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CCNA Routing and Switching ICND2 200-105

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CCNA Routing and Switching

ICND2 200-105

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Academic Edition

WENDELL ODOM, CCIE No. 1624

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Wendell Odom with contributing author Scott Hogg

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Dedications

For Kris Odom, my wonderful wife: The best part of everything we do together in life. Love you, doll.

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Reader Services

To access additional content for this book, simply register your product. To start the registration process, go to www.ciscopress.com/register and log in or create an account*. Enter the product ISBN 9781587205989 and click Submit. After the process is complete, you will find any available bonus content under Registered Products.

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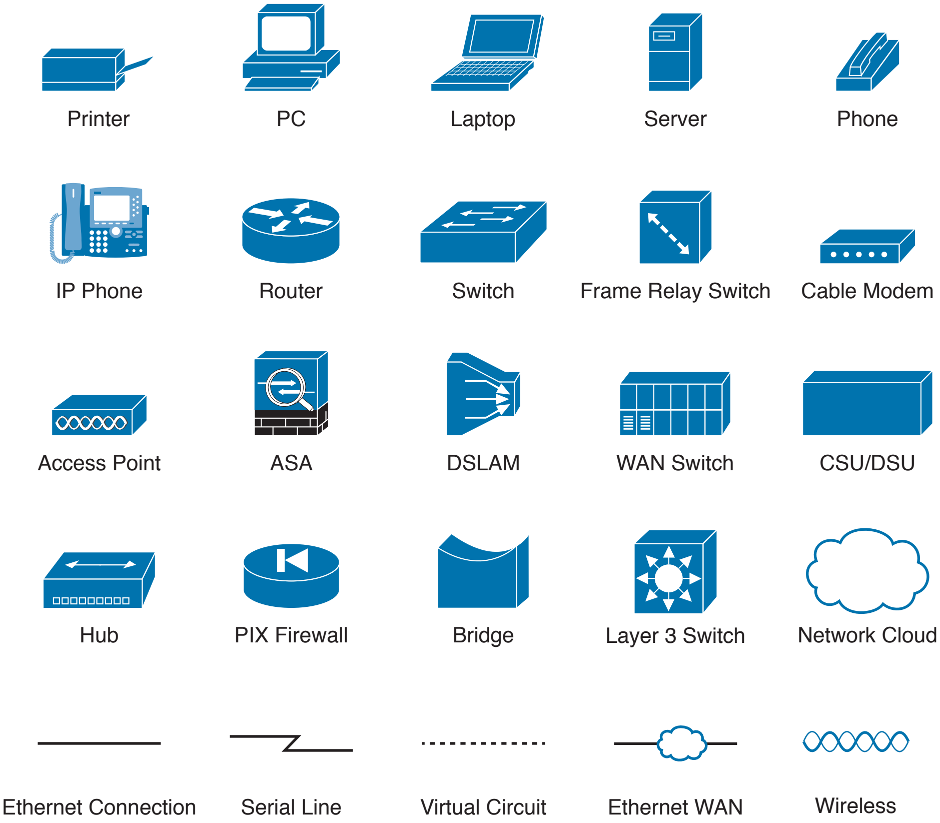

Command Syntax Conventions

The conventions used to present command syntax in this book are the same conventions used in the IOS Command Reference. The Command Reference describes these conventions as follows:

- **Boldface** indicates commands and keywords that are entered literally as shown. In actual configuration examples and output (not general command syntax), boldface indicates commands that are manually input by the user (such as a **show** command).
- *Italic* indicates arguments for which you supply actual values.
- Vertical bars (|) separate alternative, mutually exclusive elements.
- Square brackets ([ ]) indicate an optional element.
- Braces ({ }) indicate a required choice.
- Braces within brackets ([{ }]) indicate a required choice within an optional element.

Introduction

About the Exams

Congratulations! If you're reading far enough to look at this book's Introduction, you've probably already decided to go for your Cisco certification. If you want to succeed as a technical person in the networking industry at all, you need to know Cisco. Cisco has a ridiculously high market share in the router and switch marketplace, with more than 80 percent market share in some markets. In many geographies and markets around the world, networking equals Cisco. If you want to be taken seriously as a network engineer, Cisco certification makes perfect sense.

The Exams to Achieve CCENT and CCNA R&S

Cisco announced changes to the CCENT and CCNA Routing and Switching certifications, and the related 100-105 ICND1, 200-105 ICND2, and 200-125 CCNA exams, early in the year 2016. Most everyone new to Cisco certifications begins with either CCENT or CCNA Routing and Switching (CCNA R&S). However, the paths to certification are not quite obvious at first.

The CCENT certification requires a single step: pass the ICND1 exam. Simple enough.

Cisco gives you two options to achieve CCNA R&S certification, as shown in Figure I-1: pass both the ICND1 and ICND2 exams, or just pass the CCNA exam. Both paths cover the same exam topics, but the two-exam path does so spread over two exams rather than one. You also pick up the CCENT certification by going through the two-exam path, but you do not when working through the single-exam (200-125) option.

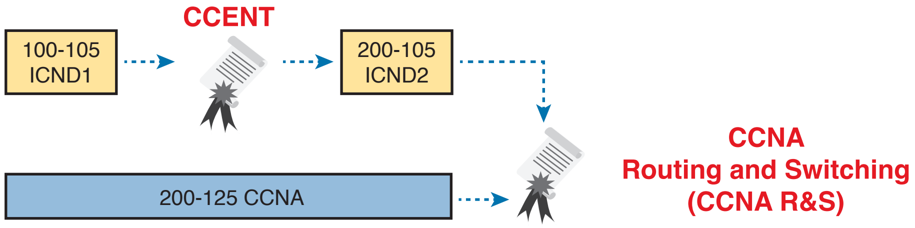

Figure I-1 *Cisco Entry-Level Certifications and Exams*

Note that Cisco has begun referencing some exams with a version number on some of their websites. If that form holds true, the exams in Figure I-1 will likely be called version 3 (or v3 for short). Historically, the 200-125 CCNA R&S exam is the seventh separate version of the exam (which warrants a different exam number), dating back to 1998. To make sure you reference the correct exam, when looking for information, using forums, and registering for the test, just make sure to use the correct exam number as shown in the figure.

Types of Questions on the Exams

The ICND1, ICND2, and CCNA R&S exams all follow the same general format. At the testing center, you sit in a quiet room with a PC. Before the exam timer begins, you have a chance to do a few other tasks on the PC; for instance, you can take a sample quiz just to get accustomed to the PC and the testing engine. Anyone who has user-level skills in getting around a PC should have no problems with the testing environment. The question types are

- Multiple-choice, single-answer
- Multiple-choice, multiple-answer
- Testlet (one scenario with several multiple-choice questions)
- Drag-and-drop

- Simulated lab (sim)
- Simlet

You should take the time to learn as much as possible by using the Cisco Certification Exam Tutorial, which you can find by going to Cisco.com and searching for "exam tutorial." This tool walks through each type of question Cisco may ask on the exam.

Although the first four types of questions in the list should be familiar to anyone who has taken standardized tests or similar tests in school, the last two types are more common to IT tests and Cisco exams in particular. Both use a network simulator to ask questions, so that you control and use simulated Cisco devices. In particular:

- **Sim questions:** You see a network topology, a lab scenario, and can access the devices. Your job is to fix a problem with the configuration.
- **Simlet questions:** This style combines sim and testlet question formats. Like a sim question, you see a network topology, a lab scenario, and can access the devices. However, like a testlet, you also see several multiple-choice questions. Instead of changing/fixing the configuration, you answer questions about the current state of the network.

Using these two question styles with the simulator enables Cisco to test your configuration skills with sim questions, and your verification and troubleshooting skills with simlet questions.

What's on the CCNA Exams…and in the Book?

Ever since I was in grade school, whenever the teacher announced that we were having a test soon, someone would always ask, "What's on the test?" Even in college, people would try to get more information about what would be on the exams. At heart, the goal is to know what to study hard, what to study a little, and what to not study at all.

You can find out more about what's on the exam from two primary sources: this book and the Cisco website.

The Cisco Published Exam Topics

First, Cisco tells the world the specific topics on each of their certification exams. For every Cisco certification exam, Cisco wants the public to know both the variety of topics and what kinds of knowledge and skills are required for each topic. Just go to http://www.cisco.com/go/certifications, look for the CCENT and CCNA Routing and Switching pages, and navigate until you see the exam topics.

Note that this book lists those same exam topics in Appendix L, "Exam Topic Cross Reference." This PDF appendix lists two cross references: one with a list of the exam topics in the order in which Cisco lists them on their website; and the other with a list of chapters in this book with the corresponding exam topics included in each chapter.

Cisco does more than just list the topic (for example, IPv4 addressing); they also list the depth to which you must master the topic. The primary exam topics each list one or more verbs that describe the skill level required. For example, consider the following exam topic, which describes one of the most important topics in both CCENT and CCNA R&S:

> Configure, verify, and troubleshoot IPv4 addressing and subnetting

Note that this one exam topic has three verbs (configure, verify, and troubleshoot). So, you should be able to not only configure IPv4 addresses and subnets, but also understand them well enough to verify that the configuration works, and to troubleshoot problems when it is not working. And if to do that you need to understand concepts and need to have other knowledge, those details are implied. The exam questions will attempt to assess whether you can configure, verify, and troubleshoot.

The Cisco exam topics provide the definitive list of topics and skill levels required by Cisco for the exams. But the list of exam topics provides only a certain level of depth. For example, the ICND1 100-105 exam topics list has 41 primary exam topics (topics with verbs), plus additional subtopics that provide more details about that technology area. Although very useful, the list of exam topics would take about five pages of this book if laid out in a list.

You should take the time to not only read the exam topics, but read the short material above the exam topics as listed at the Cisco web page for each certification and exam. Look for notices about the use of unscored items, and how Cisco intends the exam topics to be a set of general guidelines for the exams.

This Book: About the Exam Topics

This book provides a complete study system for the Cisco published exam topics for the ICND2 200-105 exam. All the topics in this book either directly relate to some ICND2 exam topic or provide more basic background knowledge for some exam topic. The scope of the book is defined by the exam topics.

For those of you thinking more specifically about the CCNA R&S certification, and the CCNA 200-125 single-exam path to CCNA, this book covers about one-half of the CCNA exam topics. The *CCENT/CCNA ICND1 100-105 Official Cert Guide* (and ICND1 100-105 exam topics) covers about half of the topics listed for the CCNA 200-125 exam, and this book (and the ICND2 200-105 exam topics) covers the other half. In short, for content, CCNA = ICND1 + ICND2.

Book Features

This book (and the related *CCENT/CCNA ICND1 100-105 Official Cert Guide*) goes beyond what you would find in a simple technology book. It gives you a study system designed to help you not only learn facts but also to develop the skills you need to pass the exams. To do that, in the technology chapters of the book, about three-quarters of the chapter is about the technology, and about one-quarter is for the related study features.

The "Foundation Topics" section of each chapter contains rich content to explain the topics on the exam and to show many examples. This section makes extensive use of figures, with lists and tables for comparisons. It also highlights the most important topics in each chapter as key topics, so you know what to master first in your study.

Most of the book's features tie in some way to the need to study beyond simply reading the "Foundation Topics" section of each chapter. The rest of this section explains these book features. And because the book organizes your study by chapter, and then by part (a part contains multiple chapters), and then a final review at the end of the book, the next section of this Introduction discusses the book features introduced by chapter, part, and for final review.

Chapter Features and How to Use Each Chapter

Each chapter of this book is a self-contained short course about one topic area, organized for reading and study as follows:

- **Foundation Topics:** This is the heading for the core content section of the chapter.
- **Chapter Review:** This section includes a list of study tasks useful to help you remember concepts, connect ideas, and practice skills-based content in the chapter.

In addition to these two main chapter features, each "Chapter Review" section presents a variety of other book features, including the following:

- **Review Key Topics:** In the "Foundation Topics" section, the Key Topic icon appears next to the most important items, for the purpose of later review and mastery. While all content matters, some is, of course, more important to learn, or needs more review to master, so these items are noted as key topics. The "Review Key Topics" section lists the key topics in a table; scan the chapter for these items to review them.

- **Chapter Summary:** This section provides a list of the key concepts covered in each chapter for quick reference and review.
- **Review Questions:** These questions help you test your understanding of the material covered in each chapter.
- **Complete Tables from Memory:** Instead of just rereading an important table of information, some tables have been marked as memory tables. These tables exist in the Memory Table app that is available on the DVD and from the companion website. The app shows the table with some content removed, and then reveals the completed table, so you can work on memorizing the content.
- **Key Terms You Should Know:** You do not need to be able to write a formal definition of all terms from scratch. However, you do need to understand each term well enough to understand exam questions and answers. This section lists the key terminology from the chapter. Make sure you have a good understanding of each term, and use the DVD Glossary to cross-check your own mental definitions.
- **Labs:** Many exam topics use the verbs "configure," "verify," and "troubleshoot"; all these refer to skills you should practice at the command-line interface (CLI) of a router or switch. The Chapter Review refers you to these other tools. The Introduction's section titled "About Building Hands-On Skills" discusses your options.
- **Command References:** Some book chapters cover a large number of router and switch commands. This section includes reference tables for the commands used in that chapter, along with an explanation. Use these tables for reference, but also use them for study—just cover one column of the table, and see how much you can remember and complete mentally.

Part Features and How to Use Part Review

The book organizes the chapters into seven parts. Each part contains a number of related chapters. Figure I-2 lists the titles of the parts and identifies the chapters in those parts by chapter numbers.

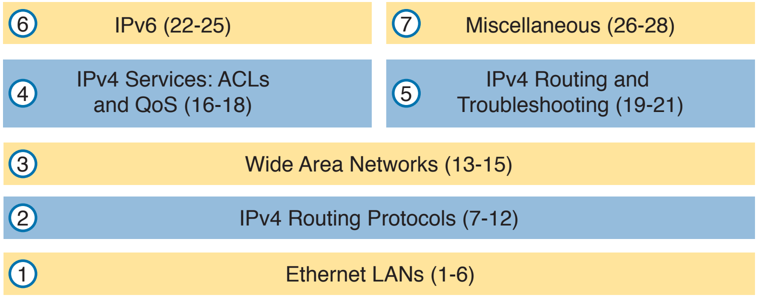
6 IPv6 (22-25)
7 Miscellaneous (26-28)
4 IPv4 Services: ACLs and QoS (16-18)
5 IPv4 Routing and Troubleshooting (19-21)
3 Wide Area Networks (13-15)
2 IPv4 Routing Protocols (7-12)
1 Ethernet LANs (1-6)

Figure I-2 *The Book Parts and Corresponding Chapter Numbers*

Each book part ends with a "Part Review" section that contains a list of activities for study and review, much like the "Chapter Review" section at the end of each chapter. However, because the Part Review takes place after completing a number of chapters, the Part Review includes some tasks meant to help pull the ideas together from this larger body of work. The following list explains the types of tasks added to each Part Review beyond the types mentioned for the Chapter Review:

- **Answer Part Review Questions:** The books come with exam software and databases of questions. One database holds questions written specifically for Part Reviews. These questions tend to connect multiple ideas together, to help you think about topics from multiple chapters, and to build the skills needed for the more challenging analysis questions on the exams.

