CHAPTER 4

Interconnecting Multiple OSPF Areas

This chapter introduces readers to the use, operation, configuration, and verification of Open Shortest Path First (OSPF) in multiple areas. After completing this chapter, you will be able to describe issues related to interconnecting multiple areas. You will see the differences among the possible types of areas and how OSPF supports the use of VLSM. At the end of this chapter, you should be able to explain how OSPF supports the use of route summarization in multiple areas and how it operates in a multiple-area NBMA environment.

NOTE This chapter covers OSPF capabilities. OSPF design is covered in the Cisco Press book *OSPF Network Design Solutions* (ISBN 1-57870-046-9).

Multiple OSPF Areas

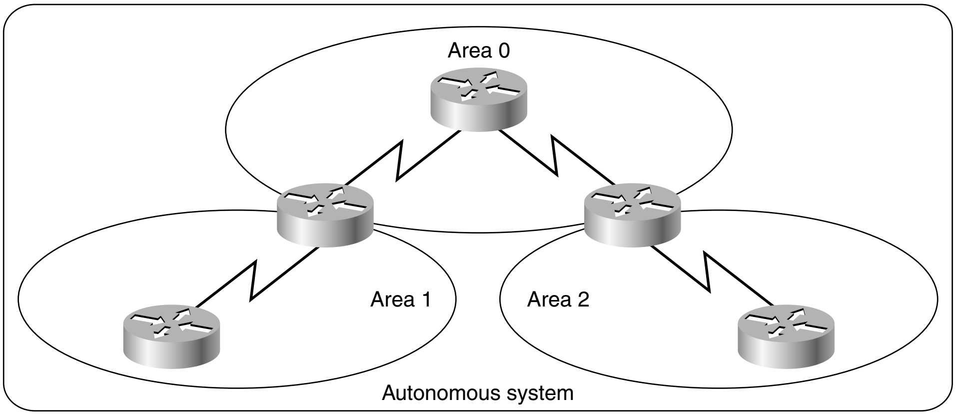
In the previous chapter, you learned how OSPF operates within a single area. Now it is time to consider what would happen if this single area ballooned into, say, 400 networks. The following issues, at a minimum, need to be addressed to understand OSPF in multiple areas:

- **Frequent calculations of the shortest path first (SPF) algorithm**—With such a large number of segments, network changes are inevitable. The routers would have to spend many more CPU cycles recalculating the routing tables because they would receive every update generated within the area.
- **Large routing table**—Each router would need to maintain at least one entry for every network—in this previous example, that would be at least 400 networks. Assuming that alternative paths would exist for 25 percent of these 400 networks, routing tables would have an additional 100 entries.
- **Large link-state table**—Because the link-state table includes the complete topology of the network, each router would need to maintain an entry for every network in the area, even if routes are not selected for the routing table.

In light of these issues, OSPF was designed to allow large areas to be separated into smaller, more manageable areas that can still exchange routing information.

OSPF's capability to separate a large internetwork into multiple areas is also referred to as hierarchical routing. Hierarchical routing enables you to separate a large internetwork (autonomous system) into smaller internetworks that are called areas, as shown in Figure 4-1. With this technique, routing still occurs between the areas (called interarea routing), but many of the internal routing operations, such as recalculating the database, are kept within an area. In Figure 4-1, for example, if Area 1 is having problems with a link going up and down, routers in other areas need not continually run their SPF calculation because they are isolated from the Area 1 problem.

Figure 4-1 *OSPF Hierarchical Routing*



The hierarchical topology of OSPF has the following advantages:

- **Reduced frequency of SPF calculations**—Because detailed route information is kept within each area, it is not necessary to flood all link-state changes to every area. Thus, not all routers need to run the SPF calculation when a topological change happens. Only those affected by the change will need to recompute routes.
- **Smaller routing tables**—When using multiple areas, detailed route entries for interarea networks are kept within the area. Instead of advertising these explicit routes outside the area, these routes can be summarized into one or more summary addresses. Advertising these summaries reduces the number of link-state advertisements (LSAs) propagated between areas, while keeping all networks reachable.
- **Reduced link-state update (LSU) overhead**—LSUs can contain a variety of LSA types, including link-state information and summary information. Rather than sending an LSU about each network within an area, you can advertise a single or a few summarized routes between areas, thus reducing the overhead associated with link-state updates passed to other areas.

Hierarchical routing enables efficient routing because it enables you to control the types of routing information that you allow in and out of an area. OSPF enables different types of routing updates by assigning characteristics to each area and the routers connecting the areas. Area and router characteristics govern how they process routing information, including what types of LSUs a router can create, receive, and send. This section provides an overview of the following OSPF multiarea components, and their usage and configuration:

- Types of routers
- Types of LSAs
- Types of areas

OSPF Design Guidelines

Studies and real-world implementations have led to the following OSPF design guidelines, as documented in *OSPF Network Design Solutions*:

Routers in a Domain	Minimum 20	Mean 510	Maximum 1000
Routers per Single Area	Minimum 20	Mean 160	Maximum 350
Areas per Domain	Minimum 1	Mean 23	Maximum 60

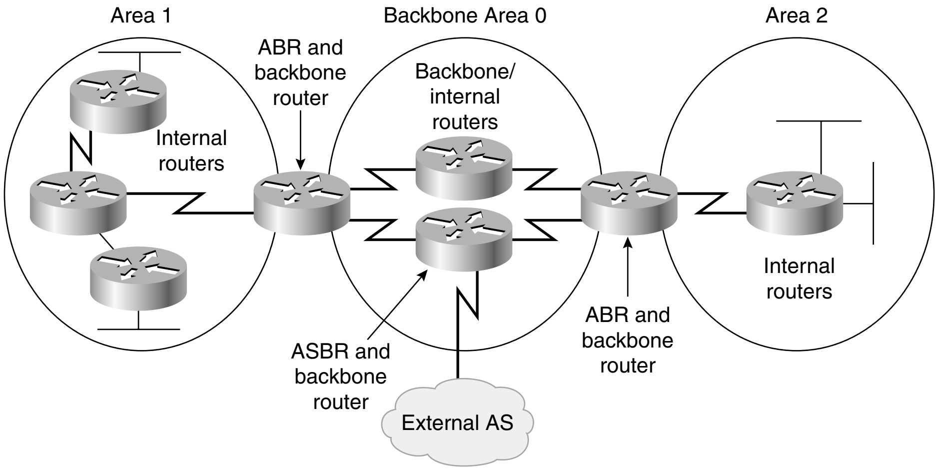
Types of Routers

Different types of OSPF routers, shown in Figure 4-2, control differently how traffic is passed to and from areas. The router types are as follows:

- **Internal router**—Routers that have all interfaces in the same area are internal routers. Internal routers within the same area have identical link-state databases.
- **Backbone router**—Routers that sit in the backbone area. They have at least one interface connected to Area 0. These routers maintain OSPF routing information using the same procedures and algorithms as internal routers. Area 0 serves as the transit area between other OSPF areas.
- **Area Border Router (ABR)**—Routers that have interfaces attached to multiple areas. These routers maintain separate link-state databases for each area to which they are connected, and route traffic destined for or arriving from other areas. ABRs are exit points for the area, which means that routing information destined for another area can get there only via the local area's ABR. ABRs may summarize information from their link-state databases of their attached areas and distribute the information into the backbone area. The backbone ABRs then forward the information to all other connected areas. An area can have one or more ABRs.

- **Autonomous System Boundary Router (ASBR)**—Routers that have at least one interface into an external internetwork (another autonomous system), such as a non-OSPF network and another interface within OSPF. These routers can import (referred to as redistribution) non-OSPF network information to the OSPF network, and vice versa.

Figure 4-2 *Types of Routers*



A router can be more than one router type. For example, if a router connects to Area 0 and Area 1, as well as to a non-OSPF network, it would be considered an ABR, an ASBR, and a backbone router.

A router has a separate link-state database for each area it is connected to. Therefore, an ABR would have a link-state database for Area 0 and another link-state database for the other area it participates in. Two routers belonging to the same area have, for that one area, identical area link-state databases.

Remember that a link-state database is synchronized between pairs of adjacent routers, meaning that it is synchronized between a router and its designated router (DR) and backup designated router (BDR).

Types of Link-State Advertisements

Table 4-1 shows the types of LSAs included in an LSU. The Name column in Table 4-1 provides the official name of the LSA. Contained in the first set of parentheses is the nomenclature used in the routing table for that specific LSA. The second set of parentheses shows how the LSA type is indicated in the OSPF database. Example 4-1 provides a sample OSPF database.

Table 4-1 *Types of LSAs*

LSA Type	Name	Description
1	Router link entry (record) (O—OSPF) (Router Link States)	Generated by each router for each area it belongs to. Describes the states of the router's link to the area. These are flooded only within a particular area. The link status and cost are two of the descriptors provided.
2	Network link entry (O—OSPF) (Net Link States)	Generated by DRs in multiaccess networks. Describes the set of routers attached to a particular network. These are flooded within the area that contains the network only.
3 or 4	Summary link entry (IA—OSPF interarea) (Summary Net Link States and Summary ASB Link States)	Originated by ABRs. Describes the links between the ABR and the internal routers of a local area. These entries are flooded throughout the backbone area to the other ABRs. Type 3 LSAs describe routes to networks within the local area and are sent to the backbone area. Type 4 LSAs describe reachability to ASBRs. These link entries are not flooded through totally stubby areas.
5	Autonomous system external link entry (E1—OSPF external type 1) (E2—OSPF external type 2) (AS External Link States)	Originated by the ASBR. Describes routes to destinations external to the autonomous system. They are flooded throughout an OSPF autonomous system except for stub, totally stubby, and not-so-stubby areas.
7	Not-so-stubby area (NSSA) autonomous system external link entry (N1—OSPF NSSA external type 1) (N2—OSPF NSSA external type 2)	Originated by the ASBR in an NSSA. These LSAs are similar to type 5 LSAs, except that they are flooded only within the NSSA. At the area border router, selected type 7 LSAs are translated into type 5 LSAs and are flooded into the backbone. See Appendix A, "Job Aids and Supplements," for further information on NSSAs.

NOTE Type 3 and 4 LSAs are *summary* LSAs; they may or may not be *summarized*.

LSAs type 6 do not appear in Table 4-1 because they are not supported by Cisco Routers.

NOTE All LSA types, except the autonomous system external link entry LSAs (type 5), are flooded throughout a single area only.

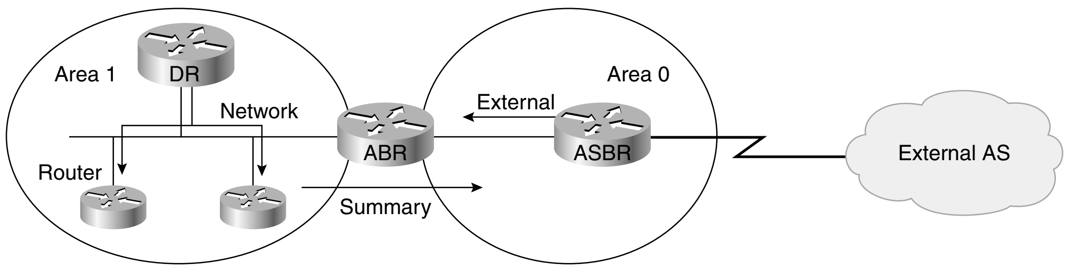
NOTE Only LSA types 1 through 5 are covered in this chapter. Types 6 and 7 LSAs are beyond the scope of this chapter. Type 7 LSAs are discussed in Appendix A. Type 6 LSAs are covered in RFC 1584.

Example 4-1 *OSPF Database Output*

```
p1r3#show ip ospf database
       OSPF Router with ID (10.64.0.1) (Process ID 1)

                 Router Link States (Area 1)
Link ID         ADV Router      Age         Seq#       Checksum Link count
10.1.2.1        10.1.2.1        651         0x80000005 0xD482   4

                 Net Link States (Area 1)
Link ID         ADV Router      Age         Seq#       Checksum
10.64.0.1       10.64.0.1       538         0x80000002 0xAD9A

                Summary Net Link States (Area 1)
Link ID         ADV Router      Age         Seq#       Checksum
10.2.1.0        10.2.1.2        439         0x80000002 0xE6F8
```

Figure 4-3 provides a representation of the different types of LSAs flooded in an OSPF network. The router link states are type 1 LSAs, the network link states are type 2 LSAs, and the summary link states are type 3 LSAs. The external link states are type 5 LSAs.

Figure 4-3 *Examples of LSAs Flooded in a Network*



Cost Associated with Summary Routes

The cost of a summary route is the smallest cost of a given interarea route that appears in the summary, plus the cost of the ABR link to the backbone. For example, if the cost of the ABR link to the backbone were 50, and if the ABR had an interarea route of 49, the total cost associated with the summary route would be 99. This calculation is done automatically for each summary route.

Calculating the Cost of External Routes

The cost of an external route differs depending on the external type configured on the ASBR. You configure the router to generate one of the following external packet types:

- **Type 1 (E1)**—If a packet is an E1, then the metric is calculated by adding the external cost to the internal cost of each link that the packet crosses. Use this packet type when you have multiple ASBRs advertising a route to the same autonomous system.
- **Type 2 (E2)**—This is the default type. If a packet is an E2, then it will always have only the external cost assigned, no matter where in the area it crosses. Use this packet type if only one router is advertising a route to the external autonomous system. Type 2 routes are preferred over type 1 routes unless two same-cost routes exist to the destination.

NOTE The process of different routing protocols exchanging routing information is referred to as redistribution. Redistribution is discussed in Chapter 8, "Optimizing Routing Update Operation."

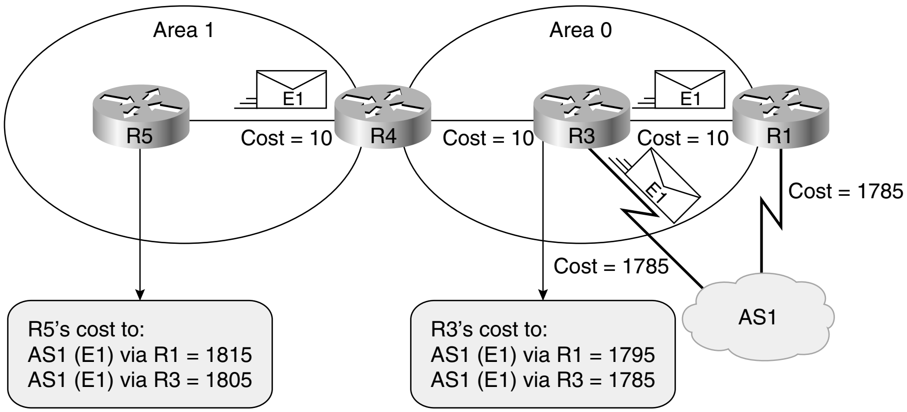
Figure 4-4 provides a graphical example of how type 1 external routes are calculated.

Types of Areas

The characteristics that you assign an area control the type of route information that it receives. The possible area types include the following:

- **Standard area**—An area that operates as discussed in Chapter 3, "Configuring OSPF in a Single Area." This area can accept (intra-area) link updates, (interarea) route summaries, and external routes.
- **Backbone area (transit area)**—When interconnecting multiple areas, the backbone area is the central entity to which all other areas connect. The backbone area is always labeled Area 0. All other areas must connect to this area to exchange and route information. The OSPF backbone has all the properties of a standard OSPF area.

Figure 4-4 *External Routes Calculations*



- **Stub area**—This refers to an area that does not accept information about routes external to the autonomous system (that is, the OSPF internetwork), such as routes from non-OSPF sources. If routers need to route to networks outside the autonomous system, they use a default route. A default route is noted as 0.0.0.0.
- **Totally stubby area**—This is an area that does not accept external autonomous system (AS) routes or summary routes from other areas internal to the autonomous system. Instead, if the router needs to send a packet to a network external to the area, it sends it using a default route. Totally stubby areas are Cisco proprietary.
- **Not-so-stubby-area**—A not-so-stubby area imports a limited number of external routes. The number of routes is limited to only those required to provide connectivity between areas. NSSAs are discussed in Appendix A.

Routing Table Results with Different Areas

Example 4-2, Example 4-3, and Example 4-4 provide a comparison of routing tables that result when using summarization, stub areas, and totally stubby areas, respectively.

