CCNP ROUTE Exam Preparation

CCNP ROUTE 642-902

Official Certification Guide

- ✔ Master the **CCNP® Route 642-902** exam with this official study guide
- ✔ Assess your knowledge with **chapter-opening quizzes**
- ✔ Review key concepts with **Exam Preparation Tasks**
- ✔ Practice with **realistic exam questions** on the CD-ROM

ciscopress.com

Wendell Odom, CCIE® No. 1624

CCNP ROUTE 642-902 Official Certification Guide

Wendell Odom

Published by:
Cisco Press
800 East 96th Street
Indianapolis, IN 46240 USA

Printed in the United States of America

First Printing January 2010

Odom, Wendell.
CCNP Route 642-902 official certification guide / Wendell Odom.
p. cm.
ISBN 978-1-58720-253-7 (hardback w/cd)
1. Routers (Computer networks)--Examinations--Study guides. 2. Routing protocols (Computer network protocols)--Examinations--Study guides. 3. Internetworking (Telecommunication)--Examinations--Study guides. 4. Telecommunications engineers--Certification--Examinations--Study guides. I. Title.
TK5105.543.O36 2010
004.6'2--dc22
2009049908

ISBN-13: 978-1-58720-253-7

ISBN-10: 1-58720-253-0

Warning and Disclaimer

This book is designed to provide information about the Cisco ROUTE exam (642-902). Every effort has been made to make this book as complete and as accurate as possible, but no warranty or fitness is implied.

The information is provided on an "as is" basis. The authors, Cisco Press, and Cisco Systems, Inc. shall have neither liability nor responsibility to any person or entity with respect to any loss or damages arising from the information contained in this book or from the use of the discs or programs that may accompany it.

The opinions expressed in this book belong to the author and are not necessarily those of Cisco Systems, Inc.

Foreword

CCNP ROUTE 642-902 Official Certification Guide is an excellent self-study resource for the CCNP ROUTE exam. Passing this exam is a crucial step to attaining the valued CCNP Routing and Switching certification.

Gaining certification in Cisco technology is key to the continuing educational development of today's networking professional. Through certification programs, Cisco validates the skills and expertise required to effectively manage the modern enterprise network.

Cisco Press Certification Guides and preparation materials offer exceptional—and flexible—access to the knowledge and information required to stay current in your field of expertise or to gain new skills. Whether used as a supplement to more traditional training or as a primary source of learning, these materials offer users the information and knowledge validation required to gain new understanding and proficiencies.

Developed in conjunction with the Cisco certifications and training team, Cisco Press books are the only self-study books authorized by Cisco and offer students a series of exam practice tools and resource materials to help ensure that learners fully grasp the concepts and information presented.

Additional authorized Cisco instructor-led courses, e-learning, labs, and simulations are available exclusively from Cisco Learning Solutions Partners worldwide. To learn more, visit http://www.cisco.com/go/training.

I hope that you find these materials to be an enriching and useful part of your exam preparation.

Erik Ullanderson
Manager, Global Certifications
Learning@Cisco
January 2010

Introduction

This book focuses on one major goal: to help you prepare to pass the ROUTE exam (642-902). To help you prepare, this book achieves other useful goals as well: It explains a wide range of networking topics, shows how to configure those features on Cisco routers, and explains how to determine if the feature is working. As a result, you also can use this book as a general reference for IP routing and IP routing protocols. However, the motivation for this book, and the reason it sits within the Cisco Press Certification Guide series, is that its primary goal is to help you pass the ROUTE exam.

The rest of this introduction focuses on two topics: the ROUTE exam and a description of this book.

The CCNP ROUTE Exam

Cisco announced the ROUTE (642-902) exam in January 2010. The term ROUTE does not act as an acronym; instead, the name describes the content of the exam, which focuses on IP routing. Generally, the exam includes detailed coverage of the EIGRP, OSPF, and BGP IP routing protocols, IPv6, and a few other smaller topics related to IP routing.

Cisco first announced its initial Professional level certifications in 1998 with the CCNP Routing and Switching certification. CCNP Routing and Switching certification from its inception has included the same kinds of IP routing topics found in today's ROUTE exam, but the exam names changed over the years. The exam names have tracked the names of the associated Cisco authorized courses for the same topics: Advanced Cisco Router Configuration (ACRC) in the early days, Building Scalable Cisco Internetworks (BSCI) for much of the last 10 years, and now ROUTE, because the newly revised (in 2010) Cisco authorized course also goes by the name ROUTE.

Like its ancestors, the ROUTE exam is a part of the certification requirements for several Cisco certifications, as follows:

- Cisco Certified Networking Professional (CCNP)
- Cisco Certified Internetworking Professional (CCIP)
- Cisco Certified Design Professional (CCDP)

Each of these certifications emphasizes different perspectives on some similar topics. CCNP focuses on the skills needed by a network engineer working for an Enterprise–that is, a company that deploys networking gear for its own purposes. CCIP focuses on the skills required by network engineers deploying gear at a service provider, with the service provider then offering network services to customers. Finally, CCDP focuses more on design–but good design requires solid knowledge of the technology and configuration. So, although this book frequently refers to the most popular certification of these three–CCNP–the ROUTE exam does apply to several certifications.

Contents of the ROUTE Exam

Every student who ever takes an exam wants to know what's on the exam. As with all their exams, Cisco publishes a set of exam topics. These exam topics give general guidance as to what's on the exam.

You can find the exam topics at the Cisco website. The most memorable way to navigate is to go to www.cisco.com/go/ccnp, and look for the ROUTE exam. Also, you can go to the Cisco Learning Network website (www.cisco.com/go/learnnetspace)–a less memorable URL, but a great Cisco certification site. The Cisco Learning Network site hosts exam information, learning tools, and forums in which you can communicate with others and learn more about this and other Cisco exams.

Table I-1 lists the ROUTE exam topics, with a reference to the part of the book that covers the topic.

Table I-1 ROUTE Exam Topics

Book Part	Exam Topic
Implement an EIGRP based solution, given a network design and a set of requirements	
II	Determine network resources needed for implementing EIGRP on a network
II	Create an EIGRP implementation plan
II	Create an EIGRP verification plan
II	Configure EIGRP routing
II	Verify EIGRP solution was implemented properly using **show** and **debug** commands
II	Document results of EIGRP implementation and verification
Implement a multi-area OSPF Network, given a network design and a set of requirements	
III	Determine network resources needed for implementing OSPF on a network
III	Create an OSPF implementation plan
III	Create an OSPF verification plan
III	Configure OSPF routing
III	Verify OSPF solution was implemented properly using show and debug commands
III	Document results of OSPF implementation and verification plan
Implement an eBGP based solution, given a network design and a set of requirements	
V	Determine network resources needed for implementing eBGP on a network
V	Create an eBGP implementation plan
V	Create an eBGP verification plan
V	Configure eBGP routing
V	Verify eBGP solution was implemented properly using show and debug commands
V	Document results of eBGP implementation and verification plan

Table I-1 ROUTE Exam Topics

Book Part	Exam Topic
Implement an IPv6 based solution, given a network design and a set of requirements	
VI	Determine network resources needed for implementing IPv6 on a network
VI	Create an IPv6 implementation plan
VI	Create an IPv6 verification plan
VI	Configure IPv6 routing
VI	Configure IPv6 interoperation with IPv4
VI	Verify IPv6 solution was implemented properly using show and debug commands
VI	Document results of IPv6 implementation and verification plan
Implement an IPv4 or IPv6 based redistribution solution, given a network design and a set of requirements	
IV, VI	Create a redistribution implementation plan based upon the results of the redistribution analysis.
IV, VI	Create a redistribution verification plan
IV, VI	Configure a redistribution solution
IV, VI	Verify that a redistribution was implemented
IV, VI	Document results of a redistribution implementation and verification plan
IV, VI	Identify the differences between implementing an IPv4 and IPv6 redistribution solution
Implement Layer 3 Path Control Solution	
IV	Create a Layer 3 path control implementation plan based upon the results of the redistribution analysis.
IV	Create a Layer 3 path control verification plan
IV	Configure Layer 3 path control
IV	Verify that a Layer 3 path control was implemented
IV	Document results of a Layer 3 path control implementation and verification plan
Implement basic teleworker and branch services	
VII	Describe broadband technologies
VII	Configure basic broadband connections
VII	Describe basic VPN technologies
VII	Configure GRE
VII	Describe branch access technologies

How to Take the ROUTE Exam

As of the publication of this book, Cisco exclusively uses testing vendor Pearson Vue (www.vue.com) for delivery of all Cisco career certification exams. To register, go to www.vue.com, establish a login, and register for the 642-902 ROUTE exam. You also need to choose a testing center near to your home.

Who Should Take This Exam and Read This Book?

This book has one primary audience, with several secondary audiences. First, this book is intended for anyone wanting to prepare for the ROUTE 642-902 exam. The audience includes self-study readers–people who pass the test by studying 100 percent on their own. It includes Cisco Networking Academy students taking the CCNP curriculum, who use this book to round out their preparation as they get close to the end of the Academy curriculum.

The broader question about the audience may well be why you should take the ROUTE exam. First, the exam is required for the aforementioned CCNP, CCIP, and CCDP certifications from Cisco. These certifications exist at the midpoint of the Cisco certification hierarchy. These certifications have broader and deeper technology requirements as compared to the Cisco Certified Entry Network Technician (CCENT) and Cisco Certified Network Associate (CCNA) certifications.

The real question then about audience for this book–at least the intended audience–is whether you have motivation to get one of these Professional-level Cisco certifications. CCNP in particular happens to be a popular, well-respected certification. CCIP, although less popular in numbers, focuses on topics more important to service providers, so it gives you a good way to distinguish yourself from others looking for jobs at SP companies. CCDP has been a solid certification for a long time, particularly for engineers who spend a lot of time designing networks with customers, rather than troubleshooting.

Format of the CCNP ROUTE Exam

The ROUTE exam follows the same general format as the other Cisco exams. When you get to the testing center and check in, the proctor will give you some general instructions and then take you into a quiet room with a PC. When you're at the PC, you have a few things to do before the timer starts on your exam—for instance, you can take a sample quiz, just to get accustomed to the PC and to the testing engine. Anyone who has user-level skills in getting around a PC should have no problems with the testing environment.

When you start the exam, you will be asked a series of questions. You answer the question and then move on to the next question. *The exam engine does not let you go back and change your answer.* Yes, that's true—when you move on to the next question, that's it for the earlier question.

The exam questions can be in one of the following formats:

- Multiple choice (MC)
- Testlet
- Drag-and-drop (DND)
- Simulated lab (Sim)
- Simlet

The first three types of questions are relatively common in many testing environments. The multiple choice format simply requires that you point-and-click on a circle beside the correct answer(s). Cisco traditionally tells you how many answers you need to choose, and the testing software prevents you from choosing too many answers. Testlets are questions with one general scenario, with multiple MC questions about the overall scenario. Drag-and-drop questions require you to left-click and hold, move a button or icon to another area, and release the clicker to place the object somewhere else—typically into a list. So, for some questions, to get the question correct, you might need to put a list of five things into the proper order.

The last two types both use a network simulator to ask questions. Interestingly, the two types actually allow Cisco to assess two very different skills. First, Sim questions generally describe a problem, and your task is to configure one or more routers and switches to fix the problem. The exam then grades the question based on the configuration you changed or added. Interestingly, Sim questions are the only questions that Cisco (to date) has openly confirmed that partial credit is given.

The Simlet questions may well be the most difficult style of question on the exams. Simlet questions also use a network simulator, but instead of answering the question by changing the configuration, the question includes one or more MC questions. The questions require that you use the simulator to examine the current behavior of a network, interpreting the output of any **show** commands that you can remember to answer the question. Although Sim questions require you to troubleshoot problems related to a configuration, Simlets require you to both analyze working networks and networks with problems, correlating **show** command output with your knowledge of networking theory and configuration commands.

The Cisco Learn Network (www.cisco.com/go/learnnetspace) website has tools that let you experience the environment and see how each of these question types work. The environment should be the same as when you passed CCNA (a prerequisite for CCNP, CCIP, and CCDP).

CCNP ROUTE 642-902 Official Certification Guide

This section lists a general description of the contents of this book. The description includes an overview of each chapter, and a list of book features seen throughout the book.

Book Features and Exam Preparation Methods

This book uses several key methodologies to help you discover the exam topics on which you need more review, to help you fully understand and remember those details, and to help you prove to yourself that you have retained your knowledge of those topics. So, this book does not try to help you pass the exams only by memorization, but by truly learning and understanding the topics.

The book includes many features that provide different ways to study to be ready for the test. If you understand a topic when you read it, but do not study it any further, you probably will not be ready to pass the test with confidence. The book features included in this book give you tools that help you determine what you know, review what you know, better learn what you don't know, and be well prepared for the exam. These tools include

- **"Do I Know This Already?" Quizzes:** Each chapter begins with a quiz that helps you determine the amount of time you need to spend studying that chapter.
- **Foundation Topics:** These are the core sections of each chapter. They explain the protocols, concepts, and configuration for the topics in that chapter.
- **Exam Preparation Tasks:** The Exam Preparation Tasks section lists a series of study activities that should be done after reading the Foundation Topics section. Each chapter includes the activities that make the most sense for studying the topics in that chapter. The activities include

— **Planning Tables:** The ROUTE exam topics includes some perspectives on how an engineer plans for various tasks. The idea is that the CCNP-level engineer in particular takes the design from another engineer, plans the implementation, and plans the verification steps–handing off the actual tasks to engineers working during change-window hours. Because the engineer plans the tasks, but may not be at the keyboard when implementing a feature, that engineer must master the configuration and verification commands so that the planned commands work for the engineer making the changes off-shift. The planning tables at the end of the chapter give you the chance to take the details in the Foundation Topics core of the chapter and think about them as if you were writing the planning documents.

— **Key Topics Review:** The Key Topics icon is shown next to the most important items in the Foundation Topics section of the chapter. The Key Topics Review activity lists the Key Topics from the chapter, and page number. Although the contents of the entire chapter could be on the exam, you should definitely know the information listed in each key topic. Review these topics carefully.

— **Memory Tables:** To help you exercise your memory and memorize some lists of facts, many of the more important lists and tables from the chapter are included in a document on the CD. This document lists only partial information, allowing you to complete the table or list. CD-only Appendix D holds the incomplete tables, and Appendix E includes the completed tables from which you can check your work.