- **Mind Maps:** Mind maps are graphical organizing tools that many people find useful when learning and processing how concepts fit together. The process of creating mind maps helps you build mental connections. The Part Review elements make use of mind maps in several ways: to connect concepts and the related configuration commands, to connect **show** commands and the related networking concepts, and even to connect terminology. (For more information about mind maps, see the section "About Mind Maps" later in this Introduction.)
- **Labs:** Each "Part Review" section will direct you to the kinds of lab exercises you should do with your chosen lab product, labs that would be more appropriate for this stage of study and review. (Check out the later section "About Building Hands-On Skills" for information about lab options.)

In addition to these tasks, many "Part Review" sections have you perform other tasks with book features mentioned in the "Chapter Review" section: repeating chapter review quiz questions, reviewing key topics, and doing more lab exercises.

Final Review

Chapter 29, "Final Review," lists a series of preparation tasks that you can best use for your final preparation before taking the exam. Chapter 29 focuses on a three-part approach to helping you pass: practicing your skills, practicing answering exam questions, and uncovering your weak spots. To that end, Chapter 29 uses the same familiar book features discussed for the Chapter Review and Part Review elements, along with a much larger set of practice questions.

Other Features

In addition to the features in each of the core chapters, this book, as a whole, has additional study resources, including the following:

- **Premium Edition Practice Test:** This Academic Edition comes with a free version of the Premium Edition Practice Test. To access this test, you will need to redeem the digital product voucher listed on the card in the DVD sleeve in the back of this book. You can take simulated ICND2 exams, as well as CCNA exams, with the Premium Edition Practice Test activation code you will get when you redeem the digital product voucher on our website. (You can take simulated ICND1 and CCNA R&S exams with the DVD in the *CCENT/CCNA ICND1 100-105 Official Cert Guide*.)
- **CCNA ICND2 Simulator Lite:** This lite version of the best-selling CCNA Network Simulator from Pearson provides you with a means, right now, to experience the Cisco CLI. No need to go buy real gear or buy a full simulator to start learning the CLI. Just install it from the DVD in the back of this book.
- **eBook:** This Academic Edition comes complete with three free eBook files. To access these files, you will need to redeem the Premium Edition eBook and Practice Test digital product voucher code found on the access card in the DVD sleeve. This will give you access to the PDF, EPUB, and Kindle versions of the eBook.
- **Mentoring Videos:** The DVD included with this book includes four other instructional videos about the following topics: OSPF, EIGRP, EIGRP metrics, plus PPP and CHAP.
- **Companion website:** The website http://www.ciscopress.com/title/9781587205989 posts up-to-the-minute materials that further clarify complex exam topics. Check this site regularly for new and updated postings written by the author that provide further insight into the more troublesome topics on the exam.
- **PearsonITCertification.com:** The website http://www.pearsonitcertification.com is a great resource for all things IT-certification related. Check out the great CCNA articles, videos, blogs, and other certification preparation tools from the industry's best authors and trainers.

- **CCNA Simulator:** If you are looking for more hands-on practice, you might want to consider purchasing the CCNA Network Simulator. You can purchase a copy of this software from Pearson at http://pearsonitcertification.com/networksimulator or other retail outlets. To help you with your studies, I have created a mapping guide that maps each of the labs in the simulator to the specific sections in these CCNA cert guides. You can get this mapping guide for free on the Extras tab of the companion website.
- **Author's website and blogs:** I maintain a website that hosts tools and links that are useful when studying for CCENT and CCNA. The site lists information to help you build your own lab, study pages that correspond to each chapter of this book and the ICND1 book, and links to my CCENT Skills blog and CCNA Skills blog. Start at http://www.certskills.com; click the Blog tab for a page about the blogs in particular, with links to the pages with the labs related to this book.

A Big New Feature: Review Applications

One of the single biggest new features of this edition of the book is the addition of study apps for many of the Chapter Review activities. In the past, all Chapter Review activities used only the book chapter, or the chapter plus a DVD-only appendix. Readers tell us they find that content useful, but the content is static.

This book and the *CCENT/CCNA ICND1 100-105 Official Cert Guide* are the first Cisco Press Cert Guides with extensive interactive applications. Basically, most every activity that can be done in the "Chapter Review" sections can now be done with an application. The apps can be found both on the DVD that comes with the book and on the book's companion website. On the DVD you can find the apps under the "Chapter and Part Review" tab.

The advantages of using these apps are as follows:

- **Easier to use:** Instead of having to print out copies of the appendixes and do the work on paper, these new apps provide you with an easy-to-use, interactive experience that you can easily run over and over.
- **Convenient:** When you have a spare 5–10 minutes, go to the book's website, and review content from one of your recently finished chapters.
- **Untethered from book/DVD:** Because these apps are available on the book's companion website in addition to the DVD, you can access your review activities from anywhere—no need to have the book or DVD with you.
- **Good for tactile learners:** Sometimes looking at a static page after reading a chapter lets your mind wander. Tactile learners may do better by at least typing answers into an app, or clicking inside an app to navigate, to help keep you focused on the activity.

Our in-depth reader surveys show that readers who use the Chapter Review tools like them, but that not everyone uses them consistently. So, we want to increase the number of people using the review tools, and make them both more useful and more interesting. Table I-1 summarizes these new applications and the traditional book features that cover the same content.

Table I-1 Book Features with Both Traditional and App Options

Feature	Traditional	App
Key Topics	Table with list; flip pages to find	Key Topics Table app
Config Checklist	Just one of many types of key topics	Config Checklist app
Memory Table	Two static PDF appendixes (one with sparse tables for you to complete, one with completed tables)	Memory Table app

Feature	Traditional	App
Key Terms	Listed in each “Chapter Review” section, with the Glossary in the back of the book	Glossary Flash Cards app
IPv4 ACL Practice	A static PDF appendix (D) with practice problems	An interactive app that asks the same problems as listed in the appendix

How to Get the Electronic Elements of This Book

Traditionally, all chapter review activities use the book chapter plus appendixes, with the appendixes often being located on the DVD. But most of that content is static—useful, but static.

If you buy the print book, and have a DVD drive, you have all the content on the DVD. Just spin the DVD and use the disk menu (which should automatically start) to explore all the content.

If you buy the print book but do not have a DVD drive, you can get the DVD files by redeeming your Premium Edition eBook and Practice Test digital product voucher code on our website. After you have redeemed this product, your book will automatically be registered on your account page. Simply go to your account page, click the **Registered Products** tab, and select **Access Bonus Content** to access the book’s companion website.

Book Organization, Chapters, and Appendixes

This book contains 28 core chapters, Chapters 1 through 28, with Chapter 29 as the “Final Review” chapter. Each core chapter covers a subset of the topics on the ICND2 exam. The core chapters are organized into sections. The core chapters cover the following topics:

Part I: Ethernet LANs

- **Chapter 1, “Implementing Ethernet Virtual LANs,”** explains the concepts and configuration surrounding virtual LANs, including VLAN trunking.
- **Chapter 2, “Spanning Tree Protocol Concepts,”** discusses the concepts behind IEEE Spanning Tree Protocol (STP) and how it makes some switch interfaces block frames to prevent frames from looping continuously around a redundant switched LAN.
- **Chapter 3, “Spanning Tree Protocol Implementation,”** shows how to configure and verify STP on Cisco switches.
- **Chapter 4, “LAN Troubleshooting,”** examines the most common LAN switching issues and how to discover those issues when troubleshooting a network. The chapter includes troubleshooting topics for STP/RSTP, Layer 2 EtherChannel, LAN switching, VLANs, and VLAN trunking.
- **Chapter 5, “VLAN Trunking Protocol,”** shows how to configure, verify, and troubleshoot the use of VLAN Trunking Protocol (VTP) to define and advertise VLANs across multiple Cisco switches.
- **Chapter 6, “Miscellaneous LAN Topics,”** as the last chapter in the book specifically about LANs, discusses a variety of small topics, including: 802.1x, AAA authentication, DHCP snooping, switch stacking, and chassis aggregation.

Part II: IPv4 Routing Protocols

- **Chapter 7, “Understanding OSPF Concepts,”** introduces the fundamental operation of the Open Shortest Path First (OSPF) protocol, focusing on link state fundamentals, neighbor relationships, flooding link state data, and calculating routes based on the lowest cost metric.
- **Chapter 8, “Implementing OSPF for IPv4,”** takes the concepts discussed in the previous chapter and shows how to configure and verify those same features.

- **Chapter 9, "Understanding EIGRP Concepts,"** introduces the fundamental operation of the Enhanced Interior Gateway Routing Protocol (EIGRP) for IPv4 (EIGRPv4), focusing on EIGRP neighbor relationships, how EIGRP calculates metrics, and how it quickly converges to alternate feasible successor routes.
- **Chapter 10, "Implementing EIGRP for IPv4,"** takes the concepts discussed in the previous chapter and shows how to configure and verify those same features.
- **Chapter 11, "Troubleshooting IPv4 Routing Protocols,"** walks through the most common problems with IPv4 routing protocols, while alternating between OSPF examples and EIGRP examples.
- **Chapter 12, "Implementing External BGP,"** examines the basics of the Border Gateway Protocol (BGP) and its use between an enterprise and an ISP, showing how to configure, verify, and troubleshoot BGP in limited designs.

Part III: Wide Area Networks

- **Chapter 13, "Implementing Point-to-Point WANs,"** explains the core concepts of how to build a leased-line WAN and the basics of the two common data link protocols on these links: HDLC and PPP.
- **Chapter 14, "Private WANs with Ethernet and MPLS,"** explores the concepts behind building a WAN service using Ethernet through different Metro Ethernet services, as well as using Multiprotocol Label Switching (MPLS) VPNs.
- **Chapter 15, "Private WANs with Internet VPNs,"** works through a variety of conceptual material, plus some configuration and verification topics, for several technologies related to using the Internet to create a private WAN connection between different enterprise sites.

Part IV: IPv4 Services: ACLs and QoS

- **Chapter 16, "Basic IPv4 Access Control Lists,"** examines how standard IP ACLs can filter packets based on the source IP address so that a router will not forward the packet.
- **Chapter 17, "Advanced IPv4 Access Control Lists,"** examines both named and numbered ACLs, and both standard and extended IP ACLs.
- **Chapter 18, "Quality of Service (QoS),"** discusses a wide variety of concepts all related to the broad topic of QoS.

Part V: IPv4 Routing and Troubleshooting

- **Chapter 19, "IPv4 Routing in the LAN,"** shows to a configuration and troubleshooting depth different methods to route between VLANs, including Router on a Stick (ROAS), Layer 3 switching with SVIs, Layer 3 switching with routed ports, and using Layer 3 EtherChannels.
- **Chapter 20, "Implementing HSRP for First-Hop Routing,"** discusses the need for a First Hop Redundancy Protocol (FHRP), and specifically how to configure, verify, and troubleshoot Hot Standby Router Protocol (HSRP)
- **Chapter 21, "Troubleshooting IPv4 Routing,"** looks at the most common IPv4 problems and how to find the root causes of those problems when troubleshooting.

Part VI: IPv6

- **Chapter 22, "IPv6 Routing Operation and Troubleshooting,"** reviews IPv6 routing as discussed in the ICND1 book. It then shows some of the most common problems with IPv6 routing and discusses how to troubleshoot these problems to discover the root cause.
- **Chapter 23, "Implementing OSPF for IPv6,"** explores OSPFv3 and its use as an IPv6 routing protocol, showing traditional configuration, verification, and troubleshooting topics.

- **Chapter 24, "Implementing EIGRP for IPv6,"** takes the EIGRP concepts discussed for IPv4 in Chapter 9 and shows how those same concepts apply to EIGRP for IPv6. It then shows how to configure, verify, and troubleshoot EIGRP for IPv6.
- **Chapter 25, "IPv6 Access Control Lists,"** examines the similarities and differences between IPv4 ACLs and IPv6 ACLs, then shows how to configure, verify, and troubleshoot IPv6 ACLs.

Part VII: Miscellaneous

- **Chapter 26, "Network Management,"** discusses several network management topics that Cisco did not choose to put into ICND1, namely: SNMP, IP SLA, and SPAN.
- **Chapter 27, "Cloud Computing,"** is one of two chapters about topics that strays from traditional CCNA R&S topics as one of the Cisco emerging technology topics. This chapter explains the basic concepts and then generally discusses the impact that cloud computing has on a typical enterprise network.
- **Chapter 28, "SDN and Network Programmability,"** is the other chapter that moves away from traditional CCNA R&S topics to discuss many concepts and terms related to how Software Defined Networking (SDN) and network programmability are impacting typical enterprise networks.

Part VIII: Final Prep

- **Chapter 29, "Final Review,"** suggests a plan for final preparation once you have finished the core parts of the book, in particular explaining the many study options available in the book.

Part IX: Appendixes (In Print)

- **Appendix A, "Numeric Reference Tables,"** lists several tables of numeric information, including a binary-to-decimal conversion table and a list of powers of 2.
- **Appendix B, "CCNA ICND2 200-105 Exam Updates,"** is a place for the author to add book content mid-edition. Always check online for the latest PDF version of this appendix; the appendix lists download instructions.
- The **Glossary** contains definitions for all of the terms listed in the "Key Terms You Should Know" sections at the conclusion of Chapters 1 through 28.

Part X: DVD Appendixes

The following appendixes are available in digital format on the DVD that accompanies this book:

- **Appendix C, "Answers to the Chapter Review Quizzes,"** includes the explanations to all the questions from Chapters 1 through 28.
- **Appendix D, "Practice for Chapter 16: Basic IPv4 Access Control Lists,"** is a copy of the *CCENT/CCNA ICND1 100-105 Official Cert Guide*'s Appendix I.
- **Appendix E, "Mind Map Solutions,"** shows an image of sample answers for all the part-ending mind map exercises.
- **Appendix F, "Study Planner,"** is a spreadsheet with major study milestones, where you can track your progress through your study.
- **Appendix G, "Learning IPv4 Routes with RIPv2,"** explains how routers work together to find all the best routes to each subnet using a routing protocol. This chapter also shows how to configure the RIPv2 routing protocol for use with IPv4. (This appendix is a copy of ICND1's Chapter 19, and is included with the ICND2 book for convenience.)
- **Appendix H, "Understanding Frame Relay Concepts,"** explains how to build a Frame Relay WAN between routers, focusing on the protocols and concepts rather than the configuration. (This chapter is a chapter that covers old exam topics from the previous edition of the book, included here for those who might be interested.)