Example 4-2 *IP Routing Table Without Any Special OSPF Capabilities: Route Summaries Without Route Summarization*

```
p1r3#show ip route
<Output Omitted>
     10.0.0.0/24 is subnetted, 15 subnets
O IA    10.3.1.0 [110/148] via 10.64.0.2, 00:03:12, Ethernet0
C       10.1.3.0 is directly connected, Serial0
O IA    10.2.1.0 [110/74] via 10.64.0.2, 00:31:46, Ethernet0
```

Example 4-2 *IP Routing Table Without Any Special OSPF Capabilities: Route Summaries Without Route Summarization (Continued)*

```
C       10.1.2.0 is directly connected, Serial1
O IA    10.3.3.0 [110/148] via 10.64.0.2, 00:03:12, Ethernet0
O IA    10.2.2.0 [110/138] via 10.64.0.2, 00:31:46, Ethernet0
O       10.1.1.0 [110/128] via 10.1.3.1, 00:31:46, Serial0
                 [110/128] via 10.1.2.1, 00:31:46, Serial
O IA    10.3.2.0 [110/212] via 10.64.0.2, 00:03:12, Ethernet0
O IA    10.2.3.0 [110/74] via 10.64.0.2, 00:31:46, Ethernet0
O IA    10.4.2.0 [110/286] via 10.64.0.2, 00:02:50, Ethernet0
O IA    10.4.3.0 [110/222] via 10.64.0.2, 00:02:50, Ethernet0
O IA    10.4.1.0 [110/222] via 10.64.0.2, 00:02:50, Ethernet0
O IA    10.66.0.0 [110/158] via 10.64.0.2, 00:02:51, Ethernet0
C       10.64.0.0 is directly connected, Ethernet0
O IA    10.65.0.0 [110/84] via 10.64.0.2, 00:03:19, Ethernet0
p1r3#
```

Example 4-3 *IP Routing Table with Route Summarization and Stub Capabilities Enabled*

```
p1r3#show ip route
<Output Omitted>
Gateway of last resort is 10.64.0.2 to network 0.0.0.0
      10.0.0.0/8 is variably subnetted, 9 subnets, 2 masks
O IA    10.2.0.0/16 [110/74] via 10.64.0.2, 00:11:11, Ethernet0
C       10.1.3.0/24 is directly connected, Serial0
O IA    10.3.0.0/16 [110/148] via 10.64.0.2, 00:07:59, Ethernet0
C       10.1.2.0/24 is directly connected, Serial1
O       10.1.1.0/24 [110/128] via 10.1.3.1, 00:16:51, Serial0
                    [110/128] via 10.1.2.1, 00:16:51, Serial1
O IA    10.4.0.0/16 [110/222] via 10.64.0.2, 00:09:13, Ethernet0
O IA    10.66.0.0/24 [110/158] via 10.64.0.2, 00:16:51, Ethernet0
C       10.64.0.0/24 is directly connected, Ethernet0
O IA    10.65.0.0/24 [110/84] via 10.64.0.2, 00:16:51, Ethernet0
O*IA 0.0.0.0/0 [110/11] via 10.64.0.2, 00:16:51, Ethernet0
p1r3#
```

Example 4-4 *IP Routing Table with Route Summarization and Totally Stub Capabilities Enabled*

```
p4r2#show ip route
Gateway of last resort is 10.66.0.1 to network 0.0.0.0
    10.0.0.0/24 is subnetted, 4 subnets
O       10.4.2.0 [110/128] via 10.4.3.2, 00:20:43, Serial1
                 [110/128] via 10.4.1.1, 00:20:43, Serial0
C       10.4.3.0 is directly connected, Serial1
C       10.4.1.0 is directly connected, Serial0
C       10.66.0.0 is directly connected, Ethernet0
O*IA 0.0.0.0/0 [110/11] via 10.66.0.1, 00:20:43, Ethernet0
```

NOTE Example 4-4 was taken from a different router than Examples 4-2 and 4-3.

OSPF Operation Across Multiple Areas

This section summarizes how routers generate link information, flood information, and build their routing tables when operating within a multiarea environment.

NOTE OSPF router operation is complex and accounts for numerous possible scenarios based on the nature of the network. This section provides a basic overview; refer to the OSPF version 2 RFC for more detailed information.

Before reviewing how ABRs and other router types process route information, you should know how a packet makes its way across multiple areas. In general, the path a packet must take is as follows:

- If the packet is destined for a network within an area, then it is forwarded from the internal router, through the area to the destination internal router.
- If the packet is destined for a network outside the area, it must go through the following path:
  - — The packet goes from the source network to an ABR.
  - — The ABR sends the packet through the backbone area to the ABR of the destination network.
  - — The destination ABR then forwards the packet through the area to the destination network.

Flooding LSUs in Multiple Areas

ABRs are responsible for generating routing information about each area to which they are connected and flooding the information through the backbone area to the other areas to which they are connected. Figure 4-5 provides a graphical representation of the different LSA types exchanged in a multiple-area environment. The general process for flooding is as follows:

Step 1 The intra-area routing process occurs, as discussed in Chapter 3. Note that the entire intra-area must be synchronized before the ABR can begin sending summary LSAs.

Step 2 The ABR reviews the resulting link-state database and generates summary LSAs.

By default, the ABR sends summary LSAs for each network that it knows about. To reduce the number of summary LSA entries, you can configure route summarization so that a single IP address can represent multiple networks. To use route summarization, your areas must use contiguous IP addressing, as discussed in Chapter 2, "Extending IP Addresses." A good IP address plan will lower the number of summary LSA entries that an ABR needs to advertise.

Step 3 The summary LSAs (types 3 and 4) are placed in an LSU and are distributed through all ABR interfaces that are not in the local area, with the following exceptions:

— If the interface is connected to a neighboring router that is in a state below the exchange state, then the summary LSA is not forwarded.

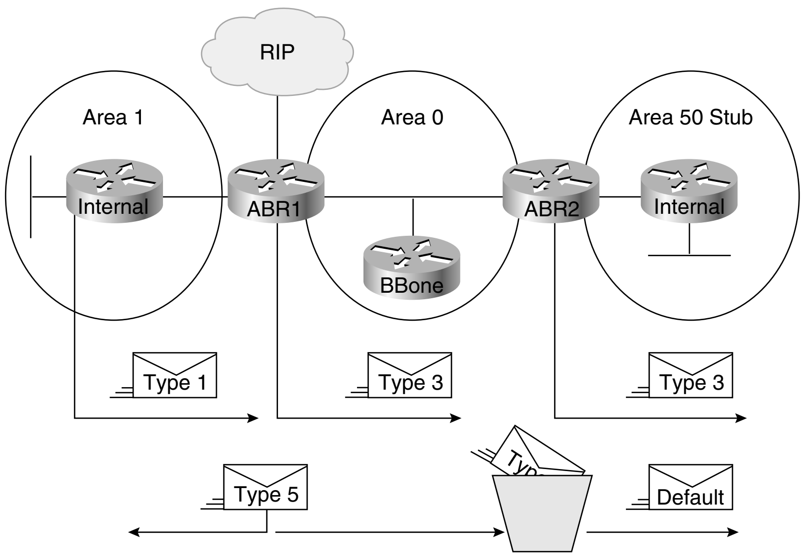
— If the interface is connected to a totally stubby area, then the summary LSA is not forwarded.

— If the summary LSA includes a type 5 (external) route and the interface is connected to a stubby or totally stubby area, then the LSA is not sent to that area.

Step 4 When an ABR or ASBR receives summary LSAs, it adds them to its link-state database and floods them to its local area. The internal routers then assimilate the information into their databases.

Note that to reduce the number of route entries maintained by internal routers, you may define the area as a form of stub area.

Figure 4-5 *Flooding LSUs to Multiple Areas*



After all router types receive the routing updates, they must add them to their link-state databases and recalculate their routing tables. The order in which paths are calculated is as follows:

Step 1 All routers first calculate the paths to destinations within their area and add these entries into the routing table. These are the type 1 and type 2 LSAs.

Step 2 All routers, unless they are in a totally stubby area, then calculate the paths to the other areas within the internetwork. These paths are the interarea route entries, or type 3 and type 4 LSAs. If a router has an interarea route to a destination and an intra-area route to the same destination, the intra-area route is kept.

Step 3 All routers, except those that are in a form of stub area, then calculate the paths to the AS external (type 5) destinations.

At this point, a router can get to any network within or outside the OSPF autonomous system.

NOTE According to RFC 2328, the order of preference for OSPF routes is as follows:

Intra-area routes, O
Interarea routes, O IA
External routes type 1, O E1
External routes type 2, O E2

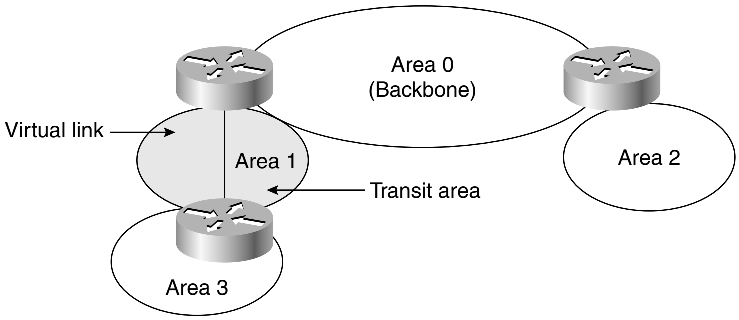
Virtual Links Overview

OSPF has certain restrictions when multiple areas are configured. One area must be defined as Area 0, the backbone area. It is called the backbone area because all communication must go through it—that is, all areas should be physically connected to Area 0 so that the routing information injected into Area 0 can be disseminated to other areas.

In some situations, however, a new area is added after the OSPF internetwork has been designed and configured, and it is not possible to provide that new area with direct access to the backbone. In these cases, a virtual link can be defined to provide the needed connectivity to the backbone area, as shown in Figure 4-6. The virtual link provides the disconnected area with a logical path to the backbone. The virtual link has two requirements, as follows:

- It must be established between two ABRs that share a common area.
- One of these two ABRs must be connected to the backbone area.

Figure 4-6 *Backbone Area Requirement Met Through Virtual Links*



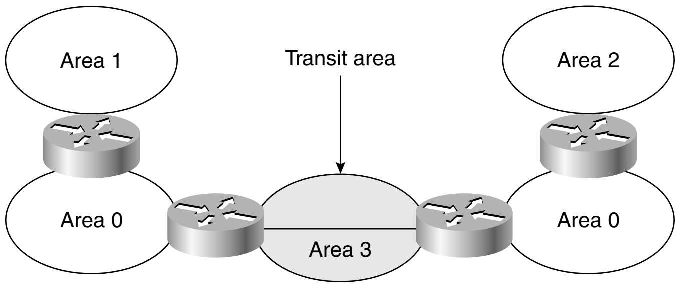
When virtual links are used, they require special processing during the SPF calculation. That is, the true next-hop router must be determined so that the true cost to get to a destination across the backbone can be calculated.

Virtual links serve the following purposes:

- Linking an area that does not have a physical connection to the backbone, as shown in Figure 4-6. This linking could occur when two organizations merge, for example.
- Patching the backbone in case discontinuity of Area 0 occurs.

Figure 4-7 illustrates the second purpose. Discontinuity of the backbone might occur, for example, if two companies, each running OSPF, are trying to merge the two separate networks into one with a common Area 0. The alternative would be to redesign the entire OSPF network and create a unified backbone.

Figure 4-7 *Discontiguous Area 0*



Another reason for creating a virtual link would be to provide redundancy in cases where a router failure causes the backbone to be split into two portions.

In Figure 4-7, the disconnected Area 0s are linked via a virtual link through the common Area 3. If a common area does not already exist, one can be created to become the transit area.

For adjacency purposes, OSPF treats two routers joined by a virtual link as an unnumbered point-to-point backbone network because they don't share a physical connection and, therefore, the IP address of their connecting interfaces is not on the same IP subnet.

TIP When an unnumbered interface is configured, it references another interface on the router. When enabling OSPF on the unnumbered interface with the **network** command, use an *address wildcard-mask* pair that refers to the interface to which the unnumbered interface is pointing.

Using and Configuring OSPF Multiarea Components

No special commands exist to activate the ABR or ASBR functionality on a router. The router takes on this role by virtue of the areas to which it is connected. As a reminder, the basic OSPF configuration steps are as follows:

Step 1 Enable OSPF on the router.

```
router(config)#router ospf process-id
```

Step 2 Identify which IP networks on the router are part of the OSPF network. For each network, you must identify what area the network belongs to. When configuring multiple OSPF areas, make sure to associate the correct network addresses with the desired area ID, as shown in Figure 4-8 and Example 4-5.

```
router(config-router)#network address wildcard-mask area area-id
```

Step 3 (Optional) If the router has at least one interface connected into a non-OSPF network, perform the proper configuration steps. At this point, the router will be acting as an ASBR. How the router exchanges (redistributes) non-OSPF route information with the other OSPF routers is discussed in Chapter 8.

NOTE Refer to Chapter 3 for details about basic OSPF configuration commands.

Example 4-5 provides the configuration for an internal router (Router A) and for an ABR (Router B), as shown in Figure 4-8.

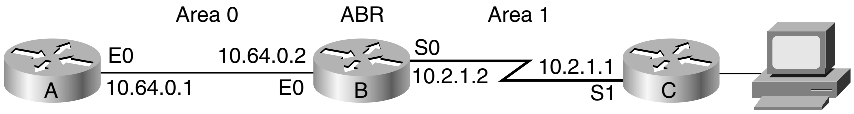
Example 4-5 *Configuring an OSPF Interarea Router and Area Border Router*

```
<Output Omitted>
RouterA(config)#interface Ethernet0
```

Example 4-5 *Configuring an OSPF Interarea Router and Area Border Router (Continued)*

```
RouterA(config-if)#ip address 10.64.0.1 255.255.255.0
!
<Output Omitted>
RouterA(config)#router ospf 77
RouterA(config-router)#network 10.0.0.0 0.255.255.255 area 0

<Output Omitted>
RouterB(config)#interface Ethernet0
RouterB(config-if)#ip address 10.64.0.2 255.255.255.0
!
RouterB(config)#interface Serial0
RouterB(config-if)#ip address 10.2.1.2 255.255.255.0
<Output Omitted>
RouterB(config)#router ospf 50
RouterB(config-router)#network 10.2.1.2 0.0.0.0 area 1
RouterB(config-router)#network 10.64.0.2 0.0.0.0 area 0
```

Figure 4-8 *Configuring Interarea Routers and ABRs*



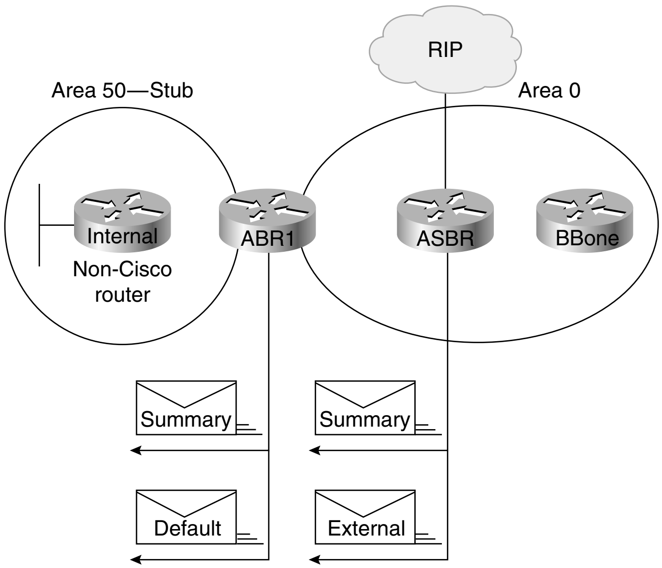
Using Stub and Totally Stubby Areas

RFCs provide for OSPF stub and OSPF NSSA configuration. NSSA is discussed in Appendix A. Totally stubby area is a Cisco proprietary standard. This section is concerned with stub areas and totally stubby areas.