— **Definition of Key Terms:** Although the exams may be unlikely to ask a question such as "Define this term," the ROUTE exam requires that you learn and know a lot of networking terminology. This section lists the most important terms from the chapter, asking you to write a short definition and compare your answer to the glossary at the end of the book.

- **CD-based practice exam:** The companion CD contains an exam engine (from Boson software, www.boson.com), which includes 100 unique multiple-choice questions. Chapter 20 gives two suggestions on how to use these questions: either as study questions, or to simulate the ROUTE exam.

- **Companion website:** The website http://www.ciscopress.com/title/9781587202537 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.

Book Organization

This book contains 20 chapters, plus appendixes. The topics all focus in some way on IP routing and IP routing protocols, making the topics somewhat focused, but with deep coverage on those topics.

The book organizes the topics into seven major parts. Parts 1 and 7 include topics with less technical depth, and Parts 2 through 6 include the major technical topics in the book. The following list outlines the major part organization of this book:

Part I: "Perspectives on Network Planning": This part includes a single chapter:

- **Chapter 1: "Planning Tasks for the CCNP Exams":** This chapter discusses the CCNP ROUTE exam's perspectives on the planning process, including network design, implementation plans, and verification plans.

Part II: "EIGRP": This part starts with a CCNA-level EIGRP review and moves through EIGRP theory, configuration, authentication, route summarization, and more in the following chapters:

- **Chapter 2: "EIGRP Overview and Neighbor Relationships":** This chapter reviews CCNA-level EIGRP topics and then closely examines the concepts, configuration, and verification of EIGRP neighbor relationships.
- **Chapter 3: "EIGRP Topology, Routes, and Convergence":** This chapter examines the EIGRP topology database and the processes by which EIGRP processes this data to choose routes. It also examines the convergence process using feasible successors and with the Query process.
- **Chapter 4: "EIGRP Route Summarization and Filtering":** This chapter discusses the theory behind route summarization and route filtering. It also shows how to configure and verify both features for EIGRP.

Part III: "OSPF": Similar to Part II, this part starts with a CCNA-level OSPF review and moves through OSPF theory, configuration, authentication, metric tuning, default routing, route filtering, and route summarization, plus OSPF multiarea issues and different stubby area types, as follows:

- **Chapter 5: "OSPF Overview and Neighbor Relationships":** This chapter reviews CCNA-level OSPF topics and then closely examines the concepts, configuration, and verification of OSPF neighbor relationships.
- **Chapter 6: "OSPF Topology, Routes, and Convergence":** This chapter examines the OSPF topology database for routes internal to OSPF. The chapter also discusses how OSPF routers choose the best internal OSPF routes and how OSPF converges when a change occurs.

- **Chapter 7: "OSPF Route Summarization, Filtering, and Default Routing":** This chapter discusses the design, configuration, and verification of OSPF route summarization and route filtering. It also discusses default routes and how to manage the size of the OSPF database and IP routing tables by using stubby areas.
- **Chapter 8: "OSPF Miscellany":** This chapter discusses two additional OSPF topics: OSPF virtual links and OSPF issues when using NBMA networks (such as Frame Relay).

Part IV: "Path Control": The term path control refers to a wide variety of topics related to IP routing and IP routing protocols. This part examines the path control topics not specifically included in the other parts of the book:

- **Chapter 9: "Basic IGP Redistribution":** This chapter examines the concepts, configuration, and verification of IGP route redistribution. In particular, this chapter looks at the mechanics of redistribution without the use of route maps for any purpose.
- **Chapter 10: "Advanced IGP Redistribution":** This chapter essentially continues Chapter 9, in this case focusing on the more complex configuration and issues. In particular, this chapter shows how to manipulate and filter routes at the redistribution function by using route maps, and how to avoid routing loops and inefficient routes when multiple redistribution points exist.
- **Chapter 11: "Policy Routing and IP Service Level Agreement":** This chapter picks up two small path control topics that simply do not fit into any other broader chapter in this book: Policy Based Routing (PBR) and IP Service Level Agreement (IP SLA).

Part V: "BGP": This part assumes no prior knowledge of BGP. It first examines BGP design issues, to give perspective on why BGP works differently than its IGP cousins OSPF and EIGRP. This part examines basic BGP concepts, configuration, and verification, including the path control functions of incluencing both inbound and outbound BGP routes:

- **Chapter 12: "Internet Connectivity and BGP":** This chapter introduces BGP. It begins with a review of Internet connectivity from a Layer 3 perspective. It then looks at the basics of how BGP works. It also examines some Internet access design issues, discussing the cases in which BGP can be helpful and the cases in which BGP has no practical use.
- **Chapter 13: "External BGP":** This chapter examines the configuration and verification of BGP between an Enterprise and its ISP(s).
- **Chapter 14: "Internal BGP and BGP Route Filtering":** This chapter examines the cases in which routers in the same ASN need to become BGP peers, creating an Internet BGP connection. It also discusses the need for BGP filtering and the mechanics of configuring BGP filtering.

- **Chapter 15: "BGP Path Control":** This chapter discusses the concept of the BGP Best Path Algorithm to choose the best BGP routes and how to influence those choices. In particular, this chapter shows the basic configuration for BGP weight, Local Preference, AS_Path length, and Multi-Exit Discriminator (MED).

Part VI: "IPv6": This part assumes no prior knowledge of IPv6. The chapters in this part work through IPv6 addressing and IGP configuration (RIPng, EIGRP for IPv6, and OSPFv3). It also discusses route redistribution for IPv6 and IPv6/IPv4 coexistence mechanisms:

- **Chapter 16: "IP Version 6 Addressing":** This chapter begins with an overview of IP Version 6 (IPv6). It then dives into IPv6 addressing concepts, plus the related protocols, including address assignment options and neighbor discovery. The chapter shows how to configure and verify IPv6 addresses on Cisco routers.
- **Chapter 17: "IPv6 Routing Protocols and Redistribution":** This chapter introduces three IPv6 IGPs: RIP Next Generation (RIPng), EIGRP for IPv6, and OSPF Version 3 (OSPFv3). The chapter focuses on basic configuration and verification. It also discusses IPv6 redistribution in comparison with IPv4 IGP redistribution.
- **Chapter 18: "IPv4 and IPv6 Coexistence":** This chapter discusses the many options to use during the potentially long migration from a purely IPv4 network to a future purely IPv6 network.

Part VII: "Branch Office Networking": This short part includes one chapter that addresses a few small topics related to branch offices that connect to their Enterprise networks using the Internet:

- **Chapter 19: "Routing over Branch Internet Connections":** Branch office routers can be configured to use the Internet as a WAN connection path back to the rest of an Enterprise network. This chapter takes a wide look at the surprisingly large number of networking functions that must occur on a branch router in such cases. It also gives examples of configurations for IPsec and GRE tunnels, DHCP server, NAT, and DSL.

Part VIII: "Final Preparation": This short part includes one chapter as well. This chapter does not include any new technical topics:

- **Chapter 20: "Final Preparation":** This chapter suggests some study strategies for your final preparation before the ROUTE exam.

In addition to the core chapters of the book, the book has several appendixes as well. Some appendixes exist in the printed book, whereas others exist in softcopy form on the CD included with the book.

Printed Appendixes

Appendixes printed in the book include

- **Appendix A, "Answers to the "Do I Know This Already?" Quizzes":** Includes the answers to all the questions from Chapters 2 through 19.
- **Appendix B, "Conversion Tables":** Lists a decimal-to-binary conversion table, decimal values 0 through 255, along with the binary equivalents. It also lists a hex-to-decimal conversion table as well.
- **Appendix C, "CCNP ROUTE Exam Updates: Version 1.0":** Covers a variety of short topics that either clarify or expand upon topics covered earlier in the book. This appendix is updated from time to time, and posted at http://www.ciscopress.com/title/9781587202537, with the most recent version available at the time of printing included here as Appendix C. (The first page of the appendix includes instructions on how to check to see if a later version of Appendix C is available online.)

CD Appendixes

The appendixes included on the CD-ROM are

- **Appendix D, "Memory Tables":** This appendix holds the key tables and lists from each chapter with some of the content removed. You can print this appendix, and as a memory exercise, complete the tables and lists. The goal is to help you memorize facts that can be useful on the exams.
- **Appendix E, "Memory Tables Answer Key":** This appendix contains the answer key for the exercises in Appendix D.
- **Appendix F, "Completed Planning Practice Tables":** The end of Chapters 2 through 19 list planning tables that you can complete to help learn the content more deeply. If you use these tables, refer to this appendix for the suggested answers.
- **Glossary:** The glossary contains definitions for all the terms listed in the "Define Key Terms" section at the conclusion of Chapters 2 through 19.

For More Information

If you have any comments about the book, you can submit those via the www.ciscopress.com. Just go to the website, select Contact Us, and type in your message.

Cisco might make changes that affect the ROUTE exam from time to time. You should always check www.cisco.com/go/ccnp for the latest details.

This chapter covers the following subjects:

LSAs and the OSPF Link State Database: This section examines LSA Types 1, 2, and 3, and how they allow OSPF routers to model the topology and choose the best routes for each known subnet.

The Database Exchange Process: This section details how neighboring routers use OSPF messages to exchange their LSAs.

Choosing the Best Internal OSPF Routes: This section examines how OSPF routers calculate the cost for each possible route to each subnet.

CHAPTER 6

OSPF Topology, Routes, and Convergence

OSPF and EIGRP both use three major branches of logic, each of which populates a different table: the neighbor table, the topology table, and the IP routing table. This chapter examines topics related to the OSPF topology table–the contents, and the processes by which routers exchange this information–and how OSPF routers choose the best routes in the topology table to be added to the IP routing table.

In particular, this chapter begins by looking at the building blocks of OSPF topology, namely the OSPF link state advertisement (LSA). Following that, the chapter examines the process by which OSPF routers exchange LSAs with each other. Finally, the last major section of the chapter discusses how OSPF chooses the best route among many when running the Shortest Path First (SPF) algorithm.

Note that this chapter focuses on OSPF Version 2, the long-available version of OSPF that supports IPv4 routes. Chapter 17, "IPv6 Routing Protocols and Redistribution," discusses OSPF Version 3, which applies to IPv6.

"Do I Know This Already?" Quiz

The "Do I Know This Already?" quiz allows you to assess if you should read the entire chapter. If you miss no more than one of these nine self-assessment questions, you might want to move ahead to the "Exam Preparation Tasks." Table 6-1 lists the major headings in this chapter and the "Do I Know This Already?" quiz questions covering the material in those headings so that you can assess your knowledge of these specific areas. The answers to the "Do I Know This Already?" quiz appear in Appendix A.

Table 6-1 *"Do I Know This Already?" Foundation Topics Section-to-Question Mapping*

Foundations Topics Section	Questions
LSAs and the OSPF Link State Database	1–3
The Database Exchange Process	4, 5
Choosing the Best OSPF Routes	6–9

1. A network design shows area 1 with three internal routers, area 0 with four internal routers, and area 2 with five internal routers. Additionally, one ABR (ABR1) connects areas 0 and 1, plus a different ABR (ABR2) connects areas 0 and 2. How many Type 1 LSAs would be listed in ABR2's LSDB?

    a. 6
    b. 7
    c. 15
    d. 12
    e. None of the other answers is correct.

2. A network planning diagram shows a large internetwork with many routers. The configurations show that OSPF has been enabled on all interfaces, IP addresses correctly configured, and OSPF working. For which of the following cases would you expect a router to create and flood a Type 2 LSA?

    a. When OSPF is enabled on a LAN interface, and the router is the only router connected to the subnet.
    b. When OSPF is enabled on a point-to-point serial link, and that router has both the higher router ID and higher interface IP address on the link.
    c. When OSPF is enabled on a Frame Relay point-to-point subinterface, has the lower RID and lower subinterface IP address, and otherwise uses default OSPF configuration on the interface.
    d. When OSPF is enabled on a working LAN interface on a router, and the router has been elected BDR.
    e. None of the other answers is correct.

3. A verification plan shows a network diagram with branch office Routers B1 through B100, plus two ABRs, ABR1, and ABR2, all in area 100. The branches connect to the ABRs using Frame Relay point-to-point subinterfaces. The verification plan lists the output of the **show ip ospf database summary 10.100.0.0** command on a router B1, one of the branches. Which of the following is true regarding the output that could be listed for this command?

    a. The output lists nothing unless 10.100.0.0 has been configured as a summary route using the **area range** command.
    b. If 10.100.0.0 is a subnet in area 0, the output lists one Type 3 LSA, specifically the LSA with the lower metric when comparing ABR1's and ABR2's LSA for 10.100.0.0.
    c. If 10.100.0.0 is a subnet in area 0, the output lists two Type 3 LSAs, one each created by ABR1 and ABR2.
    d. None, because the Type 3 LSAs would exist only in the ABR's LSDBs.

4. Which of the following OSPF messages contains entire complete LSAs used during the database exchange process?

    a. LSR
    b. LSAck
    c. LSU
    d. DD
    e. Hello

5. Routers R1, R2, R3, and R4 connect to the same 10.10.10.0/24 LAN-based subnet. OSPF is fully working in the subnet. Later, R5, whose OSPF priority is higher than the other four routers, joins the subnet. Which of the following are true about the OSPF database exchange process over this subnet at this point? (Choose two.)

    a. R5 will send its DD, LSR, and LSU packets to the 224.0.0.5 all-DR-routers multicast address.
    b. R5 will send its DD, LSR, and LSU packets to the 224.0.0.6 all-DR-routers multicast address.
    c. The DR will inform R5 about LSAs by sending its DD, LSR, and LSU packets to the 224.0.0.6 all-SPF-routers multicast address.
    d. The DR will inform R5 about LSAs by sending its DD, LSR, and LSU packets to the 224.0.0.5 all-SPF-routers multicast address.