- **Appendix I, "Implementing Frame Relay,"** takes the concepts discussed in Appendix H and shows how to configure, verify, and troubleshoot those same features. (This chapter is a chapter that covers old exam topics from the previous edition of the book, included here for those who might be interested.)
- **Appendix J, "IPv4 Troubleshooting Tools,"** focuses on how to use two key troubleshooting tools to find routing problems: the **ping** and **traceroute** commands. (This appendix is a copy of ICND1's Chapter 23, and is included with the ICND2 book for convenience.)
- **Appendix K, "Topics from Previous Editions,"** is a collection of information about topics that have appeared on previous versions of the CCNA exams. While you most likely will not encounter exam questions on these topics, the concepts are still of interest to someone with the CCENT or CCNA certification.
- **Appendix L, "Exam Topic Cross Reference,"** provides some tables to help you find where each exam objective is covered in the book.

ICND1 Chapters in this Book

For this current edition of the ICND1 and ICND2 Cert Guides, I designed several chapters to be used in both books. These chapters include some topics that are listed in the exam topics of both exams:

- Chapter 1, "Implementing Ethernet Virtual LANs" (Chapter 11 in the ICND1 100-105 book).
- Chapter 16, "Basic IPv4 Access Control Lists" (Chapter 25 in the ICND1 100-105 book).
- Chapter 17, "Advanced IPv4 Access Control Lists" (Chapter 26 in the ICND1 100-105 book).
- Chapter 21, "Troubleshooting IPv4 Routing" (Chapter 24 in the ICND1 100-105 book).

I designed these four chapters for use in both books to be a help to those reading both books while avoiding any problems for those who might be reading only this ICND2 Cert Guide. Cisco has traditionally had some topics that overlap between the two exams that make up the two-exam path to CCNA R&S, and this current pair of exams is no exception. So, for those of you who have already read the ICND1 100-105 book, you can move more quickly through the above four chapters in this book. If you did not read the ICND1 100-105 book, then you have all the material you need right here in this book.

Extra Content Found in DVD Appendixes

Note that several appendixes on the DVD, namely G, H, I, J, and K, contain extra content outside the ICND2 200-105 exam topics. This short section explains why.

First, two appendixes are here to aid the transition when Cisco announced the exams. Appendixes G (about RIP) and J (about **ping** and **traceroute**) are copies of two chapters in the ICND1 100-105 book, and are part of the exam topics for the ICND1 100-105 exam. These two chapters might be particularly useful for anyone who was far along in their studies on the date when Cisco announced the ICND1 100-105 and ICND2 200-105 exams in 2016. I included Appendixes G and J to aid that transition for those who buy the ICND2 200-105 Cert Guide but not the ICND1 100-105 Cert Guide.

Three other appendixes are included for instructors who use these books for classes, as well as for the occasional reader who is mostly interested in the technology instead of the certification. Appendixes H, I, and K contain content that is no longer mentioned by the exam topics for the current exams. Appendixes H and I are copies of complete chapters about Frame Relay from the prior edition of this book, and Appendix K is a compilation of small topics I removed from the prior edition of this book when creating this current edition. This material might be helpful to some instructors during the transition time for their courses, or for those who want to read more broadly just for the sake of learning.

You do not need to use these extra appendixes (G through K) to prepare for the ICND2 200-105 exam or the CCNA R&S 200-125 exam, but feel free to use them if you are interested.

Reference Information

This short section contains a few topics available for reference elsewhere in the book. You may read these when you first use the book, but you may also skip these topics and refer back to them later. In particular, make sure to note the final page of this introduction, which lists several contact details, including how to get in touch with Cisco Press.

Install the Pearson IT Certification Practice Test Engine and Questions

This book, like many other Cisco Press books, includes the rights to use the Pearson IT Certification Practice Test (PCPT) software, along with rights to use some exam questions related to this book. PCPT has many options, including the option to answer questions in study mode, so you can see the answers and explanations for each question as you go along; the option to take a simulated exam that mimics real exam conditions; and the option to view questions in flash card mode, where all the answers are stripped out, challenging you to answer questions from memory.

You should install PCPT so it is ready to use even for the earliest chapters. This book's Part Review sections ask you specifically to use PCPT, and you can even take the book chapter quizzes using PCPT.

NOTE The right to use the exams associated with this book is based on an activation code. Redeeming the Premium Edition eBook and Practice Test digital product voucher code in this book will automatically populate your account page with the PCPT software activation code you need to unlock your exams. *Do not lose the activation code.*

PCPT Exam Databases with This Book

This book includes an activation code that allows you to load a set of practice questions. The questions come in different exams or exam databases. When you install the PCPT software and type in the activation code, the PCPT software downloads the latest version of all these exam databases. And with the ICND2 book alone, you get six different "exams," or six different sets of questions, as listed in Figure I-3.

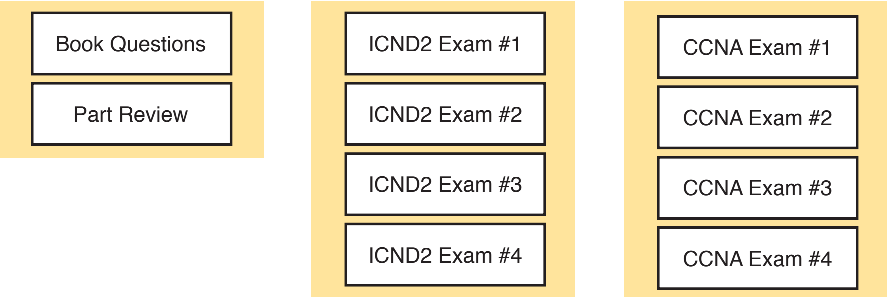

Figure I-3 *PCPT Exams/Exam Databases and When to Use Them*

You can choose to use any of these exam databases at any time, both in study mode and practice exam mode. However, many people find it best to save some of the exams until exam review time, after you have finished reading the entire book. Figure I-3 begins to suggest a plan, spelled out here:

- During Part Review, use PCPT to review the book questions for that part, using study mode.

- During Part Review, use the questions built specifically for Part Review (the Part Review questions) for that part of the book, using study mode.
- Save the remaining exams to use with the "Final Review" chapter at the end of the book; if preparing for the ICND2 exam, use those practice exams, but if preparing for the CCNA exam, use those exams.

The two modes inside PCPT give you better options for study versus practicing a timed exam event. In study mode, you can see the answers immediately, so you can study the topics more easily. Also, you can choose a subset of the questions in an exam database; for instance, you can view questions from only the chapters in one part of the book.

PCPT practice mode lets you practice an exam event somewhat like the actual exam. It gives you a preset number of questions, from all chapters, with a timed event. Practice exam mode also gives you a score for that timed event.

How to View Part Review Questions

The exam databases you get with this book include a database of questions created solely for study during the Part Review process. Book questions focus more on facts, to help you determine whether you know the facts contained within the chapter. The Part Review questions instead focus more on application of those facts to typical real scenarios, and look more like real exam questions.

To view these questions, follow the same process as you did with book questions, but select the Part Review database rather than the book database. PCPT has a clear name for this database: Part Review Questions.

About Mind Maps

Mind maps are a type of visual organization tool that you can use for many purposes. For instance, you can use mind maps as an alternative way to take notes.

You can also use mind maps to improve how your brain organizes concepts. Mind maps improve your brain's connections and relationships between ideas. When you spend time thinking about an area of study, and organize your ideas into a mind map, you strengthen existing mental connections and create new connections, all into your own frame of reference.

In short, mind maps help you internalize what you learn.

Each mind map begins with a blank piece of paper or blank window in a mind mapping application. You then add a large central idea, with branches that move out in any direction. The branches contain smaller concepts, ideas, commands, pictures…whatever idea needs to be represented. Any concepts that can be grouped should be put near each other. As need be, you can create deeper and deeper branches, although for this book's purposes, most mind maps will not go beyond a couple of levels.

NOTE Many books have been written about mind maps, but Tony Buzan often gets credit for formalizing and popularizing mind maps. You can learn more about mind maps at his website, http://www.tonybuzan.com.

For example, Figure I-4 shows a sample mind map that begins to output some of the IPv6 content from Part VIII of the ICND1 book. You might create this kind of mind map when reviewing IPv6 addressing concepts, starting with the big topic of "IPv6 addressing," and then writing down random terms and ideas. As you start to organize them mentally, you draw lines connecting the ideas, reorganize them, and eventually reach the point where you believe the organization of ideas makes sense to you.

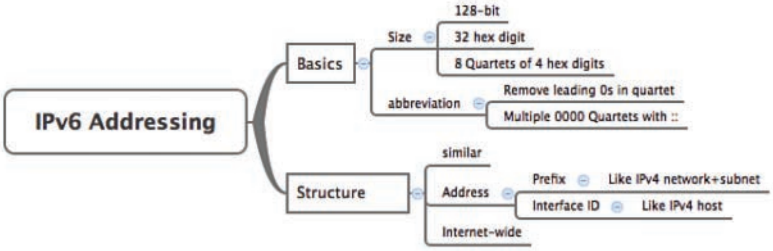

Figure I-4 *Sample Mind Map*

Mind maps may be the least popular but most effective study tool suggested in this book. I personally find a huge improvement in learning new areas of study when I mind map; I hope you will make the effort to try these tools and see if they work well for you too.

Finally, for mind mapping tools, you can just draw them on a blank piece of paper, or find and download a mind map application. I have used Mind Node Pro on a Mac, and we build the sample mind maps with XMIND, which has free versions for Windows, Linux, and OS X.

About Building Hands-On Skills

You need skills in using Cisco routers and switches, specifically the Cisco CLI. The Cisco CLI is a text-based command-and-response user interface; you type a command, and the device (a router or switch) displays messages in response. To answer sim and simlet questions on the exams, you need to know a lot of commands, and you need to be able to navigate to the right place in the CLI to use those commands.

This section walks through the options included in the book, with a brief description of lab options outside the book.

Config Lab Exercises

Some router and switch features require multiple configuration commands. Part of the skill you need to acquire is the ability to remember which configuration commands work together, which ones are required, and which ones are optional. So, the challenge level goes beyond just picking the right parameters on one command. You have to choose which commands to use, in which combination, typically on multiple devices. And getting good at that kind of task requires practice.

The Config Labs feature, introduced as a new feature in this edition of the book, helps provide that practice. Each lab presents a sample lab topology, with some requirements, and you have to decide what to configure on each device. The answer then shows a sample configuration. You job is to create the configuration, and then check your answer versus the supplied answer.

Also for the first time, this edition places the content not only outside the book but also on the author's blog site. To reach my blog sites for ICND1 content or for ICND2 content (two different blogs) and access the Config Labs feature, you can start at my blog launch site (blog.certskills.com) and click from there.

blog.certskills.com/ccent/ Wendell's CCENT (ICND1): In the menus, navigate to **Hands On > Config Lab**

blog.certskills.com/ccna/ Wendell's CCNA (ICND2): In the menus, navigate to **Hands On > Config Lab**

Both blogs are geared toward helping you pass the exams, so feel free to look around. Note that the Config Lab posts should show an image like this in the summary:

Figure I-5 *Config Lab Logo in the Author's Blogs*

These Config Labs have several benefits, including the following:

- **Untethered and responsive:** Do them from anywhere, from any web browser, from your phone or tablet, untethered from the book or DVD.
- **Designed for idle moments:** Each lab is designed as a 5- to 10-minute exercise if all you are doing is typing in a text editor or writing your answer on paper.
- **Two outcomes, both good:** Practice getting better and faster with basic configuration, or if you get lost, you have discovered a topic that you can now go back and reread to complete your knowledge. Either way, you are a step closer to being ready for the exam!
- **Blog format:** Allows easy adds and changes by me, and easy comments by you.
- **Self-assessment:** As part of final review, you should be able to do all the Config Labs, without help, and with confidence.

Note that the blog organizes these Config Lab posts by book chapter, so you can easily use these at both Chapter Review and Part Review. See the "Your Study Plan" element that follows the Introduction for more details about those review sections.

A Quick Start with Pearson Network Simulator Lite

The decision of how to get hands-on skills can be a little scary at first. The good news is that you have a free and simple first step to experience the CLI: Install and use the Pearson NetSim Lite that comes with this book.

This book comes with a lite version of the best-selling CCNA Network Simulator from Pearson, which provides you with a means, right now, to experience the Cisco CLI. No need to go buy real gear or buy a full simulator to start learning the CLI. Just install NetSim Lite from the DVD in the back of this book.

The latest version of NetSim Lite includes labs associated with Part II of this book. Part I includes concepts only, with Part II being the first part with commands. So, make sure and use NetSim Lite to learn the basics of the CLI to get a good start.

Of course, one reason that NetSim Lite comes on the DVD is that the publisher hopes you will buy the full product. However, even if you do not use the full product, you can still learn from the labs that come with NetSim Lite while deciding about what options to pursue.

NOTE The ICND1 and ICND2 books each contain a different version of the Sim Lite product, each with labs that match the book content. If you bought both books, make sure you install both Sim Lite products.

The Pearson Network Simulator

The Config Labs and the Pearson Network Simulator Lite both fill specific needs, and they both come with the book. However, you need more than those two tools.

The single best option for lab work to do along with this book is the paid version of the Pearson Network Simulator. This simulator product simulates Cisco routers and switches so that you can learn for the CCENT and CCNA R&S certifications. But more importantly, it focuses on learning for the exam by providing a large number of useful lab exercises. Reader surveys tell us that those people who use the Simulator along with the book love the learning process, and rave about how the book and Simulator work well together.

Of course, you need to make a decision for yourself, and consider all the options. Thankfully, you can get a great idea of how the full Simulator product works by using the Pearson Network Simulator Lite product included with the book. Both have the same base code and same user interface, and the same types of labs. Try the Lite version, and check out the full product. There is a full product for CCENT only, and another for CCNA R&S (which includes all the labs in the CCENT product, plus others for the ICND2 parts of the content).

Note that the Simulator and the books work on a different release schedule. For a time in 2016, the version of the Simulator available for purchase will be the Simulator created for the previous versions of the exams (ICND1 100-101, ICND2 200-101, and CCNA 200-120). That product includes approximately 80 percent of the CLI topics in the ICND1 100-105 and ICND2 200-105 books. So during that time, the Simulator is still very useful.

On a practical note, when you want to do labs while reading a chapter or doing Part Review, the Simulator organizes the labs to match the book. Just look for the "Sort by Chapter" tab in the Simulator's user interface. However, during the months in 2016 for which the available Simulator is the older edition listing the older exams in the title, you will need to refer back to a PDF that lists those labs versus this book's organization; find that PDF at http://www.ciscopress.com/title/9781587205798.

