim bootstrap` display at `Cider` confirms that it has received the C-BSR message that originated at `PBR` and was propagated via hop-by-hop multicast to all BSR-enabled routers. The presence of a single C-BSR with priority 100 is confirmed, as is election of `PBR` as the BSR:

```
[edit]
lab@Cider# run show pim rps
Instance: PIM.master
Address family INET
RP address           Type        Holdtime Timeout Groups Group prefixes
10.20.128.3          bootstrap        150     125      2 224.0.0.0/4

Address family INET6
```

The `show pim rps` display further confirms that an RP has been learned for the 224/4 range via the bootstrap protocol. With things working properly at the first C-BSR/C-RP, it's time to bring up the domain's backup C-BSR/C-RP. The configuration of `Stout` is modified and displayed:

```
[edit protocols pim]
lab@stout# show | compare
[edit protocols pim rp]
+  bootstrap-priority 50;
+  local {
+      address 10.20.128.4;
+  }
-  static {
-      address 10.20.128.3;
-  }
```

After waiting a minute or two for things to settle down, verification starts at `Stout`. The expectation is that `Stout` confirms `PBR` as the elected BSR while also listing itself as a viable contender:

```
BSR                Pri Local address           Pri State      Timeout
10.20.128.3        100 10.20.128.4              50 Candidate      123
None                 0 (null)                    0 InEligible       0
```

The output confirms those expectations and shows that BSR is operating as desired between the domain's two candidate BSRs. RP set information is displayed next:

```
[edit protocols pim]
lab@stout# run show pim rps
Instance: PIM.master
```

```
Address family INET
RP address       Type        Holdtime Timeout Groups Group prefixes
10.20.128.3      bootstrap        150     137      1 224.0.0.0/4
10.20.128.4      bootstrap        150     137      1 224.0.0.0/4
10.20.128.4      static             0    None      1 224.0.0.0/4
```

The `show pim rps` command output lists both of the domain's RPs as having been learned via bootstrap; the local RP definition at `Stout` is also listed as learned statically. Back at the last hop router, `Cider`, the state of RPs is also as expected:

```
[edit]
lab@Cider# run show pim rps
Instance: PIM.master
Address family INET
RP address       Type        Holdtime Timeout Groups Group prefixes
10.20.128.3      bootstrap        150     101      1 224.0.0.0/4
10.20.128.4      bootstrap        150     101      1 224.0.0.0/4
```

Awesome! And some folks think this multicast stuff is hard to understand. PIM join state is displayed at `Cider`. The display illustrates the bootstrap RP hashing function, in that the two joins associated with the listening SAP process hashed to a different RP:

```
[edit]
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.20.128.3
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.100

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.4
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.100
```

Once again, connectivity is verified at the sender:

```
[edit]
lab@Ale# run ping ttl 5 225.1.1.1 interface ge-0/0/0.111 bypass-routing
PING 225.1.1.1 (225.1.1.1): 56 data bytes
64 bytes from 10.10.11.3: icmp_seq=0 ttl=61 time=87.388 ms
. . .
```

So is the data-driven switch to an SPT at the last hop router:

```
[edit]
lab@Cider# run show pim join 225.1.1.1 detail
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.20.128.4
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.100
```

```
Group: 225.1.1.1
    Source: 10.10.111.1
    Flags: sparse,spt
    Upstream interface: ge-0/0/1.100
```

Before calling it quits, redundancy is verified by deactivating the RP and BSR functionality at PBR. The `confirmed` option is added to the commit to evoke automatic restoration of the previous (and currently active) configuration to save some keystrokes:

```
[edit protocols pim]
lab@PBR# deactivate rp

[edit protocols pim]
lab@PBR# show
inactive: rp {
    bootstrap-priority 100;
    local {
        address 10.20.128.3;
    }
}
interface ge-0/0/0.3141;
interface ge-0/0/0.1241;
interface ge-0/0/0.111;

[edit protocols pim]
lab@PBR# commit confirmed 3
commit confirmed will be automatically rolled back in 3 minutes
  unless confirmed
commit complete

# commit confirmed will be rolled back in 3 minutes
[edit protocols pim]
```

Failover behavior is confirmed back at `Cider`:

```
[edit]
lab@Cider# run show pim bootstrap
Instance: PIM.master

BSR                 Pri Local address            Pri State      Timeout
10.20.128.4         50  10.10.12.1                 0 InEligible     103
None                  0 (null)                     0 InEligible       0
```

The display confirms the removal of `PBR` as a candidate RP and the election of the remaining C-BSR (`Stout`), which is now the best choice. The join state takes a little while to catch up, but after a short while all joins are pointing to the remaining RP:

```
 [edit]
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.20.128.4
    Flags: sparse,rptree,wildcard
```

```
        Upstream interface: ge-0/0/1.100

    Group: 225.1.1.1
        Source: *
        RP: 10.20.128.4
        Flags: sparse,rptree,wildcard
        Upstream interface: ge-0/0/1.100

    Group: 225.1.1.1
        Source: 10.10.111.1
        Flags: sparse,spt
        Upstream interface: ge-0/0/1.100
```

Once the automatic rollback occurs at PBR, things return to the expected state, which completes verification of the PIM sparse mode with bootstrap protocol scenario:

```
[edit]
lab@Cider# run show pim bootstrap
Instance: PIM.master

BSR                 Pri Local address           Pri State      Timeout
10.20.128.3         100 10.10.12.1                0 InEligible      88
None                  0 (null)                    0 InEligible       0
```

Troubleshoot a Bootstrap Problem

The Beer-Co topology has been altered to interface to another routing domain, as shown in Figure 11-15.

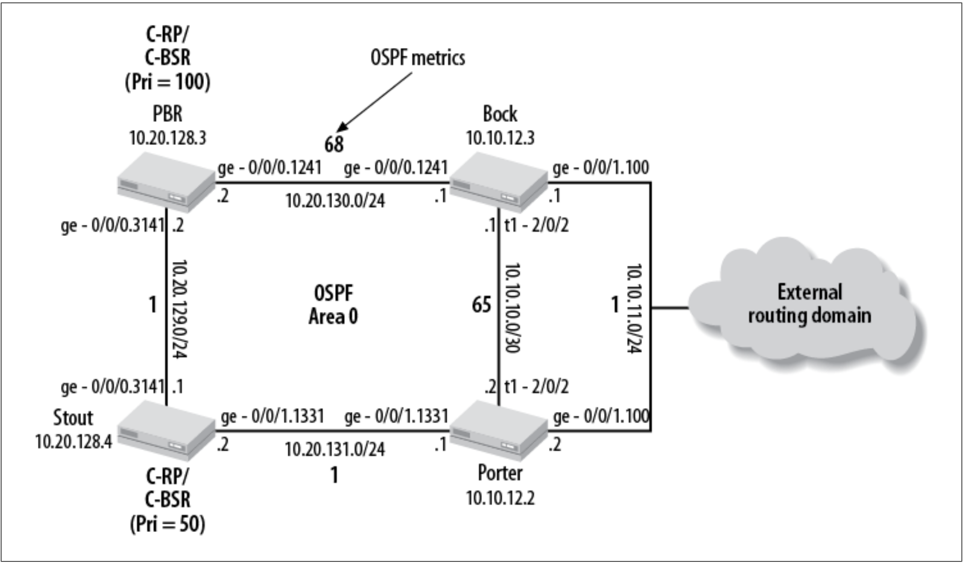


Figure 11-15. PIM BSR troubleshooting topology

Figure 11-15 details how PIMv1 has been configured on the now *external* interfaces at Bock and Porter to prevent the leaking of bootstrap protocol messages to and from the other routing domain. Recall that PIMv1 does not support bootstrap, making this a common approach to scoping BSR messages. The problem is that Bock does not display any learned BSRs, and therefore there is no bootstrap learned RP at Bock:

```
[edit]
lab@Bock# show protocols pim
interface ge-0/0/0.1241;
interface ge-0/0/1.100 {
    version 1;
}
interface t1-2/0/2.0;

[edit]
lab@Bock# run show pim bootstrap
Instance: PIM.master

BSR                  Pri Local address      Pri State      Timeout
None                   0 10.10.12.3           0 InEligible       0
None                   0 (null)               0 InEligible       0
[edit]
lab@Bock# run show pim rps
Instance: PIM.master
```

All other routers display the expected BSR and RP set information. Bock was working properly prior to the shift to PIMv1, and connectivity over all of its interfaces has been verified with successful pings to direct neighbors.

Lacking any better suggestions, PIM bootstrap tracing is added to the configuration, and after a short while trace output is observed:

```
[edit protocols pim]
lab@Bock# show traceoptions
file pim;
flag bootstrap detail;

[edit protocols pim]
lab@Bock# run monitor start pim

*** pim ***
Sep 28 02:27:19.848100 PIM ge-0/0/0.1241 RECV 10.20.130.2 ->
224.0.0.13 V2 Bootstrap sum 0x6ab2 len 46
Sep 28 02:27:19.848182    tag 52078 masklen 30 priority 100 bootstrap
router 10.20.128.3
Sep 28 02:27:19.848208       group 224.0.0.0 count 2 fragcount 2
Sep 28 02:27:19.848230          rp address 10.20.128.3 holdtime 150
priority 1
Sep 28 02:27:19.848247          rp address 10.20.128.4 holdtime 150
priority 1
Sep 28 02:27:19.857917 PIM t1-2/0/2.0 RECV 10.10.10.2 -> 224.0.0.13
V2 Bootstrap sum 0x0cba len 46
Sep 28 02:27:19.858018    tag 10599 masklen 30 priority 100 bootstrap
router 10.20.128.3
```

```
Sep 28 02:27:19.858042       group 224.0.0.0 count 2 fragcount 2
Sep 28 02:27:19.858060          rp address 10.20.128.3 holdtime 150
priority 1
Sep 28 02:27:19.858073          rp address 10.20.128.4 holdtime 150
priority 1
```

The trace output is at once good and bad; good because it shows that valid bootstrap messages are being received on both of Bock's PIMv2-enabled interfaces, and bad because no obvious error or reason is displayed as to why the messages do not result in election of a BSR at Bock. Given that things worked until the shift to PIMv1 on `ge-0/0/1.100`, you decide to temporarily deactivate the `ge-0/0/1` interface:

```
[edit]
lab@Bock# deactivate interfaces ge-0/0/1

[edit]
lab@Bock# commit
commit complete

[edit]
lab@Bock# run show pim bootstrap
Instance: PIM.master

BSR                 Pri Local address       Pri State      Timeout
10.20.128.3         100 10.10.12.3            0 InEligible     100
None                  0 (null)                0 InEligible       0
```

Quite interesting; the output confirms proper BSR election as long as the PIMv1 interface is deactivated—which makes little sense given that PIMv1 does not even support the BSR protocol! The change is rolled back to reactivate the `ge-0/0/1.100` interface.

Strange; very strange indeed—recalling that RPF checks are critical to multicast operation, you display the RPF route to 10.20.128.3 from Bock:

```
[edit]
lab@Bock# run show multicast rpf 10.20.128.3
Multicast RPF table: inet.0 , 21 entries

10.20.128.3/32
    Protocol: OSPF
    Interface: ge-0/0/1.100
    Neighbor: 10.10.11.2
```

The display shows that Bock considers 10.10.11.2 as the RFP neighbor for the 10.20.128.3 route, which is reachable over the 10.10.11.0/24 subnet. Interestingly, this is also the interface that was set to PIMv1, and this explains the problem: PIM control messages generally have to be received on the RPF interface to their source; otherwise, they are ignored. For the specific behavior discussed here, Section 3.1.3 of RFC 5059 states:

> When a Bootstrap message is received, the following initial check must be performed:
>
> 1. If the message's address is ALL-PIM-ROUTERS, and if the source address is not the RPF neighbor address, then it drops the Bootstrap message silently.

The problem now becomes clear—given the OSPF metrics in effect, Bock expects to receive BSR messages on its ge-0.0/1/100 interface and is dropping BSR messages received on those interfaces that are not on the RPF path back to the BSR. Several solutions present themselves:

- Alter IGP metrics so that Bock no longer sees its ge-0/0/1.100 interface as the RPF interface back to the BSR—that is, either increase the 10.10.11.0 subnet metric or reduce the 10.20.130.0 or 10.10.10.0 subnet metric.
- Reconfigure the network to move BSR functionality to a node whose RPF check does not point to Bock's ge-0/0/1.100 interface. This option is not really viable in the sample topology unless a new router is added.
- Add a new link, or add PIM to a previously nonmulticast-enabled link, in order to affect a new RPF topology, again with the intent of removing ge-0/0/1.100 from the RPF check back to PBR.

Policy-based filtering of bootstrap messages is not considered here because in this scenario, it relies on the administration of the remote autonomous system (AS) to apply import policy to filter bootstrap messages exchanged over the shared LAN between Bock and Porter; egress filtering at Bock and Porter does not work because this filters all bootstrap messages from the LAN—currently Bock needs to receive the bootstrap messages from Porter over the shared LAN.

Extra points for creativity?

The solution demonstrated here is based on the "add another link" option discussed earlier, except the new link is instantiated as a Generic Routing Encapsulation (GRE) tunnel, meaning no new equipment or facilities are needed! No routing protocol operates over the tunnel—Bock uses two /32 static routes to direct traffic destined to the lo0 address of PBR and Stout over the GRE tunnel. This ensures that the only traffic subjected to the tunnel is that associated with the loopback addresses of PBR and Stout. All other traffic continues to follow the IGP's shortest path, thereby causing minimal impact to existing traffic patterns. If all this were not enough, the tunnel is instantiated between the loopback address of Bock and PBR and is routed between these addresses according to the IGP's shortest path. This means the GRE tunnel and associated static routing are not affected by the failures of individual links or interfaces, and that no policy/static routes are needed to advertise reachability to the tunnel endpoints given that the lo0s of Bock and Porter are already carried in OSPF. Because the static routes are preferred over any OSPF learned route (due to preference), the problems of receiving BSR messages on the wrong RPF interface are forever eliminated once PIM is enabled over the GRE tunnel.

The changes to Bock's configuration are shown. The changes at Porter are limited to GRE interface definition and enabling PIM on the resulting GRE interface. No static routes are needed at Porter because the 10.20.128.3 and 10.20.128.4 OSPF routes at Porter already lie on the RPF path back to PBR and Stout, respectively:

```
[edit]
lab@Bock# show interfaces gr-0/0/0
unit 0 {
    tunnel {
        source 10.10.12.3;
        destination 10.10.12.2;
    }
    family inet;
}

[edit]
lab@Bock# show routing-options
static {
    route 10.20.128.3/32 next-hop gr-0/0/0.0;
    route 10.20.128.4/32 next-hop gr-0/0/0.0;
}

[edit]
lab@Bock# show protocols pim
traceoptions {
    file pim;
    flag bootstrap detail;
}
interface ge-0/0/0.1241;
interface ge-0/0/1.100 {
    version 1;
}
interface t1-2/0/2.0;
interface gr-0/0/0.0;
```

Note that an unnumbered GRE tunnel is defined, which eliminates the need to advertise reachability to the tunnel endpoints; local tunnel traffic is based on the lo0 addresses of Bock and Porter, which are already advertised by OSPF. Verification begins by examining Bock's route to the lo0 addresses of PBR and Stout:

```
[edit]
lab@Bock#run show route 10.20.128/29

inet.0: 21 destinations, 24 routes (21 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.20.128.3/32     *[Static/5] 00:04:39
                    > via gr-0/0/0.0
                    [OSPF/10] 00:16:27, metric 3
                    > to 10.10.11.2 via ge-0/0/1.100
10.20.128.4/32     *[Static/5] 00:04:39
                    > via gr-0/0/0.0
                    [OSPF/10] 00:16:27, metric 2
                    > to 10.10.11.2 via ge-0/0/1.100
[edit]
lab@Bock# run show multicast rpf 10.20.128/29
Multicast RPF table: inet.0 , 21 entries

10.20.128.3/32
    Protocol: Static
    Interface: gr-0/0/0.0
    Neighbor: (null)

10.20.128.4/32
    Protocol: Static
    Interface: gr-0/0/0.0
    Neighbor: (null)
```

The command output confirms the presence of active static routes at Bock and that the RPF interface to these lo0 addresses now points to the GRE tunnel. Note that there is no RPF neighbor (listed as null) because the tunnel is unnumbered in this example.

PIMv2 is confirmed operational on the new GRE interface, and a PIM neighbor has been detected:

```
[edit]
lab@Bock# run show pim interfaces
Instance: PIM.master

Name                   Stat Mode       IP V State Count DR address
ge-0/0/0.1241          Up   Sparse      4 2 NotDR     1 10.20.130.2
ge-0/0/1.100           Up   Sparse      4 1 NotDR     2 10.10.11.3
gr-0/0/0.0             Up   Sparse      4 2 P2P       1
pd-0/0/0.32769         Up   Sparse      4 2 P2P       0
pe-0/0/0.32770         Up   Sparse      4 2 P2P       0
t1-2/0/2.0             Up   Sparse      4 2 P2P       1
```

The RPF issue with received bootstrap messages is resolved, thus allowing Bock to learn the domain's C-BSRs. With knowledge of the domain's BSR, Bock goes on to learn the domain's RPs:

```
[edit]
lab@Bock# run show pim bootstrap
Instance: PIM.master

BSR             Pri Local address           Pri State      Timeout
10.20.128.3     100 10.10.12.3                0 InEligible     125
None              0 (null)                    0 InEligible       0

[edit]
lab@Bock# run show pim rps
Instance: PIM.master
Address family INET
RP address         Type        Holdtime Timeout Groups Group prefixes
10.20.128.3        bootstrap        150     139      1 224.0.0.0/4
10.20.128.4        bootstrap        150     139      1 224.0.0.0/4
```

IGP connectivity is confirmed from Bock to the loopback address of PBR:

```
 [edit]
lab@Bock# run traceroute 10.20.128.3
traceroute to 10.20.128.3 (10.20.128.3), 30 hops max, 40 byte packets
 1  10.10.12.2 (10.10.12.2)  105.258 ms  71.311 ms  11.741 ms
 2  10.20.131.2 (10.20.131.2)  9.808 ms  9.401 ms  9.677 ms
 3  10.20.128.3 (10.20.128.3)  10.100 ms  29.484 ms  9.734 ms
```

And the use of PIMv1 on the 10.10.11/24 subnet prevents learning of the BSR at router `Cider`. This completes the PIM bootstrap troubleshooting exercise:

```
lab@Cider# run show pim bootstrap
Instance: PIM.master

BSR                Pri Local address            Pri State      Timeout
None                 0 10.10.12.1                 0 InEligible      26
None                 0 (null)                     0 InEligible       0
```

PIM Sparse Mode with Bootstrap RP Summary

In this section, you configured the bootstrap protocol to dynamically communicate RP to group mappings. The bootstrap protocol allows all routers to select the same RP for a given group, thereby spreading the multicast load among the set of RPs, with the hashing function determining which groups are handled by which RP. This section also showed how RPF checks can cause control plane messages to be ignored, and it provided a creative solution using a GRE tunnel that required no additional hardware.

In the next section, you will deploy Anycast-RP to support dynamic RP election and load balancing with this same multicast group.

PIM-Based Anycast-RP

The final multicast configuration exercise in this chapter involves deployment of Anycast-RP, with emphasis on a PIM-only solution. An alternative configuration using MSDP is also provided.

With both auto-RP and BSR, only one RP is permitted to be active for any given group at any one time. Anycast-RP relaxes this restriction and allows multiple RPs to be active for the same group at the same time. Anycast-RP requires a mechanism by which the multiple RPs share information about active sources. This inter-RP communication has historically been performed by MSDP, but Junos also supports the PIM-only Anycast-RP solution, as specified in RFC 4610. The PIM-based solution is attractive because it eliminates all need for MSDP within an organization, allowing MSDP deployment as needed, and then only for its original purpose of interdomain multicast support.

Because of the common RP address that is shared among all the RPs, receivers simply send their joins to the metrically closest Anycast-RP, and they are unaware of the presence of multiple RPs.

The configuration objectives are as follows:

- `Stout` and `Bock` remain RPs, but both must now use 10.255.255.1 for RP functionality.
- Do not use BSR or auto-RP.
- Ensure no single points of failure.

The requirement that no dynamic RP discovery mechanisms be used may strike you as a bit odd, especially in light of the need for network resiliency to single points of failure. Recall that with Anycast-RP, all of the RPs for a given group range use the same RP address. Therefore, as long as at least one Anycast-RP remains operational, the statically defined RP address in non-RP routers continues to provide the needed connectivity. In an Anycast-RP environment, the use of a dynamic protocol to propagate knowledge of the single RP address is a bit overkill, but certainly not illegal.

Figure 11-16 provides a high-level walkthrough of an Anycast-RP operation.

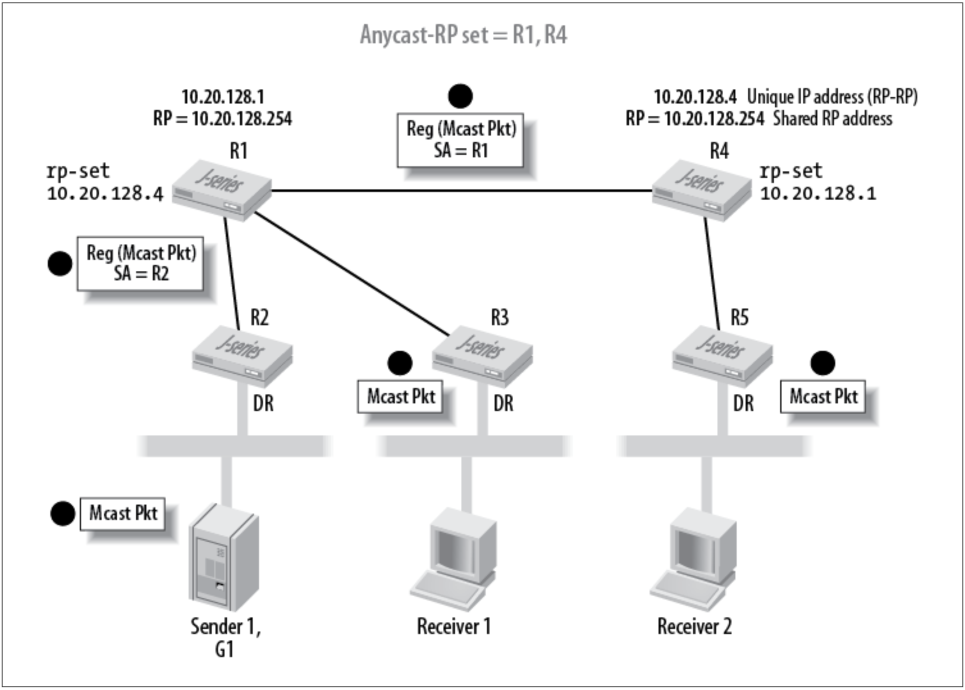


Figure 11-16. PIM Anycast-RP operation

To start, note how the domain's RPs are said to belong to an Anycast-RP set. Each RP within this set must have a unique, routable loopback address that is used for RP-RP (and other) communications, as well as a shared RP address that, in effect, represents all RPs in the set. Further, each RP in the set must have an explicit list of all other RPs, using their unique, not shared, IP address. Figure 11-17 shows how R1 and R4 have a configuration that identifies the other by the unique `lo0` IP address.

Step 1 shows Sender 1 (S1) generating native multicast to group G1. The designated router for S1 encapsulates the multicast into a register message and sends it to the Anycast-RP address at step 2. Because all RPs in the set use the same RP address, the register message is routed by the IGP to the metrically closest RP, which is R1 in this example. Note that the register message received by R1 is sourced by R2. Step 3 shows R1 sending the now native multicast (register encapsulation has been stripped) down its shared tree toward Receiver 1. At step 4, R1 creates its *own* register message with a copy of the original multicast packet, which is sent to *all* RPs in the Anycast-RP set, which in this case means that R4 receives a register message with R1 as a source. R4 behaves as any other designated router by stripping the register encapsulation and sending the native multicast down its shared tree, thus allowing R2 to obtain a copy.

Configure Anycast-RP

Figure 11-17 shows the Anycast-RP topology. It details how the domain's two RPs, `PBR` and `Stout`, share an Anycast-RP address of 10.255.255.1, in addition to maintaining their unique loopback addresses. Configuration begins with removal of any existing RP and BSR functionality at `PBR` and `Stout` (the commit is not shown):

```
[edit]
lab@PBR# delete protocols pim rp
```

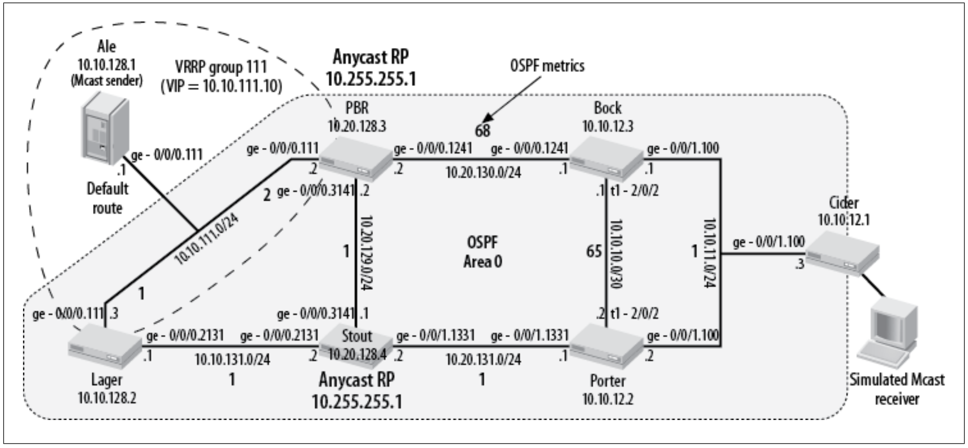


Figure 11-17. The Anycast-RP topology

This action leaves the domain with no RPs—recall that RP information was being disseminated via bootstrap, and the previous command removed all C-RP and C-BSR functionality from the domain.

Configure static RP on non-RP routers

The non-RP routers are a snap to configure; a single statement is needed to statically define the Anycast-RP address at all routers. The configuration of `Lager` is shown and is similar to all other non-RP nodes:

```
[edit]
lab@Lager#show protocols pim
rp {
    static {
        address 10.255.255.1;
    }
}
interface ge-0/0/0.2131;
interface ge-0/0/0.111;
```

After committing the changes, static RP operation is confirmed at `Cider`:

```
[edit]
lab@Cider# run show pim rps
Instance: PIM.master
Address family INET
RP address        Type        Holdtime Timeout Groups Group prefixes
10.255.255.1      static             0    None      2 224.0.0.0/4
. . .

[edit]
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: unknown (no route)

Group: 225.1.1.1
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: unknown (no route)
```

The output shows that the Anycast-RP address is correctly configured, but there is currently no route to the Anycast-RP address, which is expected given that the Anycast-RPs have not yet been configured.

Configure the Anycast-RPs

Configuration of the Anycast-RP begins with the addition of the shared Anycast-RP address to the `lo0` interface. The existing (unique) address is flagged as `primary` to ensure no disruption to the IGP/BGP control plane through continued use of the unique `lo0` address for non-PIM-related functions, such as OSPF/BGP router ID (RID) selection. Recall that when not explicitly set under `routing-options`, the RID is obtained from the primary address on the system's default interface, which is the lowest non-127.0.0.*x* address assigned to the `lo0` interface:

```
[edit interfaces lo0 unit 0 family inet]
lab@PBR# set address 10.20.128.3/32 primary

[edit interfaces lo0 unit 0 family inet]
lab@PBR# set address 10.255.255.1
```

By default, the numerically lowest local IP address is considered the interface's primary address, and the lo0 interface is the default interface when a non-127.0.0.*x* address is configured. The specifics of this example happened to use a numerically higher address for the Anycast-RP function, making declaration of the existing lo0 address as primary technically unnecessary. However, making a mistake here can lead to the difficult problem of troubleshooting missing routes due to duplicate RIDs, making the extra configuration step insurance that is well worth having.

The modified lo0 configuration is shown:

```
[edit interfaces lo0 unit 0 family inet]
lab@PBR# show
address 10.20.128.3/32 {
    primary;
}
address 10.255.255.1/32;
```

Similar changes are also made to Stout's lo0 configuration. PIM-based Anycast-RP is configured at the [edit protocols pim rp local family inet] hierarchy. The updated configuration and related set commands are shown for PBR:

```
[edit protocols pim rp local family inet]
lab@PBR# show
address 10.255.255.1;
anycast-pim {
    rp-set {
        address 10.20.128.4;
    }
}

[edit protocols pim rp local family inet]
lab@PBR# show | display set
set protocols pim rp local family inet address 10.255.255.1
set protocols pim rp local family inet anycast-pim rp-set address
10.20.128.4
```

Do

Once again, a similar configuration is added and committed at Stout, whose configuration correctly specifies PBR's unique lo0 address under its rp-set stanza.

Verify the Anycast-RPs

After a few minutes, PIM join state is examined at Cider:

```
[edit]
lab@Cider# run show pim join 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: unknown (no route)
```

The display indicates that `Cider` still does not know how to route to the Anycast-RP address. This is quickly confirmed with a `show route` command:

```
[edit]
lab@Cider# run show route 10.255.255.1
```

Going back to one of the Anycast-RPs, the problem is quickly uncovered:

```
[edit]
lab@PBR# run show ospf interface
Interface        State     Area        DR ID          BDR ID        Nbrs
ge-0/0/0.111     BDR       0.0.0.0     10.10.128.2    10.20.128.3     1
ge-0/0/0.1241    BDR       0.0.0.0     10.10.12.3     10.20.128.3     1
ge-0/0/0.3141    BDR       0.0.0.0     10.20.128.4    10.20.128.3     1
```

OSPF is not running on the `lo0` interface, which prevents the newly added 10.255.255.1 Anycast-RP address from being advertised into OSPF. Recall that Junos's default is to advertise a stub route to the interface from which the router obtains its RID. The router uses the primary address on the default interface—which is normally the `lo0` interface by default—as the RID; this is why the 10.20.128.3 `lo0` address at `PBR` has been advertised into OSPF despite OSPF not being enabled on that interface previously.

They automatically advertise the source of the RID behavior changed in release 8.5 due to PR 229200. In affected releases, you should run a passive OSPF instance on the router's `lo0` to ensure the route is advertised into OSPF, which is needed for proper PIM functioning.

