Chapter 3:
Open Short Path First Concept

CCNP ROUTE: Implementing IP Routing

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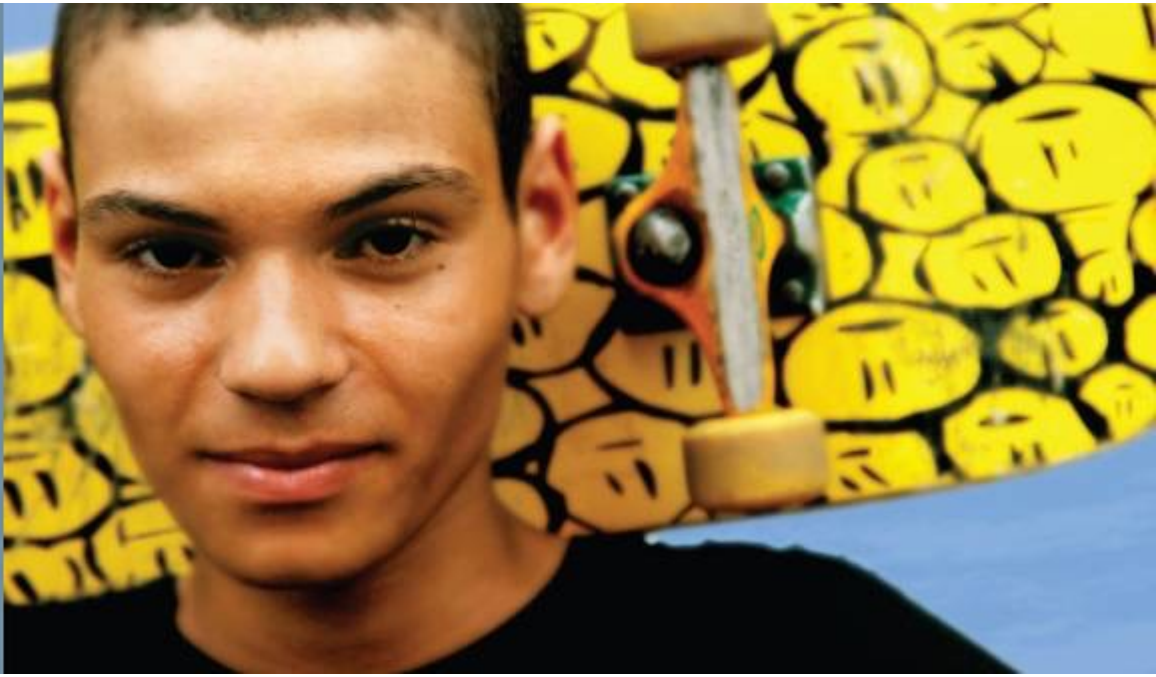
Chapter 3 Objectives

- Basic OSPF Configuration and OSPF Adjacencies
- How OSPF Builds the Routing Table
- Configuration of Summarization and Stub Areas in OSPF
- Configuration of OSPFv3 for IPv6 and IPv4

Establishing OSPF Neighbor Relationships



Establishing OSPF Neighbor Relationships

- Explain why would you choose OSPF over other routing protocols
- Describe basic operation steps with link-state protocols
- Describe area and router types in OSPF
- Explain what the design limitations of OSPF are
- List and describe OSPF message types
- Describe OSPF neighbor relationship over point-to-point link
- Describe OSPF neighbor relationship behavior on MPLS VPN
- Describe OSPF neighbor relationship behavior over L2 MPLS VPN
- List and describe OSPF neighbor states
- List and describe OSPF network types
- Configure passive interfaces

OSPF Features

- OSPF was developed by the Internet Engineering Task Force (IETF) to overcome the limitations of distance vector routing protocols.
- One of the main reasons why OSPF is largely deployed in today's enterprise networks is the fact that it is an open standard;
- OSPF offers a large level of scalability and fast convergence.
- Despite its relatively simple configuration in small and medium-size networks, OSPF implementation and troubleshooting in large-scale networks can at times be challenging.

OSPF Features

Independent transport layer protocol

- OSPF works on top of IP and uses protocol number 89.
- It does not rely on the functions of the transport layer protocols TCP or UDP.

Efficient use of updates

- When an OSPF router first discovers a new neighbor, it sends a full update with all known link-state information.
- All routers within an OSPF area must have identical and synchronized link-state information in their OSPF link-state databases.
- When an OSPF network is in a converged state and a new link comes up or a link becomes unavailable, an OSPF router sends only a partial update to all its neighbors.
- This update will then be flooded to all OSPF routers within an area.

OSPF Features

Metric

- OSPF uses a metric that is based on the cumulative costs of all outgoing interfaces from source to destination. The interface cost is inversely proportional to the interface bandwidth and can be also set up explicitly.

Update destination address

- OSPF uses multicast and unicast, rather than broadcast, for sending messages.
- The IPv4 multicast addresses used for OSPF are 224.0.0.5 to send information to all OSPF routers and 224.0.0.6 to send information to DR/BDR routers.
- The IPv6 multicast addresses are FF02::5 for all OSPFv3 routers and FF02::6 for all DR/BDR routers.
- If the underlying network does not have broadcast capabilities, you must establish OSPF neighbor relationships using a unicast address.
- For IPv6, this address will be a link-local IPv6 address.

OSPF Features

VLSM support

- OSPF is a classless routing protocol. It supports variable-length subnet masking (VLSM) and discontinuous networks.
- It carries subnet mask information in the routing updates.

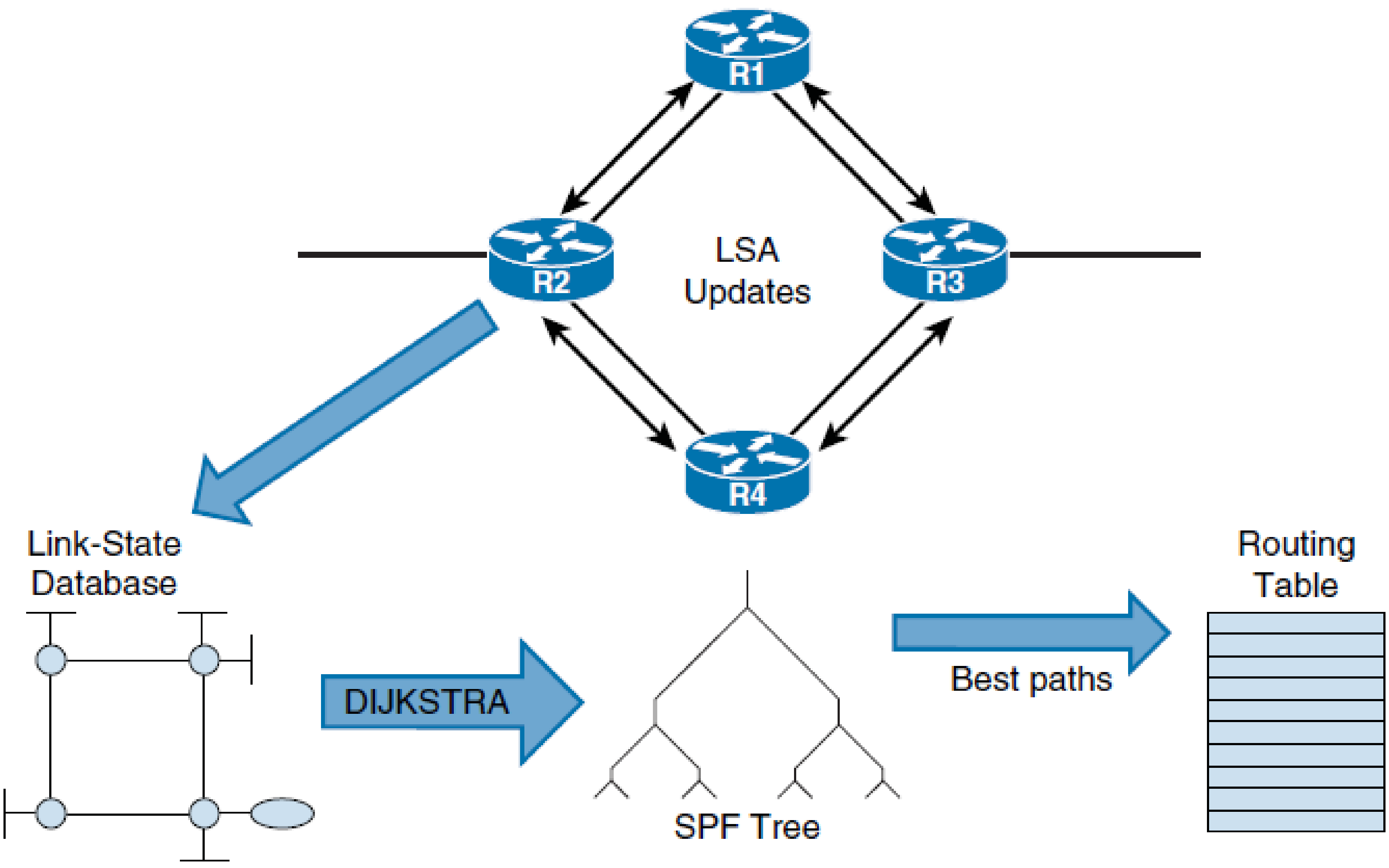
Manual route summarization

- You can manually summarize OSPF inter-area routes at the Area Border Router (ABR), and you have the possibility to summarize OSPF external routes at the Autonomous System Boundary Router (ASBR).
- OSPF does not know the concept of **auto-summarization**.

Authentication

- OSPF supports clear-text, MD5, and SHA authentication.

OSPF Operation Overview



OSPF Operation Overview

1. **Establish neighbor adjacencies**

- OSPF-enabled routers must form adjacencies with their neighbor before they can share information with that neighbor.
- An OSPF enabled router sends Hello packets out all OSPF-enabled interfaces to determine whether neighbors are present on those links.
- If a neighbor is present, the OSPF enabled router attempts to establish a neighbor adjacency with that neighbor.

OSPF Operation Overview

2. **Exchange link-state advertisements**

- After adjacencies are established, routers then exchange link-state advertisements (LSAs).
- LSAs contain the state and cost of each directly connected link.
- Routers flood their LSAs to adjacent neighbors. Adjacent neighbors receiving the LSA immediately flood the LSA to other directly connected neighbors, until all routers in the area have all LSAs.

3. **Build the topology table**

- After the LSAs are received, OSPF-enabled routers build the topology table (LSDB) based on the received LSAs.
- This database eventually holds all the information about the topology of the network.
- It is important that all routers in the area have the same information in their LSDBs.

OSPF Operation Overview

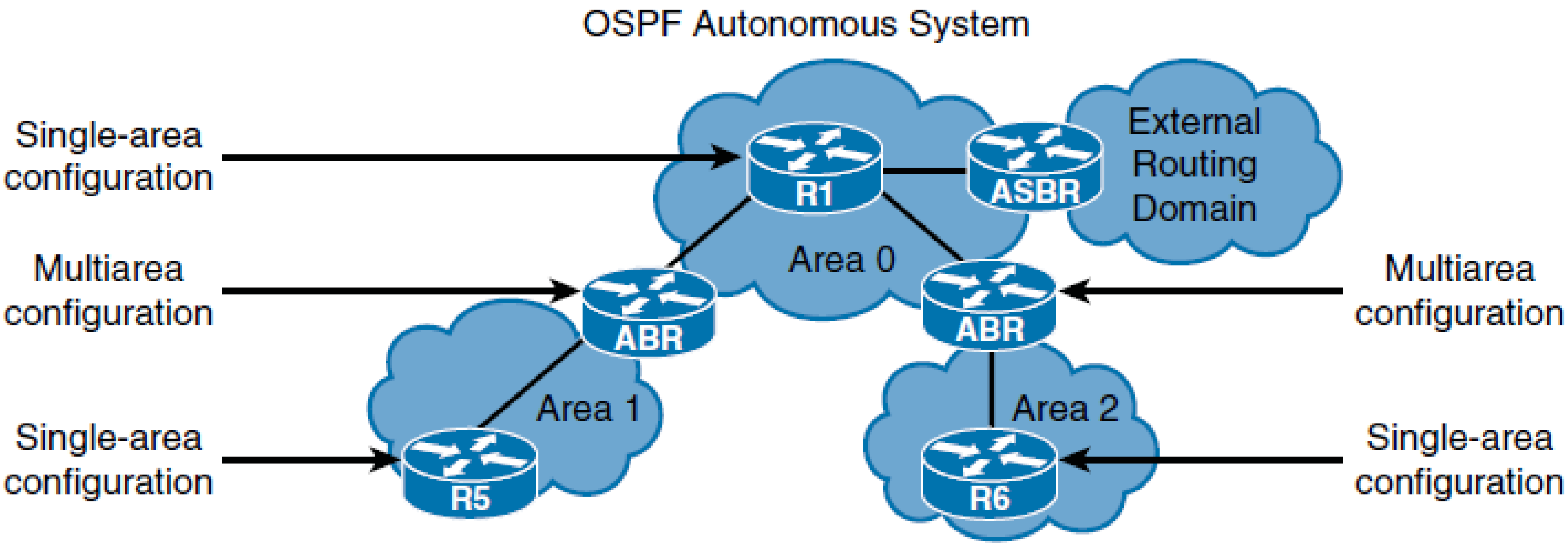
4. **Execute the SPF algorithm**

- Routers then execute the SPF algorithm. The SPF algorithm creates the SPF tree.

5. **Build the routing table**

- From the SPF tree, the best paths are inserted into the routing table. Routing decisions are made based on the entries in the routing table.

Hierarchical Structure of OSPF



Hierarchical Structure of OSPF

OSPF uses a two-layer area hierarchy:

1. Backbone area, transit area or area 0

- Two principal requirements for the backbone area are that it must connect to all other non-backbone areas and this area must be always contiguous; it is not allowed to have split up the backbone area.
- Generally, end users are not found within a backbone area.

2. Non-backbone area

- The primary function of this area is to connect end users and resources. Non-backbone areas are usually set up according to functional or geographic groupings.
- Traffic between different non-backbone areas must always pass through the backbone area.

Hierarchical Structure of OSPF

- In the multi-area topology, there are special commonly OSPF terms:

ABR (Area Border Router**)**

- A router that has interfaces connected to at least two different OSPF areas, including the backbone area:
  - it contains LSDB information for each area,
  - it makes route calculation for each area and
  - it advertises routing information between areas.

ASBR (Autonomous System Boundary Router**)**

- ASBR is a router that has at least one of its interfaces connected to an OSPF area and at least one of its interfaces connected to an external non-OSPF domain.

Internal router

- A router that has all its interfaces connected to only one OSPF area.

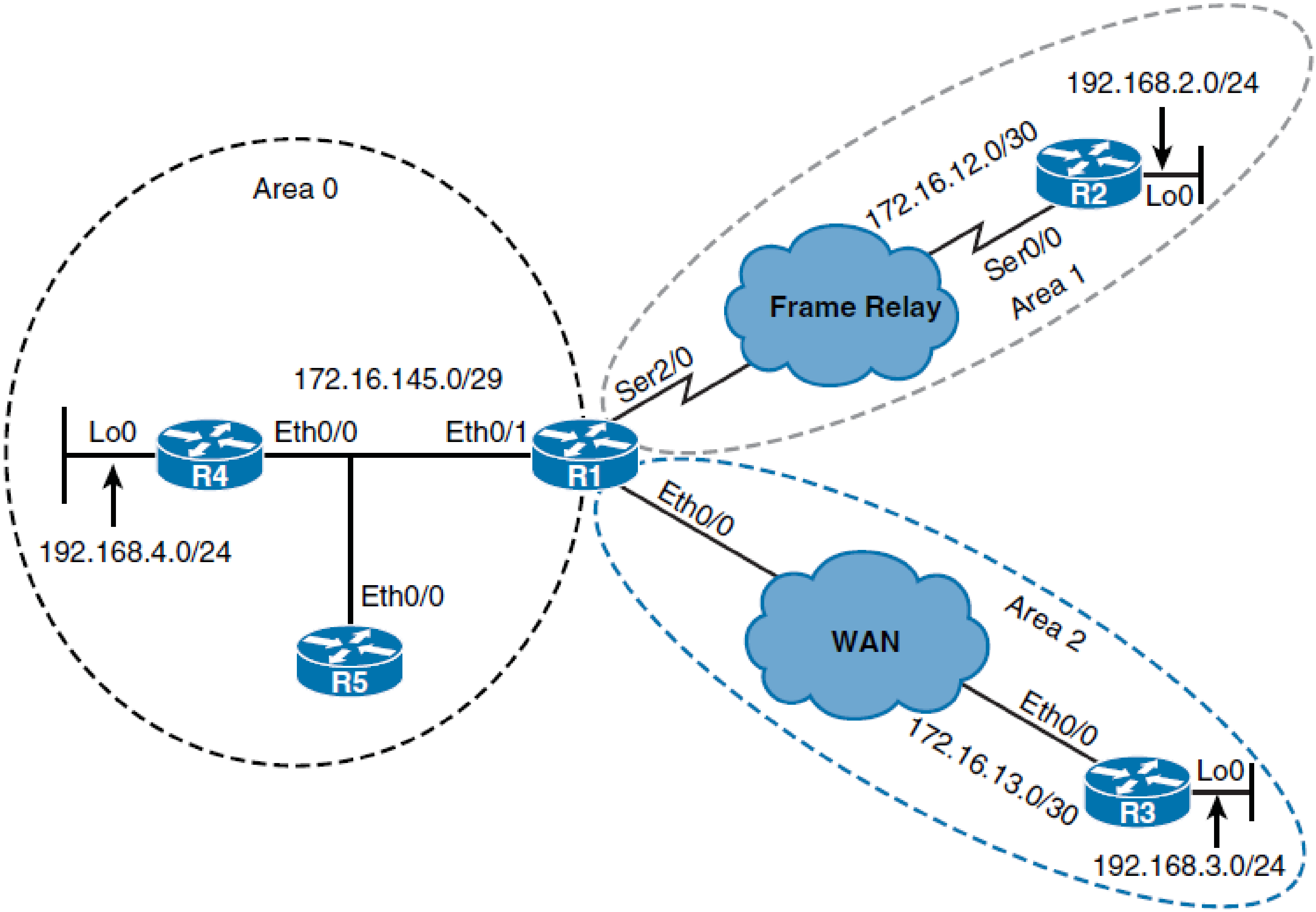
Backbone router

- A router that has at least one interface connected to the backbone area.

OSPF Packet Types

- **Type 1: Hello packet:** Hello packets are used to discover, build, and maintain OSPF neighbor adjacencies.
- **Type 2: Database Description (DBD) packet:** When the OSPF neighbor adjacency is already established, a DBD packet is used to describe LSDB so that routers can compare whether databases are in sync.
- **Type 3: Link-State Request (LSR) packet** : The router will send an LSR packet to inform OSPF neighbors to send the most recent version of the missing LSAs.
- **Type 4: Link-State Update (LSU) packet** : LSU packets are used for the flooding of LSAs and sending LSA responses to LSR packets.
- **Type 5: Link-State Acknowledgment (LSAck) packet** : LSAcks are used to make flooding of LSAs reliable.

Basic OSPF Configuration



Basic OSPF Configuration

```
R2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)# router ospf 2
R2(config-router)# network 172.16.12.0 0.0.0.3 area 1
R2(config-router)# network 192.168.2.0 0.0.0.255 area 1
```

```
R3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R3(config)# router ospf 3
R3(config-router)# network 172.16.13.0 0.0.0.3 area 2
R3(config-router)# network 192.168.3.0 0.0.0.255 area 2
```

- To enable the OSPF process on the router, use the **router ospf** *process-id* command.
- Process ID numbers between neighbors do not need to match for the routers to establish an OSPF adjacency.

Basic OSPF Configuration

```
R2# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)# router ospf 2
R2(config-router)# network 172.16.12.0 0.0.0.3 area 1
R2(config-router)# network 192.168.2.0 0.0.0.255 area 1
```

```
R3# configure terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R3(config)# router ospf 3
R3(config-router)# network 172.16.13.0 0.0.0.3 area 2
R3(config-router)# network 192.168.3.0 0.0.0.255 area 2
```

- To establish OSPF full adjacency, two neighbor routers must be in the same area.
- Any individual interface can only be attached to a single area.

Configuration of OSPF Router IDs

- To choose the OSPF router ID at the time of OSPF process initialization, the router uses the following criteria:
  1. Use the router ID specified in the **router-id** *ip-address* command.
  2. Use the highest IPv4 address of all active loopback interfaces on the router.
  3. Use the highest IPv4 address among all active nonloopback interfaces.
- At least one primary IPv4 address on an interface in the up/up state must be configured for a router to be able to choose router ID; otherwise, an error message is logged, and the OSPF process does not start.

```
R2(config-router)# router-id 2.2.2.2
% OSPF: Reload or use "clear ip ospf process" command, for this to take effect
```

```
R3(config-router)# router-id 3.3.3.3
% OSPF: Reload or use "clear ip ospf process" command, for this to take effect
```

Clearing the OSPF Processes

- OSPF routing process can be cleared for the manually configured router ID to take effect.

```
R2# clear ip ospf process
Reset ALL OSPF processes? [no]: yes
R2#
*Nov 24 08:37:24.679: %OSPF-5-ADJCHG: Process 2, Nbr 1.1.1.1 on Serial0/0 from
FULL to DOWN, Neighbor Down: Interface down or detached
R2#
*Nov 24 08:39:24.734: %OSPF-5-ADJCHG: Process 2, Nbr 1.1.1.1 on Serial0/0 from
LOADING to FULL, Loading Done
```

```
R3# clear ip ospf 3 process
Reset OSPF process 3? [no]: yes
R3#
*Nov 24 09:06:00.275: %OSPF-5-ADJCHG: Process 3, Nbr 1.1.1.1 on Ethernet0/0 from
FULL to DOWN, Neighbor Down: Interface down or detached
R3#
*Nov 24 09:06:40.284: %OSPF-5-ADJCHG: Process 3, Nbr 1.1.1.1 on Ethernet0/0 from
LOADING to FULL, Loading Done
```

OSPF Router ID Criteria

1. Use the router ID specified in the **router-id** *ip-address* command.
   - You can configure an arbitrary value in the IPv4 address format, but this value must be unique.
   - If the IPv4 address specified with the **router-id** command overlaps with the router ID of another already-active OSPF process, the **router-id** command fails.
2. Use the highest IPv4 address of all active loopback interfaces on the router.
3. Use the highest IPv4 address among all active nonloopback interfaces.