More Lab Options

If you decide against using the full Pearson Network Simulator, you still need hands-on experience. You should plan to use some lab environment to practice as much CLI interaction as possible.

First, you can use real Cisco routers and switches. You can buy them, new or used, or borrow them at work. You can rent them for a fee. If you have the right mix of gear, you could even do the Config Lab exercises from my blog on that gear, or try and re-create examples from the book.

Cisco offers a virtualization product that lets you run router and switch operating system (OS) images in a virtual environment. This tool, the Virtual Internet Routing Lab (VIRL), lets you create a lab topology, start the topology, and connect to real router and switch OS images. Check out http://virl.cisco.com for more information.

You can even rent virtual Cisco router and switch lab pods from Cisco, in an offering called Cisco Learning Labs.

All these previously mentioned options cost some money, but the next two are generally free to the user, but with a different catch for each. First, GNS3 works somewhat like VIRL, creating a virtual environment running real Cisco IOS. However, GNS3 is not a Cisco product, and cannot provide you with the IOS images for legal reasons.

Cisco also makes a simulator that works very well as a learning tool: Cisco Packet Tracer. However, Cisco intends Packet Tracer for use by people currently enrolled in Cisco Networking Academy courses, and not for the general public. So, if you are part of a Cisco Academy, definitely use Packet Tracer.

This book does not tell you what option to use, but you should plan on getting some hands-on practice somehow. The important thing to know is that most people need to practice using the Cisco CLI to be ready to pass these exams.

For More Information

If you have any comments about the book, submit them via http://www.ciscopress.com. Just go to the website, select **Contact Us**, and type your message.

Cisco might make changes that affect the CCNA certification from time to time. You should always check http://www.cisco.com/go/ccna and http://www.cisco.com/go/ccent for the latest details.

The *CCNA ICND2 200-105 Official Cert Guide* helps you attain CCNA Routing and Switching certification. This is the CCNA and ICND2 certification book from the only Cisco-authorized publisher. We at Cisco Press believe that this book certainly can help you achieve CCNA certification, but the real work is up to you! I trust that your time will be well spent.

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TCP/IP networks need IP routes. Part II collects six chapters focused on the IPv4 routing protocols discussed within the scope of ICND2.

The first four chapters in this part of the book deliver the details of OSPF Version 2 and then EIGRP. Chapter 7 begins with OSPFv2 concepts, followed by OSPFv2 implementation details (configuration and verification) in Chapter 8. Chapters 9 and 10 take the same approach to EIGRP, with one chapter of concepts (Chapter 9) and one chapter of implementation details (Chapter 10).

Chapter 11 pulls those four chapters about the OSPFv2 and EIGRP routing protocols together by discussing troubleshooting for both topics. Although they are different protocols, troubleshooting EIGRP and OSPFv2 requires the same kinds of logic and items to check. This chapter works through the details.

Finally, for the first time in the history of Cisco's CCNA R&S exam, Cisco has added more than a basic mention of BGP to the exam topics. Chapter 12 closes Part II with discussion of External BGP (eBGP), used between an enterprise and an ISP. That discussion includes basic concepts, configuration, and verification.

Part II

IPv4 Routing Protocols

Chapter 7: Understanding OSPF Concepts

Chapter 8: Implementing OSPF for IPv4

Chapter 9: Understanding EIGRP Concepts

Chapter 10: Implementing EIGRP for IPv4

Chapter 11: Troubleshooting IPv4 Routing Protocols

Chapter 12: Implementing External BGP

Part II Review

Chapter 8

Implementing OSPF for IPv4

Chapter 7, "Understanding OSPF Concepts," introduced you to the concepts, so this chapter moves on to the implementation details for Open Shortest Path First Version 2 (OSPFv2)—that is, OSPF as used for IPv4. This chapter looks at how to configure and verify a variety of OSPFv2 features.

This chapter touches on a wide variety of configuration options, so it breaks the content down into the three major sections. The first major section shows how to configure and verify basic OSPFv2 with a single-area design. With a single area, all interfaces sit in the same area, and that fact has an impact on the kinds of information lists in **show** command output. Also, the first section uses traditional OSPFv2 configuration using the OSPF **network** command. The second major section repeats the same kinds of configuration and verification as in the first major section, but now with multiarea OSPF designs.

The third major section of the chapter looks at a variety of common OSPFv2 features. These features include a completely different way to enable OSPFv2 on a Cisco router, using interface subcommands rather than the OSPF **network** command. It also includes the configuration of OSPF default routes, tuning OSPF metrics, and OSPF load balancing.

Finally, take a moment to reread the exam topics at the top of this page. Note that the exam topics specifically exclude some OSPF topics.

This chapter covers the following exam topics:

2.0 Routing Technologies

2.4 Configure, verify, and troubleshoot single area and multiarea OSPFv2 for IPv4 (excluding authentication, filtering, manual summarization, redistribution, stub, virtual-link, and LSAs)

Foundation Topics

Implementing Single-Area OSPFv2

OSPF configuration includes only a few required steps, but it has many optional steps. After an OSPF design has been chosen—a task that can be complex in larger IP internetworks—the configuration can be as simple as enabling OSPF on each router interface and placing that interface in the correct OSPF area.

This section shows several configuration examples, all with a single-area OSPF internetwork. Following those examples, the text goes on to cover several of the additional optional configuration settings. For reference, the following list outlines the configuration steps covered in this first major section of the chapter, as well as a brief reference to the required commands:

Config Checklist

Step 1. Use the **router ospf** *process-id* global command to enter OSPF configuration mode for a particular OSPF process.

Step 2. (Optional) Configure the OSPF router ID by doing the following:

A. Use the **router-id** *id-value* router subcommand to define the router ID

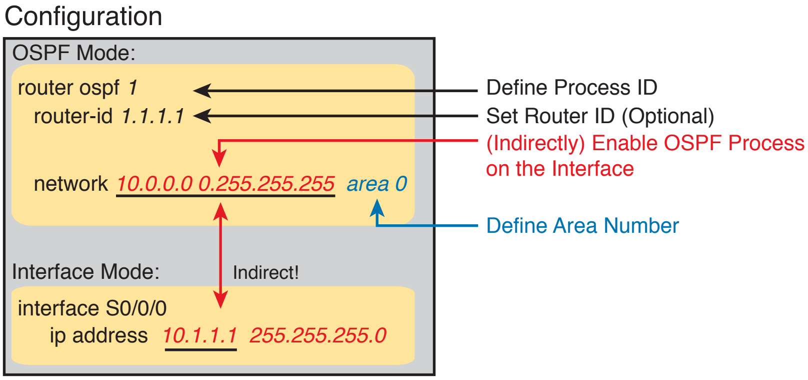
B. Use the **interface loopback** *number* global command, along with an **ip address** *address mask* command, to configure an IP address on a loopback interface (chooses the highest IP address of all working loopbacks)

C. Rely on an interface IP address (chooses the highest IP address of all working nonloopbacks)

Step 3. Use one or more **network** *ip-address wildcard-mask* **area** *area-id* router subcommands to enable OSPFv2 on any interfaces matched by the configured address and mask, enabling OSPF on the interface for the listed area.

Step 4. (Optional) Use the **passive-interface** *type number* router subcommand to configure any OSPF interfaces as passive if no neighbors can or should be discovered on the interface.

For a more visual perspective on OSPFv2 configuration, Figure 8-1 shows the relationship between the key OSPF configuration commands. Note that the configuration creates a routing process in one part of the configuration, and then indirectly enables OSPF on each interface. The configuration does not name the interfaces on which OSPF is enabled, instead requiring IOS to apply some logic by comparing the OSPF **network** command to the interface **ip address** commands. The upcoming example discusses more about this logic.



```
router ospf 1
  router-id 1.1.1.1

  network 10.0.0.0 0.255.255.255 area 0
```

```
interface S0/0/0
   ip address 10.1.1.1 255.255.255.0
```

Figure 8-1 *Organization of OSPFv2 Configuration*

OSPF Single-Area Configuration

Figure 8-2 shows a sample network that will be used for the single-area OSPF configuration examples. All links sit in area 0. The design has four routers, each connected to one or two LANs. However, note that Routers R3 and R4, at the top of the figure, connect to the same two VLANs/subnets, so they will form neighbor relationships with each other over each of those VLANs as well. (The two switches at the top of the design are acting as Layer 2 switches.)

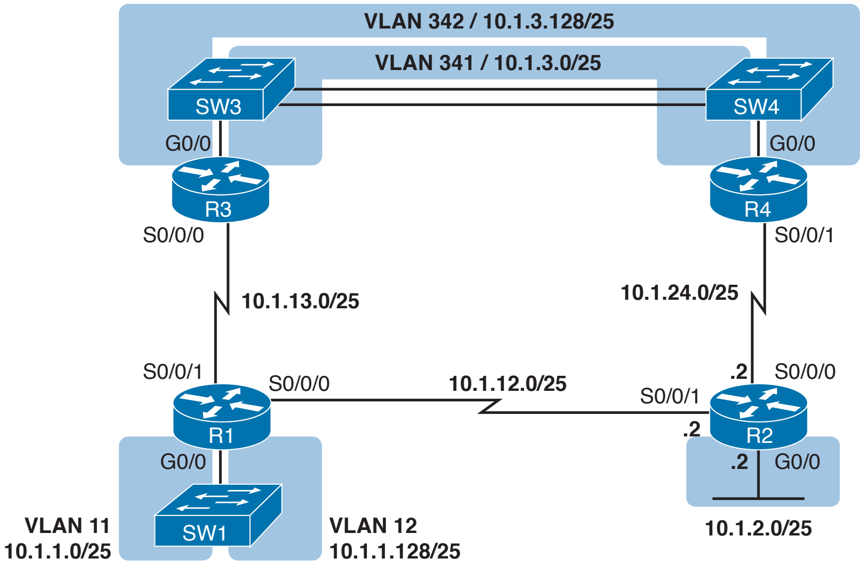


Figure 8-2 *Sample Network for OSPF Single-Area Configuration*

Example 8-1 shows the IPv4 addressing configuration on Router R3, before getting into the OSPF detail. The configuration enables 802.1Q trunking on R3's G0/0 interface, and assigns an IP address to each subinterface. (Not shown, switch S3 has configured trunking on the other side of that Ethernet link.)

Example 8-1 *IPv4 Address Configuration on R3 (Including VLAN Trunking)*

```
interface GigabitEthernet 0/0.341
 encapsulation dot1q 341
 ip address 10.1.3.1 255.255.255.128
!
interface GigabitEthernet 0/0.342
 encapsulation dot1q 342
 ip address 10.1.3.129 255.255.255.128
!
interface serial 0/0/0
 ip address 10.1.13.3 255.255.255.128
```

The beginning single-area configuration on R3, as shown in Example 8-2, enables OSPF on all the interfaces shown in Figure 8-2. First, the **router ospf 1** global command puts the user in OSPF configuration mode, and sets the OSPF *process-id*. This number just needs to be unique on the local router, allowing the router to support multiple OSPF processes in a single router by using different process IDs. (The **router** command uses the *process-id* to distinguish between the processes.) The *process-id* does not have to match on each router, and it can be any integer between 1 and 65,535.

Example 8-2 *OSPF Single-Area Configuration on R3 Using One* **network** *Command*

```
router ospf 1
 network 10.0.0.0 0.255.255.255 area 0
```

Speaking generally rather than about this example, the OSPF **network** command tells a router to find its local interfaces that match the first two parameters on the **network** command. Then, for each matched interface, the router enables OSPF on those interfaces, discovers neighbors, creates neighbor relationships, and assigns the interface to the area listed in the **network** command. (Note that the area can be configured as either an integer or a dotted-decimal number, but this book makes a habit of configuring the area number as an integer. The integer area numbers range from 0 through 4,294,967,295.)

For the specific command in Example 8-2, any matched interfaces are assigned to area 0. However, the first two parameters—the *ip_address* and *wildcard_mask* parameter values of 10.0.0.0 and 0.255.255.255—need some explaining. In this case, the command matches all three interfaces shown for Router R3; the next topic explains why.

Matching with the OSPF network Command

The key to understanding the traditional OSPFv2 configuration shown in this first example is to understand the OSPF **network** command. The OSPF **network** command compares the first parameter in the command to each interface IP address on the local router, trying to find a match. However, rather than comparing the entire number in the **network** command to the entire IPv4 address on the interface, the router can compare a subset of the octets, based on the wildcard mask, as follows:

Key Topic

Wildcard 0.0.0.0: Compare all 4 octets. In other words, the numbers must exactly match.

Wildcard 0.0.0.255: Compare the first 3 octets only. Ignore the last octet when comparing the numbers.

Wildcard 0.0.255.255: Compare the first 2 octets only. Ignore the last 2 octets when comparing the numbers.

Wildcard 0.255.255.255: Compare the first octet only. Ignore the last 3 octets when comparing the numbers.

Wildcard 255.255.255.255: Compare nothing—this wildcard mask means that all addresses will match the **network** command.

Basically, a wildcard mask value of 0 in an octet tells IOS to compare to see if the numbers match, and a value of 255 tells IOS to ignore that octet when comparing the numbers.

The **network** command provides many flexible options because of the wildcard mask. For example, in Router R3, many **network** commands could be used, with some matching all interfaces, and some matching a subset of interfaces. Table 8-1 shows a sampling of options, with notes.

Table 8-1 Example OSPF **network** Commands on R3, with Expected Results

Command	Logic in Command	Matched Interfaces
network 10.1.0.0 0.0.255.255	Match interface IP addresses that begin with 10.1	G0/0.341 G0/0.342 S0/0/0
network 10.0.0.0 0.255.255.255	Match interface IP addresses that begin with 10	G0/0.341 G0/0.342 S0/0/0

Command	Logic in Command	Matched Interfaces
network 0.0.0.0 255.255.255.255	Match all interface IP addresses	G0/0.341 G0/0.342 S0/0/0
network 10.1.13.0 0.0.0.255	Match interface IP addresses that begin with 10.1.13	S0/0/0
network 10.1.3.1 0.0.0.0	Match one IP address: 10.1.3.1	G0/0.341

The wildcard mask gives the local router its rules for matching its own interfaces. For example, Example 8-2 shows R3 using the **network 10.0.0.0 0.255.255.255 area 0** command. However, the wildcard mask allows for many different valid OSPF configurations. For instance, in that same internetwork, Routers R1 and R2 could use the configuration shown in Example 8-3, with two other wildcard masks. In both routers, OSPF is enabled on all the interfaces shown in Figure 8-2.

