Chapter 3:

Configuring the Open Shortest Path First Protocol

- CCNP-RS ROUTE

Chapter 3 Objectives

- Describe OSPF terminology and operation within various enterprise environments.
- Describe the function and operation of packets in OSPF routing.
- Configure and verify basic OSPF.
- Describe and configure OSPF in various WAN network types.
- Describe each common LSA types and how they form the layout of the OSPF LSDB.
- Explain the relationship between and how to interpret the OSPF LSDB and routing table.
- Configure and verify advanced OSPF features.
- Configure and verify OSPF authentication.

Understanding OSPF Terminology and Operation

Open Shortest Path First (OSPF)

- OSPF is a standards-based link-state IP routing protocol described in RFC 2328.
  - It was developed to meet RIP's inability to scale beyond 15 routers.
  - Proposed by IETF in 1988 and formalized in 1991.
  - There are 2 versions; OSPFv2 is for IPv4 and OSPFv3 is for IPv6.

OSPF Features

- OSPF features include:
  - Fast convergence
  - Supports VLSM
  - Efficient use of bandwidth - Routing changes trigger routing updates (no periodic updates)
  - Supports large network size
  - Routing based on best path selection
  - Grouping of members into Areas

Link-State Protocol Characteristics

- With link-state routing protocols, each router has the full picture of the network topology, and can independently make a decision based on an accurate picture of the network topology.
- To do so, each link-state router keeps a record of:
  - Its immediate neighbor routers.
  - All the other routers in the network, or in its area of the network, and their attached networks.
  - The best paths to each destination.

Link-State Protocol Advantages

- Respond quickly to network changes.
- Send triggered updates when a network change occurs.
- Send periodic updates (link-state refresh), at long intervals, such as every 30 minutes.
  - Uses LSAs to confirm topology information before the information ages out of the link-state database.

OSPF Terminology

- OSPF databases / tables:
  - OSPF adjacency database = Neighbor table
  - OSPF link-state database = Topology table
  - OSPF forwarding database = Routing table
- Link-state advertisements (LSAs)
- Link-State Database (LSDB)
- Shortest-Path First (SPF) Routing Algorithm
  - Dijkstra algorithm
- SPF Tree
- OSPF Areas
  - Backbone (transit) and standard areas.
- Types of OSPF routers:
  - Internal router, backbone router, Area Border Router (ABR), Autonomous System Boundary Router (ASBR)
  - Designated Router (DR) and Backup Designated Router (BDR)

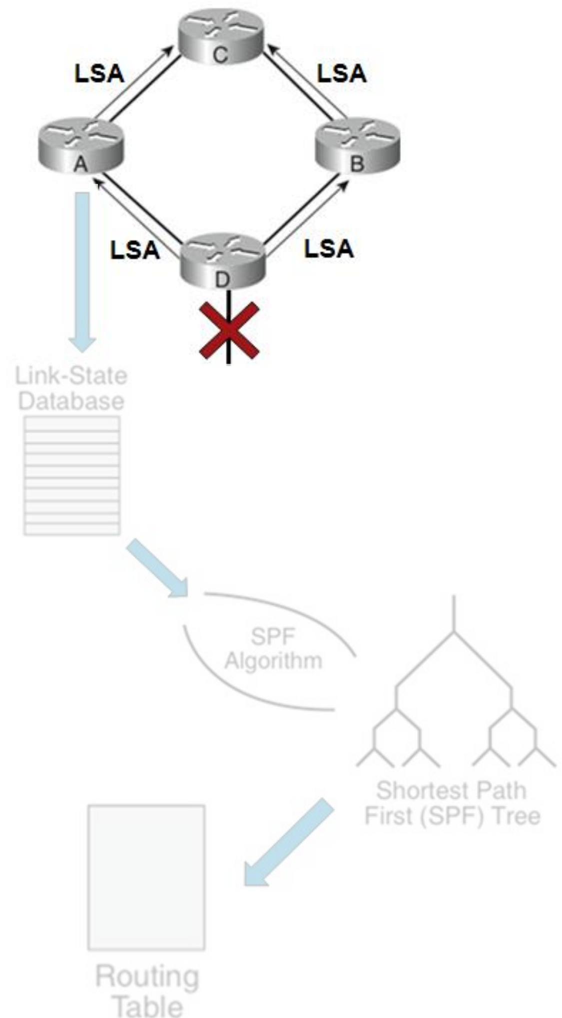
OSPF Router Tables / Databases

- OSPF maintains three databases which are used to create three tables.

Database	Table	Description
Adjacency Database	Neighbor Table	• List of all neighbors routers to which a router has established bidirectional communication. • This table is unique for each router. • Can be viewed using the show ip ospf neighbor command.
Link-state Database	Topology Table	• List of information about all other routers in the network. • The database shows the network topology. • All routers within an area have identical link-state databases. • Can be viewed using the show ip ospf database command.
Forwarding Database	Routing Table	• List of routes generated when an algorithm is run on the link-state database. • Each router's routing table is unique and contains information on how and where to send packets to other routers. • Can be viewed using the show ip route command.

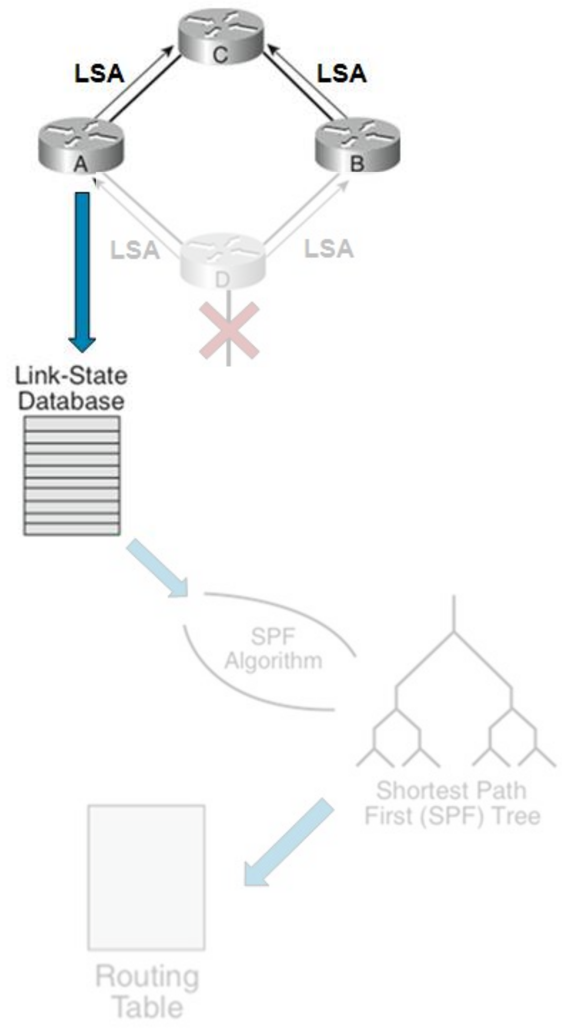
Link-State Advertisements (LSAs)

- When a change occurs in the network topology, the router experiencing the change creates a link-state advertisement (LSA) concerning that link.
  - LSAs are also called link-state protocol data units (PDUs).
- The LSA is multicasted to all neighboring devices using either 224.0.0.5 or 224.0.0.6.
- Routers receiving the LSA immediately forward it to all neighboring routers.



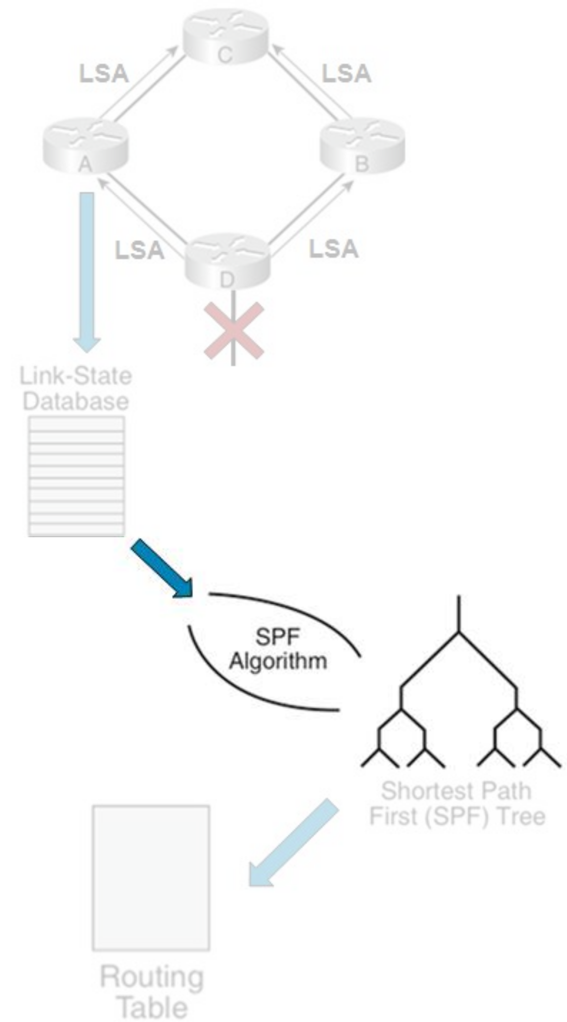
Link-State Database (LSDB)

- Routers receiving add the LSA to their link-state database (LSDB).
- The LSDB is used to calculate the best paths through the network.
- OSPF best route calculation is based on Edsger Dijkstra's shortest path first (SPF) algorithm.



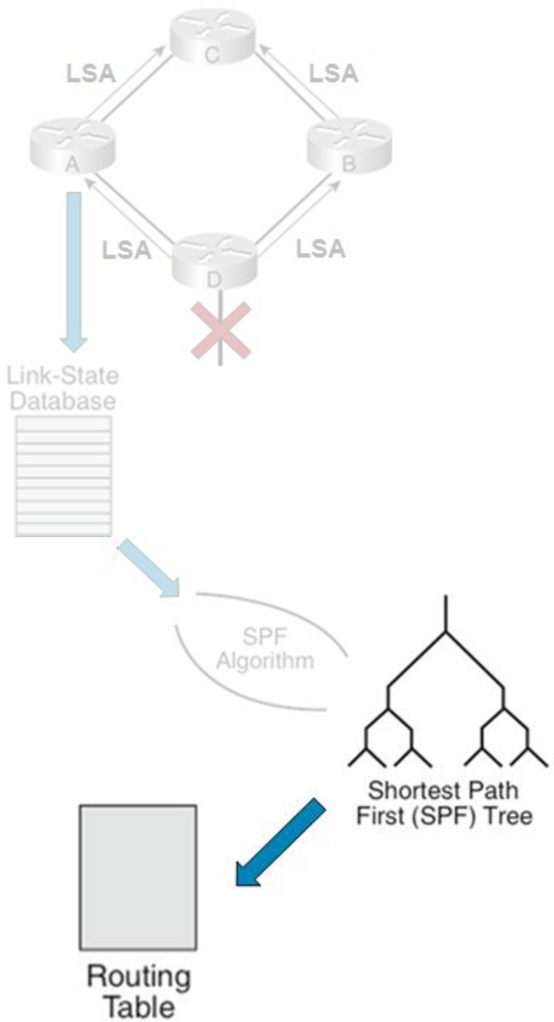
SPF Routing Algorithm

- The SPF algorithm accumulates costs along each path, from source to destination.
  - The accumulated costs is then used by the router to build a topology table.