Configuring a stub area reduces the size of the link-state database inside that area, thus reducing the memory requirements on routers. External networks (type 5 LSAs), such as those redistributed from other protocols into OSPF, are not allowed to be flooded into a stub area, as shown in Figure 4-9. Routing from these areas to the outside world is based on a default route (0.0.0.0). ABRs inject the default route (0.0.0.0) into the stub area. Having a default route means that if a packet is addressed to a network that is not in an internal router's route table, the router will automatically forward the packet to the ABR that sent a 0.0.0.0 LSA. This allows routers within the stub to reduce the size of their routing tables because a single default route replaces the many external routes.

A stub area is typically created when you have a hub-and-spoke topology, with the spoke being the stub area, such as a branch office. In this case, the branch office does not need to know about every network at the headquarters site; instead, it can use a default route to get there.

Figure 4-9 *Flooding LSAs to a Stub Area*



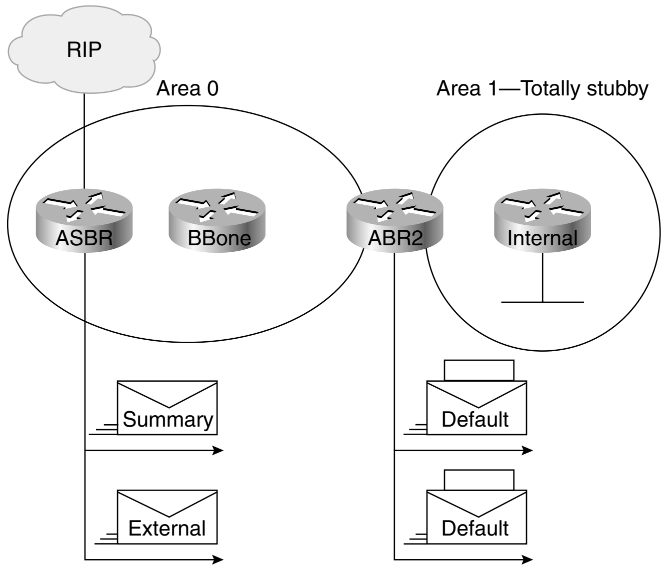
To further reduce the number of routes in a table, you can create a totally stubby area, which is a Cisco-specific feature. A totally stubby area is a stub area that blocks external type 5 LSAs and summary (type 3 and type 4) LSAs (interarea routes) from going into the area, as shown in Figure 4-10. This way, intra-area routes and the default of 0.0.0.0 are the only routes known to the stub area. ABRs inject the default summary link 0.0.0.0 into the totally stubby area. Each router picks the closest ABR as a gateway to everything outside the area.

Totally stubby areas further minimize routing information (as compared to stub areas) and increase stability and scalability of OSPF internetworks. This is typically a better solution than creating stub areas, unless the target area uses a mix of Cisco and non-Cisco routers.

An area could be qualified as a stub or totally stubby when it meets the following criteria:

- There is a single exit point from that area, or, if multiple exits (ABRs) exist, routing to outside the area does not have to take an optimal path. If the area has multiple exits, one or more ABRs will inject a default route into the stub area. In this situation, routing to other areas or autonomous systems could take a suboptimal path in reaching the destination by going out of the area via an exit point that is farther from the destination than other exit points.
- All OSPF routers inside the stub area (ABRs and internal routers) are configured as stub routers so that they will become neighbors and exchange routing information. The configuration commands for creating stub networks are covered in the next section.
- The area is not needed as a transit area for virtual links.

Figure 4-10 *Flooding LSAs to a Totally Stubby Area*



- No ASBR is internal to the stub area.
- The area is not the backbone area (not Area 0).

These restrictions are necessary because a stub or a totally stubby area is mainly configured to carry internal routes and can't have external links injected in that area.

Configuring Stub and Totally Stubby Areas

To configure an area as stub or totally stubby, do the following:

Step 1 Configure OSPF, as described earlier in this chapter.

Step 2 Define an area as stub or totally stubby by adding the **area stub** command to all routers within the area, as explained in Table 4-2:

```
router (config-router)#area area-id stub [no-summary]
```

Table 4-2 ***area stub*** *Command for Configuring Stub and Totally Stubby Areas*

area stub Command	Description
area-id	Serves as an identifier for the stub or totally stubby area. The identifier can be either a decimal value or an IP address.
no-summary	(Only for ABRs connected to totally stubby areas.) Prevents an ABR from sending summary link advertisements into the stub area. Use this option for creating a totally stubby area.

NOTE Remember that the stub flag contained in the hello packet must be set on all routers within a stubby area.

NOTE The **no-summary** keyword can be put on non-ABR routers, but it has no effect.

Step 3 (Optional, for ABRs only.) Define the cost of the default route that is injected in the stub or totally stubby area, using the **area default-cost** command, as explained in Table 4-3.

```
router (config-router)#area area-id default-cost cost
```

Table 4-3 *Changing the OSPF Cost*

area default-cost Command	Description
area-id	Identifier for the stub area. The identifier can be either a decimal value or an IP address.
cost	Cost for the default summary route used for a stub or totally stubby area. The cost value is a 24-bit number. The default cost is 1.

Stub Area Configuration Example

In Example 4-6, Area 2 is defined as the stub area, as shown in Figure 4-11. No external routes from the external autonomous system will be forwarded into the stub area.

Example 4-6 *Configuring a Stub Area*

```
R3#

interface Ethernet 0
ip address 192.168.14.1 255.255.255.0
interface Serial 0
ip address 192.168.15.1 255.255.255.252

router ospf 100
network 192.168.14.0 0.0.0.255 area 0
network 192.168.15.0 0.0.0.255 area 2
area 2 stub

R4#

interface Serial 0
ip address 192.168.15.2 255.255.255.252
```

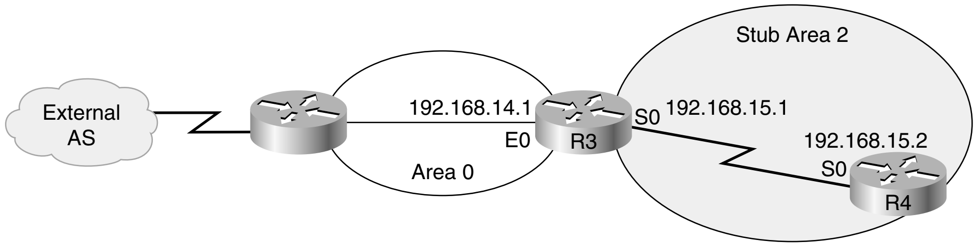
Example 4-6 *Configuring a Stub Area (Continued)*

```
router ospf 15
network 192.168.15.0 0.0.0.255 area 2
area 2 stub
```

The last line in the configuration of each router in Example 4-6, **area 2 stub**, defines the stub area. The area stub default cost has not been configured on R3, so this router advertises 0.0.0.0 (the default route) with a default cost metric of 1 plus any internal costs.

Each router in the stub area must be configured with the **area stub** command.

Figure 4-11 *Stub Area Topology*



The only routes that will appear in R4's routing table are intra-area routes (designated with an O in the routing table), the default route, and interarea routes (both designated with an IA in the routing table; the default route will also be denoted with an asterisk).

NOTE The **area stub** command determines whether the routers in the stub become neighbors. This command must be included in all routers in the stub if they are to exchange routing information.

Totally Stubby Area Configuration Example

In Example 4-7, the keyword **no-summary** has been added to the **area stub** command on R3 (the ABR). This keyword causes summary routes (interarea) to also be blocked from the stub area. Each router in the stub area picks the closest ABR as a gateway to everything outside the area, as shown in Figure 4-12.

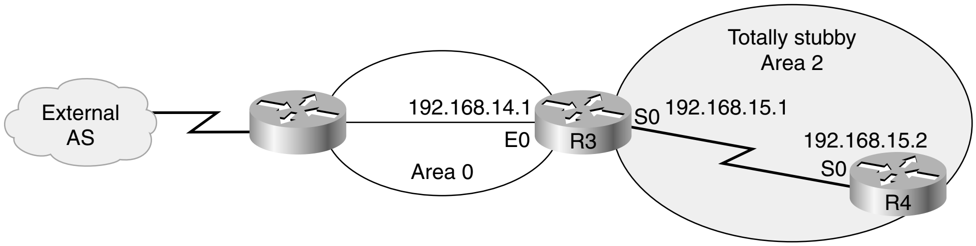
Example 4-7 *Totally Stubby Configuration Example*

```
R3#showrun
<output omitted>
router ospf 100
network 192.168.14.0 0.0.0.255 area 0
network 192.168.15.0 0.0.0.255 area 2
```

Example 4-7 *Totally Stubby Configuration Example (Continued)*

```
area 2 stub no-summary

R4#showrun
<output omitted>
router ospf 15
network 192.168.15.0 0.0.0.255 area 2
area 2 stub
```

Figure 4-12 *Totally Stubby Area*



In Example 4-7, the only routes that will appear in R4's routing table are intra-area routes (designated with an O in the routing table) and the default route. No interarea routes (designated with an IA in the routing table) will be included.

Remember that to further reduce the number of link-state advertisements sent into a stub area, you can configure **no-summary** on the ABR (R3) to prevent it from sending summary link advertisements (link-state advertisements type 3) into the stub area—thus, R4 has only intra-area routes.

NOTE As shown in Example 4-7, the difference in configuring a stub area and a totally stubby area is the keyword **no-summary** applied on the ABR

How Does OSPF Generate Default Routes?

The way that OSPF generates default routes (0.0.0.0) varies depending on the type of area into which the default route is being injected— normal areas, stub and totally stubby areas, and NSSAs.

By default, in normal areas, routers don't generate default routes. To have an OSPF router generate a default route, use the **default-information originate** [**always**] [**metric** *metric-value*] [**metric-type** *type-value*] [**route-map** *map-name*] router configuration command. This generates an external type 2 link (by default) with link-state ID 0.0.0.0 and network mask 0.0.0.0, which makes the router an Autonomous System Boundary Router (ASBR).

There are two ways to inject a default route into a normal area. If the ASBR already has the default route, you can advertise 0.0.0.0 into the area. If the ASBR doesn't have the route, you can add the keyword **always** to the **default-information originate** command, which will then advertise 0.0.0.0.

For stub and totally stubby areas, the ABR to the stub area generates a summary LSA with the link-state ID 0.0.0.0. This is true even if the ABR doesn't have a default route. In this scenario, you don't need to use the **default-information originate** command.

The ABR for the NSSA generates the default route, but not by default. To force the ABR to generate the default route, use the **area** *area-id* **nssa default-information-originate** command. The ABR generates a type 7 LSA with the link-state ID 0.0.0.0. If you want to import routes only into the normal areas, but not into the NSSA area, you can use the **no-redistribution** option on the NSSA ABR.

Multiple-Area NBMA Environment

Multiple areas can be used within nonbroadcast multiaccess (NBMA) OSPF environments. In Figure 4-13, the networks located at the corporate headquarters are in Area 0, while the fully meshed Frame Relay network and each of the regional site networks are assigned to Area 1. Area 1 is a stub area. One benefit of this design is that it eliminates the flooding of external LSAs into the Frame Relay network because OSPF does not flood external LSAs into stub areas—in this case, Area 1. Router R1 functions as an ABR, which keeps topology changes in Area 0 from causing a topological recalculation in Area 1. With this topology, the remote LAN segments must participate in Area 1, or virtual links would need to be configured so the LAN segment's areas would connect to the backbone area.

Another possible OSPF area configuration involves putting all the Frame Relay interfaces in Area 0, as shown in Figure 4-14. This permits the location of stub or transit areas at each remote site and at the headquarters, but it causes summary LSAs to be flooded throughout the Frame Relay network and results in a larger number of routers performing recalculation if any topology change takes place in Area 0.

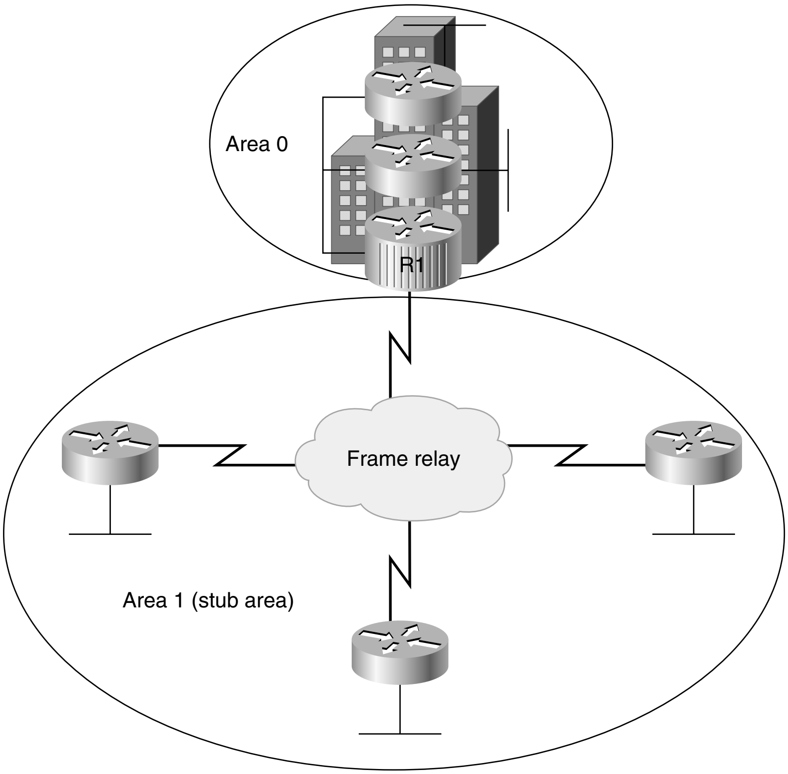
Supporting Route Summarization

Summarizing is the consolidation of multiple routes into a single advertisement. The operation and benefits of route summarization are discussed in Chapter 2 . At this point, however, you should realize the importance of proper summarization in a network. Route summarization directly affects the amount of bandwidth, CPU, and memory resources consumed by the OSPF process.

If summarization is not used, every specific-link LSA will be propagated into the OSPF backbone and beyond, causing unnecessary network traffic and router overhead. Whenever an LSA is sent, all affected OSPF routers will have to recompute their LSA databases and routes using the SPF algorithm.

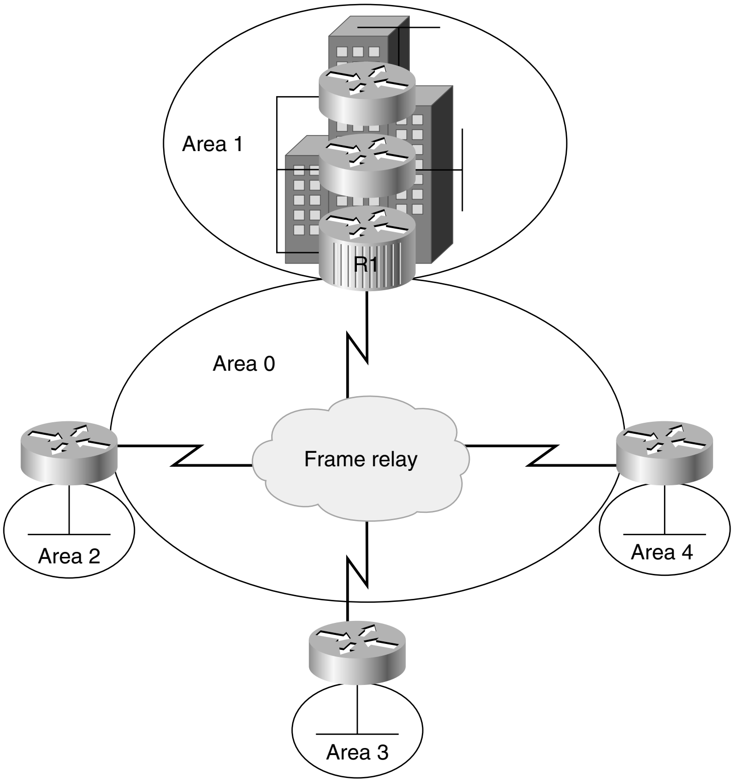
With summarization, only summarized routes will propagate into the backbone (Area 0). This process is very important because it prevents every router from having to rerun the SPF algorithm, increases the network's stability, and reduces unnecessary traffic. Also with summarization, if a network link fails, the topology change will not be propagated into the backbone (and other areas by way of the backbone). As such, flooding outside the area will not occur.

Figure 4-13 *Multiple OSPF Area with Frame Relay*



NOTE Be careful with the terminology: summary LSAs (type 3 and type 4) may or may not contain summarized routes.