Verifying the Router IDs

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

Routing Protocol is "ospf 2"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 2.2.2.2
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    172.16.12.0 0.0.0.3 area 1
    192.168.2.0 0.0.0.255 area 1
  Routing Information Sources:
    Gateway         Distance      Last Update
    1.1.1.1              110      00:02:55
  Distance: (default is 110)
```

```
R3# show ip protocols | include ID
  Router ID 3.3.3.3
```

Verifying OSPF Neighborships

```
R2# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/DR         00:01:57    172.16.12.1     Serial0/0
```

```
R3# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/DR         00:00:39    172.16.13.1     Ethernet0/0
```

- **Neighbor ID :** Represents neighbor router ID.
- **Priority :** Priority on the neighbor interface used for the DR/BDR election.
- **State :** OSPF neighbor establishment process
- **Dead Time :** Represents value of the dead timer
- **Address :** Primary IPv4 address of the neighbor router.
- **Interface :** Local interface over which an OSPF neighbor relationship is established.

Verifying the OSPF-Enabled Interfaces

```
R2# show ip ospf interface
Loopback0 is up, line protocol is up
  Internet Address 192.168.2.1/24, Area 1, Attached via Network Statement
  Process ID 2, Router ID 2.2.2.2, Network Type LOOPBACK, Cost: 1
<Output omitted>
Serial0/0 is up, line protocol is up
  Internet Address 172.16.12.2/30, Area 1, Attached via Network Statement
  Process ID 2, Router ID 2.2.2.2, Network Type NON_BROADCAST, Cost: 64
<Output omitted>
```

```
R3# show ip ospf interface
Loopback0 is up, line protocol is up
  Internet Address 192.168.3.1/24, Area 2, Attached via Network Statement
  Process ID 3, Router ID 3.3.3.3, Network Type LOOPBACK, Cost: 1
<Output omitted>
Ethernet0/0 is up, line protocol is up
  Internet Address 172.16.13.2/30, Area 2, Attached via Network Statement
  Process ID 3, Router ID 3.3.3.3, Network Type BROADCAST, Cost: 10
<Output omitted>
```

Verifying the OSPF Routes

```
R5# show ip route ospf

Gateway of last resort is not set


      172.16.0.0/16 is variably subnetted, 4 subnets, 3 masks
O IA     172.16.12.0/30 [110/74] via 172.16.145.1, 00:39:00, Ethernet0/0
O IA     172.16.13.0/30 [110/20] via 172.16.145.1, 00:19:29, Ethernet0/0
      192.168.2.0/32 is subnetted, 1 subnets
O IA     192.168.2.1 [110/75] via 172.16.145.1, 00:07:27, Ethernet0/0
      192.168.3.0/32 is subnetted, 1 subnets
O IA     192.168.3.1 [110/21] via 172.16.145.1, 00:08:30, Ethernet0/0
O     192.168.4.0/24 [110/11] via 172.16.145.4, 00:39:10, Ethernet0/0
```

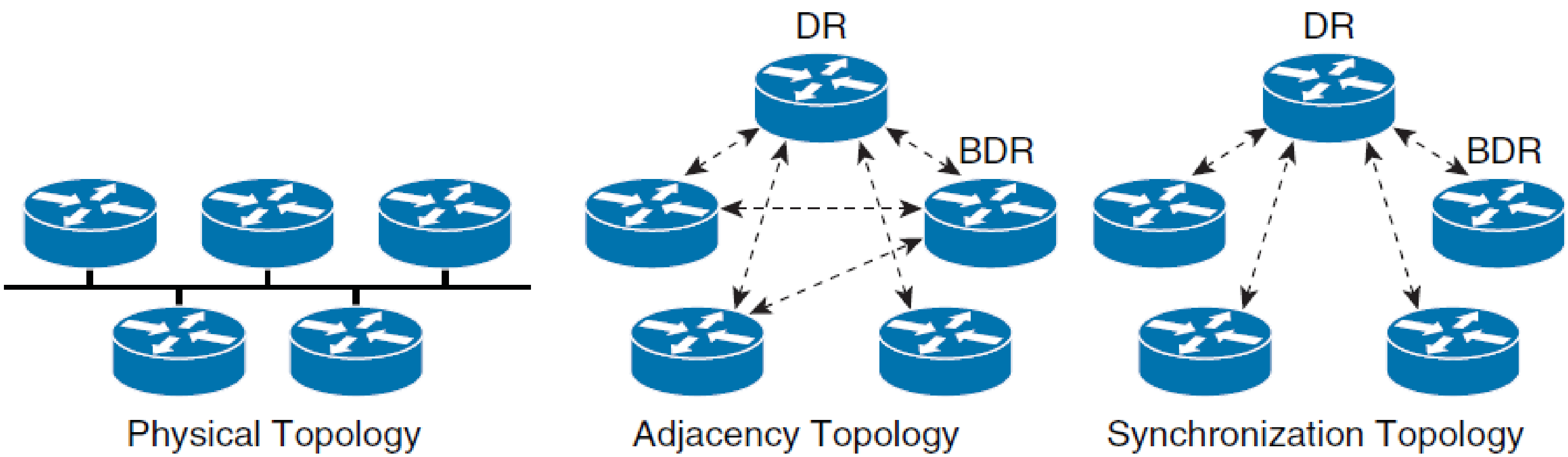
OSPF Routes

```
R5# show ip ospf route

            OSPF Router with ID (5.5.5.5) (Process ID 1)

                Base Topology (MTID 0)

    Area BACKBONE(0)

    Intra-area Route List
*   172.16.145.0/29, Intra, cost 10, area 0, Connected
      via 172.16.145.5, Ethernet0/0
*>  192.168.4.0/24, Intra, cost 11, area 0
      via 172.16.145.4, Ethernet0/0

    Intra-area Router Path List
i 1.1.1.1 [10] via 172.16.145.1, Ethernet0/0, ABR, Area 0, SPF 2

    Inter-area Route List
*>  192.168.2.1/32, Inter, cost 75, area 0
      via 172.16.145.1, Ethernet0/0
*>  192.168.3.1/32, Inter, cost 21, area 0
      via 172.16.145.1, Ethernet0/0
*>  172.16.12.0/30, Inter, cost 74, area 0
      via 172.16.145.1, Ethernet0/0
*>  172.16.13.0/30, Inter, cost 20, area 0
      via 172.16.145.1, Ethernet0/0
```

OSPF Adjacency Establishment Steps

1. **Down state** - the initial state of a neighbor conversation that indicates that no Hello's have been heard from the neighbor.
2. **Init state -** a router receives a Hello from the neighbor but has not yet seen its own router ID in the neighbor Hello packet
3. **2-Way state** - When the router sees its own router ID in the Hello packet received from the neighbor
4. **ExStart state** - In the DBD exchange process, the router with the higher router ID will become master, and it will be the only router that can increment sequence numbers. With master/slave selection complete, database exchange can start
5. **Exchange state** - To describe the content of the database, one or multiple DBD packets may be exchanged. A router compares the content of its own Database Summary list with the list received from the neighbor, and if there are differences, it adds missing LSAs to the Link State Request list.
6. **Loading state** - LSR packet is sent to the neighbor requesting full content of the missing LSAs from the LS Request list
7. **Full state** - Finally, when neighbors have a complete version of the LSDB, which means that databases on the routers are synchronized and that neighbors are fully adjacent.

Optimizing OSPF Adjacency Behavior



- As the number of routers on the segment grows, the number of OSPF adjacencies increases exponentially. Every router must synchronize its OSPF database with every other router, and in the case of a large number of routers, this leads to inefficiency.

OSPF Adjacencies on Multiaccess Networks

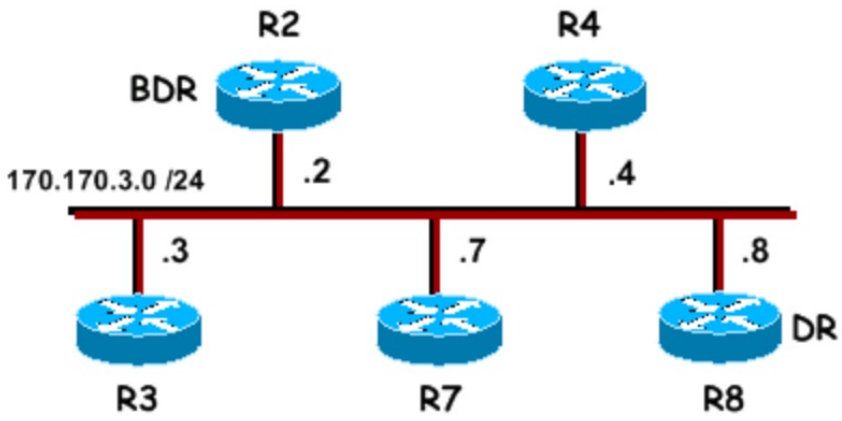
- The routers on the multiaccess segment elect a designated router (**DR**) and backup designated router (**BDR**), which centralizes communications for all routers connected to the segment.
- The DR and BDR improve network functioning in the following ways:
  - **Reducing routing update traffic:** The DR and BDR act as a central point of contact for link-state information exchange on a multiaccess network; therefore, each router must establish a full adjacency with the DR and the BDR only.
  - **Managing link-state synchronization:** The DR and BDR ensure that the other routers on the network have the same link-state information about the common segment.

OSPF Adjacencies on Multiaccess Networks

- Only LSAs are sent to the DR/BDR. The normal routing of packets on the segment will go to the best next-hop router.
- When the DR is operating, the BDR does not perform any DR functions. Instead, the BDR receives all the information, but the DR performs the LSA forwarding and LSDB synchronization tasks.
- The BDR performs the DR tasks only if the DR fails.
- When the DR fails, the BDR automatically becomes the new DR, and a new BDR election occurs.

Neighbor Status

normal behavior for OSPF



R7# **show ip ospf neighbor**

Neighbor ID	Pri	State	Dead Time	Address	Interface
170.170.3.4	1	2WAY/DROTHER	00:00:34	170.170.3.4	Ethernet0
170.170.3.3	1	2WAY/DROTHER	00:00:34	170.170.3.3	Ethernet0
170.170.3.8	1	FULL/DR	00:00:32	170.170.3.8	Ethernet0
170.170.3.2	1	FULL/BDR	00:00:39	170.170.3.2	Ethernet0

R8# **show ip ospf neighbor**

Neighbor ID	Pri	State	Dead Time	Address	Interface
170.170.3.4	1	FULL/DROTHER	00:00:37	170.170.3.4	Ethernet0
170.170.3.3	1	FULL/DROTHER	00:00:37	170.170.3.3	Ethernet0
170.170.3.7	1	FULL/DROTHER	00:00:38	170.170.3.7	Ethernet0
170.170.3.2	1	FULL/BDR	00:00:32	170.170.3.2	Ethernet0

Neighbor Status

```
R1# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
4.4.4.4           1   FULL/BDR        00:00:37    172.16.145.4    Ethernet0/1
5.5.5.5           1   FULL/DR         00:00:39    172.16.145.5    Ethernet0/1
2.2.2.2           1   FULL/DR         00:01:53    172.16.12.2     Serial2/0
3.3.3.3           1   FULL/DR         00:00:35    172.16.13.2     Ethernet0/0
```

```
R4# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/DROTHER    00:00:39    172.16.145.1    Ethernet0/0
5.5.5.5           1   FULL/DR         00:00:39    172.16.145.5    Ethernet0/0
```

```
R5# show ip ospf neighbor

Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.1           1   FULL/DROTHER    00:00:39    172.16.145.1    Ethernet0/0
4.4.4.4           1   FULL/BDR        00:00:35    172.16.145.4    Ethernet0/0
```

DR/BDR Election Process

- The DR/BDR election process takes place on broadcast and NBMA networks.
- Routers send OSPF Hello packets to discover which OSPF neighbors are active on the common Ethernet segment.
- Once OSPF neighbors are in the 2-Way state, the DR/BDR election process begins.
- The OSPF Hello packet contains three specific fields used for the DR/BDR election:
  - Designated Router, Backup Designated Router, and Router Priority.
- From all routers listed in this fields, the router with the highest **priority** becomes the DR, and the one with the next highest priority becomes the BDR.
- If the priority values are equal, the router with the highest OSPF router ID becomes the DR, and the one with the next highest OSPF router ID becomes the BDR.

DR/BDR Election Process

- On the multiaccess broadcast networks, routers use multicast destination **IPv4 address 224.0.0.6** to communicate with the DR, and the DR uses multicast destination **IPv4 address 224.0.0.5** to communicate with all other non-DR routers
- On NBMA networks, the DR and adjacent routers communicate using unicast addresses.
- The DR/BDR election process not only occurs when the network first becomes active but also when the DR becomes unavailable.
- In this case, the BDR will immediately become the DR, and the election of the new BDR starts.
- On the multi-access segment, it is normal behavior that the router in DROTHER status is FULLy adjacent with DR/BDR and in 2-WAY state with all other DROTHER routers present on the segment.

Using OSPF Priority in the DR/BDR Election

Every broadcast and NBMA OSPF-enabled interface is assigned a priority value between 0 and 255. By default, the OSPF interface priority is 1 and can be manually changed by using the **ip ospf priority** interface command.

- The router with the highest priority value is elected as the DR.
- The router with the second-highest priority value is the BDR.
- In case of a tie where two routers have the same priority value, router ID is used as the tiebreaker. The router with the highest router ID becomes the DR. The router with the second-highest router ID becomes the BDR.
- A router with a priority that is set to 0 cannot become the DR or BDR. A router that is not the DR or BDR is called a DROTHER.

Configuring the OSPF Priority on an Interface

```
R1(config)# interface ethernet 0/1
R1(config-if)# ip ospf priority 100
```

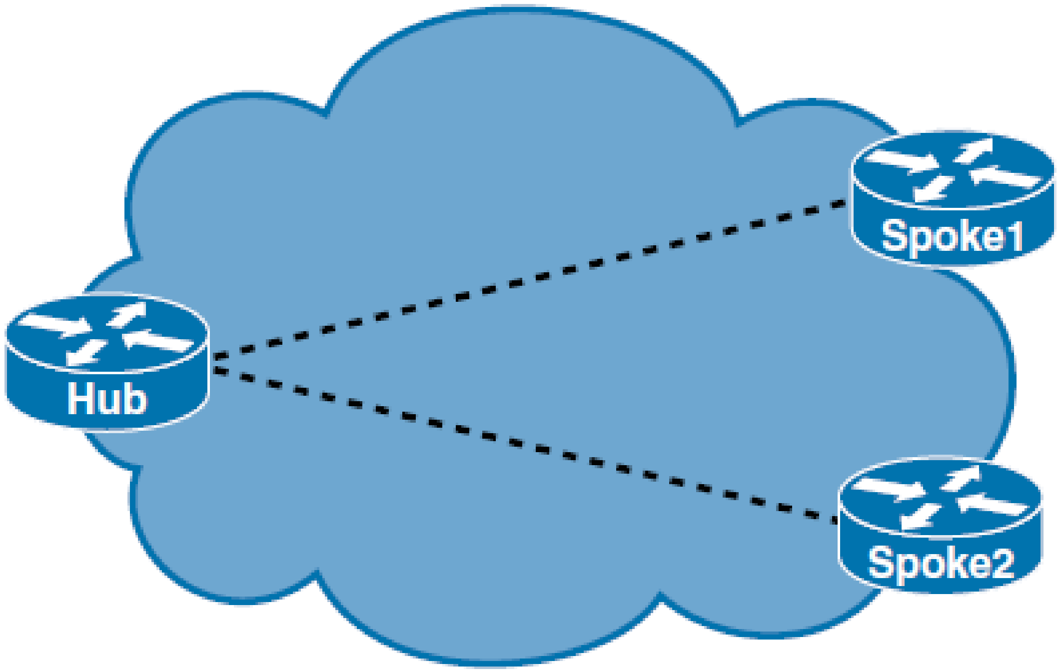
```
R4# clear ip ospf process
Reset ALL OSPF processes? [no]: yes
*Dec 10 13:08:48.610: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on Ethernet0/0 from
FULL to DOWN, Neighbor Down: Interface down or detached
*Dec 10 13:08:48.610: %OSPF-5-ADJCHG: Process 1, Nbr 5.5.5.5 on Ethernet0/0 from
FULL to DOWN, Neighbor Down: Interface down or detached
*Dec 10 13:09:01.294: %OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on Ethernet0/0 from
LOADING to FULL, Loading Done
*Dec 10 13:09:04.159: %OSPF-5-ADJCHG: Process 1, Nbr 5.5.5.5 on Ethernet0/0 from
LOADING to FULL, Loading Done
```

Verifying OSPF Neighbor Status

```
R1# show ip ospf interface ethernet 0/1
Ethernet0/1 is up, line protocol is up
  Internet Address 172.16.145.1/29, Area 0, Attached via Network Statement
  Process ID 1, Router ID 1.1.1.1, Network Type BROADCAST, Cost: 10
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           10        no          no            Base
  Transmit Delay is 1 sec, State DR, Priority 100
  Designated Router (ID) 1.1.1.1, Interface address 172.16.145.1
  Backup Designated router (ID) 5.5.5.5, Interface address 172.16.145.5
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    oob-resync timeout 40
    Hello due in 00:00:06
  Supports Link-local Signaling (LLS)
  Cisco NSF helper support enabled
  IETF NSF helper support enabled
  Index 1/3, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 1, maximum is 5
  Last flood scan time is 0 msec, maximum is 1 msec
  Neighbor Count is 2, Adjacent neighbor count is 2
    Adjacent with neighbor 4.4.4.4
    Adjacent with neighbor 5.5.5.5  (Backup Designated Router)
  Suppress hello for 0 neighbor(s)
```

OSPF Behavior in NBMA Hub-and-Spoke Topology

- OSPF treats NBMA environments like any other broadcast media environment, such as Ethernet; however, NBMA clouds are usually built as hub-and-spoke topologies using private virtual circuits (PVCs) or switched virtual circuits (SVCs)



OSPF Behavior in NBMA Hub-and-Spoke Topology

- In these cases, the physical topology does not provide multiaccess capability, on which OSPF relies. In a hub-and-spoke NBMA environment, you will need to have the hub router acting as the DR and spoke routers acting as the DROTHER routers. On the spoke router interfaces, you want to configure an OSPF priority value of 0 so that the spoke routers never participate in the DR election.

```
R4(config)# interface ethernet 0/0
R4(config-if)# ip ospf priority 0
```

```
R5(config)# interface ethernet 0/0
R5(config-if)# ip ospf priority 0
```

The Importance of MTU

- If neighbors have a mismatched IPv4 MTU configured, they will not be able to form full OSPF adjacency.
- Mismatched neighbors will stay in ExStart state

```
R3(config)# interface ethernet 0/0
R3(config-if)# ip mtu 1400
```

- By default, the IPv6 MTU must also match between OSPFv3 neighbors. However, you can override this by using the **ospfv3 mtu-ignore** interface command.

Manipulating OSPF Timers

- Similar to EIGRP, OSPF uses two timers to check neighbor reachability: the HELLO and DEAD intervals.
- OSPF requires that both hello and dead timers be identical for all routers on the segment to become OSPF neighbors.
- The default value of the OSPF hello timer on multi-access broadcast and point-to-point links is 10 seconds, and is 30 seconds on all other network types, including NBMA.
- When you configure the hello interval, the default value of the dead interval is automatically adjusted to 4 times the hello interval.
- For broadcast and point-to-point links, it is 40 seconds, and for all other OSPF network types, it is 120 seconds.

Examining the Hello/Dead Timers

```
R1# show ip ospf interface ethernet 0/1
Ethernet0/1 is up, line protocol is up
  Internet Address 172.16.145.1/29, Area 0, Attached via Network Statement
  Process ID 1, Router ID 1.1.1.1, Network Type BROADCAST, Cost: 10
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           10        no          no             Base
  Transmit Delay is 1 sec, State DROTHER, Priority 1
  Designated Router (ID) 5.5.5.5, Interface address 172.16.145.5
  Backup Designated router (ID) 4.4.4.4, Interface address 172.16.145.4
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
<Output omitted>