SPF Tree and Routing Table

- The topology table is essentially an SPF tree which contains a listing of all OSPF networks and the costs to reach them.
- The resulting best routes are then considered to be added to the routing table.

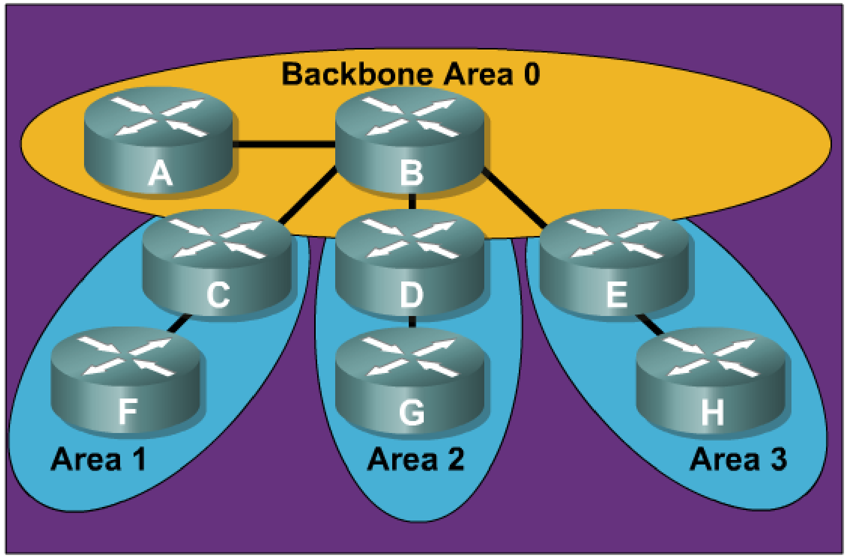


OSPF Areas

- To minimize processing and memory requirements, OSPF can divide the routing topology into a two-layer hierarchy called areas.
- Characteristics of OSPF areas include:
  - Minimizes routing table entries.
  - Localizes impact of a topology change within an area.
  - Detailed LSA flooding stops at the area boundary.
  - Requires a hierarchical network design.

OSPF Two-Layer Hierarchy

- **Backbone Area**
  - Referred to as Area 0
  - Also known as the Transit Area.
- **Regular (Standard) Areas**
  - Also known as a nonbackbone areas.
  - All regular areas must connect to the backbone area.
  - Standard areas can be further defined as stub areas, totally stubby areas, and Not-so-stubby areas (NSSAs).

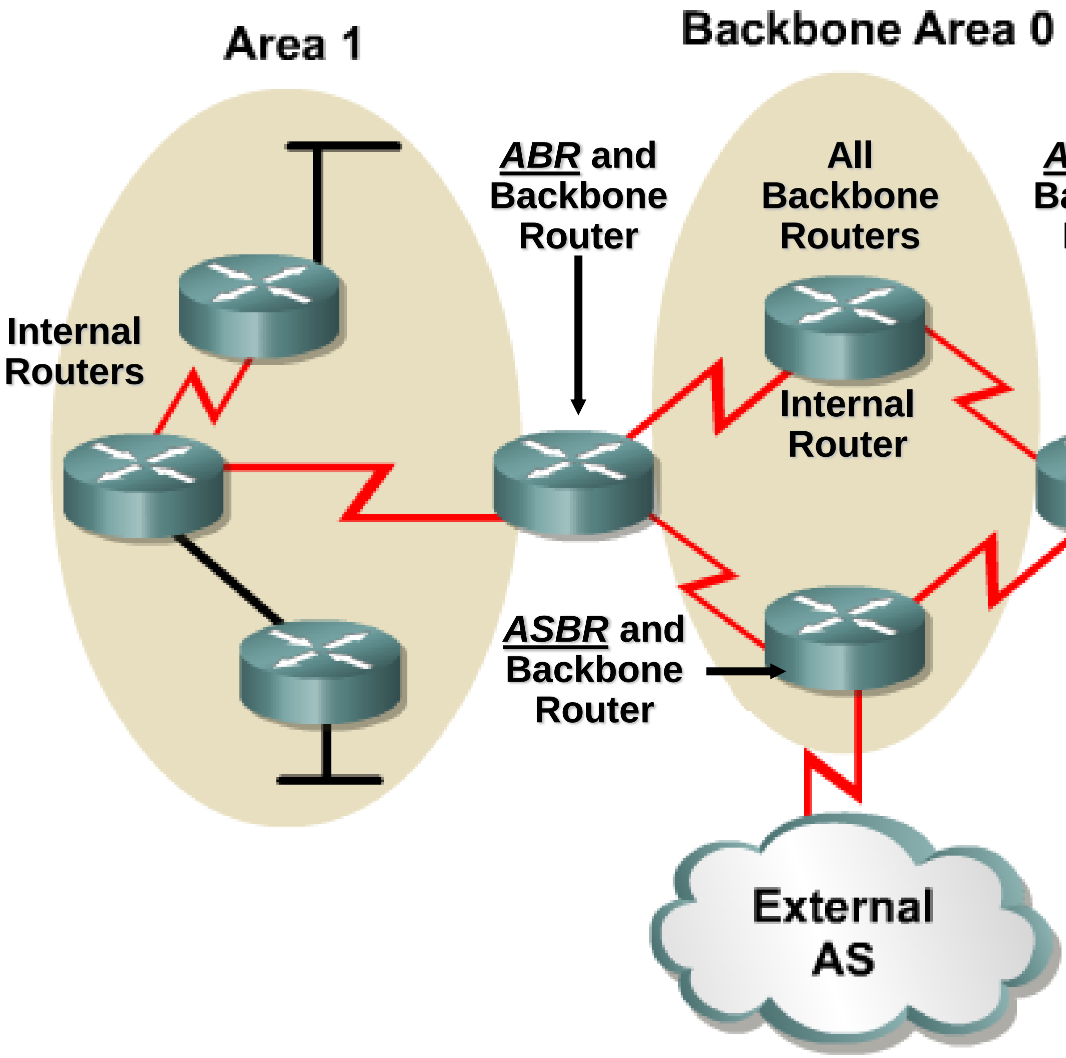


- The optimal number of routers per area varies based on factors such as network stability, but Cisco recommends:
  - An area should have no more than 50 routers.
  - A router should not be in more than 3 areas.

OSPF Router Types

- How OSPF routers exchange information is based on:
  - The function of the router.
  - The type of LSAs it can forward.
  - The type of area it resides in.
- OSPF routers may function as either:
  - Internal router
  - Backbone router
  - Area Border Router (ABR)
  - Autonomous System Boundary Router (ASBR)
- Note:
  - A router can exist as more than one router type.

OSPF Router Types



Internal Router

- Routers that have all their interfaces within the same area.
- Internal routers in the same area:
  - Have identical LSDBs.
  - Run a single copy of the routing algorithm.

Backbone Router

- OSPF design rules require that all areas be connected to a single backbone area (Area 0).
  - Area 0 is also known as Area 0.0.0.0
- An Area 0 router is referred to as a backbone router.
  - Depending on where it resides in Area 0, it may also be called an Internal router, an ABR, or an ASBR.

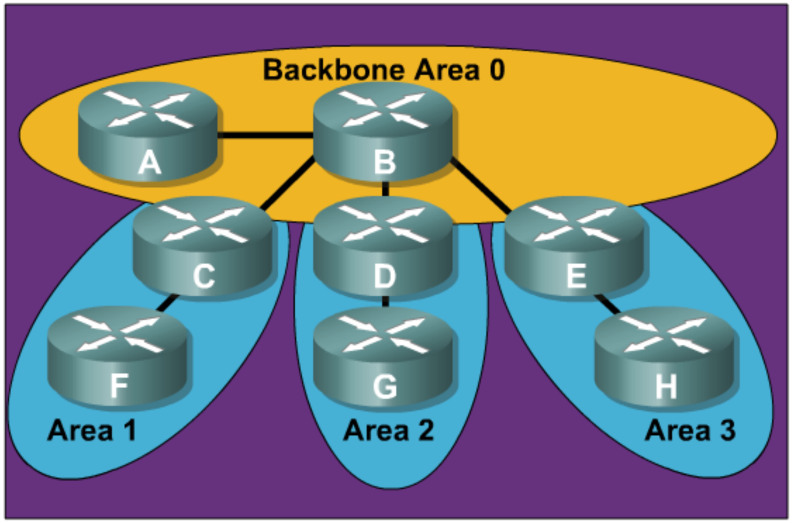
Area Border Router (ABR)

- Routers with interfaces attached to multiple areas and responsible for:
  - Joining areas together.
  - Maintaining separate link-state databases for each area.
  - Routing traffic destined to/arriving from other areas.
  - Summarizing information about each area connected and flooding the information through area 0 to the other areas connected.
  - An area can have one or more ABR.
- ABR cannot send LSU's to other areas until the entire intra-area is synchronized.

Autonomous System Boundary Router (ASBR)

- Routers that have at least one interface connected to another AS, such as a non-OSPF network.
- Routers support redistribution.
  - They can import non-OSPF network information to the OSPF network.
- Should reside in the backbone area.

OSPF Router Types



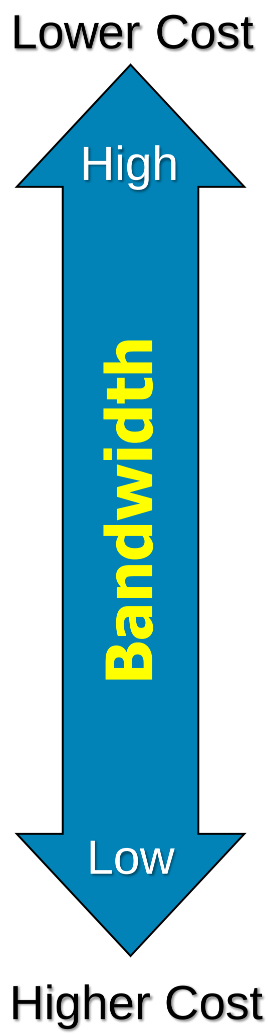
- Routers A, B, C, D and E are backbone routers.
  - Backbone routers make up Area 0.
- Routers C, D and E are area border routers (ABRs).
  - ABRs attach all other areas to Area 0.
- Routers A, B, F, G, and H are internal routers.
  - Internal routers are completely within an area and do not interconnect to any other area or autonomous system (AS).

DR and BDR Routers

- To reduce the amount of OSPF traffic on multiaccess broadcast networks such as Ethernet, OSPF elects:
  - A Designated Router (DR)
  - A Backup Designated Router (BDR)
- The DR is responsible for updating all other OSPF routers (called DROTHERs) when a change occurs in the multiaccess network.
  - The BDR monitors the DR and takes over should the DR fail.
- A router connected to multiple broadcast networks can be a DR on one segment and a regular (DROTHER) router on another segment.

OSPF Metric Calculation

- The OSPF metric calculation is based on cost.
- Cost is an indication of the overhead required to send packets across a certain interface.
- The cost of an interface is inversely proportional to the bandwidth of that interface.
  - A higher bandwidth is attributed a lower cost.
  - A lower bandwidth is attributed a higher cost.