6. R1 is internal to area 1, and R2 is internal to area 2. Subnet 10.1.1.0/24 exists in area 2 as a connected subnet off R2. ABR ABR1 connects area 1 to backbone area 0, and ABR2 connects area 0 to area 2. Which of the following LSAs must R1 use when calculating R1's best route for 10.1.1.0/24?

    a. R2's Type 1 LSA
    b. Subnet 10.1.1.0/24's Type 2 LSA
    c. ABR1's Type 1 LSA in area 0
    d. Subnet 10.1.1.0/24's Type 3 LSA in Area 0
    e. Subnet 10.1.1.0/24's Type 3 LSA in Area 1

7. Which of the following LSA types describes topology information that, when changed, requires a router in the same area to perform an SPF calculation? (Choose two.)

    a. 1
    b. 2
    c. 3
    d. 4
    e. 5
    f. 7

8. The following output was taken from Router R3. A scan of R3's configuration shows that no **bandwidth** commands have been configured in this router. Which of the following answers lists configuration settings could be a part of a configuration that results in the following output? (Choose two.)

```
R3#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Se0/0/0.2    3     34              10.10.23.3/29      647   P2P   1/1
Se0/0/0.1    3     34              10.10.13.3/29      1000  P2P   1/1
Fa0/0        3     34              10.10.34.3/24      20    BDR   1/1
```

   a. An **auto-cost reference-bandwidth 1000** command in router ospf mode
   b. An **auto-cost reference-bandwidth 2000** command in router ospf mode
   c. An **ip ospf cost 1000 interface S0/0/0.1** command in router ospf mode
   d. An **auto-cost reference-bandwidth 64700** command in router ospf mode

9. Which of the following LSA types describe information related to topology or subnets useful for calculating routes for subnets inside the OSPF domain? (Choose three.)

   a. 1
   b. 2
   c. 3
   d. 4
   e. 5
   f. 7

Foundation Topics

LSAs and the OSPF Link State Database

Every router that connects to a given OSPF area should learn the exact same topology data. Each router stores the data, composed of individual link state advertisements (LSA), in their own copy of the link state database (LSDB). Then, the router applies the Shortest Path First (SPF) algorithm to the LSDB to determine the best (lowest cost) route for each reachable subnet (prefix/length).

When a router uses SPF to analyze the LSDB, the SPF process has some similarities to how humans put a jigsaw puzzle together–but without a picture of what the puzzle looks like. Humans faced with such a challenge might first look for the obvious puzzle pieces, such as the corner and edge pieces, because they are easily recognized. You might then group puzzle pieces together if they have the same color or look for straight lines that might span multiple puzzle pieces. And of course, you would be looking at the shapes of the puzzle pieces to see which ones fit together.

Similarly, a router's SPF process must examine the individual LSAs and see how they fit together, based on their characteristics. To better appreciate the SPF process, the first section of this chapter examines the three LSA types OSPF uses to describe an Enterprise OSPF topology inside the OSPF domain. By understanding the types of LSAs, you can get a better understanding of what a router might look for to take the LSAs–the pieces of a network topology puzzle if you will–and build the equivalent of a network diagram.

For reference, Table 6-2 lists the various OSPF LSA types. Note that Chapter 9 explains three other LSA types, all used when redistributing routes into the OSPF domain.

Table 6-2 *OSPF LSA Types*

LSA Type	Common Name	Description
1	Router	Each router creates its own Type 1 LSA to represent itself for each area to which it connects. The LSDB for one area contains one Type 1 LSA per router per area, listing the RID and all interface IP addresses on that router that are in that area. Represents stub networks as well.
2	Network	One per transit network. Created by the DR on the subnet, and represents the subnet and the router interfaces connected to the subnet.
3	Net Summary	Created by ABRs to represent subnets listed in one area's type 1 and 2 LSAs when being advertised into another area. Defines the links (subnets) in the origin area, and cost, but no topology data.
4	ASBR Summary	Like a type 3 LSA, except it advertises a host route used to reach an ASBR.

Table 6-2 *OSPF LSA Types*

LSA Type	Common Name	Description
5	AS External	Created by ASBRs for external routes injected into OSPF.
6	Group Membership	Defined for MOSPF; not supported by Cisco IOS.
7	NSSA External	Created by ASBRs inside an NSSA area, instead of a type 5 LSA.
8	External Attributes	Not implemented in Cisco routers.
9–11	Opaque	Used as generic LSAs to allow for easy future extension of OSPF; for example, type 10 has been adapted for MPLS traffic engineering.

LSA Type 1: Router LSA

An LSA type 1, called a *router LSA*, identifies an OSPF router based on its OSPF router ID (RID). Each router creates a Type 1 LSA for itself and floods the LSA throughout the same area. To flood the LSA, the originating router sends the Type 1 LSA to its neighbors inside the same area, who in turn send it to their other neighbors inside the same area, until all routers in the area have a copy of the LSA.

Besides the RID of the router, this LSA also lists information about the attached links. In particular, the Type 1 LSA lists:

- For each interface on which no DR has been elected, it lists the router's interface subnet number/mask and interface OSPF cost. (OSPF refers to these subnets as *stub networks*.)
- For each interface on which a DR has been elected, it lists the IP address of the DR and a notation that the link attaches to a *transit network* (meaning a type 2 LSA exists for that network).
- For each interface with no DR, but for which a neighbor is reachable, it lists the neighbor's RID.

As with all OSPF LSAs, OSPF identifies a Type 1 LSA using a 32-bit *link state identifier* (LSID). When creating its own Type 1 LSA, each router uses its own OSPF RID value as the LSID.

Internal routers each create a single Type 1 LSA for themselves, but ABRs create multiple Type 1 LSAs for themselves: one per area. The Type 1 LSA in one area will list only interfaces in that area and only neighbors in that area. However, the router still has only a single RID, so all its Type 1 LSAs for a single router list the same RID. The ABR then floods each of its Type 1 LSAs into the appropriate area.

To provide a better backdrop for the upcoming LSA discussions, Figure 6-1 shows a sample internetwork, which will be used in most of the examples in this chapter.

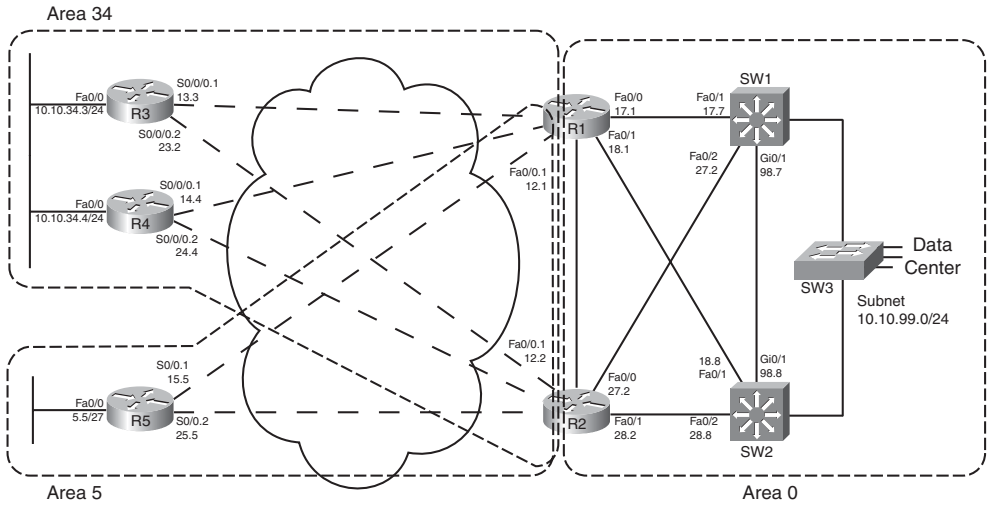

Figure 6-1 *Sample OSPF Multi-Area Design*

All routers that participate in an area, be they internal routers or ABRs, create and flood a Type 1 LSA inside the area. For example, in Figure 6-1, area 5 has one internal router (R5, RID 5.5.5.5), and two ABRs: R1 with RID 1.1.1.1 and R2 with RID 2.2.2.2. Each of these three routers create and flood their own Type 1 LSA inside area 5 so that all three routers know the same three Type 1 LSAs.

Next, to further understand the details inside a Type 1 LSA, first consider the OSPF configuration of R5 as an example. R5 has three IP-enabled interfaces: Fa0/0, S0/0/0.1, and S0/0.2. R5 uses point-to-point subinterfaces, so R5 should form neighbor relationships with both R1 and R2 with no extra configuration beyond enabling OSPF, in area 5, on all three interfaces. Example 6-1 shows this baseline configuration on R5.

Example 6-1 *R5 Configuration–IP Addresses and OSPF*

```
interface Fastethernet0/0
 ip address 10.10.5.5 255.255.255.224
 ip ospf 5 area 5
!
interface s0/0.1 point-to-point
 ip addr 10.10.15.5 255.255.255.248
 frame-relay interface-dlci 101
 ip ospf 5 area 5
!
interface s0/0.2 point-to-point
```

```
 ip addr 10.10.25.5 255.255.255.248
 frame-relay interface-dlci 102
 ip ospf 5 area 5
!
router ospf 5
 router-id 5.5.5.5
!
R5#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
se0/0.2      5     5                10.10.25.5/29      64    P2P   1/1
se0/0.1      5     5                10.10.15.5/29      64    P2P   1/1
fa0/0        5     5                10.10.5.5/27       1     DR    0/0
R5#show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
2.2.2.2         0     FULL/  -        00:00:30    10.10.25.2      Serial0/0.2
1.1.1.1         0     FULL/  -        00:00:38    10.10.15.1      Serial0/0.1
```

R5's OSPF configuration enables OSPF, for process ID 5, placing three interfaces in area 5. As a result, R5's type 1 LSA will list at least these three interfaces as links, plus it will refer to the two working neighbors. Example 6-2 displays the contents of R5's area 5 LSDB, including the detailed information in R5's Type 1 LSA, including the following:

- The LSID of R5's Type 1 LSA (5.5.5.5)
- Three links that connect to a stub network, each listing the subnet/mask
- Two links that state a connection to another router, one listing R1 (RID 1.1.1.1) and one listing R2 (RID 2.2.2.2)

Example 6-2 *R5 Configuration–IP Addresses and OSPF*

```
R5#show ip ospf database


            OSPF Router with ID (5.5.5.5) (Process ID 5)

                Router Link States (Area 5)


Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         835         0x80000002 0x006BDA 2
2.2.2.2         2.2.2.2         788         0x80000002 0x0082A6 2
5.5.5.5         5.5.5.5         787         0x80000004 0x0063C3 5

                Summary Net Link States (Area 5)
```

```
Link ID          ADV Router      Age          Seq#       Checksum
10.10.12.0       1.1.1.1         835          0x80000001 0x00F522
10.10.12.0       2.2.2.2         787          0x80000001 0x00D73C
! lines omitted for brevity

R5#show ip ospf database router 5.5.5.5

            OSPF Router with ID (5.5.5.5) (Process ID 5)

                Router Link States (Area 5)

  LS age: 796
  Options: (No TOS-capability, DC)
  LS Type: Router Links
  Link State ID: 5.5.5.5
  Advertising Router: 5.5.5.5
  LS Seq Number: 80000004
  Checksum: 0x63C3
  Length: 84
  Number of Links: 5

    Link connected to: another Router (point-to-point)
     (Link ID) Neighboring Router ID: 2.2.2.2
     (Link Data) Router Interface address: 10.10.25.5
      Number of TOS metrics: 0
       TOS 0 Metrics: 64

    Link connected to: a Stub Network
     (Link ID) Network/subnet number: 10.10.25.0
     (Link Data) Network Mask: 255.255.255.248
      Number of TOS metrics: 0
       TOS 0 Metrics: 64

    Link connected to: another Router (point-to-point)
     (Link ID) Neighboring Router ID: 1.1.1.1
     (Link Data) Router Interface address: 10.10.15.5
      Number of TOS metrics: 0
       TOS 0 Metrics: 64

    Link connected to: a Stub Network
     (Link ID) Network/subnet number: 10.10.15.0
     (Link Data) Network Mask: 255.255.255.248
      Number of TOS metrics: 0
       TOS 0 Metrics: 64
```

```
Link connected to: a Stub Network
 (Link ID) Network/subnet number: 10.10.5.0
 (Link Data) Network Mask: 255.255.255.224
  Number of TOS metrics: 0
  TOS 0 Metrics: 1
```

The first command, **show ip ospf database**, displays a summary of the LSAs known to R5. The output mainly consists of a single line per LSA, listed by LSA ID. The three highlighted lines of this command, in Example 6-2, highlight the RID of the three router (Type 1) LSAs, namely 1.1.1.1 (R1), 2.2.2.2 (R2), and 5.5.5.5 (R5).

The output of the **show ip ospf database router 5.5.5.5** command displays the detailed information in R5's router LSA. Looking at the highlighted portions, you see three stub networks–three interfaces on which no DR has been elected–and the associated subnet numbers. The LSA also lists the neighbor IDs of two neighbors (1.1.1.1 and 2.2.2.2) and the interfaces on which these neighbors can be reached.

Armed with the same kind of information in R1's and R2's Type 1 LSAs, a router has enough information to determine which routers connect, over which stub links, and then use the interface IP address configuration to figure out the interfaces that connect to the other routers. Figure 6-2 shows a diagram of area 5 that could be built just based on the detailed information held in the router LSAs for R1, R2, and R5.

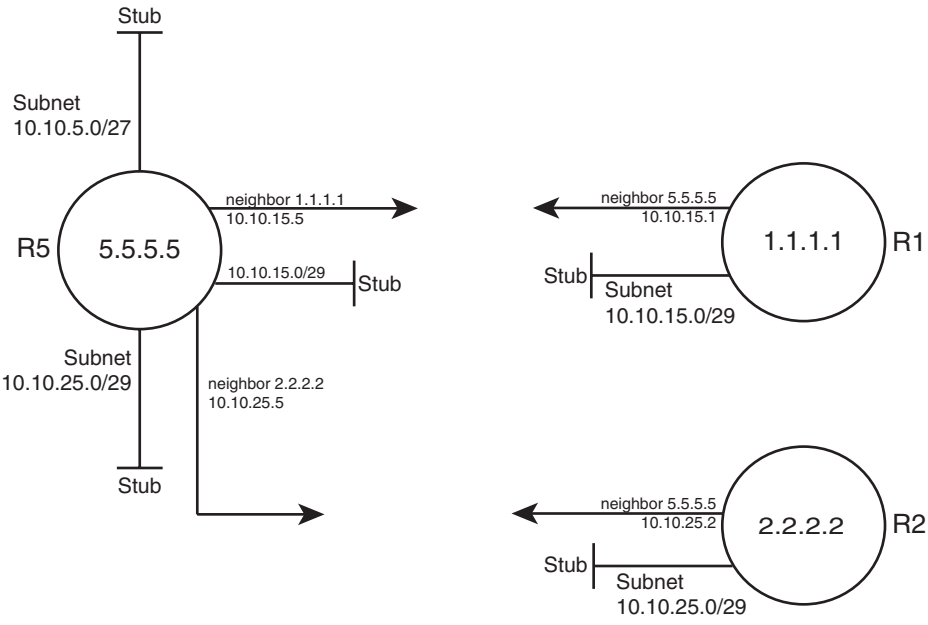

Figure 6-2 *Three Type 1 LSAs in Area 5*

Note that Figure 6-2 displays only information that could be learned from the Type 1 router LSAs inside area 5. Each Type 1 router LSA lists information about a router but only the details related to a specific area. As a result, Figure 6-2 shows R1's interface in area 5 but none of the interfaces in area 34 nor in area 0. To complete the explanation surrounding Figure 6-2, Example 6-3 lists R1's Type 1 router LSA for area 5.