A passive OSPF instance is configured to run on the `lo0` interface of both Anycast-RPs to get both of the assigned `lo0` addresses advertised into OSPF:

```
[edit]
lab@PBR# set protocols ospf area 0 interface lo0 passive
```

The OSPF database confirms that `PBR` is now advertising the 10.255.255.1 address:

```
[edit]
lab@PBR# show ospf database advertising-router 10.20.128.3 router
detail
    OSPF link state database, Area 0.0.0.0
 Type       ID             Adv Rtr        Seq      Age  Opt  Cksum  Len
Router  *10.20.128.3  10.20.128.3   0x800000b4  41  0x22 0xff76  84
  bits 0x2, link count 5
  id 10.10.111.3, data 10.10.111.2, Type Transit (2)
  TOS count 0, TOS 0 metric 2
  id 10.20.130.1, data 10.20.130.2, Type Transit (2)
  TOS count 0, TOS 0 metric 68
  id 10.20.129.1, data 10.20.129.2, Type Transit (2)
  TOS count 0, TOS 0 metric 1
  id 10.20.128.3, data 255.255.255.255, Type Stub (3)
  TOS count 0, TOS 0 metric 0
  id 10.255.255.1, data 255.255.255.255, Type Stub (3)
  TOS count 0, TOS 0 metric 0
```

The change allows Cider to route toward the Anycast-RP address, which in turn permits it to join the shared tree for 225.1.1.1:

```
[edit]
lab@Cider# run show pim join
Instance: PIM.master Family: INET

Group: 224.2.127.254
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.100

Group: 225.1.1.1
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.100
```

The current route to the Anycast-RP is displayed at Cider:

```
[edit]
lab@Cider# run show route 10.255.255.1

inet.0: 20 destinations, 20 routes (20 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.255.255.1/32    *[OSPF/10] 00:03:53, metric 2
                    > to 10.10.11.2
via ge-0/0/1.100

[edit]
lab@Cider# run traceroute 10.255.255.1
traceroute to 10.255.255.1 (10.255.255.1), 30 hops max, 40 byte packets
 1  10.10.11.2 (10.10.11.2)  79.285 ms
                   98.810 ms  99.739 ms
 2  10.255.255.1 (10.255.255.1)  10.293 ms  9.213 ms  29.762 ms
```

The output shows that Stout is the RP currently used by Cider. Failover to the metrically closest Anycast-RP is tested by increasing the path metric on the Porter-Stout link to 300:

```
lab@Porter# set protocols ospf area 0 interface ge-0/0/1.1331 metric 300
```

And the change is verified back at Cider, which still thinks it is using the same RP, but in reality, its join now goes to PBR via Bock:

```
[edit]
lab@Cider# run show pim join 225.1.1.1
Instance: PIM.master Family: INET

Group: 225.1.1.1
    Source: *
    RP: 10.255.255.1
    Flags: sparse,rptree,wildcard
    Upstream interface: ge-0/0/1.100
```

```
[edit]
lab@Cider# run show route 10.255.255.1

inet.0: 20 destinations, 20 routes (20 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

10.255.255.1/32    *[OSPF/10] 00:19:02, metric 69
                    > to 10.10.11.1
                      via ge-0/0/1.100

[edit]
lab@Cider# run traceroute 10.255.255.1
traceroute to 10.255.255.1 (10.255.255.1), 30 hops max, 40 byte packets
 1  10.10.11.1 (10.10.11.1)  19.018 ms
               12.334 ms  16.235 ms
 2  10.255.255.1 (10.255.255.1)  9.630 ms  29.665 ms  10.108 ms
```

The final PIM configuration is shown for Anycast-RP node `Stout`:

```
[edit]
lab@stout# show protocols pim
rp {
    local {
        family inet {
            address 10.255.255.1;
            anycast-pim {
                rp-set {
                    address 10.20.128.3;
                }
            }
        }
    }
}
interface ge-0/0/0.2131;
interface ge-0/0/0.3141;
interface ge-0/0/1.1331;
```

The asymmetric metrics (which is hard to say) in effect cause first hop router `Lager` to send its register message to `PBR`, while receiver `Cider` sends its join toward `Stout`. When `PBR` receives the register message from `Lager`, it generates a copy, sourced from its unique `lo0` address, and sends it to Anycast-RP set member `Stout`. This allows `Stout` to deliver a copy of the multicast packet to `Cider` over the shared tree, which in turn generates an (S,G) join to establish an SPT. Register message tracing is added to `Lager` and `Stout` to illustrate Anycast-RP interaction:

```
[edit]
lab@Lager# run traceroute 10.255.255.1
traceroute to 10.255.255.1 (10.255.255.1), 30 hops max, 40 byte
packets
 1  10.255.255.1 (10.255.255.1)  29.511 ms  38.646 ms  10.129 ms
```

The traceroute confirms that Lager sees PBR as the metrically closest RP. The multicast source is started, and register tracing is observed at Lager. Note that the register is sourced from Lager and sent to the shared Anycast-RP address:

```
[edit]
Sep 29 06:08:13.825061PIM SENT 10.10.128.2 -> 10.255.255.1 V2
Register Flags: 0x40000000 Border: 0 Null: 1 Source 10.10.111.1
Group 225.1.1.1 sum 0x43f1 len 28
```

The register stop back from the Anycast-RP indicates that an SPT has been established or that no more interested receivers are left on the shared tree:

```
lab@Lager# Sep 29 06:06:13.774885 PIM ge-0/0/0.2131 RECV 10.255.255.1
-> 10.10.128.2 V2 RegisterStop Source 10.10.111.1 Group 225.1.1.1 sum
0x80d1 len 18
```

The register message trace output is observed at Stout:

```
[edit]
lab@stout# Sep 29 06:45:28.549924 PIM ge-0/0/0.3141 RECV 10.20.128.3
-> 10.20.128.4 V2 Register Flags: 0x00000000
    Border: 0 Null: 0 Source
 10.10.111.1 Group 225.1.1.1 sum 0xdeff len 92

Sep 29 06:45:28.553631 PIM SENT 10.20.128.4 -> 10.20.128.3 V2
RegisterStop Source 10.10.111.1 Group 225.1.1.1 sum 0x80d1 len 18
```

Stout's trace shows that it receives a register from PBR—note how the register message is sent from/to the unique lo0 addresses of PBR and Stout, respectively. This mechanism differentiates registers received from first hop routers, which are sent to the Anycast-RP address, from those received from other RPs. The former are echoed to all other RPs in the RP set, whereas the latter are absorbed and acted upon locally. Lastly, the show pim source command is executed at Stout to confirm the learning of active group 225.1.1.1 via an Anycast-RP source, as indicated by the 10.255.255.1 address:

```
[edit]
lab@stout# run show pim source detail
Instance: PIM.master Family: INET

Source 10.10.111.1
    Prefix 10.10.111.0/24
    Upstream interface ge-0/0/0.2131
    Upstream neighbor 10.10.131.1
    Active groups:225.1.1.1
Source 10.255.255.1
    Prefix 10.255.255.1/32
    Upstream interface Local
    Upstream neighbor Local
    Active groups:225.1.1.1
        224.2.127.254
```

What about MSDP?

Anycast-RP using native PIM is somewhat new, and you may find that some of the routers in your network do not support this method. In this case, you will need to deploy Anycast-RP using MSDP peering between all the RPs in the domain. MSDP conveys information about active sources between the domain's RPs. A working MSDP configuration for the current Anycast-RP topology is added to `PBR` and `Stout`. The configuration of MSDP is similar to that of PIM-based Anycast-RP, and it involves listing the unique neighbor addresses of all Anycast-RPs in the domain. The shared and unique IP addresses assigned to the `lo0` interface are reused from the previous PIM-based Anycast-RP example. The modified configuration at `PBR` is as follows:

```
[edit]
lab@PBR# show protocols pim
rp {
    local {
        address 10.255.255.1;
    }
}
interface ge-0/0/0.3141;
interface ge-0/0/0.1241;
interface ge-0/0/0.111;
[edit]
lab@PBR# show protocols msdp
peer 10.20.128.4 {
    local-address 10.20.128.3;
}
```

The `local-address` statement ensures that the remote MSDP peer recognizes the connection as coming from one of its defined peers. As with loopback-based BGP peering, one end's `local-address` should match the other end's peer definition. You can use a similar statement with PIM-based anycast, but we omitted it because by default, PIM messages are sourced from the primary address on the `lo0` interface.

After starting up the multicast source, the MSDP session state and listing of learned sources is displayed at `Stout`:

```
[edit]
lab@stout# run show msdp
Peer address  Local address State     Last up/down Peer-Group SA Count
10.20.128.3   10.20.128.4   Established  00:07:56            1/1

[edit]
lab@stout# run show msdp source-active
Group address    Source address  Peer address    Originator    Flags
225.1.1.1        10.10.111.1     10.20.128.3     10.20.128.3   Accept
```

These results complete the PIM sparse mode Anycast-RP configuration and verification example.

PIM Sparse Mode with Anycast-RP Summary

This section demonstrated a PIM-based solution to Anycast-RP and showed a working example that is based on MSDP. Because Anycast-RP has inherent fault tolerance, it's common to use a static RP definition on client routers to avoid the complexities of a dynamic RP election protocol such as the bootstrap or auto-RP protocol.

Conclusion

IP multicast offers the best of all worlds when supporting one-to-many or many-to-many applications. Using a unicast model for these applications quickly stresses processing power at the source due to replication load, and maximum network bandwidth is consumed. Using broadcast is expensive for all hosts and is confined to a single segment or bridging domain. Only IP multicast offers a scalable, standardized way to handle multipoint streams in a manner that distributes replication load and conserves network bandwidth when branches have no interested listeners. Many network operators are unfamiliar with IP multicast, which limits its widespread use. Multicast should be looked at any time a network is designed or redesigned as a potentially powerful optimization tool that can also enable the rollout of emerging virtual simulation or multiplayer applications.

PIM sparse mode has become the predominant multicast routing protocol given its support of dense, sparse, and sparse-dense modes of operation and the variety of mechanisms that can be used to dynamically distribute RP information in a fault-tolerant manner. This chapter demonstrated typical PIM sparse mode deployment scenarios using static and bootstrap-based RP dissemination, and it showed PIM- and MSDP-based examples of Anycast-RP. Junos supports a wide range of IP multicast standards and makes multicast configuration and verification relatively straightforward.

Exam Topics

We examined the following Enterprise Exam Topics in this chapter:

- Distance Vector Multicast Routing Protocol (DVMRP)
- Protocol Independent Multicast dense mode (PIM-DM)
- Protocol Independent Multicast sparse mode (PIM-SM)
- Bootstrap, auto-RP, anycast
- Source-specific multicast (SSM)

Chapter Review Questions

1. Which RP dissemination mechanism supports load balancing within the same group?
   A. Auto-RP
   B. Anycast-RP
   C. Bootstrap
   D. Static
2. Which RP dissemination mechanism supports load balancing on a group-by-group basis?
   A. Auto-RP
   B. Anycast-RP
   C. Bootstrap
   D. Static
3. Which methods can you use to scope bootstrap messages?
   A. This is not possible given the hop-by-hop forwarding using the All PIM Routers address
   B. By configuring bootstrap import or export policy
   C. By configuring RP register policy
   D. By configuring PIMv2 on external interfaces
4. Which correctly describes sparse-dense mode operation?
   A. Flooding all traffic until a prune is received, then switching to sparse mode
   B. Operating in sparse mode until a join is received, then switching to dense mode
   C. Operating in sparse mode, with the exception of specific groups that are treated as dense
   D. Sparse-dense mode is needed to support Anycast-RP
5. Which correctly describes PIM register policy?
   A. It allows you to filter register messages to control RP usage
   B. It controls which C-RPs can register with the BSR for inclusion in the RP set
   C. It supports Anycast-RP by allowing inter-RP communication regarding active sources
   D. It controls when the last hop router decides to join an SPT
6. Which correctly describes the default Junos PIM sparse mode behavior?
   A. The first hop router initiates an SPT join as soon as the first packet is sent
   B. The last hop router initiates an SPT join as soon as the first packet is received

C. The first hop router initiates an RPT join before the source becomes active

D. The last hop router initiates an RPT join as soon as traffic is received over the SPT

7. What command displays dynamic multicast forwarding state in the data plane?

A. `show pim route`

B. `show multicast route`

C. `show multicast rpf`

D. `show route table inet.2`

8. Which of the following best describes an RPF check?

A. It discards packets that are received on an interface that is not used when routing back to that source

B. It never sends a multicast packet out the interface used to reach the source

C. It sends an SPT join out the interface used when routing to that source

D. All of the above

9. Which is true regarding Anycast-RP?

A. A shared 127.0.0.1 address is added to the `lo0` interface

B. The Anycast-RPs must communicate with each other using the Anycast-RP address

C. Anycast-RP messages are flooded using sparse-dense mode

D. The Anycast-RPs must communicate with each other using their unique `lo0` addresses

10. Refer to the output provided and select the best answer:

```
lab@Porter> show multicast route
Family: INET

Group: 225.1.1.1
    Source: 10.10.111.1/32
    Upstream interface: ge-0/0/1.1331
    Downstream interface list:
        ge-0/0/1.100
```

A. This is an (S,G) entry on the RPT

B. This is an (*,G) entry on the RPT

C. This entry is pruned because only one interface exists in the outgoing list

D. This entry exists in the control plane as a result of an (*,G) join

E. This entry exists in the data plane as a result of multicast traffic

11. Which of the following is true?

A. IGMPv1 supports group leaves

B. IGMPv3 supports group leaves and SSM joins

C. IGMPv2 relied on the routing protocol to perform the querier function

D. IGMP must be explicitly configured to run on PIM-enabled interfaces

12. The querier router sends a query for group 225.1.1.1. What address is the query sent to?

A. The All PIM Routers multicast address

B. The All Hosts multicast address

C. The unicast address of the host that sent the membership

D. The address associated with the group being queried

Chapter Review Answers

1. Answer: B. Only Anycast-RP allows multiple RPs to be active at the same time for the same group.
2. Answer: C. The BSR mechanism automatically balances, on a group-range basis, among a set of C-RPs using a distributed hash function.
3. Answer: B. PIM bootstrap policy can be used to filter BSR messages being sent or received. Using PIMv1 also blocks BSR, as it is not supported in that version.
4. Answer: C. Sparse-dense operation defaults to sparse mode, except for groups explicitly designated as dense.
5. Answer: A. PIM register policy allows filtering of registers at the first hop, or at the RP, which controls the number of sessions on the RP.
6. Answer: B. The last hop router is in charge of making the switch from RPT to SPT, and in Junos, this occurs upon receipt of the first packet.
7. Answer: B. The `show multicast route` command displays dynamic data plane state that results from multicast traffic. Join-related commands show control plane state.
8. Answer: D. All of the operations described are based on an RPF check.
9. Answer: D. Anycast-RP requires a shared, and unique, `lo0` address; the unique address is used for RP-RP communication.
10. Answer: E. This is a multicast route, in the data plane, which is created when allowed by join state and when data activity occurs. This is an (S,G) entry, and therefore it is not on the RPT.
11. Answer: B. IGMPv3 supports v2's group leave as well as SSM.
12. Answer: D. A group query is sent to the multicast address of the group itself.

CHAPTER 12

Junos Security Services

The release of security services incorporated into Junos represents a significant step forward in solving the needs of enterprise networks. With these services, Juniper routers can fill most roles in the enterprise or act as all-in-one devices. This chapter is not intended to provide complete coverage of the new security capabilities found in Junos. The goal is to prepare the reader with enough information so that you can install a Juniper router as a security device in the enterprise. The features and capabilities are presented in a case scenario that positions the security device as an Internet egress firewall.

The security topics include:

- A short history of security features found in Juniper products
- A description of the scenario that is used to illustrate the various security features
- A description of flow-based traffic processing
- The security features supported in Junos

Junos Software and Security

Prior to Release 8.5, Juniper had two means to support security features: the Netscreen devices and Junos service sets. Starting with Release 8.5, Junos engineers integrated these two feature sets into the Juniper routers, creating Junos software with enhanced services. For a number of releases, two versions of Junos were supported, with or without enhanced services. Starting with Release 9.4, the two operating systems became one Junos. Although the security features and flow-based processing can be turned off, for the J-series and the SRX series of devices the software architecture is based upon a session flow handling of packets.

This is *not* a security-focused book, and therefore, comprehensive coverage of security and security features is not possible. This chapter covers those features that are commonly found in an enterprise. A complete treatment of security features and services can be found in *Junos Security*, by Rob Cameron et al. (O'Reilly).

Do I Need a Router or a Security Device?

In the past, users were expected to make some tough decisions when building out a new or existing network. Specifically, they often had to choose a device based on what was more important: world-class routing or world-class services. When both were equally important, a two-box, best-of-breed solution was often proposed. In this model, you had services/security devices that were deployed with a router infrastructure. In a divide-and-conquer model such as this, each device was left to do what it did best, with the combined effect being the best of both worlds.

Although the two-box solution was workable, and in fact is often the recommended solution today, such a design suffers from several drawbacks: two boxes are more expensive than one; there is a greater chance of failure due to more components; and generally, each new box added to the network increases overall operational costs.

Best-of-breed routing and security services

The security features of Junos hold the very real promise of eliminating the need for a two-box solution. By combining the power and proven performance of Junos software and its routing protocols with enhanced security and services, users are able to get the best of both worlds, all in a single box.

Security-Based Enterprise Scenario

The following sections explain the security features (NAT, stateful filters, VPNs, and the like) and present configuration examples. It is more illustrative to give these features a context. To do this, we have taken our lab "enterprise" and added a security threat, the Internet. Figure 12-1 shows that an Internet link has been added to `PBR`. For simplicity, a single Internet link is in use. Beer-Co has a public website that is used for orders and specials. The company has a local email server and an internal DNS server that must communicate to the Internet, and all employees have full Internet access. Beer-Co uses a private addressing scheme for internal communications but has been given a set of public IP addresses by the ISP.

The allocation of the IP addresses is:

74.116.12.1
  Public web server

74.116.12.2
  DNS server

74.116.12.3
  Email server

74.116.12.4
  Public NAT entry

74.116.12.5
: PBR public interface

  Beer-Co has suppliers that use the Internet for connectivity, and one supplier, Oats.com, uses an IPSec-based VPN to interact with Beer-Co.

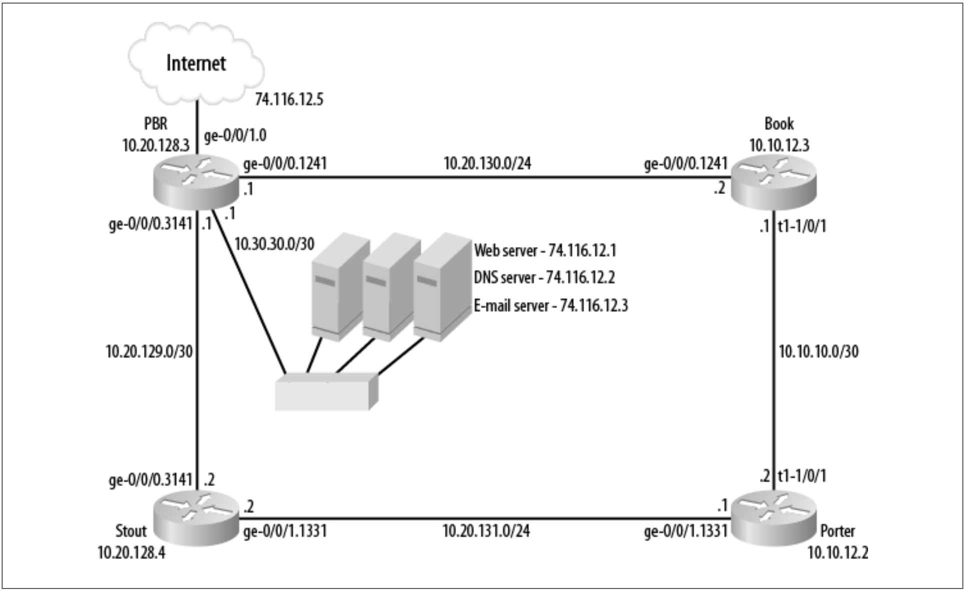


Figure 12-1. Internet access for Beer-Co Inc.

Packet- Versus Flow-Based Processing

Historically, Juniper Networks routers use a packet-based forwarding model, in which each packet is individually processed and routed. In contrast, the Juniper security devices are based on a flow model. Handling traffic as flows offers significant benefits for stateful services. In the flow model, the initial packets of a communication are subjected to various levels of packet security inspections and validity checks, in addition to a *single* route lookup. Once the packet is deemed permissible, a corresponding session state is installed into the forwarding plane to facilitate expedited forwarding for subsequent packets belonging to the same flow. In effect, the first packets are deeply scrutinized, and the remaining packets of the same session follow a fast path through the processing.

A *flow* is a unidirectional sequence of packets. The matching flow in the return direction is grouped to form a session, which is therefore composed of two unidirectional flows. The sessions reflect the applications that transit the firewall.

Architecture Changes

The addition of stateful security to Junos represents some significant changes in control plane capabilities through the introduction of new service daemons and in packet forwarding behavior with the addition of flow-based processing. This section provides a high-level overview of these changes.

Adding flow-based forwarding

One of the primary changes in Junos is the addition of flow-based processing. This is implemented along with the existing packet-based processing capabilities, such as stateless firewall filters. The changes in Junos result in a combination of packet- and flow-based treatments, as shown in Figure 12-2.

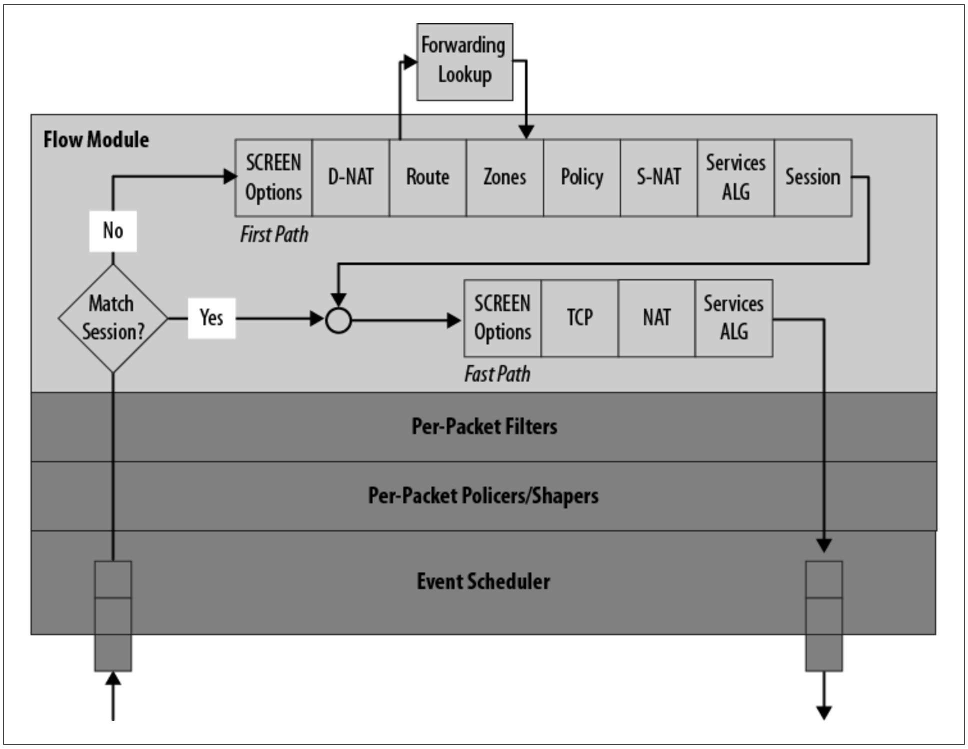


Figure 12-2. Combined packet- and flow-based processing

Figure 12-2 shows the packet and flow processing in Junos. An incoming packet is analyzed at the interface as a stateless entity for policers and firewall filters. If the packet passes these checks, the flow processing begins.

Flow-based processing is performed by the flow daemon (flwdd). This process runs in parallel with the other processes in Junos and uses extensive resources. If flow-based processing is disabled on the router, flwdd does not release the resources of the processor. Resource management is a concern for systems that perform resource-heavy tasks (e.g., full Internet feeds) and have flwdd. As of this writing, it is not possible to fully disable flwdd.

A flow is a unidirectional stream of related packets that meet the same matching criteria and share the same characteristics. Two flows are combined (ingress and egress) to form a session. Junos treats packets belonging to the same session in the same manner. Specifically, configuration settings that determine the fate of a packet—such as the security policy that applies to it, whether the packet is sent through an IPSec tunnel, or whether NAT is applied—are assessed for the first packet of a session. The resultant set of actions and services is applied to the rest of the packets in the session. The following criteria are used to determine whether a packet matches an existing session:

- Source address
- Destination address
- Source port
- Destination port
- Protocol

Flows and sessions. The stateful handling of traffic requires the creation of a session. A session is created based on the characteristics of the first packet in a flow. Sessions are used for:

- Storing security measures to be applied to the packets of the flow
- Caching information about the state of the flow—that is, logging and counting data for a flow is cached in its session
- Allocating required resources for features such as NAT and IPSec tunnels
- Providing a framework for features such as Application Layer Gateways (ALGs)

The combined effects of flow and session state bring together the following features and events that affect a packet as it undergoes flow-based processing:

- Flow-based forwarding
- Session management, including session aging and changes in routes, policy, and interfaces
- Management of VPNs, ALGs, and authentication
- Management of policies, NAT, zones, and screens

Each session resulting from a flow is associated with a timeout value. For example, the default timeout for the Transmission Control Protocol (TCP) is 30 minutes; the default timeout for the User Datagram Protocol (UDP) is 1 minute. When a flow is terminated, it is marked as invalid, and its timeout is reduced to 10 seconds. You can change the idle timeout value; it is designed to ensure that system resources are not tied up indefinitely on an otherwise defunct flow.

Session timeouts are associated with specific services within Junos. Changing a timeout for a predefined service can cause unexpected results and should be done with caution. For some services (e.g., terminal emulation), the session might be open on a desktop for hours without traffic. In these cases the service timeout can be extended to accommodate this traffic pattern.

Junos security packet walk

In this section, we will follow a packet as it traverses the Junos data plane, where it encounters a mix of packet- and flow-based handling steps. Figure 12-2 shows the steps described in the following text.

The steps shown for the first path represent the full set of checks and service instantiations that you can perform against the initial packets of a session. In contrast, the fast path represents the streamlined steps executed for previously processed (and accepted) sessions. The two-stage approach provides the ability to deeply inspect initial packets, which is computationally expensive but needed for true security, while at the same time offering high throughput by switching permitted traffic based on established session state. It should be noted that not all packets need to be touched at all possible processing points. For example, NAT is optional, and when not configured, NAT processing is not evoked. The packet processing steps are as follows:

1. Accept an incoming packet, perform class of service (CoS) behavior aggregate (BA) classification, and note the ingress interface's zone for later policy lookup.
2. Process the packet through the ingress policer/shaper.
3. Evoke the multifield CoS classification or the firewall filter.
4. Perform a lookup session; if no match, follow the first path:
    a. Conduct a firewall screen check.
    b. Perform destination NAT as required for the incoming packet.
    c. Perform a route lookup to determine the egress interface.
    d. Locate the destination (outgoing) zone, based on the route lookup result.
    e. Look up and execute policy based on incoming and outgoing zones; results include permit, deny, and reject.
    f. Allocate the source NAT address to the packet.
    g. Set up ALGs as needed to support identified applications.
    h. Install a session tuple for fast path processing of related packets.

If a session is matched, follow the fast path:

   a. Monitor the traffic for screen violations.
   b. Perform TCP checks to look for connection anomalies and match responses.
   c. Conduct NAT translation as required.
   d. Perform ALG processing as needed.

5. Whether first or fast path, perform forwarding services on the packet based on the session information.
6. Perform egress firewall filtering, which can evoke a policer action.
7. Perform egress shaping or interface-level policing; schedule and transmit the packet.

Junos Security Summary

Integrating security features into Junos software is a significant milestone in the software's evolution. Looking back at Figure 12-2, you can appreciate the combined one-two punch of these services in Junos. You can now have the best of all worlds: the familiar Junos software CLI, its proven modular design that separates the control and data planes, the two-stage commit process, commit and operational scripts, and world-class routing protocol implementations. On top of this, you also get significant security and service features and enhancements.

The combined packet- and flow-based processing means that packet-based features relating to firewall filters, policers, and shapers, packet classification, queuing, and CoS continue to operate as before. Likewise, ASP-based platforms such as the M10i and M7i will continue to use the service configurations and modes described in Chapter 9 and Appendix A, which cover Layer 2 and Layer 3 services, respectively.

For users initially deploying devices with these security features, the reverse stance on denying versus accepting packet flows by default might take a bit of getting used to. The choice of router versus secure operating contexts helps to mitigate this issue and allows you to deploy *your* router so that it operates like a traditional router or as an integrated firewall router, as required by the needs of your network.

Understanding Junos Operational Modes

A J-series Services Router or an SRX Services Gateway can operate as either a stateful firewall or a router, depending on whether it is in the secure or router context:

Secure context
   This mode allows the device to act as a prudent stateful firewall. To allow traffic to pass through the device, you must explicitly configure a security policy for that purpose. In secure context, the router forwards packets only if a security policy

permits it. All transit traffic is processed as traffic flows and assigned to sessions when permitted by the policies.

All J-series routers and SRX Services Gateways are shipped from the factory in a secure context.

Router context

This mode allows a router to act as a packet-based stateless router in which all management and transit traffic is allowed. In router context, traffic is handled in a per-packet mode of operation and no security policies are needed to provide connectivity.

Switching between secure and router contexts

Switching between secure and router contexts is performed by adding the packet mode commands to the security stanza. Once these commands are entered, all traffic is processed in a stateless manner. The remainder of the security stanza is effectively ignored. The commands are:

```
peter@pbr# show security
security {
    ...

    forwarding-options {
        family {
            inet {
                mode packet-based;
            }
            inet6 {
                mode packet-based;
            }
            mpls {
                mode packet-based;
            }
        }
    }
}
```

Default configurations

The default configuration on the J-series and SRX Services Gateways is model-dependent. Each SRX model has a different default configuration, as do the J-series routers. Our lab J-2320s have the following default configuration:

- The built-in Gigabit Ethernet interface, `ge-0/0/0`, is bound to a preconfigured zone called *trust*. All other interfaces are not bound to any zone.
- The `ge-0/0/0` interface is configured to allow management access with Secure Shell (SSH) and Hypertext Transfer Protocol (HTTP) services enabled. The following host-inbound services are configured for the `ge-0/0/0` interface in the trust zone:

—HTTP

—HTTPS

—SSH

—Telnet

—Dynamic Host Configuration Protocol (DHCP)

- TCP reset is enabled in the trust zone, and the default policy for the trust zone allows transmission of traffic from the trust zone to the untrust zone.
- All traffic within the trust zone is allowed.
- The following screens are enabled for the untrust zone:

—Internet Control Message Protocol (ICMP) Ping of Death

—IP source route options

—IP Teardrop

—TCP Land attack

—TCP SYN flood

- The default policy for the untrust zone is to deny all traffic.

The following commands load the factory default settings, which place the router into a secure context. There is no root password in the default configuration, so you must assign one using the `set system root-authentication` command before you can commit:

```
[edit]
peter@pbr# load factory-default
warning: activating factory configuration

[edit]
peter@pbr# show | no-more
## Last changed: 2010-11-28 15:44:55 PST
system {
    autoinstallation {
        delete-upon-commit; ## Deletes [system autoinstallation] upon change/commit
        traceoptions {
            level verbose;
            flag {
                all;
            }
        }
    }
    services {
        ssh;
        web-management {
            http {
                interface ge-0/0/0.0;
            }
        }
    }
    syslog {
        user * {
            any emergency;
        }
        file messages {
            any any;
            authorization info;
        }
        file interactive-commands {
            interactive-commands any;
        }
    }
    ## Warning: missing mandatory statement(s): 'root-authentication'
}
interfaces {
    ge-0/0/0 {
        unit 0;
    }
}
security {
    screen {
        ids-option untrust-screen {
            icmp {
                ping-death;
            }
            ip {
                source-route-option;
                tear-drop;
            }
            tcp {
                syn-flood {
                    alarm-threshold 1024;
                    attack-threshold 200;
                    source-threshold 1024;
                    destination-threshold 2048;
                    queue-size 2000;
                    timeout 20;
                }
                land;
            }
        }
    }
    zones {
        security-zone trust {
            tcp-rst;
            interfaces {
                ge-0/0/0.0 {
                    host-inbound-traffic {
                        system-services {
                            http;
                            https;
                            ssh;
                            telnet;
                            dhcp;
                        }
                    }
                }
            }
        }
        security-zone untrust {
            screen untrust-screen;
        }
    }
    policies {
        from-zone trust to-zone trust {
            policy default-permit {
                match {
                    source-address any;
                    destination-address any;
                    application any;
                }
                then {
                    permit;
                }
            }
        }
        from-zone trust to-zone untrust {
            policy default-permit {
                match {
                    source-address any;
                    destination-address any;
                    application any;
                }
                then {
                    permit;
                }
            }
        }
        from-zone untrust to-zone trust {
            policy default-deny {
                match {
                    source-address any;
                    destination-address any;
                    application any;
                }
                then {
                    deny;
                }
            }
        }
    }
}
```

The default configuration is the starting point for introducing all the other features that are used to secure our router. In the following sections, router `PBR` is set to act as the Internet gateway for Beer-Co. Although not shown here, the initial configuration of the interfaces and routing protocols is performed as described in the previous chapters of this book. We are going to focus only on the security features.

Operational modes summary

The operating system in the J-series routers and SRX Services Gateways supports security features that were previously found only in purpose-built firewalls. These features allow the routers to operate as a prudent firewall in the enterprise. The same device can be converted to a stateless packet mode device with the introduction of a couple of commands. This allows these devices to be used in many different roles in the enterprise.

Security Features

In the following sections we explore the common security features that are associated with Junos. These features allow us to secure a network from Internet threats while providing connectivity for users of the enterprise. This balancing act is supported by security policies that permit or deny traffic through the gateway, network address translations that hide the internal structure of our network from prying eyes, virtual private network tunnels that encrypt traffic for transmission over the Internet, and threat detection schemes that block traffic that makes it through the initial lines of defense. We present only one possible scenario for securing a network; many other possibilities are being used in enterprises today.

Branch Office and Data Center SRXs

The full set of security features supported in Junos is found in the devices referred to as Branch Office SRX series services gateways (SRX240, SRX650, etc.). A subset of these features can be found in the J-series routers and a further subset found in the larger Data Center SRXs (e.g., SRX1400, SRX3Ks, SRX5Ks). The full definition of what models support which features can be found on the Juniper website.

The features presented in the following sections are found in the Branch Office SRXs and the J-series routers. For a treatment of the features that are found exclusively in the high-end SRXs, refer to *Junos Security* (O'Reilly).

Common feature set

The features that Beer-Co is using to protect their enterprise from the threats found in the Internet include a combination of stateful security polices, NAT, VPNs, and threat detection. We add these features to the existing configurations that have been built into the enterprise. Stateless firewall filters and interface policers are a part of the security plan for Beer-Co, but these have been covered previously and will not be repeated here.

Security policies

Stateful security policies are Beer-Co's second line of defense (the firewall filters that trap all obvious malicious traffic are the first line of defense). The stateful policies are constructed from a number of referenced objects and are applied to transient traffic through the firewall. The policy components are:

Zones
: A security construct that groups interfaces and addresses that require the same security consideration. Referring to Figure 12-1, the interfaces that connect to `Bock` and `Stout` have the same security considerations, whereas the interface that connects to the Internet has a different set of security considerations. The security policies are written between zones. Given two security zones (Beer-Co and Internet), four possible sets of policies can be created: from-Beer-Co-to-Internet, from-Internet-to-Beer-Co, from-Beer-Co-to-Beer-Co, and from-Internet-to-Internet. Within each of the policy sets a series of policies are written to allow or deny specific traffic.

Interfaces
: To determine what traffic reaches which policy, the incoming and outgoing interface must be determined for the traffic. Because all interfaces are associated with a zone, once the incoming and outgoing interfaces are known, the incoming and outgoing zones can be determined and the appropriate policies can be examined. Interfaces that are not associated with a zone cannot pass transient traffic.

Addresses
: Traffic-to-policy matching is performed by determining the zones (as described previously) and by matching IP addresses in the packets. Specific addresses can be identified for special treatment (e.g., the web server address), address prefixes can be identified (e.g., all Beer-Co addresses), or a combination of the two can be created. Any address that is called out in a security policy must first be defined in an address book entry. Address book entries are associated with a specific zone. One predefined address book entry exists for all zones: the *any* address book entry.

Services
: Policy matching uses zones, addresses, and services (applications). Junos has a predefined set of services, and custom services can be defined as well. The redefined list can be reviewed with the configuration command `show groups Junos-defaults | find applications`.