OSPF Cost Formula

- **Cost = 100,000,000 / Bandwidth (bps)**
- For example:
  - 10BaseT = 100,000,000 / 10,000,000 = **10**
  - T1 = 100,000,000 / 1,544,000 = **64**

Interface Type	10^8/ bps = Cost
Fast Ethernet and faster	10^8/ 100,000,000 bps = 1
Ethernet	10^8/ 10,000,000 bps = 10
E1	10^8/2,048,000 bps = 48
T1	10^8/ 1,544,000 bps = 64
128 kbps	10^8/ 128,000 bps = 781
64 kbps	10^8/64,000 bps = 1562
56 kbps	10^8/56,000 bps = 1785

OSPF Packets

OSPF Packet

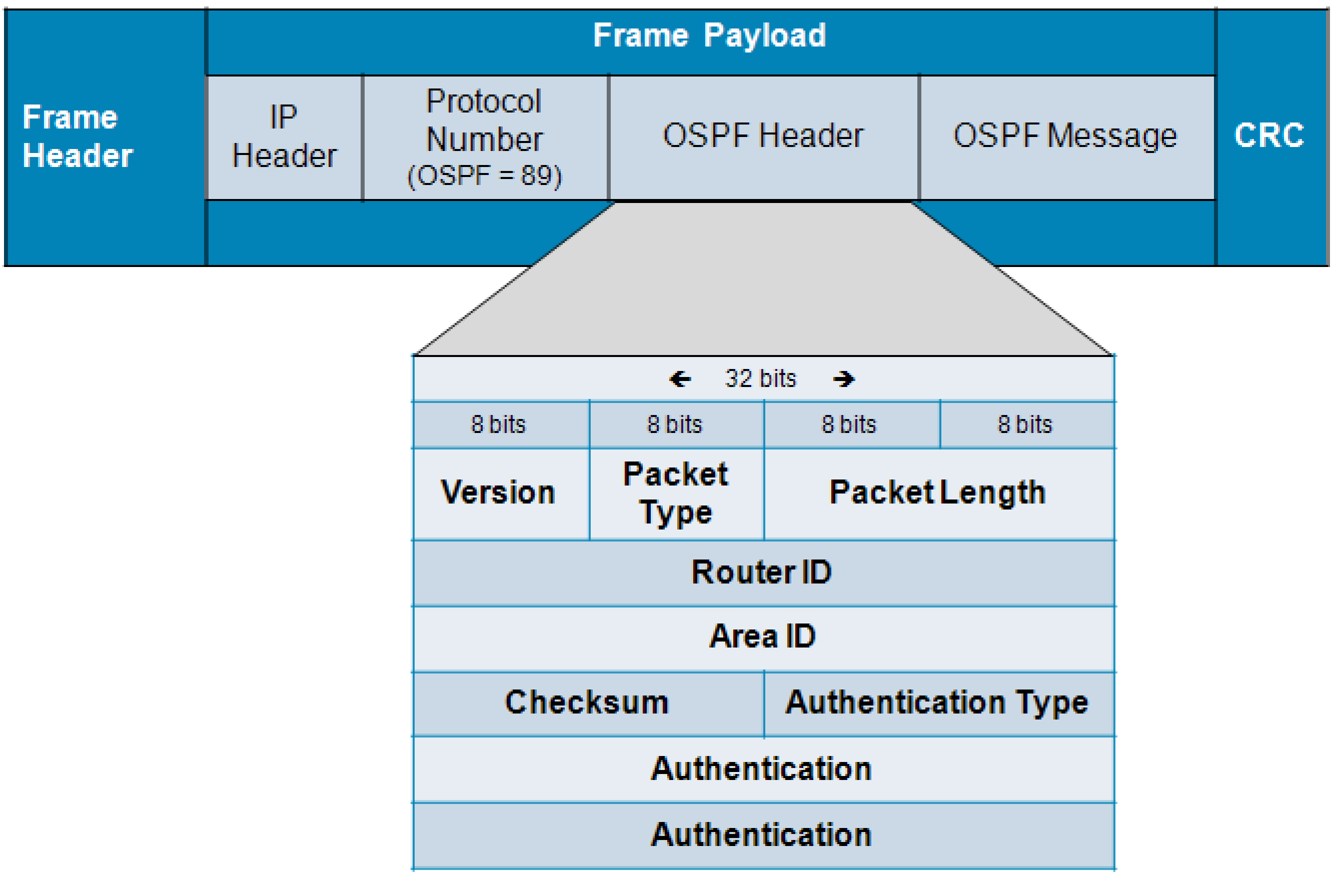
- OSPF packets are used to perform several functions, including:
  - Neighbor discovery, to form adjacencies.
  - Flooding link-state information, to facilitate LSDBs being built in each router.
  - Running SPF to calculate the shortest path to all known destinations.
  - Populating the routing table with the best routes to all known destinations.

OSPF Packet

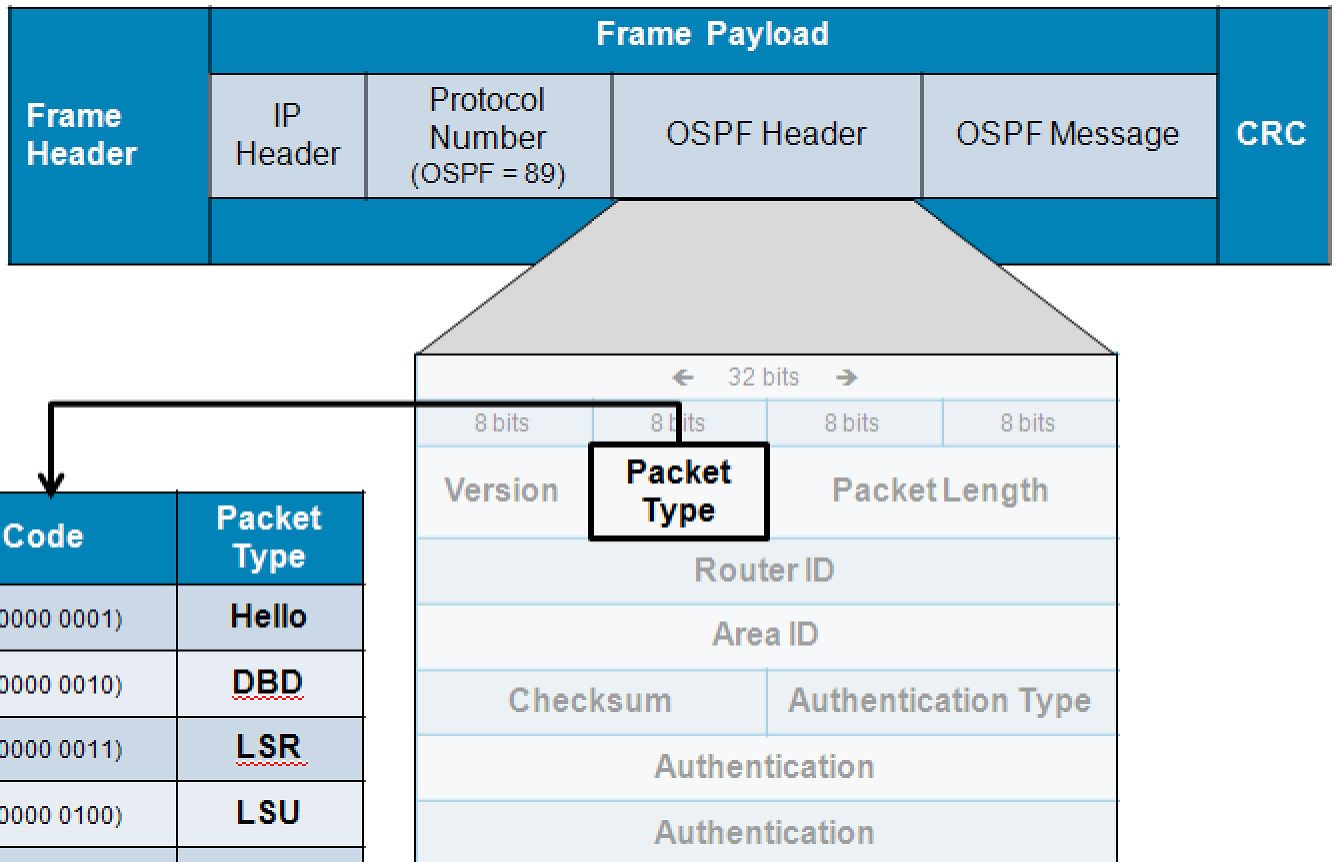
Frame Header	Frame Payload				CRC
	IP Header	Protocol Number (OSPF = 89)	OSPF Header	OSPF Message	

On a LAN, the OSPF packet is encapsulated in an Ethernet frame with a destination multicast MAC address of either: • **01-00-5E-00-00-05** • **01-00-5E-00-00-06**	The destination multicast IP address is set to either: • **224.0.0.5** (All OSPF routers listen to this address.) • **224.0.0.6** (All DR and BDR routers listen to this address. The OSPF protocol field is **89**.	The OSPF header identifies the type of OSPF packet, the router ID and the area number.	The OSPF message contains the packet type specific message information.

OSPF Header


Frame Payload
Frame Header
IP Header
Protocol Number (OSPF = 89)
OSPF Header
OSPF Message
CRC
32 bits
8 bits
8 bits
8 bits
8 bits
Version
Packet Type
Packet Length
Router ID
Area ID
Checksum
Authentication Type
Authentication
Authentication

OSPF Packet Types



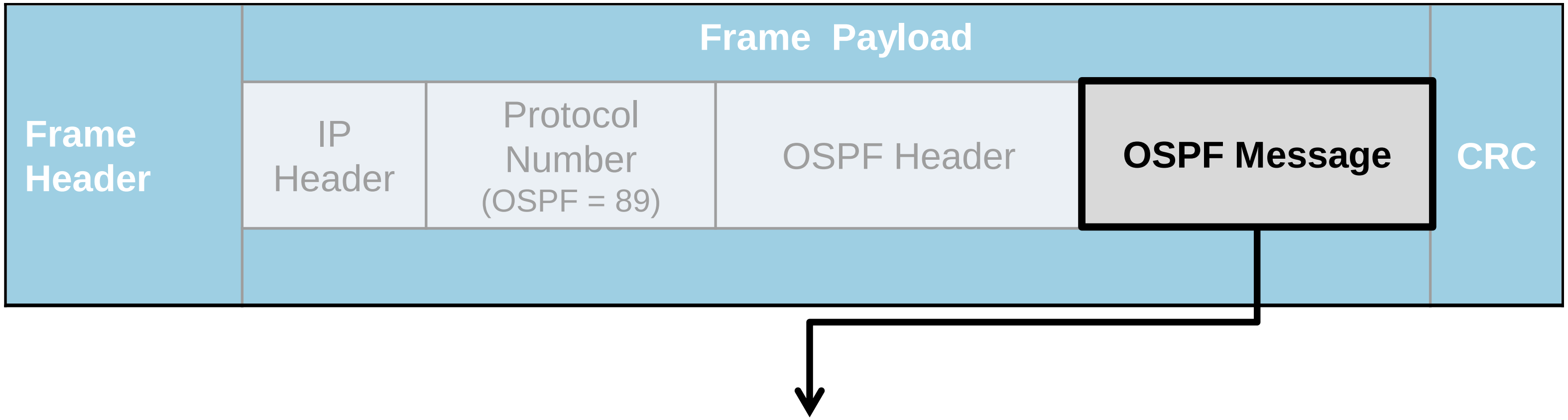
Code	Packet Type
1 (0000 0001)	**Hello**
2 (0000 0010)	**DBD**
3 (0000 0011)	**LSR**
4 (0000 0100)	**LSU**
5 (0000 0101)	**LSAck**

OSPF Packet Types

- Five packet types make OSPF capable of sophisticated and complex communications.