Example 6-3 *R1's Type 1 LSA in Area 5*

```
R5#show ip ospf database router 1.1.1.1



            OSPF Router with ID (5.5.5.5) (Process ID 5)

                Router Link States (Area 5)

  Routing Bit Set on this LSA
  LS age: 1306
  Options: (No TOS-capability, DC)
  LS Type: Router Links
  Link State ID: 1.1.1.1
  Advertising Router: 1.1.1.1
  LS Seq Number: 80000002
  Checksum: 0x6BDA
  Length: 48
  Area Border Router
  Number of Links: 2

    Link connected to: another Router (point-to-point)
     (Link ID) Neighboring Router ID: 5.5.5.5
     (Link Data) Router Interface address: 10.10.15.1
      Number of TOS metrics: 0
       TOS 0 Metrics: 64

    Link connected to: a Stub Network
     (Link ID) Network/subnet number: 10.10.15.0
     (Link Data) Network Mask: 255.255.255.248
      Number of TOS metrics: 0
       TOS 0 Metrics: 64
```

Note: Because the OSPF uses the RID for many purposes inside different LSAs–for instance, as the LSID of a type 1 LSA–Cisco recommends setting the RID to a stable, predictable value. To do this, use the OSPF **router-id** *value* OSPF subcommand, or define a loopback interface with an IP address, as discussed in Chapter 5's section "Using a Unique OSPF Router ID."

LSA Type 2: Network LSA

SPF requires that the LSDB model the topology with nodes (routers) and connections between nodes (links). In particular, each link must be between a pair of nodes. When a multiaccess data link exists—for instance, a LAN—OSPF must somehow model that LAN so that the topology represents nodes and links between only a pair of nodes. To do so, OSPF uses the concept of a Type 2 Network LSA.

OSPF routers actually choose whether to use a Type 2 LSA for a multiaccess network based on whether a designated router (DR) has or has not been elected on an interface. So, before discussing the details of the Type 2 network LSA, a few more facts about the concept of a DR need to be discussed.

Background on Designated Routers

As discussed in Chapter 5's section "OSPF Network Types," the OSPF network type assigned to a router interface tells that router whether to attempt to elect a DR on that interface. Then, when a router has heard a Hello from at least one other router, the routers elect a DR and BDR.

OSPF uses a DR in a particular subnet for two main purposes:

- To create and flood a Type 2 network LSA for that subnet
- To aid in the detailed process of database exchange over that subnet

Routers elect a DR, and a backup DR (BDR), based on information in the OSPF Hello. The Hello message lists each router's RID and a priority value. When no DR exists at the time, routers use the following election rules when neither a DR nor BDR yet exists:

- Choose the router with the highest priority (default 1, max 255, set with **ip ospf priority** *value* interface subcommand).
- If tied on priority, choose the router with highest RID.
- Choose a BDR, based on next-best priority, or if a tie, next-best (highest) RID.

Although the preceding describes the election when no DR currently exists, the rules differ a bit when a DR and BDR already exist. After a DR and BDR are elected, no election is held until either the DR or BDR fails. If the DR fails, the BDR becomes the DR-—regardless of whether a higher priority router has joined the subnet—and a new election is held to choose a new BDR. If the BDR fails, a new election is held for BDR, and the DR remains unchanged.

On LANs, the choice of DR matters little from a design perspective, but does matter from an operational perspective. Throughout this chapter, note the cases in which output of **show** commands identify the DR and its role. Now, back to the topic of Type 2 LSAs.

Note: On Frame Relay WAN links, the choice of DR may impact whether OSPF functions at all. This topic is covered in Chapter 8, "OSPF Virtual Links and Frame Relay Operations."

Type 2 Network LSA Concepts

OSPF uses the concept of a Type 2 LSA to model a multiaccess network–a network with more than two routers connected to the same subnet–while still conforming to the "a link connects only two nodes" rule for the topology. For example, consider the network in Figure 6-3 (also shown as Figure 5-4 in the previous chapter). As seen in Chapter 5, all four routers form neighbor relationships inside area 0, with the DR and BDR becoming fully adjacent with the other routers.

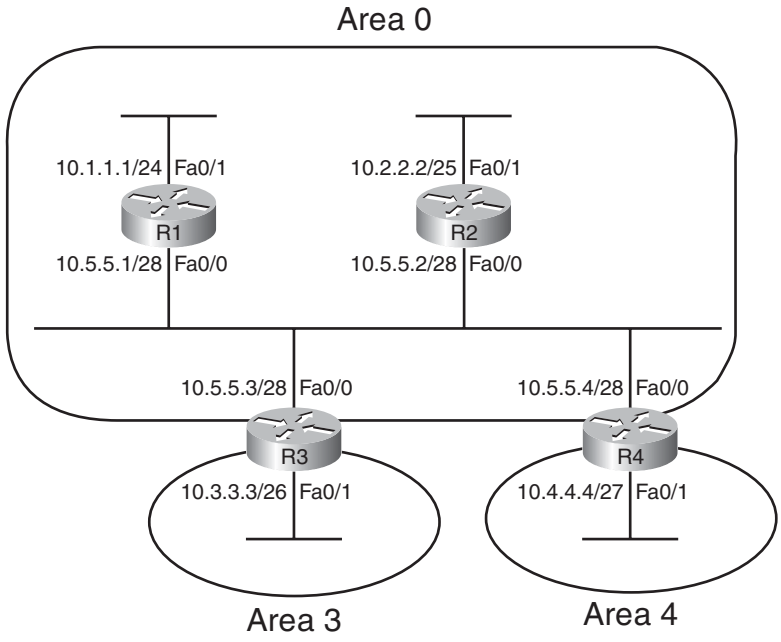

Figure 6-3 *Small Network, Four Routers, on a LAN*

OSPF cannot represent the idea of four routers connected via a single subnet by using a link connected to all four routers. Instead, OSPF defines the Type 2 network LSA, used as a *pseudonode*. Each router's Type 1 router LSA lists a connection this pseudonode, often called a *transit network*, which is then modeled by a Type 2 network LSA. The Type 2 network LSA itself then lists references back to each Type 1 router LSA connected to it–four in this example, as shown in Figure 6-4.

The elected DR in a subnet creates the Type 2 LSA for that subnet. The DR identifies the LSA by assigning an LSID of the DR's interface IP address in that subnet. The type 2 LSA also lists the DR's RID as the router advertising the LSA.

Type 2 LSA show Commands

To see these concepts in the form of OSPF **show** commands, next consider area 34 back in Figure 6-1. This design shows that R3 and R4 connect to the same LAN, which means that

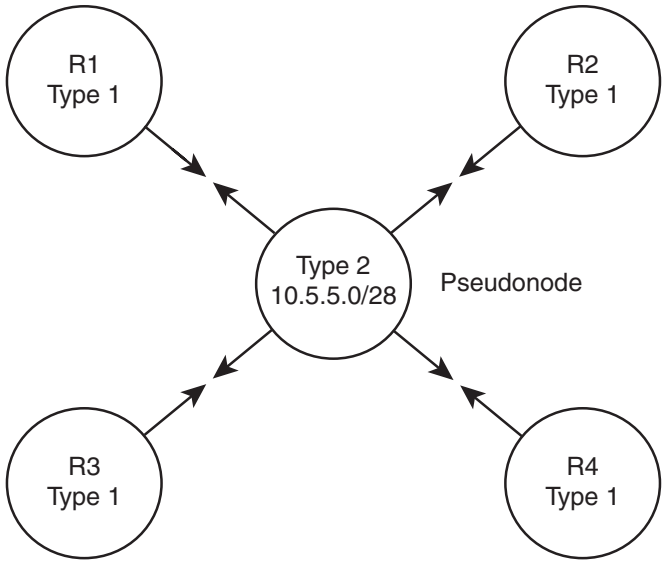

Figure 6-4 *OSPF Topology when Using a Type 2 Network LSA*

a DR will be elected. (OSPF elects a DR on LANs when at least two routers pass the neighbor requirements and can become neighbors.) If both R3 and R4 default to use priority 1, then R4 wins the election, due to its 4.4.4.4 RID (versus R3's 3.3.3.3). So, R4 creates the Type 2 LSA for that subnet and floods the LSA. Figure 6-5 depicts the area 34 topology, and Example 6-4 shows the related LSDB entries.

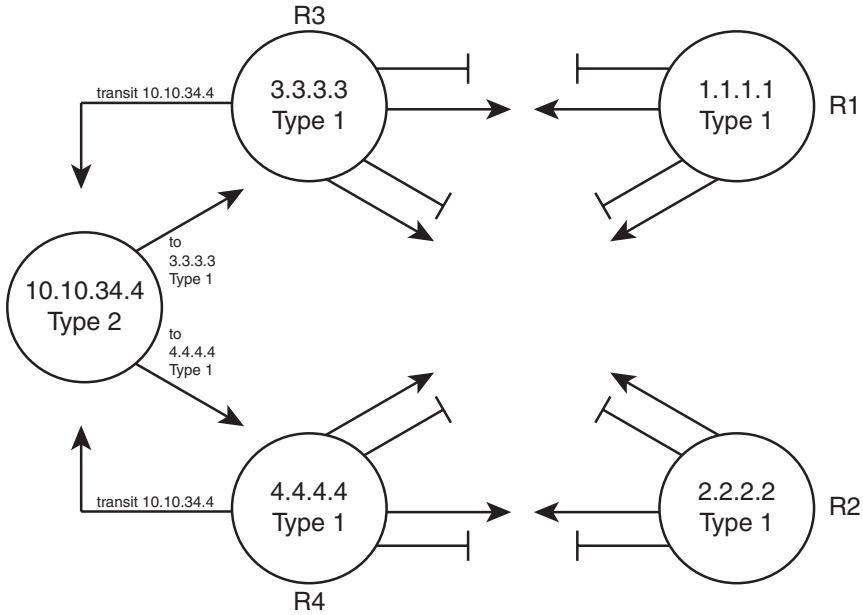

Figure 6-5 *Area 34 Topology with Four Type 1 LSAs and One Type 2 LSA*

Example 6-4 *Area 34 LSAs for R4, Network 10.10.34.0/24*

```
R5#show ip ospf database

            OSPF Router with ID (3.3.3.3) (Process ID 3)

                Router Link States (Area 34)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         1061        0x80000002 0x00EA7A 4
2.2.2.2         2.2.2.2         1067        0x80000001 0x0061D2 4
3.3.3.3         3.3.3.3         1066        0x80000003 0x00E2E8 5
4.4.4.4         4.4.4.4         1067        0x80000003 0x007D3F 5

                Net Link States (Area 34)

Link ID         ADV Router      Age         Seq#       Checksum
10.10.34.4      4.4.4.4         1104        0x80000001 0x00AB28

                Summary Net Link States (Area 34)

Link ID         ADV Router      Age         Seq#       Checksum
10.10.5.0       1.1.1.1         1023        0x80000001 0x000BF2
10.10.5.0       2.2.2.2         1022        0x80000001 0x00EC0D
! lines omitted for brevity

R3#show ip ospf database router 4.4.4.4

            OSPF Router with ID (3.3.3.3) (Process ID 3)

                Router Link States (Area 34)

  LS age: 1078
  Options: (No TOS-capability, DC)
  LS Type: Router Links
  Link State ID: 4.4.4.4
  Advertising Router: 4.4.4.4
  LS Seq Number: 80000003
  Checksum: 0x7D3F
  Length: 84
```

```
  Number of Links: 5

    Link connected to: another Router (point-to-point)
     (Link ID) Neighboring Router ID: 2.2.2.2
     (Link Data) Router Interface address: 10.10.24.4
      Number of TOS metrics: 0
       TOS 0 Metrics: 64

    Link connected to: a Stub Network
     (Link ID) Network/subnet number: 10.10.24.0
     (Link Data) Network Mask: 255.255.255.248
      Number of TOS metrics: 0
       TOS 0 Metrics: 64

    Link connected to: another Router (point-to-point)
     (Link ID) Neighboring Router ID: 1.1.1.1
     (Link Data) Router Interface address: 10.10.14.4
      Number of TOS metrics: 0
       TOS 0 Metrics: 64

    Link connected to: a Stub Network
     (Link ID) Network/subnet number: 10.10.14.0
     (Link Data) Network Mask: 255.255.255.248
      Number of TOS metrics: 0
       TOS 0 Metrics: 64

    Link connected to: a Transit Network
     (Link ID) Designated Router address: 10.10.34.4
     (Link Data) Router Interface address: 10.10.34.4
      Number of TOS metrics: 0
       TOS 0 Metrics: 1

R3#show ip ospf database network 10.10.34.4

            OSPF Router with ID (3.3.3.3) (Process ID 3)

                Net Link States (Area 34)

  Routing Bit Set on this LSA
  LS age: 1161
  Options: (No TOS-capability, DC)
  LS Type: Network Links
  Link State ID: 10.10.34.4 (address of Designated Router)
  Advertising Router: 4.4.4.4
```

```
LS Seq Number: 80000001
Checksum: 0xAB28
Length: 32
Network Mask: /24
      Attached Router: 4.4.4.4
      Attached Router: 3.3.3.3
```

The **show ip ospf database** command lists a single line for each LSA. Note that the (highlighted) heading for network LSAs lists one entry, with LSID 10.10.34.4, which is R4's Fa0/0 IP address. The LSID for Type 2 Network LSAs is the interface IP address of the DR that creates the LSA.

The **show ip ospf database router 4.4.4.4** command shows the new style of entry for the reference to a *Transit Network*, which again refers to a connection to a Type 2 LSA. The output lists a LSID of 10.10.34.4, which again is the LSID of the Type 2 LSA.