R1# show ip ospf interface serial 2/0
Serial2/0 is up, line protocol is up
  Internet Address 172.16.12.1/30, Area 1, Attached via Network Statement
  Process ID 1, Router ID 1.1.1.1, Network Type NON_BROADCAST, Cost: 64
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           64        no          no             Base
  Transmit Delay is 1 sec, State BDR, Priority 1
  Designated Router (ID) 2.2.2.2, Interface address 172.16.12.2
  Backup Designated router (ID) 1.1.1.1, Interface address 172.16.12.1
  Timer intervals configured, Hello 30, Dead 120, Wait 120, Retransmit 5
<Output omitted>
```

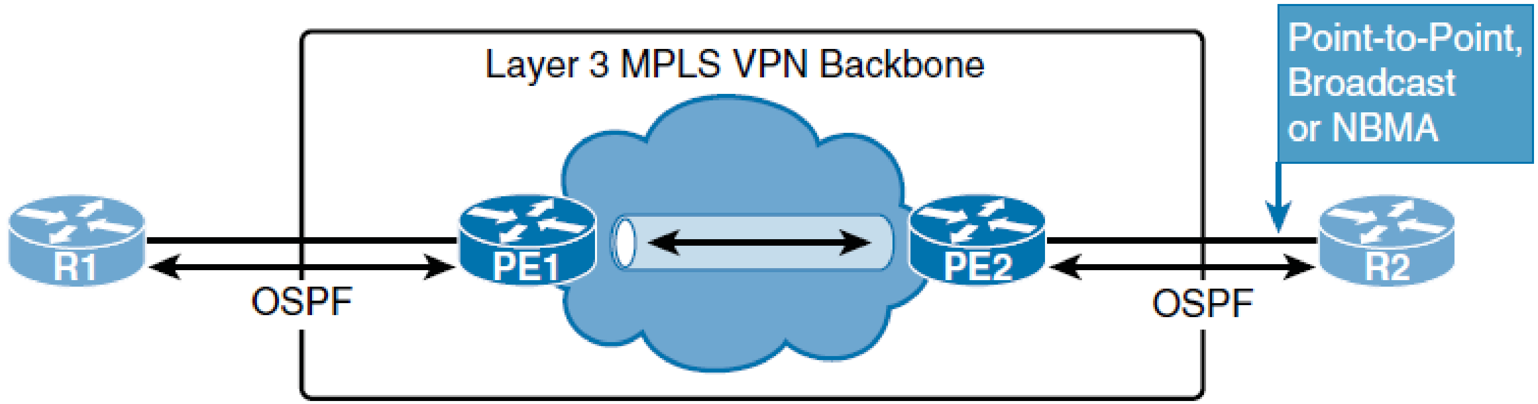
Modifying the Hello and Dead Intervals

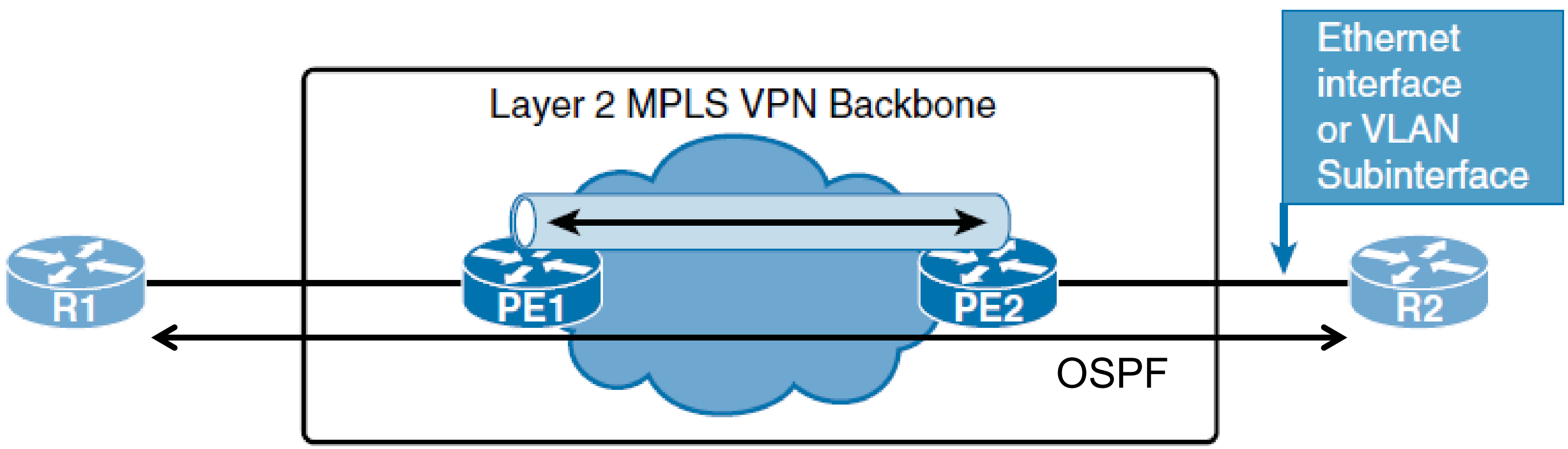
```
R1(config)# interface serial 2/0
R1(config-if)# ip ospf hello-interval 8
R1(config-if)# ip ospf dead-interval 30
*Jan 20 13:17:34.441: %OSPF-5-ADJCHG: Process 1, Nbr 2.2.2.2 on Serial2/0 from
FULL to DOWN, Neighbor Down: Dead timer expired
```

OSPF Relationship over Point-to-Point Links

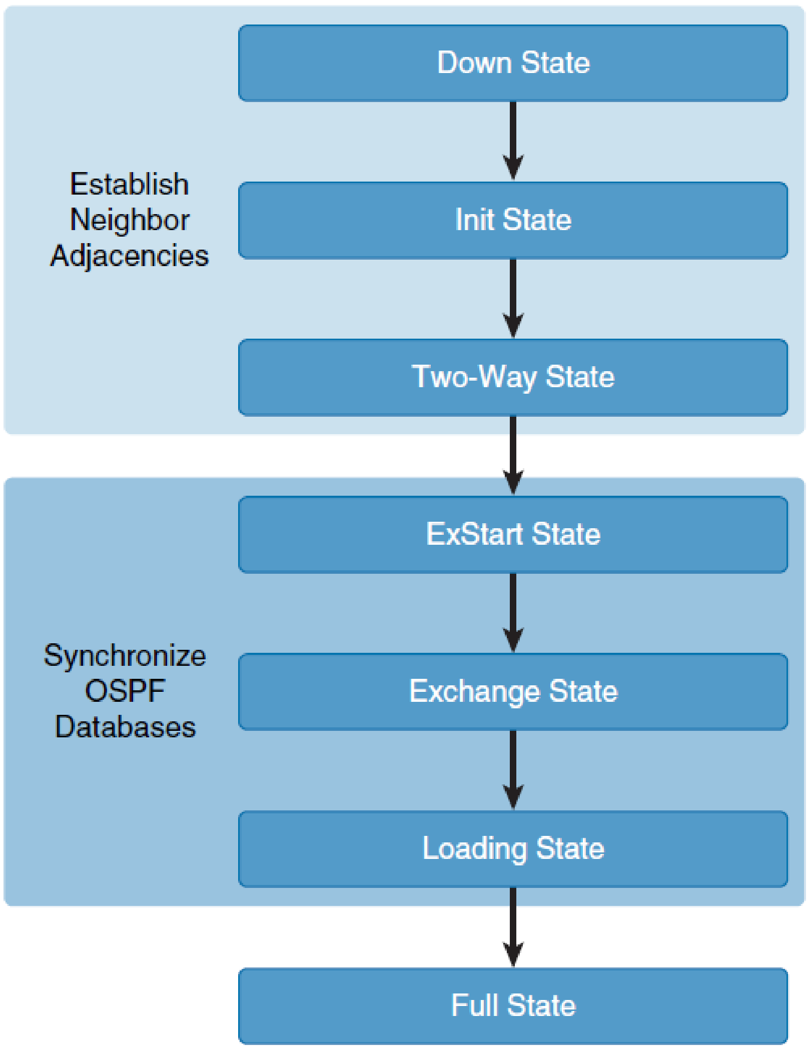
- The routers dynamically detects its neighboring routers by multicasting its Hello packets to all OSPF routers, using the 224.0.0.5 address.
- No DR or BDR election is performed
- The default OSPF hello and dead timers on point-to-point links are 10 seconds and 40 seconds, respectively.

OSPF Neighbor Relationship over MPLS





OSPF Neighbor States



- **Down:** No information has been received on the segment.
- **Init:** The interface has detected a Hello packet coming from a neighbor, but bidirectional
- **2-Way:** There is bidirectional communication with a neighbor. The router has seen itself in the Hello packets coming from a neighbor
- **ExStart:** Routers are trying to establish the initial sequence number that is going to be used in the information exchange packets.
- **Exchange:** Routers will describe their entire LSDB by sending database description (DBD) packets.
- **Loading:** In this state, routers are finalizing the information exchange.
- **Full:** In this state, adjacency is complete.

OSPF Network Types

OSPF Network Type	Uses DR/BDR	Default Hello Interval (sec)	Dynamic Neighbor Discovery	More than Two Routers Allowed in Subnet
Point-to-point	No	10	Yes	No
Broadcast	Yes	10	Yes	Yes
Nonbroadcast	Yes	30	No	Yes
Point-to-multipoint	No	30	Yes	Yes
Point-to-multipoint nonbroadcast	No	30	No	Yes
Looback	No	—	—	No

OSPF Network Types

- **Point-to-point:** Routers use multicast to dynamically discover neighbors. There is no DR/BDR election. It is a default OSPF network type for serial links and point-to-point Frame Relay subinterfaces.
- **Broadcast:** Multicast is used to dynamically discover neighbors. The DR and BDR are elected. It is a default OSPF network type for Ethernet links.
- **Non-broadcast:** Used on networks that interconnect more than two routers but without broadcast capability. Neighbors must be statically configured, followed by DR/BDR election. This network type is the default for all physical interfaces and multipoint subinterfaces using Frame Relay encapsulation.

OSPF Network Types

- **Point-to-multipoint:** OSPF treats this network type as a logical collection of point-to-point links even though all interfaces belong to the common IP subnet. Every interface IP address will appear in the routing table of the neighbors as a host /32 route. Neighbors are discovered dynamically using multicast. No DR/BDR election occurs.
- **Point-to-multipoint non-broadcast:** Cisco extension that has the same characteristics as point-to-multipoint type except for the fact that neighbors are not discovered dynamically. Neighbors must be statically defined, and unicast is used for communication.
- **Loopback:** Default network type on loopback interfaces.

Configuring Passive Interfaces

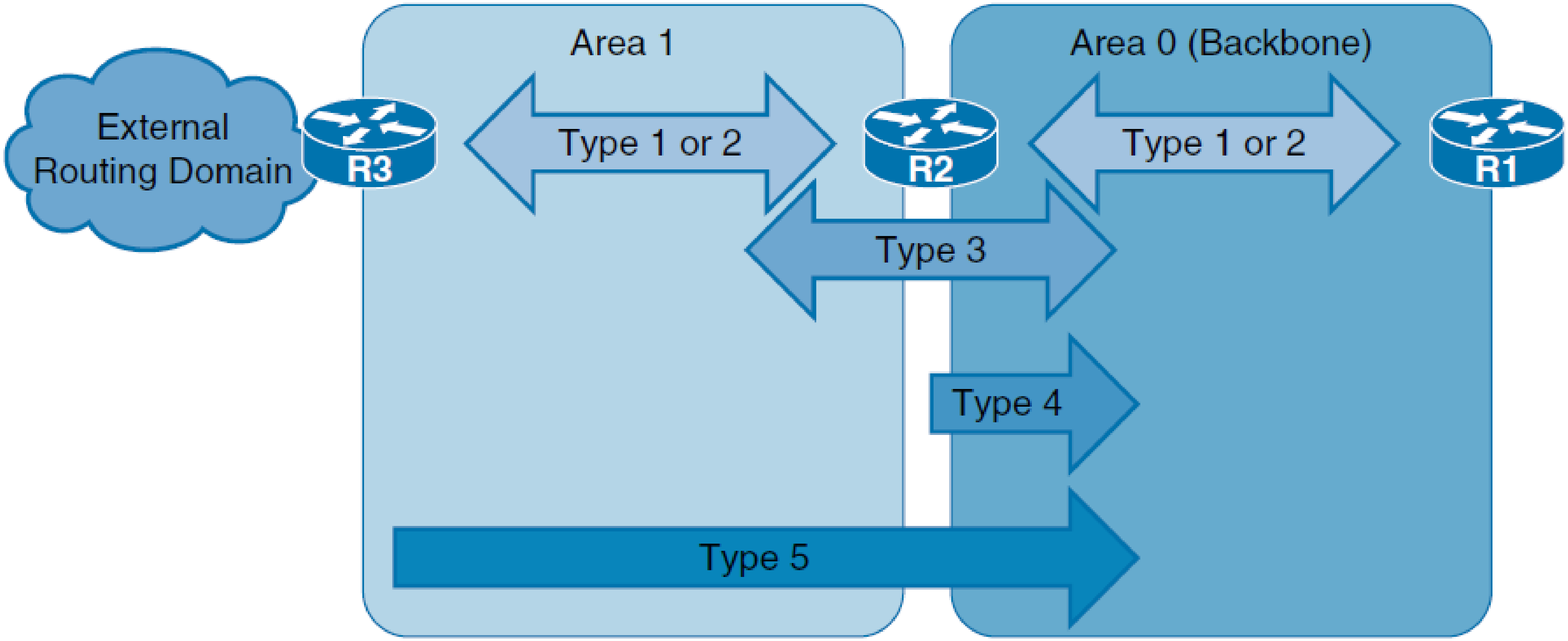
```
Router(config)# router ospf 1
Router(config-if)# passive-interface default
Router(config-if)# no passive-interface serial 1/0
```

Building the Link-State Database

Building the Link-State Database

- List and describe different LSA types
- Describe how OSPF LSAs are also reflooded at periodic intervals
- Describe the exchange of information in a network without a designated router
- Describe the exchange of information in a network with a designated router
- Explain when SPF algorithms occur
- Describe how the cost of intra-area routes is calculated
- Describe how the cost of interarea routes is calculated
- Describe rules selecting between intra-area and interarea routes

OSPF LSA Types



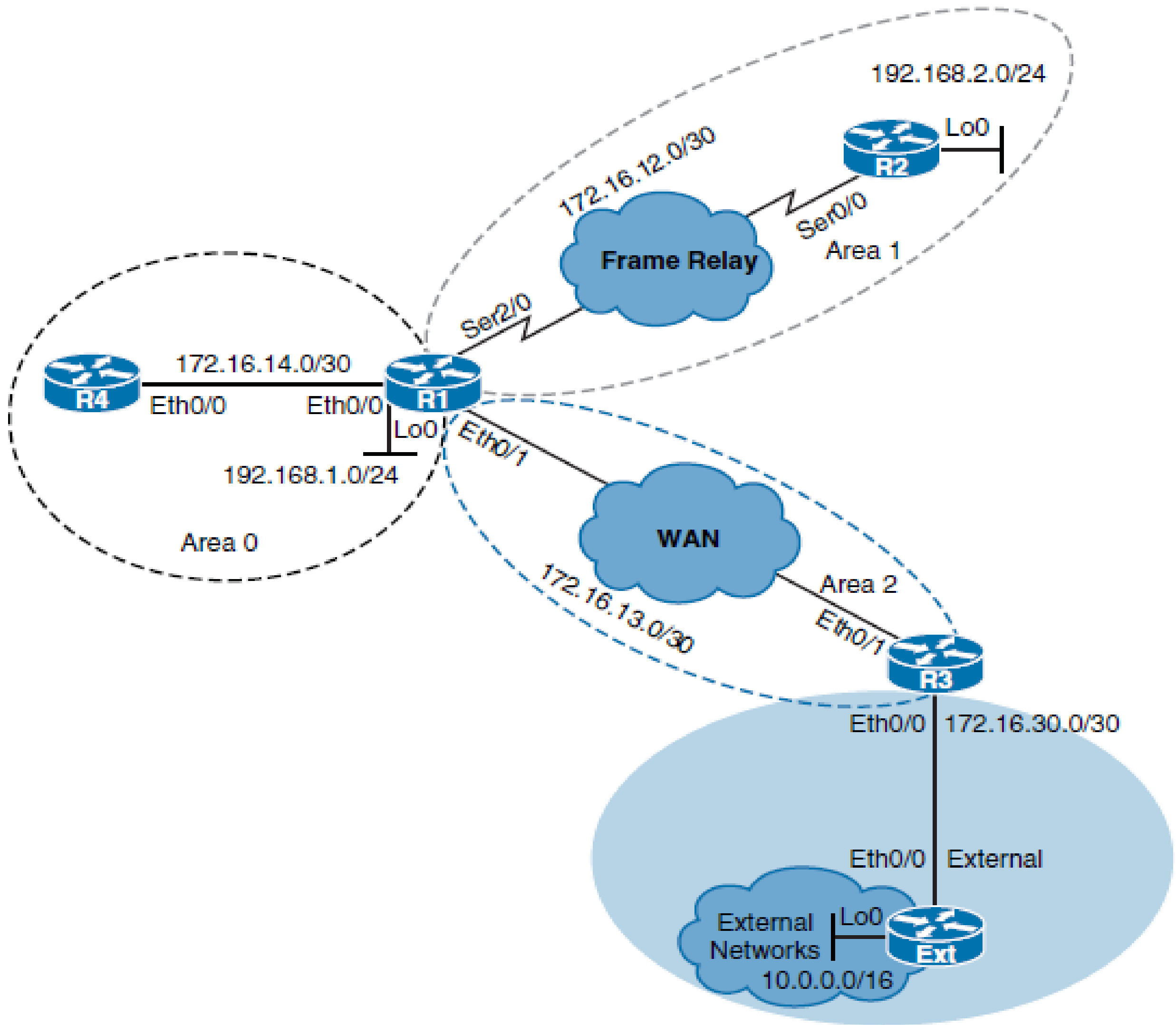
OSPF LSA Types

- **Type 1, Router LSA:** Every router generates router link advertisements for each area to which it belongs. Router link advertisements describe the state of the router links to the area and are flooded only within that particular area. The link-state ID of the type 1 LSA is the originating router ID.
- **Type 2, Network LSA:** DRs generate network link advertisements for multi-access networks. Network link advertisements describe the set of routers that are attached to a particular multiaccess network. Network link advertisements are flooded in the area that contains the network. The link-state ID of the type 2 LSA is the IP interface address of the DR.
- **Type 3, Summary LSA:** An ABR takes the information that it learned in one area and describes and summarizes it for another area in the summary link advertisement. This summarization is not on by default. The link-state ID of the type 3 LSA is the destination network number.
- **Type 4, ASBR Summary LSA:** The ASBR summary link advertisement informs the rest of the OSPF domain how to get to the ASBR. The link-state ID includes the router ID of the described ASBR.
- **Type 5, Autonomous System LSA:** Autonomous system external link advertisements, which are generated by ASBRs, describe routes to destinations that are external to the autonomous system. They get flooded everywhere, except into special areas. The link-state ID of the type 5 LSA is the external network number.

Other LSA Types

- **Type 6:** Specialized LSAs that are used in multicast OSPF applications
- **Type 7:** Used in special area type NSSA for external routes
- **Type 8, 9:** Used in OSPFv3 for link-local addresses and intra-area prefix
- **Type 10, 11:** Generic LSAs, also called *opaque* , which allow future extensions of OSPF

Examining the OSPF Link-State Database



Routing Table

```
R4# show ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      10.0.0.0/16 is subnetted, 1 subnets
O E2     10.0.0.0 [110/20] via 172.16.14.1, 00:46:48, Ethernet0/0
      172.16.0.0/16 is variably subnetted, 4 subnets, 2 masks
O IA     172.16.12.0/30 [110/74] via 172.16.14.1, 03:19:12, Ethernet0/0
O IA     172.16.13.0/30 [110/20] via 172.16.14.1, 03:19:12, Ethernet0/0
C        172.16.14.0/30 is directly connected, Ethernet0/0
L        172.16.14.2/32 is directly connected, Ethernet0/0
O     192.168.1.0/24 [110/11] via 172.16.14.1, 00:36:19, Ethernet0/0
O IA  192.168.2.0/24 [110/75] via 172.16.14.1, 00:47:59, Ethernet0/0
```

OSPF LSDB

```
R4# show ip ospf database

            OSPF Router with ID (4.4.4.4) (Process ID 1)
```

LSA1

```
                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         291         0x8000000B 0x00966C 2
4.4.4.4         4.4.4.4         1993        0x80000007 0x001C4E 1
```

LSA2

```
                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
172.16.14.2     4.4.4.4         1993        0x80000006 0x0091B5
```

LSA3

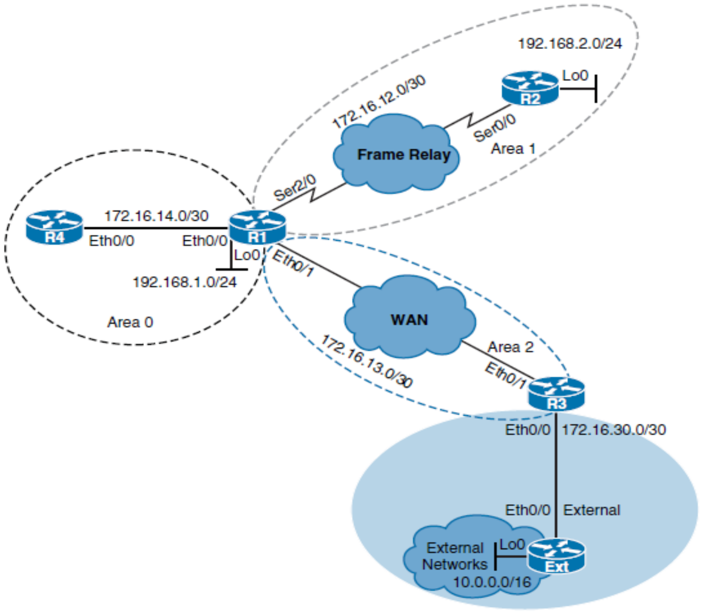
```
                Summary Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
172.16.12.0     1.1.1.1         291         0x80000007 0x00C567
172.16.13.0     1.1.1.1         291         0x80000007 0x009CC5
192.168.2.0     1.1.1.1         1031        0x80000002 0x002F5D
```

LSA4

```
                Summary ASB Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
3.3.3.3         1.1.1.1         1031        0x80000002 0x0035EB
```

LSA5

```
                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#       Checksum   Tag
10.0.0.0          3.3.3.3       977        0x80000002 0x000980     0
```



Type 1 LSA Details

```
R4# show ip ospf database router

            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Router Link States (Area 0)

  Routing Bit Set on this LSA in topology Base with MTID 0
  LS age: 321
  Options: (No TOS-capability, DC)
  LS Type: Router Links
  Link State ID: 1.1.1.1
  Advertising Router: 1.1.1.1
  LS Seq Number: 8000000B
  Checksum: 0x966C
  Length: 48
  Area Border Router
  Number of Links: 2

    Link connected to: a Stub Network
     (Link ID) Network/subnet number: 192.168.1.0
```

Locally Generated Type 1 LSAs

```
R4# show ip ospf database router self-originate

            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Router Link States (Area 0)

  LS age: 23
  Options: (No TOS-capability, DC)
  LS Type: Router Links
  Link State ID: 4.4.4.4
  Advertising Router: 4.4.4.4
  LS Seq Number: 80000008
  Checksum: 0x1A4F
  Length: 36
  Number of Links: 1

    Link connected to: a Transit Network
     (Link ID) Designated Router address: 172.16.14.2
     (Link Data) Router Interface address: 172.16.14.2
      Number of MTID metrics: 0
       TOS 0 Metrics: 10
```

Type 1 LSA

- Type 1 LSAs are generated by every router and flooded within the area.
- They describe the state of the router links in that area.
- When generating a type 1 LSA, the router uses its own router ID as the value of LSID.

OSPF Type 2 Network LSA

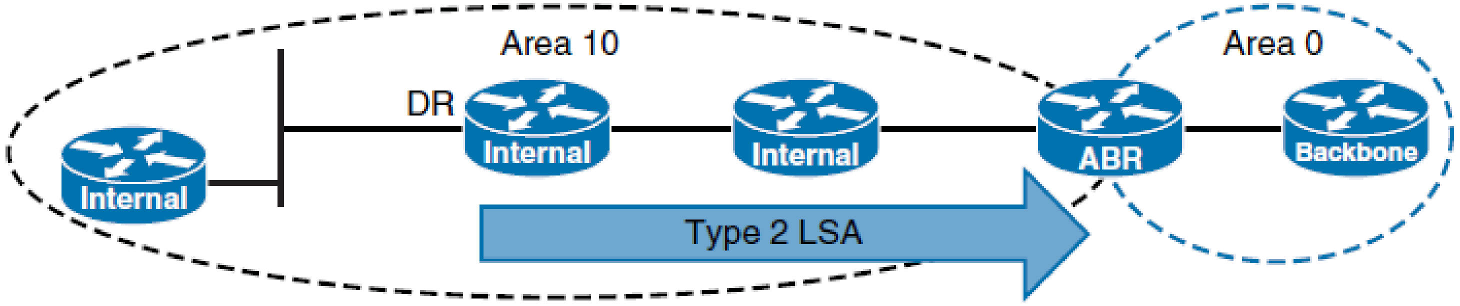
```
R4# show ip ospf database