Actions
: Each policy has an associated action that permits or denies the traffic through the firewall. Additional actions include management functions such as logging the traffic and or counting the traffic. Policies can be scheduled to be active at certain times. When traffic matches a policy that is to be sent over a VPN tunnel, a tunnel action replaces the permit action.

The creation of a policy begins with the definition of the referenced objects. There is no particular order for the definition of these objects, but there is a logical linkage that should be observed: interfaces, zones, addresses, and finally, services. In Beer-Co, the objects are:

Zone: Beer-Co

Interfaces:

- `ge-0/0/0.1241` (interface to `Bock`)
- `ge-0/0/0.3114` (interface to `Stout`)

Addresses:

- 10.0.0.0/8 (`Beer-Co`)
- 10.10.0.0/16 (`Beer-Co_East`)
- 10.20.0.0/17 (`Beer-Co_West`)

Zone: Internet

Interface: `ge-0/0/1.0` (Internet egress)

Addresses: Any

Zone: DMZ

Interface: `ge-0/0/2.0`

Addresses:

- 10.30.30.100 (web server)
- 10.30.30.102 (email server)
- 10.30.30.101 (DNS server)

Services

Junos defaults are all that are necessary for this installation.

First, we add the interfaces for the new DMZ zone and the new Internet zone to the configuration. These interfaces are untagged. The configuration is:

```
[edit]
peter@PBR# show interfaces
ge-0/0/0 {
    vlan-tagging;
    unit 0;
    unit 1241 {
        vlan-id 1241;
        family inet {
            address 10.20.130.1/30;
        }
    }
    unit 3141 {
        vlan-id 3141;
        family inet {
            address 10.20.129.1/30;
        }
    }
}
ge-0/0/1 {
    unit 0 {
        family inet {
            address 74.116.12.5/28;
        }
    }
}
ge-0/0/2 {
    unit 0 {
        family inet {
            address 10.30.30.1/24;
        }
    }
}
```

Once this configuration is present, the remainder of the policy objects can be added. Initially the zones are created, and then the interfaces and addresses are added to the zones. One piece needed to complete the zones is the concept of `host-inbound-traffic`. Traffic generated from the firewall is always allowed out. The return traffic is restricted to those services and protocols that are identified at the zone level or the interface level for `host-inbound-traffic`. For the Beer-Co zone, all inbound traffic and services will be accepted; for the Internet and DMZ zones, only `ping` and `traceroute` will be allowed. With this last piece of information, the zone configuration is:

```
[edit]
peter@PBR# show security zones
security-zone Beer-Co {
    address-book {
        address Beer-Co 10.0.0.0/8;
        address Beer-Co_East 10.10.0.0/16;
        address Beer-Co_West 10.20.0.0/16;
    }
    interfaces {
        ge-0/0/0.1241 {
            host-inbound-traffic {
                system-services {
                    any-service;
                }
                protocols {
                    all;
                }
            }
        }
        ge-0/0/0.3141 {
            host-inbound-traffic {
                system-services {
                    any-service;
                }
                protocols {
                    all;
                }
            }
        }
    }
}
security-zone Internet {
    interfaces {
        ge-0/0/1.0 {
            host-inbound-traffic {
                system-services {
                    traceroute;
                    ping;
                }
            }
        }
    }
}
security-zone DMZ {
    address-book {
        address Web_Server 10.30.30.100/32;
        address E-Mail_Server 10.30.30.102/32;
        address DNS_Server 10.30.30.101/32;
    }
    interfaces {
        ge-0/0/2.0 {
            host-inbound-traffic {
                system-services {
                    ping;
                    traceroute;
                }
            }
        }
    }
}
```

Policy creation

Once this configuration is entered and committed, it is time to actually create the security policies. This is the easy part once all the objects are in place. The rules that we create for Beer-Co are as follows:

1. All employees are allowed to access the Internet for all purposes (Internet-Access).
2. All Internet users are allowed to access the Beer-Co web server (Internet-to-Web).
3. All Internet DNS servers are allowed to access the Beer-Co DNS server (Internet-to-DNS).
4. All Internet email servers are allowed to access the Beer-Co email server (Internet-to-Email).
5. All employees are allowed to access the servers on the DMZ (DMZ-Access).
6. The DNS and email servers are allowed to access the Internet for their respective services (DMZ-Updates).
7. All employees are allowed to transit the firewall to another employee (Permit-All).

The general syntax for a security policy is:

> From-zone AAAA To-Zone BBBB Source-address CCCC Destination-address DDDD application EEEE permit/deny

Considering that the default policy for all traffic is an implicit deny, we are going to focus on the permit policies. If we allow wanted traffic, all other traffic that is not specified is denied by default. If we wanted to get fancy, we could create deny and permit statements that tailor traffic to very specific rules, but for our purposes that would be overkill, so we are going to create a series of permit policies and leave the denies to the default policy. We look at each rule in turn and create a policy that matches that rule.

Associated with the permit action for each policy, we are going to add the counting operation. This will help when troubleshooting and testing the policies. Considering that we are allowing all traffic that we want, we see no need to log the traffic that matches the policies. If we start having trouble with a server or see abuse on the system, then logging can be enabled on specific policies, which will enable us to see who is causing the problems and create policies to stop that traffic.

There is a set of default policies that allow and deny traffic for the default zones. These and the zones that they reference are deleted from the system prior to adding the new configuration.

Rule 1: All employees are allowed to access the Internet for all purposes. The zones associated with this rule are the Beer-Co zone for the `from-zone` and the Internet zone for the `to-zone`. The source address can be a couple of options: it could be the global `any`, the Beer-Co 10/8 address, or both the Beer-Co_East and Beer-Co_West addresses. The most prudent is the most specific address, so the east and west addresses are added to the policy. The destination address and the service in this rule have to be the global `any`. The policy configuration is as follows:

```
[edit]
peter@PBR# show security policies
from-zone Beer-Co to-zone Internet {
    policy Internet-Access {
        match {
            source-address [ Beer-Co_East Beer-Co_West ];
            destination-address any;
            application any;
        }
        then {
            permit;
            count;
        }
    }
}
```

Rule 2: All Internet users are allowed to access the Beer-Co web server. This policy is from the Internet Zone to the DMZ zone. The source address is the global `any`, and the destination address is the address book entry for the web server (`Web_Server`). The services are the predefined Junos services for HTTP and HTTPS traffic (ports 80 and 443, respectively). The policy configuration is as follows:

```
[edit]
peter@PBR# show security policies from-zone Internet to-zone DMZ
policy Internet-to-Web {
    match {
        source-address any;
        destination-address Web_Server;
        application [ Junos-http Junos-https ];
    }
    then {
        permit;
        count;
    }
}
```

When creating policies, it is necessary to name addresses and services exactly, and using ? is a big help for this purpose. I wanted to know the exact name of the web server address book entry, so I used ?, which shows a list of available addresses in the DMZ zone. I can now be assured that the spelling is correct for the address:

```
[edit]
peter@PBR# ...ernet-to-Web match source-address any destination-address ?
Possible completions:
  <address>            Address from address book or static_nat or
                       incoming_nat address
  DNS_Server   [security zones security-zone DMZ address-book address <*>]
  E-Mail_Server[security zones security-zone DMZ address-book address <*>]
  Web_Server   [security zones security-zone DMZ address-book address <*>]
  [                    Open a set of values
  any                  Any address
[edit]
peter@PBR# ...ource-address any destination-address Web_Server
```

Rule 3: All Internet DNS servers are allowed to access the Beer-Co DNS server. Because of the way the DNS system works, we have to allow access to the DNS server from the outside as well as allow the DNS server to reach the Internet (see rule 6). For this rule, the `from-zone` is the Internet and the `to-zone` is the DMZ. The source address is the global `any`, the destination address is the DNS server's address-book entry (`DNS_Server`), and the services are the predefined DNS protocols. The policy configuration is as follows:

```
[edit]
peter@PBR# show security policies
...
    policy Internet-to-DNS {
        match {
            source-address any;
            destination-address DNS_Server;
            application [ Junos-dns-udp Junos-dns-tcp ];
        }
        then {
            permit;
            count;
        }
    }
}
```

Rule 4: All Internet email servers are allowed to access the Beer-Co email server. This rule is similar to the rule for the DNS server, but with the destination addresses changed and the services altered for the email server. If remote employees wish to use a POP client to reach the email server, an additional service could be added for these users. We are keeping it simple for now with just SMTP access. The policy configuration is as follows:

```
[edit security policies from-zone Internet to-zone DMZ policy Internet-to-Email]
peter@PBR# show
match {
    source-address any;
    destination-address E-Mail_Server;
    application Junos-smtp;
}
then {
    permit;
    count;
}
```

Rule 5: All employees are allowed to access the servers on the DMZ. Because this rule is for employee access to Beer-Co assets, the rules can be relaxed. The `from-zone` is Beer-Co, and the `to-zone` is the DMZ. The addresses could be very restrictive, but because we are looking at internal traffic, we will be lax and use the global `any` for all addresses and the services. Our lack of prudence could come back and bite us one day, but we at Beer-Co are a trusting bunch. The policy configuration is:

```
[edit security policies from-zone Beer-Co to-zone DMZ policy DMZ-Access]
peter@PBR# show
match {
    source-address any;
    destination-address any;
    application any;
}
then {
    permit;
    count;
}
```

Rule 6: The DNS and email servers are allowed to access the Internet for their respective services. This is the reverse policy for rule 2 and can be written as a mirror image. The `from-zone` is the DMZ, the `to-zone` is the Internet, the source addresses are the servers, and the destination addresses are the global `any`. The services are all the services found in the DMZ. There are two ways of creating this policy. The first is the use of multiple entities in the addresses and services, and the other is creating address sets and service sets and identifying these objects in the policies. Because we have taken the easy way out for all other policies, we have provided the configuration that creates the service and address sets. The policy configuration is as follows:

```
[edit security policies from-zone DMZ to-zone Internet policy DMZ-Updates]
peter@PBR# show
match {
    source-address DMZ-Servers;
    destination-address any;
```

```
        ##
        ## Warning: application or application-set must be defined
        ##
        application DMZ-Services;
    }
    then {
        permit;
        count;
    }
```

When we create this and take an initial look, a warning says that we have to create the service set and the address set. Once these are created, the warnings are gone. The configuration for the service set and the address set are as follows:

```
[edit]
peter@PBR# show applications
application-set DMZ-Services {
    application Junos-dns-udp;
    application Junos-dns-tcp;
    application Junos-smtp;
    application Junos-http;
    application Junos-https;
}

[edit]
peter@PBR# show security zones security-zone DMZ address-book
address Web_Server 10.30.30.100/32;
address E-Mail_Server 10.30.30.102/32;
address DNS_Server 10.30.30.101/32;
address-set DMZ-Servers {
    address E-Mail_Server;
    address DNS_Server;
    address Web_Server;
}
```

Rule 7: All employees are allowed to transit the firewall to another employee. This final rule is necessary because intra-zone traffic is blocked in Junos. If you are familiar with ScreenOS, you will remember that intra-zone blocking was set with a knob that could be turned on or off as desired. In Junos, it is to permanently set to off, and so all traffic-to-transit interfaces must be allowed by a policy. This policy is the least prudent, with the `from-zone` and `to-zone` set to Beer-Co, and the address and service set to `any`. The policy configuration is as follows:

```
[edit security policies from-zone Beer-Co to-zone Beer-Co policy Permit-All]
peter@PBR# show
match {
    source-address any;
    destination-address any;
    application any;
}
then {
    permit;
    count;
}
```

Testing policies

There is no specific command that allows you to see what traffic would pass a policy or policy set. In lieu of that, we have tools that can help troubleshoot policy problems. The first uses the counters associated with a policy. The `show security policy detail` command allows an administrator to see what policies are being hit by traffic. A sample test scenario would be to check the policy counters, run a test ping session, and then check the counters again. The counters should be incremented by the ping traffic. In the following sample, the Permit-All policy is tested to see whether traffic from `Stout` is reaching `Bock` through the firewall.

First, we issue the `show security policy detail` command to check the state of the counters:

```
peter@PBR> show security policy from-zone Beer-Co to-zone Beer-Co policy-name
           Permit-All detail
Policy: Permit-All, action-type: permit, State: enabled, Index: 13
  Sequence number: 1
  From zone: Beer-Co, To zone: Beer-Co
  Source addresses:
    any: 0.0.0.0/0
  Destination addresses:
    any: 0.0.0.0/0
  Application: any
    IP protocol: 0, ALG: 0, Inactivity timeout: 0
      Source port range: [0-0]
      Destination port range: [0-0]
  Policy statistics:
    Input  bytes     :                   0                    0 bps
    Output bytes     :                   0                    0 bps
    Input  packets   :                   0                    0 pps
    Output packets   :                   0                    0 pps
    Session rate     :                   0                    0 sps
    Active sessions  :                   0
    Session deletions:                   0
    Policy lookups   :                   0
```

Next, we run a series of 11 pings from `Stout` to `Bock`. This should generate 11 hits on the policy. The return traffic is part of the existing session, so it is not counted a second time. Once the pings are complete, the details of the policy are observed again:

```
peter@PBR> show policy from-zone Beer-Co to-zone Beer-Co policy-name Permit-All detail
Policy: Permit-All, action-type: permit, State: enabled, Index: 13
  Sequence number: 1
  From zone: Beer-Co, To zone: Beer-Co
  Source addresses:
    any: 0.0.0.0/0
  Destination addresses:
    any: 0.0.0.0/0
  Application: any
    IP protocol: 0, ALG: 0, Inactivity timeout: 0
      Source port range: [0-0]
      Destination port range: [0-0]
  Policy statistics:
    Input  bytes     :                   1848                     27 bps
    Output bytes     :                   1848                     27 bps
    Input  packets   :                     22                      0 pps
    Output packets   :                     22                      0 pps
    Session rate     :                     11                      0 sps
    Active sessions  :                      0
    Session deletions:                     11
    Policy lookups   :                     11
```

We can see the counts have incremented by the number of pings, verifying that the traffic is passing through the proper policy.

A second means to test a policy is to view the session table and verify what policy has been used to establish a specific session. Because ping traffic initiates and closes sessions on a second-by-second basis, the use of ping for this testing is hit or miss. Instead, we will use an FTP session to verify the policy. On `Bock`, we enable the FTP service (`set system services ftp`) and commit the change. On `Stout`, we use the ftp client to access `Bock` (`ftp 10.20.130.2`). While the FTP session is open, we go back to `PBR` and look at the transit sessions between the two devices with the command `show security flow session destination-prefix 10.20.130.2`. The output shows all the sessions that are currently going to the interface address of `Bock` and shows that the policy used is Permit-All:

```
peter@PBR> show security flow session destination-prefix 10.20.130.2
Session ID: 33, Policy name: Permit-All/13, Timeout: 1780
  In: 10.20.129.2/56902 --> 10.20.130.2/21;tcp, If: ge-0/0/0.3141
  Out: 10.20.130.2/21 --> 10.20.129.2/56902;tcp, If: ge-0/0/0.1241

1 sessions displayed
```

On an operational firewall, the session table becomes quite large (tens of thousands of sessions large). Using the `show security flow session` command with a | match can take minutes to find what you are looking for, whereas using `destination-prefix` or other modifiers will provide results in a very short period of time.

As an aside, the output of the show security flow session command can be saved to a file and opened in a word processing or database applications for analysis. This process can allow an administrator to get a snapshot of what traffic is going where in the network.

The final tool that we have for testing policies is a flow traceoptions. An inactive traceoptions for the security flows is set up in advance on our firewall and used whenever a troubled policy is encountered. We can create filters for the security flow traceoptions to reduce the output to only the traffic that is under study. For our purposes, the source of the traffic is `Bock` and the destination is `Stout`. We activate the traceoptions, set the filters to the appropriate addresses, and commit the changes. Once the commit is complete, the logs are cleared and the test traffic (pings in this case) is generated. The following are the configurations for the traceoptions and the output of the traceoption logfiles once the test traffic is complete:

```
 [edit]
peter@PBR# show security flow
traceoptions {
    file flow-trace;
    flag basic-datapath;
    packet-filter STOUT-BOCK {
        source-prefix 10.20.129.2/32;
        destination-prefix 10.20.130.2/32;
    }
}
peter@pbr> clear log flow-trace
```

The test pings are generated from `Bock` to `Stout`:

```
peter@PBR>show log flow-trace
Mar 2 00:29:54 00:29:54.371918:CID-0:RT:<10.20.129.2/0->10.20.130.2/45320;1>
matched filter STOUT-BOCK:

Mar 2 00:29:54 00:29:54.371934:CID-0:RT:packet [84] ipid = 21046, @4b175872

Mar 2 00:29:54 00:29:54.371942:CID-0:RT:---- flow_process_pkt: (thd 0): flow_ctxt
type 0, common flag 0x0, mbuf 0x4b175660, rtbl_idx = 9584

Mar 2 00:29:54 00:29:54.371951:CID-0:RT: flow process pak fast ifl 69 in_ifp
ge-0/0/0.3141

Mar 2 00:29:54 00:29:54.371960:CID-0:RT:  ge-0/0/0.3141:10.20.129.2->10.20.130.2,
icmp, (8/0)

Mar 2 00:29:54 00:29:54.371971:CID-0:RT: find flow: table 0x57e72840, hash 76(0xffff),
sa 10.20.129.2, da 10.20.130.2, sp 0, dp 45320, proto 1, tok 576

Mar 2 00:29:54 00:29:54.371984:CID-0:RT:  no session found, start first path.
in_tunnel - 0, from_cp_flag - 0

Mar 2 00:29:54 00:29:54.371998:CID-0:RT:  flow_first_create_session

Mar 2 00:29:54 00:29:54.372013:CID-0:RT:  flow_first_in_dst_nat: in <ge-0/0/0.3141>,
out <N/A> dst_adr 10.20.130.2, sp 0, dp 45320

Mar 2 00:29:54 00:29:54.372023:CID-0:RT:  chose interface ge-0/0/0.3141 as incoming
nat if.

Mar 2 00:29:54 00:29:54.372035:CID-0:RT:flow_first_rule_dst_xlate: DST no-xlate:
0.0.0.0(0) to 10.20.130.2(45320)

Mar 2 00:29:54 00:29:54.372045:CID-0:RT:flow_first_routing: call flow_route_lookup():
src_ip 10.20.129.2, x_dst_ip 10.20.130.2, in ifp ge-0/0/0.3141, out ifp N/A sp 0,
dp 45320, ip_proto 1, tos 0

Mar 2 00:29:54 00:29:54.372057:CID-0:RT:Doing DESTINATION addr route-lookup

Mar 2 00:29:54 00:29:54.372084:CID-0:RT:  routed (x_dst_ip 10.20.130.2) from Beer-Co
```

```
(ge-0/0/0.3141 in 0) to ge-0/0/0.1241, Next-hop: 10.20.130.2

Mar 2 00:29:54 00:29:54.372098:CID-0:RT:  policy search from zone Beer-Co-> zone
Beer-Co (0x0,0xb108,0xb108)

...

Mar 2 00:29:54 00:29:54.372271:CID-0:RT:  Session (id:42) created for first pak 200

Mar 2 00:29:54 00:29:54.372278:CID-0:RT: flow_first_install_session======> 0x4f875860

...
```

The output of the flow traceoptions logs shows that the traffic is allowed implicitly and a session is created. If the traffic were denied, that would show in the initial policy check. The full decode of the trace is beyond the scope of this book, and this trace is shortened to show the relevant lines. Once the analysis of the logs is performed, the security flow traceoptions should be deactivated to lessen the chance that the routing engine will be affected by the added processing (`deactivate security flow traceoptions`).

Security traffic logs

The log operation of the security policies is not handled in the same way as other syslog files. Because of the size of the files, the security traffic logs are not stored on the firewall but are handed to a server of some flavor. The configuration for traffic logging has two parts. The first is adding the log action on the actual policy. Logs are created at session initiation, at session close, or both. For policies that have a deny, the `session-close` option should be used. For permitted policies, either or both can be used.

The second part of the equation is identifying the security traffic log server (in our example, the web server does double duty as our traffic log server, which is not really a bright idea, but it will work in our lab). The configuration for that is as follows:

```
peter@PBR# show security log
mode stream;
format syslog;
source-address 10.20.128.3;
stream PBR {
    format sd-syslog;
    category all;
    host {
        10.30.30.100;
    }
}
```

Multiple security streams can be defined, but caution should be used here because each stream uses CPU cycles that can cause an overload of the routing engine. The output of the security traffic log shows the headers of the packets that tripped the policy as well as the policy and the other resources used. The following is an example of the output of a security traffic log:

```
Mar 01 12:07:07 10.20.128.3 Mar  2 01:10:09 RT_FLOW: RT_FLOW_SESSION_CREATE:
session created 10.20.129.2/0->10.20.130.2/2244 icmp 10.20.129.2/0->
10.20.130.2/2244
None None 1 Permit-All Beer-Co Beer-Co 1102
Mar 01 12:07:08 10.20.128.3 Mar  2 01:10:10 RT_FLOW: RT_FLOW_SESSION_CREATE:
session created 10.20.129.2/256->10.20.130.2/2244 icmp 10.20.129.2/256->
10.20.130.2/2244
None None 1 Permit-All Beer-Co Beer-Co 1103
Mar 01 12:07:09 10.20.128.3 Mar  2 01:10:11 RT_FLOW: RT_FLOW_SESSION_CREATE:
session created 10.20.129.2/512->10.20.130.2/2244 icmp 10.20.129.2/512->
10.20.130.2/2244
None None 1 Permit-All Beer-Co Beer-Co 1104
Mar 01 12:07:10 10.20.128.3 Mar  2 01:10:11 RT_FLOW: RT_FLOW_SESSION_CREATE:
session created 10.20.129.2/768->10.20.130.2/2244 icmp 10.20.129.2/768->
10.20.130.2/2244
None None 1 Permit-All Beer-Co Beer-Co 1105
Mar 01 12:07:11 10.20.128.3 Mar  2 01:10:13 RT_FLOW: RT_FLOW_SESSION_CREATE:
session created 10.20.129.2/1024->10.20.130.2/2244 icmp 10.20.129.2/1024->
10.20.130.2/2244
None None 1 Permit-All Beer-Co Beer-Co 1106
```

Security policy summary

Security policies form the second line of defense for an enterprise network from the unknown world of the Internet. The Junos firewalls use a prudent policy philosophy that denies all transit traffic that is not specifically allowed. The policies are between firewall zones and can be made more or less granular by the use of addresses and services. For a fully open firewall, a single zone can be created that houses all interfaces and a single policy can be created to allow all traffic from that zone to that zone. In this case, the firewall is really a flow-based router. The more useful a firewall becomes, the more specific the policies become and the more configuration work you must perform. The Junos firewalls, like everything else, are only as good as the work that is entered into them.

Network Address Translation

Now that we have policies in place and we have verified that connectivity between all the elements is possible, it is time to hide the Beer-Co network from prying eyes. We do this by translating the internal 10.0.0.0 addresses to a public 74.116.12.0 address. If a scan of the Beer-Co network were performed, all that would be seen is a single subnet with eight hosts associated with it. The internal structure of the enterprise will be hidden.

An additional aspect of using NAT is the exhaustion of the IPv4 address pool. As of this writing, the last blocks of unassigned addresses have been distributed, and there are no more IPv4 addresses to be found. Understanding this dilemma, Beer-Co is using an address block associated with their ISP. The ISP has contracted with Beer-Co to use this address block. This arrangement saves addresses and provides security at the same time.

The Junos firewalls support three distinct types of address translation: static NAT, source NAT, and destination NAT. Each of these types has many variants and options, but for our purposes, we look at only the normal use of each type.

NAT configuration is performed with rules and rulesets that are assigned to a virtual router, zone, or interface. In earlier versions of Junos, there were strict limits on the number of rules per set and the number of rulesets. This severely limited the possible number of translations, and configuration games had to be played to exceed these limits. The current version of Junos has an absolute limit to the number of translations that is model-dependent and counted in the thousands.

Static NAT

Static NAT offers a one-to-one mapping of private address to public address. Outside traffic arrives with a destination address of the public side of the pair, which is translated to a private address for internal routing. When the privately addressed device initiates a session, the private source address is translated to a public address that is used on the Internet. Static NAT is bidirectional in nature and is commonly used for public-facing servers. In our lab setup, the DMZ servers all have static NATed addresses of this form:

Server	Public address	Private address
DNS server	74.116.12.2	10.30.30.101
Email server	74.116.12.3	10.30.30.102
Web server	74.116.12.1	10.30.30.100

The configuration for static NAT is performed in the security stanza and is composed of a ruleset and rules. The ruleset references the interface or zone that requires the translation. In Beer-Co, the translation can be mapped to either the Internet zone or interface `ge-0/0/1.0` because they both refer to the exact same entity. Three rules are created in the ruleset, one for each of the static NATs required. The configuration for the static NAT is as follows:

```
[edit]
peter@PBR# show security nat
static {
    rule-set DMZ {
        from zone Internet;
        rule DNS {
            match {
                destination-address 74.116.12.2/32;
            }
            then {
                static-nat prefix 10.30.30.101/32;
            }
        }
        rule Email {
            match {
                destination-address 74.116.12.3/32;
            }
            then {
                static-nat prefix 10.30.30.102/32;
            }
        }
        rule web {
            match {
                destination-address 74.116.12.1/32;
            }
            then {
                static-nat prefix 10.30.30.100/32;
            }
        }
    }
}
```

Each server is verified for incoming and outgoing traffic. The session table shows that the NAT is working. In the lab, we have a PC connected as the "Internet." This setup required an additional step: the entry of a `proxy-arp` setting for the interface. This allows the Internet interface (`ge-0/0/1.0`) to respond to arp requests for its address and the static NAT addresses that are behind it. The proxy arp configuration is:

```
[edit security nat proxy-arp]
peter@PBR# show
interface ge-0/0/1.0 {
    address {
        74.116.12.1/32;
        74.116.12.2/32;
        74.116.12.3/32;
        74.116.12.4/32;
    }
}
```

Once the proxy-arp is entered, the test traffic is good in both directions (for the purposes of testing, the application set was updated to include ICMP traffic). The sessions show that the incoming traffic is initially sent to 74.116.12.1 (public) but that the return traffic is coming from 10.30.30.100 (private). In the outgoing direction, the reverse is true: the initial traffic is coming from the private address, but the return traffic is destined for the public address:

```
peter@PBR> show security flow session source-prefix 74.116.12.10
Session ID: 4206, Policy name: test/5, Timeout: 2
  In: 74.116.12.10/25600 --> 74.116.12.1/512;icmp, If: ge-0/0/1.0
  Out: 10.30.30.100/512 --> 74.116.12.10/25600;icmp, If: ge-0/0/2.0

Session ID: 4208, Policy name: test/5, Timeout: 2
  In: 74.116.12.10/25856 --> 74.116.12.1/512;icmp, If: ge-0/0/1.0
  Out: 10.30.30.100/512 --> 74.116.12.10/25856;icmp, If: ge-0/0/2.0

Session ID: 4213, Policy name: test/5, Timeout: 4
  In: 74.116.12.10/26112 --> 74.116.12.1/512;icmp, If: ge-0/0/1.0
  Out: 10.30.30.100/512 --> 74.116.12.10/26112;icmp, If: ge-0/0/2.0

3 sessions displayed
```

```
peter@PBR> show security flow session source-prefix 10.30.30.100
Session ID: 4241, Policy name: DMZ-Updates/12, Timeout: 2
  In: 10.30.30.100/189 --> 74.116.12.10/1;icmp, If: ge-0/0/2.0
  Out: 74.116.12.10/1 --> 74.116.12.1/189;icmp, If: ge-0/0/1.0

Session ID: 4243, Policy name: DMZ-Updates/12, Timeout: 2
  In: 10.30.30.100/190 --> 74.116.12.10/1;icmp, If: ge-0/0/2.0
  Out: 74.116.12.10/1 --> 74.116.12.1/190;icmp, If: ge-0/0/1.0

Session ID: 4245, Policy name: DMZ-Updates/12, Timeout: 4
  In: 10.30.30.100/191 --> 74.116.12.10/1;icmp, If: ge-0/0/2.0
  Out: 74.116.12.10/1 --> 74.116.12.1/191;icmp, If: ge-0/0/1.0

3 sessions displayed
```

In a previous section, we discussed the order of operations for the various features. A review of Figure 12-2 shows that destination NAT is performed before the policy lookup, whereas source NAT is performed after the policy lookup. This sequencing could affect what address is put into the policy (private or public).

Source NAT

The source network address translation requirements for Beer-Co are quite simple. All traffic that originates in the Beer-Co security zone uses a single public address for all outgoing sessions. That address (74.116.12.4) is used by all outgoing traffic; this becomes more of a port and address translation mechanism rather than a simple NAT mechanism. An address pool is created that identifies the public address to be used for outgoing traffic, and a ruleset is created with a single rule matching all traffic. The configuration is as follows:

```
[edit]
peter@PBR# show security nat source
pool Beer-Co {
    address {
        74.116.12.4/32;
    }
}
rule-set ALL-Outbound {
    from zone Beer-Co;
    to zone Internet;
    rule All-Out {
        match {
            source-address 10.0.0.0/8;
        }
        then {
            source-nat {
                pool {
                    Beer-Co;
                }
            }
            }
        }
    }
```

The testing of the source NAT is verified in the same manner as the static NATs. Test traffic is created, and the session table is viewed to show that the translation is taking place. In our lab, we generate ping traffic from `Bock` to the Internet PC (74.116.12.10). The session table shows that not only was the source address translated but the source port was changed as well:

```
peter@PBR> show security flow session source-prefix 10.20.130.2/32
Session ID: 20, Policy name: self-traffic-policy/1, Timeout: 56
  In: 10.20.130.2/1 --> 224.0.0.5/1;ospf, If: ge-0/0/0.1241
  Out: 224.0.0.5/1 --> 10.20.130.2/1;ospf, If: .local..0

Session ID: 7377, Policy name: Internet-Access/4, Timeout: 2
  In: 10.20.130.2/789 --> 74.116.12.10/54025;icmp, If: ge-0/0/0.1241
  Out: 74.116.12.10/54025 --> 74.116.12.4/8420;icmp, If: ge-0/0/1.0

Session ID: 7378, Policy name: Internet-Access/4, Timeout: 2
  In: 10.20.130.2/790 --> 74.116.12.10/54025;icmp, If: ge-0/0/0.1241
  Out: 74.116.12.10/54025 --> 74.116.12.4/12842;icmp, If: ge-0/0/1.0

Session ID: 7382, Policy name: Internet-Access/4, Timeout: 4
  In: 10.20.130.2/791 --> 74.116.12.10/54025;icmp, If: ge-0/0/0.1241
  Out: 74.116.12.10/54025 --> 74.116.12.4/27476;icmp, If: ge-0/0/1.0

Session ID: 7383, Policy name: Internet-Access/4, Timeout: 4
  In: 10.20.130.2/792 --> 74.116.12.10/54025;icmp, If: ge-0/0/0.1241
  Out: 74.116.12.10/54025 --> 74.116.12.4/26135;icmp, If: ge-0/0/1.0

5 sessions displayed
```

Destination NAT

In the Beer-Co environment, no destination NAT is required. If it were, the configuration would be the same as the source NAT or static NAT. The traffic to be translated is identified in a rule that is assigned to a ruleset. The orientations of the addresses in the rule are the same as for static NAT: the public addresses are the from objects and the private addresses are the to objects. An example of a destination NAT is as follows:

```
[edit]
peter@PBR# show security nat destination
pool WEB {
    address 10.30.30.100/32;
}
rule-set INBound {
    from zone Internet;
    rule WEB {
        match {
            destination-address 74.116.12.1/32;
        }
        then {
            destination-nat pool WEB;
            }
        }
    }
```

NAT summary

All NAT is configured through the use of NAT rulesets and rules. The rulesets define where the interesting traffic should originate and terminate, and the rules define the individual translations. The operation of NAT can be verified by any of the troubleshooting tools defined for the policies discussed earlier, but the session table is the easiest to use.

Virtual Private Networks

The Junos-based routers support numerous virtual private network (VPN) protocols. The most common protocol used for securing transmissions is based on the Secure IP protocol, or IPSec. This protocol has many options, and entire books have been written on the configuration and description of IPSec. For most purposes the protocol's defaults are used:

- Encapsulation of traffic in the Security Encapsulation Payload (ESP) protocol
- Session key exchange using the main mode of Internet Key Exchange (IKE)
- Session encryption using the latest encryption scheme, AES-256
- Session authentication using the latest authentication scheme, SHA-1

The explanation of these options and all the details of the IPSec protocol are beyond the scope of this book.

Junos supports two different approaches for placing traffic into an IPSec tunnel: policy-based tunnels and route-based tunnels. In the policy-based approach, as the name implies, the interesting traffic is identified in a security policy that uses a tunnel action in lieu of permit. In a route-based tunnel, a tunnel interface is created, and the interesting traffic is sent to the interface by means of routes and is permitted by policies. The configuration of the two is very similar in all aspects, except that in a route-based tunnel, the VPN is bound to a tunnel interface.