Type	Packet Name	Description
1	Hello	Discovers neighbors and builds adjacencies between them.
2	DBD	Database description Checks for database synchronization between routers.
3	LSR	Link-state request Requests specific link-state records from another router.
4	LSU	Link-state update Sends specifically requested link-state records.
5	LSAck	Link-State Acknowledgment Acknowledges the other packet types.

OSPF Message



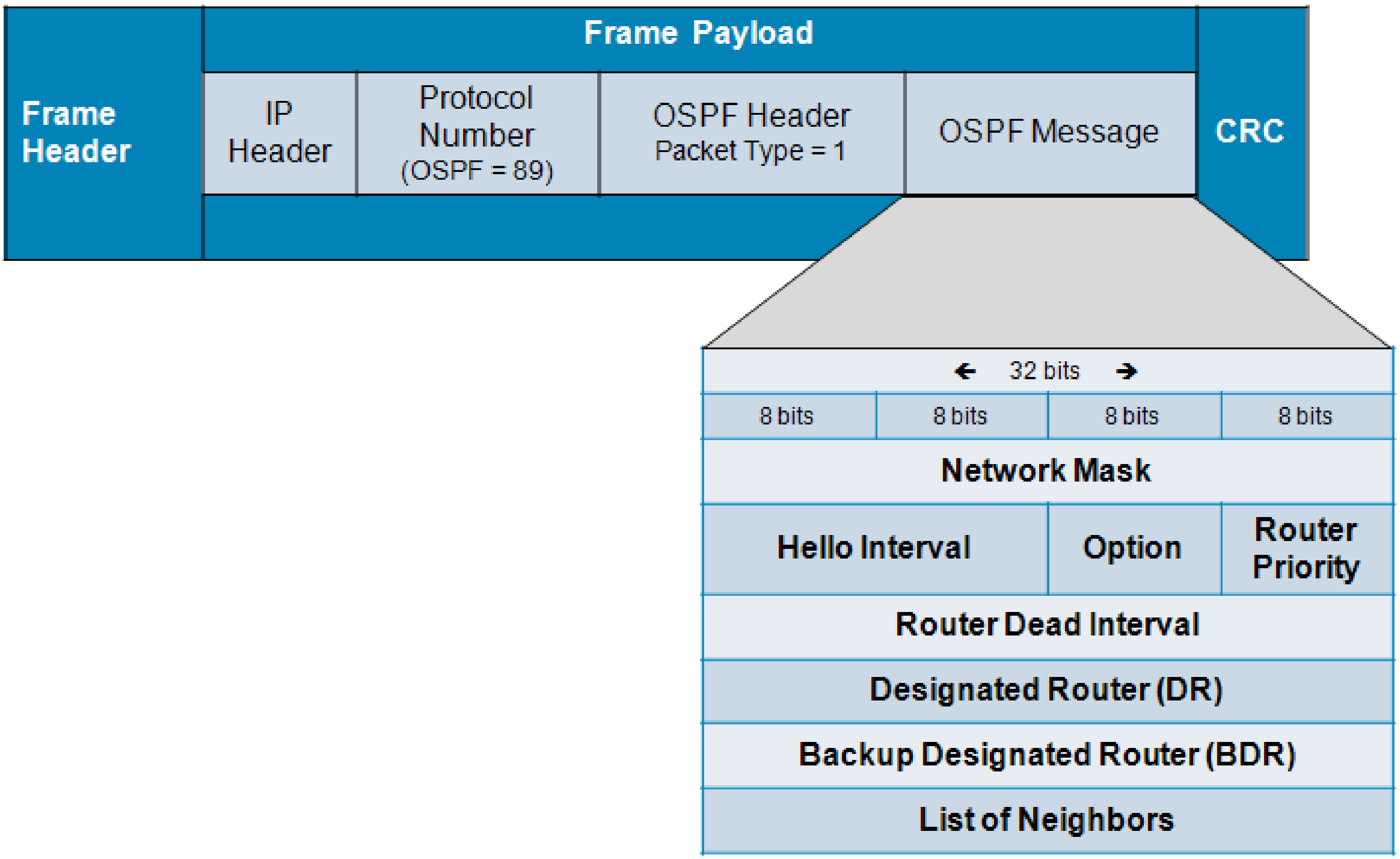
The OSPF message contains different information, depending on the packet type:

Packet Type	Contains
Type 1 - Hello	Contains a list of known neighbors.
Type 2 - DBD	Contains a summary of the LSDB, which includes all known router IDs and their last sequence number, among a number of other fields.
Type 3 - LSR	Contains the type of LSU needed and the router ID of the router that has the needed LSU.
Type 4 - LSU	Contains the full LSA entries. Multiple LSA entries can fit in one OSPF update packet.
Type 5 - LSAck	Data field is empty.

Type 1 - OSPF Hello Packet

- Hello packets are used to:
  - Discover directly connected OSPF neighbors.
  - Establish and maintain neighbor adjacencies with these directly connected neighbors.
  - Advertise parameters on which two routers must agree to become neighbors.
  - Elect the Designated Router (DR) and Backup Designated Router (BDR) on multi-access networks like Ethernet and Frame Relay.

Type 1 - OSPF Hello Packet



Type 1 - OSPF Hello Packet

- Hello packet fields must match on neighboring routers for them to establish an adjacency:
  - Hello interval
  - Dead interval
  - Network type.
  - Area id
  - Authentication password
  - Stub area flag
  - Mask
- Two routers on the same network segment may not form an OSPF adjacency if:
  - They are not in the same area
  - The subnet masks do not match, causing the routers to be on separate networks.
  - The OSPF Hello or Dead Timers do not match.
  - The OSPF network types do not match.
  - The OSPF **`network`** command is missing or incorrect.

Type 1 - OSPF Hello Packet

- By default, OSPF Hello packets are transmitted to 224.0.0.5 (all OSPF routers) every:
  - **10 seconds** (Default on broadcast and point-to-point networks).
  - **30 seconds** (Default on NBMA networks – Frame Relay).
- The Dead interval is the period, expressed in seconds, that the router will wait to receive a Hello packet before declaring the neighbor "down."
  - If the Dead interval expires before the routers receive a Hello packet, OSPF will remove that neighbor from its link-state database.
  - The router floods the link-state information about the "down" neighbor out all OSPF enabled interfaces.
- Cisco uses a default of 4 times the Hello interval.
  - **40 seconds** (Default on broadcast and point-to-point networks).
  - **120 seconds** (Default on NBMA networks – Frame Relay).

Type 2 - OSPF DBD Packet

- The Database Description (DBD) packets contain an abbreviated list of the sending router's link-state database and is used by receiving routers to check against the local link-state database.
- The link-state database must be identical on all link-state routers within an area to construct an accurate SPF tree.

Type 3 - OSPF LSR Packet

- The Link State Request (LSR) packet is used by the receiving routers to request more information about any entry in the DBD.

Type 4 - OSPF LSU Packet

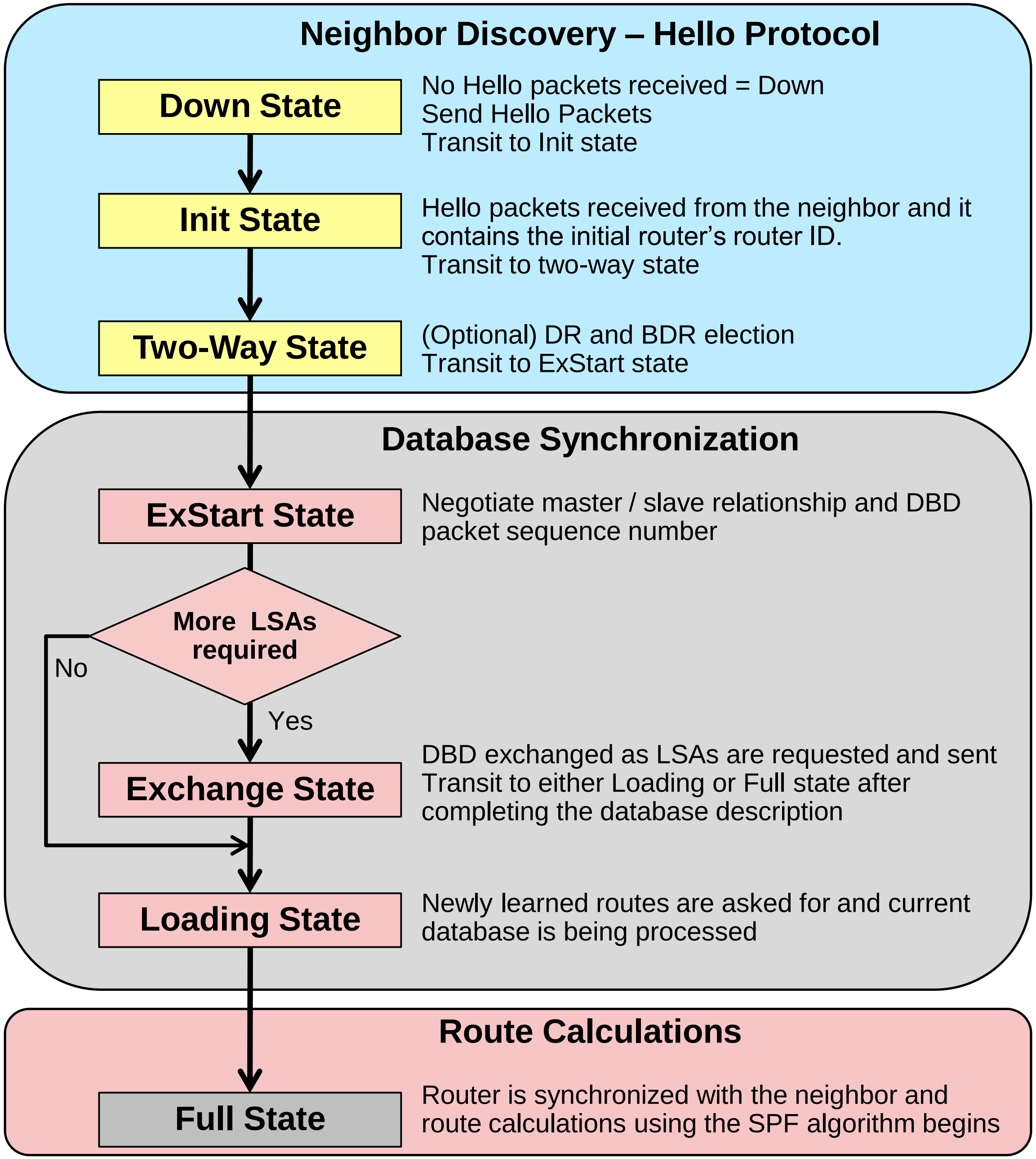
- The Link-State Update (LSU) packets are used for OSPF routing updates.
  - They reply to LSRs as well as to announce new information.
- LSUs contain seven different types of Link-State Advertisements (LSAs).
- LSUs contains the full LSA entries.
  - Multiple LSA entries can fit in one OSPF update packet.