Example 8-3 *OSPF Configuration on Routers R1 and R2*

```
! R1 configuration next - one network command enables OSPF
! on all three interfaces
router ospf 1
 network 10.1.0.0 0.0.255.255 area 0
```

```
! R2 configuration next - One network command per interface
router ospf 1
 network 10.1.12.2 0.0.0.0 area 0
 network 10.1.24.2 0.0.0.0 area 0
 network 10.1.2.2 0.0.0.0 area 0
```

Finally, note that other wildcard mask values can be used as well, as long as the wildcard mask in binary is one unbroken string of 0s and another single string of binary 1s. Basically, that includes all wildcard masks that could be used to match all IP addresses in a subnet, as discussed in the "Finding the Right Wildcard Mask to Match a Subnet" section of Chapter 16, "Basic IPv4 Access Control Lists" (which is Chapter 25 of the ICND1 Cert Guide). For example, a mask of 0.255.255.0 would not be allowed.

NOTE The first two parameters of the **network** command are the address and the wildcard mask. By convention, if the wildcard mask octet is 255, the matching address octet should be configured as a 0. Interestingly, IOS will actually accept a **network** command that breaks this rule, but then IOS will change that octet of the address to a 0 before putting it into the running configuration file. For example, IOS will change a typed command that begins with **network 1.2.3.4 0.0.255.255** to **network 1.2.0.0 0.0.255.255**.

Verifying OSPFv2 Single Area

As mentioned in Chapter 7, OSPF routers use a three-step process to eventually add OSPF-learned routes to the IP routing table. First, they create neighbor relationships. Then they build and flood LSAs, so each router in the same area has a copy of the same LSDB. Finally, each router independently computes its own IP routes using the SPF algorithm and adds them to its routing table.

The **show ip ospf neighbor**, **show ip ospf database**, and **show ip route** commands display information for each of these three steps, respectively. To verify OSPF, you can use the same sequence.

Or, you can just go look at the IP routing table, and if the routes look correct, OSPF probably worked.

For example, first, examine the list of neighbors known on Router R3 from the configuration in Examples 8-1, 8-2, and 8-3. R3 should have one neighbor relationship with R1, over the serial link. It also has two neighbor relationships with R4, over the two different VLANs to which both routers connect. Example 8-4 shows all three.

Key Topic

Example 8-4 *OSPF Neighbors on Router R3 from Figure 8-2*

```
R3# show ip ospf neighbor

Neighbor ID     Pri   State         Dead Time   Address         Interface
1.1.1.1           0   FULL/  -      00:00:33    10.1.13.1       Serial0/0/0
10.1.24.4         1   FULL/DR       00:00:35    10.1.3.130      GigabitEthernet0/0.342
10.1.24.4         1   FULL/DR       00:00:36    10.1.3.4        GigabitEthernet0/0.341
```

The detail in the output mentions several important facts, and for most people, working right to left works best in this case. For example, looking at the headings:

Interface: This is the local router's interface connected to the neighbor. For example, the first neighbor in the list is reachable through R3's S0/0/0 interface.

Address: This is the neighbor's IP address on that link. Again, for this first neighbor, the neighbor, which is R1, uses IP address 10.1.13.1.

State: While many possible states exist, for the details discussed in this chapter, FULL is the correct and fully working state in this case.

Neighbor ID: This is the router ID of the neighbor.

Next, Example 8-5 shows the contents of the LSDB on Router R3. Interestingly, when OSPF is working correctly in an internetwork with a single-area design, all the routers will have the same LSDB contents. So, the **show ip ospf database** command in Example 8-5 should list the same exact information, no matter on which of the four routers it is issued.

Example 8-5 *OSPF Database on Router R3 from Figure 8-2*

```
R3# show ip ospf database

            OSPF Router with ID (10.1.13.3) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         498         0x80000006 0x002294 6
2.2.2.2         2.2.2.2         497         0x80000004 0x00E8C6 5
10.1.13.3       10.1.13.3       450         0x80000003 0x001043 4
10.1.24.4       10.1.24.4       451         0x80000003 0x009D7E 4

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
10.1.3.4        10.1.24.4       451         0x80000001 0x0045F8
10.1.3.130      10.1.24.4       451         0x80000001 0x00546B
```

For the purposes of this book, do not be concerned about the specifics in the output of this command. However, for perspective, note that the LSDB should list one “Router Link State” (Type 1 Router LSA) for each of the routers in the same area. In this design, all four routers are in the same area, so there are four highlighted Type 1 LSAs listed.

Next, Example 8-6 shows R3’s IPv4 routing table with the **show ip route** command. Note that it lists connected routes as well as OSPF routes. Take a moment to look back at Figure 8-2, and look for the subnets that are not locally connected to R3. Then look for those routes in the output in Example 8-5.

Example 8-6 *IPv4 Routes Added by OSPF on Router R3 from Figure 8-2*

```
R3# show ip route
Codes: L - local, 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
! Legend lines omitted for brevity


      10.0.0.0/8 is variably subnetted, 11 subnets, 2 masks
O        10.1.1.0/25 [110/65] via 10.1.13.1, 00:13:28, Serial0/0/0
O        10.1.1.128/25 [110/65] via 10.1.13.1, 00:13:28, Serial0/0/0
O        10.1.2.0/25 [110/66] via 10.1.3.130, 00:12:41, GigabitEthernet0/0.342
                     [110/66] via 10.1.3.4, 00:12:41, GigabitEthernet0/0.341
C        10.1.3.0/25 is directly connected, GigabitEthernet0/0.341
L        10.1.3.1/32 is directly connected, GigabitEthernet0/0.341
C        10.1.3.128/25 is directly connected, GigabitEthernet0/0.342
L        10.1.3.129/32 is directly connected, GigabitEthernet0/0.342
O        10.1.12.0/25 [110/128] via 10.1.13.1, 00:13:28, Serial0/0/0
C        10.1.13.0/25 is directly connected, Serial0/0/0
L        10.1.13.3/32 is directly connected, Serial0/0/0
O        10.1.24.0/25
           [110/65] via 10.1.3.130, 00:12:41, GigabitEthernet0/0.342
           [110/65] via 10.1.3.4, 00:12:41, GigabitEthernet0/0.341
```

First, take a look at the bigger ideas confirmed by this output. The code of “O” on the left identifies a route as being learned by OSPF. The output lists five such IP routes. From Figure 8-2, five subnets exist that are not connected subnets off Router R3. Looking for a quick count of OSPF routes, versus nonconnected routes in the diagram, gives a quick check of whether OSPF learned all routes.

Next, take a look at the first route (to subnet 10.1.1.0/25). It lists the subnet ID and mask, identifying the subnet. It also lists two numbers in brackets. The first, 110, is the administrative distance of the route. All the OSPF routes in this example use the default of 110. The second number, 65, is the OSPF metric for this route.

Additionally, the **show ip protocols** command is also popular as a quick look at how any routing protocol works. This command lists a group of messages for each IPv4 routing protocol running on a router. Example 8-7 shows a sample, this time taken from Router R3.

Example 8-7 *The* **show ip protocols** *Command on R3*

```
R3# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 10.1.13.3
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.0.0.0 0.255.255.255 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
    1.1.1.1              110      06:26:17
    2.2.2.2              110      06:25:30
    10.1.24.4            110      06:25:30
  Distance: (default is 110)
```

The output shows several interesting facts. The first highlighted line repeats the parameters on the **router ospf 1** global configuration command. The second highlighted item points out R3's router ID, as discussed further in the next section. The third highlighted line repeats more configuration, listing the parameters of the **network 10.0.0.0 0.255.255.255 area 0** OSPF subcommand. Finally, the last highlighted item in the example acts as a heading before a list of known OSPF routers, by router ID.

Configuring the OSPF Router ID

While OSPF has many other optional features, most enterprise networks that use OSPF choose to configure each router's OSPF router ID. OSPF-speaking routers must have a router ID (RID) for proper operation. By default, routers will choose an interface IP address to use as the RID. However, many network engineers prefer to choose each router's router ID, so command output from commands like **show ip ospf neighbor** lists more recognizable router IDs.

To choose its RID, a Cisco router uses the following process when the router reloads and brings up the OSPF process. Note that when one of these steps identifies the RID, the process stops.

Key Topic

1. If the **router-id** *rid* OSPF subcommand is configured, this value is used as the RID.
2. If any loopback interfaces have an IP address configured, and the interface has an interface status of up, the router picks the highest numeric IP address among these loopback interfaces.
3. The router picks the highest numeric IP address from all other interfaces whose interface status code (first status code) is up. (In other words, an interface in up/down state will be included by OSPF when choosing its router ID.)

The first and third criteria should make some sense right away: the RID is either configured or is taken from a working interface's IP address. However, this book has not yet explained the concept of a *loopback interface*, as mentioned in Step 2.

A loopback interface is a virtual interface that can be configured with the **interface loopback** *interface-number* command, where *interface-number* is an integer. Loopback interfaces are always in an "up and up" state unless administratively placed in a shutdown state. For example, a simple configuration of the command **interface loopback 0**, followed by **ip address 2.2.2.2 255.255.255.0**, would create a loopback interface and assign it an IP address. Because loopback interfaces do not rely on any hardware, these interfaces can be up/up whenever IOS is running, making them good interfaces on which to base an OSPF RID.

Example 8-8 shows the configuration that existed in Routers R1 and R2 before the creation of the **show** command output in Examples 8-4, 8-5, and 8-6. R1 set its router ID using the direct method, while R2 used a loopback IP address.

Example 8-8 *OSPF Router ID Configuration Examples*

```
! R1 Configuration first
router ospf 1
 router-id 1.1.1.1
 network 10.1.0.0 0.0.255.255 area 0
```

```
! R2 Configuration next
!
interface Loopback2
 ip address 2.2.2.2 255.255.255.255
```

Each router chooses its OSPF RID when OSPF is initialized, which happens when the router boots or when a CLI user stops and restarts the OSPF process (with the **clear ip ospf process** command). So, if OSPF comes up, and later the configuration changes in a way that would impact the OSPF RID, OSPF does not change the RID immediately. Instead, IOS waits until the next time the OSPF process is restarted.

Example 8-9 shows the output of the **show ip ospf** command on R1, after the configuration of Example 8-8 was made, and after the router was reloaded, which made the OSPF router ID change.

Example 8-9 *Confirming the Current OSPF Router ID*

```
R1# show ip ospf
 Routing Process "ospf 1" with ID 1.1.1.1
! lines omitted for brevity
```

OSPF Passive Interfaces

Once OSPF has been enabled on an interface, the router tries to discover neighboring OSPF routers and form a neighbor relationship. To do so, the router sends OSPF Hello messages on a regular time interval (called the Hello Interval). The router also listens for incoming Hello messages from potential neighbors.

Sometimes, a router does not need to form neighbor relationships with neighbors on an interface. Often, no other routers exist on a particular link, so the router has no need to keep sending those repetitive OSPF Hello messages.

When a router does not need to discover neighbors off some interface, the engineer has a couple of configuration options. First, by doing nothing, the router keeps sending the messages, wasting some small bit of CPU cycles and effort. Alternately, the engineer can configure the interface as an OSPF passive interface, telling the router to do the following:

Key Topic

- Quit sending OSPF Hellos on the interface.
- Ignore received Hellos on the interface.
- Do not form neighbor relationships over the interface.

By making an interface passive, OSPF does not form neighbor relationships over the interface, but it does still advertise about the subnet connected to that interface. That is, the OSPF configuration enables OSPF on the interface (using the **network** router subcommand), and then makes the interface passive (using the **passive-interface** router subcommand).

To configure an interface as passive, two options exist. First, you can add the following command to the configuration of the OSPF process, in router configuration mode:

passive-interface *type number*

Alternately, the configuration can change the default setting so that all interfaces are passive by default, and then add a **no passive-interface** command for all interfaces that need to not be passive:

passive-interface default

no passive interface *type number*

For example, in the sample internetwork in Figure 8-2 (used in the single-area configuration examples), Router R1, at the bottom left of the figure, has a LAN interface configured for VLAN trunking. The only router connected to both VLANs is Router R1, so R1 will never discover an OSPF neighbor on these subnets. Example 8-10 shows two alternative configurations to make the two LAN subinterfaces passive to OSPF.

Example 8-10 *Configuring Passive Interfaces on R1 and R2 from Figure 8-2*

```
! First, make each subinterface passive directly
router ospf 1
 passive-interface GigabitEthernet0/0.11
 passive-interface GigabitEthernet0/0.12

! Or, change the default to passive, and make the other interfaces
! not be passive

router ospf 1
 passive-interface default
 no passive-interface serial0/0/0
 no passive-interface serial0/0/1
```

In real internetworks, the choice of configuration style reduces to which option requires the least number of commands. For example, a router with 20 interfaces, 18 of which are passive to OSPF, has far fewer configuration commands when using the **passive-interface default** command to change the default to passive. If only two of those 20 interfaces need to be passive, use the default setting, in which all interfaces are not passive, to keep the configuration shorter.

Interestingly, OSPF makes it a bit of a challenge to use **show** commands to find whether or not an interface is passive. The **show running-config** command lists the configuration directly, but if you cannot get into enable mode to use this command, note these two facts:

The **show ip ospf interface brief** command lists all interfaces on which OSPF is enabled, *including passive interfaces*.

The **show ip ospf interface** command lists a single line that mentions that the interface is passive.

Example 8-11 shows these two commands on Router R1, with the configuration shown in the top of Example 8-10. Note that subinterfaces G0/0.11 and G0/0.12 both show up in the output of **show ip ospf interface brief**.

Example 8-11 *Displaying Passive Interfaces*

```
R1# show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Gi0/0.12     1     0               10.1.1.129/25      1     DR    0/0
Gi0/0.11     1     0               10.1.1.1/25        1     DR    0/0
Se0/0/0      1     0               10.1.12.1/25       64    P2P   0/0
Se0/0/1      1     0               10.1.13.1/25       64    P2P   0/0

R1# show ip ospf interface g0/0.11
GigabitEthernet0/0.11 is up, line protocol is up
  Internet Address 10.1.1.1/25, Area 0, Attached via Network Statement
  Process ID 1, Router ID 10.1.1.129, Network Type BROADCAST, Cost: 1
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           1         no          no            Base
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 10.1.1.129, Interface address 10.1.1.1
  No backup designated router on this network
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    oob-resync timeout 40
    No Hellos (Passive interface)
! Lines omitted for brevity
```

Implementing Multiarea OSPFv2

Configuring the routers in a multiarea design is almost just like configuring OSPFv2 for a single area. The only difference is that the configuration places some interfaces on each ABR in different areas. The differences come in the verification and operation of OSPFv2.