There are many reasons for using one form or the other, but for Beer-Co, the reason is interoperability. The vendor that will be using the tunnel for transactions has a Cisco ASA to terminate the secure tunnel. When a Juniper firewall is communicating to a Cisco firewall with IPSec, a route-based tunnel is used. The route-based firewall allows a parameter called the proxy ID to be manipulated easily. The Cisco ASA configuration for Beer-Co is as follows:

```
crypto isakmp policy 1
 encr aes 256
 hash sha1
 authentication pre-share
 group 2
 lifetime 28800
!
crypto isakmp key abc#123456 address 74.116.12.5
crypto ipsec transform-set AES_256 esp-aes 256 esp-sha-hmac

crypto map VPN 1 ipsec-isakmp
 description Beer-Co
 set peer 74.116.12.5
 set transform-set AES_256
 match address OATs_to_Beer-Co

ip access-list extended OATs_to_Beer-Co
 permit ip host 192.168.12.1 host 10.10.1.1
 permit ip host 192.168.12.2 host 10.10.1.1
```

This defines the IPSec context, the transform set, the VPN configuration, and the access lists. Not shown are the routes that map traffic to the proper gateway. The public interface for the Oats.com ASA is 65.9.134.12. We at Beer-Co, sober or not, are concerned with the security of our network, so all traffic from Oats.com is treated as untrusted and is allowed only to the servers that handle the transactions. This server (10.10.1.1) is located in the Beer-Co security zone. There are many ways to protect this traffic, but one way is to create a zone specifically for the Oats.com VPN, install the interface into that zone, and create a set of policies that control the traffic to and from that zone. This is our approach because it offers the most security and flexibility for the incoming traffic. The configuration for the interface, zone, and policies is as follows:

```
[edit]
peter@PBR# show interfaces st0.0
family inet {
    address 10.10.1.100/24;
}

peter@PBR# show security zone security-zone Internet
interfaces {
    ge-0/0/1.0 {
        host-inbound-traffic {
            system-services {
                traceroute;
                ping;
                ike;
            }
        }
    }
}

peter@PBR# show security zones security-zone Oats.com
address-book {
    address Oat.com 192.168.12.0/24;
interfaces {
    st0.0 {
        host-inbound-traffic {
            system-services {
                ping;
                ike;
            }
        }
    }
}
[edit]
peter@PBR# show security policies from-zone Beer-Co to-zone Oats.com
policy Server_Permit {
    match {
        source-address Intranet_server;
        destination-address Oat.com;
        application any;
    }
    then {
        permit;
        count;
    }
}

[edit]
peter@PBR# show security policies from-zone Oats.com to-zone Beer-Co
policy Oat-in {
    match {
        source-address Oat.com;
        destination-address Intranet_server;
        application any;
    }
    then {
        permit;
        count;
    }
}
peter@PBR# show routing-options
static {
    route 0.0.0.0/0 next-hop 74.116.12.10;
    route 192.168.12.0/24 next-hop st0.0;
}
```

There is no specific order to the creation of the tunnel. The interface has to exist prior to the IPSec configuration pointing to it, but other than that, all the other configuration can be done whenever. For our purposes, we like to create the infrastructure first and then set up the IPSec and IKE protocols. That way, once the tunnel becomes active, we can test it with actual traffic between the source and destination devices. You might notice that we have allowed ping host-inbound-traffic (in addition to IKE) for the Oats.com zone; this is for testing purposes only, and it can be deleted once the tunnel is up and operational.

The first step in creating the secured VPN tunnel is creating a phase 1 proposal that matches the Cisco ASA `isakmp` policy:

```
[edit]
peter@PBR# show security ike proposal oat-ike-proposal
authentication-method pre-shared-keys;
dh-group group2;
```

```
authentication-algorithm sha1;
encryption-algorithm aes-256-cbc;
lifetime-seconds 28800;
```

Next, we create the IKE policy and reference the proposal that defines the use of the main mode for key exchange:

```
[edit]
peter@PBR# show security ike policy oat_ike_policy
mode main;
proposals oat-ike-proposal;
pre-shared-key ascii-text "$9$d/bwgaJDkqfXxUjkqf5RhcSvWNdboZU"; ## SECRET-DATA
```

The policy is referenced in a IKE gateway stanza that includes the outgoing interface and the remote VPN address:

```
[edit]
peter@PBR# show security ike gateway oat_ike_gateway
ike-policy oat_ike_policy;
address 65.9.134.12;
external-interface ge-0/0/1.0;
```

This configuration defines the phase 1 portion of the secure tunnel. The phase 2 portion of the configuration involves a similar set of steps. First, create the IPSec proposal that defines the encryption algorithms, the authentication algorithms, and the tunneling protocols used for this tunnel:

```
[edit]
peter@PBR# show security ipsec proposal oat_ipsec_proposal
protocol esp;
authentication-algorithm hmac-sha1-96;
encryption-algorithm aes-256-cbc;
```

As in the IKE configuration, the proposal is referenced in a IPSec policy that includes the definition of perfect forwarding security (PFS) for session key creation (our tunnel is not using PFS, but this is where it would be programmed):

```
[edit]
peter@PBR# show security ipsec policy oat_ipsec_policy
proposals oat_ipsec_proposal;
```

Now the VPN can be configured to associate these pieces with the `proxy-identity` and the interface. Also included in the VPN is a definition that specifies when to set up the tunnel. Should it be set up immediately without waiting for traffic, or should interesting traffic be seen prior to the tunnel being established? The latter is more secure, whereas the former is easier to troubleshoot. For now we use the immediate setting, but later we can use the more secure on-demand setting. The VPN configuration is as follows:

```
[edit]
peter@PBR# show security ipsec vpn oat_ipsec_vpn
bind-interface st0.0;
ike {
    gateway oat_ike_gateway;
    proxy-identity {
        local 10.10.1.1/32;
```

```
            remote 192.168.12.0/24;
            service any;
        }
        ipsec-policy oat_ipsec_policy;
    }
    establish-tunnels immediately;
```

Once this configuration is committed on the firewall, we have to verify that the tunnel is operational. The easiest way to verify the up/down status of the tunnel is to look at the security association for the tunnel. Two different security associations (SAs) are created when establishing the tunnel: the first is for the key exchange, which is a temporary SA, and the second is for the traffic session, which is active for as long as the tunnel is in place. The commands to view the security associations are as follows:

```
peter@PBR> show security ike security-associations detail
IKE peer 65.9.134.12, Index 4,
  Role: Responder, State: UP
  Initiator cookie: 549e06e7b48aa86e, Responder cookie: d076500299672f0f
  Exchange type: Main, Authentication method: Pre-shared-keys
  Local: 74.116.12.5:500, Remote: 65.9.134.12:500
  Lifetime: Expires in 27691 seconds
  Algorithms:
   Authentication        : sha1
   Encryption            : aes-cbc (256 bits)
   Pseudo random function: hmac-sha1
  Traffic statistics:
   Input  bytes  :                  912
   Output bytes  :                  844
   Input  packets:                    5
   Output packets:                    4
  Flags: Caller notification sent
  IPSec security associations: 1 created, 0 deleted
  Phase 2 negotiations in progress: 0
peter@PBR> show security ipsec security-associations detail
  Virtual-system: Root
  Local Gateway: 74.116.12.5, Remote Gateway: 65.9.134.12
  Local Identity: ipv4(any:0,[0..3]=10.10.1.1)
  Remote Identity: ipv4_subnet(any:0,[0..7]=192.168.12.0/24)
    DF-bit: clear
    Direction: inbound, SPI: c831a1bb, AUX-SPI: 0
    Hard lifetime: Expires in 2438 seconds
    Lifesize Remaining:  Unlimited
    Soft lifetime: Expires in 1861 seconds
    Mode: tunnel, Type: dynamic, State: installed, VPN Monitoring: -
    Protocol: ESP, Authentication: hmac-sha1-96, Encryption: aes-cbc (256 bits)
    Anti-replay service: enabled, Replay window size: 64

    Direction: outbound, SPI: 85304c96, AUX-SPI: 0
    Hard lifetime: Expires in 2438 seconds
    Lifesize Remaining:  Unlimited
    Soft lifetime: Expires in 1861 seconds
    Mode: tunnel, Type: dynamic, State: installed, VPN Monitoring: -
    Protocol: ESP, Authentication: hmac-sha1-96, Encryption: aes-cbc (256 bits)
    Anti-replay service: enabled, Replay window size: 64
```

If the SAs are up and operational, then it is time to send traffic over the tunnel. You know they are up when you see either an UP status or an SPI that is complete. If the SAs are not up, it is time for some deeper troubleshooting. We ping from our server to the Oats client and receive a positive response (phew!). To verify that the traffic is actually following the tunnel, we view the traffic statistics associated with the tunnel:

```
peter@PBR> show security ipsec statistics
ESP Statistics:
  Encrypted bytes:            5624
  Decrypted bytes:            1008
  Encrypted packets:            37
  Decrypted packets:            12
AH Statistics:
  Input bytes:                   0
  Output bytes:                  0
  Input packets:                 0
  Output packets:                0
Errors:
  AH authentication failures: 0, Replay errors: 0
  ESP authentication failures: 0, ESP decryption failures: 0
  Bad headers: 0, Bad trailers: 0
```

On a route-based VPN, you can also view the status of the interface and monitor the traffic statistics of the interface as you would any other interface. In this case, the interface is st0.0 rather than an Ethernet or serial interface. The commands and associated output are as follows:

```
peter@PBR> show interfaces st0.0 detail
  Logical interface st0.0 (Index 70) (SNMP ifIndex 149) (Generation 152)
    Flags: Point-To-Point SNMP-Traps Encapsulation: Secure-Tunnel
    Traffic statistics:
     Input  bytes  :                8316
     Output bytes  :                8473
     Input  packets:                  99
     Output packets:                  74
    Local statistics:
     Input  bytes  :                 504
     Output bytes  :                5365
     Input  packets:                   6
     Output packets:                  37
    Transit statistics:
     Input  bytes  :                7812                 1000 bps
     Output bytes  :                3108                  900 bps
     Input  packets:                  93                    1 pps
     Output packets:                  37                    1 pps
    Security: Zone: Oats.com
    Allowed host-inbound traffic : ping
    Flow Statistics :
    Flow Input statistics :
      Self packets :                    6
      ICMP packets :                    99
      VPN packets :                     0
      Multicast packets :               0
      Bytes permitted by policy :       504
      Connections established :         87
    Flow Output statistics:
      Multicast packets :               0
      Bytes permitted by policy :       3108
    Flow error statistics (Packets dropped due to):
      Address spoofing:                 0
      Authentication failed:            0
      Incoming NAT errors:              0
      Invalid zone received packet:     0
      Multiple user authentications:    0
      Multiple incoming NAT:            0
      No parent for a gate:             0
      No one interested in self packets: 0
      No minor session:                 0
      No more sessions:                 0
      No NAT gate:                      0
      No route present:                 0
      No SA for incoming SPI:           0
      No tunnel found:                  0
      No session for a gate:            0
      No zone or NULL zone binding      0
      Policy denied:                    6
      Security association not active:  0
      TCP sequence number out of window: 0
      Syn-attack protection:            0
      User authentication errors:       0
    Protocol inet, MTU: 9192, Generation: 165, Route table: 0
      Flags: None
      Addresses, Flags: Is-Preferred Is-Primary
        Destination: 10.40.1/24, Local: 10.40.1.100, Broadcast: Unspecified,
        Generation: 174

peter@pbr> monitor interface st0.0

PBR                                Seconds: 32               Time: 05:44:10
                                                          Delay: 0/0/0
Interface: st0.0, Enabled, Link is Up
Flags: Point-To-Point SNMP-Traps
Encapsulation: Secure-Tunnel
Local statistics:                                          Current delta
  Input bytes:                    504                                [0]
  Output bytes:                  5365                                [0]
  Input packets:                   36                                [0]
  Output packets:                  37                                [0]
Remote statistics:
  Input bytes:                   4620 (664 bps)                   [2604]
  Output bytes:                  3108 (0 bps)                     [2400]
  Input packets:                   55 (0 pps)                       [31]
  Output packets:                  37 (0 pps)                        [30]
Traffic statistics:
  Input bytes:                   5124  Output bytes:   ,          [2604]
```

In our lab we have the luxury of a controlled environment and direct access to all the devices. If you are not so lucky, you will end up spending time troubleshooting the tunnels. The basic tool for troubleshooting IPSec tunnels is IKE traceoptions. Prior to setting up the traceoptions, look in the *kmd* logfile for status messages. This is the default logfile for IPSec functions, and the answer to the problem might be found there. If not, set up the IKE traceoptions; the most useful flag is `ike`. If no file is defined, the messages are found in the kmd logfile. The following shows the traceoptions configuration and the trace file output:

```
[edit]
peter@PBR# show security ike traceoptions
flag ike;

[edit]
peter@PBR# run show log kmd | last 50
Mar  2 06:06:23 ike_encode_packet: Start, SA = { 0x560cde57 d4512fc3 - 44aac029
6ddd365b } / 4255b965, nego = 0
Mar  2 06:06:23 ike_finalize_qm_hash_1: Hash[0..20] = bafd3635 26c44f63 ...
Mar  2 06:06:23 ike_send_packet: Start, send SA = { 560cde57 d4512fc3 - 44aac029
6ddd365b}, nego = 0, src = 74.116.12.5:500, dst = 65.9.134.12:500, routing table
id = 0
Mar  2 06:06:23 ike_send_notify: Connected, SA = { 560cde57 d4512fc3 - 44aac029
6ddd365b}, nego = -1
Mar  2 06:06:23 ike_get_sa: Start, SA = { 560cde57 d4512fc3 - 44aac029 6ddd365b }
/ 4255b965, remote = 65.9.134.12:500
Mar  2 06:06:23 ike_sa_find: Found SA = { 560cde57 d4512fc3 - 44aac029 6ddd365b }
Mar  2 06:06:23 ike_st_o_done: ISAKMP SA negotiation done
Mar  2 06:06:23 ike_send_notify: Connected, SA = { 560cde57 d4512fc3 - 44aac029
6ddd365b}, nego = -1
Mar  2 06:06:23 ike_free_negotiation_isakmp: Start, nego = -1
Mar  2 06:06:23 ike_free_negotiation: Start, nego = -1
Mar  2 06:06:23 ike_decode_packet: Start
Mar  2 06:06:23 ike_decode_packet: Start, SA = { 560cde57 d4512fc3 - 44aac029
6ddd365b} / 4255b965, nego = 0
Mar  2 06:06:23 ike_decode_payload_sa: Start
Mar  2 06:06:23 ike_decode_payload_t: Start, # trans = 1
Mar  2 06:06:23 ike_st_i_encrypt: Check that packet was encrypted succeeded
Mar  2 06:06:23 ike_st_i_qm_hash_2: Start, hash[0..20] = 06a5d05e 1563197c ...
Mar  2 06:06:23 ike_st_i_qm_sa_values: Start
Mar  2 06:06:23 ike_st_i_qm_nonce: Nonce[0..64] = 4c0b89b5 86bb8045 ...
Mar  2 06:06:23 ike_st_i_status_n: Start, doi = 1, protocol = 3, code = unknown
(40001), spi[0..4] = bed09c6b 00000000 ..., data[0..8] = 00010004 c0a90c64 ...
Mar  2 06:06:23 ike_st_i_private: Start
Mar  2 06:06:23 ike_st_o_qm_hash_3: Start
Mar  2 06:06:23 ike_st_o_private: Start
Mar  2 06:06:23 ike_policy_reply_private_payload_out: Start
Mar  2 06:06:23 ike_st_o_encrypt: Marking encryption for packet
Mar  2 06:06:23 74.116.12.5:500 (Initiator) <-> 65.9.134.12:500 { 560cde57
d4512fc3 - 44aac029 6ddd365b [0] / 0x4255b965 } QM; MESSAGE: Phase 2 connection
succeeded, No PFS, group = 0
Mar  2 06:06:23 ike_qm_call_callback: MESSAGE: Phase 2 connection succeeded,
No PFS, group = 0
Mar  2 06:06:23 74.116.12.5:500 (Initiator) <-> 65.9.134.12:500 { 560cde57
d4512fc3 - 44aac029 6ddd365b [0] / 0x4255b965 } QM; MESSAGE: SA[0][0] = ESP aes,
life = 0 kB/3600 sec, group = 0, tunnel, hmac-sha1-96, key len = 256, key rounds = 0
Mar  2 06:06:23 ike_qm_call_callback: MESSAGE: SA[0][0] = ESP aes, life = 0 kB/3600
sec, group = 0, tunnel, hmac-sha1-96, key len = 256, key rounds = 0
```

```
Mar  2 06:06:23 ike_st_o_qm_wait_done: Marking for waiting for done
Mar  2 06:06:23 ike_encode_packet: Start, SA = { 0x560cde57 d4512fc3 - 44aac029
6ddd365b } / 4255b965, nego = 0
Mar  2 06:06:23 ike_send_packet: Start, send SA = { 560cde57 d4512fc3 - 44aac029
6ddd365b}, nego = 0, src = 74.116.12.5:500, dst = 65.9.134.12:500, routing table
id = 0
Mar  2 06:06:23 ike_send_notify: Connected, SA = { 560cde57 d4512fc3 - 44aac029
6ddd365b}, nego = 0
```

Virtual private networks summary

Virtual private networks based on the IPSec protocol offer security for sensitive traffic that is transmitted over a hostile network. The Junos implementation of IPSec provides a full set of options and capabilities to allow interoperability with most vendors. In the previous sections, we provided the configurations and verification for a single implementation of this flexible protocol, representing what we believe is the most common approach to secure tunneling. These configurations should support most implementations.

Attack Detection and Prevention

The Junos firewalls have an attack detection mechanism that is activated prior to the stateful security policies. This mechanism is called the *attack screen*, or just *screen*. Screens can monitor for scans, denial-of-service attacks, and packet anomalies. They are applied to a security zone and monitor all traffic on all interfaces for that zone. In the factory default configuration, a number of screens are configured on the untrust security zone. The screens are grouped by attack type:

Scan/Spoof/Sweep Defense
: Limits the number of port scans and address sweeps allowed from a single host. It also monitors and blocks address spoofing on incoming packets.

MS-Windows Defense
: Limits the number of WinNuke attacks.

Denial-of-Service Defense
: Limits the number of common denial of service attacks, including Land attack, Ping of Death, Large Pings, Teardrop, and ICMP fragment.

IP Options Anomalies
: Monitors and limits the number of IP options that are allowed, including source-route, security, record route, and timestamp.

TCP/IP Anomalies
: Monitors and limits the number of TCP flag anomalies that can occur.

Flood Defense
: Provides protection from ICMP and UDP protocol floods.

Configuring screens

The attack screens are configured in two parts. Initially, we define the screens to be used, the parameter settings for those screens (timers, thresholds, etc.), and a name for this screen's `ids-options` group. Next we reference the `ids-options` group in a zone. We can define multiple groups and assign each to a different zone, or we can reference the same group in multiple zones. Rather than reinventing the wheel, we are going to explain the configuration of the default screens and apply them to our Internet zone.

The default security screen `ids-options` are as follows:

```
peter@pbr# show security screen
    screen {
        ids-option untrust-screen {
            icmp {
                ping-death;
            }
            ip {
                source-route-option;
                tear-drop;
            }
            tcp {
                syn-flood {
                    alarm-threshold 1024;
                    attack-threshold 200;
                    source-threshold 1024;
                    destination-threshold 2048;
                    queue-size 2000;
                    timeout 20;
                }
                land;
            }
        }
    }
```

The full list of the screens can be found in the SRX Security Configuration Guide, available on the Juniper tech pub site. This guide provides a description of the attacks, the screen operations, and the parameters that can be set for each screen. The screen definitions that we used in the preceding example are as follows:

`ping-death`
: Detects and rejects oversized (greater than 65,507 bytes of data) ICMP packet sizes, even when fragmented.

`source-route-option`
: Blocks packets with either the loose or strict source route IP option set.

`tear-drop`
: Drops traffic that has overlapping fragmentation segments.

`syn-flood`
: Intercepts, proxies, or drops TCP SYN messages based on the parameters set:

`alarm-threshold 1024`
: The point in messages per second at which an alarm is set for incoming messages above the attack threshold.

`attack-threshold 200`
: The point in messages per second at which the firewall starts proxying SYN messages to the same destination address and port number.

`source-threshold 1024`
: The point in messages per second at which the firewall starts dropping SYN segments from a single IP address.

`destination-threshold 2048`
: The point in messages per second at which the firewall starts dropping SYN segments to the same destination IP address, regardless of destination port number.

`queue-size 2000`
: The total amount of SYN segments that the firewall will proxy waiting for an ACK prior to dropping all additional SYN segments.

`timeout 20`
: The amount of time in seconds that a SYN segment will be held in the queue waiting for an ACK. When this timer expires, the SYN segment is dropped.

`land`
: Drops TCP SYN segments in which the source and destination address are the same.

Remember that back in Chapter 8 we discussed setting up firewalls and policers for the routers that monitor the traffic before the screens. If we set a policer in a firewall that limits the amount of TCP traffic to the DMZ, the screens add no benefit. The best practice is to perform the blocking as close to the ingress interface as possible. If the same protection can be configured in a firewall filter or a screen, we recommend using the filter.

Once the screens are configured, they are assigned to one or more zones on the firewall. In our case we assigned them to the Internet zone as the following:

```
peter@pbr# show security zones security zone internet
   screen untrust-screen;
   interfaces {
      ge-0/0/1.0 {
          host-inbound-traffic {
               system-services {
                  ssh;
                }
           }
      }
   }
```

Attack detection and prevention summary

The Junos firewalls have many means to protect the enterprise network from attacks, implementing the concept of defense in depth. Firewall filters drop traffic that is obviously malicious, security policies drop traffic that does not meet the security guidelines, and IDP looks for allowed traffic that contains attacks. The screen functions protect against traffic that would not meet any of these criteria, but still poses a threat in other ways. In our enterprise, the screens protect the internal networks from denial-of-service attacks that could otherwise crash or disable our servers. In the next section, we look at the other end of security: the redundancy capabilities of Junos.

Clustering

Security in the enterprise includes multiple areas, specifically informational security and survivability, and firewalls from Juniper provide support for both. In the preceding sections we configured the firewall in Beer-Co to provide informational security. In this section, we configure the firewalls in a cluster. Clustering provides survivability for the hardware and software components of the firewall, and consists of connecting two firewalls with control and data connections (see Figure 12-3).

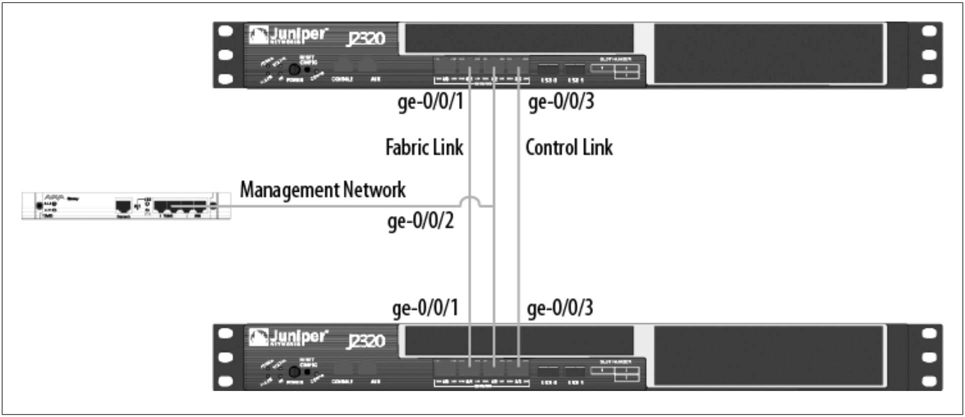


Figure 12-3. J2320s clustered

When connected, the two firewalls create a single extended chassis that encompasses all the interfaces of the two firewalls. The flexible PIC concentrators (FPCs) in a cluster are renumbered in the second firewall to begin where the first chassis leaves off. To illustrate this point, a portion of the `show interfaces terse` command on a cluster of J2320s is shown next. The FPCs 4, 5, and 6 are on the second firewall:

```
root@PBR> show interfaces terse
Interface               Admin Link Proto    Local                 Remote
ge-0/0/0                up    down
ge-0/0/0.1241           up    down inet     10.20.130.1/30
ge-0/0/0.3141           up    down inet     10.20.129.1/30
```

```
ge-0/0/0.32767          up    down
ge-0/0/1                up    up
ge-0/0/1.0              up    up   aenet     --> fab0.0
se-1/0/0                up    down
se-1/0/1                up    down
t1-2/0/0                up    up
t1-2/0/1                up    up
ge-4/0/0                up    down
ge-4/0/1                up    up
ge-4/0/1.0              up    up   aenet     --> fab1.0
se-5/0/0                up    down
se-5/0/1                up    down
t1-6/0/0                up    up
t1-6/0/1                up    up
```

Clustering components

There are four major components when clustering Junos firewalls: control links, fabric links, redundant Ethernet interfaces, and the clustering configuration. The control and the fabric (fab) links tie the two devices together into a single chassis, the redundant Ethernet (Reth) interfaces provide HSRP-like redundant services to connected devices, and the configuration controls the ownership and monitoring of the chassis cluster:

Control links
: A single control link or redundant control links can be installed between the firewalls. The use of redundant links is reserved for the Data Center SRX devices. The control link is used to synchronize the configuration between the REs of the devices and to control the actual states of the operating systems. The control links are defined differently for all Junos firewalls; refer to the hardware guide for the devices you are clustering to determine the location of their control links. For the J2320s, the control link uses the `ge-0/0/3` port.

Fabric links
: A single Ethernet interface can be identified as the fabric link. The fab link extends the switching fabric between the two devices and also passes session information between the devices. The fab interfaces are normal Gigabit interfaces that are configured for the fab purpose.

Redundant Ethernet (Reth) interfaces
: The Reth interfaces provide redundant links to connected devices. The links need to be connected to a Layer 2 switch to provide automatic failover capability. Reth interfaces typically occupy the same port on the two firewalls. In our environment, we are not going to use the services of Reth interfaces.

Configuration
: The clustering configuration is entered on both devices in the cluster. The configuration is composed of a group stanza that identifies the unique aspects of each node (node name, management port address, management routes), the cluster identifier, and the failover and monitoring parameters. The next section shows the configuration used at Beer-Co.

When these components are applied, the clustered firewall offers redundant REs, an expanded switching fabric, and the option of redundant interfaces.

Clustering configuration

The clustering configuration is comprised of a number of distinct entities that might not be present on all device types. When two firewalls are clustered, only one of the REs controls the extended chassis. The other RE is in standby mode (you can log into it and look around, but it does not have a routing daemon operating). Because of this, the configuration is read by the active RE and operated upon by that device. In order for the other device to be managed, it must have device-specific information. This is accomplished through a group configuration that is specific per node. The group configuration can have many elements, but two are required: the host name and the OOB management port (`fxp0`) address. Refer to the following example and to Figure 12-3 for the group configuration:

```
 [edit]
peter@PBR-node0# show groups
node0 {
    system {
        host-name PBR-node0;
    }
    interfaces {
        fxp0 {
            unit 0 {
                family inet {
                    address 10.20.128.13/24;
                }
            }
        }
    }
}
node1 {
    system {
        host-name PBR-node1;
    }
    interfaces {
        fxp0 {
            unit 0 {
                family inet {
                    address 10.20.128.14/24;
                }
            }
        }
    }
}
```

The second configuration entity is the definition of the fabric links used between the devices. These links must terminate on the same FPC and port on both devices. The interface should be a gigabit Ethernet interface, although fast Ethernet and 10 Gig ports can be used. For the J-series, a gigabit Ethernet interface is required. For our setup, the ge-0/0/1 interface is used for the fab link. The relevant interface configuration settings are as follows:

```
[edit]
peter@PBR-node0# show interfaces | find fab
fab0 {
    fabric-options {
        member-interfaces {
            ge-0/0/1;
        }
    }
}
fab1 {
    fabric-options {
        member-interfaces {
            ge-4/0/1;
        }
    }
}
```

The control ports on the higher-end SRXs are variable, so these must be defined in the configuration in addition to the fab links. In the smaller SRXs and the J-series, the control ports are fixed, so no configuration is necessary.

The clustering configuration defines the redundancy group priorities and the monitored elements. If you are using Reths, a second redundancy group is configured, so each group switches independently of the other in the case of a failure. In our configuration no Reths are used, so we have only the default redundancy group (group 0). The configuration for the clustering is as follows:

```
 [edit]
peter@PBR-node0# show chassis cluster
redundancy-group 0 {
    node 0 priority 1;
    node 1 priority 100;
}
```

The Junos firewalls can operate in active/active mode or active/passive mode. In active/active mode, each redundancy group is primary on a different node. This spreads the load among all the firewall's processing power.

Once the configuration is committed, a set of operational commands are used to initialize the cluster that defines the cluster-id and node-id. The RE of the node with the higher priority becomes the active RE of the cluster. The operational commands are entered on both nodes of the cluster and are shown here for node 0:

```
peter@PBR-node0> set chassis cluster cluster-id 1 node 0 reboot
```

Verifying clustering

Once the cluster is physically connected and the configuration is committed, the two firewalls operate as a single entity. We verify the operation with a couple of commands:

```
{primary:node0}
peter@PBR-node0> show chassis cluster status
Cluster ID: 1
Node                  Priority          Status    Preempt  Manual failover

Redundancy group: 0 , Failover count: 1
    node0                   1           primary       no       no
    node1                   100         secondary     no       no
```

This command shows that both nodes are up and operational, and that the redundancy group is active on node 0. If a manual switchover is required (to activate the route on the standby RE), the operational command would be:

```
peter@PBR-node0> request chassis cluster failover redundancy-group 0 node 1
```

Rerunning the status command now shows that the control is given to node 1, and the prompt shows this as well:

```
{secondary-hold:node0}
peter@PBR-node0> show chassis cluster status
Cluster ID: 1
Node                  Priority          Status    Preempt  Manual failover

Redundancy group: 0 , Failover count: 2
    node0                   1           secondary-hold no       no
    node1                   100         primary       no       no
```

There is a hidden command that shows much more information about the status of the cluster (`show chassis cluster information`). This command (and all hidden commands) should be used with caution—there must be a reason why it is hidden.

Prior to returning control to node 0, we must reset the failover parameters and then issue the failover request again:

```
peter@PBR-node0> request chassis cluster failover reset redundancy-group 0
node0:
--------------------------------------------------------------------------
No reset required for redundancy group 0.

node1:
--------------------------------------------------------------------------
Successfully reset manual failover for redundancy group 0


{secondary:node0}
peter@PBR-node0> request chassis cluster failover redundancy-group 0 node 0
node0:
--------------------------------------------------------------------------
```

```
Initiated manual failover for redundancy group 0

Note: If the Unified threat management feature is being used, please have
have all redundancy-groups primary on the same node.
```

There is a hold-down timer associated with the switching of the active nodes; this prevents flapping between the nodes. The timer is configurable and defaults to 5 minutes. If the preceding failover is performed within this timer, an error is presented.

Once the failback is performed, the normal displays of chassis hardware, sessions, and the like will all have node 0 and node 1 sections:

```
{primary:node0}
peter@PBR-node0> show security flow session
node0:
--------------------------------------------------------------------------

0 sessions displayed

node1:
--------------------------------------------------------------------------

0 sessions displayed

{primary:node0}
peter@PBR-node0> show chassis hardware
node0:
--------------------------------------------------------------------------
Hardware inventory:
Item             Version  Part number  Serial number     Description
Chassis                                JN119F556ADD      J2320
Midplane         REV 06   710-017558   AABZ1397
System IO        REV 10   710-017562   AABW4806          J23X0 System IO
Crypto Module                                            Crypto Acceleration
Routing Engine   REV 14   710-017560   AABY9504          RE-J2320-2000
FPC 0                                                    FPC
  PIC 0                                                  4x GE Base PIC
FPC 1            REV 17   750-010356   AG10200058        FPC
  PIC 0                                                  2x Serial
FPC 2            REV 15   750-010355   AI10250081        FPC
  PIC 0                                                  2x T1
Power Supply 0

node1:
--------------------------------------------------------------------------
Hardware inventory:
Item             Version  Part number  Serial number     Description
Chassis                                JN119E4DDADD      J2320
Midplane         REV 06   710-017558   AABZ1455
System IO        REV 10   710-017562   AABW4869          J23X0 System IO
Crypto Module                                            Crypto Acceleration
Routing Engine   REV 14   710-017560   AABY9625          RE-J2320-2000
FPC 0                                                    FPC
  PIC 0                                                  4x GE Base PIC
FPC 1            REV 17   750-010356   AG10200057        FPC
```

```
  PIC 0                                                  2x Serial
FPC 2            REV 15   750-010355   AI10250101        FPC
  PIC 0                                                  2x T1
Power Supply 0
```

Clustering summary

Clustering Junos firewalls provides survivability from device, processor, and link failures. It allows two firewalls to act as a single chassis of interfaces under the control of a single RE. Traffic sessions, routes, and configurations are tracked by both REs, and in the event of a failure, the backup takes control of the chassis. Clustering provides another level of security for your enterprise.

Conclusion

The security service found in Junos on the J-series and the SRX devices represents a significant increase in security, and the services capabilities in general for supported platforms. With Junos security services, users are no longer forced to compromise either services or routing when they opt for a single-box solution. Formerly, this required a multiple-chassis, best-of-breed approach, which added cost and complexity to the network.

In addition to the one-box benefits, that one box runs Junos software, albeit with security services enabled. This means that all the benefits and advantages of Junos are still available, and the majority of operational experience carries over directly, allowing you to immediately feel at home when using the security services.

Exam Topics

Currently, the Juniper Networks Certified Internet Expert (JNCIE-ER) examination is based on ASP service sets. This is subject to change within the next year. Candidates should consult the Juniper Networks website for up-to-date information on certification examination tracks and topics.

Chapter Review Questions

1. What is the default context of an SRX or J-series router?
   A. The default is the secure context.
   B. The default is the routing context.
   C. Both contexts are there by default; it depends on whether policies are configured.
   D. Both contexts are there by default; it depends on the host-inbound-traffic configuration.