Type 5 - OSPF LSAck Packet

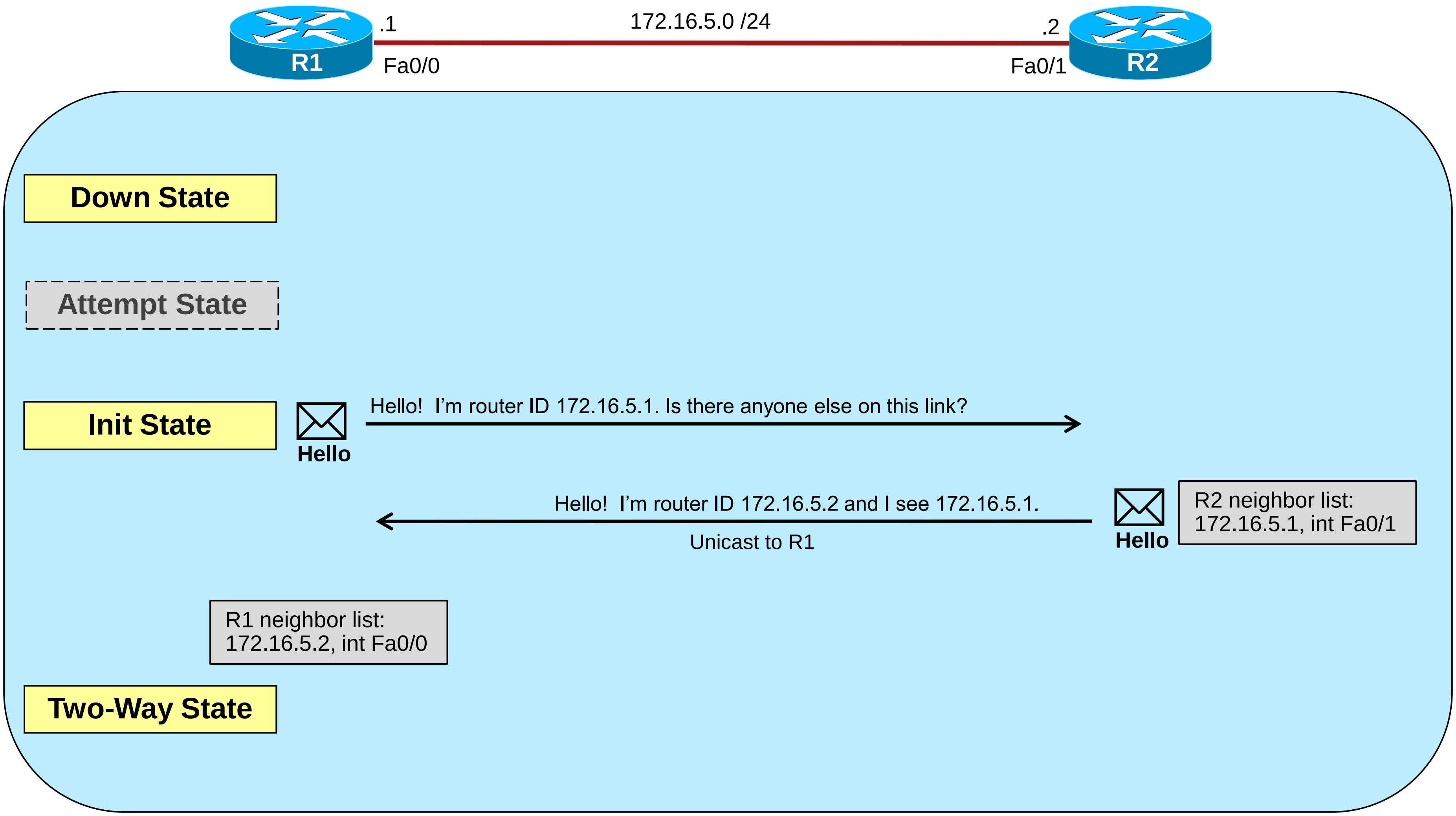
- LSAck - Link-State Acknowledgement Packet:
  - When an LSU is received, the router sends a LSAck to confirm receipt of the LSU.
  - The LSAck data field is empty.

OSPF States

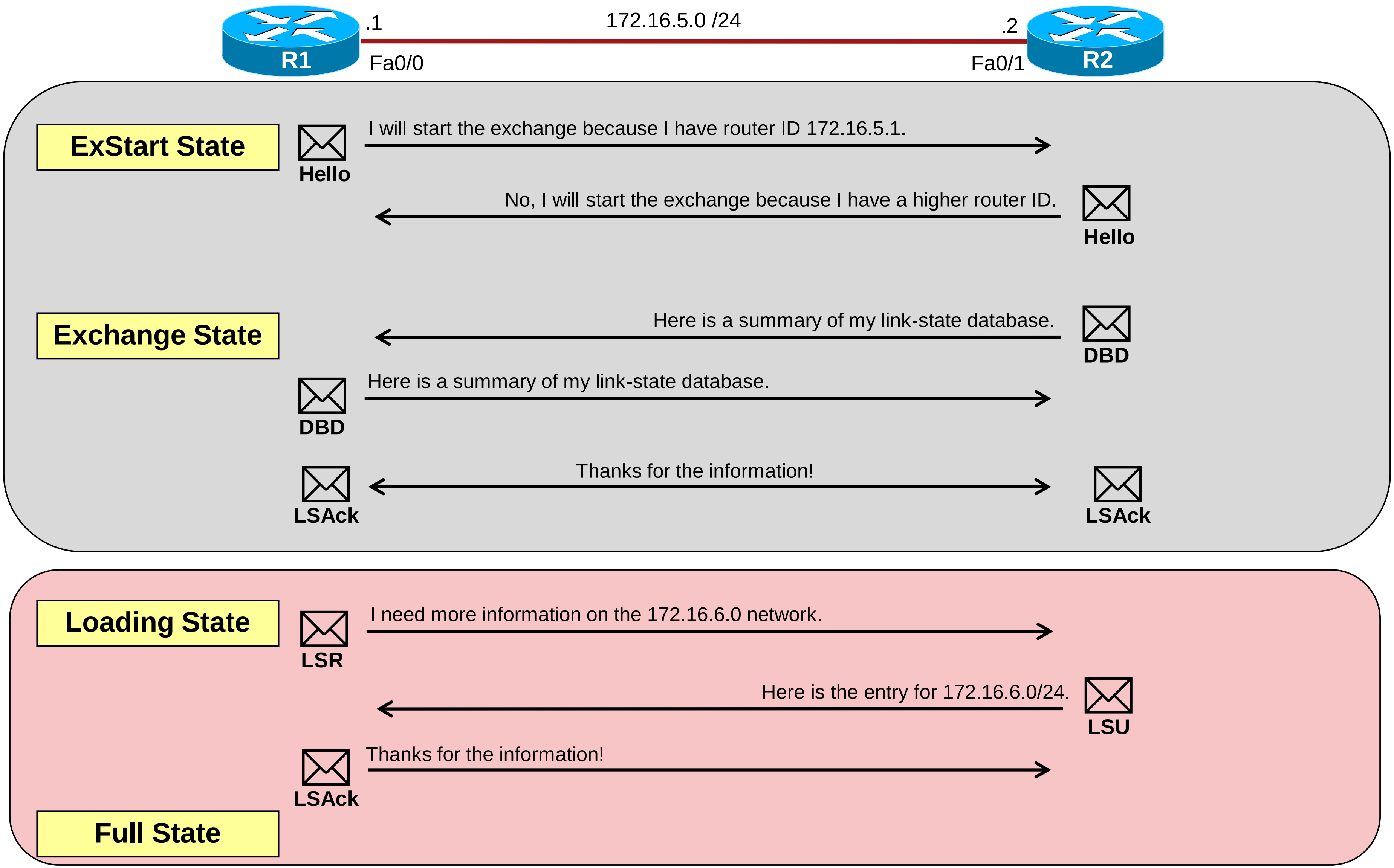
- When an OSPF router is initially connected to a network it attempts to create adjacencies with neighbors.
- To do so, it progresses through these various states using the 5 OSPF packet types.



Neighbor Discovery – Hello Protocol



Database Synchronization & Route Calc



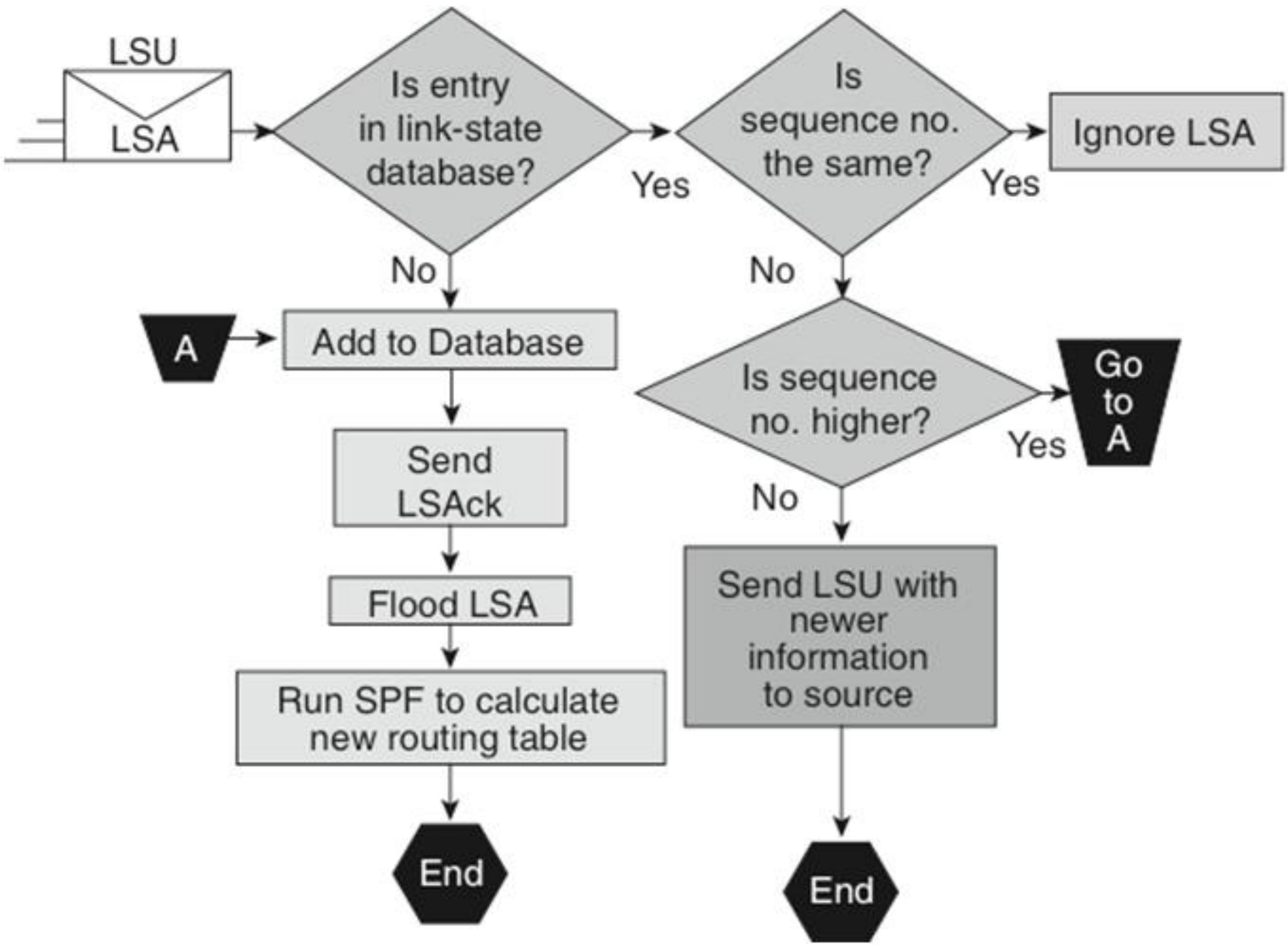
Adjacent OSPF Neighbors

- Once neighbors adjacencies have been established, the Hello packet continues to be transmitted every 10 seconds (default) between neighbors.
  - As long as the other routers keep receiving the Hello packets, the transmitting router and its networks reside in the topology database.
- After the topological databases are synchronized, updates (LSUs) are sent only to neighbors when:
  - A change is perceived (Incremental updates)
  - Every 30 minutes (Condensed version is forwarded).