Finally, the **show ip ospf database network 10.10.34.4** command shows the details of the Type 2 LSA, based on its LSID of 10.10.34.4. Near the bottom, the output lists the attached routers, based on RID. The SPF process can then use the cross-referenced information, as shown in Figure 6-5, to determine which routers connect to this transit network (pseudonode). The SPF process has information in both the Type 1 LSAs that refer to the transit network link to a Type 2 LSA, and the Type 2 LSA has a list of RIDs of Type 1 LSAs that connect to the Type 2 LSA, making the process of modeling the network possible.

OSPF can model all the topology inside a single area using Type 1 and 2 LSAs. When a router uses its SPF process to build a model of the topology, it can then calculate the best (lowest cost) route for each subnet in the area. The next topic completes the LSA picture for internal OSPF routes by looking at Type 3 LSAs, which are used to model interarea routes.

LSA Type 3: Summary LSA

OSPF areas exist in part so that engineers can reduce the consumption of memory and compute resources in routers. Instead of having all routers, regardless of area, know all Type 1 and Type 2 LSAs inside an OSPF domain, ABRs do not forward Type 1 and Type 2 LSAs from one area into another area, and vice versa. This convention results in smaller per-area LSDBs, saving memory and reducing complexity for each run of the SPF algorithm, which saves CPU and improves convergence time.

However, even though ABRs do not flood Type 1 and Type 2 LSAs into other areas, routers still need to learn about subnets in other areas. OSPF advertises these interarea routes using the Type 3 summary LSA. ABRs generate a Type 3 LSA for each subnet in one area, and advertises each Type 3 LSA into the other areas.

For example, if subnet A exists in area 3, then the routers in area 3 learn of that subnet as part of Type 1 and Type 2 LSAs. However, an ABR connected to area 3 will not forward

the Type 1 and Type 2 LSAs into other areas, instead creating a Type 3 LSA for each subnet (including subnet A). The routers inside the other areas can then calculate a route for the subnets (like subnet A) that exist inside another area.

Type 3 summary LSAs do not contain all the detailed topology information, so in comparison to Types 1 and 2, these LSAs summarize the information–hence the name *summary LSA*. Conceptually, a Type 3 LSA appears to be another subnet connected to the ABR that created and advertised the Type 3 LSA. The routers inside that area can calculate their best route to reach the ABR, which gives the router a good loop-free route to reach the subnet listed in a Type 3 LSA.

An example can certainly help in this case. First, consider the comparison shown in the top and bottom of Figure 6-6. The top depicts the topology shown back in Figure 6-1 if that design had used a single area. In that case, every router would have a copy of each Type 1 LSA (shown as a router name in the figure), and each Type 2 (abbreviated as T2 in the figure). The bottom of Figure 6-6 shows the area 5 topology, when holding to the three area design shown in Figure 6-1.

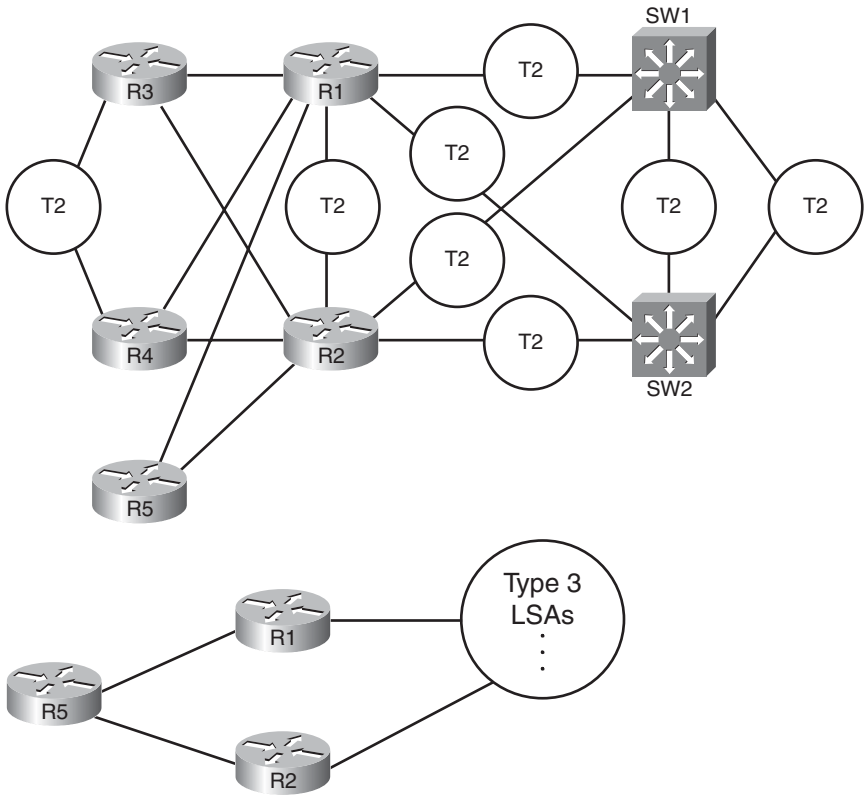

Figure 6-6 *Comparing a Single Area LSDB to a Three Area LSDB*

The ABR creates and floods each Type 3 LSA into the next area. The ABR assigns an LSID of the subnet number being advertised. It also adds its own RID to the LSA as well, so that routers know which ABR advertised the route. It also includes the subnet mask. The correlation between the advertising router's RID and the LSID (subnet number) allows the OSPF processes to create the part of the topology as shown with Type 3 LSAs at the bottom of Figure 6-6.

Example 6-5 focuses on the Type 3 LSAs in Area 34 of the network shown in Figure 6-1. Ten subnets exist outside area 34. As ABRs, both R1 and R2 create and flood a Type 3 LSA for each of these 10 subnets, resulting in 20 Type 3 LSAs listed in the output of the **show ip ospf database** command inside area 34. Then, the example focuses specifically on the Type 3 LSA for subnet 10.10.99.0/24.

Example 6-5 *Type 3 LSAs in Area 34*

```
R3#show ip ospf database



            OSPF Router with ID (3.3.3.3) (Process ID 3)

                Router Link States (Area 34)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         943         0x80000003 0x00E87B 4
2.2.2.2         2.2.2.2         991         0x80000002 0x005FD3 4
3.3.3.3         3.3.3.3         966         0x80000004 0x00E0E9 5
4.4.4.4         4.4.4.4         977         0x80000004 0x007B40 5

                Net Link States (Area 34)

Link ID         ADV Router      Age         Seq#       Checksum
10.10.34.4      4.4.4.4         977         0x80000002 0x00A929

                Summary Net Link States (Area 34)

Link ID         ADV Router      Age         Seq#       Checksum
10.10.5.0       1.1.1.1         943         0x80000002 0x0009F3
10.10.5.0       2.2.2.2         991         0x80000002 0x00EA0E
10.10.12.0      1.1.1.1         943         0x80000002 0x00F323
10.10.12.0      2.2.2.2         991         0x80000002 0x00D53D
10.10.15.0      1.1.1.1         943         0x80000002 0x0021BA
10.10.15.0      2.2.2.2         993         0x80000003 0x008313
10.10.17.0      1.1.1.1         946         0x80000002 0x00BC55
10.10.17.0      2.2.2.2         993         0x80000002 0x00A864
10.10.18.0      1.1.1.1         946         0x80000002 0x00B15F
10.10.18.0      2.2.2.2         994         0x80000002 0x009D6E
```

```
10.10.25.0      1.1.1.1         946         0x80000002 0x00355C
10.10.25.0      2.2.2.2         993         0x80000002 0x009439
10.10.27.0      1.1.1.1         946         0x80000002 0x0058AE
10.10.27.0      2.2.2.2         993         0x80000002 0x0030D3
10.10.28.0      1.1.1.1         947         0x80000002 0x004DB8
10.10.28.0      2.2.2.2         993         0x80000002 0x0025DD
10.10.98.0      1.1.1.1         946         0x80000002 0x004877
10.10.98.0      2.2.2.2         993         0x80000002 0x002A91
10.10.99.0      1.1.1.1         946         0x80000002 0x003D81
10.10.99.0      2.2.2.2         993         0x80000002 0x001F9B

R3#show ip ospf database summary 10.10.99.0

            OSPF Router with ID (3.3.3.3) (Process ID 3)

                Summary Net Link States (Area 34)

  Routing Bit Set on this LSA
  LS age: 1062
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 10.10.99.0 (summary Network Number)
  Advertising Router: 1.1.1.1
  LS Seq Number: 80000002
  Checksum: 0x3D81
  Length: 28
  Network Mask: /24
        TOS: 0  Metric: 2

  Routing Bit Set on this LSA
  LS age: 1109
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 10.10.99.0 (summary Network Number)
  Advertising Router: 2.2.2.2
  LS Seq Number: 80000002
  Checksum: 0x1F9B
  Length: 28
  Network Mask: /24
        TOS: 0  Metric: 2
```

Note: The Type 3 Summary LSA is not used for the purpose of route summarization. OSPF does support route summarization, and Type 3 LSAs may indeed advertise such a summary, but the Type 3 LSA does not inherently represent a summary route. The term

summary reflects the idea that the information is sparse compared to the detail inside Type 1 and Type 2 LSAs.

The upcoming section "Calculating the Cost of Inter-area Routes" discusses how a router determines the available routes to reach subnets listed in a Type 3 LSA and how a router chooses which route is best.

Limiting the Number of LSAs

By default, Cisco IOS does not limit the number of LSAs a router can learn. However, it may be useful to protect a router from learning too many LSAs to protect router memory. Also, with a large number of LSAs, the router may be unable to process the LSDB with SPF well enough to converge in a reasonable amount of time.

The maximum number of LSAs learned from other routers can be limited by a router using the **max-lsa** *number* OSPF subcommand. When configured, if the router learns more than the configured number of LSAs from other routers (ignoring those created by the router itself), the router reacts. The first reaction is to issue log messages. The router ignores the event for a time period, after which the router repeats the warning message. This ignore-and-wait strategy can proceed through several iterations, ending when the router closes all neighborships, discards its LSDB, and then starts adding neighbors again. (The ignore time, and the number of times to ignore the event, can be configured with the **max-lsa** command.)

Summary of Internal LSA Types

OSPF uses Type 1, 2, and 3 LSAs to calculate the best routes for all routes inside the OSPF routing domain. Later, Chapter 9 explains Types 4, 5, and 7, which OSPF uses to calculate routes for external routes–routes redistributed into OSPF.

Table 6-3 summarizes some of the key points regarding OSPF Type 1, 2, and 3 LSAs. In particular for the ROUTE exam, the ability to sift through the output of various **show ip ospf database** commands can be important. Knowing what the OSPF LSID represents can help you interpret the output, and knowing the keywords used with the **show ip ospf database** *lsa-type lsid* commands can also be very useful. Table 6-3 summarizes these details.

Table 6-3 *Facts about LSA Types 1, 2, and 3*

LSA Type (Number)	LSA Type (Name)	This Type Represents	Display Using show ip ospf database *keyword*...	LSID Is Equal To	Created By
1	Router	A router	**router**	RID of router	Each router creates its own

Table 6-3 *Facts about LSA Types 1, 2, and 3*

LSA Type (Number)	LSA Type (Name)	This Type Represents	Display Using show ip ospf database *keyword*...	LSID Is Equal To	Created By
2	Network	A subnet in which a DR exists	**network**	DR's IP address in the subnet	The DR in that subnet
3	Summary	Subnet in another area	**summary**	Subnet number	An ABR

The Database Exchange Process

Every router in an area, when OSPF stabilizes after topology changes occur, should have an identical LSDB for that area. Internal routers (routers inside a single area) have only that area's LSAs, but an ABR's LSDB will contain LSAs for each area to which it connects. The ABR does, however, know which LSAs exist in each area.

OSPF routers flood both the LSAs they create, and the LSAs they learn from their neighbors, until all routers in the area have a copy of each of the most recent LSAs for that area. To manage and control this process, OSPF defines several messages, processes, and neighbor states that indicate the progress when flooding LSAs to each neighbor. This section begins by listing reference information for the OSPF messages and neighbor states. Next, the text describes the flooding process between two neighbors when a DR does not exist, followed by a description of the similar process used when a DR does exist. This section ends with a few items related to how the routers avoid looping the LSA advertisements and how they periodically reflood the information.

OSPF Message and Neighbor State Reference

For reference, Table 6-4 lists the OSPF message types that will be mentioned in the next few pages. Additionally, Table 6-5 lists the various neighbor states as well. Although useful for study, when you first learning this topic, feel free to skip these tables for now.

Key Topic

Table 6-4 *OSPF Message Types and Functions*

Message Name/number	Description
Hello (1)	Used to discover neighbors, supply information used to confirm two routers should be allowed to become neighbors, to bring a neighbor relationship to a 2-way state, and to monitor a neighbor's responsiveness in case it fails
Database Description (DD or DBD) (2)	Used to exchange brief versions of each LSA, typically on initial topology exchange, so that a router knows a list of that neighbor's known LSAs

Table 6-4 *OSPF Message Types and Functions*

Message Name/number	Description
Link-State Request (LSR) (3)	A packet that lists the LSIDs of LSAs the sender of the LSR would like the receiver of the LSR to supply during database exchange
Link-State Update (LSU) (4)	A packet that contains fully detailed LSAs, typically sent in response to an LSR message
Link-State Acknowledgment (LSAck) (5)	Sent to confirm receipt of an LSU message

Table 6-5 *OSPF Neighbor State Reference*

State	Meaning
Down	No Hellos have been received from this neighbor for more than the dead interval.
Attempt	Used when the neighbor is defined with the **neighbor** command, after sending a Hello, but before receiving a Hello from that neighbor.
Init	A Hello has been received from the neighbor, but it did not have the local router's RID in it or lists parameters that do not pass the neighbor verification checks. This is a permanent state when Hello parameters do not match.
2Way	A Hello has been received from the neighbor, it has the router's RID in it, and all neighbor verification checks passed.
ExStart	Currently negotiating the DD sequence numbers and master/slave logic used for DD packets.
Exchange	Finished negotiating the DD process particulars, and currently exchanging DD packets.
Loading	All DD packets are exchanged, and the routers are currently sending LSR, LSU, and LSAck packets to exchange full LSAs.
Full	Neighbors are fully adjacent, meaning they believe that their LSDBs for that area are identical. Routing table (re)calculations can begin.