2. What is true regarding zones?
   A. You are limited to no more than five.
   B. Each zone is restricted to a single interface.
   C. Policy is needed to communicate between zones, unless in router context.
   D. Policy is needed to communicate between zones.
3. What is the minimal security stanza to allow initial connectivity in a Junos firewall?
   A. A single zone, with all interfaces.
   B. A single zone, with all interfaces and a permit all policy.
   C. A zone per interface and a full mesh of policies.
   D. None of the above; no security stanza is necessary.
4. What is the name of the services interface on a Junos firewall?
   A. `sp-0/0/0`
   B. `st-0/0/0`
   C. `es-0/0/0`
   D. The zone-based nature means that a services interface is not required.
5. Does the following session entry, as taken from `PBR`, indicate that NAT has been performed?

```
Session ID: 1285, Policy name: self-traffic-policy/1, Timeout: 1784
  In: 172.16.1.2/59024 --> 172.16.1.1/179;tcp, If: .local..0
  Out: 172.16.1.1/179 --> 172.16.1.2/59024;tcp, If: ge-0/0/1.0
```

   A. No, NAT is not being performed.
   B. Yes, NAT is being performed.
   C. Only Source NAT is being performed.
   D. Only Destination NAT is being performed.
6. Which platform or platforms support Junos firewall functions?
   A. M7i
   B. MX240
   C. J-series
   D. SRX

Chapter Review Answers

1. Answer: C. The default operation is secure context.
2. Answer: D. Policy is always needed to permit traffic between zones.
3. Answer: B. The minimal security stanza is assigning all interfaces to a single zone and creating a policy that allows traffic from that zone to that zone.

4. Answer: D. The L3 services are no longer needed and have no interface support.
5. Answer: A. The use of 172.16.1.0/24 addressing indicates that no NAT has been performed.
6. Answer: C, D. ASIC-based platforms such as the M7i and MX240 do not support security services. The J-series and SRX platforms provide this support.

APPENDIX A

Junos Layer 3 Services

Service is a broad term that includes Layer 2 as well as Layer 3 functions. In Chapter 9, we looked at the Layer 2 services found in Junos. Layer 3 services have undergone a dramatic change since the first edition of this book. Layer 3 services—which include NAT, IDP, VPNs, and stateful policies—are now configured as part of the security stanza described in Chapter 12 of this book. The legacy Layer 3 services (prior to Junos 9.4) are covered here for completeness. Note that as of this writing, the Juniper Networks Certified Internet Expert (JNCIE-ER) examination is based on the legacy services, and so readers interested in passing the JNCIE-ER examination will need to be familiar with ASP-based service definitions described here.

As stated previously for Layer 2 services and repeated here for clarity, for the M-series routers, enabling these services will require an additional piece of hardware: a Physical Interface Card (PIC) for packet processing. A J-series or an MX series router supports most of the Layer 3 features in software, so no additional hardware is necessary.

Layer 3 Services

The Junos Layer 3 services include stateful firewall, NAT, IDS, and IPSec tunnels. We will cover the details of the services here and the configuration later in this appendix.

On the ASP or Multiservices-100 PIC, you must choose to enable *either* Layer 2 *or* Layer 3 services; the ASM on the M7i and the J-series router support *both* Layer 2 and Layer 3 concurrently.

Stateful Firewall

Usually when certain traffic needs to be blocked on a router, a simple stateless packet filter is applied to an interface. On a Juniper router, these are called *firewall filters* (other vendors call these *access lists*). Regardless of the name, all stateless filters function in the same manner—they look at a packet and operate on a series of match rules. If the packet matches a rule, it can be either accepted or discarded.

The important point about a packet filter is that it works on a packet-by-packet basis and does not associate a packet with a traffic flow or stream. In other words, it does not maintain any connection state. This type of filter will work in many situations when applications are using well-known port numbers or TCP applications, where the initiator is always in the same direction. Stateless packet filters become more difficult when the application uses random port numbers—TCP initiators are not always the same—or when UDP input and output flows need to be associated with each other. For example, if a Domain Name System (DNS) server was located outside your network, you could easily write a packet filter that allows outbound access to UDP port 53, but you would need to write a rule for the inbound packet as well. The source port would be port 53, but the destination port could be any port from 1024 to 65534, depending on which random port the host chose. Allowing this large of a UDP port opens up a large hole in your network.

A stateful firewall will track *flows* of traffic for a given application such as DNS, which will provide for much stronger security. This means that if a packet hits the firewall rule and is accepted based on the match conditions, the system will calculate the return packet, so no reverse rule will have to be created. A flow is usually defined by parameters such as source and destination addresses, source and destination port numbers, and protocol values. A bidirectional flow between the source and destination devices is often called a *session* or a *conversation*. Once a session or conversation is created, it is stored in memory, so the firewall rules do not need to process any additional packets that are part of that flow. These conversations will be stored until a period of inactivity occurs, which is 30 seconds by default for most protocols. You can modify this globally under the service interface:

```
lab@hops# set interfaces sp-0/0/0 services-options inactivity-timeout ?
Possible completions:
  <inactivity-timeout>  Inactivity timeout period for established sessions
```

A flow is removed from the table under the following conditions:

- If a TCP RESET or FIN packet is received. The flow is marked for deletion and is removed in approximately five seconds.
- If the TCP flow appears to be idle (no traffic). In this case, the router implements a TCP tickle by sending an ACK message with the last seen sequence number, minus one numeral, to the end host. This verifies whether the ports are open. If no response is received, the flow is marked for deletion in approximately five seconds.
- If the forward flow of the UDP conversation reaches the inactivity timeout period. Since the reverse flow will be created based on the forward flow, this flow will not be tracked for inactivity.

The stateful firewall will also add a layer of protection by checking to make sure there are no strange protocol anomalies that could indicate a denial of service (DoS) attack. Some examples of protocol anomalies that are checked include the following:

- The Time to Live (TTL) in the IP packet equals 0.
- The source IP address equals the destination IP address.
- An IP fragment is missed.
- The TCP or UDP port is set to 0.
- TCP flags are set to an invalid combination.
- A SYN packet is received without a SYN-ACK response.
- The first flow packet is not a SYN packet.
- ICMP unreachable errors occur for SYN or UDP packets.

This is a small list of the possible anomalies; please consult the Juniper Technical Documentation for a more complete list.

Application Layer Gateways

Most of the time, the stateful firewall will easily be able to predict the packets that will be required for the return flow of a conversation by simply reversing the source and destination port numbers, addresses, and so forth. However, some applications, such as FTP, H.323, RTSP used by RealAudio, and SIP, are more difficult to predict because the application may initiate separate connections for data and control flows or may generate new protocol flows based on an open connection. In this case, special care must be taken to analyze the packets and allow the new connections to be established. Each application may have a unique set of parameters that must be examined, which are implemented as Application Layer Gateways (ALGs).

The classic example of why an ALG is needed is when you look at an application such as an active outgoing FTP, which uses both a control and a data channel. First, the TCP three-way handshake is established between the client (84.10.113.0) and the server (84.10.113.1) using a destination port of 21:

```
02:21:00.500569  In IP 84.10.113.0.4290 > 84.10.113.1.21: Syn
02:21:00.500627 Out IP 84.10.113.1.21 > 84.10.113.0.4290: Syn Ack
02:21:00.510683  In IP 84.10.113.0.4290 > 84.10.113.1.21: .   Ack
```

Then the server initiates a new connection for the data transfer using a new source port of 20 and a destination port that the client gives to the server in the initial connection using a `PORT` command (56958, in this case):

```
02:26:28.024058 Out IP 84.10.113.1.20 > 84.10.113.0.56958: Syn
02:26:28.032298  In IP 84.10.113.0.56958 > 84.10.113.1.20: Syn Ack
02:26:28.032362 Out IP 84.10.113.1.20 > 84.10.113.0.56958: . Ack
```

So, the problem with the active mode FTP application and standard firewall rules is that the connections are initiated by both the server and the client, and the connection initiated by the server to the client is using an unpredictable port number.

The ALG solves this problem by looking deep into the packets during the initial connection phase for the `PORT` command, indicating which port number the client will be expecting from the server during the data phase and allowing the firewall to create a predictable pinhole for the server-to-client connection.

If passive FTP is used, all connections are initiated from the client to the server, but the ALG must still monitor the `PORT` command from the server to open the data connection.

Another example in which ALG is needed is when you're using H.323, the umbrella specification for a family of protocols for transporting voice and video over data networks. H.323 involves protocols that open control and data channels similar to our FTP example. In a common setup and data flow, these steps occur:

1. First, an H.225 connection is created for call signaling, the media (audio and video), the stream packetization, the media stream synchronization, and the control message formats.
2. During the H.225 connection, information is exchanged to also establish an H.245 connection.
3. An H.245 connection is established to convey control information for the media flow, such as encryption and flow control as well as port information for RTP/RTCP flows.
4. RTP/RTCP data traffic flows begin.

The ALG that is used for H.323 is more complex than in the FTP example, but the general idea of watching one conversation to open more flows is the same. The ALG watches the H.225 connection for information to open the H.245 connection and then watches this connection to open the media connections.

Since these ALGs can be very complex, most of them are already created in the Juniper Networks router for you, although you can create custom ALGs. You can view all the Juniper-defined ALGs by issuing the `show groups junos-defaults applications` command from configuration mode. All default system applications will begin with the `junos` keyword.

Network Address Translation

NAT is simply the changing of the IP address (source, destination, or both) of the packet as it traverses the router. These translations are stored in a table to allow for traffic flows from the source to the destination systems. Additionally, port numbers could also be translated (often referred to as Network Address Port Translation [NAPT] or Port Address Translation [PAT]). Traditionally, NAT was used to hide private addresses behind a public network or to try to conserve address space by mapping multiple port numbers to a single IP address. When NAT is configured, you must answer the following questions:

- Which IP address is going to be translated: the source IP (source-NAT), the destination IP (destination-NAT), or both (bidirectional NAT)?
- Does port translation need to occur?
- Does the mapping need to be the same (static) or can a pool of addresses and ports be used (dynamic)?

Next, you must examine the type of NAT that must be configured. The NAT types available on a Juniper router include the following:

Static source NAT
: Maps a pool of private IP addresses to a pool of public addresses on a one-to-one basis. This means traffic from a private address, such as 192.168.2.1, will always be mapped to the same public address, such as 207.12.18.2.

Dynamic source NAT
: Maps a pool of private IP addresses to a pool of public addresses. This mapping is dynamic, so 192.168.2.1 could be translated to the configured public address pool.

Source NAT with port translation
: Maps a pool of private IP addresses to a single address or pool of public addresses, while also translating the port numbers. This allows for one-to-many NAT, when many private IP addresses are translated to a single public address.

Destination NAT
: Behaves the same as source NAT, except it operates on the incoming flow of the destination address. Destination NAT will translate an incoming public address to one or many private addresses. One use of this is to allow the Internet to use a public address to contact a server on the internal network that is configured with a private IP address.

Bidirectional NAT
: A combination of a source NAT and destination NAT in which Host A can initiate a session with Host B and Host B can also initiate a session with Host A. This is common when an email server is onsite.

Twice NAT
: Defined in RFC 2663 and similar to bidirectional NAT. The major difference is that in twice NAT, the source and destination addresses are translated within the same flow, whereas bidirectional NAT would use different flows.

You can configure NAT on a Juniper Networks router as a standalone service or combine it with another service, such as stateful firewall.

Intrusion Detection Services

Intrusion detection monitors traffic flows and looks for hostile patterns. If such a pattern exists, the event can be logged. Intrusion detection and prevention (IDP) takes this one step further by stopping an attack once a hostile pattern is recognized. The Juniper Networks router is limited in its IDP implementation, as it does not match on any higher-layer signature attacks. Essentially, the IDP implantation can aid in protecting your network from attacks such as the following:

Port scanning
: When a hostile machine probes the network for open ports to attack.

SYN flood attacks
: When a high number of SYN packets are received in an attempt to flood the network.

IP fragmentation attacks
: Protects against packets with the `more fragments` flag set, such as attacks like Teardrop and Boink. Teardrop attacks exploit the reassembly of fragmented IP packets by offsetting the options in the IP header. When the sum of the offset and size of one fragmented packet differ from that of the next fragmented packet, the packets overlap, and the server attempting to reassemble the packet can crash.

ICMP floods
: When ICMP echo requests overload its victim with so many requests that all its resources respond until it can no longer process valid network traffic.

When any of these attacks occur, events are logged and are sent to a collector for analysis, or in the case of flood attacks, are rate-limited. You also can prevent SYN floods by configuring SYN cookie protection that will cause the router to operate as a *SYN proxy*.

IPSec VPN

When securing data over a public network, often a tunnel is configured between the two networks. A tunnel simply encapsulates your data into another packet or frame to transport it across the public network. For instance, you can create a tunnel to connect Remote Office A to Corporate Office B over the public Internet, as shown in Figure A-1, to create a virtual private network (VPN).

> The purpose of this book is not to teach IPSec theory; a number of books do that well, such as *IPSec: The New Security Standard for the Internet, Intranets, and Virtual Private Networks* (Prentice Hall).

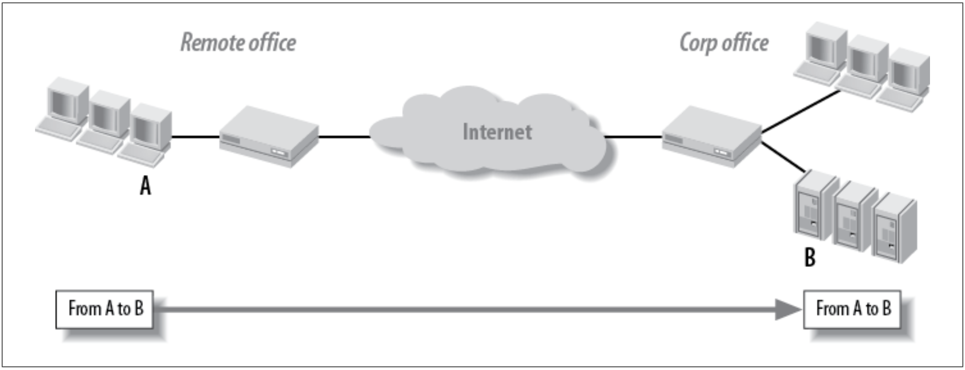


Figure A-1. Connecting a remote office to the corporate office

You can use many tunneling protocols for this connection, but one of the most widely deployed protocols for transporting IP traffic is IPSec. IPSec can provide the following security functions:

Source authentication
: Ensures that the data is from the expected sender. This is accomplished by the ingress router of the IPSec tunnel, creating a one-way hash value of certain parameters of the packet as well as a password (preshared key) that is known by both endpoints. It will insert this hash value into the packet so that when the receiving endpoint examines the packet, it can compare this value with the hash that will be locally computed. If they are the same, the authentication passes; if they are different, the authentication fails. Common algorithms to accomplish this are Message Digest 5 (MD5) and the Secure Hash Algorithm (SHA-1).

> A *hash function* is a predictable mathematical calculation that takes some variable-size input and produces a fixed-size string called a *hash*. A key attribute of a hash is that it is a one-way operation—so, the hash value can be created based on the input but the input cannot be recreated based on the hash value. Hash functions are used in both authentication and data integrity.

Data integrity
: Ensures that the data was not altered during packet transmission. A hash value is computed and is placed into the packet based on packet fields. The receiving router will compute a hash based on the same fields of the packet and then compare the computed hash value with the received hash value. If they are not equivalent, the data was altered and the packet will be dropped. The hash algorithm that is used is normally MD5 or SHA-1.

Confidentiality
: Ensures that the data cannot be read over the public infrastructure. IPSec provides confidentiality by encrypting the traffic using the Data Encryption Standard (DES), Triple DES (3DES), or Advanced Encryption Standard (AES) algorithm.

Replay protection
: Even though data can be encrypted, a hostile device can intercept a packet, re-create it, and send a flood of that packet to the endpoint to try to create a DoS attack. To protect against this, sequence numbers are verified to avoid packet duplication.

When an IPSec tunnel is made, the tunnel endpoints create a security association (SA) with each VPN. An SA is a list of the protocols, algorithms, and protected networks upon which both endpoints have agreed. These SAs can be created manually on each side, or dynamically with the use of the Internet Key Exchange (IKE) protocol. IKE consists of two phases: Phase 1 establishes the protocols and shared secrets needed to create a secure channel; and Phase 2 uses this secure channel to exchange the protocols, algorithms, and other parameters that will be used for the data exchange, thus creating the SAs. When Phase 2 has completed, data can flow securely between the two endpoints, as shown in Figure A-2.

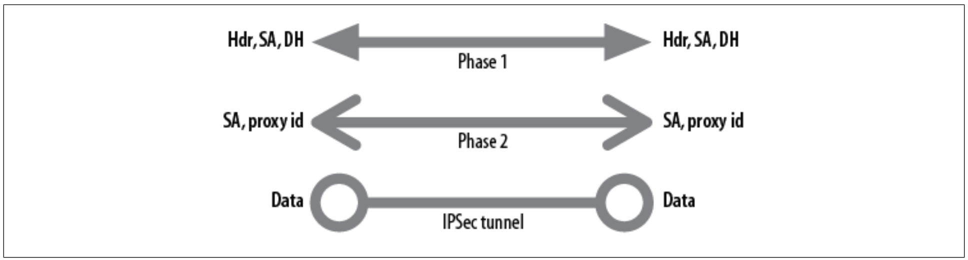


Figure A-2. IPSec VPN dynamic tunnel establishment

Layer 3 Services Summary

This section examined many Layer 3 services, including NAT, stateful firewall, IDP, and IPSec-based VPNs. In the next section, we will put this theory into practice as we configure and operationally verify various network layer services.

Layer 3 Services Configuration

The first step when configuring Layer 3 services on your router is to enable the hardware for those services. If the ASP or Multiservices PIC is used, you must specify the layer of service as either Layer 2 or Layer 3:

```
lab@sake# set chassis fpc 1 pic 2 adaptive-services service-package ?
Possible completions:
  layer-2               Layer 2 service package
  layer-3               Layer 3 service package
[edit]

lab@sake# show chassis hardware
Hardware inventory:
Item             Version Part number Serial number Description
Chassis                              A1609         M7i
Midplane          REV 04 710-008761  CR6773        M7i Midplane
Power Supply 1 Rev 06 740-008537  6039089       AC Power Supply
Routing Engine REV 01 740-011202  1000618737    RE-850
CFEB              REV 08 750-010464  CR5380        Internet Processor II
FPC 0                                              E-FPC
  PIC 0           REV 11 750-002992  CT2202        4x F/E, 100 BASE-TX
  PIC 2           REV 08 750-005724  CR1650        2x OC-3 ATM-II IQ, MM
FPC 1                                              E-FPC
  PIC 2           REV 07 750-009487  CP5197        ASP - Integrated
  PIC 3           REV 10 750-009098  CR4858        2x F/E, 100 BASE-TX
```

The ASM, MX series, and J-series routers do not contain this limitation and can support *both* types of services concurrently. The main building block when configuring Junos services is called a *service set*, which is a list of service interfaces, service types, and service rules applied to either an interface or a routing next hop. A service set can contain one type of Layer 3 service or a grouping of services such as NAT, IDS, and stateful firewall. If an IPSec VPN is required, you must place it in its own unique service set.

To match which packet will be processed by each service set, you must write a set of rules with a match condition and an action. These rules have a similar format to Junos policies and stateless firewall filter rules, containing a `from` statement for the match portion and a `then` statement for the action. But a major difference is that service rules are always processed in a stateful manner, so the match clauses do not need to account for return traffic. The match clauses will have a variety of options depending on the service configured, and the actions will define which service to apply. You also can combine the rules for each service to form a rule set, as shown in Figure A-3.

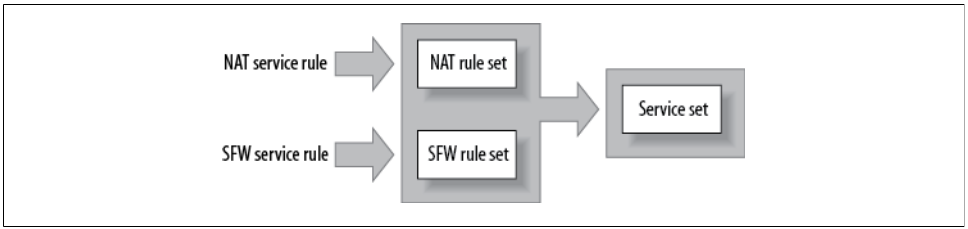


Figure A-3. CLI rule, rule set, and service set relationship

When you create your service set, you'll need to decide whether it should be applied as an interface or a next hop. An interface-style service set is applied directly to the interface affecting traffic as it leaves and enters the interface.

An interface-style service set tracks session on a per-service-set basis. This means that the same service set could be applied to multiple physical interfaces to design around asymmetrical traffic flows.

A next hop–style service set makes use of two logical service interfaces, called the *inside* and *outside* interfaces. Traffic is mapped to these interfaces as a result of a routing next hop lookup. The traffic can enter or exit *either* the inside or the outside interface depending on the configuration, which depends primarily on the routing configuration and stateful-firewall rules.

Both types of service styles use the service interface, named `sp-`, in the definition of the service set. This interface is the software interface that the router will send traffic to if a Layer 3 service is required. The interface-style service set requires a single logical unit to be configured with IPv4 support enabled:

```
lab@Porter# set interfaces sp-0/0/0 unit 0 family inet

lab@Porter# show interfaces
sp-0/0/0 {
    unit 0 {
        family inet;
```

When configuring the `sp-` interface, the system generally reserves unit 0 for service logging and other communication from the service PIC; however, you can use it for an interface-style service set not used in a virtual router. Next hop service sets cannot use unit 0.

The next hop service set requires the service interface to be logically divided into an inside and outside interface:

```
[edit]
lab@Porter# set interfaces sp-0/0/0 unit 1 service-domain inside family inet
[edit]
lab@Porter# set interfaces sp-0/0/0 unit 2 service-domain outside family inet

[edit]
lab@Porter# show interfaces sp-0/0/0
unit 0 {
    family inet;
}
unit 1 {
    family inet;
    service-domain inside;
}
unit 2 {
    family inet;
    service-domain outside;
}
```

After creating the service interfaces, you'll need to create the service rules and the service sets. When creating the service rules, one item you must configure is a direction of either *input* or *output*, as shown in Figure A-4. The direction that is recorded for a packet must match for the service rule to match. This direction is straightforward for an interface-style service set, as input is for incoming traffic to the physical interface, and output is for traffic leaving the physical interface.

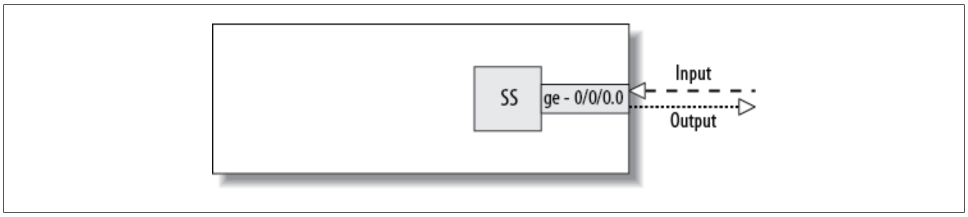


Figure A-4. Directions for interface-style service sets

But when you look at a next hop–style service set, the direction is a bit more complex because now the next hop could point to two possible logical interfaces. If the next hop points to the inside interface, the direction is *input*, and if the next hop points to the outside interface, the direction is *output*. The direction for next hop–style service sets is often misconfigured, which causes traffic to be serviced incorrectly. Figure A-5 shows the proper directions that you should use when creating service rules.

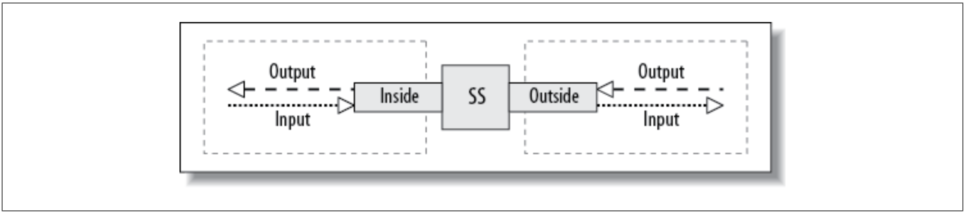


Figure A-5. Directions for next hop–style service sets

When configuring service rules for next hop–style service sets, you should consider traffic flow from the perspective of the inside interface. Traffic that the router routes to the inside interface is considered input traffic on the inside interface and is considered input traffic by the router when it evaluates service rules. Traffic that the router receives on the outside interface, processes, and then transmits out the inside interface is considered output traffic on the outside interface and is considered output traffic by the router when it evaluates service rules. In general, it may be much less confusing to point traffic to the inside interface when possible, as the directions seem to be as expected, while the outside interface appears to be opposite from what is expected. Although traffic mapping to an inside interface may make more sense in the human mind, the router makes no logical distinction, so mapping to either the inside or the outside configuration will work.

Since next hop–style service sets are a little more complex, it seems as though interface-style service sets would be preferred. Each service set, however, has its own advantages and disadvantages, as detailed in Table A-1.

For instance, an interface-style service set has the following limitations:

- It cannot support multicast traffic matched through the service set (including IPSec tunnels).
- It cannot have overlapping address spaces (such as RFC 1918) that need to be NATed.
- It cannot run routing protocols over the service sets, such as IPSec tunnels.
- Locally generated traffic will not match the rules.

So, to solve any of those four general limitations, you *must* use a next hop service set.

Interface-style service sets do have their place, though; they are much easier to configure for simple tasks, and they are easier to apply to multiple interfaces. If the same service needs to be applied to multiple interfaces with separate route tables for individual customers, a next hop service set would require multiple service sets, whereas an interface-style service set might require only a single service set. Also, an interface-style service set allows for the use of an external interface address for certain NAT circumstances that a next hop service set cannot accomplish. Therefore, you should choose a service set based on which features need to be supported. Table A-1 can assist you as a general guideline for choosing your service style.

You will have to apply the service set for it to take effect. You can apply it directly to the interface unit (interface style) or reference the service interface (next hop).

First, here is an example of a service set applied directly to interface `t1-2/0/2`:

```
lab@Porter# show interfaces t1-2/0/2
description Porter-to-Bock;
unit 0 {
    family inet {
        service {
            input {
                service-set test-rule;
            }
            output {
                service-set test-rule;
            }
        }
        address 10.10.10.2/30;
    }
}
```

Table A-1. *Summary of service-style feature support*

Service style	General configuration complexity	Multicast support	Routing protocols over IPSec	Overlapping NAT addresses
Interface	Easy	No	No	No
Next hop	Hard	Yes	Yes	Yes

Service style	PAT with external interface in the NAT pool	Treat IPSec tunnels as a link	Number of security zones supported
Interface	Yes	No	One
Next hop	No	Yes	Many

The service set `test-rule` is applied to the interface at the logical unit level and is applied for `family inet` (IPv4) traffic. The strange piece of this configuration is the fact that the service set must be applied as *both* an input and an output service, and it *must* be the same service set. This means direction is never inferred when applying a service set to an interface. Recall that the direction of a rule is decided in the service rule and not in the direction in which the service set is applied to the interface!

Applying the service set to both the input and the output of an interface has no real purpose in the current implementation; it was created as part of the original specification outline. There was a thought that asymmetrical traffic with different service sets would be supported, but it was decided later not to implement that function in Junos.

If a next hop service type is used, simply configure the router to forward packets to either the inside or the outside service interface. This is usually done by creating a static route that points to the service interface, which in turn creates another route table to point traffic to the service interface or runs a routing protocol over the service interface. This example sends all 5.5.0/19 traffic to the `sp-0/0/0.1` (inside) interface:

```
[edit]
lab@Porter# show routing-options
static {
    route 5.5.0.0/19 next-hop sp-0/0/0.1;
}
```

This verifies that the route is active:

```
[edit]
lab@Porter# run show route protocol static

inet.0: 10 destinations, 10 routes (10 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

5.5.0.0/19         *[Static/5] 00:00:08
                    > via sp-0/0/0.1
```

Logging and Tracing

Since you can configure system logging and tracing in a variety of places in the configuration file, it can be confusing which statement is actually doing the logging. The rule in Junos is that the more specific configuration will always override the more global configuration. The levels of logging possible, in order of global to specific, are as follows:

Interface logging

```
lab@PBR# set sp-0/0/0 services-options syslog host 1.1.1.1 services ?
Possible completions:
  <[Enter]>    Execute this command
  alert              Conditions that should be corrected immediately
  any                All levels
  critical           Critical conditions
  emergency          Panic conditions
  error              Error conditions
  info               Informational messages
  none               No messages
  notice             Conditions that should be handled specially
  warning            Warning messages
  |                  Pipe through a command
```

Service set logging

```
lab@PBR# set services service-set telnet-set syslog host 1.1.1.1 services ?
Possible completions:
  <[Enter]>    Execute this command
  alert              Conditions that should be corrected immediately
  any                All levels
  critical           Critical conditions
  emergency          Panic conditions
  error              Error conditions
  info               Informational messages
  none               No messages
  notice             Conditions that should be handled specially
  warning            Warning messages
  |                  Pipe through a command
```

Feature rule (stateful firewall, IPSec, etc.) logging

```
set stateful-firewall rule restricted-telnet term 1 then syslog
```

So, if logging was enabled at the service interface level and three service sets were configured, all three service sets would inherit the service-level logging settings. If a single service set also enabled logging, those settings would override the service-level logging for that service set. The remaining service sets would inherit the service interface logging settings.

There are also different types of logging: standard syslog and traceoptions. Syslog will send a system log message to a syslog server or the local router, and traceoptions will only send information to the local router. When you are viewing services, traceoptions usually gives you a view of the actual software operations on the Routing Engine (RE) and not the service PIC itself.

You can send syslog information to a remote syslog server by indicating a host, or send it to the local router by specifying the keyword `local`:

```
sp-0/0/0 {
    services-options {
        syslog {
            host local {
                services any;
            }
        }
    }
```

If you specify that the syslog messages should be sent to the local router, you can send the messages to the default system log of *messages* or to another designated file. Also, for those messages to actually appear, you will have to configure the router to accept messages for the `local2` facility. To place these syslog entries in the *messages* file, you can use this configuration:

```
[edit]
lab@PBR# set system syslog file messages local2 any
```

An example of the types of syslog messages is messages that show which rules have been matched and created. Here, router PBR is monitoring the *messages* file in real time, and you can see that a stateful-firewall rule was matched and a flow was created based on that match:

```
[edit]
lab@PBR# run monitor start messages

*** messages ***
Aug 10 06:45:50  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_SFW
_RULE_ACCEPT: proto 6 (TCP) application: any, ge-0/0/0.413:64.8.12.5:
10.10.12.3:23, Match SFW accept rule-set: , rule: restricted-telnet,
term: 1
Aug 10 06:45:50  (FPC Slot 0, PIC Slot 0) {telnet-set}[FWNAT]: ASP_SFW_CREATE_ACCEPT_
FLOW: proto 6 (TCP) application: any, ge-0/0/0.413:64.8.12.5:3225 -> 10.10.12.3:23,
creating forward or watch
flow
```

If you need to examine the service's software operation, you can configure traceoptions at the PIC level. If no file is specified, the information will be placed into a file called *spd*:

```
lab@PBR# set services adaptive-services-pics traceoptions flag ?
Possible completions:
  all                  Trace everything
  configuration        Trace configuration events
  kernel-object        Trace kernel object management
  routing-protocol     Trace routing protocol events
  routing-socket       Trace routing socket events
  snmp                 Trace SNMP operations
```

Here is an example of the types of messages you would see in *spd*. In this code snippet, software sockets have been created and resources have been assigned when services were configured:

```
lab@PBR# run show log spd
Aug 10 07:13:27 spd process starting, pid 12555
Aug 10 07:13:27 rpd session connected
Aug 10 07:13:27 registered async opaque handler for traps
Aug 10 07:13:27 Added sp-0/0/0 snmpindex 21 fpc_slot 0 pic_slot 0 to database
Aug 10 07:13:27 Loading initial state from kernel...
Aug 10 07:13:27 Processed ASP_CFG_GLOBAL_OPTIONS config object
Aug 10 07:13:27 Adding blob to set: id = 1, type = 16, size = 92, pic = sp-0/0/0 (0)
Aug 10 07:13:27 Blob id = 1, type = 16, size = 92 is new, adding
Aug 10 07:13:27 Imported config object (type 16, id 1)
Aug 10 07:13:27 Adding blob to set: id = 1, type = 16, size = 92, pic = sp-0/0/0 (0)
Aug 10 07:13:27 State initialization from kernel complete
Aug 10 07:13:27 ------ Finished with RTSOCK initialization ------
Aug 10 07:13:28 get_pic_index sp-0/0/0.1 pic index 0
Aug 10 07:13:28 get_pic_index sp-0/0/0.1 pic index 0
Aug 10 07:13:28 Adding blob to set: id = 2, type = 12, size = 912, pic = sp-0/0/0 (0)
Aug 10 07:13:28 get_pic_index sp-0/0/0 pic index 0
Aug 10 07:13:28 Adding blob to set: id = 1, type = 16, size = 92, pic = sp-0/0/0 (0)
Aug 10 07:13:28 Blob id = 1 is not changed, skipping
Aug 10 07:13:28 Blob id = 2, type = 12, size = 912 is new, adding
Aug 10 07:13:28 Added service set telnet-set (id 2, pic sp-0/0/0 (0))
Aug 10 07:13:28 Adding blob to set: id = 2, type = 12, size = 912, pic = sp-0/0/0 (0)
Aug 10 07:13:28 rpd session established
```

Layer 3 Services Configuration Summary

This section described the various Layer 3 service offerings as well as the CLI configuration steps that were needed. We also discussed the option of interface-style or next hop–style service sets. We will cover examples of each of these services in the next sections.