Link-State Data Structures

- Each LSA entry has its own aging timer, which the link-state age field carries.
- The default aging timer value for OSPF is 30 minutes (1800 seconds).
- After an LSA entry ages, the router that originated the entry sends the LSA, with a higher sequence number, in a link-state update (LSU), to verify that the link is still active.
  - The LSU can contain one or more LSAs.
  - This LSA validation method saves on bandwidth compared to distance-vector routers, which send their entire routing table at short, periodic intervals.

Link-State Data Structures



OSPF Administrative Distance

Route Source	Administrative Distance
Connected	0
Static	1
EIGRP Summary	5
External BGP	20
Internal EIGRP	90
IGRP	100
OSPF	110
IS IS	115
RIP	120
External EIGRP	170
Internal BGP	200

Planning OSPF Routing Implementations

Planning to Deploy OSPF

- Prior to deploying an OSPF routing solution, the following should be considered:
  - IP addressing plan
  - Network topology
  - OSPF areas
- Once the requirements have been assessed, the implementation plan can be created.

Implementing OSPF

- The information necessary to implement OSPF routing includes the following:
  - The IP addresses to be configured on individual router interfaces.
  - A list of routers on which OSPF is to be enabled, along with the OSPF process number to use and the connected networks that are to run OSPF and that need to be advertised (per individual router).
  - The area in which each interface is to be configured.
  - Metrics that need to be applied to specific interfaces, or OSPF traffic engineering.
- In the implementation plan, OSPF tasks include the following:
  - Enabling the OSPF routing protocol, directly on an interface or by using the correct **`network`** command under the OSPF routing process configuration mode.
  - Assigning the correct area id to the interface, via the OSPF configuration on the interface or under the OSPF routing process configuration mode.
  - Optionally configuring the metric to appropriate interfaces.

Verifying OSPF

- After implementing OSPF, verification should confirm proper deployment on each router.
- Verification tasks include verifying:
  - Verifying that the appropriate OSPF neighbor relationships and adjacencies are established
  - Verifying that the OSPF LSDB is populated with the necessary information.
  - Verifying that IP routing table is populated with the necessary information.
  - Verifying that there is connectivity in the network between routers and to other devices.
  - Verifying that OSPF behaves as expected in a case of a topology change, by testing link failure and router failure events.

Documenting

- After a successful OSPF deployment, the solution and verification process and results should be documented for future reference.
- Documentation should include:
  - A topology map
  - The IP addressing plan
  - The area hierarchy
  - The networks and interfaces included in OSPF on each router
  - The default and any special metrics configured
  - The verification results.

Configuring and Verifying Basic OSPF

Enable OSPF Routing

- Define OSPF as the IP routing protocol.

```
Router(config)#
```

```
router ospf process-id
```

- The *process-id* is an internally used number that identifies the OSPF routing process.
  - The *process-id* does not need to match process IDs on other routers
  - It can be any positive integer in the range from 1 to 65535.

Identify OSPF Networks

- Define OSPF networks to advertise to OSPF neighbors.

```
Router(config-router)#
```

```
network ip-address [wildcard-mask] area area-id
```

- The `ip-address` parameter can be a network, a subnet, or the address of a directly connected interface.
- The `wildcard-mask` is an inverse mask used to determine how to interpret the address.
  - The mask has wildcard bits, where 0 is a match and 1 is “don’t care.”
  - For example, 0.0.255.255 indicates a match in the first 2 octets.
- The `area-id` parameter specifies the OSPF area to be associated with the address.

The Wildcard Mask

- Recall that a wildcard mask is the inverse of a subnet mask.
- An easy way to calculate the inverse of the subnet mask, is to subtract the subnet mask from **255.255.255.255**.
- For example, the inverse of subnet mask **255.255.255.252** is **0.0.0.3**.

```
  255.255.255.255
– 255.255.255.252
    0.  0.  0.  3
```

Identify OSPF Networks

- Optional method to enable OSPF explicitly on an interface.

```
Router(config-if)#
```

```
ip ospf process-id area area-id
```

(**ip ospf** *process-id* **area** *area-id*)

- The *process-id* parameter can be a network, a subnet, or the address of a directly connected interface.
- The *area-id* parameter specifies the OSPF area to be associated with the address.
- Because this command is configured explicitly for the interface, it takes precedence over the **network area** command.

Define the Interface Bandwidth

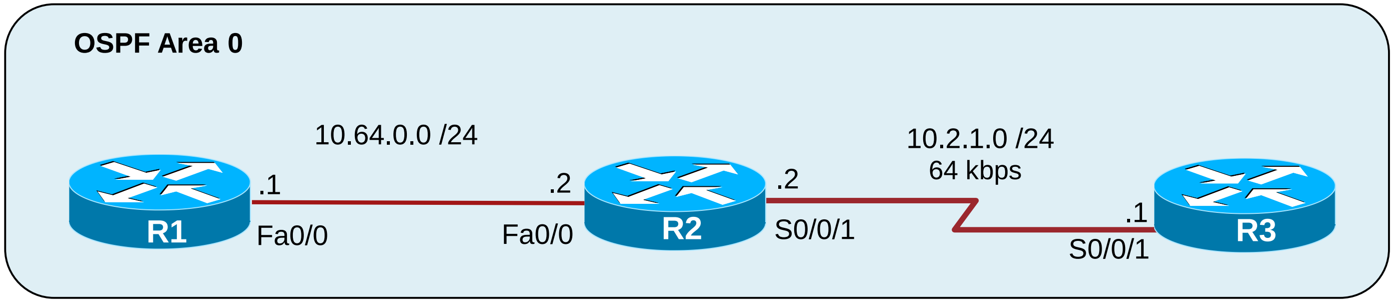
- Defines the interface's bandwidth (optional).

```
Router(config-if)#
```

```
bandwidth kilobits
```

- The *kilobits* parameter indicates the intended bandwidth in kbps.
  - For example, to set the bandwidth to 512,000 bps, use the **bandwidth 512** command.
- The configured bandwidth is used by routing protocols in the metric calculation.
- The command does not actually change the speed of the interface.

Configuring Single-Area OSPF Example

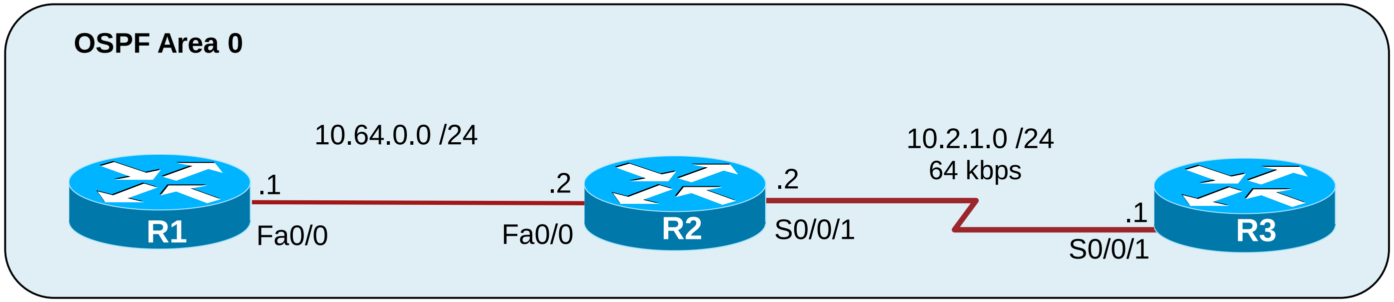



```
R1(config)# interface Fa0/0
R1(config-if)# ip address 10.64.0.1 255.255.255.0
R1(config-if)# no shut
R1(config-if)# exit
R1(config)#
```

```
R2(config)# interface Fa0/0
R2(config-if)# ip address 10.64.0.2 255.255.255.0
R2(config-if)# no shut
R2(config-if)# interface S0/0/1
R2(config-if)# ip address 10.2.1.2 255.255.255.0
R2(config-if)# bandwidth 64
R2(config-if)# no shut
R2(config-if)# exit
R2(config)#
```

```
R3(config)# interface S0/0/1
R3(config-if)# ip address 10.2.1.1 255.255.255.0
R3(config-if)# bandwidth 64
R3(config-if)# no shut
R3(config-if)# exit
R3(config)#
```

Configuring Single-Area OSPF Example

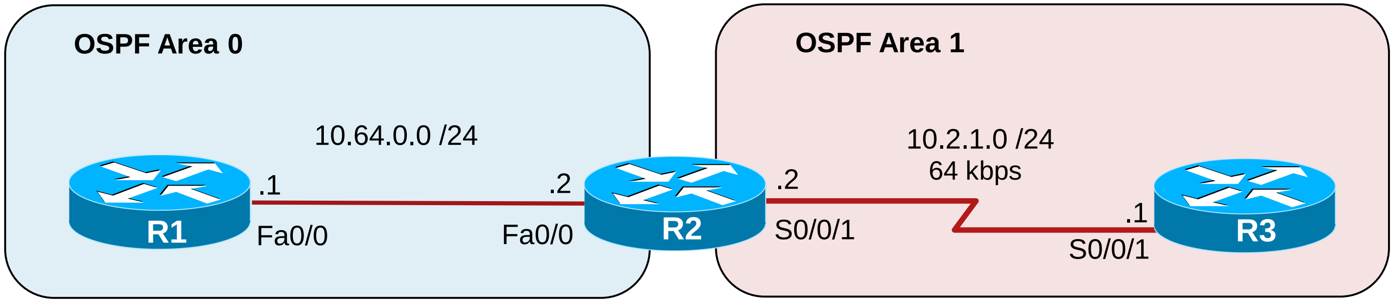



```
R1(config)# router ospf 1
R1(config-router)# network 10.0.0.0 0.255.255.255 area 0
R1(config-router)#
```

```
R2(config)# router ospf 50
R2(config-router)# network 10.2.1.2 0.0.0.0 area 0
R2(config-router)# network 10.64.0.2 0.0.0.0 area 0
R2(config-router)#
```

```
R3(config)# router ospf 100
R3(config-router)# network 10.2.1.1 0.0.0.0 area 0
R3(config-router)#
```

Configuring Multi-Area OSPF Example

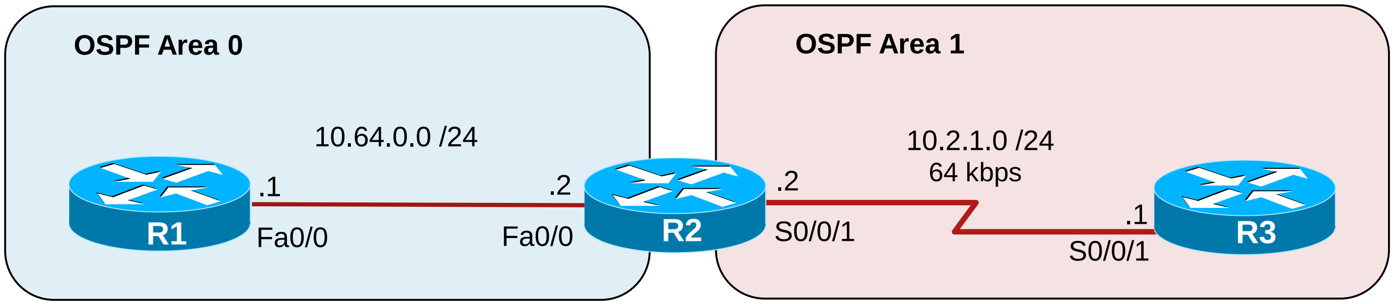



```
R1(config)# router ospf 1
R1(config-router)# network 10.0.0.0 0.255.255.255 area 0
R1(config-router)#
```

```
R2(config)# router ospf 50
R2(config-router)# network 10.2.1.2 0.0.0.0 area 1
R2(config-router)# network 10.64.0.2 0.0.0.0 area 0
R2(config-router)#
```

```
R3(config)# router ospf 100
R3(config-router)# network 10.2.1.1 0.0.0.0 area 1
R3(config-router)#
```