Exchange Without a Designated Router

As discussed in Chapter 5, the OSPF interface network type tells that router whether to attempt to elect a DR on that interface. The most common case for which routers do not elect a DR occur on point-to-point topologies, such as true point-to-point serial links and point-to-point subinterfaces. This section examines the database exchange process on such interfaces, in preparation for the slightly more complex process when using a DR on an OSPF broadcast network type, like a LAN.

Every OSPF neighborship begins by exchanging Hellos until the neighbors (hopefully) reach the 2-Way state. During these early stages, the routers discover each other by sending multicast Hellos and then check each other's parameters to make sure all items match

(as listed in Chapter 5's Table 5-5). Figure 6-7 shows the details, with the various neighbor states listed on the outside of the figure and the messages listed in the middle.

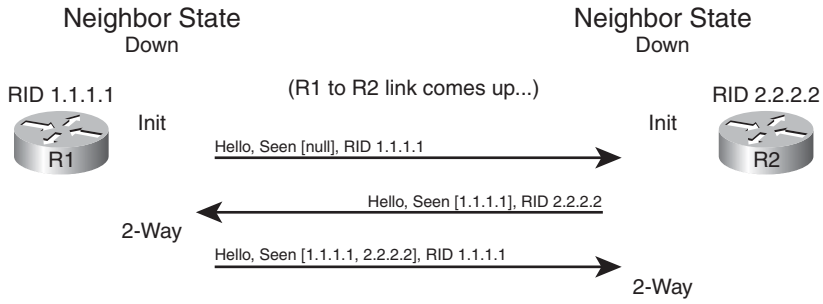

Figure 6-7 *Neighbor Initialization–Early Stages*

Figure 6-7 shows an example that begins with a failed neighborship, so the neighborship is in a down state. When a router tries to reestablish the neighborship, each router sends a multicast Hello and moves to an INIT state. After a router has both received a Hello and verified that all the required parameters agree, the router lists the other router's RID in the Hello as being seen, as shown in the bottom two Hello messages in the figure. When a router receives a Hello that lists its own RID as having been seen by the other router, the router can transition to 2-Way state.

When a router has reached the 2-Way state with a neighbor, as shown at the end of Figure 6-7, the router then decides whether it should exchange its LSDB entries. When no DR exists, the answer is always "yes." Each router next follows this general process:

Step 1. Discover the LSAs known to the neighbor but unknown to me.

Step 2. Discover the LSAs known by both routers, but the neighbor's LSA is more up to date.

Step 3. Ask the neighbor for a copy of all the LSAs identified in the first two steps.

Figure 6-8 details the messages and neighbor states used to exchange the LSAs between two neighbors.

Figure 6-8 shows many details. As with Figure 6-7, Figure 6-8 shows neighbor states on the outer edges of the flows (refer to Table 6-5 for reference). Routers display these neighbor states (in the **show ip ospf neighbor** command variants), so a particular state may be useful in determining how far two neighbors have gotten in the database exchange process. The more important neighbor states will be mentioned throughout the chapter.

The inner portions of Figure 6-8 represent the OSPF message flows, with Table 6-2 earlier in the chapter listing the messages for reference. The next several pages examine the process shown in Figure 6-8 in more detail.

Discovering a Description of the Neighbor's LSDB

After a router has decided to move forward from 2-Way state and exchange its LSDB with a neighbor, the routers use the sequence shown in Figure 6-8. The next step in that process

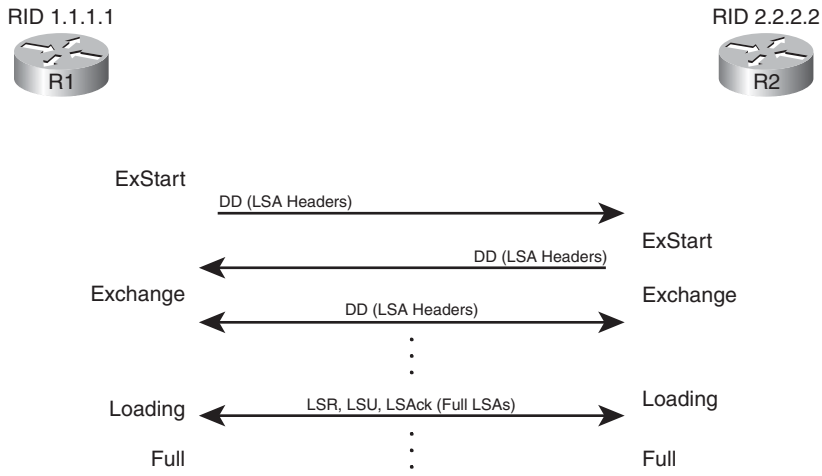

Figure 6-8 *Overview of the Database Exchange Process Between Two Neighbors*

requires both routers to tell each other the LSIDs of all their known LSAs in that area. The primary goal is for each neighbor to realize which LSAs it does not know, so it can then ask for those full LSAs to be sent. To learn the list of LSAs known by the neighbor, the neighboring routers follow these steps:

Step 1. Multicast database description packets (abbreviated as both DD and DBD, depending on the reference) to 224.0.0.5, which is the all SPF routers multicast address.

Step 2. When sending the first DD message, transition to the *ExStart* state until one router, the one with the higher RID, becomes master in a master/slave relationship.

Step 3. After electing a master, transition the neighbor to the *Exchange* state.

Step 4. Continue multicasting DD messages to each other until both routers have the same shared view of the LSIDs known collectively by both routers, in that area.

Note that the DD messages themselves do not list the entire LSAs, but rather LSA headers. These headers include the LSIDs of the LSAs and the LSA sequence number. The LS sequence number for an LSA begins at value 0x80000001 (hex) when initially created; the router creating the LSA increments the sequence number, and refloods the LSA, whenever the LSA changes. For example, if an interface moves from up to down state, that router changes its Type 1 LSA to list that interface state as down, increments the LSA sequence number, and refloods the LSA.

The master router for each exchange controls the flow of DD messages, with the slave responding to the master's DD messages. The master keeps sending DD messages until it lists all its known LSIDs in that area. The slave responds by placing LSA headers in its DD messages. Some of those LSA headers simply repeat what the slave heard from the master, for the purpose of acknowledging to the master that the slave learned that LSA header

from the master. Additionally, the slave also includes the LSA headers for any LSAs that the master did not list.

This exchange of DD messages ends with each router knowing a list of LSAs that it does not have in its LSDB, but that the other router does have those LSAs. Additionally, each router also ends this process with a list of LSAs that the local router already knows, but for which the other router has a more recent copy (based on the sequence number).

Exchanging the LSAs

When the two neighbors realize that they have a shared view of the list of LSIDs, they transition to the Loading state and start exchanging the full LSAs–but only those that they do not yet know about or those that have changed.

For example, when the two routers in Figure 6-8 first become neighbors, neither router will have a copy of the Type 1 LSA for the other router. So, R1 will request that R2 send its LSA with LSID 2.2.2.2; R2 will send its Type 1 LSA; and R1 will acknowledge receipt. The mechanics work like this:

Step 1. Transition the neighbor state to Loading.

Step 2. For any missing LSAs, send a *Link State Request* (LSR) message, listing the LSID of the requested LSA.

Step 3. Respond to any LSR messages with an *Link State Update* (LSU), listing one or more LSAs in each message.

Step 4. Acknowledge receipt by either sending a *Link State Acknowledgment* (LSAck) message (called explicit acknowledgment), or by sending the same LSA that was received back to the other router in an LSU message (implicit acknowledgment).

Step 5. When all LSAs have been sent, received, and acknowledged, transition the neighborship to the FULL state (fully adjacent).

Note: Because this section examines the case without a DR, all these messages flow as multicasts to 224.0.0.5, the all SPF routers multicast address, unless the neighbors have been defined with an OSPF **neighbor** command.

By the end of this process, both routers should have an identical LSDB for the area to which the link has been assigned. At that point, the two routers can run the SPF algorithm to choose the currently best routes for each subnet.

Exchange with a Designated Router

Database exchange with a DR differs slightly than database exchange when no DR exists. The majority of the process is similar, with the same messages, meanings, and neighbor states. The big difference is the overriding choice of with whom each router chooses to perform database exchange.

Non-DR routers do not exchange their databases directly with all neighbors on a subnet. Instead, they exchange their database with the DR. Then, the DR exchanges any new/changed LSAs with the rest of the OSPF routers in the subnet.

The concept actually follows along with the idea of a Type 2 LSA as seen earlier in Figure 6-4. Figure 6-9 represents four Type 1 LSAs, for four real routers on the same LAN, plus a single Type 2 LSA that represents the multiaccess subnet. The DR created the Type 2 LSA as part of its role in life.

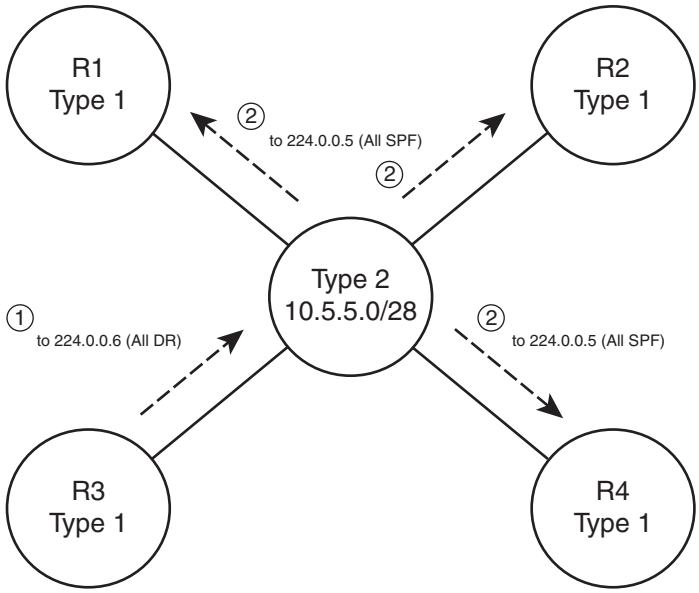

Figure 6-9 *Conceptual View–Exchanging the Database with a Pseudonode*

Figure 6-9 shows two conceptual steps for database exchange. The non-DR router (R3) first exchanges its database with the pseudonode, and then the type 2 pseudonode exchanges its database with the other routers. However, the pseudonode is a concept, not a router; to make the process depicted in Figure 6-9 work, the DR takes on the role of the Type 2 pseudonode. The messages differ slightly as well, as follows:

- The non-DR performs database exchange with the same messages, as shown in Figure 6-9, but sends these messages to the 224.0.0.6 All-DR-routers multicast address.
- The DR performs database exchange with the same messages but sends the messages to the 224.0.0.5 all-SPF-routers multicast address.

Key Topic

Consider these two conventions one at a time. First, the messages sent to 224.0.0.6 are processed by the DR and the BDR only. The DR actively participates, replying to the messages, with the BDR acting as a silent bystander. In effect, this allows the non-DR router to exchange their database directly with the DR and BDR, but with none of the other routers in the subnet.

Next, consider the multicast messages from the DR to the 224.0.0.5 all-SPF-router multicast address. All OSPF routers process these messages, so the rest of the routers—the DROthers to use the IOS term—also learn the newly exchanged LSAs. This process completes the second step shown in the conceptual Figure 6-9, where the DR, acting like the pseudonode, floods the LSAs to the other OSPF routers in the subnet.

The process occurs in the background and can be generally ignored. However, for operating an OSPF network, an important distinction must be made. With a DR in existence, a DROther router performs the database exchange process (as seen in Figure 6-9) with the DR/BDR only and not any other DROther routers in the subnet. For example, in Figure 6-9, R1 acts as DR, R2 acts as BDR, and R3/R4 act as DROther routers. Because the underlying process does not make R3 and R4 perform database exchange with each other, the routers do not reach the FULL neighbor state, remaining in 2-Way state.

Example 6-6 shows the resulting output for the LAN shown in Figure 6-9, with four routers. The output, taken from DROther R3, shows a 2-Way state with R4, the other DROther. It also shows on interface Fa0/0 that its own priority is 1. This output also shows a neighbor count (all neighbors) of 3 and an adjacent neighbor count (all fully adjacent neighbors) of 2, again because the neighborship between DROthers R3 and R4 is not a full adjacency.

Example 6-6 *Demonstrating OSPF FULL and 2-Way Adjacencies*

```
R3#show ip ospf interface fa0/0
FastEthernet0/0 is up, line protocol is up
  Internet Address 172.16.1.3/24, Area 0
  Process ID 75, Router ID 3.3.3.3, Network Type BROADCAST, Cost: 1
  Transmit Delay is 1 sec, State DROTHER, Priority 2
  Designated Router (ID) 1.1.1.1, Interface address 172.16.1.1
  Backup Designated router (ID) 2.2.2.2, Interface address 172.16.1.2
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    oob-resync timeout 40
    Hello due in 00:00:02
  Supports Link-local Signaling (LLS)
  Cisco NSF helper support enabled
  IETF NSF helper support enabled
  Index 1/1, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 0, maximum is 4
  Last flood scan time is 0 msec, maximum is 0 msec
  Neighbor Count is 3, Adjacent neighbor count is 2
    Adjacent with neighbor 1.1.1.1  (Designated Router)
    Adjacent with neighbor 2.2.2.2  (Backup Designated Router)
  Suppress hello for 0 neighbor(s)
```

```
R3#show ip ospf neighbor fa0/0

Neighbor ID      Pri   State           Dead Time   Address         Interface
1.1.1.1            4   FULL/DR         00:00:37    172.16.1.1
FastEthernet0/0
2.2.2.2            3   FULL/BDR        00:00:37    172.16.1.2
FastEthernet0/0
44.44.44.44        1   2WAY/DROTHER    00:00:36    172.16.1.4      FastEthernet0/0
```

Flooding Throughout the Area

So far in this section, the database exchange process has focused on exchanging the database between neighbors. However, LSAs need to be flooded throughout an area. To do so, when a router learns new LSAs from one neighbor, that router then knows that its other neighbors in that same area may not know of that LSA. Similarly, when an LSA changes, for example, when an interface changes state, a router may learn the same old LSA but with a new sequence number, and again need to flood the changed LSA to other neighbors in that area.

Figure 6-10 shows a basic example of the process. In this case, R2, R3, and R4 have established neighbor relationships, with four LSAs in their LSDB in this area. R1 is again the new router added to the internetwork.