IPSec VPNs

IPSec VPNs tunnel IP traffic across an IP network to provide security features such as data privacy and integrity. When building an IPSec tunnel, you must decide on a few parameters:

- Protocol (Encapsulating Security Payload [ESP], authentication header [AH], or Bundle)
- Encryption algorithm (Advanced Encryption Standard [AES], Data Encryption Standard [DES], Triple DES [3DES], or none)
- Authentication algorithm (Message Digest 5 [MD5], Secure Hash Algorithm [SHA-1])

- Perfect forward secrecy (on/off)
- Anti-replay (on/off)

Together, these parameters form a *proposal*. The proposal must be equivalent on each side of the tunnel for the tunnel to become established. These proposals can be statically configured or dynamically negotiated using the Internet Key Exchange (IKE) protocol. Static proposals are rarely used, as they are cumbersome to manage, prone to error, and difficult to change on the fly. IKE uses a method of key exchanges to exchange parameters in a secure manner over two phases. Phase 1 establishes the parameters needed to exchange information to form a secure IPSec tunnel. Phase 2 establishes the actual security parameters for that IPSec tunnel. When viewing commands on the router, Phase 1 is seen as an IKE security association, and Phase 2 is seen as an IPSec security association.

Since multiple tunnels can be established between two peers, there has to be some way to identify which packets belong to each tunnel. To do this, a database is created with entries called security associations (SAs) for each tunnel. An SA identifies each tunnel by the following parameters:

- Destination IP address
- Security protocol and parameters (protocol, encryption, and authentication)
- Security Parameter Index (SPI)
- Secret keys

Example IPSec Tunnel Configuration

When configuring an IPSec tunnel, as with all Layer 3 services, you will need a service set. These service sets contain the rules for matching traffic that should transit the IPSec tunnel. The rules can include policies that link the various proposals that the tunnel will use (see Figure A-6). There can be separate policies and proposals for the Phase 1 (IKE) and Phase 2 (IPSec) SAs.

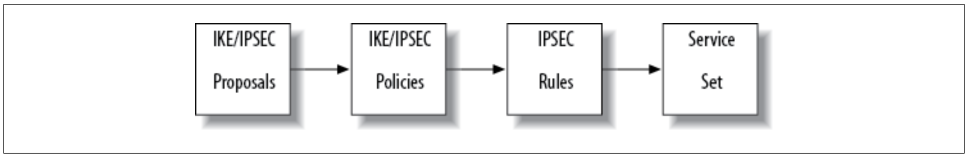


Figure A-6. IPSec rule, policy, and proposal relationships

`PBR` is going to form an IPSec tunnel with the extranet `Cans` for traffic to a 128.3.3/24 address block to secure traffic (see Figure A-7). The remote endpoint of the tunnel is 128.3.3.4 and the local address on `PBR` is 172.16.1.2. `PBR` is learning the 123.3.3/24 subnet via BGP with `Wheat`.

The tunnel will be set up with the default parameters shown in Table A-2.

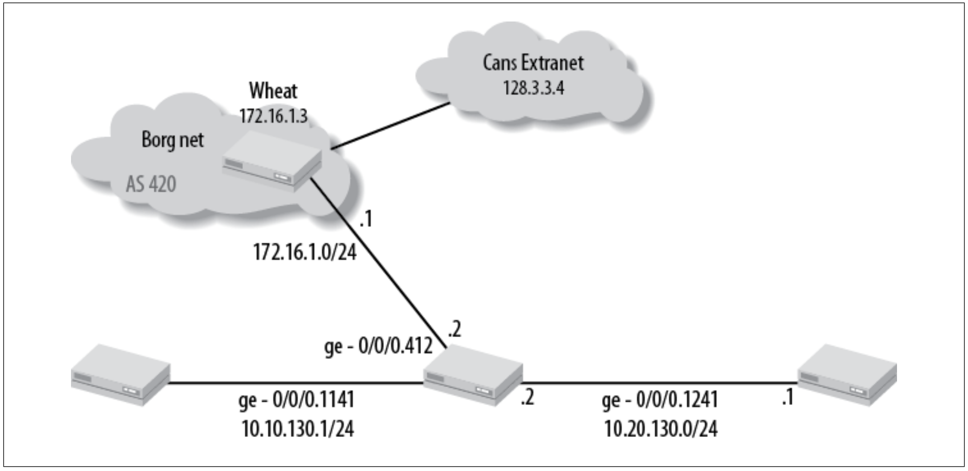


Figure A-7. Sample topology

Table A-2. Default parameters for tunnel

	IKE	IPSec
Mode	Main	N/A
Protocol	N/A	ESP
Encryption	3DES-CBC (cipher block chaining)	3DES-CBC
Authentication	SHA-1	Hashed Message Authentication Code (HMAC)-SHA-1-96
Lifetime	3,600 seconds	28,800 seconds
Additional options	N/A	Antireplay, no Perfect Forward Secrecy (PFS) protocol

Interface-style service set

First we will implement the tunnel as an interface-style service set and then as a next hop service set. Begin by creating the service interface to use for the interface-style service set:

```
[edit interfaces]
lab@PBR# set sp-0/0/0 unit 0 family inet
```

Now create the rule to match traffic sent to the tunnel and, minimally, an IKE policy to be applied. An IKE policy referencing either a preshared key or a certificate is required, and IPSec policies are optional. With this configuration, the tunnel will inherit the default parameters listed in Table A-2:

```
[edit services ipsec-vpn]

ike {
        policy min-policy {
            pre-shared-key ascii-text "$9$BSJ1RSdVYJUH8XGDHkPfIEh";
## SECRET-DATA
```

```
        }
    }
```

Create the IPSec VPN rule to match on the required traffic and send it through the tunnel toward the endpoint. The IKE policy will also need to be applied, along with a direction in which to *encrypt* traffic:

```
lab@PBRt# show services
ipsec-vpn {
   rule secure-extranet {
      term 1 {
        from {
           destination-address {
             128.3.3.0/24;
           }
        }
        then {
          remote-gateway 128.3.3.4;
          dynamic {
            ike-policy min-policy;
         }
      }
   }
   match-direction output;
}
   }
```

The router automatically created bidirectional SAs, so when specifying traffic to be secured in the outbound direction, the router automatically secures the inbound direction. This means that when specifying an interface-style service set, the output direction is generally used, whereas a next hop–style service set will use the input direction.

Next, we need to create the service set that maps the IPSec rule and the service interface. Additionally, we need to configure the local gateway for the IPSec tunnel. This will be the address used to source all IPSec packets as well as the address to which the remote tunnels will connect. You can have only a single gateway address in a service set, but you can configure multiple remote gateways in the IPSec rules:

```
[edit services]
lab@PBR# show service-set basic-vpn
interface-service {
    service-interface sp-0/0/0.0;
}
ipsec-vpn-options {
    local-gateway 172.16.1.2;
}
ipsec-vpn-rules secure-extranet;
```

Apply the service set to the tunnel's outbound interface:

```
lab@PBR# top show interfaces ge-0/0/0 unit 412
description PBR-to-Wheat;
```

```
    vlan-id 412;
    family inet {
        service {
            input {
                service-set basic-vpn;
            }
            output {
                service-set basic-vpn;
            }
        }
        address 172.16.1.2/24;
```

After committing the configuration, view the tunnel status with the `show service ipsec` command. Here the tunnel appears to be down, as no Phase 2 SAs appear:

```
lab@PBR# run show services ipsec-vpn ipsec security-associations
Service set: basic-vpn
  Rule: secure-extranet, Term: 1, Tunnel index: 1
  Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
  Tunnel MTU: 1500

  --- No IPSec SA information available ---
```

Issuing a ping to the remote gateway address of 128.3.3.4 on `PBR` indicates the problem:

```
lab@PBR# ping 128.3.3.4
PING 128.3.3.4 (128.3.3.4): 56 data bytes
ping: sendto: No route to host
ping: sendto: No route to host
ping: sendto: No route to host
ping: sendto: No route to host
^C
--- 128.3.3.4 ping statistics ---
4 packets transmitted, 0 packets received, 100% packet loss
n
```

Recall that the 128.3.3/24 network was learned via BGP. When viewing the BGP neighbor status toward `Wheat`, the session appears to be down, as seen by the connect state:

```
lab@PBR# run show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table   Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0          0          0          0        0          0        0
Peer           AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
172.16.1.1    420     198       184     0      7        6:30 Connect
```

The BGP session is down because the service set is applied to the session's interface. Remember that once a service set is applied to an interface, any traffic that does not match the term is serviced by default. To avoid this problem, you should apply a service filter to skip the procession of BGP traffic. The default action of a service filter is `skip`, so make sure other traffic is serviced accordingly:

```
[edit firewall]
lab@PBR# show
family inet {
    service-filter allow-bgp {
        term 1 {
            from {
                protocol tcp;
                port bgp;
            }
            then skip;
        }
    }
        term 2 {
            then service;
        }

}
```

Apply the service filter to the interface in both directions:

```
    lab@PBR# top show interfaces ge-0/0/0 unit 412
    description PBR-to-Wheat;
    vlan-id 412;
    family inet {
        service {
            input {
                service-set basic-vpn service-filter allow-bgp;
            }
            output {
                service-set basic-vpn service-filter allow-bgp;
            }
        }
        address 172.16.1.2/24;
```

After the service filter has been applied, the BGP session and the IPSec tunnel will become established. Verify the tunnel using the `show services ipsec` command. First, verify Phase 1, ensuring that the state is matured:

```
[edit firewall family inet service-filter allow-bgp]
lab@PBR# run show services ipsec-vpn ike security-associations
Remote Address  State         Initiator cookie  Responder cookie
Exchange type
128.3.3.4       Matured       773036d8a2d22e7b  ef23082150245a03
Main
```

Often, an operator will view the IKE SA, and when nothing appears, the operator will assume that the IPSec tunnel is down. This is not always the case, as IKE associations appear only on an "as needed" basis. So, if the IPSec SA has been established, the IKE SA may time out. Using default parameters, the lifetime of an IKE SA is 3,600 seconds and the lifetime of IPSec is 28,800 seconds, which means that a stable network may not have an active IKE SA for up to 7 hours! Make sure that if any changes occur that could prevent two-way IKE communication between the remote peers, the IPSec SA is cleared to force a renegotiation of the IKE SA. Otherwise, a filter-blocking IKE message may not been seen for several hours before the IPSec SA reaches its lifetime.

Now verify that Phase 2 has an inbound and outbound SA for bidirectional traffic flows:

```
[edit firewall family inet service-filter allow-bgp]
lab@PBR# run show services ipsec-vpn ipsec security-associations
Service set: basic-vpn

  Rule: secure-extranet, Term: 1, Tunnel index: 1
  Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
  Tunnel MTU: 1500
    Direction SPI         AUX-SPI     Mode       Type     Protocol
    inbound   2579118494  0           tunnel     dynamic  ESP
    outbound  247425684   0           tunnel     dynamic  ESP
```

By default, the establishment of an IPSec tunnel is data-driven. This means that the tunnel is not established until a packet matches a rule that requires the tunnel. If you want to change this behavior, use the `establish-tunnels immediately` command.

When IPSec is deployed on the router, the router must know how to direct traffic to the service Physical Interface Card (PIC) or service module to authenticate, de-encrypt, and de-encapsulate the packet. The router accomplishes this by creating forwarding table entries based on the source IP address, destination IP address, and protocol tuple. These entries will be seen as /72s in the forwarding table with a next hop of `service`:

```
[edit firewall family inet service-filter allow-bgp]
lab@PBR# run show route forwarding-table | find /72
172.16.1.2.128.3.3.4.50/72
                   user     0              service   324     3
172.16.1.2.128.3.3.4.51/72
                   user  0              service   324   3
172.16.1.3/32      user  0 172.16.1.1    ucst    332    5 ge-0/0/0.412
172.16.1.255/32    dest  0 172.16.1.255  bcst    320    1 ge-0/0/0.412
224.0.0.0/4        perm  1               mdsc     13    1
224.0.0.1/32       perm  0 224.0.0.1     mcst      9    3
224.0.0.5/32       user  1 224.0.0.5     mcst      9    3
255.255.255.255/32 perm  0               bcst     10    1

Routing table: _ _juniper_private1_ _.inet
Internet:
Destination        Type RtRef Next hop      Type Index NhRef Netif
default            perm     0               rjct    62     1
10.0.0.1/32        intf     1 10.0.0.1      locl   321     2
10.0.0.16/32       intf     0 10.0.0.16     locl   322     1
224.0.0.0/4        perm     0               mdsc    61     1
224.0.0.1/32       perm     0 224.0.0.1     mcst    57     1
255.255.255.255/32 perm     0               bcst    58     1
```

The consequence of these entries, if you are using an interface-style service set, is that traffic received on any interface, regardless of where the service set is applied, will be serviced.

Next hop–style service set

The same IPSec VPN is now implemented using a next hop–style service set. As with every next hop–style service set, you must configure the two "legs" of the inside and outside service sets:

```
sp-0/0/0 {
    unit 0 {
        family inet;
    }
    unit 1 {
        family inet;
        service-domain inside;
    }
    unit 2 {
        family inet;
        service-domain outside;
    }
}
```

Then you need to create the IPSec rules. These rules will look the same as they did in the previous example using interface-style service sets, with one notable exception: *rule direction*. Since traffic is going to be mapped to the inside interface for encryption, a `match-direction` of `input` should be used:

```
ipsec-vpn {
    rule secure-extranet {
        term 1 {
            from {
                destination-address {
                    128.3.3.0/24;
                }
            }
            then {
                remote-gateway 128.3.3.4;
                dynamic {
                    ike-policy min-policy;
                }
            }
        }
        match-direction input;
    }
```

Now traffic is mapped to the inside service interface to be encrypted in the IPSec tunnel. You can accomplish this mapping in a variety of ways; the simplest is with a static route:

```
lan@PBR set routing-options static route 128.3.3/24 next-hop sp-0/0/0.1
```

After committing the configuration and sending traffic from `Bock` to the extranet 128.3.3/24 subnet, the IKE and IPSec SAs are created:

```
[edit]
lab@PBR# run show services ipsec-vpn ike security-associations
Remote AddressState   Initiator cookie Responder cookie Exchange type
128.3.3.4      Matured 833d31c69f915b75 4326d4b9c69e624f Main
```

```
lab@PBR# run show services ipsec-vpn ipsec security-associations
Service set: basic-vpn

  Rule: secure-extranet, Term: 1, Tunnel index: 1
  Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
  IPSec inside interface: sp-0/0/0.1, Tunnel MTU: 1500
    Direction SPI         AUX-SPI     Mode       Type     Protocol
    inbound   612210302   0           tunnel     dynamic  ESP
    outbound  1652494959  0           tunnel     dynamic  ESP
```

Also verify that the traffic from `Bock` to the extranet is actually being encrypted *and* decrypted by viewing the IPSec statistics:

```
lab@PBR# run show services ipsec-vpn ipsec statistics
PIC: sp-0/0/0, Service set: basic-vpn

ESP Statistics:
  Encrypted bytes:              4400
  Decrypted bytes:              5336
  Encrypted packets:              50
  Decrypted packets:              63
AH Statistics:
  Input bytes:                     0
  Output bytes:                    0
  Input packets:                   0
  Output packets:                  0
Errors:
  AH authentication failures: 0, Replay errors: 0
  ESP authentication failures: 0, ESP decryption failures: 0
  Bad headers: 0, Bad trailers: 0
```

The interface-style service set requires a service filter to allow the external BGP session to be established; however, these filters do not exist in next hop–style service sets, nor are they required. Simply ensure that only traffic that should be serviced is mapped to the service interface.

Besides the usual `show` command to troubleshoot IPSec tunnels, you also can configure IKE traceoptions via `set services ipsec-vpn traceoptions flag ike`. These messages are automatically placed into a file called *kmd*.

IPSec over GRE

Sometimes the names for network features seem to be created out of thin air, with no rhyme or reason. This is the case with an IPSec over GRE tunnel. The name does not accurately describe the feature, as it actually is a Generic Routing Encapsulation (GRE) tunnel that is secured with IPSec. A better name would be GRE over IPSec, but as we all know, network engineering can't be that logical. The most common usage of IPSec over GRE tunnels is to interoperate with older Cisco IOS codes that do not support routing over IPSec tunnels. In these cases, routing is configured over GRE and then IPSec is added. In Junos, routing over IPSec tunnels is accomplished by using next hop–style service sets. However, when implementing IPSec over GRE, you can use either service set type, with one exception. If the GRE endpoints are the same as the IPSec tunnel endpoints, you should use interface-style service sets.

You could use a next hop–style service set if the tunnel endpoints are the same and FBF was used to map the GRE packets to the IPSec tunnel, but this adds an additional level of complexity that you should avoid if possible.

As in Figure A-7, an IPSec over GRE tunnel will be configured between `PBR` and the `Cans` extranet. First, an unnumbered GRE interface is created from `PBR` to `Cans`:

```
lab@PBR# show interfaces gr-0/0/0
unit 0 {
    tunnel {
        source 172.16.1.2;
        destination 128.3.3.4;
    }
    family inet;
}
```

To aid in troubleshooting, you could add an IP address to the GRE tunnel, but it is not necessary.

Traffic to the extranet is mapped via a static route that points to the **`gr-0/0/0.0`** interface:

```
[edit]
lab@PBR# show routing-options static route 128.3.3.0/24
next-hop gr-0/0/0.0;
```

Next, you need to configure unique proposals that map to Cisco defaults:

```
    ipsec {
        proposal cisco-interop {
            protocol esp;
            authentication-algorithm hmac-md5-96;
            encryption-algorithm des-cbc;
        }
        policy ipsecgre {
            perfect-forward-secrecy {
                keys group1;
            }
            proposals cisco-interop;
        }
    }
    ike {
        proposal cisco-interop-ike {
            authentication-method pre-shared-keys;
            dh-group group1;
```

```
                authentication-algorithm md5;
                encryption-algorithm des-cbc;
            }
            policy main_ike {
                proposals cisco-interop-ike;
                pre-shared-key ascii-text "$9$JhUi.QF/0BEP5BEcyW8ZUjHP5z
36AuO"; ## SECRET-DATA
            }
        }
```

Then, you need to create the rule to map the GRE packets to the IPSec tunnel. You can do this by matching on the source IP address and destination IP address of the GRE tunnel, as well as by mapping the Cisco interoperable proposals to the IPSec tunnels:

```
lab@PBR# show services | find ipsec-vpn
ipsec-vpn {
    rule map-gre {
        term 1 {
            from {
                source-address {
                    172.16.1.2/32;
                }
                destination-address {
                    128.3.3.4/32;
                }
            }
            then {
                remote-gateway 128.3.3.4;
                dynamic {
                    ike-policy main_ike;
                    ipsec-policy ipsecgre;
                }
            }
        }
        match-direction output;
    }
```

A service set is then created and applied to the interface between `PBR` and `Wheat`:

```
lab@PBR# show services
service-set ipsec-gre {
    interface-service {
        service-interface sp-0/0/0.0;
    }
    ipsec-vpn-options {
        local-gateway 172.16.1.2;
    }
    ipsec-vpn-rules map-gre;
}
lab@PBR# show interfaces
ge-0/0/0 {
    vlan-tagging;
    unit 412 {
        description PBR-to-Wheat;
        vlan-id 412;
        family inet {
            service {
                input {
                    service-set ipsec-gre                }
                output {
                    service-set ipsec-gre
                }
            }
            address 172.16.1.2/24;
        }
    }
```

Two additional pieces of configuration should probably be added: IKE traceoptions and automatic tunnel establishment. IKE traceoptions will be used to help troubleshoot if the IPSec tunnel does not come up, and automatic tunnel establishment will be used to avoid lost packets that could result when GRE packets are sent before the IPSec tunnel is fully established:

```
[edit]
lab@PBR# set services ipsec-vpn establish-tunnels immediately

[edit]
lab@PBR# set services ipsec-vpn traceoptions flag ike traceoptions {
```

After the configuration is committed, the tunnel is established:

```
[edit]
lab@PBR# run show services ipsec-vpn ipsec security-associations
Service set: ipsec-gre

  Rule: map-gre, Term: 1, Tunnel index: 1
  Local gateway: 172.16.1.2, Remote gateway: 128.3.3.4
  Tunnel MTU: 1500
    Direction SPI         AUX-SPI     Mode       Type     Protocol
    inbound   4232427354  0           tunnel     dynamic  ESP
    outbound  83055442    0           tunnel     dynamic  ESP
```

However, traffic does not flow across the tunnel, and the BGP session to `Wheat` is down. The solution to this problem screams service filter!

```
[edit]
lab@PBR# run show bgp summary
Groups: 1 Peers: 1 Down peers: 1
Table   Tot Paths  Act Paths Suppressed  History Damp State  Pending
inet.0         0          0          0        0          0        0
Peer               AS      InPkt     OutPkt    OutQ   Flaps Last
Up/Dwn State|#Active/Received/Damped...
172.16.1.1   420   11892    10737       0       4       11:53 Active
```

It is obvious that we need to build a service filter to skip the BGP traffic from being serviced, while also ensuring that the GRE traffic gets sent down the IPSec tunnel. What might not be so obvious is that we need a service filter in *both* directions, because when GRE packets are encapsulated inside the system and the packets are circulated, the input interface becomes the next hop outgoing interface, as shown here and later in Figure A-14:

```
lab@PBR> show configuration firewall
family inet {
    service-filter match-vpn-input {
        term service {
            from {
                source-address {
                    128.3.3.4/32;
                }
                destination-address {
                    172.16.1.2/32;
                }
            }
            then service;
        }
        term skip {
            then skip;
        }
    }
    service-filter match-vpn-output {
        term service {
            from {
                source-address {
                    172.16.1.2/32;
                }
                destination-address {
                    128.3.3.4/32;
                }
            }
            then service;
        }
        term skip {
            then skip;
        }
    }
}
```

Apply the service filters to the WAN interface on PBR:

```
lab@PBR> show configuration interfaces ge-0/0/0 unit 412
description PBR-to-Wheat;
vlan-id 412;
family inet {
    service {
        input {
            service-set ipsec-gre service-filter match-vpn-input;
        }
        output {
            service-set ipsec-gre service-filter match-vpn-output;
        }
    }
    address 172.16.1.2/24;
```

Generate some test traffic to the extranet on the internal router Bock:

```
lab@Bock> ping 128.3.3.3 rapid count 100
PING 128.3.3.3 (128.3.3.3): 56 data bytes
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

```
!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
--- 128.3.3.3 ping statistics ---
100 packets transmitted, 100 packets received, 0% packet loss
round-trip min/avg/max/stddev = 9.666/18.435/40.117/9.181 ms
```

Verify that the packets are both encrypted and decrypted to and from the `Cans` extranet:

```
lab@PBR# run show services ipsec-vpn ipsec statistics

PIC: sp-0/0/0, Service set: ipsec-gre

ESP Statistics:
  Encrypted bytes:            11200
  Decrypted bytes:            11200
  Encrypted packets:            100
  Decrypted packets:            100
AH Statistics:
  Input bytes:                    0
  Output bytes:                   0
  Input packets:                  0
  Output packets:                 0
Errors:
  AH authentication failures: 0, Replay errors: 0
  ESP authentication failures: 0, ESP decryption failures: 0
  Bad headers: 0, Bad trailers: 0
```

For reference purposes only, here is an example of what the configuration may look like on the Cisco side in the extranet:

```
crypto isakmp policy 1
 hash md5
 authentication pre-share
crypto isakmp key test address 172.16.1.2
crypto isakmp keepalive 10 2 periodic

!
!
crypto ipsec transform-set esp_des_set esp-des esp-md5-hmac
!
!
crypto map gre-to-ipsec 1 ipsec-isakmp
 set peer 172.16.1.2
 set transform-set esp_des_set
 set pfs group1
 match address 110


access-list 110 permit ip host 128.3.3.4 host 172.16.1.2

interface tunnel1
 tunnel mode gre ip
 tunnel destination 172.16.1.2
 tunnel source 128.3.3.4

interface fast0
 crypto map gre-to-ipsec
```

Summary of IPSec VPNs

IPSec VPNs provide a secure method for protecting data over a private or public network. These could be VPNs with default proposals or VPNs with very specific authentication and encryption methods. Also, you can use these VPNs for a variety of applications, including securing access to an extranet, providing remote office connectivity, and providing a backup link for your internal network. Some of these VPNs may have dynamic endpoints or require GRE tunnels for interoperability with other vendors. You can accomplish all of this using Junos and services.

The next section details another service that is offered: NAT.

NAT

NAT is simply a way to change the source or destination IP address of a packet because of public address exhaustion or a security mechanism to protect internal hosts. The internal hosts can be mapped to their own individual public addresses, or a pool of addresses could be used. Also, many addresses could be mapped to a single address utilizing different Transmission Control Protocol/User Datagram Protocol (TCP/UDP) port numbers for the flow, referred to as Port Address Translation (PAT). The most common NAT scenarios are listed here (and shown in Figure A-8):

Destination NAT without port mapping
: The incoming public address is mapped to a private address. This is usually used to hide an internal server's address from the outside world.

Destination NAT with port mapping
: The incoming destination address and port are mapped to a private address. This allows for many services to be tied to the same destination address differentiated by port numbers. This is normally used when only a single external address is given that must map to multiple private connections.

NAT source without port translation
: The outgoing private source IP address is mapped to a public IP address. This is used when inside hosts want to reach external networks and the host information wants to remain hidden.

NAT source with port translation
: The outgoing private IP address is mapped to a public IP and the port number is also changed. This is used when multiple sources are mapped to a few public IP addresses.

Twice NAT
: This is used when both the source IP and the destination IP need to be changed. This could be a mail server that needs both inbound and outbound connections. Twice NAT is supported in Junos 8.3 and later.

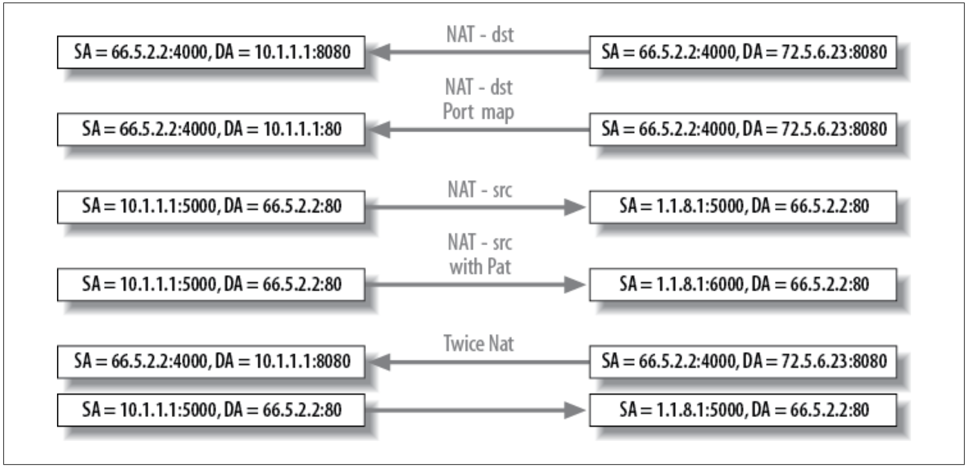

NAT - dst
SA = 66.5.2.2:4000, DA = 10.1.1.1:8080
SA = 66.5.2.2:4000, DA = 72.5.6.23:8080
NAT - dst
Port map
SA = 66.5.2.2:4000, DA = 10.1.1.1:80
SA = 66.5.2.2:4000, DA = 72.5.6.23:8080
NAT - src
SA = 10.1.1.1:5000, DA = 66.5.2.2:80
SA = 1.1.8.1:5000, DA = 66.5.2.2:80
NAT - src
with Pat
SA = 10.1.1.1:5000, DA = 66.5.2.2:80
SA = 1.1.8.1:6000, DA = 66.5.2.2:80
Twice Nat
SA = 66.5.2.2:4000, DA = 10.1.1.1:8080
SA = 66.5.2.2:4000, DA = 72.5.6.23:8080
SA = 10.1.1.1:5000, DA = 66.5.2.2:80
SA = 1.1.8.1:5000, DA = 66.5.2.2:80

Figure A-8. Common NAT deployments

The translated address can be either specified in the NAT rule or created as a pool of addresses. If PAT is required, you must use a pool. You can reuse a pool in multiple NAT rules. In the pool, you can specify a single address, a prefix, or a range of addresses. You also can enable port translation in the pool to select a range of port values or have the system automatically choose a value:

```
lab@PBR# set services nat pool example ?
Possible completions:
> address               Address or address prefix for NAT
> address-range         Range of addresses for NAT
+ apply-groups          Groups from which to inherit configuration data
+ apply-groups-except   Don't inherit configuration data from these
groups
> port                  Specify ports for NAT
[edit]
```

The pool is then applied as a source or destination pool in the NAT rule.

You also can configure an *overload pool* if the primary pool becomes exhausted.

In addition, you can apply a prefix without using a pool of addresses:

```
[edit]
lab@PBR# set services nat rule example term 1 then translated ?
Possible completions:
+ apply-groups          Groups from which to inherit configuration data
+ apply-groups-except   Don't inherit configuration data from these groups
  destination-pool      NAT pool for destination translation
  destination-prefix    NAT prefix for destination translation
  overload-pool         NAT pool to be used when source pool is overloaded
```

```
   overload-prefix      NAT prefix to be used when source pool is overloaded
   source-pool          NAT pool for source translation
   source-prefix        NAT prefix for source translation
 > translation-type     Type of translation to perform
```

When deciding how to configure NAT, several questions drive the correct solutions:

- Is the source IP address and/or destination IP address going to be translated?
- Is port translation going to occur?
- Are the addresses going to be statically mapped or dynamically mapped?
- Should an address pool be used?

We will examine a few common scenarios in the following sections.

Source NAT with No PAT

A simple source NAT for all private addresses to an external address pool of 55.55.5/27 is implemented on `PBR` using the preferred solution of a next hop service set, as shown in Figure A-9.

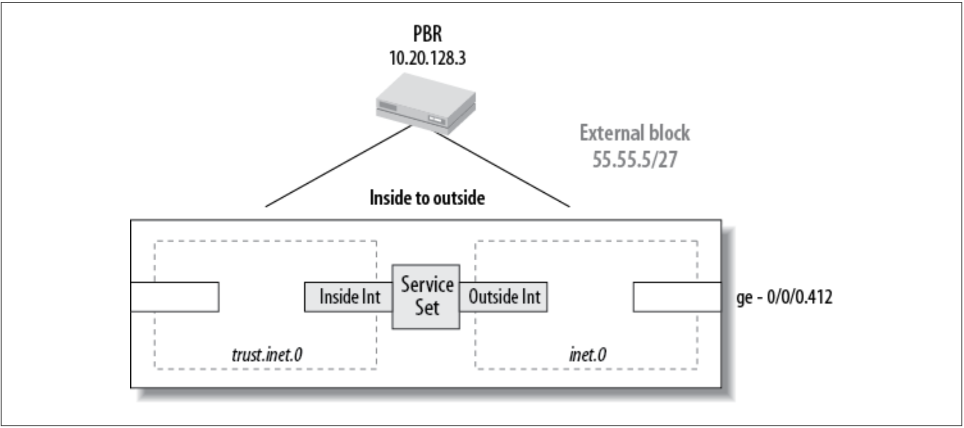


Figure A-9. Source NAT example

First, an address pool called `ext-block` is created without port translation. An address block is not necessary but is used for future scalability:

```
lab@PBR# show services
nat {
    pool ext-block {
        address 55.55.5.0/27;
    }
```

Then a rule is created to translate all source addresses using this address block. This must be a dynamic translation since there is no matching source subnet:

```
    rule basic-source {
        match-direction input;
```

```
            term 1 {
                then {
                    translated {
                        source-pool ext-block;
                        translation-type source dynamic;
                    }
                }
            }
        }
    }
```

A next hop service set is created to map the NAT rule:

```
service-set Trust-Untrust {
    nat-rules basic-source;
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
}
```

The external address block must be reachable by the outside world. Since `PBR` already has a hazy BGP relationship with AS 420, this address block is sent via BGP:

```
[edit]
lab@PBR# show protocols bgp
export [ send-agg send-ext-block ];
group as_420 {
    type external;
    neighbor 172.16.1.1 {
        peer-as 420;
    }
}
lab@PBR# run show bgp summary
Groups: 1 Peers: 1 Down peers: 0
Table   Tot Paths  Act Paths Suppressed History Damp State  Pending
inet.0          7          5          0       0          0        0
Peer        AS      InPkt     OutPkt    OutQ   Flaps Last Up/Dwn State|#Active/
Received/Damped...
172.16.1.1       420       7852       7077       0       2  2d 7:07:42 5/7/0 0/0/0

lab@PBR# run show route advertising-protocol bgp 172.16.1.1 55/8
inet.0: 21 destinations, 26 routes (20 active, 0 holddown, 5 hidden)
  Prefix                  Nexthop      MED     Lclpref    AS path
* 55.55.5.0/27            Self                            I
```

Next, we create a VR to represent the internal trust (internal) portion of the network. The LAN interface of `PBR` is added, as well as the inside service interface. Also, the OSPF configuration is moved over the VR. This includes a policy called `send-default` (not shown) that sends a default route into OSPF for Internet connectivity. Also, a loopback is added for use in OSPF. Lastly, a default route is created to send all non-internal traffic to the inside service interface:

```
[edit]
lab@PBR# show routing-instances
```

```
trust {
    instance-type virtual-router;
    interface ge-0/0/0.1241;
    interface sp-0/0/0.1;
    interface lo0.0;
    routing-options {
        static {
            route 0.0.0.0/0 next-hop sp-0/0/0.1;
        }
    }
    protocols {
        ospf {
            export send-default;
            area 0.0.0.0 {
                interface ge-0/0/0.1241;
                interface lo0.1;
            }
        }
    }
}
```

For completeness, the policies on PBR are shown here. Please refer to Chapter 5 for a policy discussion:

```
[edit]
lab@PBR# show policy-options
prefix-list internal-subnets {
    10.10.12.0/22;
    10.10.128.0/22;
    10.20.128.0/22;
}
policy-statement send-agg {
    from protocol aggregate;
    then accept;
}
policy-statement send-default {
    from {
        route-filter 0.0.0.0/0 exact accept;
    }
}
policy-statement send-ext-block {
    from {
        route-filter 55.55.5.0/27 exact accept;
    }
}
```

Verify that all the static routes are active on the router in both the routing instance trust and the main route table. The 55.55.5/27 static route in the main instance was automatically created due to the NAT rule with a very low preference of 1, which points to the outside interface for return NAT traffic. The default route was manually created during the VR configuration:

```
lab@PBR# run show route protocol static

inet.0: 21 destinations, 26 routes (20 active, 0 holddown, 5 hidden)
```

```
+ = Active Route, - = Last Active, * = Both

55.55.5.0/27       *[Static/1] 00:14:38
                    > via sp-0/0/0.2

trust.inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[Static/5] 00:19:31
                    > via sp-0/0/0.1
```

Also, verify that all the internal routes are received via OSPF in the VR's route table, `trust.inet.0`:

```
[edit]
lab@PBR# run show route table trust

trust.inet.0: 16 destinations, 16 routes (16 active, 0 holddown, 0 hidden)
+ = Active Route, - = Last Active, * = Both

0.0.0.0/0          *[Static/5] 00:19:59
                    > via sp-0/0/0.1
10.10.8.0/27       *[OSPF/10] 00:13:32, metric 67
                    > to 10.20.130.1 via ge-0/0/0.1241
10.10.10.0/30      *[OSPF/10] 00:19:50, metric 66
                    > to 10.20.130.1 via ge-0/0/0.1241
10.10.11.0/24      *[OSPF/10] 00:19:50, metric 2
                    > to 10.20.130.1 via ge-0/0/0.1241
10.10.12.1/32      *[OSPF/10] 00:13:32, metric 2
                    > to 10.20.130.1 via ge-0/0/0.1241
10.10.12.2/32      *[OSPF/10] 00:13:32, metric 66
                    > to 10.20.130.1 via ge-0/0/0.1241
10.10.12.3/32      *[OSPF/10] 00:19:50, metric 1
                    > to 10.20.130.1 via ge-0/0/0.1241
10.20.128.4/32     *[OSPF/10] 00:13:32, metric 67
                    > to 10.20.130.1 via ge-0/0/0.1241
10.20.128.128/32   *[Direct/0] 00:19:59
                    > via lo0.1
10.20.129.0/24     *[OSPF/10] 00:13:32, metric 68
                    > to 10.20.130.1 via ge-0/0/0.1241
10.20.130.0/24     *[Direct/0] 00:19:59
                    > via ge-0/0/0.1241
10.20.130.2/32     *[Local/0] 00:19:59
                      Local via ge-0/0/0.1241
10.20.131.0/24     *[OSPF/10] 00:13:32, metric 67
                    > to 10.20.130.1 via ge-0/0/0.1241
10.30.1.1/32       *[OSPF/10] 00:13:32, metric 67
                    > to 10.20.130.1 via ge-0/0/0.1241
64.8.12.6/32       *[OSPF/150] 00:13:32, metric 0, tag 0
                    > to 10.20.130.1 via ge-0/0/0.1241
224.0.0.5/32       *[OSPF/10] 00:20:00, metric 1
                      MultiRecv
```

Now verify that the OSPF network is running correctly in the VR. Don't forget the `instance` switch!