            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         486         0x8000000B 0x00966C 2
4.4.4.4         4.4.4.4         142         0x80000008 0x001A4F 1

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
172.16.14.2     4.4.4.4         142         0x80000007 0x008FB6
<Output omitted>
```

OSPF Type 2 Network LSA

```
R4# show ip ospf database network

            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Net Link States (Area 0)

  Routing Bit Set on this LSA in topology Base with MTID 0
  LS age: 170
  Options: (No TOS-capability, DC)
  LS Type: Network Links
  Link State ID: 172.16.14.2 (address of Designated Router)
  Advertising Router: 4.4.4.4
  LS Seq Number: 80000007
  Checksum: 0x8FB6
  Length: 32
  Network Mask: /30
        Attached Router: 4.4.4.4
        Attached Router: 1.1.1.1
```

Type 2 LSA

- The DR of the network is responsible for advertising the network LSA
- A type 2 network LSA lists each of the attached routers that make up the network, including the DR itself, and the subnet mask that is used on the link.
- The type 2 LSA then floods to all routers within the transit network area
- Type 2 LSAs never cross an area boundary.
- The LSID for a network LSA is the IP interface address of the DR that advertises it



OSPF Type 3 Summary LSA

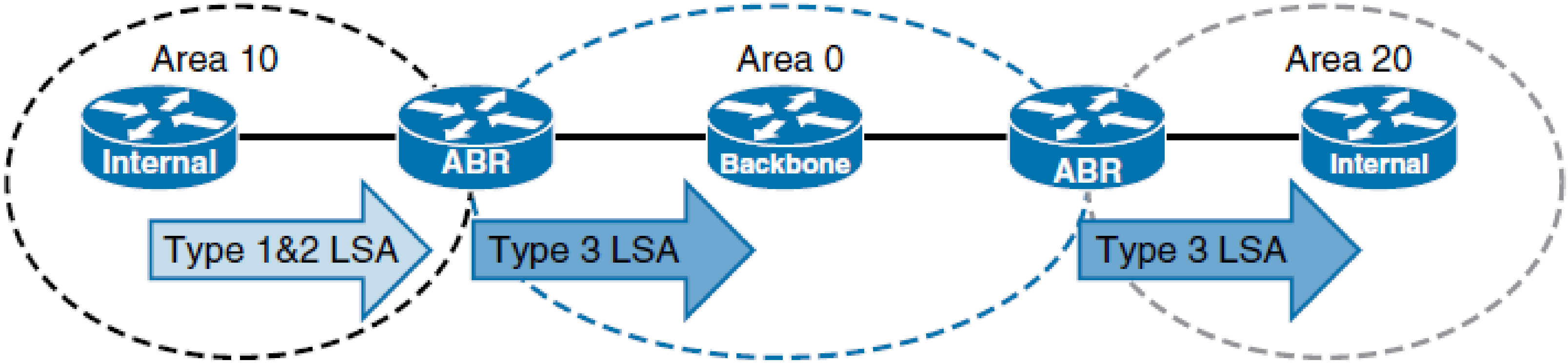
```
R4# show ip ospf database

            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Router Link States (Area 0)
Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         583         0x8000000B 0x00966C 2
4.4.4.4         4.4.4.4         238         0x80000008 0x001A4F 1
                Net Link States (Area 0)
Link ID         ADV Router      Age         Seq#       Checksum
172.16.14.2     4.4.4.4         238         0x80000007 0x008FB6
                Summary Net Link States (Area 0)
Link ID         ADV Router      Age         Seq#       Checksum
172.16.12.0     1.1.1.1         583         0x80000007 0x00C567
172.16.13.0     1.1.1.1         583         0x80000007 0x009CC5
192.168.2.0     1.1.1.1         1322        0x80000002 0x002E5D
<Output omitted>
```

OSPF Type 3 Summary LSA

```
R4# show ip ospf database summary

            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Summary Net Link States (Area 0)

  Routing Bit Set on this LSA in topology Base with MTID 0
  LS age: 608
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 172.16.12.0 (summary Network Number)
  Advertising Router: 1.1.1.1
  LS Seq Number: 80000007
  Checksum: 0xC567
  Length: 28
  Network Mask: /30
        MTID: 0         Metric: 64

  Routing Bit Set on this LSA in topology Base with MTID 0
  LS age: 608
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
```

Type 3 LSA

- The ABRs generate type 3 summary LSAs to describe any networks that are owned by an area to the rest of the areas in the OSPF autonomous system
- Summary LSAs are flooded throughout a single area only, but are regenerated by ABRs to flood into other areas.
- By default, OSPF does not automatically summarize groups of contiguous subnets.
- As a best practice, you can use manual route summarization on ABRs to limit the amount of information that is exchanged between the areas.

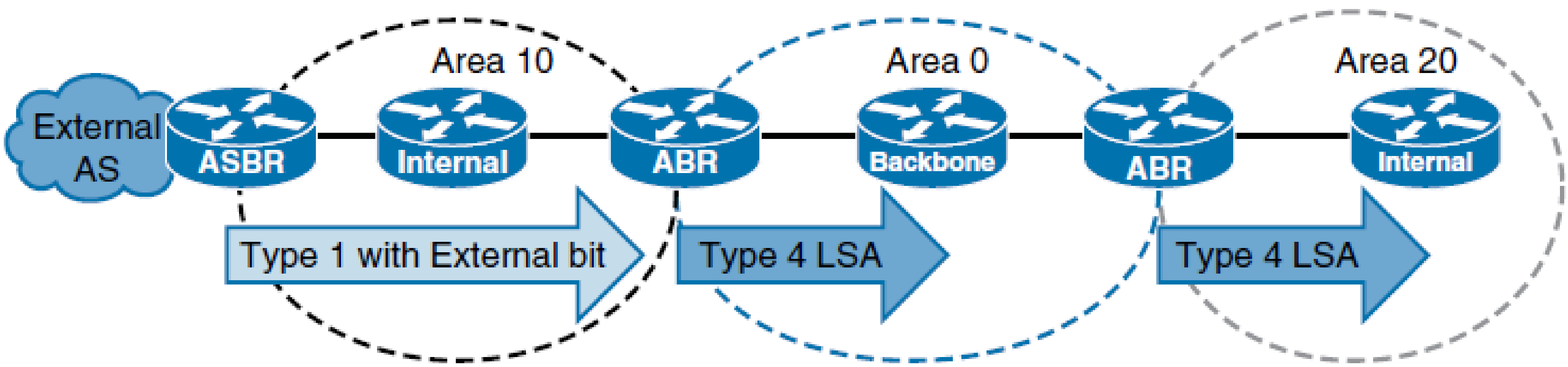


OSPF Type 4 ASBR Summary LSA

```
R4# show ip ospf database asbr-summary

            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Summary ASB Link States (Area 0)

  Routing Bit Set on this LSA in topology Base with MTID 0
  LS age: 1420
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(AS Boundary Router)
  Link State ID: 3.3.3.3 (AS Boundary Router address)
  Advertising Router: 1.1.1.1
  LS Seq Number: 80000002
  Checksum: 0x35EB
  Length: 28
  Network Mask: /0
        MTID: 0          Metric: 10
```

Type 4 LSA

- A type 4 LSA identifies the ASBR and provides a route to the ASBR.
- The link-state ID is set to the ASBR router ID.
- All traffic that is destined to an external autonomous system requires routing table knowledge of the ASBR that originated the external routes.

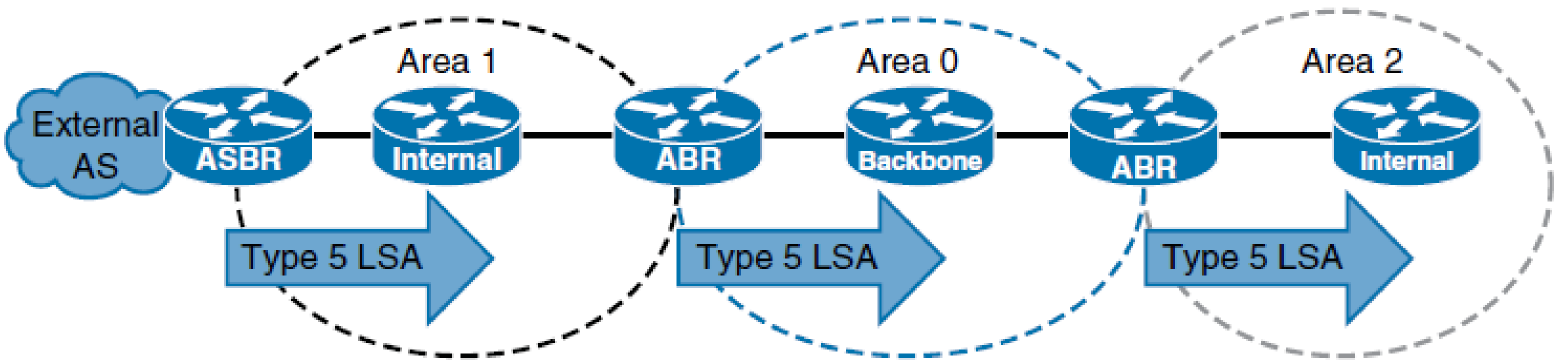


OSPF Type 5 External LSA

```
R4# show ip ospf database external

            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Type-5 AS External Link States

  Routing Bit Set on this LSA in topology Base with MTID 0
  LS age: 1434
  Options: (No TOS-capability, DC, Upward)
  LS Type: AS External Link
  Link State ID: 10.0.0.0 (External Network Number )
  Advertising Router: 3.3.3.3
  LS Seq Number: 80000002
  Checksum: 0x980
  Length: 36
  Network Mask: /16
        Metric Type: 2 (Larger than any link state path)
        MTID: 0
        Metric: 20
        Forward Address: 0.0.0.0
        External Route Tag: 0
```

Type 5 LSA

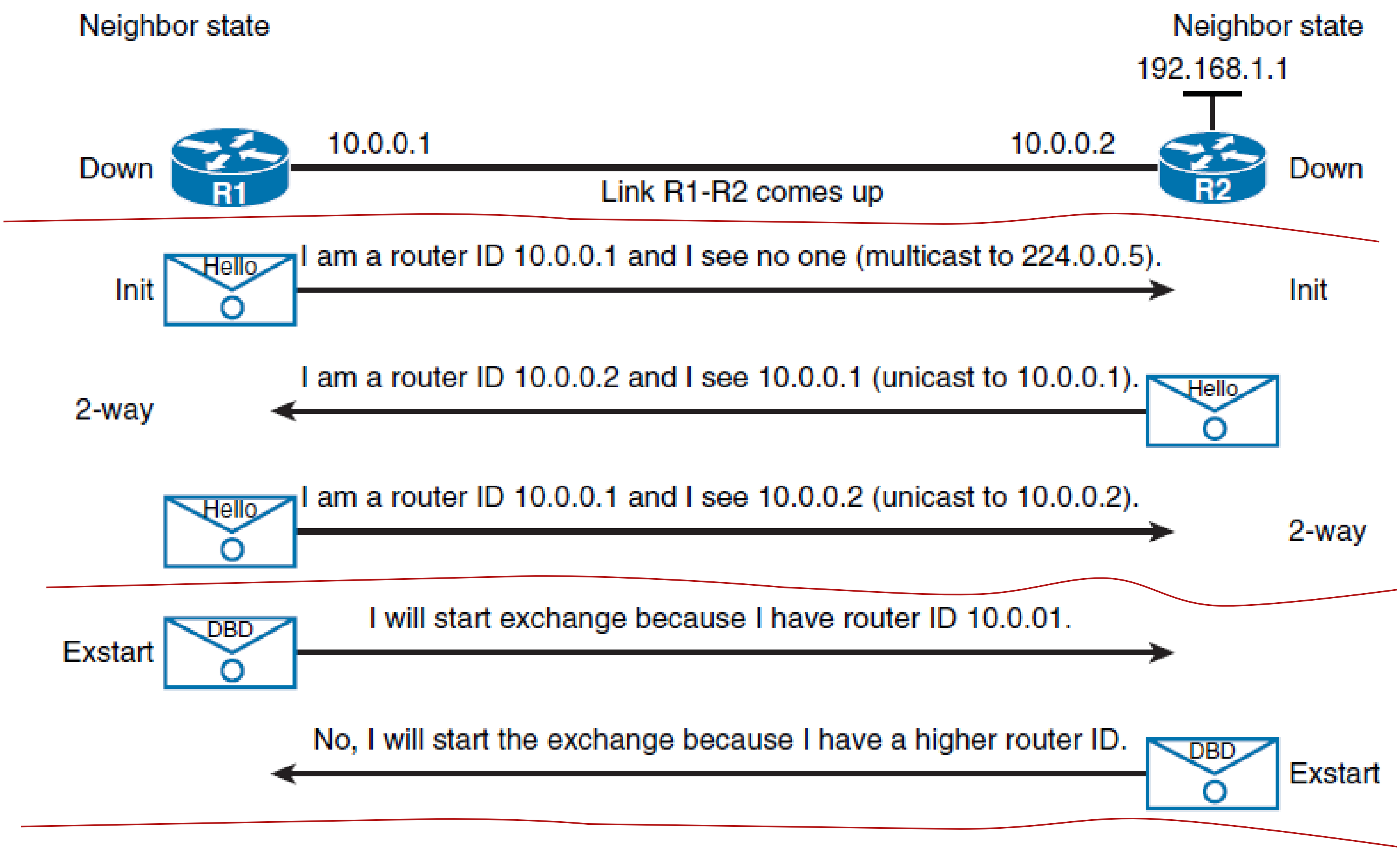
- The LSID is the external network number.
- Information described in the type 5 LSA combined with the information received in the type 4 LSA, which describes the ASBR capability of router R3. This way, R4 learns how to reach the external networks.



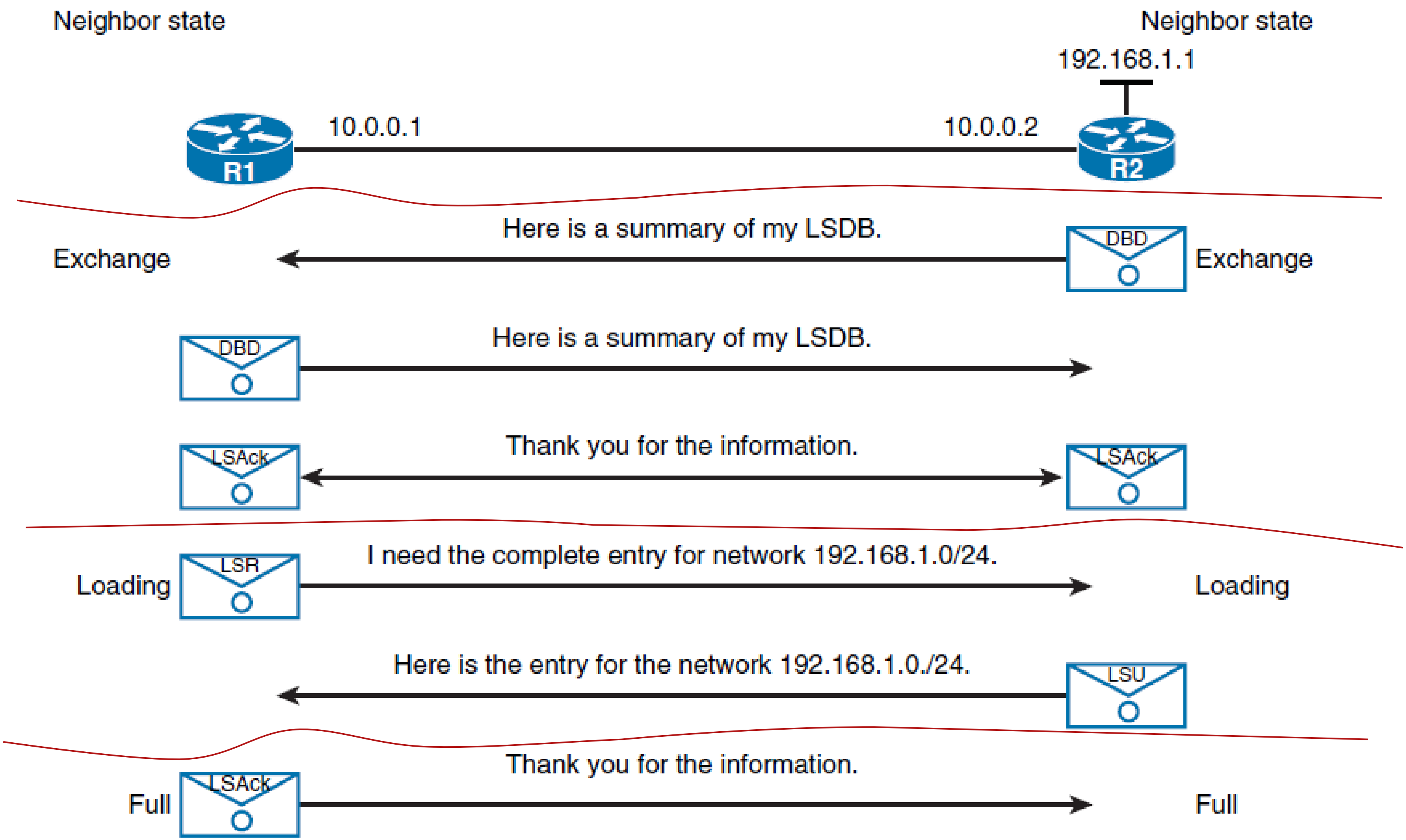
Periodic OSPF Database Changes

- Although OSPF does not refresh routing updates periodically, it does reflood LSAs every 30 minutes.
- Each LSA includes the link-state age variable, which counts the age of the LSA packet
- In a normally operating network, you will not see the age variable with values higher than 1800 seconds.
- When an LSA reaches a max age of 60 minutes in the LSDB, it is removed from the LSDB, and the router will perform a new SPF calculation
- The router floods the LSA to other routers, informing them to remove the LSA as well.
- Because this update is only used to refresh the LSDB, it is sometimes called a ***paranoid update***

Exchanging and Synchronizing LSDBs



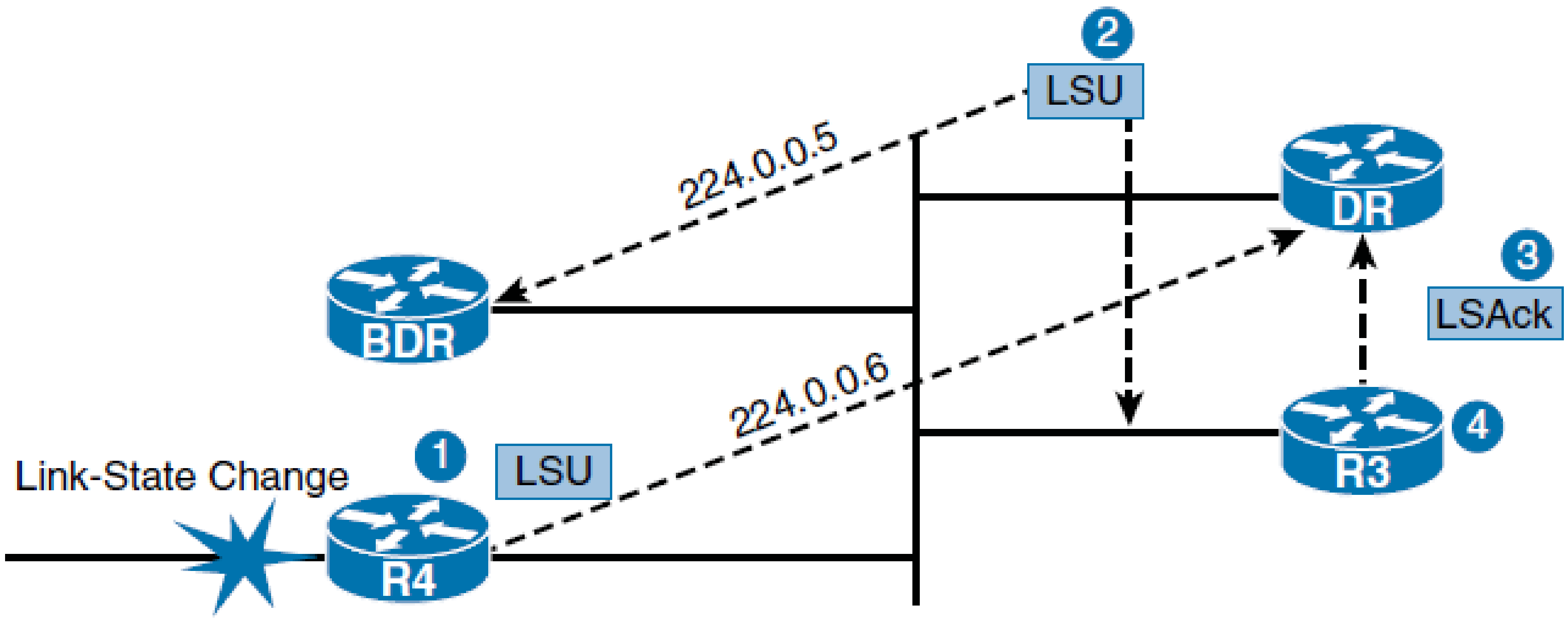
Exchanging and Synchronizing LSDBs



Synchronizing the LSDB on Multiaccess Networks

- When routers form a neighbor relationship on a multiaccess segment, the DR and BDR election takes place when routers are in the 2-Way state.
- The router with a highest OSPF priority, or highest router ID in case of a tie, is elected as a DR. Similarly, the router with the second highest priority or router ID becomes the BDR.
- While the DR and BDR proceed in establishing the neighborship with all routers on the segment, other routers establish full adjacency only with the DR and BDR.
- The neighbor state of other neighbors stays in the 2-Way state.
- Non-DR router exchange their databases only with the DR.
- The DR takes care to synchronize any new or changed LSAs with the rest of the routers on the segment.

Synchronizing the LSDB on Multiaccess Networks



Running the SPF Algorithm

- Every time there is a change in the network topology, OSPF needs to reevaluate its shortest path calculations. OSPF uses SPF to determine best paths toward destinations.
- The network topology that is described in the LSDB is used as an input for calculation.
- Network topology change can influence best path selection; therefore, routers must rerun SPF each time there is an intra-area topology change.
- Inter-area changes, which are described in type 3 LSAs, do not trigger the SPF recalculation because the input information for the best path calculation remains unchanged.
- The router determines the best paths for inter-area routes based on the calculation of the best path toward the ABR.

Verifying OSPF Frequency of the SPF Algorithm