Figure 4-14 *Multiple OSPF Area in Frame Relay with a Centralized Area 0*



Two types of summarization exist, as follows:

- **Interarea route summarization**—Interarea route summarization is done on ABRs and applies to routes from within each area. It does not apply to external routes injected into OSPF via redistribution. To take advantage of summarization, network numbers within areas should be assigned in a contiguous way to be capable of consolidating these addresses into one range.
- **External route summarization**—External route summarization is specific to external routes that are injected into OSPF via redistribution. Here again, it is important to ensure that the external address ranges that are being summarized are contiguous. Summarizing overlapping ranges from two different routers could cause packets to be sent to the wrong destination. Usually only ASBRs summarize external routes, but ABRs can also do this.

Variable-Length Subnet Masking

Variable-length subnet masking (VLSM) is discussed in Chapter 2.

OSPF carries subnet mask information and therefore supports multiple subnet masks for the same major network. Discontiguous subnets are also supported by OSPF because subnet masks are part of the link-state database. However, other protocols such as Routing Information Protocol version 1 (RIPv1) and Interior Gateway Routing Protocol (IGRP) do not support VLSM or discontiguous subnets. If the same major network crosses the boundaries of an OSPF and RIP or IGRP domain, VLSM information redistributed into RIP or IGRP will be lost and static routes will have to be configured in the RIP or IGRP domains.

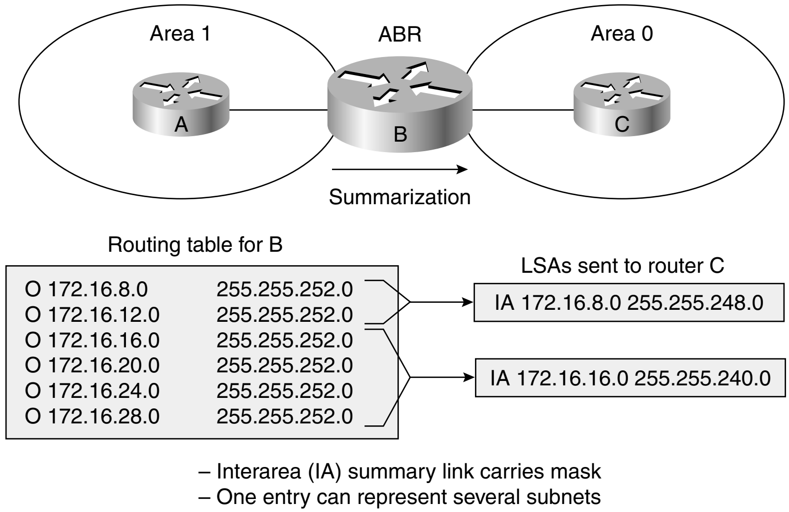
Because OSPF supports VLSM, it is possible to develop a true hierarchical addressing scheme. This hierarchical addressing results in very efficient summarization of routes throughout the network.

Using Route Summarization

To take advantage of summarization, as discussed in Chapter 2, network numbers in areas should be assigned in a contiguous way, thus enabling the grouping of addresses into one range, as shown in Figure 4-15.

In Figure 4-15, the list of six networks in Router B's routing table can be summarized into two summary address advertisements.

Figure 4-15 *Summarization Between Two Areas*



The third octet of each address is shown in binary in Table 4-4, to illustrate which addresses can be summarized.

Table 4-4 *Binary Calculation of the Summarization on Router B*

Bit Value	128	64	32	16	8	4	2	1	Decimal Value of Octet
The first two addresses can be summarized using a /21 prefix	0	0	0	0	1	0	0	0	8
	0	0	0	0	1	1	0	0	12
The last four addresses can be summarized using a /20 prefix	0	0	0	1	0	0	0	0	16
	0	0	0	1	0	1	0	0	20
	0	0	0	1	1	0	0	0	24
	0	0	0	1	1	1	0	0	28
Actual mask is /22 (255.255.252.0)									

Configuring Route Summarization

In OSPF, summarization is off by default. To configure route summarization on the ABR, do the following:

Step 1 Configure OSPF, as discussed earlier in this section.

Step 2 Instruct the ABR to summarize routes for a specific area before injecting them into a different area, using the following **area range** command. This command is defined in Table 4-5.

```
router(config-router)#area area-id range address mask
```

Table 4-5 ***area range*** *Command*

area range Command	Description
area-id	Identifier of the area about which routes are to be summarized
address	Summary address designated for a range of addresses
mask	IP subnet mask used for the summary route

To configure route summarization on an ASBR to summarize external routes, do the following:

Step 1 Configure OSPF, as discussed earlier in this section.

Step 2 Instruct the ASBR to summarize external routes before injecting them into the OSPF domain, using the **summary-address** command, explained in Table 4-6.

```
router(config-router)#summary-address address mask [prefix mask][not-
advertise] [tag tag]
```

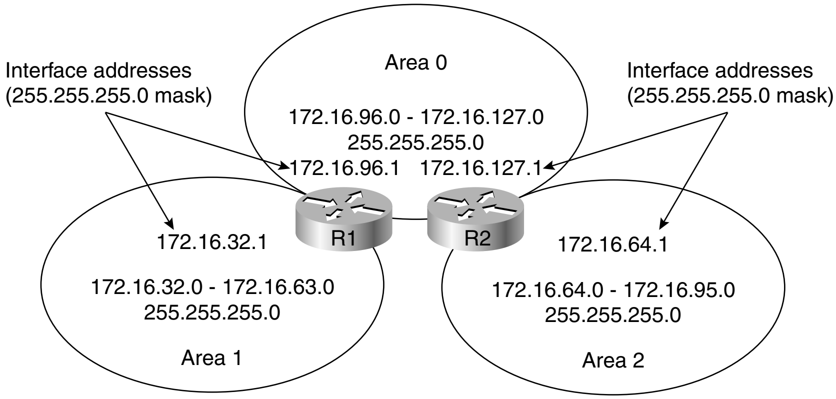
Table 4-6 ***summary-address*** *Command*

summary-address Command	Description
address	Summary address designated for a range of addresses
mask	IP subnet mask used for the summary route
prefix	IP route prefix for the destination
mask	IP subnet mask used for the summary route
not-advertise	(Optional) Used to suppress routes that match the prefix/mask pair
tag	(Optional) Tag value that can be used as a match value for controlling redistribution via route maps, or other routing protocols such as EIGRP and BGP

NOTE The OSPF **summary-address** command summarizes only external routes. This command is usually used on the ASBR that is injecting the external routes into OSPF, but may also be used on an ABR. Use the **area range** command for summarization of routes between OSPF areas (in other words, for summarization of IA routes).

Figure 4-16 provides the graphical representation of Example 4-8, where route summarization can occur in both directions.

Figure 4-16 *Summarization on Multiple Areas*



Example 4-8 *Summarization Configuration on ABRs*

```
R1#
router ospf 100
  network 172.16.32.1  0.0.0.0 area 1
  network 172.16.96.1  0.0.0.0 area 0
  area 0 range 172.16.96.0  255.255.224.0
  area 1 range 172.16.32.0  255.255.224.0

R2#
router ospf 100
  network 172.16.64.1 0.0.0.0 area 2
  network 172.16.127.1 0.0.0.0 area 0
  area 0 range 172.16.96.0  255.255.224.0
  area 2 range 172.16.64.0  255.255.224.0
```

In the configuration on router R1, the following is true:

- **area 0 range 172.16.96.0 255.255.224.0**—Identifies Area 0 as the area containing the range of networks to be summarized into Area 1. The ABR R1 is summarizing the range of subnets from 172.16.96.0 to 172.16.127.0 into one range: 172.16.96.0 255.255.224.0. This summarization is achieved by masking the first 3 left-most bits of subnet 96 using the mask 255.255.224.0.
- **area 1 range 172.16.32.0 255.255.224.0**—Identifies Area 1 as the area containing the range of networks to be summarized into Area 0. The ABR R1 is summarizing the range of subnets from 172.16.32.0 to 172.16.63.0 into one range: 172.16.32.0 255.255.224.0.

The configuration on router R2 works exactly the same way.

Note that, depending on your network topology, you may not want to summarize Area 0 networks. For example, if you have more than one ABR between an area and the backbone area, sending a summary LSA with the explicit network information will ensure that the shortest path is selected. If you summarize the addresses, a suboptimal path selection may occur.

Configuring Virtual Links

To configure a virtual link, do the following:

Step 1 Configure OSPF, as described earlier in this section.

Step 2 On each router that will make the virtual link, create the virtual link using the **area virtual-link** command, as explained in Table 4-7. The routers that make the links are the ABR that connects the remote area to the transit area and the ABR that connects the transit area to the backbone area.

```
router(config-router)#area area-id virtual-link router-id
```

Table 4-7 ***area virtual-link*** *Configuration Command*

area virtual-link Command	Description
area-id	Area ID assigned to the transit area for the virtual link (decimal or dotted decimal format). There is no default.
router-id	Router ID of the virtual link neighbor.

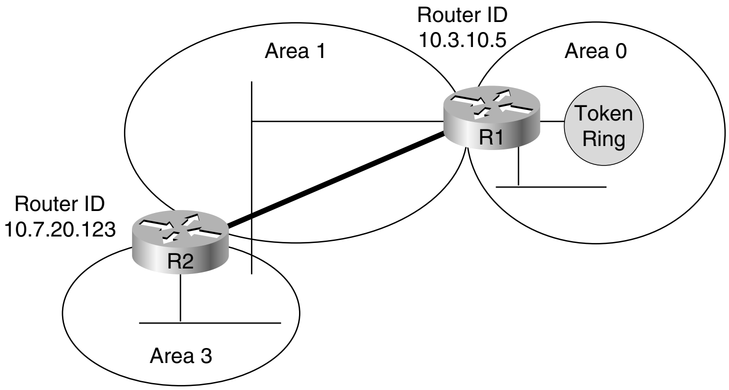
If you do not know the neighbor's router ID, you can Telnet to it and enter the **show ip ospf interface** command, as displayed in Example 4-9.

Example 4-9 ***show ip ospf interface*** *Command Output*

```
remoterouter#show ip ospf interface ethernet 0
Ethernet0 is up, line protocol is up
  Internet Address 10.64.0.2/24, Area 0
  Process ID 1, Router ID 10.64.0.2, Network Type BROADCAST, Cost: 10
  Transmit Delay is 1 sec, State DR, Priority 1
  Designated Router (ID) 10.64.0.2, Interface address 10.64.0.2
  Backup Designated router (ID) 10.64.0.1, Interface address 10.64.0.1
```

In Figure 4-17, Area 3 does not have a direct physical connection to the backbone (Area 0), which is an OSPF requirement because the backbone is a collection point for LSAs. ABRs forward summary LSAs to the backbone, which in turn forwards the traffic to all areas. All interarea traffic transits the backbone.

Figure 4-17 *Need for a Virtual Link*



To provide connectivity to the backbone, a virtual link must be configured between R2 and R1. Area 1 will be the transit area, and R1 will be the entry point into Area 0. R2 will have a logical connection to the backbone through the transit area.

In Figure 4-17, both sides of the virtual link must be configured. Example 4-10 shows the configuration of R1 and R2; in these configurations:

- R2 has the command **area 1 virtual-link 10.3.10.5**. With this command, Area 1 is defined to be the transit area, and the router ID of the other side of the virtual link is configured.
- R1 has the command **area 1 virtual-link 10.7.20.123**. With this command, Area 1 is defined to be the transit area, and the router ID of the other side of the virtual link is configured.

Example 4-10 *Virtual Link Configuration on Routers R1 and R2*

```
R1#showrun
<output omitted>
router ospf 100
network 10.2.3.0 0.0.0.255 area 0
network 10.3.2.0 0.0.0.255 area 1
area 1 virtual-link 10.7.20.123

R2#showrun
<output omitted>
router ospf 63
 network 10.3.0.0 0.0.0.255 area 1
 network 10.7.0.0 0.0.0.255 area 3
area 1 virtual-link 10.3.10.5
```

Verifying OSPF Operation

The same **show** commands listed in Chapter 3 can be used to verify OSPF operation in multiple areas. Some additional commands include the following:

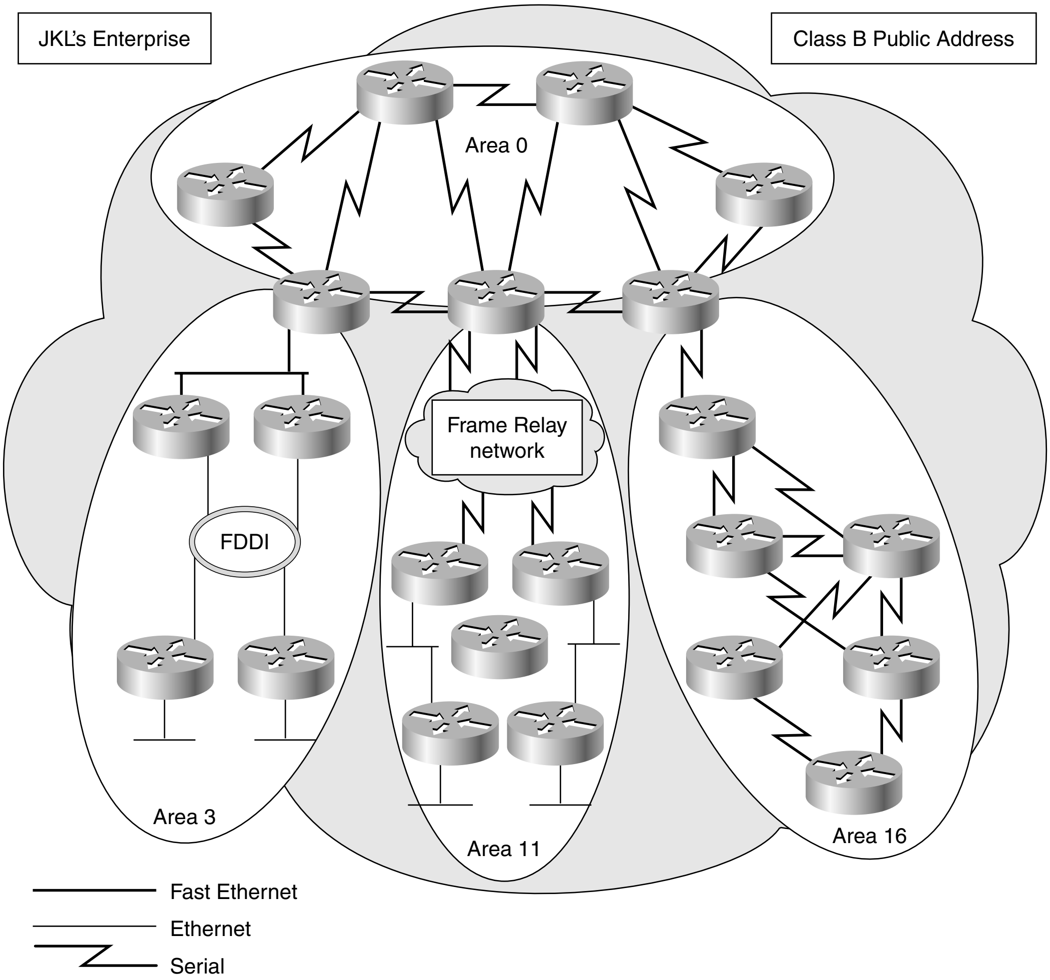
- **show ip ospf border-routers**—Displays the internal OSPF routing table entries to ABRs and ASBRs.
- **show ip ospf virtual-links**—Displays parameters about the current state of OSPF virtual links.
- **show ip ospf process-id**—Displays information about each area to which the router is connected, and indicates whether the router is an ABR, an ASBR, or both.
- **show ip ospf** [*process-id area-id*] **database** [*keyword*]—Displays the contents of the topological database maintained by the router. Several keywords can be used with this command to get specific information about links:
  - **network**—Displays network link-state information.
  - **summary**—Displays summary information about router link states.
  - **asbr-summary**—Displays information about ASBR link states.
  - **external**—Displays information about autonomous system external link states.
  - **database-summary**—Displays database summary information and totals.

Case Study: OSPF Multiarea

Refer to Chapter 1, "Routing Principles," for introductory information on the running case study.

This section provides an overview of JKL's recently redesigned corporate network, as shown in Figure 4-18. This topology embodies many of the characteristics that a properly addressed hierarchical network should exhibit.