This second major section of the chapter provides a second set of configurations to contrast multiarea configuration with single-area configuration. This new scenario shows the configuration for the routers in the multiarea OSPF design based on Figures 8-3 and 8-4. Figure 8-3 shows the internetwork topology and subnet IDs, and Figure 8-4 shows the area design. Note that Figure 8-3 lists the last octet of each router's IPv4 address near each interface, rather than the entire IPv4 address, to reduce clutter.

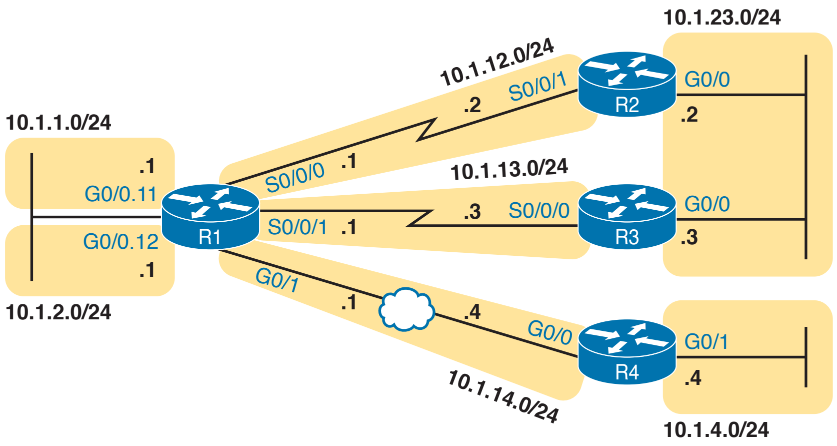


Figure 8-3 *Subnets for a Multiarea OSPF Configuration Example*

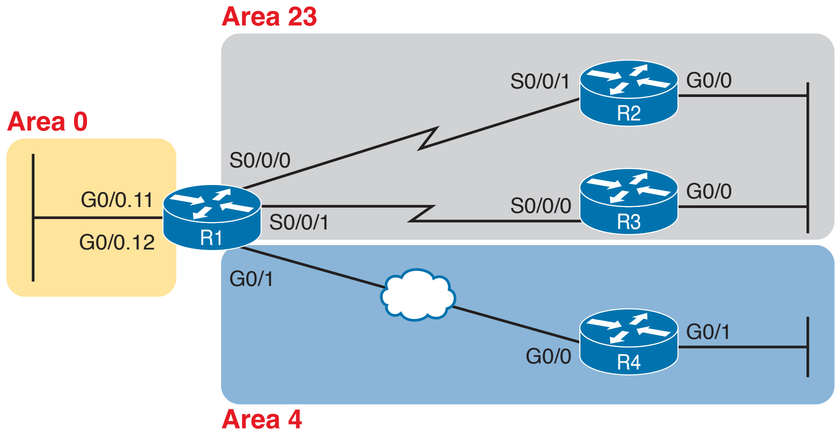


Figure 8-4 *Area Design for an Example Multiarea OSPF Configuration*

Take a moment to think about the area design shown in Figure 8-4, and look for the ABRs. Only R1 connects to the backbone area at all. The other three routers are internal routers in a single area. So, as it turns out, three of the four routers have single-area configurations, with all interfaces in the same area.

Note that the examples in this section use a variety of configuration options just so you can see those options. The options include different ways to set the OSPF RID, different wildcard masks on OSPF **network** commands, and the use of passive interfaces where no other OSPF routers should exist off an interface.

Single-Area Configurations

Example 8-12 begins the configuration example by showing the OSPF and IP address configuration on R2. Note that R2 acts as an internal router in area 23, meaning that the configuration will refer to only one area (23). The configuration sets R2's RID to 2.2.2.2 directly with the **router-id** command. And, because R2 should find neighbors on both its two interfaces, neither can reasonably be made passive, so R2's configuration lists no passive interfaces.

Example 8-12 *OSPF Configuration on R2, Placing Two Interfaces into Area 23*

```
interface GigabitEthernet0/0
 ip address 10.1.23.2 255.255.255.0
!
interface serial 0/0/1
 ip address 10.1.12.2 255.255.255.0
!
router ospf 1
 network 10.0.0.0 0.255.255.255 area 23
 router-id 2.2.2.2
```

Example 8-13 continues reviewing a few commands with the configuration for both R3 and R4. R3 puts both its interfaces into area 23, per its **network** command, sets its RID to 3.3.3.3 by using a loopback interface, and, like R2, cannot make either of its interfaces passive. The R4 configuration is somewhat different, with both interfaces placed into area 4, setting its RID based on a nonloopback interface (G0/0, for OSPF RID 10.1.14.4), and making R4's G0/1 interface passive, because no other OSPF routers sit on that link. (Note that the choice to use one method over another to set the OSPF RID is simply to show the variety of configuration options.)

Example 8-13 *OSPF Single-Area Configuration on R3 and R4*

```
! First, on R3
interface GigabitEthernet0/0
 ip address 10.1.23.3 255.255.255.0
!
interface serial 0/0/0
 ip address 10.1.13.3 255.255.255.0
!
interface loopback 0
 ip address 3.3.3.3 255.255.255.0
!
router ospf 1
 network 10.0.0.0 0.255.255.255 area 23
```

```
! Next, on R4
interface GigabitEthernet0/0
 description R4 will use this interface for its OSPF RID
 ip address 10.1.14.4 255.255.255.0
!
interface GigabitEthernet0/1
 ip address 10.1.4.4 255.255.255.0
!
router ospf 1
 network 10.0.0.0 0.255.255.255 area 4
 passive-interface GigabitEthernet0/1
```

Multiarea Configuration

The only router that has a multiarea config is an ABR, by virtue of the configuration referring to more than one area. In this design (as shown in Figure 8-4), only Router R1 acts as an ABR, with interfaces in three different areas. Example 8-14 shows R1's OSPF configuration. Note that the configuration does not state anything about R1 being an ABR; instead, it uses multiple **network** commands, some placing interfaces into area 0, some into area 23, and some into area 4.

Key Topic

Example 8-14 *OSPF Multiarea Configuration on Router R1*

```
interface GigabitEthernet0/0.11
 encapsulation dot1q 11
 ip address 10.1.1.1 255.255.255.0
!
interface GigabitEthernet0/0.12
 encapsulation dot1q 12
 ip address 10.1.2.1 255.255.255.0
!
```

```
interface GigabitEthernet0/1
 ip address 10.1.14.1 255.255.255.0
!
interface serial 0/0/0
 ip address 10.1.12.1 255.255.255.0
!
interface serial 0/0/1
 ip address 10.1.13.1 255.255.255.0
!
router ospf 1
 network 10.1.1.1 0.0.0.0 area 0
 network 10.1.2.1 0.0.0.0 area 0
 network 10.1.12.1 0.0.0.0 area 23
 network 10.1.13.1 0.0.0.0 area 23
 network 10.1.14.1 0.0.0.0 area 4
 router-id 1.1.1.1
 passive-interface GigabitEthernet0/0.11
 passive-interface GigabitEthernet0/0.12
```

Focus on the highlighted **network** commands in the example. All five commands happen to use a wildcard mask of 0.0.0.0, so that each command requires a specific match of the listed IP address. If you compare these **network** commands to the various interfaces on Router R1, you can see that the configuration enables OSPF, for area 0, on subinterfaces G0/0.11 and G0/0.12, area 23 for the two serial interfaces, and area 4 for R1's G0/1 interface.

NOTE Many networks make a habit of using a 0.0.0.0 wildcard mask on OSPF **network** commands, requiring an exact match of each interface IP address, as shown in Example 8-14. This style of configuration makes it more obvious exactly which interfaces match which **network** command.

Finally, note that R1's configuration also sets its RID directly and makes its two LAN subinterfaces passive.

So, what's the big difference between single-area and multiarea OSPF configuration? Practically nothing. The only difference is that with multiarea, the ABR's **network** commands list different areas.

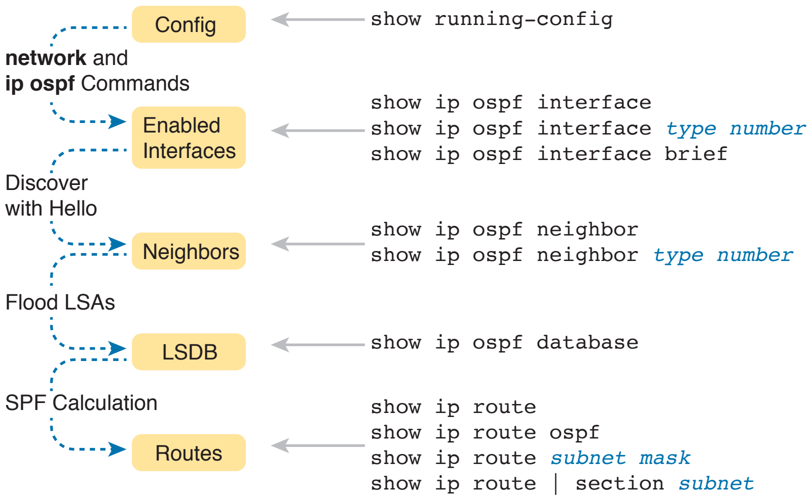
Verifying the Multiarea Configuration

The next few pages look at how to verify a few of the new OSPF features introduced in this chapter. Figure 8-5 summarizes the most important OSPF verification commands for reference.

This section looks at the following topics:

- Verifying the ABR interfaces are in the correct (multiple) areas
- Finding which router is DR and BDR on multiaccess links
- A brief look at the LSDB
- Displaying IPv4 routes

Key Topic



```
show running-config

show ip ospf interface
show ip ospf interface type number
show ip ospf interface brief

show ip ospf neighbor
show ip ospf neighbor type number

show ip ospf database

show ip route
show ip route ospf
show ip route subnet mask
show ip route | section subnet
```

Figure 8-5 *OSPF Verification Commands*

Verifying the Correct Areas on Each Interface on an ABR

The easiest place to make a configuration oversight with a multiarea configuration is to place an interface into the wrong OSPF area. Several commands mention the OSPF area. The **show ip protocols** command basically relists the OSPF **network** configuration commands, which indirectly identify the interfaces and areas. Also, the **show ip ospf interface** and **show ip ospf interface brief** commands directly show the area configured for an interface; Example 8-15 shows an example of the briefer version of these commands.

Key Topic

Example 8-15 *Listing the OSPF-Enabled Interfaces and the Matching OSPF Areas*

```
R1# show ip ospf interface brief
Interface     PID   Area           IP Address/Mask    Cost  State Nbrs F/C
Gi0/0.12      1     0              10.1.2.1/24        1     DR    0/0
Gi0/0.11      1     0              10.1.1.1/24        1     DR    0/0
Gi0/1         1     4              10.1.14.1/24       1     BDR   1/1
Se0/0/1       1     23             10.1.13.1/24       64    P2P   1/1
Se0/0/0       1     23             10.1.12.1/24       64    P2P   1/1
```

In the output, to correlate the areas, just look at the interface in the first column and the area in the third column. Also, for this example, double-check this information with Figures 8-3 and 8-4 to confirm that the configuration matches the design.

Verifying Which Router Is DR and BDR

Several **show** commands identify the DR and BDR in some way, as well. In fact, the **show ip ospf interface brief** command output, just listed in Example 8-15, lists the local router's state, showing that R1 is DR on two subinterfaces and BDR on its G0/1 interface.

Example 8-16 shows two other examples that identify the DR and BDR, but with a twist. The **show ip ospf interface** command lists detailed output about OSPF settings, per interface. Those details include the RID and interface address of the DR and BDR. At the same time, the **show ip ospf neighbor** command lists shorthand information about the neighbor's DR or BDR role as well; this command does not say anything about the local router's role.

Example 8-16 *Discovering the DR and BDR on the R1–R4 Ethernet (from R4)*

```
R4# show ip ospf interface gigabitEthernet 0/0
GigabitEthernet0/0 is up, line protocol is up
  Internet Address 10.1.14.4/24, Area 4, Attached via Network Statement
  Process ID 1, Router ID 10.1.14.4, Network Type BROADCAST, Cost: 1
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           1         no          no             Base
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 10.1.14.4, Interface address 10.1.14.4
  Backup Designated router (ID) 1.1.1.1, Interface address 10.1.14.1
!
! Lines omitted for brevity
R4# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/BDR        00:00:33    10.1.14.1       GigabitEthernet0/0
```

First, focus on the highlighted lines from the **show ip ospf interface** command output. It lists the DR as RID 10.1.14.4, which is R4. It also lists the BDR as 1.1.1.1, which is R1.

The end of the example shows the **show ip ospf neighbor** command on R4, listing R4's single neighbor, with Neighbor RID 1.1.1.1 (R1). The command lists R4's concept of its neighbor state with neighbor 1.1.1.1 (R1), with the current state listed as FULL/BDR. The FULL state means that R4 has fully exchanged its LSDB with R1. BDR means that the neighbor (R1) is acting as the BDR, implying that R4 (the only other router on this link) is acting as the DR.

Example 8-16 also shows the results of an DR/BDR election, with the router using the higher RID winning the election. The rules work like this:

- When a link comes up, if two (or more) routers on the subnet send and hear each other's Hello messages, they elect a DR and BDR, with the higher OSPF RID becoming DR, and the second highest RID becoming the BDR.
- Once the election has completed, new routers entering the subnet do not take over the DR or BDR role, even if they have better (higher) RID.

In this case, Routers R1 and R4, on the same Ethernet, heard each other's Hellos. R1, with RID 1.1.1.1, has a lower-value RID than R4's 10.1.14.1. As a result, R4 (10.1.14.1) won the DR election.

Verifying Interarea OSPF Routes

Finally, all this OSPF theory and all the **show** commands do not matter if the routers do not learn IPv4 routes. To verify the routes, Example 8-17 shows R4's IPv4 routing table.

Example 8-17 *Verifying OSPF Routes on Router R4*

```
R4# show ip route
Codes: L - local, 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, H - NHRP, l - LISP
       + - replicated route, % - next hop override
```

```
      10.0.0.0/8 is variably subnetted, 9 subnets, 2 masks
O IA     10.1.1.0/24 [110/2] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
O IA     10.1.2.0/24 [110/2] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
C        10.1.4.0/24 is directly connected, GigabitEthernet0/1
L        10.1.4.4/32 is directly connected, GigabitEthernet0/1
O IA     10.1.12.0/24 [110/65] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
O IA     10.1.13.0/24 [110/65] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
C        10.1.14.0/24 is directly connected, GigabitEthernet0/0
L        10.1.14.4/32 is directly connected, GigabitEthernet0/0
O IA     10.1.23.0/24 [110/66] via 10.1.14.1, 11:04:43, GigabitEthernet0/0
```

This example shows a couple of new codes that are particularly interesting for OSPF. As usual, a single character on the left identifies the source of the route, with O meaning OSPF. In addition, IOS notes any interarea routes with an IA code as well. (The example does not list any intra-area OSPF routes, but these routes would simply omit the IA code; earlier Example 8-6 lists some intra-area OSPF routes.) Also, note that R4 has routes to all seven subnets in the topology used in this example: two connected routes and five interarea OSPF routes.