Alternate Multi-Area OSPF Configuration




```
R1(config)# router ospf 1
R1(config-router)# network 10.0.0.0 0.255.255.255 area 0
R1(config-router)#
```

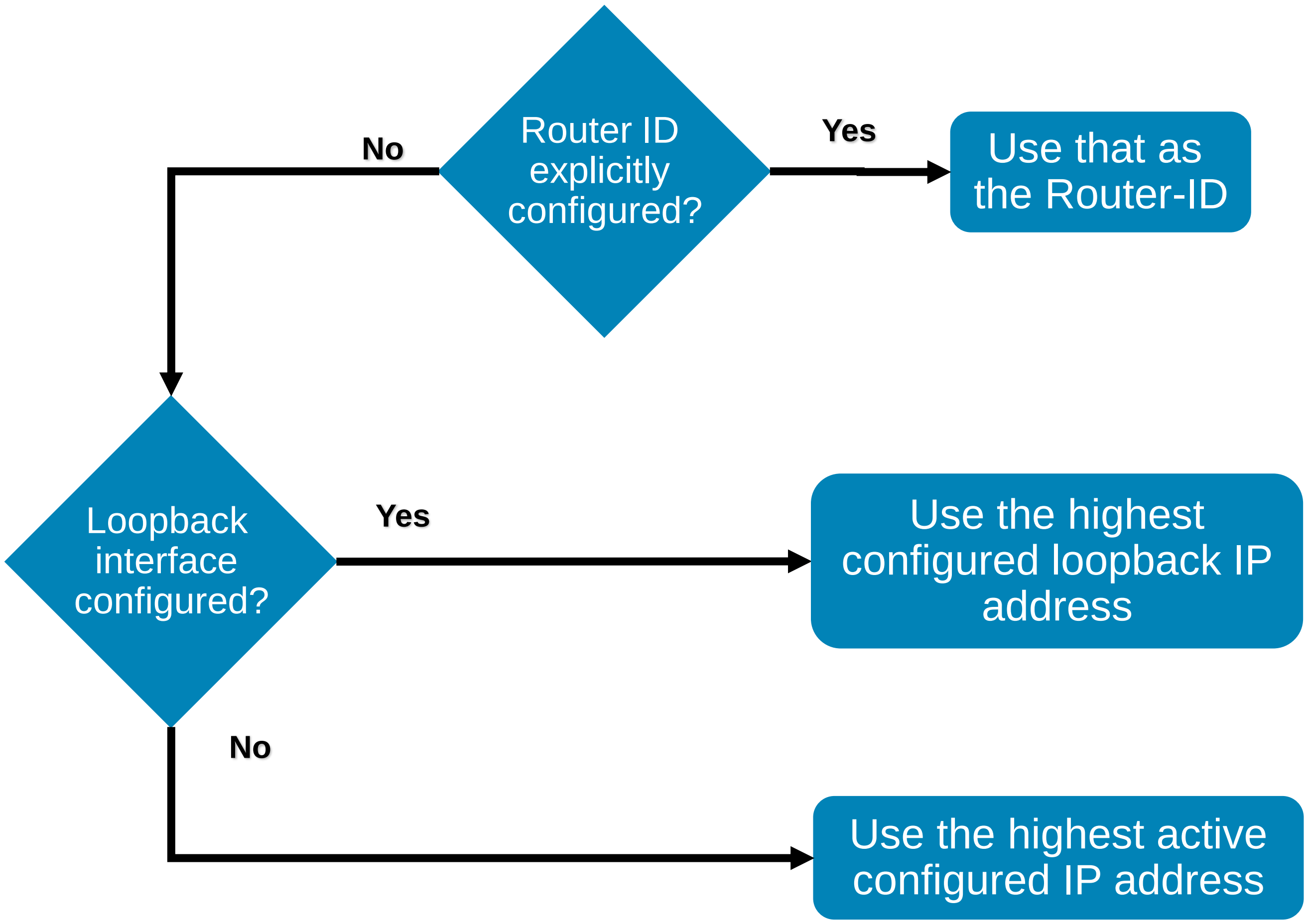
```
R2(config)# interface S0/0/1
R2(config-if)# ip ospf 50 area 1
R2(config-if)# exit
R2(config)#
R2(config)# router ospf 50
R2(config-router)# network 10.64.0.2 0.0.0.0 area 0
R2(config-router)#
```

```
R3(config)# router ospf 100
R3(config-router)# network 10.2.1.1 0.0.0.0 area 1
R3(config-router)#
```

OSPF Router ID

- A router is known to OSPF by the OSPF router ID number.
  - LSDBs use the OSPF router ID to differentiate one router from the next.
- By default, the router ID is the highest IP address on an active interface at the moment of OSPF process startup.
  - However, for stability reason, it is *recommended* that the **`router-id`** command or a loopback interface be configured.

OSPF Router ID



Define the Router ID

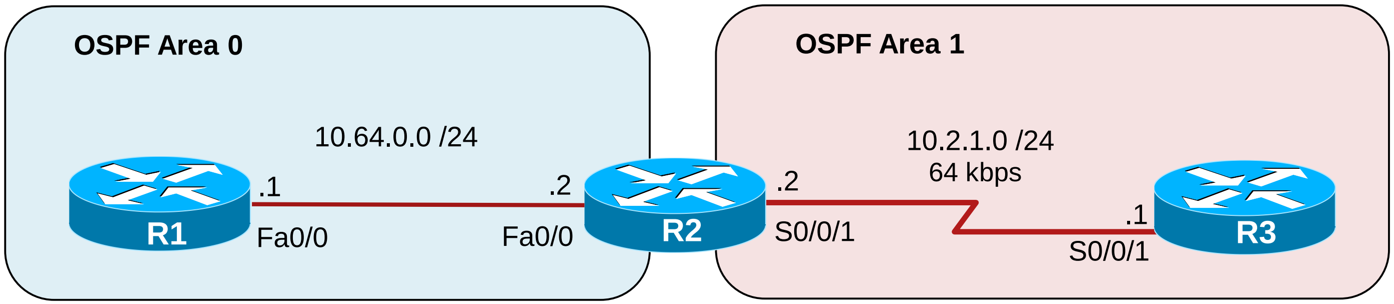
- Assign a specific router ID to the router.

```
Router(config-router)#
```

router-id *ip-address*

- Any unique arbitrary 32-bit value in an IP address format (dotted decimal) can be used.
- If this command is used on an OSPF process that is already active, then the new router ID takes effect:
  - After the next router reload.
  - After a manual restarting of the OSPF process using the **clear ip ospf process** privileged EXEC command.

Verifying the Router-ID




```
R2# show ip ospf
Routing Process "ospf 50" with ID 10.64.0.2
<output omitted>
```

Verifying OSPF

Command	Description
`show ip protocols`	Displays OSPF process ID, router ID, networks router is advertising & administrative distance
`show ip ospf neighbors`	Displays OSPF neighbor relationships.
`show ip route`	Displays the routing table.
`show ip ospf interface`	Displays hello interval and dead interval
`show ip ospf database`	Displays OSPF database
`show ip ospf`	Displays OSPF process ID, router ID, OSPF area information & the last time SPF algorithm calculated

Verifying OSPF: show ip protocols

Verify routing protocol information on the router.

```
R1# show ip protocols
Routing Protocol is “ospf 1”
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 10.64.0.1
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.0.0.0 0.255.255.255 area 0
  Reference bandwidth unit is 100 mbps
<output omitted>
```

Verifying OSPF: show ip ospf neighbors

Display OSPF neighbors.

```
R2# show ip ospf neighbor

Neighbor ID    Pri   State           Dead Time   Address     Interface
10.64.0.1      1     FULL/DROTHER    00:00:30    10.64.0.1   FastEthernet0/0
10.2.1.1       1     FULL/  -        00:00:34    10.2.1.1    Serial0/0/1
```

The interface on which this router has formed adjacency with the neighbor.

Lists the neighbors in the order they were learned.

The OSPF priority of the interface.

The OSPF state of the interface. FULL state means that the router and its neighbor have identical OSPF link-state databases.

The amount of time remaining that the router will wait to receive an OSPF Hello packet from the neighbor before declaring the neighbor down.

The IP address of the neighbor's interface to which this router is directly connected.

Verifying OSPF: show ip route ospf

Verify that the router recognizes OSPF routes.

```
R1# show ip route ospf
10.0.0.0/8 is variably subnetted, 3 subnets, 2 masks
O IA    10.2.1.0/24 [110/782] via 10.64.0.2, 00:03:05, FastEthernet0/0
R1#
```

Clearing the OSPF Routing Table

- To clear all routes from the IP routing table, use:

  Router# **clear ip route ***

- To clear a specific route from the IP routing table, use:

  Router# **clear ip route A.B.C.D**

Verifying OSPF: show ip ospf interface

Verify OSPF configured interfaces.

```
R1# show ip ospf interface fastEthernet 0/0
FastEthernet0/0 is up, line protocol is up
  Internet Address 10.64.0.1/24, Area 0
  Process ID 1, Router ID 10.64.0.1, Network Type BROADCAST, Cost: 1
  Transmit Delay is 1 sec, State DROTHER, Priority 0
  Designated Router (ID) 10.64.0.2, Interface address 10.64.0.2
  No backup designated router on this network
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    oob-resync timeout 40
    Hello due in 00:00:04
  Supports Link-local Signaling (LLS)
  Index 1/1, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 1, maximum is 4
  Last flood scan time is 0 msec, maximum is 4 msec
  Neighbor Count is 1, Adjacent neighbor count is 1
    Adjacent with neighbor 10.64.0.2 (Designated Router)
  Suppress hello for 0 neighbor(s)
```

Verifying OSPF: show ip ospf

Verify general OSPF information.

```
R2# show ip ospf
Routing Process “ospf 50” with ID 10.64.0.2
<output omitted>
Area BACKBONE(0)
        Area has no authentication
        SPF algorithm last executed 00:01:25.028 ago
        SPF algorithm executed 7 times
<output omitted>
    Area 1
        Number of interfaces in this area is 1
        Area has no authentication
        SPF algorithm last executed 00:00:54.636 ago
        SPF algorithm executed 3 times
 <output omitted>
R2#
```