Figure 4-18 *JKL's Enterprise Redesigned Network*



Following are some issues to consider when analyzing Figure 4-18:

- Requirements for a hierarchical topology
- Address allocation with route summarization
- Limits for routing update traffic
- Elements that affect convergence time
- Effects of an NBMA topology
- Ease of configuration and management

Case Study Solution

Over the past few years, JKL Corporation had experienced continuous growth in all of its business sectors. In some areas, the growth was very rapid and business needs overshadowed good design principles. These growth spikes caused the address space to become fragmented and caused the size of the topology tables and routing tables to increase dramatically. Management was alerted to the fact that the network was no longer easily scalable and that continued growth would only compound the problems. Rather than wait for the scaling issues to dramatically affect their ability to do business, management ordered a complete overhaul and upgrade of the network. For more than a year, portions of the network were readdressed and reconfigured to form a hierarchical topology that emphasized proper address allocation, summary routes, and ease of troubleshooting.

Proper design allowed Area 0 to be small, redundant, and free of host devices. Thanks to proper address allocation, individual areas pass summary routes into Area 0 that enable traffic between areas to be forwarded efficiently (because of the small number of entries in the Area 0 routing tables) through the backbone. Area 0 design employed redundant links to assist in rapid convergence in case of a link failure in the core of the network.

Although the backbone area must be numbered as zero, the numbers for the other areas can be chosen arbitrarily. In Figure 4-18, three areas are shown, although more areas exist in the actual network. These three areas were selected because they demonstrate different technologies and topologies that OSPF supports. This multiarea topology demonstrates the different router types (internal router, backbone router, Area Border Router, and Autonomous System Border Router). This topology also offers an opportunity to reinforce where the different types of LSAs (router, summary, default, and so on) are used.

Area 3 demonstrates a purely LAN-based topology. Therefore, the neighbor relationships will be done automatically following DR/BDR elections.

Area 11 shows a partial-mesh (hub-and-spoke) switched network topology. In this area, the neighbor either will be acquired dynamically or will be, preferably, manually configured. Also, you must remember to use the **broadcast** keyword on the frame-relay map commands to allow routing updates to pass through the switched portion of the network.

Area 16 is an example of a WAN-based, point-to-point topology. In this area, no DRs/DBRs are elected and the neighborship is automatic. This area offers a favorable topology in which an effective use of VLSM would help with address allocation.

A hierarchical topology in this case offers several benefits:

- Route summarization is available
- Area 0 routing table is small and efficient
- Link-state changes are localized to one area
- Convergence within an area is rapid

This case study gives you a chance to confirm that proper network design, especially of large networks, provides numerous advantages when it comes to controlling the types and frequency of routing information allowed in and out of areas.

Summary

After reading this chapter, you should be able to describe the issues with interconnecting multiple areas, understand how OSPF addresses each of these issues, and explain the differences among the possible types of areas, routers, and LSAs. You should also be able to show how OSPF supports the use of VLSM, how it applies route summarization in multiple areas, and how it operates in a multiple-area NBMA environment.

Finally, you should be able to configure a multiarea OSPF network and verify OSPF operations in multiple areas.

Configuration Exercise: Configuring a Multiarea OSPF Network

Complete the following exercise to configure OSPF with multiple areas.

Configuration Exercises

In this book, Configuration Exercises are used to provide practice in configuring routers with the commands presented. If you have access to real hardware, you can try these exercises on your routers; refer to Appendix H, "Configuration Exercise Equipment Requirements and Backbone Configurations," for a list of recommended equipment and configuration commands for the backbone routers. However, even if you don't have access to any routers, you can go through the exercises and keep a log of your own "running configurations" on separate sheets of paper. Commands used and answers to the Configuration Exercises are provided at the end of the exercise.

In these exercises, you are in control of a pod of three routers; there are assumed to be 12 pods in the network. The pods are interconnected to a backbone. In most of the exercises, there is only one router in the backbone; in some cases, another router is added to the backbone. Each of the Configuration Exercises in this book assumes that you have completed the previous exercises on your pod.

Objectives

In this Configuration Exercise, you will configure the p*x*r1 router serial interface S3 to be in OSPF Area 0. Then you will configure all other router serial interfaces to be part of a specific OSPF area, other than 0. You will then verify connectivity to the backbone_r1 router, summarize the subnets in your OSPF area, and check again for connectivity to backbone_r1 router.

When the previous tasks will have been completed, you will reconfigure your OSPF area to be a stub area and then a totally stubby area, and verify connectivity to the backbone_r1 router.

As an additional exercise, you may want to reconfigure your OSPF area to be a not-so-stubby area (NSSA) and verify connectivity to the backbone_r1 router. You will use loopback interfaces to simulate type 7 external routes into your NSSA. You will then summarize the simulated type 7 external routes into Area 0.

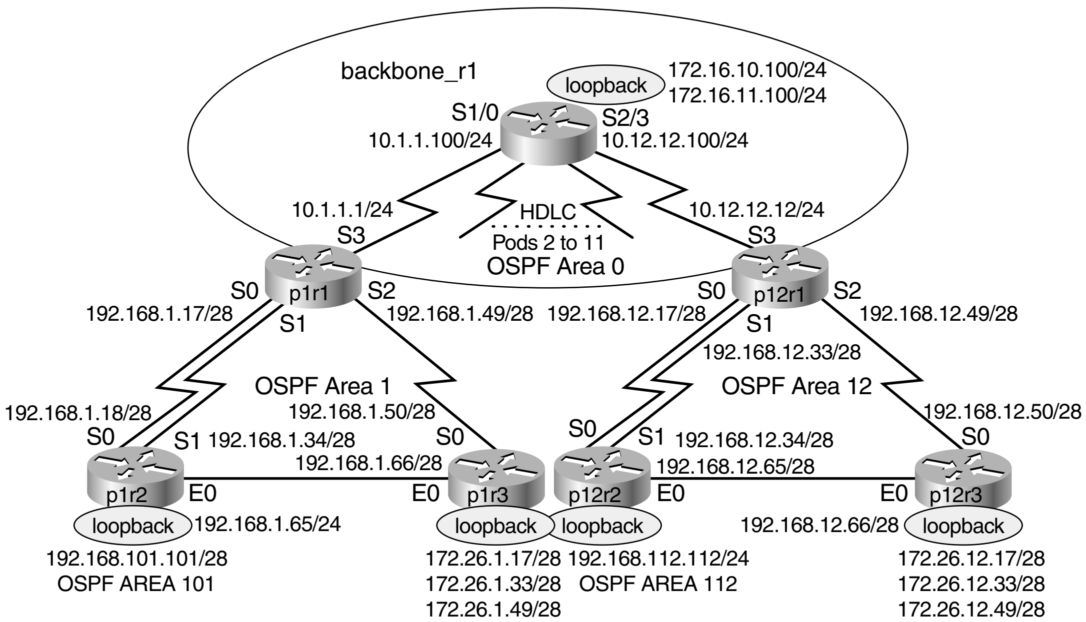
Also as an optional practice, you can configure an OSPF virtual link to support an OSPF area not directly connected to Area 0.

You will use the **show** and **debug** commands to verify OSPF operations of all these exercises.

Visual Objective

Figure 4-19 illustrates the topology used for this multiarea OSPF Configuration Exercise.

Figure 4-19 *Configuration of Multiarea OSPF Network*



Command List

In this Configuration Exercise, you will use the commands listed in Table 4-8 in logical order. Refer to this list if you need configuration command assistance during the Configuration Exercise.

Table 4-8 *Commands Used in the Configuration Exercise*

Command	Description
router ospf 200	Enables OSPF with a process ID of 200
network 10.*x*.*x*.*x* 0.0.0.0 area 0	Specifies the interfaces on which to run OSPF, and their areas
area *x* range 192.168.*x*.0 255.255.255.0	Summarizes addresses
area *x* stub [no-summary]	Configures an area as a stub or totally stubby area
area *x* virtual-link 192.168.*x*.49	Creates an OSPF virtual link
area *x* nssa	Configures an area as a not-so-stubby-area (NSSA)
summary-address 172.16.0.0 255.255.0.0	Summarizes external addresses into OSPF
show ip ospf	Displays general information about the OSPF routing process
show ip ospf neighbor	Displays information about OSPF neighbors
show ip ospf database	Displays the entries in the OSPF link-state database
show ip ospf interface	Displays OSPF-specific information about an interface
show ip ospf virtual-links	Displays the status of the OSPF virtual links
debug ip ospf adj	Shows the events involved in the building or breaking of an OSPF adjacency

Setup

Setup is as follows:

Step 1 On p*x*r1, disable Frame Relay switching.

Reconfigure the p*x*r1 serial interfaces (S0, S1, S2, and S3) to be running HDLC encapsulation. Change the p*x*r1 serial interface S0, S1, S2, and S3 to the correct IP address configuration:

p*x*r1 S0	192.168.*x*.17/28
p*x*r1 S1	192.168.*x*.33/28
p*x*r1 S2	192.168.*x*.49/28
p*x*r1 S3	10.*x*.*x*.*x*/24

Apply the **no shut** command to Serial 1 and Serial 3 interfaces on your p*x*r1 router.

Step 2 On p*x*r2, remove the S0.1 subinterface.

```
p1r2(config)#no interface s0.1 point-to-point
```

Change the p*x*r2 S0 interface encapsulation back to HDLC. Reconfigure the IP address on your p*x*r2 S0 to 192.168.*x*.18/28. Apply the **no shut** command to Ethernet 0 and Serial 1 interfaces on p*x*r2.

Step 3 On p*x*r3, remove the S0.1 subinterface.

```
p1r3(config)#no interface s0.1 point-to-point
```

Change the p*x*r3 S0 interface encapsulation back to HDLC. Reconfigure the IP address on your p*x*r3 S0 to 192.168.*x*.50/28. Apply the **no shut** command to Ethernet 0 and interface on p*x*r3.

Step 4 On your p*x*r2 router, create a loopback interface (loopback 10) with the following IP address:

Pod	pxr2 Loopback10 Interface IP Address
1	192.168.101.101/24
2	192.168.102.102/24
3	192.168.103.103/24
4	192.168.104.104/24
5	192.168.105.105/24
6	192.168.106.106/24
7	192.168.107.107/24
8	192.168.108.108/24
9	192.168.109.109/24
10	192.168.110.110/24
11	192.168.111.111/24
12	192.168.112.112/24

Create three loopback interfaces on your p*x*r3 router using the following IP addresses:

Router	Int Loopback11	Int Loopback12	Int Loopback13
p1r3	172.26.1.17/28	172.26.1.33/28	172.26.1.49/28
p2r3	172.26.2.17/28	172.26.2.33/28	172.26.2.49/28
p3r3	172.26.3.17/28	172.26.3.33/28	172.26.3.49/28

Router	Int Loopback11	Int Loopback12	Int Loopback13
p4r3	172.26.4.17/28	172.26.4.33/28	172.26.4.49/28
p5r3	172.26.5.17/28	172.26.5.33/28	172.26.5.49/28
p6r3	172.26.6.17/28	172.26.6.33/28	172.26.6.49/28
p7r3	172.26.7.17/28	172.26.7.33/28	172.26.7.49/28
p8r3	172.26.8.17/28	172.26.8.33/28	172.26.8.49/28
p9r3	172.26.9.17/28	172.26.9.33/28	172.26.9.49/28
p10r3	172.26.10.17/28	172.26.10.33/28	172.26.10.49/28
p11r3	172.26.11.17/28	172.26.11.33/28	172.26.11.49/28
p12r3	172.26.12.17/28	172.26.12.33/28	172.26.12.49/28

Task 1: Enabling OSPF with Multiple Areas and Area Summarization

Complete the following steps:

Step 1 Type in the command to configure the p*x*r1 router to run OSPF, with the S3 interface as the only interface within your pod to be in Area 0.

Step 2 What commands would you type to configure all the 192.168.*x*.*y*/28 interfaces on all routers in your pod to be in area *x*, where *x* = your pod number?

Pod	OSPF Area Number
1	Area 1
2	Area 2
3	Area 3
4	Area 4
5	Area 5
6	Area 6
7	Area 7
8	Area 8
9	Area 9
10	Area 10
11	Area 11
12	Area 12

Step 3 Verify you have full connectivity within your pod.

Step 4 Telnet to the backbone_r1 router; the password is cisco. Display its routing table. Do you see your pod's subnets as O IA routes in the backbone_r1 routing table? What type of routes are O IA routes?

Exit the Telnet to the backbone_r1 router.

Step 5 Display the p*x*r1 routing table. Which types of OSPF routes are in the routing table? (If there is another pod configured for OSPF, you should see three types; otherwise, you should see two types.)

Display the p*x*r2 routing table. Which three types of OSPF routes are in the routing table?

Which router within your pod is the Area Border Router (ABR)?

At the ABR, summarize all the 192.168.*x*.y/28 subnets in your area (area *x*) into a single summarized route of 192.168.*x*.0/24.

Telnet to the backbone_r1 router; the password is cisco. Display the backbone_r1 router's routing table to verify that your subnets are summarized properly. Exit the Telnet to the backbone_r1 router.

Step 6 Save the current configurations of all the routers within your pod to NVRAM.

Task 2: Enabling OSPF Stub Area

Complete the following steps:

Step 1 Configure your pod's OSPF area (area *x*) into a stub area. For this step, on which router(s) do you need to configure?

Step 2 Do you still see the O IA routes in the p*x*r2 and p*x*r3 routing table?

Do you still see the O E2 route in the p*x*r2 and p*x*r3 routing table? Explain your answer.

Do you see any additional routes in the p*x*r2 and p*x*r3 routing table that were not there before?

Step 3 Use the **show ip ospf** command to verify that your OSPF area *x* is a stub area.

Step 4 Verify you have full connectivity within your pod and to the backbone_r1 router loopback interfaces (you may also see routes to the other pods).

Step 5 Save the current configurations of all the routers within your pod to NVRAM.

Task 3: Enabling OSPF Totally Stubby Area

Complete the following steps:

Step 1 Configure your pod's OSPF area into a totally stubby area. For this step, on which router(s) do you need to configure?

Do you still see the O IA routes in the p*x*r2 and p*x*r3 routing table? Please explain your answer.

Step 2 Verify that you have full connectivity within your pod and to the backbone_r1 router loopback interfaces (you may also see routes to the other pods).

Step 3 Save the current configurations of all the routers within your pod to NVRAM.

Task 4: Enabling OSPF Not-So-Stubby Area (Optional)

Step 1 Remove the totally stubby area configuration commands and then reconfigure your pod's OSPF area into an NSSA area. For this step, which router(s) do you need to configure? (On the p*x*r1 router, use the **default-information-originate** option when configuring NSSA.)

NOTE On p*x*r1, you must remove the totally stubby area configuration command and then remove the stub area configuration command to completely remove any stub characteristics before configuring NSSA.

Step 2 Do you see any O IA routes in the p*x*r2 and p*x*r3 routing table?

Do you see any O*N2 route in the p*x*r2 and p*x*r3 routing table?

What type of route is the O*N2 route?

Step 3 Verify that you have full connectivity within your pod and to the backbone_r1 router (you may also see routes to the other pods).

Step 4 Save the current configurations of all the routers within your pod to NVRAM.

Step 5 The loopback interfaces that you created on p*x*r3 in setup are used to simulate type 7 external routes into your NSSA. Use the **redistribute** command at your p*x*r3 routers to redistribute only the loopback interfaces into your NSSA. Route redistribution will be discussed in Chapter 8. For now, just enter the following commands to perform the redistribution at the p*x*r3 router:

```
router ospf 200
redistribute connected metric-type 1 subnets route-map passlb
route-map passlb
match ip address 1
access-list 1 permit 172.26.x.0 0.0.0.255
```

x is your pod number.

Step 6 Do you see any O N1 routes in the routing table of p*x*r1? What type of routes are those?

Telnet to the backbone_r1 router. Do you see your 172.26.*x*.0 routes in the backbone_r1 routing table? What type of routes are those? Exit the Telnet session to the backbone_r1 router when you're done.

Step 7 At your p*x*r1 router, summarize the three external loopback interface addresses into a single summarized route of 172.26.*x*.0 255.255.255.0, where *x* = your pod number.