Additional OSPF Features

So far this chapter has focused on the most common OSPF features using the traditional configuration using the OSPF **network** command. This final of three major sections discusses some very popular but optional OSPFv2 configuration features, as listed here in their order of appearance:

- Default routes
- Metrics
- Load balancing
- OSPF interface configuration

OSPF Default Routes

In some cases, routers benefit from using a default route. The ICND1 Cert Guide showed many of the details, with the configuration of static default routes in Chapter 18, learning default routes with DHCP in Chapter 20, and advertising default routes with RIP in Chapter 19. For those exact same reasons, networks that happen to use OSPFv2 can use OSPF to advertise default routes.

The most classic case for using a routing protocol to advertise a default route has to do with an enterprise's connection to the Internet. As a strategy, the enterprise engineer uses these design goals:

- All routers learn specific routes for subnets inside the company; a default route is not needed when forwarding packets to these destinations.
- One router connects to the Internet, and it has a default route that points toward the Internet.
- All routers should dynamically learn a default route, used for all traffic going to the Internet, so that all packets destined to locations in the Internet go to the one router connected to the Internet.

Figure 8-6 shows the idea of how OSPF advertises the default route, with the specific OSPF configuration. In this case, a company connects to an ISP with its Router R1. That router has a static default route (destination 0.0.0.0, mask 0.0.0.0) with a next-hop address of the ISP router. Then, the use of the OSPF **default-information originate** command (Step 2) makes the router advertise a default route using OSPF to the remote routers (B1 and B2).

NOTE The example in Figure 8-6 uses a static default route, but it could have used a default route as learned from the ISP with DHCP, as well as learning a default route with External BGP (eBGP), as discussed in Chapter 12, "Implementing External BGP."

Key Topic

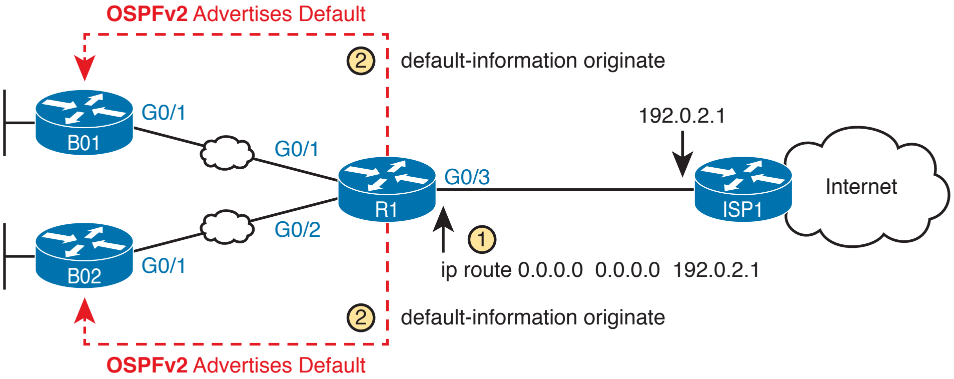

OSPFv2 Advertises Default
2 default-information originate
G0/1
B01
G0/1
192.0.2.1
G0/3
R1
ISP1
Internet
G0/2
B02
G0/1
1
ip route 0.0.0.0 0.0.0.0 192.0.2.1
2 default-information originate
OSPFv2 Advertises Default

Figure 8-6 *Using OSPF to Create and Flood a Default Route*

Figure 8-7 shows the default routes that result from OSPF's advertisements in Figure 8-6. On the far left, the branch routers all have OSPF-learned default routes, pointing to R1. R1 itself also needs a default route, pointing to the ISP router, so that R1 can forward all Internet-bound traffic to the ISP.

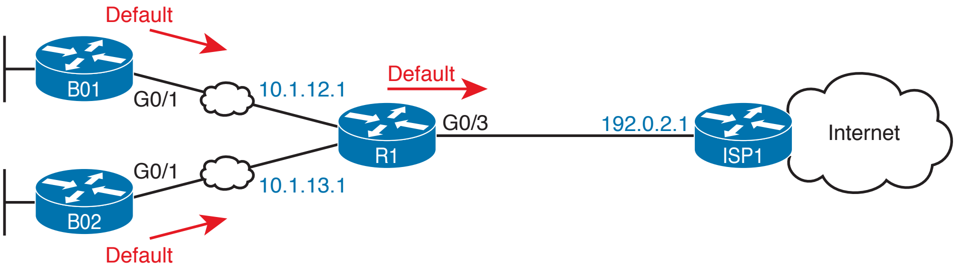


Figure 8-7 *Default Routes Resulting from the* **default-information originate** *Command*

Finally, this feature gives the engineer control over when the router originates this default route. First, R1 needs a default route, either defined as a static default route, learned from the ISP with DHCP, or learned from the ISP with a routing protocol like eBGP. The **default-information originate** command then tells R1 to advertise a default route when its own default route is working, and to advertise the default route as down when its own default route fails.

NOTE Interestingly, the **default-information originate always** router subcommand tells the router to always advertise the default route, no matter whether the router's default route is working or not.

Example 8-18 shows details of the default route on both R1 and branch router B01. Beginning with Router R1, in this case, Router R1 used DHCP to learn its IP address on its G0/3 interface from the ISP. R1 then creates a static default route with the ISP router's IP address of 192.0.2.1 as the next-hop address, as highlighted in the output of the **show ip route static** command output.

Example 8-18 *Default Routes on Routers R1 and B01*

```
! The next command is from Router R1. Note the static code for the default route
R1# show ip route static
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
! Rest of the legend omitted for brevity

Gateway of last resort is 192.0.2.1 to network 0.0.0.0

S*    0.0.0.0/0 [254/0] via 192.0.2.1
```

```
! The next command is from router B01; notice the External route code for the default
BO1# show ip route ospf
Codes: L - local, 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
! Rest of the legend omitted for brevity

Gateway of last resort is 10.1.12.1 to network 0.0.0.0

O*E2  0.0.0.0/0 [110/1] via 10.1.12.1, 00:20:51, GigabitEthernet0/1
      10.0.0.0/8 is variably subnetted, 6 subnets, 2 masks
O        10.1.3.0/24 [110/3] via 10.1.12.1, 00:20:51, GigabitEthernet0/1
O        10.1.13.0/24 [110/2] via 10.1.12.1, 00:20:51, GigabitEthernet0/1
```

Keeping the focus on the command on Router R1, note that R1 indeed has a default route, that is, a route to 0.0.0.0/0. The "Gateway of last resort," which refers to the default route currently used by the router, points to next-hop IP address 192.0.2.1, which is the ISP router's IP address. (Refer back to Figure 8-7 for the particulars.)

Next look to the bottom half of the example, and router BO1's OSPF-learned default route. BO1 lists a route for 0.0.0.0/0 as well. The next-hop router in this case is 10.1.12.1, which is Router R1's IP address on the WAN link. The code on the far left is O*E2, meaning: an OSPF-learned route, which is a default route, and is specifically an external OSPF route. Finally, BO1's gateway of last resort setting uses that one OSPF-learned default route, with next-hop router 10.1.12.1.

OSPF Metrics (Cost)

Earlier, the Chapter 7 section "Calculating the Best Routes with SPF" discussed how SPF calculates the metric for each route, choosing the route with the best metric for each destination subnet. OSPF routers can influence that choice by changing the OSPF interface cost on any and all interfaces.

Cisco routers allow two different ways to change the OSPF interface cost. The one straightforward way is to set the cost directly, with an interface subcommand: **ip ospf cost** *x*. The other method is to let IOS choose default costs, based on a formula, but to change the inputs to the formula. This second method requires a little more thought and care and is the focus of this next topic.

Setting the Cost Based on Interface Bandwidth

The default OSPF cost values can actually cause a little confusion, for a couple of reasons. So, to get through some of the potential confusion, this section begins with some examples.

First, IOS uses the following formula to choose an interface's OSPF cost. IOS puts the interface's bandwidth in the denominator, and a settable OSPF value called the *reference bandwidth* in the numerator:

Reference_bandwidth / Interface_bandwidth

With this formula, the following sequence of logic happens:

1. A higher interface bandwidth—that is, a faster bandwidth—results in a lower number in the calculation.
2. A lower number in the calculation gives the interface a lower cost.
3. An interface with a lower cost is more likely to be used by OSPF when calculating the best routes.

Now for some examples. Assume a default reference bandwidth, set to 100 Mbps, which is the same as 100,000 Kbps. (The upcoming examples will use a unit of Kbps just to avoid math with fractions.) Assume defaults for interface bandwidth on serial, Ethernet, and Fast Ethernet interfaces, as shown in the output of the **show interfaces** command, respectively, of 1544 Kbps, 10,000 Kbps (meaning 10 Mbps), and 100,000 Kbps (meaning 100 Mbps). Table 8-2 shows the results of how IOS calculates the OSPF cost for some interface examples.

Table 8-2 OSPF Cost Calculation Examples with Default Bandwidth Settings

Interface	Interface Default Bandwidth (Kbps)	Formula (Kbps)	OSPF Cost
Serial	1544 Kbps	100,000/1544	64
Ethernet	10,000 Kbps	100,000/10,000	10
Fast Ethernet	100,000 Kbps	100,000/100,000	1

Example 8-19 shows the cost settings on R1's OSPF interfaces, all based on default OSPF (reference bandwidth) and default interface bandwidth settings.

Example 8-19 *Confirming OSPF Interface Costs*

```
R1# show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Gi0/0.12     1     0               10.1.2.1/24        1     DR    0/0
Gi0/0.11     1     0               10.1.1.1/24        1     DR    0/0
Gi0/1        1     4               10.1.14.1/24       1     BDR   1/1
Se0/0/1      1     23              10.1.13.1/24       64    P2P   1/1
Se0/0/0      1     23              10.1.12.1/24       64    P2P   1/1
```

To change the OSPF cost on these interfaces, the engineer simply needs to use the **bandwidth** *speed* interface subcommand to set the bandwidth on an interface. The interface bandwidth does not change the Layer 1 transmission speed at all; instead, it is used for other purposes, including routing protocol metric calculations. For instance, if you add the **bandwidth 10000** command to a serial interface, with a default reference bandwidth, the serial interface's OSPF cost could be calculated as 100,000 / 10,000 = 10.

Note that if the calculation of the default metric results in a fraction, OSPF rounds down to the nearest integer. For instance, the example shows the cost for interface S0/0/0 as 64. The calculation used the default serial interface bandwidth of 1.544 Mbps, with reference bandwidth 100 (Mbps), with the 100 / 1.544 calculation resulting in 64.7668394. OSPF rounds down to 64.

The Need for a Higher Reference Bandwidth

This default calculation works nicely as long as the fastest link in the network runs at 100 Mbps. The default reference bandwidth is set to 100, meaning 100 Mbps, the equivalent of 100,000 Kbps. As a result, with default settings, faster router interfaces end up with the same OSPF cost, as shown in Table 8-3, because the lowest allowed OSPF cost is 1.

Table 8-3 Faster Interfaces with Equal OSPF Costs

Interface	Interface Default Bandwidth (Kbps)	Formula (Kbps)	OSPF Cost
Fast Ethernet	100,000 Kbps	100,000/100,000	1
Gigabit Ethernet	1,000,000 Kbps	100,000/1,000,000	1
10 Gigabit Ethernet	10,000,000 Kbps	100,000/10,000,000	1
100 Gigabit Ethernet	100,000,000 Kbps	100,000/100,000,000	1

To avoid this issue, and change the default cost calculation, you can change the reference bandwidth with the **auto-cost reference-bandwidth** *speed* OSPF mode subcommand. This command sets a value in a unit of megabits per second (Mbps). To avoid the issue shown in Table 8-3, set the reference bandwidth value to match the fastest link speed in the network. For instance, **auto-cost reference-bandwidth 10000** accommodates links up to 10 Gbps in speed.

NOTE Cisco recommends making the OSPF reference bandwidth setting the same on all OSPF routers in an enterprise network.

For convenient study, the following list summarizes the rules for how a router sets its OSPF interface costs:

Key Topic

1. Set the cost explicitly, using the **ip ospf cost** *x* interface subcommand, to a value between 1 and 65,535, inclusive.
2. Change the interface bandwidth with the **bandwidth** *speed* command, with *speed* being a number in kilobits per second (Kbps).
3. Change the reference bandwidth, using router OSPF subcommand **auto-cost reference-bandwidth** *ref-bw*, with a unit of megabits per second (Mbps).

OSPF Load Balancing

When a router uses SPF to calculate the metric for each of several routes to reach one subnet, one route may have the lowest metric, so OSPF puts that route in the routing table. However, when the metrics tie for multiple routes to the same subnet, the router can put multiple equal-cost routes in the routing table (the default is four different routes) based on the setting of the **maximum-paths** *number* router subcommand. For example, if an internetwork has six possible paths between some parts of the network, and the engineer wants all routes to be used, the routers can be configured with the **maximum-paths 6** subcommand under **router ospf**.

The more challenging concept relates to how the routers use those multiple routes. A router could load balance the packets on a per-packet basis. For example, if the router has three equal-cost OSPF routes for the same subnet in the routing table, the router could send the one packet over the first route, the next packet over the second route, the next packet over the third route, and then start over with the first route for the next packet. Alternatively, the load balancing could be on a per-destination IP address basis.

Note that the default setting of **maximum-paths** varies by router platform.

OSPFv2 Interface Configuration

The newer interface-style OSPF configuration works mostly like the old style, for almost all features, with one important exception. The interface configuration enables OSPF directly on the interface with the **ip ospf** interface subcommand, while the traditional OSPFv2 configuration enables OSPFv2 on an interface, but indirectly, using the **network** command in OSPF configuration mode. The rest of the OSPF features discussed throughout this chapter are not changed by the use of OSPFv2 interface configuration.

Basically, instead of matching interfaces with indirect logic using **network** commands, you directly enable OSPFv2 on interfaces by configuring an interface subcommand on each interface.

OSPFv2 Interface Configuration Example

To show how OSPF interface configuration works, this example basically repeats the example shown earlier in the book using the traditional OSPFv2 configuration with **network** commands. So, before looking at the OSPFv2 interface configuration, take a moment to look back at Figures 8-3 and 8-4, along with Examples 8-12, 8-13, and 8-14. Once reviewed, for easier reference, Figure 8-8 repeats Figure 8-4 for reference in the upcoming interface configuration examples.

To convert from the old-style configuration in Examples 8-12, 8-13, and 8-14, simply do the following:

Config Checklist

Step 1. Use the **no network** *network-id* **area** *area-id* subcommands in OSPF configuration mode to remove the **network** commands.