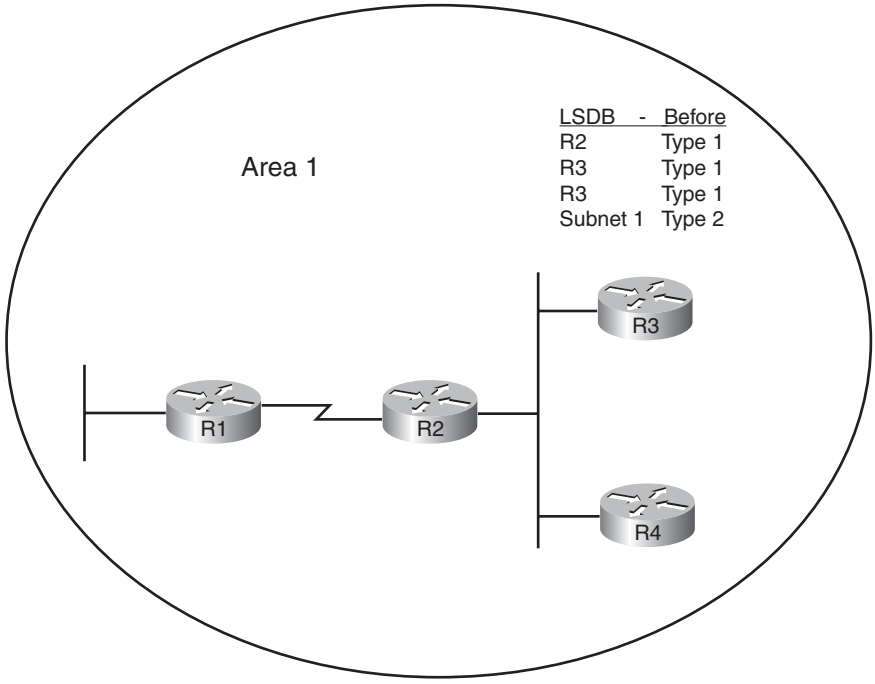

Figure 6-10 *Flooding Throughout an Area*

First, consider what happens as the new R1-R2 neighborship comes up and goes through database exchange. When R1 loads, and the link comes up, R1 and R2 reach a full state and have a shared view of the Area 1 LSDB. R2 has learned all R1's new LSAs (should only be R1's Type 1 router LSA), and R1 has learned all the area 1 LSAs known to R2, including the Type 1 LSAs for R3 and R4.

Next, think about the LSDBs of R3 and R4 at this point. The database exchange between R1-R2 did not inform R3 nor R4 about any of the new LSAs known by R1. So, R2, when it learns of R1's Type 1 LSA, sends DD packets to the DR on the R2/R3/R4 LAN. LSR/LSU packets follow, resulting in R3 and R4 learning about the new LSA for R1. If more routers existed in area 1, the flooding process would continue throughout the entire area, until all routers know of the best (highest sequence number) copy of each LSA.

The flooding process prevents the looping of LSAs as a side-effect of the database exchange process. Neighbors use DD messages to learn the LSA headers known by the neighbor, and then only request the LSAs known by the neighbor but not known by the local router. By requesting only unknown LSAs or new versions of old LSAs, routers prevent the LSAs advertisements from looping.

Periodic Flooding

Although OSPF does not send routing updates on a periodic interval, as do distance vector protocols, OSPF does reflood each LSA every 30 minutes based on each LSA's age variable. The router that creates the LSA sets this age to 0 (seconds). Each router then increments the age of its copy of each LSA over time. If 30 minutes pass with no changes to an LSA–meaning no other reason existed in that 30 minutes to cause a reflooding of the LSA–the owning router increments the sequence number, resets the timer to 0, and refloods the LSA.

Because the owning router increments the sequence number and resets the LSAge every 1800 seconds (30 minutes), the output of various **show ip ospf database** commands should also show an age of less than 1800 seconds. For example, referring back to Example 6-5, the Type 1 LSA for R1 (RID 1.1.1.1) shows an age of 943 seconds and a sequence number of 0x80000003. Over time the sequence number should increment once per every 30 minutes, with the LSAge cycle upward toward 1800 and then back to 0 when the LSA is reflooded.

Note also that when a router realizes it needs to flush an LSA from the LSDB for an area, it actually sets the age of the LSA to the MaxAge setting (3600) and refloods the LSA. All the other routers receive the LSA, see the age is already at the maximum, causing those routers to also remove the LSA from their LSDBs.

Choosing the Best OSPF Routes

All this effort to define LSA types, create areas, and fully flood the LSAs has one goal in mind: to allow all routers in that area to calculate the best, loop-free routes for all known subnets. Although the database exchange process may seem laborious, the process by which SPF calculates the best routes requires a little less thought, at least to the level re-

quired for the CCNP ROUTE exam. In fact, the choice of the best route for a given subnet, and calculated by a particular router, can be summarized as follows:

- Analyze the LSDB to find all possible routes to reach the subnet.
- For each possible route, add the OSPF interface cost for all outgoing interfaces in that route.
- Pick the route with the lowest total cost.

Key Topic

For humans, if you build a network diagram, note the OSPF cost for each interface (as shown with **show ip ospf interface**), you can easily add up the costs for each router's possible routes to each subnet and tell which route OSPF will choose. The routers must use a more complex SPF algorithm to derive a mathematical model of the topology based on the LSAs. This section examines both the simpler human view of metric calculation and folds in some of the basics of what SPF must do on a router to calculate the best routes. It also goes through the options for tuning the metric calculation to influence the choice of routes.

OSPF Metric Calculation for Internal OSPF Routes

The process of calculating the cost from a router to each subnet may be intuitive to most people. However, spending a few minutes considering the details is worthwhile, in part to link the concepts with the LSAs, and to be better prepared for questions on the ROUTE exam. This section breaks the discussion into three sections: intra-area routes, interarea routes, a short discussion about cases when both intra-area and interarea routes exist for the same subnet, and an explanation of SPF calculations.

Calculating the Cost of Intra-Area Routes

When a router analyzes the LSDB to calculate the best route to each subnet, it does the following:

Step 1. Finds all subnets inside the area, based on the stub interfaces listed in the Type 1 LSAs and based on any Type 2 network LSAs

Step 2. Runs SPF to find all possible paths through the area's topology, from itself to each subnet

Step 3. Calculates the OSPF interface costs for all outgoing interfaces in each route, picking the lowest total cost route for each subnet as the best route

Key Topic

For example, Figure 6-11 shows the routers and links inside area 34, as a subset of the internetwork also shown in Figure 6-1. Figure 6-11 shows the interface numbers and OSPF costs.

Following the basic three-step process, at Step 1, R1 can determine that subnet 10.10.34.0/24 exists in area 34 because of the Type 2 LSA created by the DR in that subnet. For Step 2, R1 can then run SPF and determine four possible routes, two of which are clearly more reasonable to humans: R1-R3 and R1-R4. (The two other possible routes, R1-R3-R2-R4 and R1-R4-R2-R3, are possible and would be considered by OSPF but would clearly be higher cost.) For Step 3, R1 does the simple math of adding the costs of the outgoing interfaces in each route, as follows:

- R1-R3: Add R1's S0/0/0.3 cost (647) and R3's Fa0/0 cost (10), total 657
- R1-R4: Add R1's S0/0/0.4 cost (647) and R4's Fa0/0 cost (10), total 657

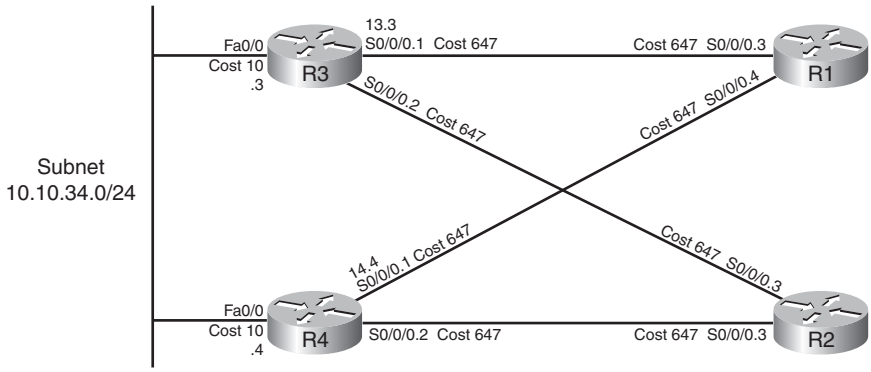

Figure 6-11 *Area 34 Portion of Figure 6-1*

The metrics tie, so with a default setting of **maximum-paths 4**, R1 adds both routes to its routing table. In particular, the routes list the metric of 657, and the next-hop IP address on the other end of the respectively links: 10.10.13.3 (R3's S0/0/0.1) and 10.10.14.4 (R4's S0/0/0.1).

Note that OSPF supports equal-cost load balancing, but it does not support unequal-cost load balancing. The **maximum-paths** OSPF subcommand can be set as low as 1, with the maximum being dependent on router platform and IOS version. Modern IOS versions typically support 16 or 32 concurrent routes to one destination (maximum).

Calculating the Cost of Interarea Routes

From a human perspective, the cost for interarea routes can be calculated just like for intra-area routes if we have the full network diagram, subnet numbers, and OSPF interface costs. To do so, just find all possible routes from a router to the destination subnet, add up the costs of the outgoing interfaces, and choose the router with the lowest total cost.

However, OSPF routers cannot do the equivalent for interarea routes, because routers internal to one area do not have topological data–LSA Types 1 and 2–for other areas. Instead, ABRs create and flood Type 3 summary LSAs into an area, listing the subnet number and mask, but not listing details about routers and links in the other areas. For example, Figure 6-12 shows both Areas 34 and 0 from Figure 6-1, including interface costs. Then consider how OSPF determines the lowest-cost route from router R3 for subnet 10.10.99.0/24, the Data Center subnet on the right.

R3 has a large number of possible routes to reach subnet 10.10.99.0/24. For example, just to get from R3 to R1, there are several possibilities: R3-R1, R3-R4-R1, and R3-R2-R1. From R1 the rest of the way to subnet 10.10.99.0/24, many more possibilities exist. The SPF algorithm has to calculate all possible routes inside an area to the ABR, so with more redundancy, SPF's run time goes up. And SPF has to consider all the options, whereas we humans can rule out some routes quickly because they appear to be somewhat ridiculous.

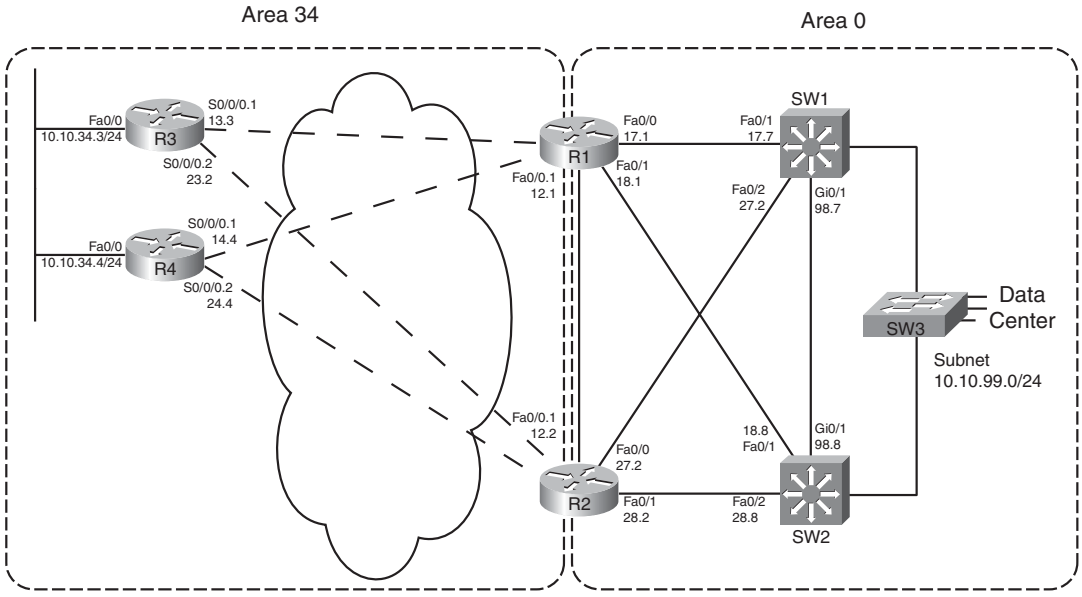

Figure 6-12 *Area 34 and Area 0 Portion of Figure 6-1*

Because of the area design, with R1 and R2 acting as ABRs, R3 does not process all the topology shown in Figure 6-12. Instead, R3 relies on the Type 3 Summary LSAs created by the ABRs, which have the following information:

- The subnet number/mask represented by the LSA
- The cost of the ABR's lowest-cost route to reach the subnet
- The RID of the ABR

Example 6-7 begins to examine the information R3 will use to calculate its best route for subnet 10.10.99.0/24, on the right side of Figure 6-12. To see these details, Example 6-7 lists several commands taken from R1. It lists R1's best route (actually two that tie) for subnet 10.10.99.0/24, with cost 11. It also lists the Type 3 LSA R1 generated by R1 for 10.10.99.0/24, again listing cost 11, and listing the Type 3 LSA created by ABR R2 and flooded into area 34.

Example 6-7 *Route and Type 3 LSA on R1 for 10.10.99.0/24*

```
R1#show ip route ospf
      10.0.0.0/8 is variably subnetted, 15 subnets, 3 masks
O        10.10.5.0/27 [110/648] via 10.10.15.5, 00:04:19, Serial0/0/0.5
O        10.10.23.0/29 [110/711] via 10.10.13.3, 00:04:19, Serial0/0/0.3
```

```
O        10.10.24.0/29 [110/711] via 10.10.14.4, 00:04:19, Serial0/0/0.4
O        10.10.25.0/29 [110/711] via 10.10.15.5, 00:04:19, Serial0/0/0.5
O        10.10.27.0/24 [110/11] via 10.10.17.7, 00:04:19, FastEthernet0/0
                       [110/11] via 10.10.12.2, 00:04:19, FastEthernet0/0.1
O        10.10.28.0/24 [110/11] via 10.10.18.8, 00:04:19, FastEthernet0/1
                       [110/11] via 10.10.12.2, 00:04:19, FastEthernet0/0.1
O        10.10.34.0/24 [110/648] via 10.10.14.4, 00:04:19, Serial0/0/0.4
                       [110/648] via 10.10.13.3, 00:04:19, Serial0/0/0.3
O        10.10.98.0/24 [110/11] via 10.10.18.8, 00:04:19, FastEthernet0/1
                       [110/11] via 10.10.17.7, 00:04:19, FastEthernet0/0
O        10.10.99.0/24 [110/11] via 10.10.18.8, 00:04:19, FastEthernet0/1
                       [110/11] via 10.10.17.7, 00:04:19, FastEthernet0/0

R1#show ip ospf database summary 10.10.99.0

            OSPF Router with ID (1.1.1.1) (Process ID 1)

! omitting output for area 5...
                Summary Net Link States (Area 34)

  LS age: 216
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 10.10.99.0 (summary Network Number)
  Advertising Router: 1.1.1.1

  LS Seq Number: 80000003
  Checksum: 0x951F
  Length: 28
  Network Mask: /24
        TOS: 0  Metric: 11


  LS age: 87
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 10.10.99.0 (summary Network Number)
  Advertising Router: 2.2.2.2

  LS Seq Number: 80000002
  Checksum: 0x7938
  Length: 28
  Network Mask: /24
       TOS: 0  Metric: 11
```

Note: The examples use default bandwidth settings, but with all routers configured with the **auto-cost reference-bandwidth 1000** command. This command is explained in the upcoming section "Reference Bandwidth."