```
R1# show ip ospf | begin Area
    Area BACKBONE(0) (Inactive)
        Number of interfaces in this area is 1
        Area has no authentication
        SPF algorithm last executed 00:35:04:959 ago
        SPF algorithm executed 5 times
        Area ranges are
        Number of opaque link LSA 0. Checksum Sum 0x000000
```

OSPF Best Path Calculation

- Once LSDBs are synchronized among OSPF neighbors, each router needs to determine on its own the best paths over the network topology.
- SPF it compares total costs of specific paths against each other. The paths with the lowest costs are selected as the best paths.
- OSPF cost is computed automatically for each interface that is assigned into an OSPF process, using the following formula:

  Cost = Reference bandwidth / Interface bandwidth
- The cost value is a 16-bit positive number between 1 and 65,535, where a lower value is a more desirable metric.
- Reference bandwidth is set to 100 Mbps by default.
- On high-bandwidth links (100 Mbps and more), automatic cost assignment no longer works
- “On these links, OSPF costs must be set manually on each interface.”
- The OSPF cost is recomputed after every bandwidth change, and the Dijkstra’s algorithm determines the best path by adding all link costs along a path.

Examining the Interface Bandwidth and OSPF Cost

```
R1# show interface serial 2/0
Serial2/0 is up, line protocol is up
  Hardware is M4T
  Internet address is 172.16.12.1/30
  MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation FRAME-RELAY, crc 16, loopback not set
<Output omitted>


R1# show ip ospf interface serial 2/0
Serial2/0 is up, line protocol is up
  Internet Address 172.16.12.1/30, Area 1, Attached via Network Statement
  Process ID 1, Router ID 1.1.1.1, Network Type NON_BROADCAST, Cost: 64
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           64        no          no            Base
  Transmit Delay is 1 sec, State BDR, Priority 1
  Designated Router (ID) 2.2.2.2, Interface address 172.16.12.2
  Backup Designated router (ID) 1.1.1.1, Interface address 172.16.12.1
  Timer intervals configured, Hello 30, Dead 120, Wait 120, Retransmit 5
 <Output omitted>
```

Default OSPF Costs

Link Type	Default Cost
T1 (1.544-Mbps serial link)	64
Ethernet	10
Fast Ethernet	1
Gigabit Ethernet	1
10-Gigabit Ethernet	1

Modifying the Reference Bandwidth

```
R1(config)# router ospf 1
R1(config-router)# auto-cost reference-bandwidth 10000
% OSPF: Reference bandwidth is changed.
        Please ensure reference bandwidth is consistent across all routers.
```

```
R1# show ip ospf interface serial 2/0
Serial2/0 is up, line protocol is up
  Internet Address 172.16.12.1/30, Area 1, Attached via Network Statement
  Process ID 1, Router ID 1.1.1.1, Network Type NON_BROADCAST, Cost: 6476
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0           6476      no          no             Base
<Output omitted>
```

Changing the Interface Bandwidth and OSPF Cost

```
R1(config)# interface serial 2/0
R1(config-if)# bandwidth 10000
```

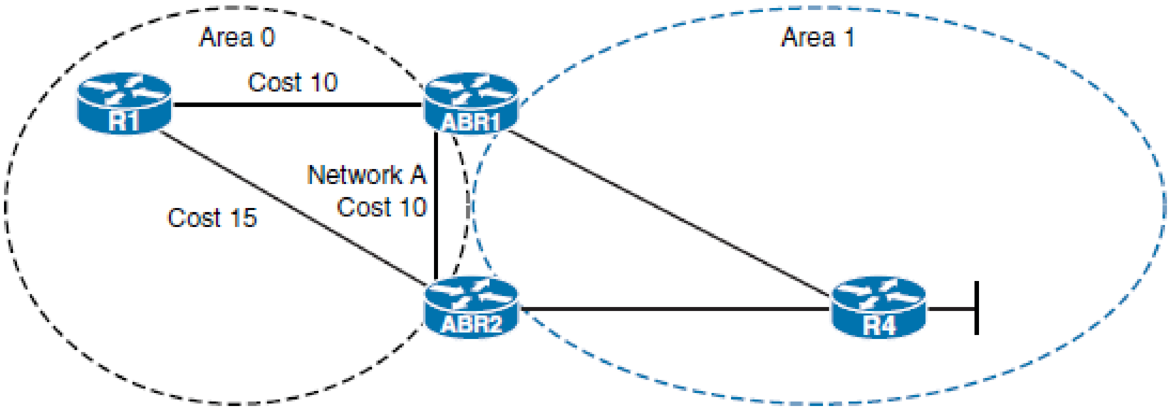
```
R1# show interfaces serial 2/0
Serial2/0 is up, line protocol is up
  Hardware is M4T
  Internet address is 172.16.12.1/30
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 20000 usec,
<Output omitted>
R1# show ip ospf interface serial 2/0
Serial2/0 is up, line protocol is up
  Internet Address 172.16.12.1/30, Area 1, Attached via Network Statement
  Process ID 1, Router ID 1.1.1.1, Network Type NON_BROADCAST, Cost: 1000
  Topology-MTID    Cost    Disabled    Shutdown     Topology Name
        0          1000      no           no            Base
<Output omitted>
```

```
R1(config)# interface serial 2/0
R1(config-if)# ip ospf cost 500
```

```
R1# show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Lo0          1     0               192.168.1.1/24     1     P2P   0/0
Et0/0        1     0               172.16.14.1/30     1000  DR    1/1
Se2/0        1     1               172.16.12.1/30     500   BDR   1/1
Et0/1        1     2               172.16.13.1/30     1000  BDR   1/1
```

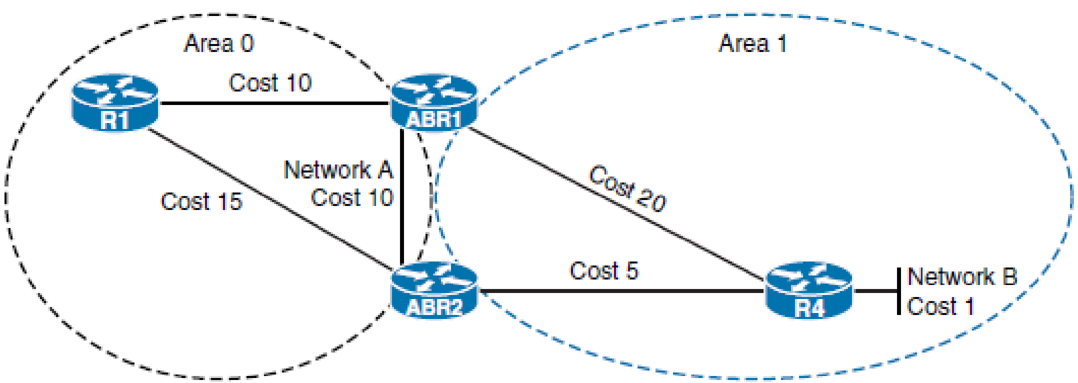
Calculating the Cost of Intra-Area Routes

- To calculate the cost of intra-area routes, the router first analyzes OSPF database and identifies all subnets within its area.
- For each possible route, OSPF calculates the cost to reach the destination by summing up the individual interface costs.
- For each subnet, the route with the lowest total cost is selected as the best route.



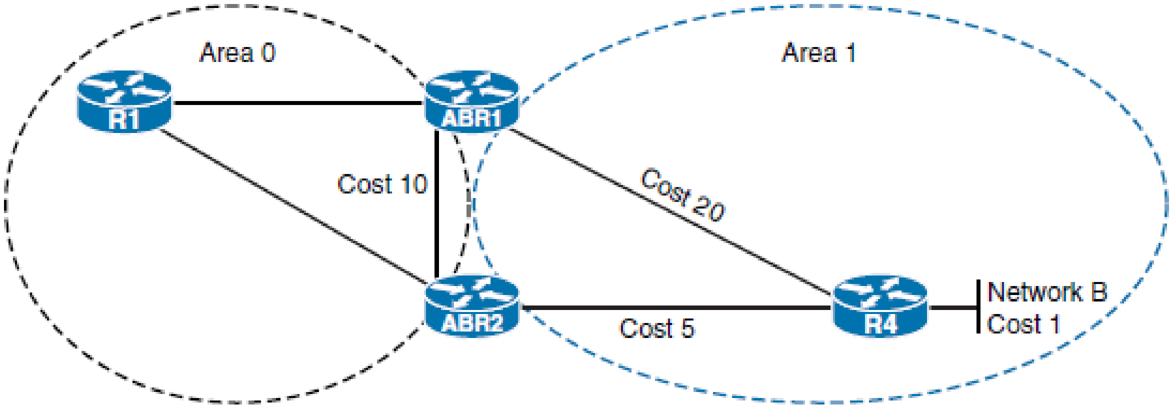
Calculating the Cost of Inter-area Routes

- The internal OSPF router within an area receives only summarized info about inter-area routes.
- As a result, the cost of an inter-area route cannot be calculated the same way as for the intra-area routes.
- When ABRs propagate information about the inter-area routes with type 3 LSAs, they include their lowest cost to reach a specific subnet in the advertisement.
- The internal router adds its cost to reach a specific ABR to the cost announced in a type 3 LSA.
- Then it selects the route with the lowest total cost as the best route.



Selecting Between Intra-Area and Inter-area Routes

- To eliminate the single point of failure on area borders, at least two ABRs are used in most networks.
- As a result, ABR can learn about a specific subnet from internal routers and also from the other ABR.
- ABR can learn an intra-area route and also an inter-area route for the same destination.
- Even though the inter-area route could have lower cost to the specific subnet, the intra-area path is always the preferred choice.



Optimizing OSPF Behavior

Optimizing OSPF Behavior

- Describe the properties of OSPF route summarization
- Describe benefits of route summarization in OSPF
- Configure summarization on ABR
- Configure summarization on ASBR
- Configure the cost of OSPF default route
- Describe how you can use default routes and stub routing to direct traffic toward the Internet
- Describe the NSSA areas
- Configure the default route using the **default-information originate** command

OSPF Route Summarization

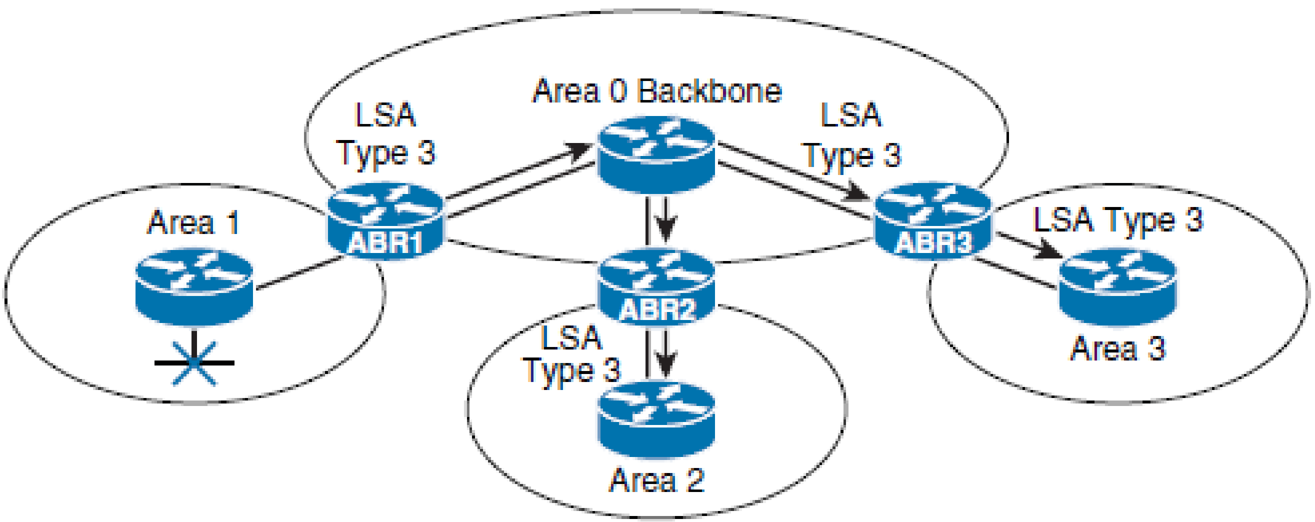
- Route summarization is a key to scalability in OSPF.
- Route summarization helps solve two major problems:
  - Large routing tables
  - Frequent LSA flooding throughout the autonomous system
- Every time that a route disappears in one area, routers in other areas also get involved in shortest-path calculation.
- To reduce the size of the area database, you can configure summarization on an area boundary or autonomous system boundary.

OSPF Route Summarization Process

- Normally, type 1 and type 2 LSAs are generated inside each area and translated into type 3 LSAs in other areas.
- With route summarization, the ABRs or ASBRs consolidate multiple routes into a single advertisement. ABRs summarize type 3 LSAs, and ASBRs summarize type 5 LSAs.
- Instead of advertising many specific prefixes, advertise only one summary prefix.
- Route summarization requires a good addressing plan—an assignment of subnets and addresses that is based on the OSPF area structure and lends itself to aggregation at the OSPF area borders.

Benefits of Route Summarization

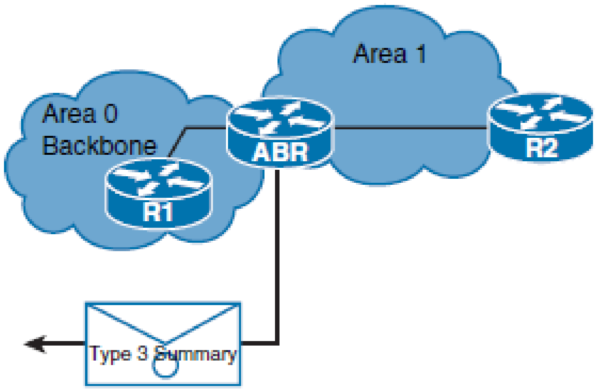
- Route summarization directly affects the amount of bandwidth, CPU power, and memory resources that the OSPF routing process consumes.
- With route summarization, only the summarized routes are propagated into the backbone (area 0) increasing the stability of the network
- The routes being advertised in the type 3 LSAs are appropriately added to or deleted from the router's routing table, but an SPF calculation is not done.



OSPF Route Summarization

- OSPF offers two methods of route summarization:
  - Summarization of internal routes performed on the ABRs
  - Summarization of external routes performed on the ASBRs

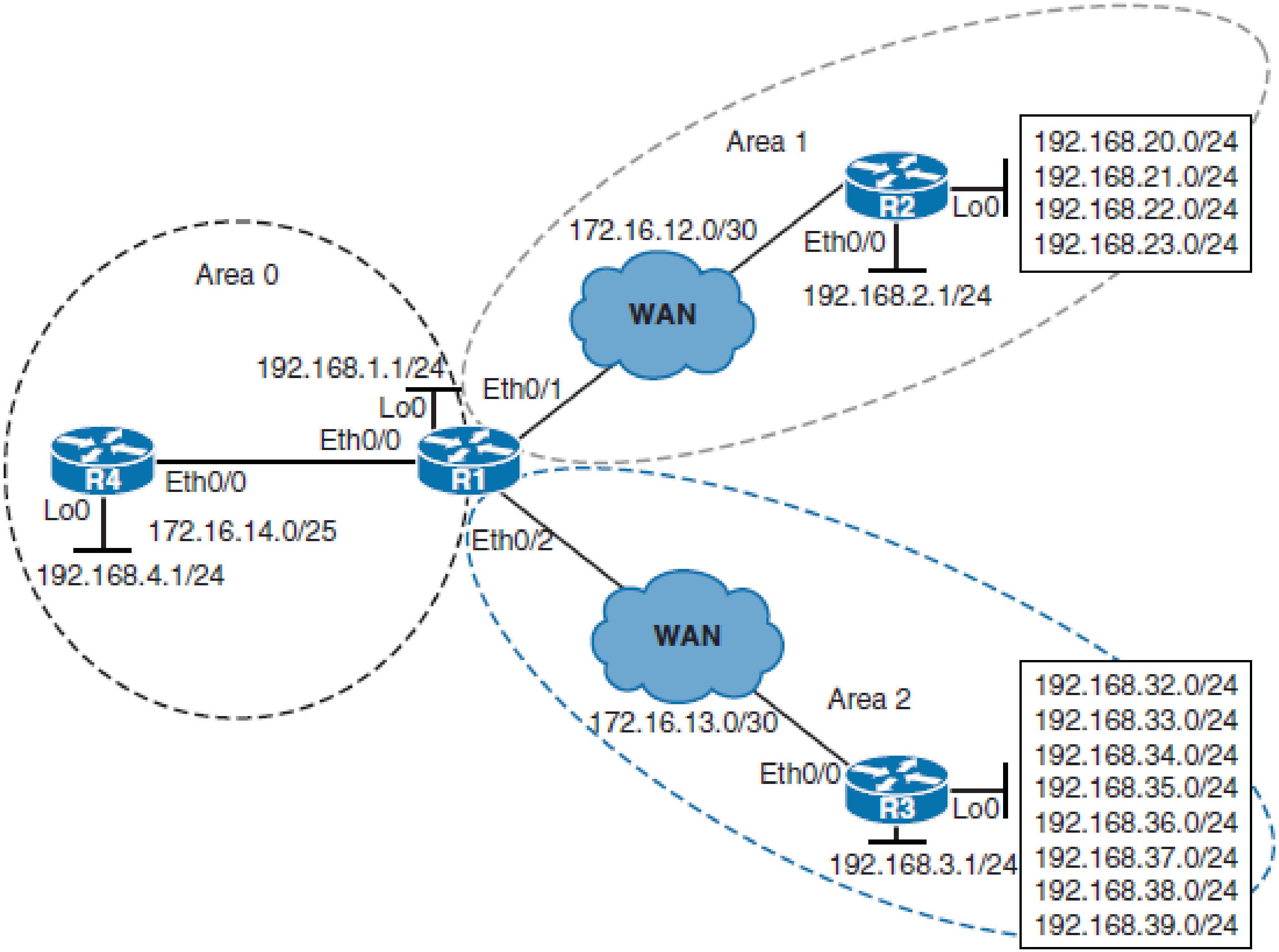
ABR's Summarization



Parameter	Description
area-id	Identifier of the area about which routes are to be summarized. It can be specified as either a decimal value or as an IP address.
ip-address	IP address.
mask	IP address mask.
advertise	(Optional) Sets the address range status to advertise and generates a type 3 summary LSA.
not-advertise	(Optional) Sets the address range status to DoNotAdvertise. The Type 3 summary LSA is suppressed, and the component networks remain hidden from other networks.
cost *cost*	(Optional) Metric or cost for this summary route, which is used during OSPF SPF calculation to determine the shortest paths to the destination. The value can be 0 to 16,777,215.

- **area** *area-id* **range** *ip-address mask* [**advertise** | **not-advertise**] [**cost** *cost*]

Configuring OSPF Route Summarization



Configuring OSPF Route Summarization

```
R1# show ip route ospf
<Output omitted>

O     192.168.2.0/24 [110/11] via 172.16.12.2, 00:41:47, Ethernet0/1
O     192.168.3.0/24 [110/11] via 172.16.13.2, 00:40:01, Ethernet0/2
O     192.168.4.0/24 [110/11] via 172.16.14.2, 00:38:09, Ethernet0/0
O     192.168.20.0/24 [110/11] via 172.16.12.2, 00:41:37, Ethernet0/1
O     192.168.21.0/24 [110/11] via 172.16.12.2, 01:03:46, Ethernet0/1
O     192.168.22.0/24 [110/11] via 172.16.12.2, 01:03:36, Ethernet0/1
O     192.168.23.0/24 [110/11] via 172.16.12.2, 01:03:26, Ethernet0/1
O     192.168.32.0/24 [110/11] via 172.16.13.2, 00:40:14, Ethernet0/2
O     192.168.33.0/24 [110/11] via 172.16.13.2, 00:57:01, Ethernet0/2
O     192.168.34.0/24 [110/11] via 172.16.13.2, 00:01:16, Ethernet0/2
O     192.168.35.0/24 [110/11] via 172.16.13.2, 00:01:06, Ethernet0/2
O     192.168.36.0/24 [110/11] via 172.16.13.2, 00:00:56, Ethernet0/2
O     192.168.37.0/24 [110/11] via 172.16.13.2, 00:00:46, Ethernet0/2
O     192.168.38.0/24 [110/11] via 172.16.13.2, 00:00:32, Ethernet0/2
O     192.168.39.0/24 [110/11] via 172.16.13.2, 00:00:18, Ethernet0/2
```

Configuring OSPF Route Summarization

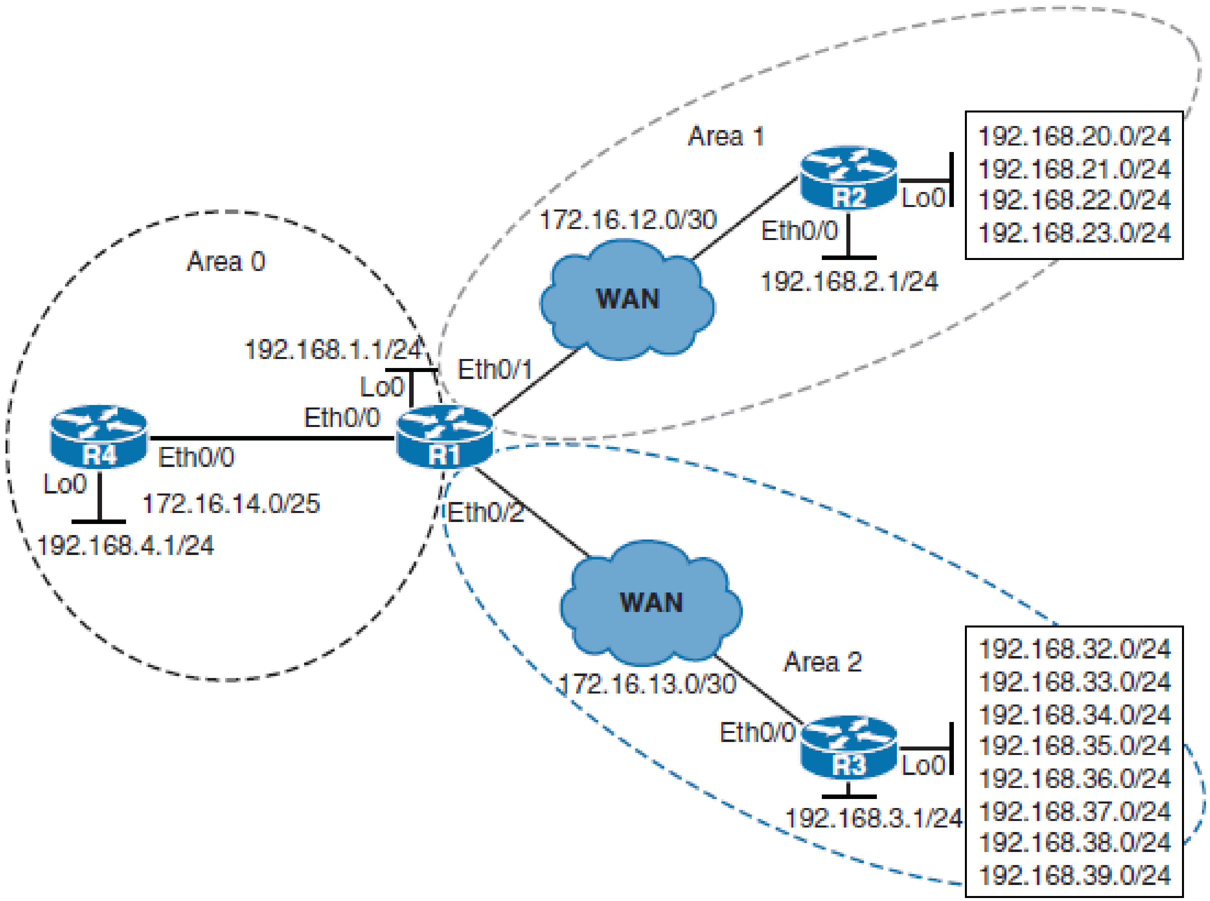
```
R4# show ip route ospf
<Output omitted>