Step 2. Add one **ip ospf** *process-id* **area** *area-id* command in interface configuration mode under each interface on which OSPF should operate, with the correct OSPF process (*process-id*) and the correct OSPF area number.

For example, Example 8-12 had a single **network** command that enabled OSPF on two interfaces on Router R2, putting both in area 23. Example 8-20 shows the replacement newer style of configuration.

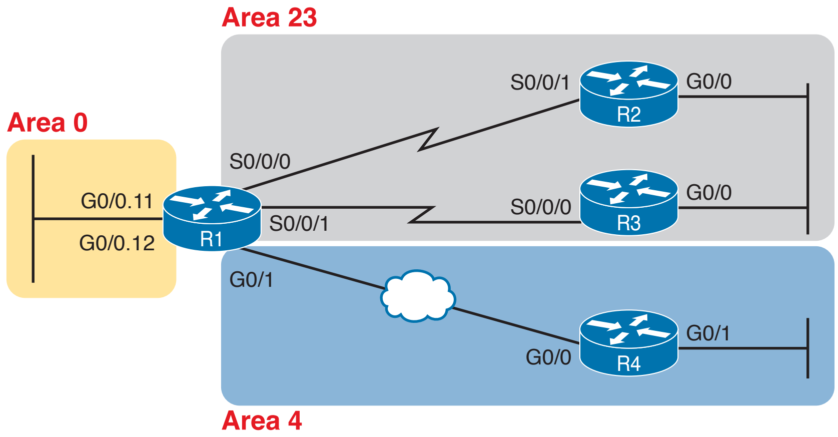


Figure 8-8 *Area Design Used in the Upcoming OSPF Example*

Example 8-20 *New-Style Configuration on Router R2*

```
interface GigabitEthernet0/0
 ip address 10.1.23.2 255.255.255.0
 ip ospf 1 area 23
!
```

```
interface serial 0/0/1
 ip address 10.1.12.2 255.255.255.0
 ip ospf 1 area 23

router ospf 1
 router-id 2.2.2.2
! Notice – no network commands here!
```

Verifying OSPFv2 Interface Configuration

OSPF operates the same way whether you use the new style or old style of configuration. The OSPF area design works the same, neighbor relationships form the same way, routers negotiate to become the DR and BDR the same way, and so on. However, you can see a few small differences in command output when using the newer OSPFv2 configuration if you look closely.

The **show ip protocols** command relists most of the routing protocol configuration, just in slightly different format, as shown in Example 8-21. With the newer-style configuration, the output lists the phrase "Interfaces Configured Explicitly," with the list of interfaces configured with the new **ip ospf** *process-id* **area** *area-id* commands, as highlighted in the example. With the old configuration, the output lists the contents of all the **network** commands, just leaving out the "network" word itself. Note that in the next two examples, R2 has been reconfigured to use OSPF interface configuration as shown in the previous example (Example 8-20), while Router R3 still uses the older-style **network** commands per earlier configuration Example 8-13.

Example 8-21 *Differences in* **show ip protocols** *Output: Old- and New-Style OSPFv2 Configuration*

```
R2# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 1"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 2.2.2.2
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
  Routing on Interfaces Configured Explicitly (Area 23):
    Serial0/0/1
    GigabitEthernet0/0
  Routing Information Sources:
    Gateway         Distance      Last Update
    3.3.3.3              110       00:04:59
    1.1.1.1              110       00:04:43
  Distance: (default is 110)
! Below, showing only the part that differs on R3:
R3# show ip protocols
! … beginning lines omitted for brevity
  Routing for Networks:
    10.0.0.0 0.255.255.255 area 23
! … ending line omitted for brevity
```

Basically, the **show ip protocols** command output differs depending on the style of configuration, either relisting the interfaces when using interface configuration or relisting the network commands if using **network** commands.

Next, the **show ip ospf interface** [*interface*] command lists details about OSPF settings for the interface(s) on which OSPF is enabled. The output also makes a subtle reference to whether that interface was enabled for OSPF with the old or new configuration style. As seen in Example 8-22, R2's new-style interface configuration results in the highlighted text, "Attached via Interface Enable," whereas R3's old-style configuration lists "Attached via Network Statement."

Key Topic

Example 8-22 *Differences in* **show ip ospf interface** *Output with OSPFv2 Interface Configuration*

```
R2# show ip ospf interface g0/0
GigabitEthernet0/0 is up, line protocol is up
  Internet Address 10.1.23.2/24, Area 23, Attached via Interface Enable
  Process ID 1, Router ID 22.2.2.2, Network Type BROADCAST, Cost: 1
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           1         no          no            Base
  Enabled by interface config, including secondary ip addresses
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 2.2.2.2, Interface address 10.1.23.2
  Backup Designated router (ID) 3.3.3.3, Interface address 10.1.23.3
```

```
! Showing only the part that differs on R3:
R3# show ip ospf interface g0/0
GigabitEthernet0/0 is up, line protocol is up
  Internet Address 10.1.23.3/24, Area 23, Attached via Network Statement
! … ending line omitted for brevity
```

Note that the briefer version of this command, the **show ip ospf interface brief** command, does not change whether the configuration uses traditional **network** commands or the alternative interface configuration with the **ip ospf** interface subcommand.

Review Activities

Chapter Summary

- The OSPF **network** command is used to match the IP addresses that are configured on the interfaces. Those that match are inserted into the OSPF process.
- The OSPF **network** command uses wildcard masks to control which bits in an octet are matched.
- The **show ip ospf neighbor** command can be used to find information about any OSPF neighborships, including the interface, the state, the neighbor's address, and the neighbor's router ID.
- To select a router ID for OSPF, a router goes through a process. When a router ID has been found, the process stops. The process is any value configured with the **router-id** command; the highest configured IPv4 address of any enabled loopback interface; and the highest configured IPv4 address of any physically up (up/up or up/down) physical interface.
- An OSPF interface configured as passive will quit sending OSPF Hello messages, will ignore any received Hello messages, and will not form any neighborships.
- The only OSPF router configured into multiple areas is an Area Border Router (ABR).
- The **show ip ospf interface** [*type number* | **brief**] command can be used to display which interfaces are enabled into the OSPF process.
- The **show ip ospf neighbor** [*type number*] command can be used to display any OSPF neighborships.
- The **show ip ospf database** command can be used to display the OSPF LSDB.
- The **show ip route** [**ospf** | *subnet mask*] command can be used to display OSPF routes in the current routing table.
- The **show ip protocols** and **show ip ospf interface** [**brief**] commands can be used to display which areas are configured on a device.
- The OSPF **default-information originate** command is used along with a configured static default route to advertise a default route into OSPF.
- OSPF uses three rules to set interface costs: setting the cost explicitly with the **ip ospf cost** *cost* command, changing the interface bandwidth with the **bandwidth** *bandwidth* command, or changing the reference bandwidth with the **auto-cost reference-bandwidth** *reference-bandwidth* command.
- The output of the **show ip protocols** and **show ip ospf interface** commands will differ depending on whether OSPF was configured with the old (**network**) or new (interface commands) configuration style.

Review Questions

1. Which of the following **network** commands, following the command **router ospf 1**, tells this router to start using OSPF on interfaces whose IP addresses are 10.1.1.1, 10.1.100.1, and 10.1.120.1?

   A. **network 10.0.0.0 255.0.0.0 area 0**

   B. **network 10.0.0.0 0.255.255.255 area 0**

   C. **network 10.0.0.1 0.0.0.255 area 0**

   D. **network 10.0.0.1 0.0.255.255 area 0**

2. Which of the following **network** commands, following the command **router ospf 1**, tells this router to start using OSPF on interfaces whose IP addresses are 10.1.1.1, 10.1.100.1, and 10.1.120.1?
   - A. **network 10.1.0.0 0.0.255.255 area 0**
   - B. **network 10.0.0.0 0.255.255.0 area 0**
   - C. **network 10.1.1.0 0.x.1x.0 area 0**
   - D. **network 10.1.1.0 255.0.0.0 area 0**
   - E. **network 10.0.0.0 255.0.0.0 area 0**

3. Which of the following commands list the OSPF neighbors off interface serial 0/0? (Choose two answers.)
   - A. **show ip ospf neighbor**
   - B. **show ip ospf interface brief**
   - C. **show ip neighbor**
   - D. **show ip interface**
   - E. **show ip ospf neighbor serial 0/0**

4. Routers R1, R2, and R3 are internal routers in areas 1, 2, and 3, respectively. Router R4 is an ABR connected to the backbone area (0) and to areas 1, 2, and 3. Which of the following answers describes the configuration on Router R4, which is different from the other three routers, that makes it an ABR?
   - A. The **abr enable** router subcommand.
   - B. The **network** router subcommands refer to a single nonbackbone area.
   - C. The **network** router subcommands refer to multiple areas, including the backbone.
   - D. The router has an interface in area 0, whereas an OSPF neighbor's interface sits in a different area.

5. An engineer connects to Router R1 and issues a **show ip ospf neighbor** command. The status of neighbor 2.2.2.2 lists FULL/BDR. What does the BDR mean?
   - A. R1 is an Area Border Router.
   - B. R1 is a backup designated router.
   - C. Router 2.2.2.2 is an Area Border Router.
   - D. Router 2.2.2.2 is a backup designated router.

6. An engineer migrates from a more traditional OSPFv2 configuration that uses **network** commands in OSPF configuration mode to instead use OSPFv2 interface configuration. Which of the following commands configures the area number assigned to an interface in this new configuration?
   - A. The **area** command in interface configuration mode
   - B. The **ip ospf** command in interface configuration mode
   - C. The **router ospf** command in interface configuration mode
   - D. The **network** command in interface configuration mode

7. Which of the following configuration settings on a router does not influence which IPv4 route a router chooses to add to its IPv4 routing table when using OSPFv2?
   - A. **auto-cost reference-bandwidth**
   - B. **delay**
   - C. **bandwidth**
   - D. **ip ospf cost**

Chapter Review

One key to doing well on the exams is to perform repetitive spaced review sessions. Review this chapter's material using either the tools in the book, DVD, or interactive tools for the same material found on the book's companion website. Refer to the "Your Study Plan" element for more details. Table 8-4 outlines the key review elements and where you can find them. To better track your study progress, record when you completed these activities in the second column.

Table 8-4 Chapter Review Tracking

Review Element	Review Date(s)	Resource Used:
Review key topics		Book, DVD/website
Review key terms		Book, DVD/website
Answer chapter review questions		Book, PCPT
Do labs		Blog
Review Config Checklists		Book, DVD/website
Review command tables		Book

Review All the Key Topics

Key Topic

Table 8-5 Key Topics for Chapter 8

Key Topic Element	Description	Page Number
List	Example OSPF wildcard masks and their meaning	187
Example 8-4	Example of the **show ip ospf neighbor** command	189
List	Rules for setting the router ID	191
List	Actions IOS takes when an OSPF interface is passive	192
Example 8-14	Example of a multiarea OSPFv2 configuration	196
Figure 8-5	Popular OSPF **show** commands and their general purposes	198
Example 8-15	Example of the **show ip ospf interface brief** showing interfaces in multiple areas	198
Figure 8-6	Actions taken by the OSPF **default-information originate** command	201
List	Rules for setting OSPF interface cost	204
Example 8-22	Differences in **show ip ospf interface** output with OSPF interface configuration	207

Key Terms You Should Know

reference bandwidth, interface bandwidth, maximum paths

Command References

Tables 8-6 and 8-7 list configuration and verification commands used in this chapter. As an easy review exercise, cover the left column in a table, read the right column, and try to recall the command without looking. Then repeat the exercise, covering the right column, and try to recall what the command does.

Table 8-6 Chapter 8 Configuration Command Reference

Command	Description
router ospf *process-id*	Enters OSPF configuration mode for the listed process.
network *ip-address wildcard-mask* area *area-id*	Router subcommand that enables OSPF on interfaces matching the address/wildcard combination and sets the OSPF area.
ip ospf *process-id* **area** *area-number*	Interface subcommand to enable OSPF on the interface and to assign the interface to a specific OSPF area.
ip ospf cost *interface-cost*	Interface subcommand that sets the OSPF cost associated with the interface.
bandwidth *bandwidth*	Interface subcommand that directly sets the interface bandwidth (Kbps).
auto-cost reference-bandwidth *number*	Router subcommand that tells OSPF the numerator in the Reference_bandwidth / Interface_bandwidth formula used to calculate the OSPF cost based on the interface bandwidth.
router-id *id*	OSPF command that statically sets the router ID.
interface loopback *number*	Global command to create a loopback interface and to navigate to interface configuration mode for that interface.
maximum-paths *number-of-paths*	Router subcommand that defines the maximum number of equal-cost routes that can be added to the routing table.
passive-interface *type number*	Router subcommand that makes the interface passive to OSPF, meaning that the OSPF process will not form neighbor relationships with neighbors reachable on that interface.
passive-interface *default*	OSPF subcommand that changes the OSPF default for interfaces to be passive instead of active (not passive).
no passive-interface *type number*	OSPF subcommand that tells OSPF to be active (not passive) on that interface or subinterface.
default-information originate [**always**]	OSPF subcommand to tell OSPF to create and advertise an OSPF default route, as long as the router has some default route (or to always advertise a default, if the **always** option is configured).

Table 8-7 Chapter 8 EXEC Command Reference

Command	Description
show ip ospf	Lists information about the OSPF process running on the router, including the OSPF router ID, areas to which the router connects, and the number of interfaces in each area.
show ip ospf interface brief	Lists the interfaces on which the OSPF protocol is enabled (based on the **network** commands), including passive interfaces.
show ip ospf interface [*type number*]	Lists a long section of settings, status, and counters for OSPF operation on all interfaces, or on the listed interface, including the Hello and Dead Timers.
show ip protocols	Shows routing protocol parameters and current timer values.
show ip ospf neighbor [*type number*]	Lists brief output about neighbors, identified by neighbor router ID, including current state, with one line per neighbor; optionally, limits the output to neighbors on the listed interface.

Command	Description
show ip ospf neighbor *neighbor-ID*	Lists the same output as the **show ip ospf neighbor** detail command, but only for the listed neighbor (by neighbor RID).
show ip ospf database	Lists a summary of the LSAs in the database, with one line of output per LSA. It is organized by LSA type (first type 1, then type 2, and so on).
show ip route	Lists all IPv4 routes.
show ip route ospf	Lists routes in the routing table learned by OSPF.
show ip route *ip-address mask*	Shows a detailed description of the route for the listed subnet/mask.
clear ip ospf process	Resets the OSPF process, resetting all neighbor relationships and also causing the process to make a choice of OSPF RID.

Answers to the Review Questions:

1 B **2** A **3** A, E **4** C **5** D **6** B, **7** B

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