For routers in one area to calculate the cost of an interarea route, the process is simple when you realize that the Type 3 LSA lists the ABR's best cost to reach that interarea subnet. To calculate the cost:

Step 1. Calculate the intra-area cost from that router to the ABR listed in the type 3 LSA.

Step 2. Add the cost value listed in the Type 3 LSA. (This cost represents the cost from the ABR to the destination subnet.)

Key Topic

A router applies these two steps for each possible route to reach the ABR. Following the example of router R3 and subnet 10.10.99.0/24, Figure 6-13 shows the components of the calculation.

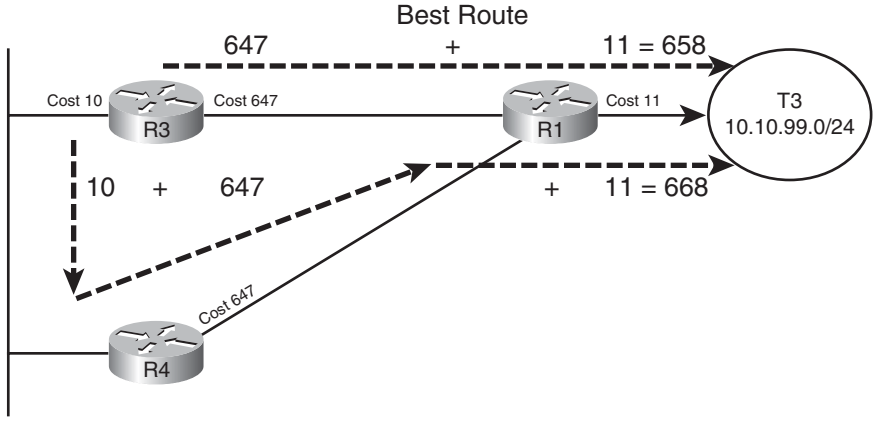

Figure 6-13 *R3's Calculation of Cost for 10.10.99.0/24*

Figure 6-13 shows the calculation of both routes, with intra-area cost to reach R1 either 647 or 657 in this case. For both routes, the cost listed in the Type 3 LSA sourced by R1, cost 11, is added.

When more than one ABR exists, as is the case as shown in Figure 6-12, each ABR should have created a Type 3 LSA for the subnet. In fact, the output in Example 6-7 showed the Type 3 LSA for 10.10.99.0/24 created by both R1 and another created by R2. For instance, in the internetwork used throughout this chapter, ABRs R1 and R2 would create a Type 3 LSA for 10.10.99.0/24. So, in this particular example, R3 would also have to calculate the best route to reach 10.10.99.0/24 through ABR R2. Then, R3 would choose the best route among all routes for 10.10.99.0/24.

Each router repeats this process for all known routes to reach the ABR, considering the Type 3 LSAs from each ABR. In this case, R3 ties on metrics for one route through R1 and one through R2, so R3 adds both routes to its routing table, as shown in Example 6-8.

Example 6-8 *Route and Type 3 LSA on R1 for 10.10.99.0/24*

```
R3#show ip route 10.10.99.0 255.255.255.0
Routing entry for 10.10.99.0/24
  Known via "ospf 3", distance 110, metric 658, type inter area
  Last update from 10.10.13.1 on Serial0/0/0.1, 00:08:06 ago
  Routing Descriptor Blocks:
  * 10.10.23.2, from 2.2.2.2, 00:08:06 ago, via Serial0/0/0.2
      Route metric is 658, traffic share count is 1
    10.10.13.1, from 1.1.1.1, 00:08:06 ago, via Serial0/0/0.1
      Route metric is 658, traffic share count is 1

R3#show ip route ospf
     10.0.0.0/8 is variably subnetted, 15 subnets, 3 masks
O IA    10.10.5.0/27 [110/1304] via 10.10.23.2, 00:07:57, Serial0/0/0.2
                     [110/1304] via 10.10.13.1, 00:07:57, Serial0/0/0.1
O IA    10.10.12.0/24 [110/657] via 10.10.23.2, 00:08:17, Serial0/0/0.2
                      [110/657] via 10.10.13.1, 00:08:17, Serial0/0/0.1
! lines omitted for brevity
O IA    10.10.99.0/24 [110/658] via 10.10.23.2, 00:08:17, Serial0/0/0.2
                      [110/658] via 10.10.13.1, 00:08:17, Serial0/0/0.1
```

Besides the information that matches the expected outgoing interfaces per the figures, the output also flags these routes as interarea routes. The first command lists "type inter area" explicitly, and the **show ip route ospf** command lists the same information with the code "O IA," meaning OSPF, interarea. Simply put, interarea routes are routes for which the subnet is known from a Type 3 summary LSA.

Special Rules Concerning Intra-area and Interarea Routes on ABRs

OSPF has a couple of rules concerning intra-area and interarea routes that take precedence over the simple comparison of the cost calculated for the various routes. The issue exists when more than one ABR connects to the same two areas. Many designs use two routers between the backbone and each nonbackbone area for redundancy, so this design occurs in many OSPF networks.

The issue relates to the fact that with two or more ABRs, the ABRsthemselves, when calculating their own routing tables, can calculate both an intra-area route and interarea route for subnets in the backbone area. For example, consider the perspective of Router R1 from the last several examples, as depicted in Figure 6-14.

Conceptually, R1 could calculate both the intra-area route and interarea route to 10.10.99.0/24. However, the OSPF cost settings could be set so that the lower cost route

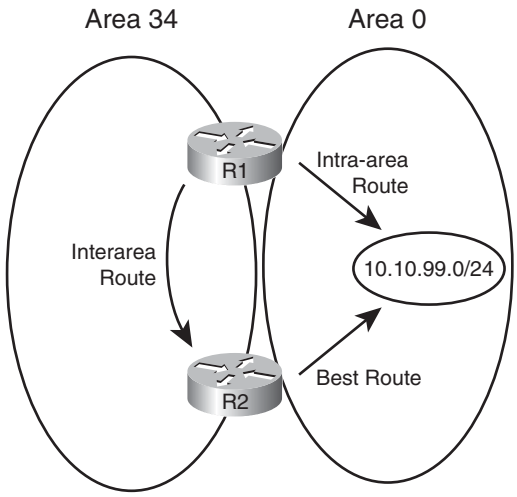

Figure 6-14 *R1's Choice: Intra-Area or Interarea Route to 10.10.99.0/24*

for R1 actually goes through area 34, to ABR R2, and then on through Area 0 to 10.10.99.0/24. However, two OSPF rules prevent such a choice by R1:

Step 1. When choosing the best route, an intra-area route is always better than a competing interarea route, regardless of metric.

Step 2. If an ABR learns a Type 3 LSA inside a nonbackbone area, the ABR ignores that LSA when calculating its own routes.

Because of the first rule, R1 would never choose the interarea route if the intra-area route were available. The second rule goes further, stating that R1 could never choose the interarea route at all–R1 simply ignores that LSA for the purposes of choosing its own best IP routes.

Metric and SPF Calculations

Before moving on to discuss how to influence route choices by changing the OSPF interface costs, first take a moment to consider the CPU-intensive SPF work done by a router. SPF does the work to piece together topology information to find all possible routes to a destination. As a result, SPF must execute when the intra-area topology changes, because changes in topology impact the choice of best route. However, changes to Type 3 LSAs do not drive a recalculation of the SPF algorithm, because the Type 3 LSAs do not actually describe the topology.

To take the analysis a little deeper, remember that an internal router, when finding the best interarea route for a subnet, uses the intra-area topology to calculate the cost to reach the ABR. When each route is identified, the internal router adds the intra-area cost to the ABR, plus the corresponding Type 3 LSA's cost. A change to the Type 3 LSA–it fails, comes back up, or the metric changes–does impact the choice of best route, so the changed Type 3 LSA must be flooded. However, no matter the change, the change does not affect the topology between a router and the ABR—and SPF focuses on processing that topology data. So, only changes to Type 1 and 2 LSAs require an SPF calculation.

You can see the number of SPF runs, and the elapsed time since the last SPF run, using several variations on the **show ip ospf** command. Each time a Type 3 LSA changes and is flooded, SPF does not run, and the counter does not increment. However, each time a Type 1 or 2 LSA changes, SPF runs, and the counter increments. Example 6-9 highlights the counter that shows the number of SPF runs on that router, in that area, and the time since the last run. Note that ABRs list a group of messages per area, showing the number of runs per area.

Example 6-9 *Example with New Route Choices but No SPF Run*

```
R3#show ip ospf  ¦ begin Area 34
     Area 34
          Number of interfaces in this area is 3
          Area has no authentication
          SPF algorithm last executed 00:41:02.812 ago
          SPF algorithm executed 15 times
          Area ranges are
          Number of LSA 25. Checksum Sum 0x0BAC6B
          Number of opaque link LSA 0. Checksum Sum 0x000000
          Number of DCbitless LSA 0
          Number of indication LSA 0
          Number of DoNotAge LSA 0
          Flood list length 0
```

Metric Tuning

Engineers have a couple of commands available that allow them to tune the values of the OSPF interface cost, thereby influencing the choice of best OSPF route. This section discusses the three methods: changing the reference bandwidth, setting the interface bandwidth, and setting the OSPF cost directly.

Changing the Reference Bandwidth

OSPF calculates the default OSPF cost for an interface based on the following formula:

$$\frac{\text{Reference-brandwidth}}{\text{interface-bandwidth}}$$

The reference-bandwidth, which you can set using the **auto-cost reference-bandwidth** *bandwidth* router subcommand, sets the numerator of the formula for that one router, with a unit of Mbps. This setting may be different on different routers, but Cisco recommends using the same setting on all routers in an OSPF routing domain.

For example, serial interfaces default to a bandwidth setting of 1544, meaning 1544 Kbps. The reference bandwidth defaults to 100, meaning 100 Mbps. After converting the reference bandwidth units to Kbps to match the bandwidth, the cost, calculated per the defaults, for serial links would be

$$\frac{100{,}000}{1544} = 64$$

Note: OSPF always rounds down when the calculation results in a fraction.

The primary motivation for changing the reference bandwidth is to accommodate good defaults for higher-speed links. With a default of 100 Mbps, the cost of FastEthernet interfaces calculates to cost 1. However, the minimum OSPF cost is 1, so Gigabit Ethernet and 10 Gigabit interfaces also then default to OSPF cost 1. By setting the OSPF reference bandwidth so that there is some difference in cost between the higher speed links, OSPF can then choose routes that use those higher speed interfaces.

Note: Although Cisco recommends that all routers use the same reference bandwidth, the setting is local to each router.

Note that in the examples earlier in this chapter, the bandwidth settings used default settings, but the **auto-cost reference-bandwidth 1000** command was used on each router to allow different costs for FastEthernet and Gigabit interfaces.

Setting Bandwidth

You can indirectly set the OSPF cost by configuring the **bandwidth** *speed* interface subcommand. In such cases, the formula shown in the previous section is used, just with the configured bandwidth value.

While on the topic of the interface bandwidth subcommand, a couple of seemingly trivial facts may matter to your choice of how to tune the OSPF cost. First, on serial links, the bandwidth defaults to 1544. On subinterfaces of those serial interfaces, the same bandwidth default is used.

On Ethernet interfaces, if not configured with the **bandwidth** command, the interface bandwidth matches the actual speed. For example, on an interface that supports autonegotiation for 10/100, the bandwidth is either 100,000 (kbps, or 100 Mbps) or 10,000 (Kbps, or 10 Mbps) depending on whether the link currently runs at 100 or 10 Mbps, respectively.

Configuring Cost Directly

The most controllable method to configure OSPF costs, but the most laborious, is to configure the interface cost directly. To do so, use the **ip ospf cost** *value* interface subcommand, substituting your chosen value as the last parameter.

Verifying OSPF Cost Settings

Several commands can be used to display the OSPF cost settings of various interfaces. Example 6-10 shows several, along with the configuration of all three methods for changing the OSPF cost. In this example, the following has been configured:

- The reference bandwidth is set to 1000.
- Interface S0/0/0.1 has its bandwidth set to 1000 Kbps.
- Interface Fa0/0 has its cost set directly to 17.

Example 6-10 *R3 with OSPF Cost Values Set*

```
router ospf 3
 auto-cost reference-bandwidth 1000
interface S0/0/0.1
 bandwidth 1000
interface fa0/0
 ip ospf cost 17


R3#show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Se0/0/0.2    3     34              10.10.23.3/29      647   P2P   1/1
Se0/0/0.1    3     34              10.10.13.3/29      1000  P2P   1/1
Fa0/0        3     34              10.10.34.3/24      17    BDR   1/1

R3#show ip ospf interface fa0/0
FastEthernet0/0 is up, line protocol is up
  Internet Address 10.10.34.3/24, Area 34
  Process ID 3, Router ID 3.3.3.3, Network Type BROADCAST, Cost: 17
  Enabled by interface config, including secondary ip addresses
  Transmit Delay is 1 sec, State BDR, Priority 1
  Designated Router (ID) 4.4.4.4, Interface address 10.10.34.4
  Backup Designated router (ID) 3.3.3.3, Interface address 10.10.34.3
! lines omitted for brevity
```

Index

A

B

C

D

E

F

G

H

I

J - K - L

M

N

O

P

Q - R

S

T

U

V

W - X - Y - Z