      172.16.0.0/16 is variably subnetted, 4 subnets, 3 masks
O IA     172.16.12.0/30 [110/20] via 172.16.14.1, 01:17:30, Ethernet0/0
O IA     172.16.13.0/30 [110/20] via 172.16.14.1, 01:17:30, Ethernet0/0
O     192.168.1.0/24 [110/11] via 172.16.14.1, 01:17:30, Ethernet0/0
O IA  192.168.2.0/24 [110/21] via 172.16.14.1, 00:49:23, Ethernet0/0
O IA  192.168.3.0/24 [110/21] via 172.16.14.1, 00:47:37, Ethernet0/0
O IA  192.168.20.0/24 [110/21] via 172.16.14.1, 00:49:08, Ethernet0/0
O IA  192.168.21.0/24 [110/21] via 172.16.14.1, 01:11:23, Ethernet0/0
O IA  192.168.22.0/24 [110/21] via 172.16.14.1, 01:11:13, Ethernet0/0
O IA  192.168.23.0/24 [110/21] via 172.16.14.1, 01:11:03, Ethernet0/0
O IA  192.168.32.0/24 [110/21] via 172.16.14.1, 00:47:50, Ethernet0/0
O IA  192.168.33.0/24 [110/21] via 172.16.14.1, 01:04:37, Ethernet0/0
O IA  192.168.34.0/24 [110/21] via 172.16.14.1, 00:02:26, Ethernet0/0
O IA  192.168.35.0/24 [110/21] via 172.16.14.1, 00:02:16, Ethernet0/0
O IA  192.168.36.0/24 [110/21] via 172.16.14.1, 00:02:06, Ethernet0/0
O IA  192.168.37.0/24 [110/21] via 172.16.14.1, 00:01:56, Ethernet0/0
O IA  192.168.38.0/24 [110/21] via 172.16.14.1, 00:01:43, Ethernet0/0
O IA  192.168.39.0/24 [110/21] via 172.16.14.1, 00:01:28, Ethernet0/0
```

Configuring OSPF Route Summarization

```
R4# show ip ospf database

            OSPF Router with ID (4.4.4.4) (Process ID 1)

                Summary Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
172.16.12.0     1.1.1.1         553         0x80000008 0x00A5BC
172.16.13.0     1.1.1.1         553         0x80000008 0x009AC6
192.168.2.0     1.1.1.1         1541        0x80000006 0x0008B5
192.168.3.0     1.1.1.1         3607        0x80000007 0x008C3A
192.168.20.0    1.1.1.1         1541        0x8000000B 0x00376F
192.168.21.0    1.1.1.1         1800        0x80000004 0x003A72
192.168.22.0    1.1.1.1         1800        0x80000004 0x002F7C
192.168.23.0    1.1.1.1         1800        0x80000004 0x002486
192.168.32.0    1.1.1.1         3607        0x80000007 0x004C5D
192.168.33.0    1.1.1.1         3607        0x80000008 0x003F68
192.168.34.0    1.1.1.1         3607        0x80000002 0x00406C
192.168.35.0    1.1.1.1         3607        0x80000002 0x003576
192.168.36.0    1.1.1.1         3607        0x80000002 0x002A80
192.168.37.0    1.1.1.1         3607        0x80000002 0x001F8A
192.168.38.0    1.1.1.1         3607        0x80000002 0x001494
192.168.39.0    1.1.1.1         3607        0x80000002 0x00099E
```

Configuring Summarization on the ABR

```
R1(config)# router ospf 1
R1(config-router)# area 1 range 192.168.20.0 255.255.252.0
R1(config-router)# area 2 range 192.168.32.0 255.255.248.0
```



Configuring OSPF Route Summarization

```
R2# show ip route ospf
<Output omitted>

      172.16.0.0/16 is variably subnetted, 4 subnets, 3 masks
O IA     172.16.13.0/30 [110/20] via 172.16.12.1, 05:27:05, Ethernet0/0
O IA     172.16.14.0/25 [110/20] via 172.16.12.1, 05:07:35, Ethernet0/0
O IA  192.168.1.0/24 [110/11] via 172.16.12.1, 05:27:09, Ethernet0/0
O IA  192.168.3.0/24 [110/21] via 172.16.12.1, 01:24:16, Ethernet0/0
O IA  192.168.4.0/24 [110/21] via 172.16.12.1, 04:32:02, Ethernet0/0
O IA  192.168.32.0/21 [110/21] via 172.16.12.1, 00:57:42, Ethernet0/0
```

```
R3# show ip route ospf
<Output omitted>

      172.16.0.0/16 is variably subnetted, 4 subnets, 3 masks
O IA     172.16.12.0/30 [110/20] via 172.16.13.1, 05:25:50, Ethernet0/0
O IA     172.16.14.0/25 [110/20] via 172.16.13.1, 05:10:02, Ethernet0/0
O IA  192.168.1.0/24 [110/11] via 172.16.13.1, 05:25:50, Ethernet0/0
O IA  192.168.2.0/24 [110/21] via 172.16.13.1, 04:38:07, Ethernet0/0
O IA  192.168.4.0/24 [110/21] via 172.16.13.1, 04:34:29, Ethernet0/0
O IA  192.168.20.0/22 [110/21] via 172.16.13.1, 01:00:19, Ethernet0/0
```

Configuring OSPF Route Summarization

```
R4# show ip route ospf
<Output omitted>

      172.16.0.0/16 is variably subnetted, 4 subnets, 3 masks
O IA     172.16.12.0/30 [110/20] via 172.16.14.1, 05:16:24, Ethernet0/0
O IA     172.16.13.0/30 [110/20] via 172.16.14.1, 05:16:24, Ethernet0/0
O     192.168.1.0/24 [110/11] via 172.16.14.1, 05:16:24, Ethernet0/0
O IA  192.168.2.0/24 [110/21] via 172.16.14.1, 04:48:17, Ethernet0/0
O IA  192.168.3.0/24 [110/21] via 172.16.14.1, 01:36:53, Ethernet0/0
O IA  192.168.20.0/22 [110/21] via 172.16.14.1, 01:10:29, Ethernet0/0
O IA  192.168.32.0/21 [110/21] via 172.16.14.1, 01:10:19, Ethernet0/0
```

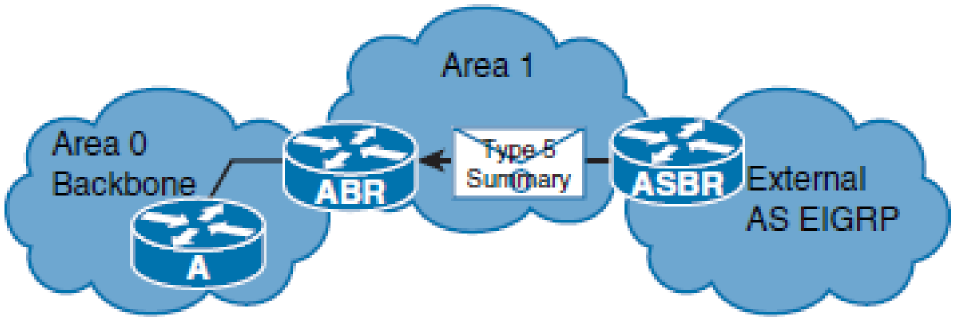
Configuring OSPF Route Summarization

```
R4# show ip ospf database
<Output omitted>

                Summary Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum
172.16.12.0     1.1.1.1         599         0x8000000B 0x009FBF
172.16.13.0     1.1.1.1         599         0x8000000B 0x0094C9
192.168.2.0     1.1.1.1         1610        0x80000009 0x0002B8
192.168.3.0     1.1.1.1         98          0x80000004 0x0001BD
192.168.20.0    1.1.1.1         599         0x8000000F 0x002085
192.168.32.0    1.1.1.1         98          0x80000005 0x009B0C
```

Configuring OSPF Route Summarization

```
R1# show ip route ospf
<Output omitted>

O      192.168.2.0/24 [110/11] via 172.16.12.2, 01:18:25, Ethernet0/1
O      192.168.3.0/24 [110/11] via 172.16.13.2, 01:18:25, Ethernet0/2
O      192.168.4.0/24 [110/11] via 172.16.14.2, 01:18:25, Ethernet0/0
O      192.168.20.0/22 is a summary, 01:18:25, Null0
O      192.168.20.0/24 [110/11] via 172.16.12.2, 01:18:25, Ethernet0/1
O      192.168.21.0/24 [110/11] via 172.16.12.2, 01:18:25, Ethernet0/1
O      192.168.22.0/24 [110/11] via 172.16.12.2, 01:18:25, Ethernet0/1
O      192.168.23.0/24 [110/11] via 172.16.12.2, 01:18:25, Ethernet0/1
O      192.168.32.0/21 is a summary, 01:18:25, Null0
O      192.168.32.0/24 [110/11] via 172.16.13.2, 01:18:25, Ethernet0/2
O      192.168.33.0/24 [110/11] via 172.16.13.2, 01:18:25, Ethernet0/2
O      192.168.34.0/24 [110/11] via 172.16.13.2, 01:18:25, Ethernet0/2
O      192.168.35.0/24 [110/11] via 172.16.13.2, 01:18:25, Ethernet0/2
O      192.168.36.0/24 [110/11] via 172.16.13.2, 01:18:25, Ethernet0/2
O      192.168.37.0/24 [110/11] via 172.16.13.2, 01:18:25, Ethernet0/2
O      192.168.38.0/24 [110/11] via 172.16.13.2, 01:18:25, Ethernet0/2
O      192.168.39.0/24 [110/11] via 172.16.13.2, 01:18:25, Ethernet0/2
```

Summarization on ASBR's



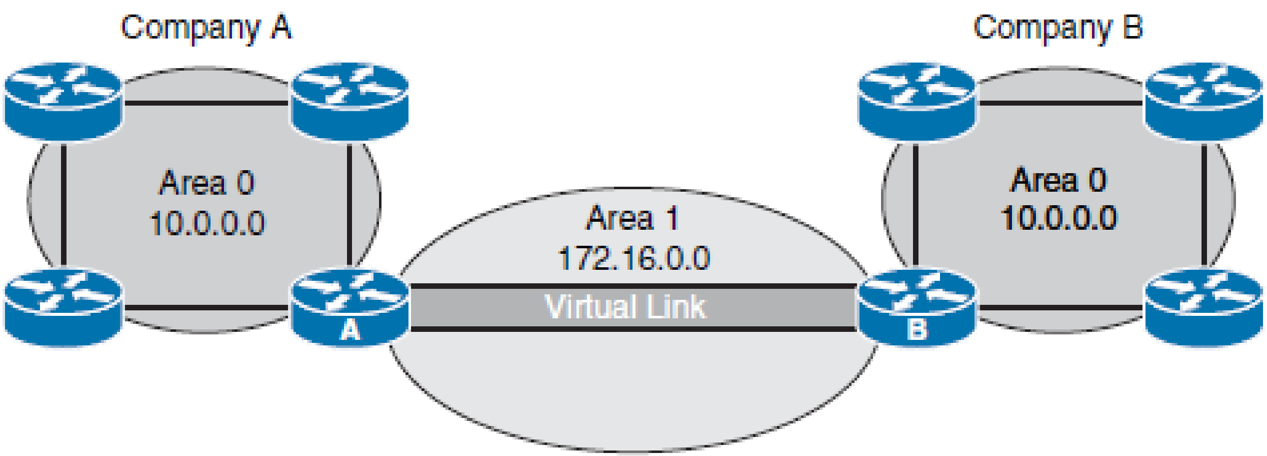
Parameter	Description
ip-address	Summary address designated for a range of addresses.
mask	IP subnet mask used for the summary route.
prefix	IP route prefix for the destination.
mask	IP subnet mask used for the summary route.
not-advertise	(Optional) Suppress routes that match the specified prefix/mask pair. This keyword applies to OSPF only.
tag *tag*	(Optional) Tag value that can be used as a "match" value for controlling redistribution via route maps. This keyword applies to OSPF only.

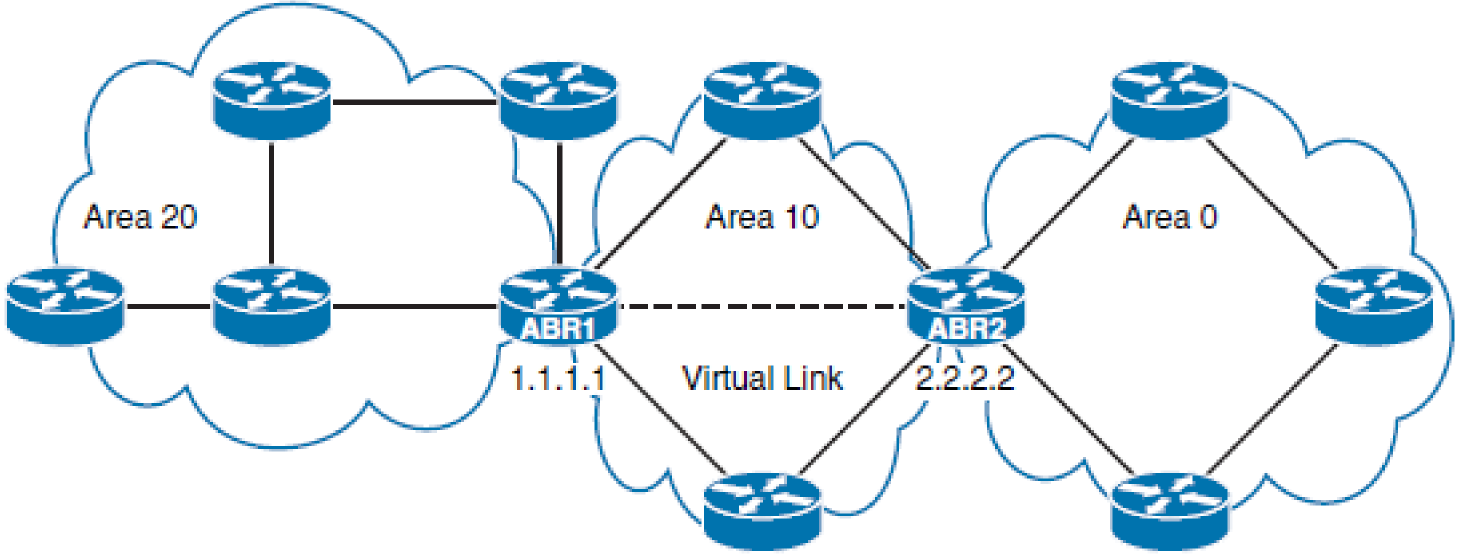
- **summary-address** {{ *ip-address mask* } | { *prefix mask* }} [**not-advertise**] [**tag** *tag*]

OSPF Virtual Links

- OSPF's two-tiered area hierarchy requires that if more than one area is configured, one of the areas must be area 0, the backbone area.
- All other areas must be directly connected to area 0, and area 0 must be contiguous.
- OSPF expects all nonbackbone areas to inject routes into the backbone, so that the routes can be distributed to other areas.
- A virtual link is a link that allows discontiguous area 0s to be connected, or a disconnected area to be connected to area 0, via a transit area.

OSPF Virtual Links





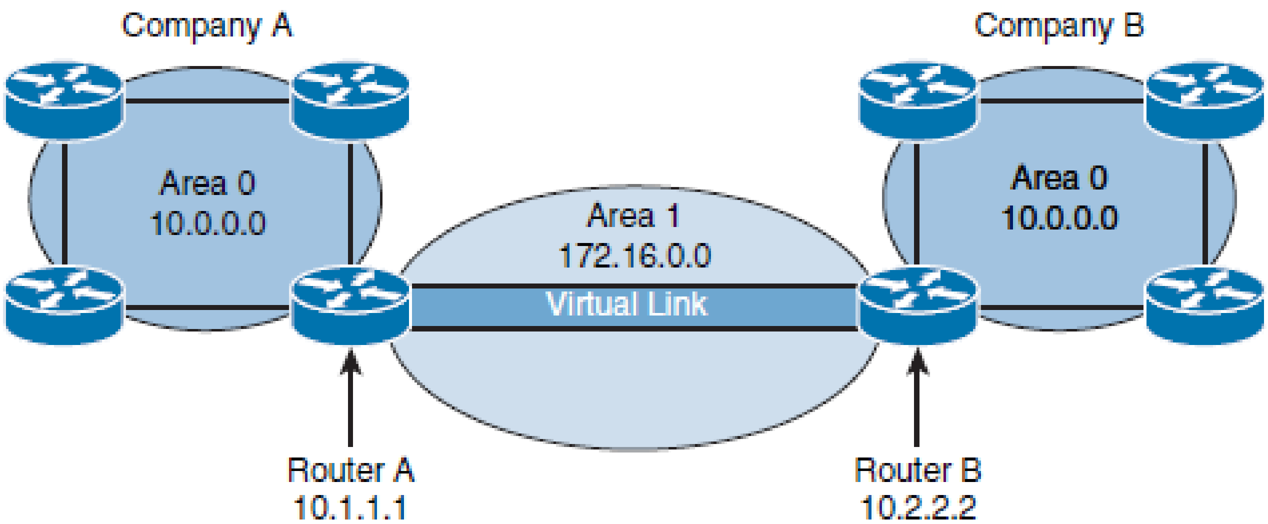
Virtual Links Issues

- The OSPF virtual link feature should be used only in very specific cases, for temporary connections or for backup after a failure.
- Virtual links should not be used as a primary backbone design feature.
- The virtual link relies on the stability of the underlying intra-area routing.
- Virtual links cannot go through more than one area, nor through stub areas.
- If a virtual link needs to be attached to the backbone across two nonbackbone areas, two virtual links are required, one per area.

Virtual Links Configuration Issues

- The OSPF database treats the virtual link between ABR1 and ABR2 as a direct link.
- For greater stability, loopback interfaces are used as router IDs, and virtual links are created using these loopback addresses.
- The hello protocol works over virtual links as it does over standard links, in 10-second intervals.
- An LSA usually refreshes every 30 minutes. However, LSAs learned through a virtual link have the DoNotAge (DNA) option set so that the LSA does not age out. This DNA technique is required to prevent excessive flooding over the virtual link.

Configuring OSPF Virtual Links




```
router ospf 1000
  network 172.16.0.0 0.0.255.255 area 1
  network 10.0.0.0 0.255.255.255 area 0
  area 1 virtual-link 10.2.2.2
```