Telnet to the backbone_r1 router; the password is cisco. Display the backbone_r1 router's routing table to verify that your external routes are summarized properly. Exit the Telnet session to the backbone_r1 router.

Step 8 Save the current configurations of all the routers within your pod to NVRAM.

Step 9 (Bonus step) Currently, your pod's external summarized route shows up as O E1 type route at the backbone_r1 router and at any other pods that are configured. Change it so that it shows up as O E2 type route at the backbone_r1 router and any other pods.

Bonus Questions

How is the OSPF cost metric calculated on Cisco routers?

Which type of external OSPF route will have its metric incremented as it is distributed into the OSPF domain, type 1 or type 2?

Summarize the following subnet address range into the minimum number of routes: 172.25.168.0/24 to 172.25.175.0/24

Task 5: Enabling OSPF Virtual Link to Support an OSPF Area Not Connected to Area 0 (Optional)

Complete the following steps:

Step 1 In this task, you will be setting up virtual links. Virtual links do not support stub areas, so before you can perform the next task, you need to remove the stub area commands.

Do not remove the loopback interfaces on any of your routers. You will need to use them again in the later Configuration Exercises.

At your p*x*r1 router, remove any **area stub** or **area nssa** commands. Save the current configuration of p*x*r1 to NVRAM. Note: if you have configured NSSA, you must remove the **area x nssa default-information-originate** command and then remove the **area x nssa** command to completely remove any NSSA characteristics. Otherwise, you must remove the totally stubby area configuration command and then remove the stub area configuration command to completely remove any stub characteristics.

At your p*x*r2 router, remove any **area stub** or **area nssa** commands from your p*x*r2 router. Save the current configuration of p*x*r2 to NVRAM.

At your p*x*r3 router, remove any **area stub** or **area nssa** commands. Save the current configuration of p*x*r3 to NVRAM.

Step 2 At your p*x*r2 router, place that loopback interface you created in setup into the following assigned OSPF area:

Pod	pxr2 loopback10 Interface IP Address	OSPF Area
1	192.168.101.101/24	101
2	192.168.102.102/24	102
3	192.168.103.103/24	103
4	192.168.104.104/24	104
5	192.168.105.105/24	105
6	192.168.106.106/24	106
7	192.168.107.107/24	107
8	192.168.108.108/24	108
9	192.168.109.109/24	109
10	192.168.110.110/24	110
11	192.168.111.111/24	111
12	192.168.112.112/24	112

Step 3 Enter the command to check the OSPF router ID of your p*x*r2 router.

What is the current OSPF router ID of p*x*r2?

Step 4 Create an OSPF virtual link to support the OSPF area (10*x*) that you created in Step 1. At which routers do you need to configure the virtual link?

Step 5 Use the **show ip ospf virtual-links** command to verify that your virtual link is up.

Step 6 Verify that the p*x*r1 routing table shows your p*x*r2 loopback interface as an O IA route.

From p*x*r1, ping your p*x*r2 loopback interface. Was the ping successful?

Step 7 (Challenge step) Telnet to the backbone_r1 router; the password is cisco. Display its routing table. Notice that your area summarization from Task 1 is no longer working. You should see all your 192.168.*x*.*y* subnets in the backbone_r1 router now. Why?

Hint: Enter the **show ip ospf** command at your p*x*r2 router. What type of OSPF router is p*x*r2 now with the virtual link defined?

At the p*x*r2 router, summarize all the 192.168.*x*.*y*/28 subnets in your area (area *x*) into a single summarized route of 192.168.*x*.0/24.

Telnet to the backbone_r1 router; the password is cisco. Display the backbone_r1 router's routing table to verify that your subnets are summarized properly.

Step 8 Save the current configurations of all the routers within your pod to NVRAM.

Completion Criteria

You have successfully completed this Configuration Exercise if you correctly supplied the commands required to configure and to verify a multiple-area OSPF network, and if you were able to correctly answer the questions in the Configuration Exercises. At the end of this exercise, all the routers should have full connectivity to each other; each pod will be running OSPF in its own area, and the p*x*r1 routers will be ABRs to Area 0.

Answers to Configuration Exercise: Configuring a Multiarea OSPF Network

This section provides the answers to the questions in the Configuration Exercise. The answers are in **bold**.

Answers to Setup

Step 1 On p*x*r1, disable Frame Relay switching.

Reconfigure the p*x*r1 serial interfaces (S0, S1, S2, and S3) to be running HDLC encapsulation. Change the p*x*r1 serial interface S0, S1, S2, and S3 to the correct IP address configuration:

p*x*r1 S0	192.168.*x*.17/28
p*x*r1 S1	192.168.*x*.33/28
p*x*r1 S2	192.168.*x*.49/28
p*x*r1 S3	10.*x*.*x*.*x*/24

Apply the **no shut** command to Serial 1 and Serial 3 interfaces on your p*x*r1 router.

```
p1r1(config)#no frame-relay switching
p1r1(config)#int s0
p1r1(config-if)#encapsulation hdlc
p1r1(config-if)#ip address 192.168.1.17 255.255.255.240
p1r1(config-if)#exit
p1r1(config)#int s1
p1r1(config-if)#encapsulation hdlc
p1r1(config-if)#ip address 192.168.1.33 255.255.255.240
p1r1(config-if)#no shut
p1r1(config-if)#exit
p1r1(config)#int s2
p1r1(config-if)#encapsulation hdlc
p1r1(config-if)#ip address 192.168.1.49 255.255.255.240
p1r1(config-if)#no shut
p1r1(config-if)#exit
p1r1(config)#int s3
p1r1(config-if)#encapsulation hdlc
p1r1(config-if)#ip address 10.1.1.1 255.255.255.0
p1r1(config-if)#no shut
```

Step 2 On p*x*r2, remove the S0.1 subinterface.

```
p1r2(config)#no interface s0.1 point-to-point
```

Change the p*x*r2 S0 interface encapsulation back to HDLC. Reconfigure the IP address on your p*x*r2 S0 to 192.168.*x*.18/28. Apply the **no shut** command to Ethernet 0 and Serial 1 interfaces on p*x*r2.

```
p1r2(config)#int s0
p1r2(config-if)#encapsulation hdlc
p1r2(config-if)#ip address 192.168.1.18 255.255.255.240
p1r2(config-if)#exit
p1r2(config)#int s1
p1r2(config-if)#no shutdown
p1r2(config-if)#exit
p1r2(config)#int e0
p1r2(config-if)#no shutdown
```

Step 3 On p*x*r3, remove the S0.1 subinterface.

```
p1r3(config)#no interface s0.1 point-to-point
```

Change the p*x*r3 S0 interface encapsulation back to HDLC. Reconfigure the IP address on your p*x*r3 S0 to 192.168.*x*.50/28. Apply the **no shut** command to Ethernet 0 and interface on p*x*r3.

```
p1r3(config)#int s0
p1r3(config-if)#encapsulation hdlc
p1r3(config-if)#ip address 192.168.1.50 255.255.255.240
p1r3(config-if)#exit
p1r3(config)#int e0
p1r3(config-if)#no shutdown
```

Step 4 On your p*x*r2 router, create a loopback interface (loopback 10) with the following IP address:

Pod	pxr2 Loopback10 Interface IP Address
1	192.168.101.101/24
2	192.168.102.102/24
3	192.168.103.103/24
4	192.168.104.104/24
5	192.168.105.105/24
6	192.168.106.106/24
7	192.168.107.107/24
8	192.168.108.108/24
9	192.168.109.109/24
10	192.168.110.110/24
11	192.168.111.111/24
12	192.168.112.112/24

```
p1r2(config)#int loopback 10
p1r2(config-if)#ip address 192.168.101.101 255.255.255.0
```

Create three loopback interfaces on your p*x*r3 router using the following IP addresses:

Router	Int Loopback11	Int Loopback12	Int Loopback13
p1r3	172.26.1.17/28	172.26.1.33/28	172.26.1.49/28
p2r3	172.26.2.17/28	172.26.2.33/28	172.26.2.49/28
p3r3	172.26.3.17/28	172.26.3.33/28	172.26.3.49/28
p4r3	172.26.4.17/28	172.26.4.33/28	172.26.4.49/28

(Continued)

Router	Int Loopback11	Int Loopback12	Int Loopback13
p5r3	172.26.5.17/28	172.26.5.33/28	172.26.5.49/28
p6r3	172.26.6.17/28	172.26.6.33/28	172.26.6.49/28
p7r3	172.26.7.17/28	172.26.7.33/28	172.26.7.49/28
p8r3	172.26.8.17/28	172.26.8.33/28	172.26.8.49/28
p9r3	172.26.9.17/28	172.26.9.33/28	172.26.9.49/28
p10r3	172.26.10.17/28	172.26.10.33/28	172.26.10.49/28
p11r3	172.26.11.17/28	172.26.11.33/28	172.26.11.49/28
p12r3	172.26.12.17/28	172.26.12.33/28	172.26.12.49/28

```
p1r3(config)#int loopback 11
p1r3(config-if)#ip address 172.26.1.17 255.255.255.240
p1r3(config-if)#int loopback 12
p1r3(config-if)#ip address 172.26.1.33 255.255.255.240
p1r3(config-if)#int loopback 13
p1r3(config-if)#ip address 172.26.1.49 255.255.255.240
```

Answers to Task 1: Enabling OSPF with Multiple Areas and Area Summarization

Complete the following steps:

Step 1 Type in the command to configure the p*x*r1 router to run OSPF, with the S3 interface as the only interface within your pod to be in Area 0.

```
p1r1(config)#router ospf 200
p1r1(config-router)#network 10.0.0.0 0.255.255.255 area 0
```

Step 2 What commands would you type to configure all the 192.168.*x*.*y*/28 interfaces on all routers in your pod to be in area *x*, where *x* = your pod number?

Pod	OSPF Area Number
1	Area 1
2	Area 2
3	Area 3
4	Area 4
5	Area 5
6	Area 6

continues

(Continued)

Pod	OSPF Area Number
7	Area 7
8	Area 8
9	Area 9
10	Area 10
11	Area 11
12	Area 12

```
p1r1(config)#router ospf 200
p1r1(config-router)#network 192.168.1.0 0.0.0.255 area 1

p1r2(config)#router ospf 200
p1r2(config-router)#network 192.168.1.0 0.0.0.255 area 1

p1r3(config)#router ospf 200
p1r3(config-router)#network 192.168.1.0 0.0.0.255 area 1
```

Step 3 Verify that you have full connectivity within your pod.

```
p1r1#ping p1r2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.65, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/32/36 ms


p1r1#ping p1r3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.66, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 28/31/32 ms


p1r2#ping p1r1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.17, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/32/32 ms


p1r2#ping p1r3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.66, timeout is 2 seconds:
!!!!!
```

```
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/4 ms


p1r3#ping p1r1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.17, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/32/32 ms


p1r3#ping p1r2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.65, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/3/4 ms
```

Step 4 Telnet to the backbone_r1 router; the password is cisco. Display its routing table. Do you see your pod's subnets as O IA routes in the backbone_r1 routing table? What type of routes are O IA routes?

```
p1r1#telnet bbr1
Trying bbr1 (10.1.1.100)... Open


User Access Verification

Password:
backbone_r1>show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
C       172.16.10.0 is directly connected, Loopback100
C       172.16.11.0 is directly connected, Loopback101
     10.0.0.0/24 is subnetted, 2 subnets
C       10.1.1.0 is directly connected, Serial1/0
C       10.2.2.0 is directly connected, Serial1/1
     192.168.1.0/28 is subnetted, 4 subnets
O IA    192.168.1.64 [110/3134] via 10.1.1.1, 00:01:15, Serial1/0
O IA    192.168.1.32 [110/3124] via 10.1.1.1, 00:03:08, Serial1/0
O IA    192.168.1.48 [110/3124] via 10.1.1.1, 00:03:08, Serial1/0
O IA    192.168.1.16 [110/3124] via 10.1.1.1, 00:03:08, Serial1/0
backbone_r1>
```

Yes, the backbone_r1 router has OIA routes. The OIA routes are interarea routes.

Exit the Telnet to the backbone_r1 router.

```
backbone_r1>exit

[Connection to bbr1 closed by foreign host]
p1r1#
```

Step 5 Display the p*x*r1 routing table. Which types of OSPF routes are in the routing table? (If there is another pod configured for OSPF, you should see three types; otherwise, you should see two types.)

Intra-area (0) routes and external type 2 (0 E2) routes can be seen. If there was another pod configured, interarea (OIA) routes would also be seen.

```
p1r1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
O E2    172.16.10.0 [110/20] via 10.1.1.100, 00:02:30, Serial3
O E2    172.16.11.0 [110/20] via 10.1.1.100, 00:02:30, Serial3
     10.0.0.0/24 is subnetted, 2 subnets
O       10.2.2.0 [110/3124] via 10.1.1.100, 00:04:17, Serial3
C       10.1.1.0 is directly connected, Serial3
     192.168.1.0/28 is subnetted, 4 subnets
O       192.168.1.64 [110/1572] via 192.168.1.34, 00:02:30, Serial1
                     [110/1572] via 192.168.1.18, 00:02:30, Serial0
                     [110/1572] via 192.168.1.50, 00:02:30, Serial2
C       192.168.1.32 is directly connected, Serial1
C       192.168.1.48 is directly connected, Serial2
C       192.168.1.16 is directly connected, Serial0
p1r1#
```

Display the p*x*r2 routing table. Which three types of OSPF routes are in the routing table?

```
p1r2#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
```

```
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
O E2    172.16.10.0 [110/20] via 192.168.1.17, 00:02:47, Serial0
                    [110/20] via 192.168.1.33, 00:02:47, Serial1
O E2    172.16.11.0 [110/20] via 192.168.1.17, 00:02:47, Serial0
                    [110/20] via 192.168.1.33, 00:02:47, Serial1
     10.0.0.0/24 is subnetted, 2 subnets
O IA    10.2.2.0 [110/4686] via 192.168.1.33, 00:02:47, Serial1
                 [110/4686] via 192.168.1.17, 00:02:47, Serial0
O IA    10.1.1.0 [110/3124] via 192.168.1.33, 00:02:47, Serial1
                 [110/3124] via 192.168.1.17, 00:02:47, Serial0
     192.168.1.0/28 is subnetted, 4 subnets
C       192.168.1.64 is directly connected, Ethernet0
C       192.168.1.32 is directly connected, Serial1
O       192.168.1.48 [110/1572] via 192.168.1.66, 00:02:49, Ethernet0
C       192.168.1.16 is directly connected, Serial0
C    192.168.101.0/24 is directly connected, Loopback10
p1r2#
```

Which router within your pod is the Area Border Router (ABR)?

Router p*x*r1 is the ABR.

At the ABR, summarize all the 192.168.*x*.y/28 subnets in your area (area *x*) into a single summarized route of 192.168.*x*.0/24.

```
p1r1(config)#router ospf 200
p1r1(config-router)#area 1 range 192.168.1.0 255.255.255.0
```

Telnet to the backbone_r1 router; the password is cisco. Display the backbone_r1 router's routing table to verify that your subnets are summarized properly. Exit the Telnet to the backbone_r1 router.

```
p1r1#telnet bbr1
Trying bbr1 (10.1.1.100)... Open


User Access Verification

Password:
backbone_r1>show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
```

```
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
C       172.16.10.0 is directly connected, Loopback100
C       172.16.11.0 is directly connected, Loopback101
     10.0.0.0/24 is subnetted, 2 subnets
C       10.1.1.0 is directly connected, Serial1/0
C       10.2.2.0 is directly connected, Serial1/1
O IA 192.168.1.0/24 [110/3134] via 10.1.1.1, 00:00:30, Serial1/0
backbone_r1>
backbone_r1>exit

[Connection to bbr1 closed by foreign host]
p1r1#
```

Step 6 Save the current configurations of all the routers within your pod to NVRAM.

```
p1r1#copy run start
Destination filename [startup-config]?
Building configuration...


p1r2#copy run start
Destination filename [startup-config]?
Building configuration...


p1r3#copy run start
Destination filename [startup-config]?
Building configuration...
```

Answers to Task 2: Enabling OSPF Stub Area

Complete the following steps:

Step 1 Configure your pod's OSPF area (area *x*) into a stub area. For this step, on which router(s) do you need to configure?

```
p1r1(config)#router ospf 200
p1r1(config-router)#area 1 stub

p1r2(config)#router ospf 200
p1r2(config-router)#area 1 stub

p1r3(config)#router ospf 200
p1r3(config-router)#area 1 stub
```

Step 2 Do you still see the O IA routes in the p*x*r2 and p*x*r3 routing table?