```
[edit]
lab@PBR# run show ospf database instance trust

    OSPF link state database, Area 0.0.0.0
 Type       ID              Adv Rtr          Seq      Age  Opt  Cksum  Len
Router   10.10.12.1     10.10.12.1     0x8000016d 817  0x22 0x30df  48
Router   10.10.12.2     10.10.12.2     0x8000022a 817  0x22 0x7889  84
Router   10.10.12.3     10.10.12.3     0x8000017b 739  0x22 0x3575  84
Router   10.20.128.4    10.20.128.4    0x800004fc 818  0x22 0xa79b  60
Router  *10.20.128.128 10.20.128.128 0x8000000c 160  0x22 0x5f14  48
Router   10.30.1.1      10.30.1.1      0x80000227 818  0x22 0x4ef0  48
Network  10.10.8.1      10.10.12.2     0x800000a1 817  0x22 0x45e7  32
Network  10.10.11.1     10.10.12.3     0x80000003 816  0x22 0xbef1  32
Network *10.20.130.2    10.20.128.128 0x80000004   9  0x22 0x1320  32
Network  10.20.131.2    10.20.128.4    0x8000020b 818  0x22 0xf32f  32
    OSPF AS SCOPE link state database
 Type       ID             Adv Rtr           Seq      Age  Opt  Cksum  Len
Extern  *0.0.0.0        10.20.128.128 0x80000001 562  0x22 0x7f14  36
Extern   64.8.12.6      10.30.1.1      0x8000009b 818  0x22 0xf84   36
```

Traffic is sent to the Internet and verified by looking at the `show services stateful-firewall flows` output. When a NAT service set is applied, a stateful firewall that accepts all traffic is actually also applied. Notice that the source is being translated from 10.20.120.1 to 55.55.5.1 with no port translation, and the return flow is automatically created. Also, the state is `watch` because an ICMP Application Layer Gateway (ALG) is being used:

```
[edit]
lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
Flow                                State    Dir       Frm count
ICMP        128.3.3.27:62239 ->      55.55.5.1      Watch    O   188
    NAT dest         55.55.5.1:62239   ->     10.20.130.1:0
ICMP       10.20.130.1:62239 ->     128.3.3.27      Watch    I   196
    NAT source     10.20.130.1:62239   ->      55.55.5.1:62239
```

You also can view the ALG by looking at the output of the `conversations` command, which is Junos terminology for the transit and receive flow:

```
lab@PBR# run show services stateful-firewall conversations extensive
Interface: sp-0/0/0, Service set: Trust-Untrust

Conversation: ALG protocol: icmp
  Number of initiators: 1, Number of responders: 1
Flow                                 State    Dir       Frm count
ICMP       10.20.130.1:62239 ->     128.3.3.27      Watch    I   211
    NAT source     10.20.130.1:62239   ->      55.55.5.1:62239
  Byte count: 17724
  Flow role: Master, Timeout: 30, Protocol detail: echo request
ICMP        128.3.3.27:62239 ->      55.55.5.1      Watch    O   203
    NAT dest         55.55.5.1:62239   ->     10.20.130.1:0
  Byte count: 17052
  Flow role: Responder, Timeout: 30, Protocol detail: echo reply
```

The NAT pool is also examined, and although a /27 is configured in the pool, only 30 addresses have been allocated, excluding the 55.55.5.0 and 55.55.5.31 addresses:

```
lab@PBR# run show services nat pool
Interface: sp-0/0/0, Service set: Trust-Untrust
NAT pool          Type    Address              Port      Ports used
ext-block         dynamic        55.55.5.1-55.55.5.30
```

Source NAT with PAT

Now we will add port translation; refer back to "Source NAT with No PAT" on page 676 to see the VR, rules, service setup, and so on. To enable PAT, simply add the port command in the address pool definition:

```
[edit]
lab@PBR# set services nat pool ext-block port automatic
```

After the change is committed, it still appears that the flows are not performing any port translation:

```
[edit]
lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
Flow                              State    Dir       Frm count
ICMP         128.3.3.27:62239 ->       55.55.5.1       Watch    O   188
    NAT dest          55.55.5.1:62239   ->     10.20.130.1:0
ICMP        10.20.130.1:62239 ->      128.3.3.27       Watch    I   196
    NAT source     10.20.130.1:62239   ->       55.55.5.1:62239
```

You can verify this by looking at the NAT pool and seeing that no ports have been assigned:

```
lab@PBR# run show services nat pool
Interface: sp-0/0/0, Service set: Trust-Untrust
NAT pool          Type    Address            Port        Ports used
ext-block         dynamic           55.55.5.1-55.55.5.30
```

The port translation is not occurring because the change was done on the fly and the session had not timed out. To create a new session in the flow table, you must first clear the flows:

```
lab@PBR# run clear services stateful-firewall flows
Interface    Service set                          Conv removed
sp-0/0/0     Trust-Untrust                                   1
```

Now the port number is being changed from 62239 to 1024, as expected:

```
[edit services nat pool ext-block]
lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
Flow                              State    Dir       Frm count
ICMP         128.3.3.27:1024  ->       55.55.5.1       Watch    O   8
    NAT dest          55.55.5.1:1024    ->     10.20.130.1:62239
ICMP        10.20.130.1:62239 ->      128.3.3.27       Watch    I   8
    NAT source     10.20.130.1:62239   ->       55.55.5.1:1024
```

You can verify this by viewing the port range allowed (512–65535), and by the fact that a single port is shown to be in use out of the pool:

```
[edit services nat pool ext-block]
lab@PBR# run show services nat pool
Interface: sp-0/0/0, Service set: Trust-Untrust
NAT pool          Type    Address               Port       Ports used
ext-block         dynamic      55.55.5.1-55.55.5.30  512-65535    1
```

Destination NAT

Another common application is to change the incoming public IP address to a private IP address inside the network. Often, this is done to open a particular service from the WAN interface, frequently referred to as a *pinhole* for its hopefully diminutive access. In this case study, a custom application called *slingbox* is running over TCP and is using a port range of 4000–4050. This will be coming into public IP address 55.55.5.27 and will be mapped to internal address 10.10.12.3. Destination NAT must always be of type static, so the incoming public address range must map to the outgoing private address range.

Since a unique application must be used for this pinhole, first you must define an application that will later be referenced in the NAT rule. This application is called `custom-app`:

```
lab@PBR# show | find applications
applications {
    application custom-app {
        protocol tcp;
        destination-port 4000-4050;
    }
}
```

Create the NAT rule by referencing the incoming public destination address 55.55.5.27 and the `custom-app`, and by translating this address to 10.10.12.3. Use a `destination-prefix` instead of a `destination-pool`, as this is a single address mapping. Since this is a destination NAT that is added to the previously created next hop service set, specify a direction of output, because traffic will be received and directed to the outside interface by the already created 55.55.5/27 static route:

```
[edit services nat]
lab@PBR# show | find rule

        rule pin-hole {
            match-direction output;
            term 1 {
                from {
                    destination-address {
                        55.55.5.27/32;
                    }
                    applications custom-app;
                }
                then {
                    translated {
                        destination-prefix 10.10.12.3/32;
                        translation-type destination static;
                    }
                }
            }
        }
    }
```

Then add the rule to the previously created service set:

```
    service-set Trust-Untrust {
        nat-rules basic-source;
        nat-rules pin-hole;
        next-hop-service {
            inside-service-interface sp-0/0/0.1;
            outside-service-interface sp-0/0/0.2;
        }
    }
}
```

Remember that you can combine multiple rules into a rule set if desired.

Traffic is incoming to PBR's WAN interface and the destination NAT is verified. This flow happens to have an incoming port number of 4020, which does fall into the custom application range:

```
lab@PBR# run show services stateful-firewall conversations
Interface: sp-0/0/0, Service set: Trust-Untrust
Conversation: ALG protocol: tcp
  Number of initiators: 1, Number of responders: 1
Flow                               State    Dir       Frm count
TCP          172.16.1.1:4216  ->    55.55.5.27:4020  Forward  O    1
    NAT dest       55.55.5.27:4020     ->      10.10.12.3:4020
TCP          10.10.12.3:4020  ->    172.16.1.1:4216  Forward  I    1
    NAT source     10.10.12.3:4020     ->      55.55.5.27:4020
```

NAT and the stateful firewall

By default, when NAT rules are exclusively applied in a service set, a stateful firewall is implicitly applied. This default stateful firewall matches on all traffic with an action of `accept` and is created in *both* directions. If a stateful-firewall rule is created later and applied to the service set, the default stateful-firewall rules are removed. This means that to allow for NAT traffic, you may need to create new stateful-firewall rules if a stateful-firewall rule is later applied to the service set. In a simple example, a stateful-firewall rule is created to allow all Junos ALGs and other traffic outbound from the internal network to the Internet:

```
stateful-firewall {
    rule allow-outbound {
        match-direction input;
        term 1 {
            from {
                application-sets junos-algs-outbound;
            }
            then {
                accept;
            }
        }
        term 2 {
            then {
                accept;
            }
        }
    }
}
```

Apply this stateful-firewall rule to the service set that already contains the NAT rules:

```
service-set Trust-Untrust {
    stateful-firewall-rules allow-outbound;
    nat-rules basic-source;
    nat-rules pin-hole;
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
}
```

Verify the source NAT and that all works as expected since the stateful firewall is allowing all outbound flows:

```
[edit]
lab@PBR# run show services stateful-firewall conversations
Interface: sp-0/0/0, Service set: Trust-Untrust

Conversation: ALG protocol: icmp
  Number of initiators: 1, Number of responders: 1
Flow                                State    Dir       Frm count
ICMP       10.20.130.1:11552 ->     128.3.3.27      Watch    I  31
    NAT source     10.20.130.1:11552   ->       55.55.5.1:1024
ICMP        128.3.3.27:1024  ->      55.55.5.1      Watch    O   31
    NAT dest         55.55.5.1:1024    ->     10.20.130.1:11552
```

Note that when test traffic is sent from ISP router `Wheat` to `PBR` for incoming destination NAT, the traffic is dropped by the newly applied stateful firewall that allows only outbound flows to be initiated, not inbound flows:

```
lab@Wheat> telnet 55.55.5.27 port 4020
Trying 55.55.5.27...

lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
```

```
Flow                               State    Dir       Frm count
TCP        172.16.1.1:3469  ->     55.55.5.27:4020  Drop     0    0
```

So, to allow incoming NAT processing to occur in the output interface, the packet must be allowed through the stateful firewall. The incoming service flow when multiple service rules are applied is:

Stateful firewall→NAT

You cannot set this order at this point, which means that the stateful firewall must match on the static NAT address:

```
[edit service stateful-firewall]
lab@PBR# show | find rule allow-pin-hole

rule allow-pin-hole {
    match-direction output;
    term 1 {
        from {
            destination-address {
                55.55.5.27/32;
            }
        }
        then {
            accept;
        }
    }
}
```

Apply the new rule to the service set:

```
lab@PBR# show services service-set Trust-Untrust
stateful-firewall-rules allow-outbound;
stateful-firewall-rules allow-pin-hole;
nat-rules basic-source;
nat-rules pin-hole;
next-hop-service {
    inside-service-interface sp-0/0/0.1;
    outside-service-interface sp-0/0/0.2;
}
```

Now destination NAT works as expected, and TV can sling around the world with our special application:

```
lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: Trust-Untrust
Flow                                State    Dir       Frm count
TCP        10.10.12.3:4020  ->     172.16.1.1:1059  Forward  I   1
    NAT source      10.10.12.3:4020    ->      55.55.5.27:4020
TCP        172.16.1.1:1059  ->     =55.55.5.27:4020  Forward  O   1
    NAT dest        55.55.5.27:4020    ->      10.10.12.3:4020

[edit]
```

Since multiple stateful-firewall rules are applied, this may be another place where a rule set could be helpful:

```
service-set Trust-Untrust {
    stateful-firewall-rule-sets in-out;
    nat-rules basic-source;
    nat-rules pin-hole;
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
}
rule-set in-out {
    rule allow-outbound;
    rule allow-pin-hole;
}
```

Twice NAT

Lastly, you can configure twice NAT on the router, which involves changing the source IP address for outbound flows and the destination address for inbound flows (see Figure A-10). This is really no different from the scenarios we've already discussed, except that you must configure a source and a destination address, as well as a source prefix or pool and a destination prefix or pool. In the example that follows, traffic that matches 10.58.254.24 or 10.58.254.35 will be source-NAT'd using a static pool called `src-pool`.

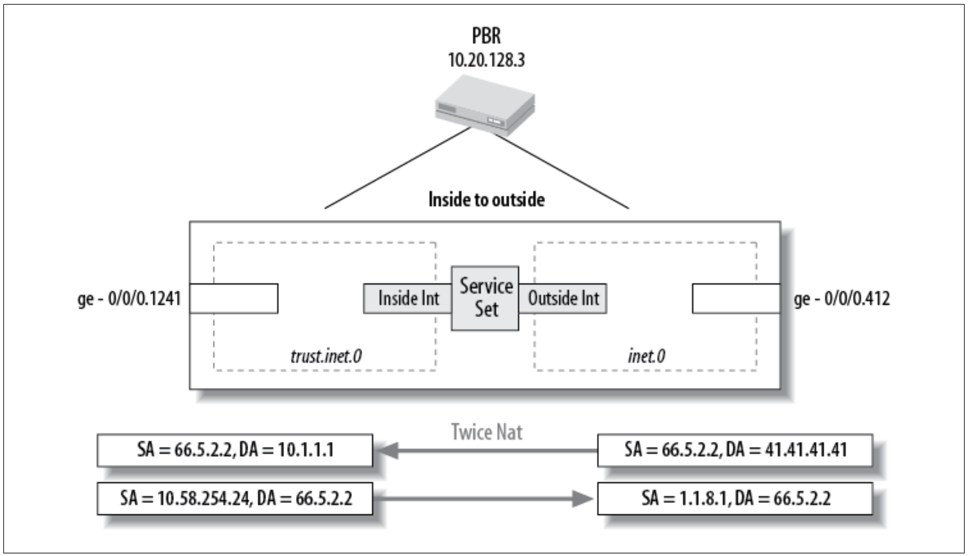


Figure A-10. Twice NAT example

Traffic destined for 41.41.41.41/32 will be destination-NAT'd using a NAT pool called `dst_pool`:

```
[edit services nat]]
lab@Bock# show
rule twice-nat {
    match-direction input;
    term my-term1 {
        from {
            destination-address {
                41.41.41.41/32;
            }
            source-address-range {
                low 10.58.254.34 high 10.58.254.35;
            }
        }
        then {
            translated {
                source-pool src-pool;
                destination-pool dst_pool;
                translation-type source static destination static;
            }
        }
    }
}
```

At the time of this writing, you cannot configure ALGs when twice NAT is configured.

Summary of NAT

NAT has become a common language and requirement for networks in every facet of the world due to the exhaustion of IPv4 addresses as well as a way to protect internal resources. Various types of NAT are defined, including source IP translation, destination IP translation, and port translation. Which method you choose should depend on a variety of factors, such as the number of public IPs that are assigned to the network, the number of incoming Internet connections allowed, and the level of invisibility required. In fact, you can combine many of these concepts into a newer standard called twice NAT.

IDS

Junos services support a limited set of IDSs to help detect attacks such as port scanning and anomalies in traffic patterns. It also supports some attack prevention by limiting the number of flows, sessions, and rates. In addition, it protects against SYN attacks by implementing a SYN cookie mechanism. Since the intrusion detection and prevention (IDP) service does not support higher-layer application signatures, we must examine another solution.

The IDP solution is really more of a monitoring tool than an actual prevention tool. So, how does Juniper make the IDP claim? One response is that protection against a SYN attack can be configured. To prevent a SYN attack, the router will operate as a type of SYN "proxy" and will utilize cookie values. Essentially, when this feature is turned on, the router will respond to the initial SYN packet with a SYN-ACK packet that contains a unique cookie value in the sequence number field. If the initiator responds with the same cookie in the sequence field, the TCP flow is accepted; if the responder does not respond or if it responds with the wrong cookie, the flow is dropped. To kick off this defense, we must configure a SYN cookie threshold.

To enable the SYN cookie defense, an IDS rule action must contain a threshold that indicates when the feature should be enabled and an MSS value to avoid having the router manage segmented fragments when acting as a SYN proxy:

```
[edit]
lab@PBR# set services ids rule simple-ids term 1 then syn-cookie ?
Possible completions:
+ apply-groups         Groups from which to inherit configuration data
+ apply-groups-except  Don't inherit configuration data from these
groups
  mss                  MSS value for TCP delayed binding (128..8192)
  threshold            Threshold above which SYN cookies are enabled
[edit]
```

You would then apply this rule to a service set as you would any other service previously discussed.

Since IDP and stateful firewalls are processed in parallel, you should configure a stateful-firewall rule alongside the IDS rule. If you forget a rule, the default stateful firewall of `allow all` will be used.

Along with SYN cookie protection, the IDS is used to detect attacks and gather information to create rules to stop these attacks. When looking at the possible IDS rule actions for detection of attacks, you can:

- Set up thresholds to monitor certain sources, destinations, or source and destination pairs
- Force "good" entries to the IDS table for tracking purposes
- Log packets when they hit a certain threshold:

```
lab@PBR# set services ids rule all term 1 then ?
Possible completions:
> aggregation          Define aggregation parameters
+ apply-groups            Groups from which to inherit configuration data
+ apply-groups-except     Don't inherit configuration data from these groups
```

```
    force-entry              Force entries in IDS tables for matching traffic
    ignore-entry             Ignore IDS events for matching traffic
  > logging               Define system logging parameters
  > session-limit         Define IDS session limit parameters
  > syn-cookie            Define SYN cookie parameters
```

For example, here is a rule that logs packets as soon as an event happens (threshold 1), enables SYN cookie protection at five SYN packets per second, and forces all entries to be recorded:

```
[edit]
lab@PBR# show services
ids {
    rule all {
        match-direction input;
        term 1 {
            then {
                force-entry;
                logging {
                    threshold 1;
                    syslog;
                }
                syn-cookie {
                    threshold 5;
                    mss 1500;
                }
            }
        }
    }
}
service-set Trust-Untrust {
    ids-rules all;
    next-hop-service {
        inside-service-interface sp-0/0/0.1;
        outside-service-interface sp-0/0/0.2;
    }
}
```

The IDS tables can then be matched by source, destination, or pair:

```
[edit]
lab@PBR# run show services ids ?
Possible completions:
  destination-table     Show attack destination address table
  pair-table            Show attack source and destination address pair table
  source-table          Show attack source address table
```

Here is some output (not from this example) that shows some of the different types of anomalies that can be tracked:

```
user@underdogs> show services ids destination-table extensive
Interface: sp-1/3/0, Service set: null-sfw
Sorting order: Packets
Source address      Dest address   Time    Flags       Application

any             ->   10.58.255.146   35m52s SYN cookie
```

```
    Bytes:   34.0 m, Packets:  798.0 k, Flows:  266.0 k, Anomalies: 2251.0 k
      Anomalies                               Count   Rate(eps) Elapsed
      First packet of TCP session not SYN     160.0 k       0       14s
      TCP source or destination port zero     634.0 k   154.6     3m37s
      UDP source or destination port zero     633.0 k   170.0     3m37s
      ICMP header length check failed            2875     0.9     3m37s
      IP fragment assembly timeout            820.0 k    12.8     3m18s
      UDP header length check failed              385     0.5     3m53s
      TCP header length check failed              383     0.5     3m53s

  Total IDS table entries:
  87
  Total failed IDS table entry insertions
  0
  Total number of
```

Combining Services

When combining multiple services, the general path must be remembered in the forward and reverse directions (see Figure A-11). This is especially true when NAT is deployed to determine whether the pre- or post-NAT address should be used to match a rule. In the forward path from a LAN interface to a WAN interface, IDS and stateful firewall are performed first, then NAT, and finally IPSec. This means that the stateful firewall must match on a pre-NAT address, whereas the IPSec tunnel would match on the post-NAT address.

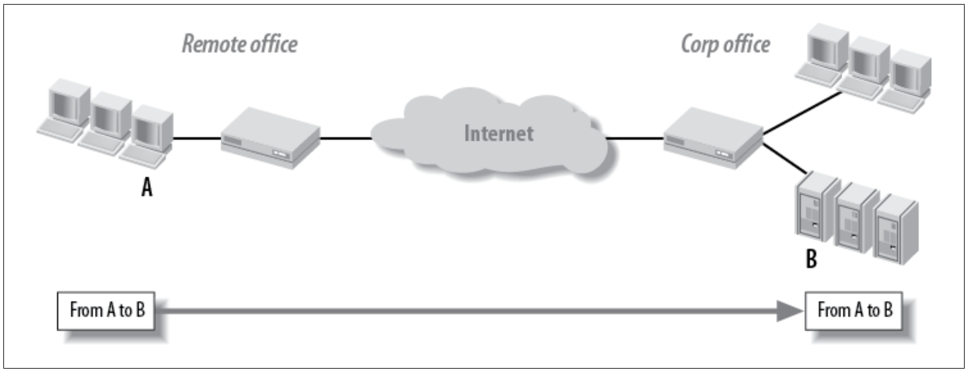


Figure A-11. Service path

In the return path, the IPSec packet will be processed first, then NAT, and finally the stateful firewall. This still allows IPSec to match a public address and the stateful firewall to match on a private address.

Everything becomes much more complicated when IPSec over GRE is implemented in the router with other services turned on. This is because Junos treats GRE packets in a very peculiar fashion after GRE encapsulation. After a packet is encapsulated in a GRE packet, it is marked with an input interface as the next hop outgoing interface.

This causes GRE packets to be blocked if any input filters or input services are allowed that do not allow for this service.

In Figure A-12, an IP packet comes into the `ge-1/0/0.42` interface and a route lookup is performed that directs the packet into a GRE tunnel, which has an egress interface of `se-1/0/0`. After the GRE encapsulation, the input interface changes to the output interface. So, at the final stage, any stateful-firewall processing or stateless filters are going to see the packet coming into interface `se-1/0/0` and out of interface `se-1/0/0`, which is unexpected!

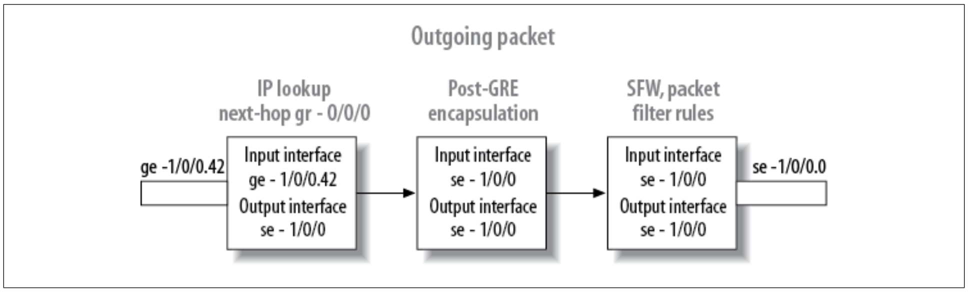

Outgoing packet
IP lookup next-hop gr - 0/0/0
Post-GRE encapsulation
SFW, packet filter rules
ge -1/0/0.42
Input interface ge - 1/0/0.42 Output interface se - 1/0/0
Input interface se - 1/0/0 Output interface se - 1/0/0
Input interface se - 1/0/0 Output interface se - 1/0/0
se -1/0/0.0

Figure A-12. GRE processing with services

Stateful Firewall, NAT, and IPSec over GRE Together

To illustrate the uniqueness of GRE encapsulation, we will again examine the IPSec over GRE tunnel. This is the same tunnel we configured in "IPSec over GRE" on page 668. Just to recap, here is the complete IPSec over GRE configuration rule set that is applied as an interface-style service set:

```
service-set ipsec-gre {
    interface-service {
        service-interface sp-0/0/0.0;
    }
    ipsec-vpn-options {
        local-gateway 172.16.1.2;
    }
    ipsec-vpn-rules map-gre;
}
ipsec-vpn {
    rule map-gre {
        term 1 {
            from {
                source-address {
                    172.16.1.2/32;
                }
                destination-address {
                    128.3.3.4/32;
                }
            }
            then {
                remote-gateway 128.3.3.4;
                dynamic {
                    ike-policy main_ike;
                    ipsec-policy ipsecgre;
                }
            }
        }
        match-direction output;
    }
    ipsec {
        proposal cisco-interop {
            protocol esp;
            authentication-algorithm hmac-md5-96;
            encryption-algorithm des-cbc;
        }
        policy ipsecgre {
            perfect-forward-secrecy {
                keys group1;
            }
            proposals cisco-interop;
        }
    }
    ike {
        proposal cisco-interop-ike {
            authentication-method pre-shared-keys;
            dh-group group1;
            authentication-algorithm md5;
            encryption-algorithm des-cbc;
        }
        policy main_ike {
            proposals cisco-interop-ike;
            pre-shared-key ascii-text "$9$JhUi.QF/0BEP5BEcyW8ZUjHP5z
36AuO"; ## SECRET-DATA
        }
    }
    traceoptions {
        flag ike;
    }
    establish-tunnels immediately;
}
```

Stateful-firewall and NAT rules are to be configured from the LAN side of router `PBR` to the WAN side of the router for all internally sourced traffic. Since IPSec requires its own service set, a new service set called **`trust-untrust`** will be created that references the same service interface and a single NAT and stateful-firewall rule:

```
[edit services]

service-set trust-untrust {
    stateful-firewall-rules allow-outbound;
    nat-rules basic-source;
    interface-service {
        service-interface sp-0/0/0.0;
    }
}
```

A stateful-firewall rule is created to match on traffic that is sourced from the internal network. Notice that only ALGs are allowed from the internal subnet, whereas the second term contains no condition. The second term does not contain this condition in order to allow some management traffic and BGP traffic to flow between the 172.16.1/24 network between PBR and Wheat:

```
stateful-firewall {
    rule allow-outbound {
        match-direction output;
        term alg {
            from {
                source-address {
                    10.0.0.0/8;
                }
                application-sets junos-algs-outbound;
            }
            then {
                accept;
            }
        }
        term other {
            then {
                accept;
            }
        }
    }
}
```

Also, a source NAT rule is applied for all internal traffic using port translation:

```
nat {
    pool ext-block {
        address 55.55.5.0/27;
        port automatic;
    }
    rule basic-source {
        match-direction output;
        term 1 {
            from {
                source-address {
                    10.0.0.0/8;
                }
            }
            then {
                translated {
                    source-pool ext-block;
                    translation-type source dynamic;
                }
            }
        }
    }
}
```

The new service set is applied to the WAN interface on PBR. Take a look at the previous example to view the service filters match-vpn-input and match-vpn-output:

```
[edit interfaces ge-0/0/0 unit 412]
lab@PBR# show
description PBR-to-Wheat;
vlan-id 412;
family inet {
    service {
        input {
            service-set ipsec-gre service-filter match-vpn-input;
            service-set trust-untrust;
        }
        output {
            service-set ipsec-gre service-filter match-vpn-output;
            service-set trust-untrust;
        }
    }
    address 172.16.1.2/24;
```

After the configuration is committed, observe the flows through the stateful firewall. GRE packets are being dropped that were destined to 128.3.3.4. Notice that the direction is input, since after GRE encapsulation, the packet appears to be coming into the outgoing WAN interface. Because the stateful-firewall rules are now written to allow incoming GRE packets, the packets are dropped:

```
[edit services stateful-firewall rule allow-outbound]

lab@PBR# run show services stateful-firewall flows
Interface: sp-0/0/0, Service set: trust-untrust
Flow                                        State    Dir   Frm count
TCP    172.16.1.1:179   -> 172.16.1.2:2439  Forward  I          11
TCP    172.16.1.2:2439  -> 172.16.1.1:179   Forward  O          12
GRE    172.16.1.2:0     ->  128.3.3.4:0     Drop     I           0
```

Since the packets are being dropped by the stateful firewall, they are not even reaching the IPSec tunnel. You can see this by observing the 0 packet counts on the IPSec statistics:

```
[edit services service-set trust-untrust]
lab@PBR# run show services ipsec-vpn ipsec statistics

PIC: sp-0/0/0, Service set: ipsec-gre

ESP Statistics:
  Encrypted bytes:              0
  Decrypted bytes:              0
  Encrypted packets:            0
  Decrypted packets:            0
AH Statistics:
  Input bytes:                  0
  Output bytes:                 0
  Input packets:                0
  Output packets:               0
Errors:
  AH authentication failures: 0, Replay errors: 0
  ESP authentication failures: 0, ESP decryption failures: 0
  Bad headers: 0, Bad trailers: 0
```

We must now create a service filter to allow the GRE packets to bypass the stateful firewall and be encapsulated into the IPSec packet. This service filter must match on the source and destination IP addresses of the tunnel, as seen from the discard flows. Don't forget to service all other packets besides the GRE packets:

```
 [edit firewall]
lab@PBR# show | find allow-gre
    service-filter allow-gre {
        term gre {
            from {
                source-address {
                    172.16.1.2/32;
                }
                destination-address {
                    128.3.3.4/32;
                }
            }
            then skip;
        }
        term all {
            then service;
        }
    }
}
```

Apply the service filter as an input service filter for the stateful firewall containing the service set:

```
[edit interfaces ge-0/0/0 unit 412]
lab@PBR# set family inet input service-set trust-untrust service-
filter allow-gre

[edit interfaces ge-0/0/0 unit 412]
lab@PBR# show
description PBR-to-Wheat;
vlan-id 412;
family inet {
    service {
        input {
            service-set ipsec-gre service-filter match-vpn-input;
            service-set trust-untrust service-filter allow-gre;
        }
        output {
            service-set ipsec-gre service-filter match-vpn-output;
            service-set trust-untrust;
        }
    }
    address 172.16.1.2/24;
}
```

After the filter has been applied, the service filter packets are encrypted and decrypted in the IPSec tunnel:

```
lab@PBR> show services ipsec-vpn ipsec statistics
```

```
PIC: sp-0/0/0, Service set: ipsec-gre

ESP Statistics:
  Encrypted bytes:           51408
  Decrypted bytes:           51408
  Encrypted packets:           459
  Decrypted packets:           459
AH Statistics:
  Input bytes:                   0
  Output bytes:                  0
  Input packets:                 0
  Output packets:                0
Errors:
  AH authentication failures: 0, Replay errors: 0
  ESP authentication failures: 0, ESP decryption failures: 0
  Bad headers: 0, Bad trailers: 0
```

In addition, other internal flows are source-NAT'd as expected:

```
lab@PBR> show services stateful-firewall conversations
Interface: sp-0/0/0, Service set: trust-untrust

Conversation: ALG protocol: icmp
  Number of initiators: 1, Number of responders: 1
Flow                                    State    Dir       Frm count
IC   10.20.130.1:30242 ->  77.7.7.7       Watch    O               3
    NAT source     10.20.130.1:30242   ->      55.55.5.1:1033
ICMP 77.7.7.7:1033  ->      55.55.5.1     Watch    I               3
    NAT dest         55.55.5.1:1033    ->     10.20.130.1:30242

Conversation: ALG protocol: tcp
  Number of initiators: 1, Number of responders: 1
Flow                                        State    Dir  Frm count
TCP     172.16.1.2:1075  ->  172.16.1.1:179   Forward  O         77
TCP     172.16.1.1:179   ->  172.16.1.2:1075  Forward  I         76
```

The Life of a Packet

When you've decided which services you need in your network, implementing them can seem like a daunting task. Which configuration do you apply first? Which addresses do you apply to a given service when applying a rule? How about if you have a class of service (CoS) applied? Where do packet filters fit into the packet flow?

Figures A-13 and A-14 should help you sort through this mystery and decide where configuration processes occur. These diagrams are not meant to represent every possible scenario, but rather to give you a general feel for the complex processing that could be involved. The exact processing will depend on whether a next hop– or an interface-style service set is applied (for more on CoS concepts, refer to Chapter 10).

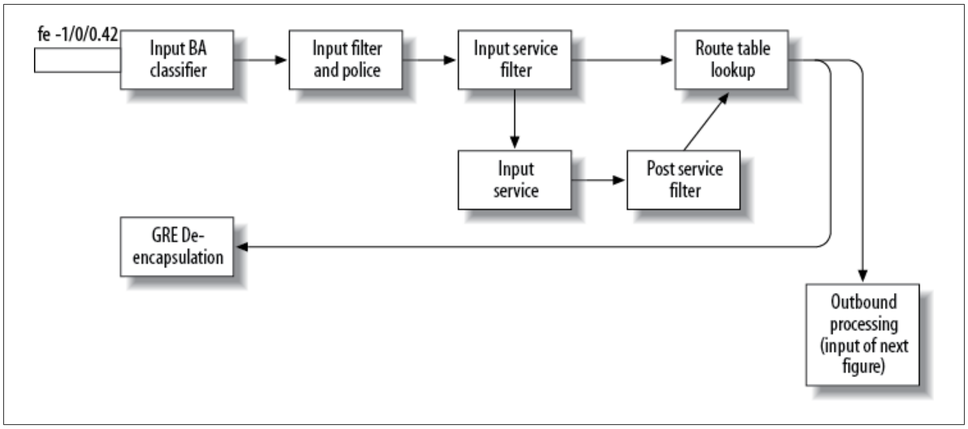


Figure A-13. Incoming packet processing

The steps outlined in Figure A-13 are as follows:

1. The packet enters the incoming interface.
2. The packet is classified by a behavior aggregate (BA) classifier.
3. The packet is processed by an input filter and policer (and may be reclassified).
4. The packet enters a service filter, and it is either serviced or skipped; if it is skipped, jump to step 7.
5. The input service is performed.
6. A post-service filter is applied.
7. The route lookup occurs.
8. If the result of the route lookup is a GRE packet, go to step 9; if not, send on for output processing.
9. De-encapsulate the GRE packet and go back to step 1.

After the packet is done with the input processing, it moves toward output processing (see Figure A-14).

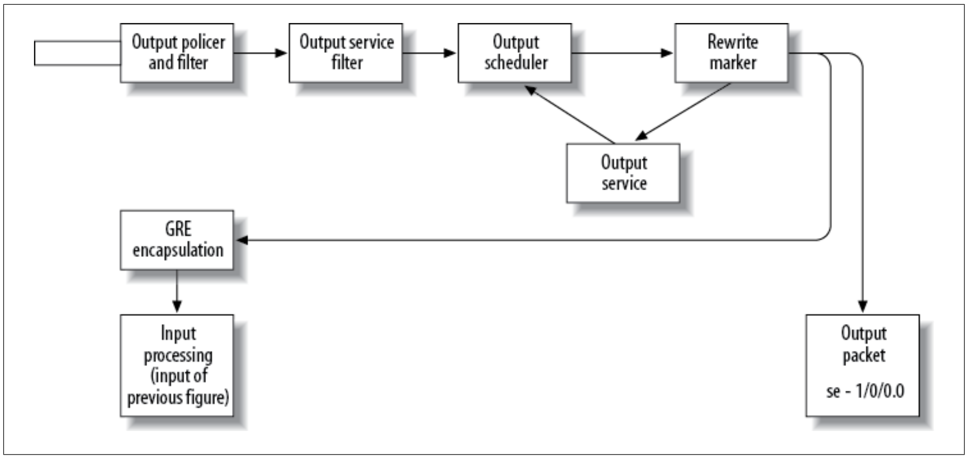


Figure A-14. Outbound packet processing

The steps outlined in Figure A-14 are as follows:

1. The packet is received from input processing and enters the output policer or filter.
2. The packet then goes through an output service filter to determine whether the packet will be marked for service. If the packet matches the service filter, the output interface is set to the service interface; if there is no match, the output interface is the outgoing physical interface.
3. The packet is sent to an output scheduler.
4. A write of the Type of Service (ToS) byte could occur. If the output interface is a service interface, go back to step 3; otherwise, go to step 5.
5. If the packet needs to be GRE-encapsulated, go to step 6; otherwise, go to step 7.
6. GRE encapsulation occurs, and the packet is sent back to the input processing stage, where it is sent to step 1 of Figure A-13 (input filters); after the GRE encapsulation, the input interface is the next hop outgoing interface of the GRE tunnel.
7. The packet is sent out the physical output interface.

Considerations Regarding Order of Operations

The packet processing order just discussed can be practically applied when designing the branch office connectivity for your network (see Figure A-15). If connectivity is provided via IPSec VPNs and CoS is applied, where should the packet be classified? If an IPSec packet enters a router, the packet can be classified by setting the CoS value in the outer IP header using a BA classifier. However, after the packet is de-encapsulated, it enters the input filtering stage and is not sent through another BA classifier. That means that if packet classification is required on the de-encapsulated packet, you must use a multifield classifier (a firewall filter).

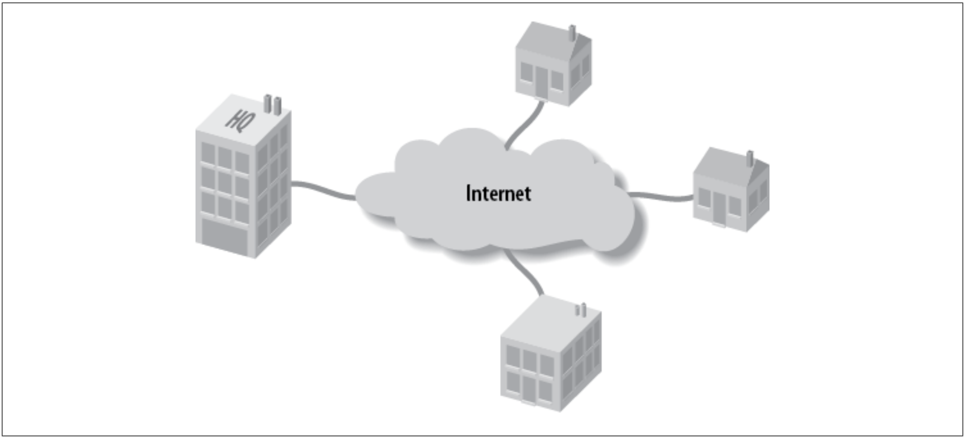


Figure A-15. Branch office connectivity

In comparison, if remote connectivity is provided by GRE tunnels, similar to IPSec tunnels, the incoming GRE packet could be classified using a BA classifier. The difference, however, is that once the GRE packet is de-encapsulated, it sends the inner packet through another BA classifier. This means you should apply the same classifier to the incoming interface and the `gr-` interface to avoid reclassification. Also, don't forget that when a GRE packet is encapsulated, it is reprocessed through all input filters and services on the output interface.

The possible scenarios could fill an entire book, so be sure to consult Figures A-13 and A-14 for application to your network.

Conclusion

IP networks have changed drastically since they were first deployed 25 years ago, when addresses were plentiful and simple filters sufficed. In today's modern data networks, the concepts of yesteryear won't float for long. Packet filters will always have their place, but without tracking state, they will always have limitations; thus, the need for stateful firewalls. With IPv4 exhaustion coming to fruition, NAT has taken a front seat in network design and is now almost a requirement.

You can deploy these services individually or as a combined security design. When combining these services, be sure to verify each step along the way to avoid a broken configuration that is a bear to troubleshoot.

Exam Topics

We examined the following Enterprise Exam Topics in this appendix:

- Configure and apply an interface-style service set.
- Configure a next hop–style service set.
- Identify the match direction given a network diagram.
- Understand and implement various types of service sets.
- Describe NAT and PAT.
- Configure a stateful firewall via the CLI.
- Monitor a stateful firewall.
- Configure NAT and PAT via the CLI.
- Monitor NAT and PAT via the CLI.
- Explain IPSec VPN processing on M-series and J-series routers.
- Configure an IPSec VPN via the CLI.
- Configure a route-based GRE tunnel (over IPSec) via the CLI.
- Monitor IPSec VPNs.
- IPSec tunnels as backup links.
- Routing over an IPSec or GRE tunnel.

Appendix Review Questions

1. Why are VRs the preferred implementation choice when deploying next hop–style service sets? (Choose two.)
   A. Added security benefits
   B. More features can be implemented
   C. Simplicity in configuration
   D. Automatic rules
2. Which match direction should be specified when creating an IPSec tunnel?
   A. De-encapsulation direction
   B. Both directions
   C. Encapsulation direction
   D. No direction
3. True or False: A single proposal can be applied to an IPSec tunnel.
4. Which type of service set would allow for OSPF routing over an IPSec tunnel?
   A. Next hop
   B. Interface

Do

C. Virtual router

D. Route set

5. After an IP packet is encapsulated by a GRE header, what is the incoming interface of the packet set to?

   A. `service interface`

   B. `gre interface`

   C. `outgoing interface`

   D. `loopback interface`

6. Which type of NAT would be used to hide all local PCs' addresses as they connect to the Internet?

   A. Destination

   B. Half-Cone

   C. Twice NAT

   D. Source NAT

7. The following source NAT rule is applied to a next hop service set but doesn't seem to be working:

```
rule basic-source {
        match-direction output;
        term 1 {
            then {
                translated {
                    source-pool ext-block;
                    translation-type source dynamic;
                }
            }
        }
    }
}
```

   What is the possible issue?

   A. Missing a `from` statement

   B. Can't use dynamic translation for source NAT

   C. The match direction is incorrect

   D. Missing the `accept` action

8. True or False: IPSec VPNs must have their own service set.

9. If packets need to be skipped in an interface-style service set, what should be configured?

   A. A service rule allowing traffic to be skipped

   B. A post-service filter allowing traffic to be skipped

   C. A service filter allowing traffic to be skipped

   D. A firewall filter allowing traffic to be skipped

10. Which NAT type is *not* supported on a Juniper router?
    A. Dynamic source
    B. Static source
    C. Dynamic destination
    D. Static destination
11. What are the advantages of using a NAT pool? (Choose two.)
    A. Can reuse pool in other rules
    B. Can implement discontinuous addresses
    C. Doesn't have to reference in a rule
    D. Can enable port translation
12. Why might there not be an active IKE SA for a configured and operational VPN?
    A. SA is no longer needed
    B. VPN has yet to time out
    C. IKE SA was never established
    D. GRE tunnel was used instead

Appendix Review Answers

1. Answer: A, C. VRs add a security benefit over other solutions because the interfaces and route tables are separated from the main table. Also, VRs avoid the complexity of rib-groups that plague other solutions.
2. Answer: C. The direction that encapsulates the packet into the IPSec tunnel should be used. In an interface-style service set, this is normally set to `output` whereas a next hop service set usually uses `input`.
3. Answer: False. You can apply multiple proposals to the IPSec tunnel; only one proposal has to match on each side for tunnel establishment.
4. Answer: A. You must use a next hop–style service set to support routing protocols.
5. Answer: C. Strangely enough, after a packet gets GRE encapsulation, the incoming interface is set to the next hop outgoing interface. This causes the GRE packet to be subject to input filters and services on the outgoing interface.
6. Answer: D. If a PC wants to be hidden from the outside world, you should deploy source NAT. This changes the "private" source IP to one or more "public" IP addresses.
7. Answer: C. One of the most common configuration errors when making service rules is not specifying the correct direction, especially when using next hop–style service sets, and match directions often seem backward when compared to interface-style service sets. Remember that traffic mapped to the inside interface is input traffic and traffic mapped to the outside interface is output traffic.

8. Answer: True. At the time of this writing, IPSec VPNs are always a unique service set, and no other service rules can be combined in the set. If you need to implement other services on top of IPSec, they must have their own unique service set.
9. Answer: C. Service filters allow for some traffic to be skipped through a service set. They also allow certain services to be selected.
10. Answer: C. At the time of this writing, dynamic destination NAT is not supported. All destination NAT must be statically mapped to the same IP address.
11. Answer: A, D. NAT pools provide greater scalability, as they can be reused in multiple terms and in multiple rules. Also, a pool is required if port translation needs to be enabled.
12. Answer: A. The IKE SA is needed only during the initial tunnel establishment to negotiate the IPSec tunnel parameters. After the IPSec tunnel is established, the IKE SA will time out and will reestablish only on an as-needed basis.

APPENDIX B
Upgrading Junos

This appendix reviews a number of options for upgrading the Junos operating system on a Juniper Networks router.

Migrating to a Newer Version of Junos

From Junos 9.3 forward, the compact flash requires a minimum of 512 MB, and from Junos 9.0, M-series devices require 1 GB flash. Not having enough free compact flash space available to perform an upgrade is common, especially on routers that have large logs, trace files, or old software packages lying about in users' home directories. The migration guide provides detailed instructions on how to free up compact flash space to enhance the chances of being able to upgrade to Junos on systems with 256 MB compact flash chips. The instructions have you delete various temporary and unneeded files using combinations of CLI and root shell mode commands, some of which are demonstrated on the following pages.

Free Up Space

The limited compact flash storage space, combined with the lack of a hard drive for storing images that are being unpacked for installation, can create problems when you attempt to upgrade or downgrade Junos versions on any Juniper router. The following steps are general approaches to freeing up compact flash space. You will need root access to delete any files that are owned by root.

First, we use the CLI cleanup utility to rid ourselves of the low-hanging fruit:

```
peter@propane> request system storage cleanup

List of files to delete:

         Size Date         Name
    11B Apr 17 07:41 /cf/var/jail/tmp/alarmd.ts
  2054B Apr 17 07:58 /cf/var/log/interactive-commands.0.gz
  28.1K Apr 17 07:58 /cf/var/log/messages.0.gz
```

```
    4462B Apr 17 07:41 /cf/var/tmp/cleanup-pkgs.log
       0B Apr 17 07:41 /cf/var/tmp/eedebug_bin_file
      34B Apr 17 07:41 /cf/var/tmp/gksdchk.log
   124.0K Mar  2 09:22 /cf/var/tmp/gres-tp/env.dat
       0B Mar  2 09:24 /cf/var/tmp/gres-tp/lock
       4B Apr 17 07:41 /cf/var/tmp/idp_license_info
      76B Apr 17 07:41 /cf/var/tmp/krt_gencfg_filter.txt
    4984B Mar  2 08:51 /cf/var/tmp/sampled.pkts
       0B Mar  2 09:24 /cf/var/tmp/spu_kmd_init
  Delete these files ? [yes,no] (no) yes
```

Next, delete the backup software package, if present. This package is used after an upgrade to revert back to the previous version using a `request system software roll back` command. The rollback image is no longer needed, as the current software environment is being upgraded:

```
peter@propane> request system software delete-backup
Delete backup system software package [yes,no] (no) yes

peter@propane>
```

An alternative is to use a script that Juniper created for the purpose of freeing up space on the compact flash card. This script, which is loaded on the router and run, has the same outcome as running the commands shown previously. The instructions for using the script are as follows:

1. Download the *upgrade-helper* script from *http://kb.juniper.net/KB11204* to */root* or another suitable location.
2. Execute the script by starting the shell and entering the command string `root@propane% sh ./upgrade-helper` (the assumption is that the command is run from the same location as where the helper script was loaded). The router responds with:

   ```
   Upgrade helper script started
   ATTENTION: PLEASE RUN THIS SCRIPT AGAIN IMMEDIATELY AFTER REBOOTING.
   Rebooting system.
   ```

   The system reboots.
3. Once rebooted, log in, enter the shell (for root users this is unnecessary), and execute the *upgrade-helper* script again.

Confirm that you have enough compact flash space

The release notes for Junos provide the following compact flash space guidelines:

> To copy the software image to the router and install using that image, you need at least twice the size of the image of available space on the compact flash. For example, a Junos 10.4 OS package of 197 MB will need 394 MB of free compact flash.
>
> To install the software image to the router you need at least the size of the image. You use the `no-copy`, `unlink` and `no-validate` options with the `request system software add` command to minimize the storage requirements.

The following list describes the options mentioned in the release notes:

- The `unlink` option removes the package early in the process to free up memory space.
- The `no-copy` option specifies that a copy of the package is not saved in */var/sw/pkg*.
- The `no-validate` option prevents the Junos software from validating the software package against the current configuration.

The `show system storage` command displays used and free space on the compact flash:

```
peter@propane> root> show system storage
Filesystem        Size       Used       Avail  Capacity   Mounted on
/dev/ad0s1a       920M       326M        589M       36%  /
devfs             1.0K       1.0K          0B      100%  /dev
/dev/md0          452M       452M          0B      100%  /junos
/cf               920M       326M        589M       36%  /junos/cf
devfs             1.0K       1.0K          0B      100%  /junos/dev/
procfs            4.0K       4.0K          0B      100%  /proc
/dev/bo0s1e        19M        15K         19M        0%  /config
/dev/md1          168M        15M        140M       10%  /mfs
/cf/var/jail      920M       326M        589M       36%  /jail/var
/cf/var/log       920M       326M        589M       36%  /jail/var/log
devfs             1.0K       1.0K          0B      100%  /jail/dev
/dev/md2           39M       4.0K         36M        0%  /mfs/var/run/utm

root>
.
```

In this case, 589 MB of space is available on the flash, which is more than sufficient when the `no-copy` and `unlink` switches are added.

Install the Junos Upgrade

You are now ready to upgrade the router to run the latest Junos OS. It is assumed that you have obtained the desired package from the Juniper support website, and that the image is in place on the router being migrated. Good housekeeping says the package should be stored in the */var/tmp* directory, but this requires root access.

Tips for Freeing More Space

Large files left in user directories or in nonstandard places may consume so much space that you are not able to load a new software package. If you have shell access, try this handy command:

```
peter@propane> start shell
% find -x /cf -type f -exec du {} \; | sort -n
find: /cf/var/cron/tabs: Permission denied
. . .
0       /cf/etc/namedb/resolver.cache
. . .
448     /cf/var/log/dcd
1024    /cf/var/log/chassisd
```

```
1440    /cf/var/log/httpd
107776  /cf/var/tmp/junos-jsr-10.4R1.8-domestic.tgz
114512  /cf/packages/junos-10.0R1.8-domestic
```

The output is sorted from smallest to largest files found, so you want to focus on the entries near the end of the display. Once you know where the large files are, it is a simple matter to delete or move them off the router as desired. In this example, the largest files on the systems are the soon-to-be-installed Junos OS in */var/tmp* and the currently installed Junos version in */var/cf*. Any other large files in user directories or in the */tmp* or */var/tmp* directory are good candidates for deletion. You can remove the files from the CLI with the `file delete` command and the path for the files (wildcards can be used here) or alternately from the shell with the `root@host% rm -rf /var/tmp/*` command. (This command removes all files in the */var/tmp* directory and recursively removes directories in that directory, so be careful!)

Note that symbolic links result in */var/home* being mapped to */cf/var/home*; therefore, you can use either path:

```
peter@propane% cd /var/home/
peter@propane% pwd
/cf/var/home
```

Once you have freed up enough space, it is time to perform the upgrade and issue the `request system software add` command, followed by the path and name of the Junos package to be installed. In this example, you must include the `no-copy` and `unlink` switches because of space issues described previously, and you should also add the `no-validate` switch. If the update is successful, the process will complete and ask for a reboot; if the process is not successful, error messages will be displayed and the old image will be used:

```
peter@propane> request system software add jsr-10.4r1.8-domestic.tgz no-
copy unlink no-validate
```

You can mount a normal USB drive on a Junos device by using the `mount_msdosfs` command. This allows you to download an image to your computer and use the good old sneakernet to bring the image to the router. For most devices, the full command is `root% mount_msdosfs /dev/da0s1 /var/tmp/usb`. This will create a directory on the system from which you can copy or load an image. Be sure to use the `umount` command when you are finished.

If desired, you can add the `reboot` switch to the `request system software` command to avoid having to reboot the router to complete installation. In this case, we can reboot at our leisure, but the suspense is getting heavy, so it's time to get it on, so to speak:

```
lab@propane> request system reboot
Reboot the system ? [yes,no] (no) yes
```

After a few minutes, the installation completes, and your router is back:

```
RDM Embedded 7 [04-Aug-2006] http://www.birdstep.com
Copyright (c) 1992-2006 Birdstep Technology, Inc.  All Rights Reserved.

Unix Domain sockets Lock manager
Lock manager 'lockmgr' started successfully.
Error: Profile database dictionary file missing.
Profile database initialized
Local package initialization:.
starting local daemons:.
kern.securelevel: -1 -> 1
Sun Apr 17 08:35:36 UTC 2011

Amnesiac (ttyd0)

login: peter
Password:
```

Using a USB drive to load a new image

When you have to upgrade the image on multiple routers in your network, using a USB drive can save you time and keystrokes. Rather than copy the image to the compact flash, requesting the add command, and rebooting, the USB drive is inserted, the router is rebooted from it, and then a snapshot of the current image is saved to compact flash. This process assumes that you have added the new image to one of the routers using a process similar to the one described previously. Once you have a single router with the new image, create a bootable USB drive with a snapshot of the image, and insert a USB drive into the port of the upgraded router. From the CLI, enter the following command:

```
peter@propane> request system snapshot media usb partition as-primary

Clearing current label...
Partitioning usb media (da0) ...
Partitions on snapshot:

  Partition  Mountpoint  Size    Snapshot argument
      a      /           1024MB  root-size
      e      /config     196MB   config-size
      g      /data       693MB   data-size
Running newfs (1024MB) on usb media / partition (da0s1a)...
Running newfs (196MB) on usb media /config partition (da0s1e)...
Running newfs (693MB) on usb media /data partition (da0s1g)...
Copying '/dev/ad0s1a' to '/dev/da0s1a' .. (this may take a few minutes)
Copying '/dev/ad0s1e' to '/dev/da0s1e' .. (this may take a few minutes)
The following filesystems were archived: / /config

peter@propane>
```

At this point you have an image on the USB drive. Go to the next router to be upgraded, and insert the USB drive in that device. Mount the USB drive from the shell with the `mount` command. Once mounted, reboot the router using the USB drive. Perform a snapshot of the image, and reboot once again from the compact flash. Here are example commands and the router responses for this upgrade process:

```
peter@propane> start shell
% su
Password:
root@propane% mount /dev/da0s1 /var/tmp/usb
root@propane% exit
exit
% exit
exit

peter@propane> show system storage
Filesystem        Size        Used       Avail  Capacity   Mounted on
/dev/ad0s1a       460M        326M        129M       72%  /
devfs             1.0K        1.0K          0B      100%  /dev
/dev/md0          452M        452M          0B      100%  /junos
/cf               460M        326M        129M       72%  /junos/cf
devfs             1.0K        1.0K          0B      100%  /junos/dev/
procfs            4.0K        4.0K          0B      100%  /proc
/dev/bo0s1e        19M         15K         19M        0%  /config
/dev/md1          168M         15M        140M       10%  /mfs
/cf/var/jail      460M        326M        129M       72%  /jail/var
/cf/var/log       460M        326M        129M       72%  /jail/var/log
devfs             1.0K        1.0K          0B      100%  /jail/dev
/dev/md2           39M        4.0K         36M        0%  /mfs/var/run/utm
/dev/da0s1        856M        152M        696M       18%  /cf/var/tmp/usb

peter@propace> request system reboot media usb

Clearing current label...

Trying to boot from USB device ...
Loading /boot/loader
.....

login: peter
Password:

--- JUNOS 10.4R1.9 built 2010-12-04 09:16:15 UTC ---
--- NOTICE: System is running on alternate media device  (/dev/da0s1a).
---
```

Upgrading from a USB drive when the compact flash is not large enough

In some instances it is necessary to upgrade a device, even when there is not enough room on the compact flash to hold the new image. In these cases a USB drive can be used to provide additional storage for the router. The process involves adding the USB drive to the router memory system, copying the image to the USB drive, and upgrading the image from that drive. The procedure listed here is for images that are newer than 8.5. For older Junos images, refer to *http://kb.juniper.net/KB8017* (the device names are different—`da0c` versus `da0`—in the older procedures).

The step-by-step procedures are as follows:

1. Connect the USB flash drive to the USB port of the router.
2. Log into the device as root (required for many of the following commands), and format the USB drive from the shell (`start shell`) using the low-level copy `dd` command:

   ```
   root@propane> start shell
   root@propane % dd if=/dev/zero of=/dev/da0 bs=128k
   ```

   The `dd` command does not provide any input to the user and might take a couple of minutes to complete.

   If the `dd` command fails to format the USB drive, use the `snapshot` command provided in the previous section.

3. Label the USB flash drive using the `disklabel` command:

   ```
   root@propane% disklabel -R -w da0 auto
   ```

   For earlier versions of Junos, use the `-r` modifier rather than the `-R` shown here.
4. Create the filesystem on the USB flash drive by using the `newfs` command:

   ```
   root@pbr% newfs -U /dev/da0
             /dev/da0: nanMB (1000944 sectors) block size 16384,
             fragment size 2048 using 4 cylinder groups of 122.19MB, 7820 blks,
             15744 inodes with soft updates
             super-block backups (for fsck -b #) at:
              32, 250272, 500512, 750752
   ```

   For earlier versions of Junos, the device name is `da0c`, not the `da0` shown here.
5. Create a directory on the flash drive to be used as a mounting identifier for the drive and a copy location for the image. Use the `mkdir` command to create the directory called */var/tmp/usb*:

   ```
   root@pbr% mkdir /var/tmp/usb
   ```

6. Now that the device is aligned with the existing filesystem, we have to mount the USB device using `mount` command:

   ```
   root@pbr% mount /dev/da0 /var/tmp/usb
   ```

   Removing the USB flash drive without issuing the `umount` command could cause operational problems or filesystem corruption.

7. Verify that the USB drive has successfully mounted using command `df -h`:

   ```
   root@pbr% df -h
             Filesystem      Size    Used    Avail Capacity  Mounted on
   ```

```
          /dev/ad0s1a     851M    277M    565M    33%    /
          devfs           1.0K    1.0K      0B   100%    /dev
          devfs           1.0K    1.0K      0B   100%    /dev/
          /dev/md0        133M    133M      0B   100%    /junos
          /cf             851M    277M    565M    33%    /junos/cf
          devfs           1.0K    1.0K      0B   100%    /junos/dev/
          procfs          4.0K    4.0K      0B   100%    /proc
          /dev/bo0s1e      95M     16K     94M     0%    /config
          /dev/md1        336M    7.2M    302M     2%    /mfs
          /cf/var/jail    851M    277M    565M    33%    /jail/var
          devfs           1.0K    1.0K      0B   100%    /jail/dev
          /dev/da0        481M    4.0K    442M     0%    /cf/var/tmp/usb
```

8. The USB flash drive now can be used for any purposes within the router. Our purpose is to add room to store the upgrade image. We copy the image from our FTP server to the new */var/tmp/usb* directory, thereby freeing up space on the compact flash drive. We can copy from the shell or the CLI. In the following example, we are copying from the command line:

```
root@pbr> file copy ftp://1.1.1.1/junos-jsr-10.4R1.9-domestic.tgz
/var/tmp/usb
          /var/tmp//...transferring.file.........PQ6d3g/100% of
48 MB 4209 kBps 00m00s
```

9. Verify that the image is present on the USB drive:

```
root@pbr> file list detail /var/tmp/usb
          /var/tmp/usb:
          total 36946
          drwxrwxr-x  2 root  operator       512 Feb 13  2011 .snap/
          -rw-r--r--  1 root  wheel   18874368 Feb 13 23:07 junos-
jsr-10.4R1.9-domestic.tgz
```

10. Finally, it is time to upgrade your router using the USB drive as the image file source. Use the `no-copy` and `no-link` options to reduce the storage requirements (see the earlier definitions of these knobs), and point the loader to the directory on the USB drive. Remember that you can use the Tab key for auto-complete. We added the `reboot` knob as well, just to save time:

```
root@pbr request system software add /var/tmp/usb/
           junos-jseries-8.5R2.10-domestic.tgz no-copy no-link reboot
```

11. When the router reboots, the USB drive is unmounted from the filesystem. It can be unmounted manually using the `umount` command. Because the `umount` command does not have any response, use the `file list /var/tmp/usb` command to verify that the drive is not present. Once unmounted, it is safe to remove the USB drive from the device. The `unmount` command is:

```
root@pbr% umount /var/tmp/usb
```

Loading an SRX from a USB drive

Unclustered Branch Office SRX devices (SRX100, SRX210, SRX220, SRX240, and SRX650) can be upgraded easily, even without access to the command line. The SRX has a feature that allows the reset button to act as an upgrade button when an appropriate USB device is attached. An appropriate USB device is one that has been formatted for Junos and has a software image and an *autoinstall.conf* file.

The *autoinstall.conf* file is nothing more than a placeholder so that the SRX recognizes this USB drive as a bootable device. It is an empty file that simply has the name *autoinstall.conf*.

Use the following steps to upgrade an unclustered Branch Office SRX:

1. Format a USB drive as defined in the previous section, and copy the image to the drive.
2. Create a file called *autoinstall.conf* on your desktop, and copy it to the USB drive.
3. Assure that the SRX to be upgraded has enough memory to perform a normal upgrade. (If this is not the case, this process will not work.)
4. Insert the USB flash drive into the USB port of the SRX, and monitor the status LED on the front panel. When the LED blinks amber, then steadily light amber, this indicates that the USB has been detected and is a bootable drive (i.e., it has the *autoinstall.conf* file present). If the LEDs do not show amber, either the flash drive is not set up correctly or the device needs to be power cycled.
5. When the proper LED indications are seen (steady amber), press the recessed Reset Config button. This will cause the SRX to install the image it finds on the USB drive. Once the installation is complete, the status LED turns a steady green.
6. At this point, remove the USB drive. The SRX will automatically restart with the new Junos version.

If the status LED turns red, an error has occurred in the installation. At this point, console access is required to determine what has gone awry (corrupted image, not enough space, incompatible configuration, etc.).

Upgrade Summary

For multiple reasons, the normal process of upgrading the image on a Junos-based device might be impossible. The normal culprit is a lack of space on the compact flash card. To sidestep this issue and others, the procedures outlined in this appendix will help.

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We'd like to hear your suggestions for improving our indexes. Send email to *index@oreilly.com*.

Colophon

The animal on the cover of *Junos Enterprise Routing*, second edition, is Tengmalm's owl (*Aegolius funereus*), known in North America as the boreal owl. The bird's namesake is Swedish naturalist Peter Gustaf Tengmalm, who is noted for his contributions to owl classification. The small owl (8–12 inches long) is distinguished by its pale or bright yellow eyes and its brown body spotted with white flecks. Its belly is usually off-white.

This solitary, largely unsociable owl lives in thick forests and high altitudes in Eurasia (it is common in Scandinavia). It is somewhat less prevalent in Alaska, Canada, and the northern United States. These owls often nest in the old homes of woodpeckers. These nocturnal hunters feed on birds, insects, and small mammals. Their asymmetrically located ears help them precisely locate prey by sound, even through snow.

Some identify the bird's call with the peal of a funeral bell or a mourner's cry; hence the *funereus* in its species name. The owl's territorial call, by contrast, sounds like the word "poop" sung several times in rapid succession. When wooing a female, the male sings a series of stutters that eventually crescendo in a long trill of up to 350 notes. In North America, scientists named the owl after the Greek god of the north wind, Boreas, referring not to the owl's voice, but to its northern habitats.

The cover image is from *Dover's Animals*. The cover font is Adobe ITC Garamond. The text font is Linotype Birka; the heading font is Adobe Myriad Condensed; and the code font is LucasFont's TheSansMonoCondensed.