```
router ospf 1000
  network 172.16.0.0 0.0.255.255 area 1
  network 10.0.0.0 0.255.255.255 area 0
  area 1 virtual-link 10.1.1.1
```

area *area-id* **virtual-link** *router-id* [**authentication** [**message-digest** | **null**]][**hello-interval** *seconds*] [**retransmit-interval** *seconds*] [**transmitdelay** *seconds*] [**dead-interval** *seconds*] [[**authentication-key** *key*] | [**message-digest-key** *key-id* **md5** *key*]]

Configuring OSPF Virtual Links

Parameter	Description
area-id	Specifies the area ID of the transit area for the virtual link. This ID can be either a decimal value or in dotted-decimal format, like a valid IP address. There is no default. The transit area cannot be a stub area.
router-id	Specifies the router ID of the virtual link neighbor. The router ID appears in the **show ip ospf** display. This value is in an IP address format. There is no default.
authentication	(Optional) Specifies an authentication type.
message-digest	(Optional) Specifies the use of MD5 authentication.
null	(Optional) Overrides simple password or MD5 authentication if configured for the area. No authentication is used.
hello-interval *seconds*	(Optional) Specifies the time (in seconds) between the hello packets that the Cisco IOS Software sends on an interface. The unsigned integer value is advertised in the Hello packets. The value must be the same for all routers and access servers attached to a common network. The default is 10 seconds.

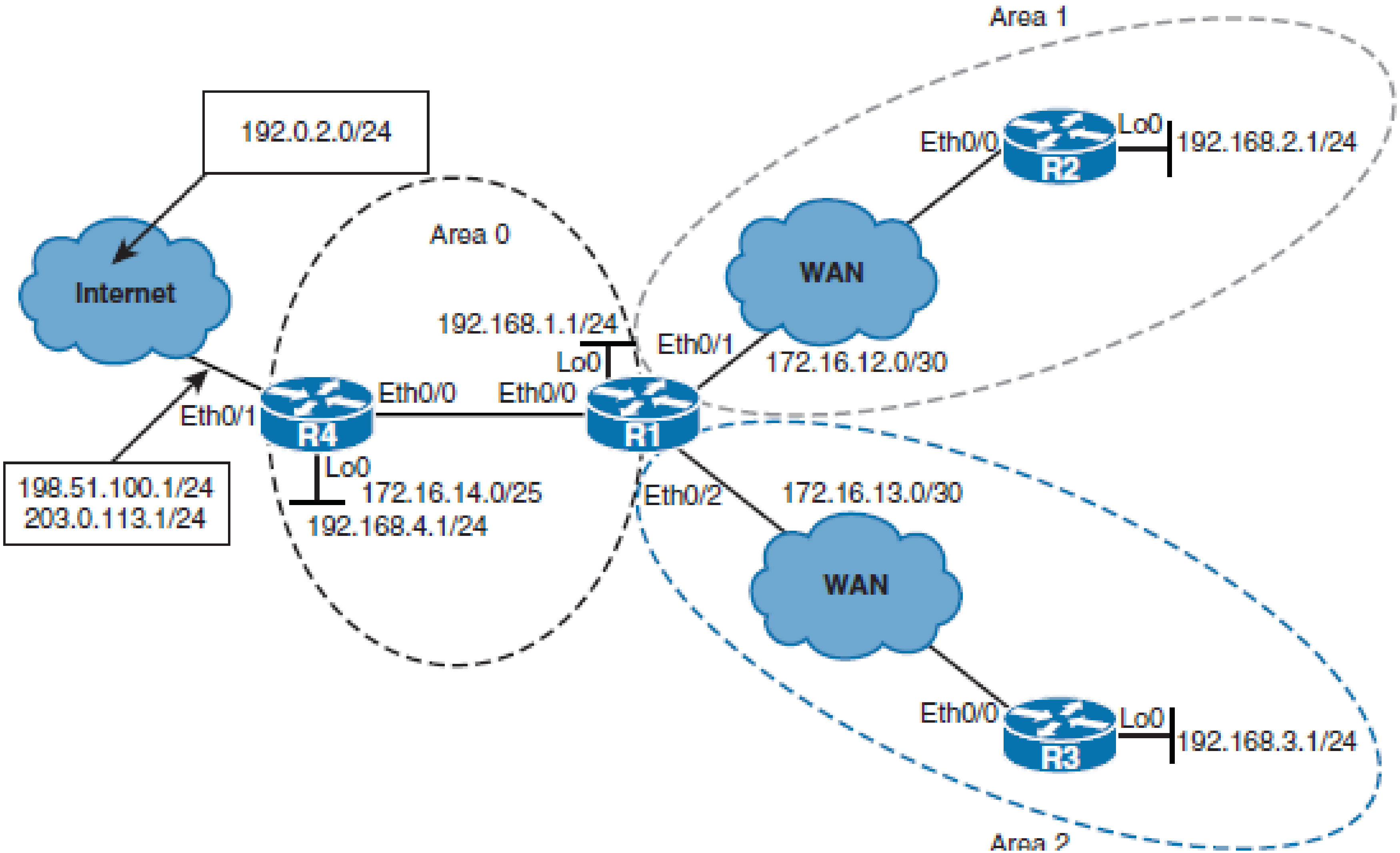
Configuring OSPF Virtual Links

Parameter	Description
retransmit-interval *seconds*	(Optional) Specifies the time (in seconds) between LSA retransmissions for adjacencies belonging to the interface. The value must be greater than the expected round-trip delay between any two routers on the attached network. The default is 5 seconds.
transmit-delay *seconds*	(Optional) Specifies the estimated time (in seconds) to send an LSU packet on the interface. This integer value must be greater than 0. LSAs in the update packet have their age incremented by this amount before transmission. The default value is 1 second.
dead-interval *seconds*	(Optional) Specifies the time (in seconds) that must pass without hello packets being seen before a neighboring router declares the router down. This is an unsigned integer value. The default is 4 times the default hello interval, or 40 seconds. As with the hello interval, this value must be the same for all routers and access servers attached to a common network.
authentication-key *key*	(Optional) Specifies the password used by neighboring routers for simple password authentication. It is any continuous string of up to eight characters. There is no default value.
message-digest-key *key-id* **md5** *key*	(Optional) Identifies the key ID and key (password) used between this router and neighboring routers for MD5 authentication. There is no default value.

OSPF Stub Areas

- The stub and totally stubby areas are deployed to reduce the size of the OSPF database and routing table:
  - **Stub area:** This area type does not accept information about routes external to the autonomous system, such as routes from non-OSPF sources. If routers need to route to networks outside the autonomous system, they use a default route, indicated as 0.0.0.0. Stub areas cannot contain ASBRs (except that the ABRs may also be ASBRs). The stub area does not accept external routes.
  - **Totally stubby area:** This Cisco proprietary area type does not accept external autonomous system routes or summary routes from other areas internal to the autonomous system. If a router needs to send a packet to a network external to the area, it sends the packet using a default route. Totally stubby areas cannot contain ASBRs (except that the ABRs may also be ASBRs). A totally stubby area does not accept external or interarea routes.

Configuring OSPF Stub Areas



Configuring OSPF Stub Areas

```
R2# show ip route ospf
<Output omitted>

      172.16.0.0/16 is variably subnetted, 4 subnets, 3 masks
O IA     172.16.13.0/30 [110/20] via 172.16.12.1, 00:56:16, Ethernet0/0
O IA     172.16.14.0/25 [110/20] via 172.16.12.1, 00:56:16, Ethernet0/0
O IA  192.168.1.0/24 [110/11] via 172.16.12.1, 00:56:16, Ethernet0/0
O IA  192.168.3.0/24 [110/21] via 172.16.12.1, 00:54:50, Ethernet0/0
O IA  192.168.4.0/24 [110/21] via 172.16.12.1, 00:46:00, Ethernet0/0
O E2  198.51.100.0/24 [110/20] via 172.16.12.1, 00:01:47, Ethernet0/0
O E2  203.0.113.0/24 [110/20] via 172.16.12.1, 00:01:47, Ethernet0/0
```

```
R3# show ip route ospf
<Output omitted>

      172.16.0.0/16 is variably subnetted, 4 subnets, 3 masks
O IA     172.16.12.0/30 [110/20] via 172.16.13.1, 00:53:58, Ethernet0/0
O IA     172.16.14.0/25 [110/20] via 172.16.13.1, 00:53:58, Ethernet0/0
O IA  192.168.1.0/24 [110/11] via 172.16.13.1, 00:53:58, Ethernet0/0
O IA  192.168.2.0/24 [110/21] via 172.16.13.1, 00:53:58, Ethernet0/0
O IA  192.168.4.0/24 [110/21] via 172.16.13.1, 00:45:10, Ethernet0/0
O E2  198.51.100.0/24 [110/20] via 172.16.13.1, 00:00:57, Ethernet0/0
O E2  203.0.113.0/24 [110/20] via 172.16.13.1, 00:00:57, Ethernet0/0
```

Configuring OSPF Stub Areas

```
R1(config)# router ospf 1
R1(config-router)# area 1 stub
%OSPF-5-ADJCHG: Process 1, Nbr 2.2.2.2 on Ethernet0/1 from FULL to DOWN, Neighbor
Down: Adjacency forced to reset
```

```
R2(config)# router ospf 1
R2(config-router)# area 1 stub
%OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on Ethernet0/0 from LOADING to FULL, Loading
Done
```

- Configuring a stub area reduces the size of the LSDB inside the area, resulting in reduced memory requirements for routers in that area. External network LSAs (type 5), such as those that are redistributed from other routing protocols into OSPF, are not permitted to flood into a stub area.
- The **area stub** router configuration mode command is used to define an area as a stub area. Each router in the stub area must be configured with the **area stub** command. The
- Hello packets that are exchanged between OSPF routers contain a stub area flag that must match on neighboring routers. Until the **area 1 stub** command is enabled on R2 in this scenario, the adjacency between R1 and R2 will be down.

Configuring OSPF Stub Areas

```
R2# show ip route ospf
<Output omitted>

O*IA  0.0.0.0/0 [110/11] via 172.16.12.1, 00:19:27, Ethernet0/0
      172.16.0.0/16 is variably subnetted, 4 subnets, 3 masks
O IA     172.16.13.0/30 [110/20] via 172.16.12.1, 00:19:27, Ethernet0/0
O IA     172.16.14.0/25 [110/20] via 172.16.12.1, 00:19:27, Ethernet0/0
O IA  192.168.1.0/24 [110/11] via 172.16.12.1, 00:19:27, Ethernet0/0
O IA  192.168.3.0/24 [110/21] via 172.16.12.1, 00:19:27, Ethernet0/0
O IA  192.168.4.0/24 [110/21] via 172.16.12.1, 00:19:27, Ethernet0/0

R2# ping 192.0.2.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.0.2.1, timeout is 2 seconds:
U.U.U
Success rate is 0 percent (0/5)

R2# ping 203.0.113.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 203.0.113.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/1 ms
```

Propagating a Default Route Using OSPF

```
R4# show ip route static
<Output omitted>
Gateway of last resort is 198.51.100.2 to network 0.0.0.0
S*    0.0.0.0/0 [1/0] via 198.51.100.2
R4(config)# router ospf 1
R4(config-router)# default-information originate
```

OSPF Totally Stubby Areas

```
R1(config)# router ospf 1
R1(config-router)# area 2 stub no-summary
 %OSPF-5-ADJCHG: Process 1, Nbr 3.3.3.3 on Ethernet0/2 from FULL to
DOWN, Neighbor Down: Adjacency forced to reset
```

```
R3(config)# router ospf 1
R3(config-router)# area 2 stub
%OSPF-5-ADJCHG: Process 1, Nbr 1.1.1.1 on Ethernet0/0 from LOADING to FULL, Loading
Done
```

OSPF Totally Stubby Areas

```
R3# show ip route ospf
<Output omitted>
Gateway of last resort is 172.16.13.1 to network 0.0.0.0
O*IA  0.0.0.0/0 [110/11] via 172.16.13.1, 00:18:08, Ethernet0/0
```

```
R3# show ip ospf data
<Output omitted>
                Summary Net Link States (Area 2)

Link ID         ADV Router      Age         Seq#       Checksum
0.0.0.0         1.1.1.1         1285        0x80000001 0x0093A6
```

```
R3# ping 192.0.2.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.0.2.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 1/1/1 ms
```

Cost of the Default Route in a Stub Area

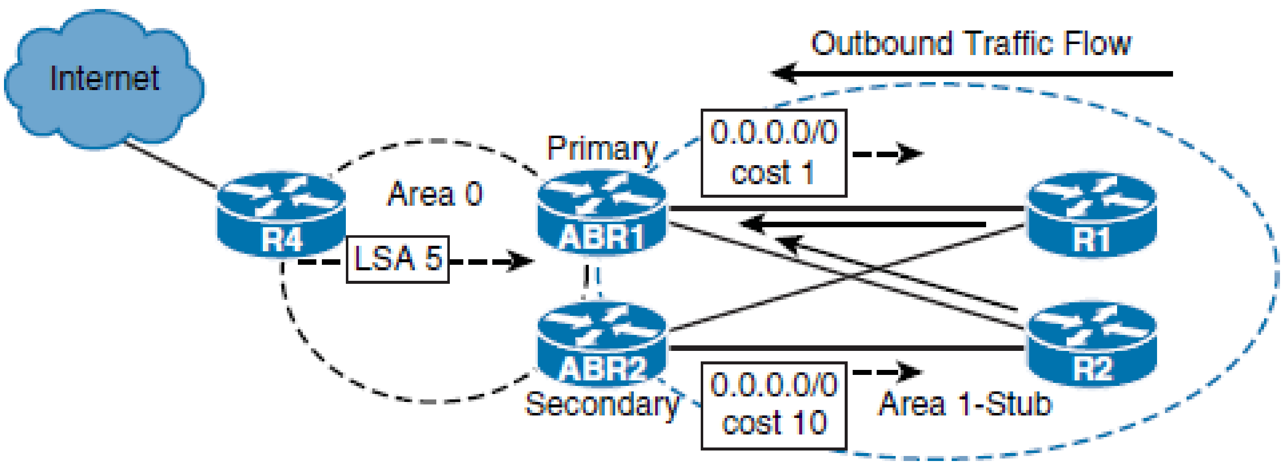
- By default, the ABR of a stub area will advertise a default route with a cost of 1.
- You can change the cost of the default route by using the **area default-cost** command.
- The *default-cost* option provides the metric for the summary default route that is generated by the ABR into the stub area.

area *area-id* **default-cost** *cost*

Parameter	Description
area-id	Identifier for the stub or NSSA. The identifier can be specified as either a decimal value or as an IP address.
cost	Cost for the default summary route used for a stub or NSSA. The acceptable value is a 24-bit number.

Cost of the Default Route in a Stub Area

- The option of tuning the cost of the default route in the stub area is useful in stub areas with redundant exit points to the backbone area



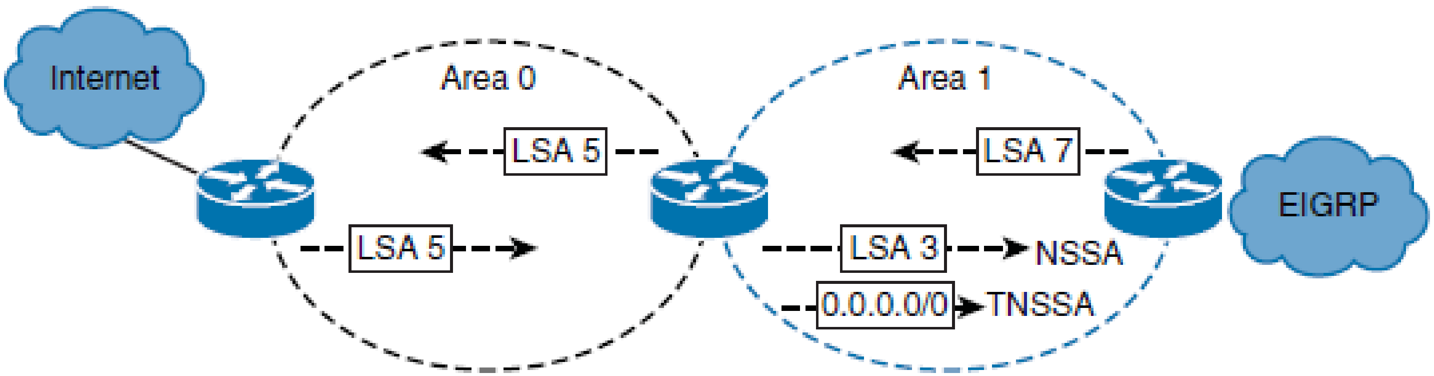
The default-information originate Command

- **default-information originate [always] [metric** *metric-value* **] [metric-type** *typevalue* **] [route-map** *map-name* **]**

Parameter	Description
always	(Optional) Always advertises the default route regardless of whether the software has a default route.
metric *metric-value*	(Optional) Metric used for generating the default route. If you omit a value and do not specify a value using the default-metric router configuration command, the default metric value is 1. The value used is specific to the protocol.
metric-type *type-value*	(Optional) External link type associated with the default route advertised into the OSPF routing domain. It can be one of the following values: 1: Type 1 external route 2: Type 2 external route The default is type 2 external route.
route-map *map-name*	(Optional) Routing process will generate the default route if the route map is satisfied.

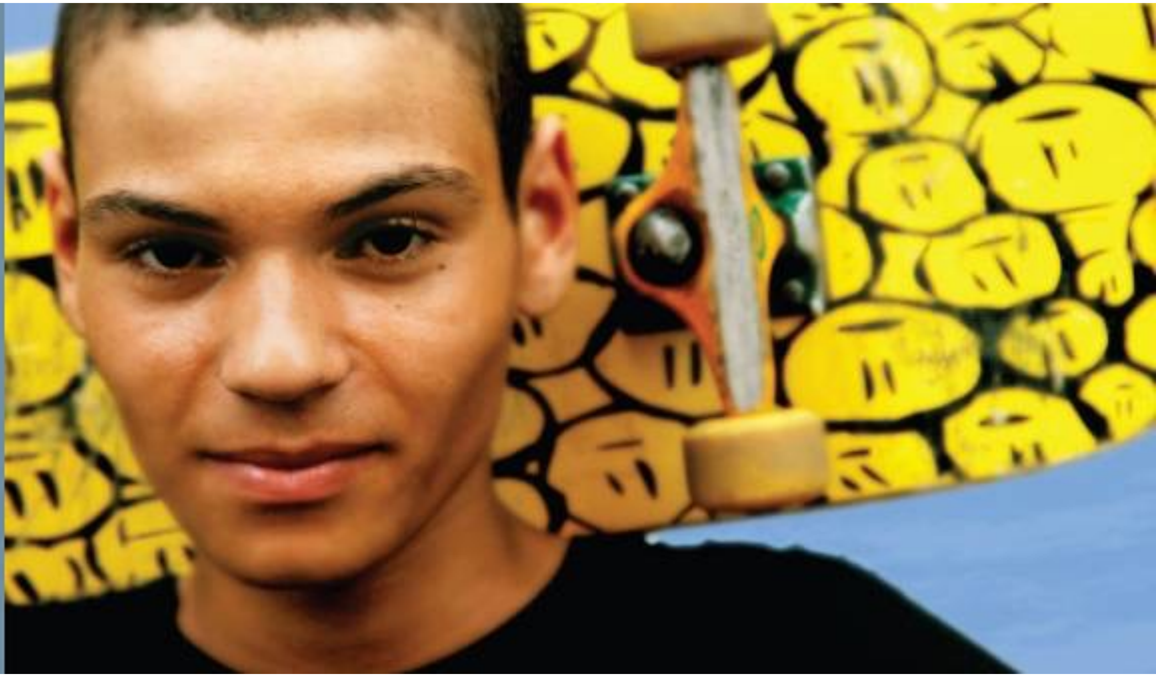
Other Stubby Area Types

- The NSSA is a nonproprietary extension of the existing stub area feature that allows the injection of external routes in a limited fashion into the stub area.



- The **area nssa** router configuration mode command is used to define each router in the NSSA area as not-so-stubby
- The **area nssa** command with the **no-summary** keyword is used to define the ABR as totally not-so-stubby.

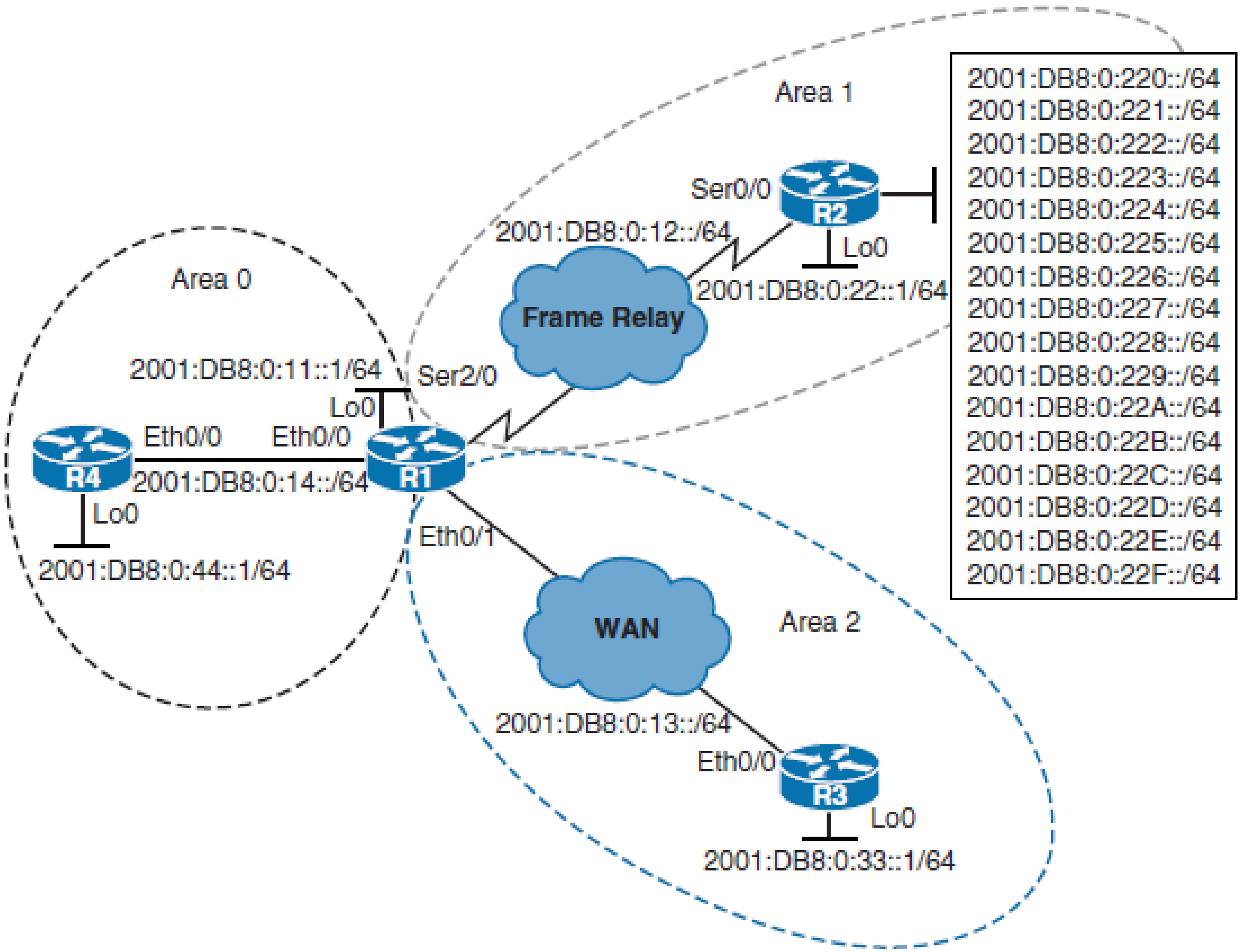
OSPFv3



OSPFv3

- Implement OSPFv3 in a dual-stack (IPv4/IPv6) environment
- Configure external route summarization and load balancing in OSPFv3
- Explain the limitations and where you need to be careful when configuring OSPFv3

Configuring OSPFv3



Configuring OSPFv3

- Cisco IOS routers offer two OSPF configuration methods for IPv6:
- Using the traditional **ipv6 router ospf** global configuration command
- Using the new-style **router ospfv3** global configuration command

Configuring OSPFv3

- OSPFv3 is the IPv6-capable version of the OSPF routing protocol. It is a rewrite of the OSPF protocol to support IPv6, although the foundation remains the same as in IPv4 and OSPFv2.
- The OSPFv3 metric is still based on interface cost.
- The packet types and neighbor discovery mechanisms are the same in OSPFv3 as they are for OSPFv2.
- OSPFv3 also supports the same interface types, including broadcast, point-to-point, point-to-multipoint,
- NBMA, and virtual links.
- LSAs are still flooded throughout an OSPF domain, and many of the LSA types are the same, though a few have been renamed or newly created.

Enabling OSPFv3

```
R1(config)# ipv6 unicast-routing
R1(config)# ipv6 router ospf 1
R1(config-rtr)# router-id 1.1.1.1
R1(config-rtr)# passive-interface Loopback0
```

```
R1(config)# interface Loopback0
R1(config-if)# ipv6 ospf 1 area 0
R1(config-if)# exit
R1(config)# interface Ethernet0/0
R1(config-if)# ipv6 ospf 1 area 0
R1(config-if)# exit
R1(config)# interface Serial2/0
R1(config-if)# ipv6 ospf 1 area 1
R1(config-if)# exit
R1(config)# interface Ethernet0/1
R1(config-if)# ipv6 ospf 1 area 2
 %OSPFv3-5-ADJCHG: Process 1, Nbr 4.4.4.4 on Ethernet0/0 from LOADING to FULL,
Loading Done
 %OSPFv3-5-ADJCHG: Process 1, Nbr 3.3.3.3 on Ethernet0/1 from LOADING to FULL,
Loading Done
```

OSPFv3 Adjacencies and Routing Table

```
R1# show ipv6 ospf neighbor

            OSPFv3 Router with ID (1.1.1.1) (Process ID 1)

Neighbor ID     Pri   State           Dead Time   Interface ID    Interface
4.4.4.4           1   FULL/DR         00:00:37    3               Ethernet0/0
3.3.3.3           1   FULL/DR         00:00:35    4               Ethernet0/1
R1# show ipv6 route ospf
<Output omitted>
O   2001:DB8:0:33::/64 [110/11]
     via FE80::A8BB:CCFF:FE00:AD10, Ethernet0/1
O   2001:DB8:0:44::/64 [110/11]
     via FE80::A8BB:CCFF:FE00:AE00, Ethernet0/0
```

Specifying the Neighbor on an NBMA Interface

- OSPF adjacencies over NBMA links require that IPv6 connectivity for both the link-local and the global addresses is established. Depending on the transport network, this may require mapping of IPv6 addresses to Layer 2 circuit identifiers

```
R1(config)# interface serial 2/0
R1(config-if)# ipv6 ospf neighbor FE80::2
 %OSPFv3-5-ADJCHG: Process 1, Nbr 2.2.2.2 on Serial2/0 from LOADING to FULL, Loading
Done
```

Specifying the Neighbor on an NBMA Interface

```
R1# show running-config interface serial 2/0
Building configuration...