Yes

```
p1r2#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is 192.168.1.33 to network 0.0.0.0

     10.0.0.0/24 is subnetted, 2 subnets
O IA    10.2.2.0 [110/4686] via 192.168.1.33, 00:00:14, Serial1
                 [110/4686] via 192.168.1.17, 00:00:14, Serial0
O IA    10.1.1.0 [110/3124] via 192.168.1.33, 00:00:14, Serial1
                 [110/3124] via 192.168.1.17, 00:00:14, Serial0
     192.168.1.0/28 is subnetted, 4 subnets
C       192.168.1.64 is directly connected, Ethernet0
C       192.168.1.32 is directly connected, Serial1
O       192.168.1.48 [110/1572] via 192.168.1.66, 00:00:14, Ethernet0
C       192.168.1.16 is directly connected, Serial0
C    192.168.101.0/24 is directly connected, Loopback10
O*IA 0.0.0.0/0 [110/1563] via 192.168.1.33, 00:00:15, Serial1
               [110/1563] via 192.168.1.17, 00:00:15, Serial0
```

```
p1r3#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is 192.168.1.49 to network 0.0.0.0

     172.26.0.0/28 is subnetted, 3 subnets
C       172.26.1.48 is directly connected, Loopback13
C       172.26.1.32 is directly connected, Loopback12
C       172.26.1.16 is directly connected, Loopback11
     10.0.0.0/24 is subnetted, 2 subnets
O IA    10.2.2.0 [110/4686] via 192.168.1.49, 00:00:19, Serial0
O IA    10.1.1.0 [110/3124] via 192.168.1.49, 00:00:19, Serial0
     192.168.1.0/28 is subnetted, 4 subnets
C       192.168.1.64 is directly connected, Ethernet0
O       192.168.1.32 [110/1572] via 192.168.1.65, 00:00:19, Ethernet0
C       192.168.1.48 is directly connected, Serial0
O       192.168.1.16 [110/1572] via 192.168.1.65, 00:00:20, Ethernet0
O*IA 0.0.0.0/0 [110/1563] via 192.168.1.49, 00:00:20, Serial0
p1r3#
```

Do you still see the O E2 route in the p*x*r2 and p*x*r3 routing table? Explain your answer.

No. All the area routers are configured as stub, so the ABR, p*x*r1, does not pass any external routes within its OSPF updates.

Do you see any additional routes in the p*x*r2 and p*x*r3 routing table that were not there before?

Router p*x*r2 and router p*x*r3 now have a default route pointing to the ABR, p*x*r1.

Step 3 Use the **show ip ospf** command to verify that your OSPF area *x* is a stub area.

```
p1r2#show ip ospf
 Routing Process "ospf 200" with ID 192.168.101.101
 Supports only single TOS(TOS0) routes
 SPF schedule delay 5 secs, Hold time between two SPFs 10 secs
 Minimum LSA interval 5 secs. Minimum LSA arrival 1 secs
 Number of external LSA 0. Checksum Sum 0x0
 Number of DCbitless external LSA 0
 Number of DoNotAge external LSA 0
 Number of areas in this router is 1. 0 normal 1 stub 0 nssa
    Area 1
        Number of interfaces in this area is 3
        It is a stub area
        Area has no authentication
        SPF algorithm executed 8 times
        Area ranges are
        Number of LSA 8. Checksum Sum 0x29602
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0

p1r3#show ip ospf
 Routing Process "ospf 200" with ID 172.26.1.49
 Supports only single TOS(TOS0) routes
 SPF schedule delay 5 secs, Hold time between two SPFs 10 secs
 Minimum LSA interval 5 secs. Minimum LSA arrival 1 secs
 Number of external LSA 0. Checksum Sum 0x0
 Number of DCbitless external LSA 0
 Number of DoNotAge external LSA 0
 Number of areas in this router is 1. 0 normal 1 stub 0 nssa
    Area 1
        Number of interfaces in this area is 2
        It is a stub area
        Area has no authentication
        SPF algorithm executed 6 times
        Area ranges are
        Number of LSA 7. Checksum Sum 0x25804
```

```
Number of DCbitless LSA 0
Number of indication LSA 0
Number of DoNotAge LSA 0
```

Step 4 Verify that you have full connectivity within your pod and to the backbone_r1 router loopback interfaces (you may also see routes to the other pods).

```
p1r1#ping 172.16.10.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.10.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 28/30/32 ms

p1r1#ping 172.16.11.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.11.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/32/32 ms


p1r2#ping 172.16.10.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.10.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 56/58/64 ms

p1r2#ping 172.16.11.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.11.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 56/58/60 ms


p1r3#ping 172.16.10.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.10.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 60/60/64 ms


p1r3#ping 172.16.11.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.11.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 60/60/60 ms
p1r3#
```

Step 5 Save the current configurations of all the routers within your pod to NVRAM.

```
p1r1#copy run start
Destination filename [startup-config]?
Building configuration...

p1r2#copy run start
Destination filename [startup-config]?
Building configuration...

p1r3#copy run start
Destination filename [startup-config]?
Building configuration...
```

Answers to Task 3: Enabling OSPF Totally Stubby Area

Complete the following steps:

Step 1 Configure your pod's OSPF area into a totally stubby area. For this step, on which router(s) do you need to configure?

Add the no-summary option to the ABR, p*x*r1.

```
p1r1(config)#router ospf 200
p1r1(config-router)#area 1 stub no-summary
```

Do you still see the O IA routes in the p*x*r2 and p*x*r3 routing table? Please explain your answer.

No, you have only a default route pointing at the ABR. The ABR does not pass interarea or external routes to p*x*r2 and p*x*r3.

```
p1r2#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is 192.168.1.66 to network 0.0.0.0

     192.168.1.0/28 is subnetted, 4 subnets
C       192.168.1.64 is directly connected, Ethernet0
C       192.168.1.32 is directly connected, Serial1
O       192.168.1.48 [110/1572] via 192.168.1.66, 00:00:05, Ethernet0
C       192.168.1.16 is directly connected, Serial0
C    192.168.101.0/24 is directly connected, Loopback10
O*IA 0.0.0.0/0 [110/1573] via 192.168.1.66, 00:00:05, Ethernet0
p1r2#
```

```
p1r3#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is 192.168.1.49 to network 0.0.0.0

     172.26.0.0/28 is subnetted, 3 subnets
C       172.26.1.48 is directly connected, Loopback13
C       172.26.1.32 is directly connected, Loopback12
C       172.26.1.16 is directly connected, Loopback11
     192.168.1.0/28 is subnetted, 4 subnets
C       192.168.1.64 is directly connected, Ethernet0
O       192.168.1.32 [110/1572] via 192.168.1.65, 00:00:01, Ethernet0
C       192.168.1.48 is directly connected, Serial0
O       192.168.1.16 [110/1572] via 192.168.1.65, 00:00:02, Ethernet0
O*IA 0.0.0.0/0 [110/1563] via 192.168.1.49, 00:00:02, Serial0
p1r3#
```

Step 2 Verify that you have full connectivity within your pod and to the backbone_r1 router loopback interfaces (you may also see routes to the other pods).

```
p1r1#ping 172.16.10.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.10.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 28/28/28 ms
p1r1#ping 172.16.11.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.11.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/32/32 ms
p1r1#

p1r2#ping 172.16.10.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.10.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 56/59/60 ms
p1r2#ping 172.16.11.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.11.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 56/59/60 ms
p1r2#

p1r3#ping 172.16.10.100
```

```
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.10.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 60/60/60 ms
p1r3#ping 172.16.11.100

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.11.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 60/60/60 ms
p1r3#
```

Step 3 Save the current configurations of all the routers within your pod to NVRAM.

```
p1r1#copy run start
Destination filename [startup-config]?
Building configuration...


p1r2#copy run start
Destination filename [startup-config]?
Building configuration...


p1r3#copy run start
Destination filename [startup-config]?
Building configuration...
```

Answers to Task 4: Enabling OSPF Not-So-Stubby Area (Optional)

Step 1 Remove the totally stubby area configuration commands and then reconfigure your pod's OSPF area into an NSSA area. For this step, which router(s) do you need to configure? (On the p*x*r1 router, use the **default-information-originate** option when configuring NSSA.)

NOTE On p*x*r1, you must remove the totally stubby area configuration command and then remove the stub area configuration command to completely remove any stub characteristics before configuring NSSA.

All routers in the area require the configuration.

```
p1r1(config)#router ospf 200
plrl(config-router)#no area 1 stub no-summary
p1r1(config-router)#no area 1 stub
p1r1(config-router)#area 1 nssa default-information-originate


p1r2(config)#router ospf 200
p1r2(config-router)#no area 1 stub
```

```
p1r2(config-router)#area 1 nssa
```

```
p1r3(config)#router ospf 200
p1r3(config-router)#no area 1 stub
p1r3(config-router)#area 1 nssa
```

Step 2 Do you see any O IA routes in the p*x*r2 and p*x*r3 routing table?

Yes

```
p1r2#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is 192.168.1.33 to network 0.0.0.0

     10.0.0.0/24 is subnetted, 2 subnets
O IA    10.2.2.0 [110/4686] via 192.168.1.33, 00:00:33, Serial1
                 [110/4686] via 192.168.1.17, 00:00:33, Serial0
O IA    10.1.1.0 [110/3124] via 192.168.1.33, 00:00:33, Serial1
                 [110/3124] via 192.168.1.17, 00:00:33, Serial0
     192.168.1.0/28 is subnetted, 4 subnets
C       192.168.1.64 is directly connected, Ethernet0
C       192.168.1.32 is directly connected, Serial1
O       192.168.1.48 [110/1572] via 192.168.1.66, 00:00:33, Ethernet0
C       192.168.1.16 is directly connected, Serial0
C    192.168.101.0/24 is directly connected, Loopback10
O*N2 0.0.0.0/0 [110/1] via 192.168.1.33, 00:00:34, Serial1
               [110/1] via 192.168.1.17, 00:00:34, Serial0
```

```
p1r3#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is 192.168.1.49 to network 0.0.0.0

     172.26.0.0/28 is subnetted, 3 subnets
C       172.26.1.48 is directly connected, Loopback13
C       172.26.1.32 is directly connected, Loopback12
C       172.26.1.16 is directly connected, Loopback11
     10.0.0.0/24 is subnetted, 2 subnets
O IA    10.2.2.0 [110/4686] via 192.168.1.49, 00:00:49, Serial0
O IA    10.1.1.0 [110/3124] via 192.168.1.49, 00:00:49, Serial0
```

```
     192.168.1.0/28 is subnetted, 4 subnets
C       192.168.1.64 is directly connected, Ethernet0
O       192.168.1.32 [110/1572] via 192.168.1.65, 00:00:49, Ethernet0
C       192.168.1.48 is directly connected, Serial0
O       192.168.1.16 [110/1572] via 192.168.1.65, 00:00:50, Ethernet0
O*N2 0.0.0.0/0 [110/1] via 192.168.1.49, 00:00:50, Serial0
p1r3#
```

Do you see any O*N2 route in the p*x*r2 and p*x*r3 routing table?

Yes

What type of route is the O*N2 route?

Default route, NSSA (LSA type 7), external route type 2

Step 3 Verify that you have full connectivity within your pod and to the backbone_r1 router (you may also see routes to the other pods).

```
p1r1#ping p1r2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.65, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/33/36 ms
p1r1#ping p1r3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.66, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/32/36 ms
p1r1#ping bbr1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.1.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 28/30/32 ms
p1r1#


p1r2#ping p1r1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.17, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/32/32 ms
p1r2#ping p1r3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.66, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/4/4 ms
p1r2#ping bbr1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.1.100, timeout is 2 seconds:
!!!!!
```

```
Success rate is 100 percent (5/5), round-trip min/avg/max = 60/60/60 ms
p1r2#


p1r3#ping p1r1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.17, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 28/34/48 ms
p1r3#ping p1r2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.1.65, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/3/4 ms
p1r3#ping bbr1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.1.1.100, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 56/57/60 ms
p1r3#
```

Step 4 Save the current configurations of all the routers within your pod to NVRAM.

```
p1r1#copy run start
Destination filename [startup-config]?
Building configuration...


p1r2#copy run start
Destination filename [startup-config]?
Building configuration...


p1r3#copy run start
Destination filename [startup-config]?
Building configuration...
```

Step 5 The loopback interfaces that you created on p*x*r3 in setup are used to simulate type 7 external routes into your NSSA. Use the **redistribute** command at your p*x*r3 routers to redistribute only the loopback interfaces into your NSSA. Route redistribution will be discussed in Chapter 8. For now, just enter the following commands to perform the redistribution at the p*x*r3 router:

```
router ospf 200
redistribute connected metric-type 1 subnets route-map passlb
route-map passlb
match ip address 1
access-list 1 permit 172.26.x.0 0.0.0.255
```

x is your pod number.

For Pod 1:

```
p1r3(config)#router ospf 200
p1r3(config-router)#redistribute connected metric-type 1 subnets route-map passlb
p1r3(config-router)#route-map passlb
p1r3(config-route-map)#match ip address 1
p1r3(config-route-map)#access-list 1 permit 172.26.1.0 0.0.0.255
```

Step 6 Do you see any O N1 routes in the routing table of p*x*r1? What type of routes are those?

Yes. N1—OSPF NSSA external type 1.

```
p1r1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
O E2    172.16.10.0 [110/20] via 10.1.1.100, 00:01:34, Serial3
O E2    172.16.11.0 [110/20] via 10.1.1.100, 00:01:34, Serial3
     172.26.0.0/28 is subnetted, 3 subnets
O N1    172.26.1.48 [110/1582] via 192.168.1.50, 00:01:34, Serial2
O N1    172.26.1.32 [110/1582] via 192.168.1.50, 00:01:34, Serial2
O N1    172.26.1.16 [110/1582] via 192.168.1.50, 00:01:34, Serial2
     10.0.0.0/24 is subnetted, 2 subnets
O       10.2.2.0 [110/3124] via 10.1.1.100, 00:06:41, Serial3
C       10.1.1.0 is directly connected, Serial3
     192.168.1.0/28 is subnetted, 4 subnets
O       192.168.1.64 [110/1572] via 192.168.1.50, 00:01:35, Serial2
                     [110/1572] via 192.168.1.34, 00:01:35, Serial1
                     [110/1572] via 192.168.1.18, 00:01:35, Serial0
C       192.168.1.32 is directly connected, Serial1
C       192.168.1.48 is directly connected, Serial2
C       192.168.1.16 is directly connected, Serial0
p1r1#
```

Telnet to the backbone_r1 router. Do you see your 172.26.*x*.0 routes in the backbone_r1 routing table? What type of routes are those? Exit the Telnet session to the backbone_r1 router when you're done.

```
p1r1#bbr1
Trying bbr1 (10.1.1.100)... Open


User Access Verification

Password:
backbone_r1>show ip route
```

```
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
C       172.16.10.0 is directly connected, Loopback100
C       172.16.11.0 is directly connected, Loopback101
     172.26.0.0/28 is subnetted, 3 subnets
O E1    172.26.1.48 [110/3154] via 10.1.1.1, 00:02:06, Serial1/0
O E1    172.26.1.32 [110/3154] via 10.1.1.1, 00:02:06, Serial1/0
O E1    172.26.1.16 [110/3154] via 10.1.1.1, 00:02:06, Serial1/0
     10.0.0.0/24 is subnetted, 2 subnets
C       10.1.1.0 is directly connected, Serial1/0
C       10.2.2.0 is directly connected, Serial1/1
O IA 192.168.1.0/24 [110/3134] via 10.1.1.1, 00:06:35, Serial1/0
backbone_r1>
backbone_r1>exit

[Connection to bbr1 closed by foreign host]
p1r1#
```

The routes are OE1-OSPF external type 1.

Step 7 At your p*x*r1 router, summarize the three external loopback interface addresses into a single summarized route of 172.26.*x*.0 255.255.255.0, where *x* = your pod number.

```
p1r1(config)#router ospf 200
p1r1(config-router)#summary-address 172.26.1.0 255.255.255.0
```

Telnet to the backbone_r1 router; the password is cisco. Display the backbone_r1 router's routing table to verify that your external routes are summarized properly. Exit the Telnet session to the backbone_r1 router.

```
p1r1#telnet bbr1
Trying bbr1 (10.1.1.100)... Open


User Access Verification

Password:
backbone_r1>show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
```

```
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
C       172.16.10.0 is directly connected, Loopback100
C       172.16.11.0 is directly connected, Loopback101
     172.26.0.0/24 is subnetted, 1 subnets
O E1    172.26.1.0 [110/1582] via 10.1.1.1, 00:00:13, Serial1/0
     10.0.0.0/24 is subnetted, 2 subnets
C       10.1.1.0 is directly connected, Serial1/0
C       10.2.2.0 is directly connected, Serial1/1
O IA 192.168.1.0/24 [110/3134] via 10.1.1.1, 00:10:46, Serial1/0
backbone_r1>exit

[Connection to bbr1 closed by foreign host]
p1r1#
```

Step 8 Save the current configurations of all the routers within your pod to NVRAM.

```
p1r1#copy run start
Destination filename [startup-config]?
Building configuration...


p1r2#copy run start
Destination filename [startup-config]?
Building configuration...


p1r3#copy run start
Destination filename [startup-config]?
Building configuration...
```

Step 9 (Bonus step) Currently, your pod's external summarized route shows up as O E1 type route at the backbone_r1 router and at any other pods that are configured. Change it so that it shows up as O E2 type route at the backbone_r1 router and at any other pods.

```
p1r3(config)#router ospf 200
p1r3(config-router)#no redistribute connected metric-type 1 subnets route-map passlb
p1r3(config-router)#redistribute connected metric-type 2 subnets route-map passlb
```

Answers to Bonus Questions

How is the OSPF cost metric calculated on Cisco routers?

The metric is a factor of the bandwdith: 10^8 ÷ bandwidth

Which type of external OSPF route will have its metric incremented as it is distributed into the OSPF domain, type 1 or type 2?

Type 1

Summarize the following subnet address range into the minimum number of routes: 172.25.168.0/24 to 172.25.175.0/24

Summarized: 172.25.168.0/21

Answers to Task 5: Enabling OSPF Virtual Link to Support an OSPF Area Not Connected to Area 0 (Optional)

Complete the following steps:

Step 1 In this task, you will be setting up virtual links. Virtual links do not support stub areas, so before you can perform the next task, you need to remove the stub area commands.

Do not remove the loopback interfaces on any of your routers. You will need to use them again in the later Configuration Exercises.

At your p*x*r1 router, remove any **area stub** or **area nssa** commands. Save the current configuration of p*x*r1 to NVRAM. Note: if you have configured NSSA, you must remove the **area x nssa default-information-originate** command and then remove the **area x nssa** command to completely remove any NSSA characteristics. Otherwise, you must remove the totally stubby area configuration command and then remove the stub area configuration command to completely remove any stub characteristics.

```
p1r1(config)#router ospf 200
p1r1(config-router)#no area 1 nssa default-information-originate
plrl(config-router)#no area 1 nssa

p1r1#copy run start
Destination filename [startup-config]?
Building configuration...
```

At your p*x*r2 router, remove any **area stub** or **area nssa** commands. Save the current configuration of p*x*r2 to NVRAM.

```
p1r2(config)#router ospf 200
p1r2(config-router)#no area 1 nssa

p1r2#copy run start
Destination filename [startup-config]?
Building configuration...
```

At your p*x*r3 router, remove any **area stub** or **area nssa** commands. Save the current configuration of p*x*r3 to NVRAM.

```
p1r3(config)#router ospf 200
p1r3(config-router)#no area 1 nssa

p1r3#copy run start
Destination filename [startup-config]?
Building configuration...
```

Step 2 At your p*x*r2 router, place that loopback interface you created in setup into the following assigned OSPF area:

Pod	pxr2 loopback10 Interface IP Address	OSPF Area
1	192.168.101.101/24	101
2	192.168.102.102/24	102
3	192.168.103.103/24	103
4	192.168.104.104/24	104
5	192.168.105.105/24	105
6	192.168.106.106/24	106
7	192.168.107.107/24	107
8	192.168.108.108/24	108
9	192.168.109.109/24	109
10	192.168.110.110/24	110
11	192.168.111.111/24	111
12	192.168.112.112/24	112

```
p1r2(config)#router ospf 200
p1r2(config-router)#network 192.168.101.101 0.0.0.0 area 101
```

Step 3 Enter the command to check the OSPF router ID of your p*x*r2 router.

```
p1r2#show ip ospf interface
Ethernet0 is up, line protocol is up
  Internet Address 192.168.1.65/28, Area 1
  Process ID 200, Router ID 192.168.101.101, Network Type BROADCAST, Cost: 10
  Transmit Delay is 1 sec, State DR, Priority 2
  Designated Router (ID) 192.168.101.101, Interface address 192.168.1.65
  Backup Designated router (ID) 172.26.1.49, Interface address 192.168.1.66
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:07
  Neighbor Count is 1, Adjacent neighbor count is 1
    Adjacent with neighbor 172.26.1.49  (Backup Designated Router)
  Suppress hello for 0 neighbor(s)
```

```
Loopback10 is up, line protocol is up
  Internet Address 192.168.101.101/24, Area 101
  Process ID 200, Router ID 192.168.101.101, Network Type LOOPBACK, Cost: 1
  Loopback interface is treated as a stub Host
Serial0 is up, line protocol is up
  Internet Address 192.168.1.18/28, Area 1
  Process ID 200, Router ID 192.168.101.101, Network Type POINT_TO_POINT, Cost:
1562
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:04
  Neighbor Count is 0, Adjacent neighbor count is 0
  Suppress hello for 0 neighbor(s)
Serial1 is up, line protocol is up
  Internet Address 192.168.1.34/28, Area 1
  Process ID 200, Router ID 192.168.101.101, Network Type POINT_TO_POINT, Cost:
1562
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:03
  Neighbor Count is 0, Adjacent neighbor count is 0
  Suppress hello for 0 neighbor(s)
p1r2#
```

What is the current OSPF router ID of p*x*r2?

For p1r2, during this Configuration Exercise: Router ID 192.168.101.101

Step 4 Create an OSPF virtual link to support the OSPF area (10*x*) that you created in Step 1. At which routers do you need to configure the virtual link?

```
p1r1(config)#router ospf 200
p1r1(config-router)#area 1 virtual-link 192.168.101.101

p1r2(config)#router ospf 200
p1r2(config-router)#area 1 virtual-link 192.168.1.49
```

Step 5 Use the **show ip ospf virtual-links** command to verify that your virtual link is up.

```
p1r2#show ip ospf virtual-links
Virtual Link OSPF_VL0 to router 192.168.1.49 is up
  Run as demand circuit
  DoNotAge LSA allowed.
  Transit area 1, via interface Serial0, Cost of using 1562
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:08
    Adjacency State FULL (Hello suppressed)
p1r2#
```

```
p1r1#show ip ospf virtual-links
Virtual Link OSPF_VL0 to router 192.168.101.101 is up
  Run as demand circuit
  DoNotAge LSA allowed.
  Transit area 1, via interface Serial0, Cost of using 1562
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:05
    Adjacency State FULL (Hello suppressed)
p1r1#
```

Step 6 Verify that the p*x*r1 routing table shows your p*x*r2 loopback interface as an O IA route.

```
p1r1#show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, * - candidate default
       U - per-user static route, o - ODR
       T - traffic engineered route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
O E2    172.16.10.0 [110/20] via 10.1.1.100, 00:01:22, Serial3
O E2    172.16.11.0 [110/20] via 10.1.1.100, 00:01:22, Serial3
     172.26.0.0/28 is subnetted, 3 subnets
O E2    172.26.1.48 [110/20] via 192.168.1.50, 00:01:22, Serial2
O E2    172.26.1.32 [110/20] via 192.168.1.50, 00:01:22, Serial2
O E2    172.26.1.16 [110/20] via 192.168.1.50, 00:01:22, Serial2
     10.0.0.0/24 is subnetted, 2 subnets
O       10.2.2.0 [110/3124] via 10.1.1.100, 00:01:22, Serial3
C       10.1.1.0 is directly connected, Serial3
     192.168.1.0/28 is subnetted, 4 subnets
O       192.168.1.64 [110/1572] via 192.168.1.50, 00:01:33, Serial2
                     [110/1572] via 192.168.1.34, 00:01:33, Serial1
                     [110/1572] via 192.168.1.18, 00:01:33, Serial0
C       192.168.1.32 is directly connected, Serial1
C       192.168.1.48 is directly connected, Serial2
C       192.168.1.16 is directly connected, Serial0
     192.168.101.0/32 is subnetted, 1 subnets
O IA    192.168.101.101 [110/1563] via 192.168.1.34, 00:01:30, Serial1
```

From p*x*r1, ping your p*x*r2 loopback interface. Was the ping successful?

```
p1r1#ping 192.168.101.101

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.101.101, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/32/32 ms
p1r1#
```

Step 7 (Challenge step) Telnet to the backbone_r1 router; the password is cisco. Display its routing table. Notice that your area summarization from Task 1 is no longer working. You should see all your 192.168.*x.y* subnets in the backbone_r1 router now. Why?

```
p1r1#telnet bbr1
Trying bbr1 (10.1.1.100)... Open


User Access Verification

Password:
backbone_r1>show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set

     172.16.0.0/24 is subnetted, 2 subnets
C       172.16.10.0 is directly connected, Loopback100
C       172.16.11.0 is directly connected, Loopback101
     172.26.0.0/28 is subnetted, 3 subnets
O E2    172.26.1.48 [110/20] via 10.1.1.1, 00:02:22, Serial1/0
O E2    172.26.1.32 [110/20] via 10.1.1.1, 00:02:22, Serial1/0
O E2    172.26.1.16 [110/20] via 10.1.1.1, 00:02:22, Serial1/0
     10.0.0.0/24 is subnetted, 2 subnets
C       10.1.1.0 is directly connected, Serial1/0
C       10.2.2.0 is directly connected, Serial1/1
     192.168.1.0/24 is variably subnetted, 5 subnets, 2 masks
O IA    192.168.1.64/28 [110/3134] via 10.1.1.1, 00:02:22, Serial1/0
O IA    192.168.1.32/28 [110/4686] via 10.1.1.1, 00:02:22, Serial1/0
O IA    192.168.1.48/28 [110/4696] via 10.1.1.1, 00:02:25, Serial1/0
O IA    192.168.1.0/24 [110/3134] via 10.1.1.1, 00:02:25, Serial1/0
O IA    192.168.1.16/28 [110/4686] via 10.1.1.1, 00:02:25, Serial1/0
     192.168.101.0/32 is subnetted, 1 subnets
O IA    192.168.101.101 [110/3125] via 10.1.1.1, 00:02:25, Serial1/0
```

Hint: Enter the **show ip ospf** command at your p*x*r2 router. What type of OSPF router is p*x*r2 now with the virtual link defined?

```
p1r2#show ip ospf
 Routing Process "ospf 200" with ID 192.168.101.101
 Supports only single TOS(TOS0) routes
 It is an area border router
 SPF schedule delay 5 secs, Hold time between two SPFs 10 secs
 Minimum LSA interval 5 secs. Minimum LSA arrival 1 secs
 Number of external LSA 5. Checksum Sum 0x2F1CC
 Number of DCbitless external LSA 0
 Number of DoNotAge external LSA 0
 Number of areas in this router is 3. 3 normal 0 stub 0 nssa
    Area BACKBONE(0)
        Number of interfaces in this area is 1
        Area has no authentication
        SPF algorithm executed 2 times
        Area ranges are
        Number of LSA 11. Checksum Sum 0x5EC4A
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 4
    Area 1
        Number of interfaces in this area is 3
        Area has no authentication
        SPF algorithm executed 28 times
        Area ranges are
        Number of LSA 16. Checksum Sum 0x6A13D
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
    Area 101
        Number of interfaces in this area is 1
        Area has no authentication
        SPF algorithm executed 3 times
        Area ranges are
        Number of LSA 10. Checksum Sum 0x59BE0
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
```

```
p1r1#show ip ospf
 Routing Process "ospf 200" with ID 192.168.1.49
 Supports only single TOS(TOS0) routes
 It is an area border router
 SPF schedule delay 5 secs, Hold time between two SPFs 10 secs
 Minimum LSA interval 5 secs. Minimum LSA arrival 1 secs
 Number of external LSA 5. Checksum Sum 0x2F1CC
 Number of DCbitless external LSA 0
 Number of DoNotAge external LSA 0
 Number of areas in this router is 2. 2 normal 0 stub 0 nssa
```

```
    Area BACKBONE(0)
        Number of interfaces in this area is 2
        Area has no authentication
        SPF algorithm executed 15 times
        Area ranges are
        Number of LSA 11. Checksum Sum 0x5EC4A
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 7
    Area 1
        Number of interfaces in this area is 3
        Area has no authentication
        SPF algorithm executed 34 times
        Area ranges are
           192.168.1.0/24 Active(1572) Advertise
        Number of LSA 13. Checksum Sum 0x53104
        Number of DCbitless LSA 0
        Number of indication LSA 0
        Number of DoNotAge LSA 0
```

Both p*x*r1 and p*x*r2 are ABRs, but only p*x*r1 is summarizing. p*x*r2 sends the subnet route information to the backbone_r1.

At the p*x*r2 router, summarize all the 192.168.*x*.*y*/28 subnets in your area (area *x*) into a single summarized route of 192.168.*x*.0/24.

```
p1r2(config)#router ospf 200
p1r2(config-router)#area 1 range 192.168.1.0 255.255.255.0
```

Telnet to the backbone_r1 router; the password is cisco. Display the backbone_r1 router's routing table to verify that your subnets are summarized properly.

```
p1r2#telnet bbr1
Trying bbr1 (10.1.1.100)... Open


User Access Verification

Password:
backbone_r1>show ip route
Codes: C - connected, S - static, I - IGRP, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2, E - EGP
       i - IS-IS, L1 - IS-IS level-1, L2 - IS-IS level-2, ia - IS-IS inter area
       * - candidate default, U - per-user static route, o - ODR
       P - periodic downloaded static route

Gateway of last resort is not set
```

```
     172.16.0.0/24 is subnetted, 2 subnets
C       172.16.10.0 is directly connected, Loopback100
C       172.16.11.0 is directly connected, Loopback101
     172.26.0.0/28 is subnetted, 3 subnets
O E2    172.26.1.48 [110/20] via 10.1.1.1, 00:05:12, Serial1/0
O E2    172.26.1.32 [110/20] via 10.1.1.1, 00:05:12, Serial1/0
O E2    172.26.1.16 [110/20] via 10.1.1.1, 00:05:12, Serial1/0
     10.0.0.0/24 is subnetted, 2 subnets
C       10.1.1.0 is directly connected, Serial1/0
C       10.2.2.0 is directly connected, Serial1/1
O IA 192.168.1.0/24 [110/3134] via 10.1.1.1, 00:00:11, Serial1/0
     192.168.101.0/32 is subnetted, 1 subnets
O IA    192.168.101.101 [110/3125] via 10.1.1.1, 00:05:12, Serial1/0
backbone_r1>exit

[Connection to bbr1 closed by foreign host]
p1r2#
```

Step 8 Save the current configurations of all the routers within your pod to NVRAM.

```
p1r1#copy run start
Destination filename [startup-config]?
Building configuration...


p1r2#copy run start
Destination filename [startup-config]?
Building configuration...


p1r3#copy run start
Destination filename [startup-config]?
Building configuration...
```

Review Questions

Answer the following questions, and then refer to Appendix G, "Answers to the Review Questions," for the answers.

1. Define hierarchical routing and explain what internetwork problems it solves.
2. An internal router will receive type 5 LSAs if it is what type of area?
3. What area types are connected to the backbone area?
4. The backbone must be configured as what area?

5 Write a brief description of the following LSA types:

Type 1: Router link entry (record)

Type 2: Network link entry

Type 3 or 4: Summary link entry

Type 5: Autonomous system external link entry

6 Describe the path a packet must take to get from one area to another.

7 When is a default route injected into an area?

8 What are the four types of OSPF routers?

9 Which router generates a type 2 LSA?

10 What are the advantages of configuring a totally stubby area?

11 What command is used on an ABR to summarize routes for a specific area?