Current configuration : 404 bytes
!
interface Serial2/0
 ip address 172.16.12.1 255.255.255.252
 encapsulation frame-relay
 ipv6 address FE80::1 link-local
 ipv6 address 2001:DB8:0:12::1/64
 ipv6 ospf 1 area 1
 ipv6 ospf neighbor FE80::2
 serial restart-delay 0
 frame-relay map ip 172.16.12.2 102 broadcast
 frame-relay map ipv6 2001:DB8:0:12::2 102 broadcast
 frame-relay map ipv6 FE80::2 102 broadcast
 no frame-relay inverse-arp
end
```

OSPFv3 LSDB

```
R1# show ipv6 ospf database

          OSPFv3 Router with ID (1.1.1.1) (Process ID 1)

              Router Link States (Area 0)

ADV Router       Age         Seq#          Fragment ID  Link count  Bits
 1.1.1.1         854         0x80000003    0             1           B
 4.4.4.4         871         0x80000002    0             1           None

              Net Link States (Area 0)

ADV Router       Age         Seq#          Link ID    Rtr count
 4.4.4.4         871         0x80000001    3          2

              Inter Area Prefix Link States (Area 0)

ADV Router       Age         Seq#          Prefix
 1.1.1.1         845         0x80000001    2001:DB8:0:12::/64
 1.1.1.1         845         0x80000001    2001:DB8:0:13::/64
 1.1.1.1         845         0x80000001    2001:DB8:0:33::/64

              Link (Type-8) Link States (Area 0)

ADV Router       Age         Seq#          Link ID    Interface
 1.1.1.1         870         0x80000001    3          Et0/0
 4.4.4.4         1056        0x80000002    3          Et0/0

              Intra Area Prefix Link States (Area 0)

ADV Router       Age         Seq#          Link ID    Ref-lstype  Ref-LSID
 1.1.1.1         865         0x80000003    0          0x2001      0
 4.4.4.4         871         0x80000003    0          0x2001      0
 4.4.4.4         871         0x80000001    3072       0x2002      3
```

Renamed LSA

- **Inter-area prefix LSAs for ABRs (Type 3):** Type 3 LSAs advertise internal networks to routers in other areas (inter-area routes). Type 3 LSAs may represent a single network or a set of networks summarized into one advertisement. Only ABRs generate summary LSAs. In OSPF for IPv6, addresses for these LSAs are expressed as prefix/ prefix length instead of address and mask. The default route is expressed as a prefix with length 0.
- **Inter-area router LSAs for ASBRs (Type 4):** Type 4 LSAs advertise the location of an ASBR. Routers that are trying to reach an external network use these advertisements to determine the best path to the next hop. ASBRs generate Type 4 LSAs.

New LSA

- **Link LSAs (Type 8):** Type 8 LSAs have local-link flooding scope and are never flooded beyond the link with which they are associated. Link LSAs provide the link-local address of the router to all other routers attached to the link. They inform other routers attached to the link of a list of IPv6 prefixes to associate with the link. In addition, they allow the router to assert a collection of option bits to associate with the network LSA that will be originated for the link.
- **Intra-area prefix LSAs (Type 9):** A router can originate multiple intra-area prefix LSAs for each router or transit network, each with a unique link-state ID. The linkstate ID for each intra-area prefix LSA describes its association to either the router LSA or the network LSA. The link-state ID also contains prefixes for stub and transit networks.

OSPFv3 for IPv4 and IPv6

- The newest OSPFv3 configuration approach utilizes a single OSPFv3 process.
- It is capable of supporting IPv4 and IPv6 within a single OSPFv3 process.
- OSPFv3 builds a single database with LSAs that carry IPv4 and IPv6 information.
- The OSPF adjacencies are established separately for each address family.
- Settings that are specific to an address family (IPv4/IPv6) are configured inside that address family router configuration mode.

Configuring OSPFv3 Using the router ospfv3

```
R1(config)# router ospfv3 1
R1(config-router)# router-id 1.1.1.1
R1(config-router)# passive-interface Loopback0
```

```
R1# show running-config | section router
router ospfv3 1
 router-id 1.1.1.1
 !
 address-family ipv6 unicast
  passive-interface Loopback0
  router-id 1.1.1.1
 exit-address-family
```

- The **address-family ipv6 unicast** has been automatically created on R1. Cisco IOS Software has parsed the previous old-style OSPFv3 configuration and found that the OSPF process was enabled only for IPv6.

OSPFv3 Old-Style OSPF Configuration Commands

```
interface Loopback0
 ipv6 ospf 1 area 0
!
interface Ethernet0/0
 ipv6 ospf 1 area 0
!
interface Ethernet0/1
 ipv6 ospf 1 area 2
!
interface Serial2/0
 ipv6 ospf 1 area 1
 ipv6 ospf neighbor FE80::2
```

OSPFv3 New-Style OSPF Configuration Commands

```
R1(config)# interface Loopback 0
R1(config-if)# ospfv3 1 ipv6 area 0
R1(config-if)# exit
R1(config)# interface Ethernet 0/0
R1(config-if)# ospfv3 1 ipv6 area 0
R1(config-if)# exit
R1(config)# interface Serial 2/0
R1(config-if)# ospfv3 1 ipv6 area 1
R1(config-if)# exit
R1(config)# interface Ethernet 0/1
R1(config-if)# ospfv3 1 ipv6 area 2
```

- The preferred interface mode command for the new style OSPFv3 configuration is the **`ospfv3`** *`process-id`* **`{ipv4|ipv6} area`** *`area-id`* command.
- It allows you to selectively activate the OSPFv3 process for an address family (IPv4 or IPv6) on a given interface.

Enabling OSPFv3 for IPv4

```
R1(config)# interface Loopback0
R1(config-if)# ospfv3 1 ipv4 area 0
R1(config-if)# exit
R1(config)# interface Ethernet0/0
R1(config-if)# ospfv3 1 ipv4 area 0
R1(config-if)# exit
R1(config)# interface Ethernet0/1
R1(config-if)# ospfv3 1 ipv4 area 2
R1(config)# exit
R1(config-if)# interface Serial2/0
R1(config-if)# ospfv3 1 ipv4 area 1
R1(config-if)# ospfv3 1 ipv4 neighbor FE80::2
R1(config-if)# exit
R1(config)# router ospfv3 1
R1(config-router)# address-family ipv4 unicast
R1(config-router-af)# passive-interface Loopback0
%OSPFv3-5-ADJCHG: Process 1, IPv4, Nbr 0.0.0.0 on Serial2/0 from ATTEMPT to DOWN,
Neighbor Down: Interface down or detached
%OSPFv3-5-ADJCHG: Process 1, IPv4, Nbr 3.3.3.3 on Ethernet0/1 from LOADING to FULL,
Loading Done
%OSPFv3-5-ADJCHG: Process 1, IPv4, Nbr 4.4.4.4 on Ethernet0/0 from LOADING to FULL,
Loading Done
```

OSPFv3 Adjacencies for Both IPv4 and IPv6 Address Families

```
R1# show ospfv3 neighbor

          OSPFv3 1 address-family ipv4 (router-id 1.1.1.1)

Neighbor ID     Pri   State           Dead Time   Interface ID    Interface
4.4.4.4           1   FULL/DR         00:00:34    3               Ethernet0/0
2.2.2.2           1   FULL/DR         00:01:38    3               Serial2/0
3.3.3.3           1   FULL/DR         00:00:36    4               Ethernet0/1

          OSPFv3 1 address-family ipv6 (router-id 1.1.1.1)

Neighbor ID     Pri   State           Dead Time   Interface ID    Interface
4.4.4.4           1   FULL/DR         00:00:35    3               Ethernet0/0
2.2.2.2           1   FULL/DR         00:01:58    3               Serial2/0
3.3.3.3           1   FULL/DR         00:00:34    4               Ethernet0/1
```

OSPFv3 LSDB

```
R1# show ospfv3 database inter-area prefix
          OSPFv3 1 address-family ipv4 (router-id 1.1.1.1)
                Inter Area Prefix Link States (Area 0)
  LS Type: Inter Area Prefix Links
  Advertising Router: 1.1.1.1
 <Output omitted>
  Prefix Address: 172.16.12.0
  Prefix Length: 30, Options: None
 <Output omitted>

         OSPFv3 1 address-family ipv6 (router-id 1.1.1.1)
                Inter Area Prefix Link States (Area 0)
  LS Type: Inter Area Prefix Links
  Advertising Router: 1.1.1.1
 <Output omitted>
  Prefix Address: 2001:DB8:0:12::
  Prefix Length: 64, Options: None
 <Output omitted>
```

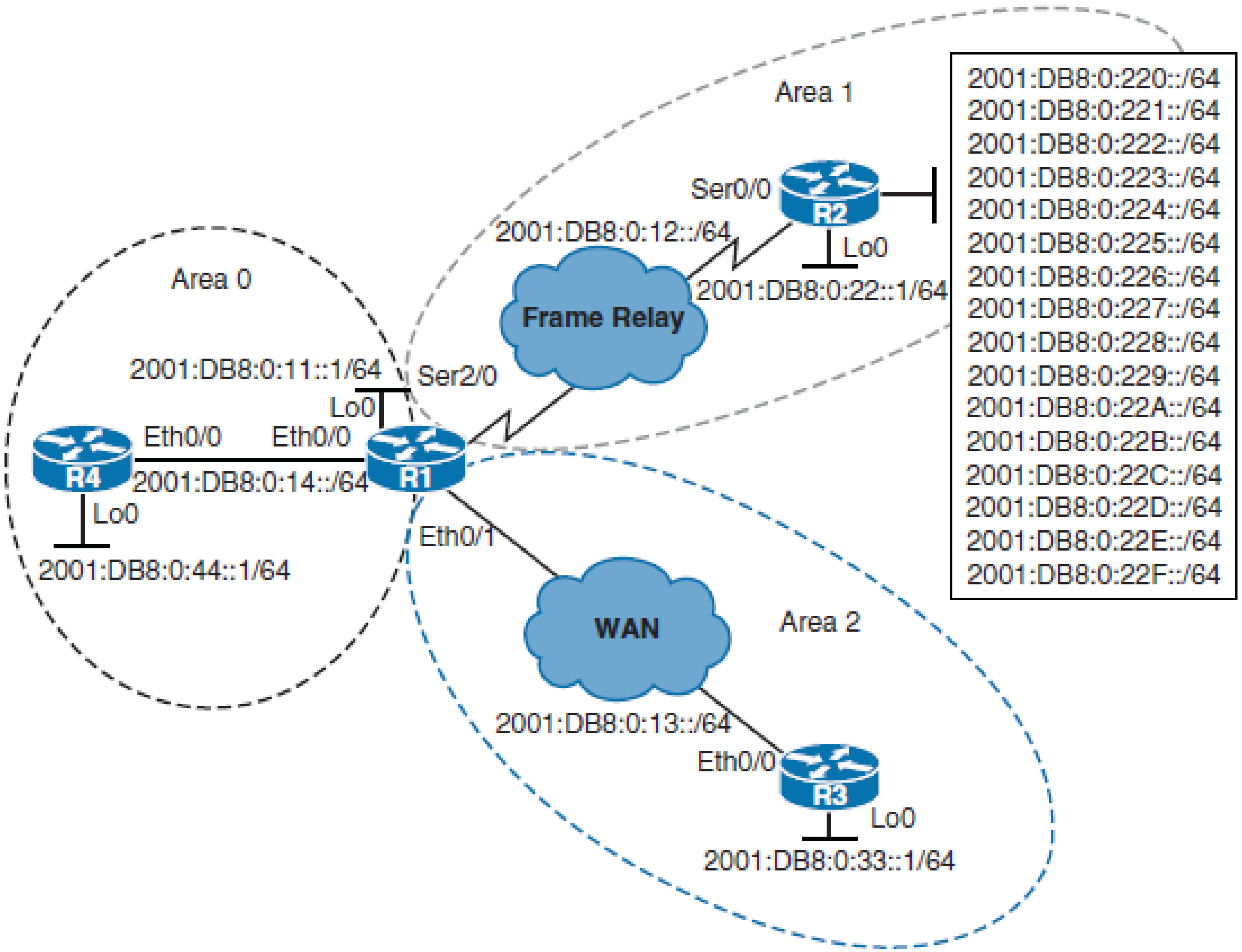
IPv4 Routing Table with OSPFv3 Routes

```
R1# show ip route ospfv3
<Output omitted>

      192.168.2.0/32 is subnetted, 1 subnets
O        192.168.2.2 [110/64] via 172.16.12.2, 00:27:49, Serial2/0
      192.168.3.0/32 is subnetted, 1 subnets
O        192.168.3.3 [110/10] via 172.16.13.2, 00:30:08, Ethernet0/1
      192.168.4.0/32 is subnetted, 1 subnets
O        192.168.4.4 [110/10] via 172.16.14.4, 00:30:08, Ethernet0/0
```

OSPFv3 ipv6 Routing Table

```
R3# show ipv6 route ospf
<Output omitted>
OI   2001:DB8:0:11::1/128 [110/10]
      via FE80::A8BB:CCFF:FE00:AB10, Ethernet0/1
OI   2001:DB8:0:12::/64 [110/74]
      via FE80::A8BB:CCFF:FE00:AB10, Ethernet0/1
OI   2001:DB8:0:14::/64 [110/20]
      via FE80::A8BB:CCFF:FE00:AB10, Ethernet0/1
OI   2001:DB8:0:22::/64 [110/75]
      via FE80::A8BB:CCFF:FE00:AB10, Ethernet0/1
OI   2001:DB8:0:44::/64 [110/21]
      via FE80::A8BB:CCFF:FE00:AB10, Ethernet0/1
OI   2001:DB8:0:220::/64 [110/75]
      via FE80::A8BB:CCFF:FE00:AB10, Ethernet0/1
OI   2001:DB8:0:221::/64 [110/75]
      via FE80::A8BB:CCFF:FE00:AB10, Ethernet0/1
OI   2001:DB8:0:222::/64 [110/75]
      via FE80::A8BB:CCFF:FE00:AB10, Ethernet0/1
```

Configuring OSPFv3



Area 2 Routers Configured as a Totally Stubby Area

```
R1(config)# router ospfv3 1
R1(config-router)# address-family ipv6 unicast
R1(config-router-af)# area 2 stub no-summary
%OSPFv3-5-ADJCHG: Process 1, IPv6, Nbr 3.3.3.3 on Ethernet0/1 from FULL to DOWN,
Neighbor Down: Adjacency forced to reset
```

```
R3(config)# router ospfv3 1
R3(config-router)# address-family ipv6 unicast
R3(config-router-af)# area 2 stub
%OSPFv3-5-ADJCHG: Process 1, IPv6, Nbr 1.1.1.1 on Ethernet0/1 from LOADING to FULL,
Loading Done
```

```
R3# show ipv6 route ospf
<Output omitted>
OI   ::/0 [110/11]
      via FE80::A8BB:CCFF:FE00:AB10, Ethernet0/1
R3# show ip route ospfv3
<Output omitted>
O IA     172.16.12.0/30 [110/74] via 172.16.13.1, 00:09:55, Ethernet0/1
O IA     172.16.14.0/25 [110/20] via 172.16.13.1, 00:09:55, Ethernet0/1
       192.168.1.0/32 is subnetted, 1 subnets
O IA     192.168.1.1 [110/10] via 172.16.13.1, 00:09:55, Ethernet0/1
       192.168.2.0/32 is subnetted, 1 subnets
O IA     192.168.2.2 [110/74] via 172.16.13.1, 00:09:55, Ethernet0/1
       192.168.4.0/32 is subnetted, 1 subnets
O IA     192.168.4.4 [110/20] via 172.16.13.1, 00:09:55, Ethernet0/1
```

OSPFv3 Summarization

```
R1(config)# router ospfv3 1
R1(config-router)# address-family ipv6 unicast
R1(config-router-af)# area 1 range 2001:DB8:0:220::/60
```

```
R4# show ipv6 route ospf
<Output omitted>
O    2001:DB8:0:11::1/128 [110/10]
      via FE80::A8BB:CCFF:FE00:AB00, Ethernet0/0
OI   2001:DB8:0:12::/64 [110/74]
      via FE80::A8BB:CCFF:FE00:AB00, Ethernet0/0
OI   2001:DB8:0:13::/64 [110/20]
      via FE80::A8BB:CCFF:FE00:AB00, Ethernet0/0
OI   2001:DB8:0:22::/64 [110/75]
      via FE80::A8BB:CCFF:FE00:AB00, Ethernet0/0
OI   2001:DB8:0:33::/64 [110/21]
      via FE80::A8BB:CCFF:FE00:AB00, Ethernet0/0
OI   2001:DB8:0:220::/60 [110/75]
      via FE80::A8BB:CCFF:FE00:AB00, Ethernet0/0
```

Configuring Advanced OSPFv3

- *Configuring the* **summary-prefix** *Command on an ASBR*

summary-prefix *prefix* [**not-advertise** | **tag** *tag-value*] [**nssa-only**]

Parameter	Description
prefix	IPv6 route prefix for the destination.
not-advertise	(Optional) Suppresses routes that match the specified prefix and mask pair. This keyword applies to OSPFv3 only.
tag *tag-value*	(Optional) Specifies the tag value that can be used as a match value for controlling redistribution via route maps. This keyword applies to OSPFv3 only.
nssa-only	(Optional) Limits the scope of the prefix to the area. Sets the NSSA-only attribute for the summary route (if any) generated for the specified prefix.

```
Router(config)# router ospfv3 1
Router(config-router)# address-family ipv6 unicast
Router(config-router-af)# summary-prefix 2001:db8:1::/56
```

OSPFv3 Caveats

- The OSPFv3 address families feature is supported as of Cisco IOS Release 15.1(3)S and Cisco IOS Release 15.2(1)T.
- Cisco devices that run software older than these releases and third-party devices will not form neighbor relationships with devices running the address family feature for the IPv4 address family because they do not set the address family bit.
- Therefore, those devices will not participate in the IPv4 address family SPF calculations and will not install the IPv4 OSPFv3 routes in the IPv6 Routing Information Base (RIB).

Chapter 3 Summary

- OSPF uses a two-layer hierarchical approach dividing networks into a backbone area (area 0) and nonbackbone areas.
- For its operation, OSPF uses five packet types: Hello, DBD, LSR, LSU, and LSAck.
- OSPF neighbors go through several different neighbor states before adjacency results in Full state.
- OSPF elects DR/BDR routers on a multiaccess segment to optimize exchange of information.
- The most common OSPF network types are point-to-point, broadcast, nonbroadcast, and loopback.
- OSPF uses several different LSA types to describe the network topology.
- LSAs are stored in an LSDB, which is synchronized with every network change.

Chapter 3 Summary

- OSPF calculates interface costs based on default reference bandwidth and interface bandwidth.
- Using SPF, OSPF determines the total lowest cost paths and selects them as the best routes.
- Intra-area routes are always preferred over interarea routes.
- Route summarization improves CPU utilization, reduces LSA flooding, and reduces routing table sizes.
- The **area range** command is used summarize at the ABR. The **summary-address** command is sued to summarize at the ASBR.
- Default routes can be used in OSPF to prevent the need for specific route to each destination network.
- OSPF uses the **default-information originate** command to inject a default route.
- There are several OSPF area types: normal, backbone, stub, totally stubby, NSSA, and totally stubby NSSA.
- Use the **area** *area-id* command to define an area as stubby.
- Use the **area** *area-id* **stub** command with the **no-summary** keyword only on the ABR to define an area as totally stubby.

Chapter 3 Summary

- For stub areas, external routes are not visible in the routing table, but are accessible via the intra-area default route.
- For totally stubby areas, interarea and external routes are not visible in the routing table, but are accessible via the intra-area default route.
- OSPFv3 for IPv6 supports the same basic mechanisms that OSPFv2 for IPv4, including the use of areas to provide network segmentation and LSAs to exchange routing updates.
- OSPFv3 features two new LSA types and has renamed two traditional LSA types.
- OSPFv3 uses link-local addresses to source LSAs.
- OSPFv3 is enabled per-interface on Cisco routers.
- New-style OSPFv3 and traditional OSPFv3 for IPv6, configured with **ipv6 router ospf** , can coexist in the network to provide IPv6 routing.

Chapter 3 Labs

- **CCNPv7_ROUTE_Lab3-1_OSPF-Virtual-Links**
- **CCNPv7_ROUTE_Lab3-2_Multi-Area-OSPF**
- **CCNPv7_ROUTE_Lab3-3_OSPFv3-Address-Families**

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