Understanding OSPF Network Types

OSPF Network Types

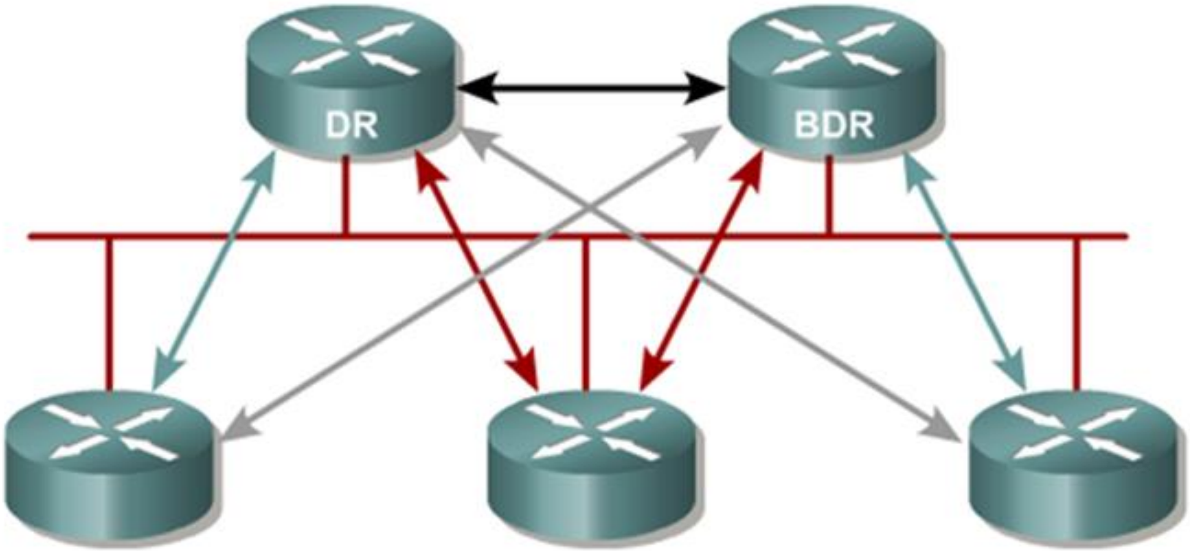
- OSPF defines three types of network:

Network Type	Description	Example
Broadcast	• A multiaccess broadcast network. • DR / BDR required.	All Ethernet networks
Point-to-point	• A network that joins a single pair of routers. • No DR / BDR required.	Serial link using PPP / HDLC

Nonbroadcast multiaccess (NBMA)	• A network that interconnects more than two routers but that has no broadcast capability.
	• DR / BDR may or may not be required.
	• There are five modes of OSPF operation available for NBMA networks:
	  • RFC-compliant modes:
	    • non-broadcast
	    • point-to-multipoint
	  • Cisco proprietary modes:
	    • broadcast
	    • point-to-multipoint non-broadcast
	    • point-to-point
	• The choice of mode depends on the topology of the NBMA network.
		Frame Relay
		ATM
		X.25

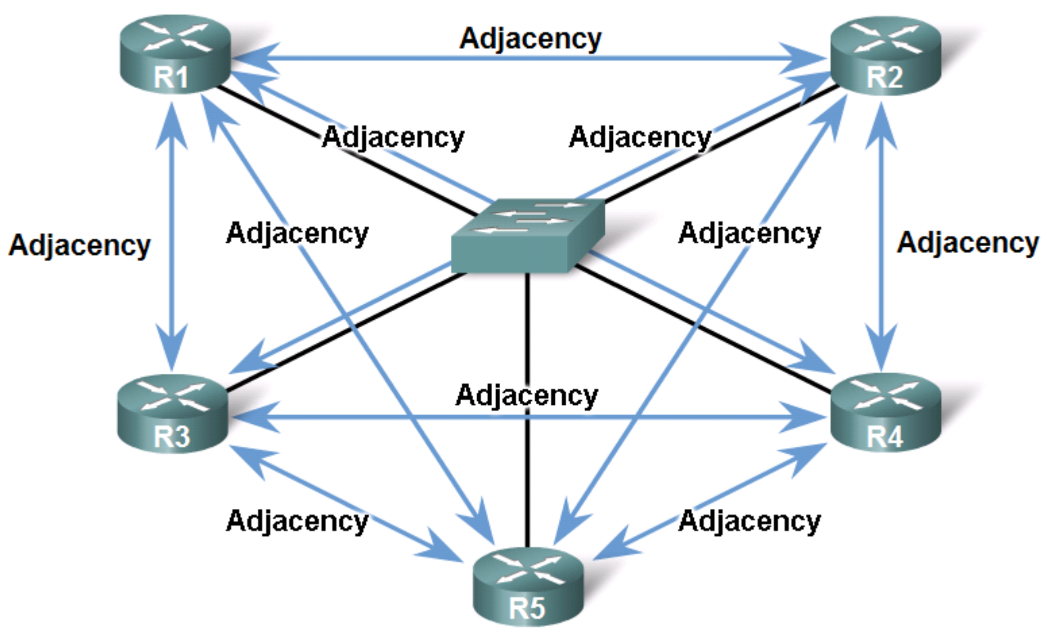
Broadcast

- DR /BDR election required since there could be many devices.
  - Establishing adjacencies with all routers in a broadcast network would easily overload a router due to the overhead of maintaining those adjacencies.
  - Instead, OSPF routers form full adjacencies with the DR and BDR only.
- Packets to all OSPF routers are forwarded to 224.0.0.5.
- Packets to the DR / BDR are forwarded to 224.0.0.6.



Broadcast Challenge: Multiple Adjacencies

- A challenge of broadcast network is the number of adjacencies that would be required.
  - One adjacency for every pair of routers.
  - This would increase network traffic and load on each router to manage each individual adjacency.

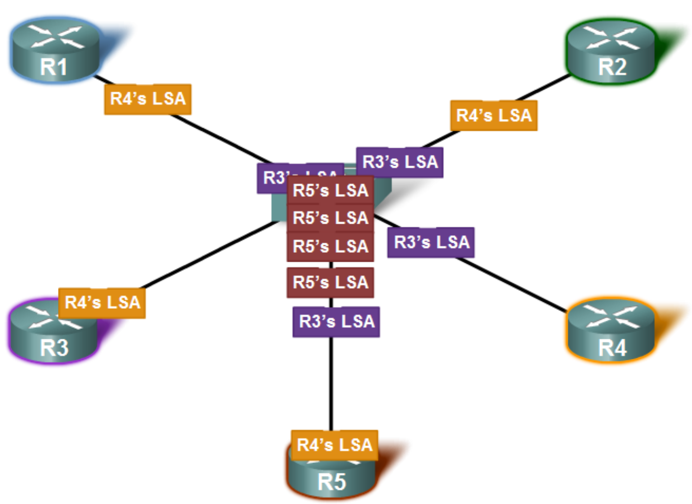


Routers n	Adjacencies n(n-1)/2
5	**10**
10	45
20	190
100	4,950

Broadcast Challenge: Extensive LSAs

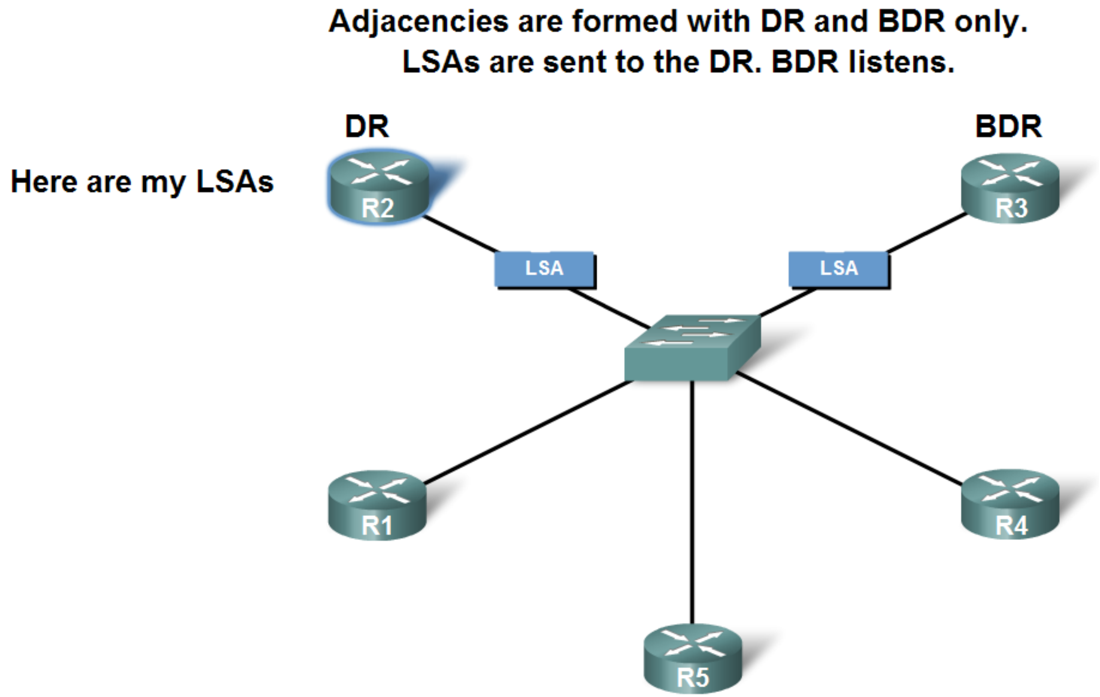
- Another challenge is the increase in network LSAs.
  - Every LSA sent out also requires an acknowledgement.
- Consequence:
  - Lots of bandwidth consumed
  - Chaotic traffic

LSA Flooding Scenario



Solution: Designated Router

- A designated router (DR) and backup designated router (BDR) solve these challenges because they:
  - Reduce routing update traffic
  - Manage link-state synchronization



Designated Router (DR)

- The DR is elected and becomes responsible for maintaining the topology table for the segment.
- This DR has two main functions:
  - To become adjacent to all other routers on the network segment.
  - To act as a spokesperson for the network.
- As spokesperson the DR becomes the focal point for collecting and sending routing information (LSAs).

Backup Designated Router (BDR)

- For fault tolerance, a second router is elected as the BDR.
  - The BDR must also become adjacent to all routers on the network and must serve as a second focal point for LSAs.
  - However, the BDR is not responsible for updating the other routers or sending network LSAs.
- The BDR keeps a timer on the DR's update activity to ensure that it is operational.
  - If the BDR does not detect activity from the DR after the timer expires, the BDR immediately becomes the DR and a new BDR is elected.

DR/BDR

- DRs and BDRs are elected on a per-network basis and therefore each network segment has its own DR and BDR.
  - For example, a router connected to multiple multiaccess broadcast networks can be a DR on one segment and a regular (DROTHER) router on another segment.
- The election process is accomplished dynamically using the Hello protocol.
  - However, the election can be manually manipulated the **`ip ospf priority`** *`number`* interface configuration command.
- After a DR and BDR have been selected, any router added to the broadcast network establishes full adjacencies with the DR and BDR only.

Assigning Router Priority

- Assign a specific OSPF priority to the router.

```
Router(config-if)#
```

ip ospf priority *number*

- A router interface can have a priority number between 0 - 255:
  - 0 = DROTHER - Router cannot be a DR
  - 1 = Favorable - Default for all routers
  - 255 = Very favorable - Ensures at least of a tie.
- The priority must be configured before the election takes place to figure into the election.
- To display an interface's priority value and other key information use the **show ip ospf interface** command.

The Election of the DR

1. All neighbors with a priority > 0 are listed.
2. The router with highest priority is elected BDR.

   If there is a tie, the highest router IDs are used.
3. If there is no DR, the BDR is promoted as DR.
4. The neighbor with the next highest priority is elected BDR.

Manipulating the Election Process

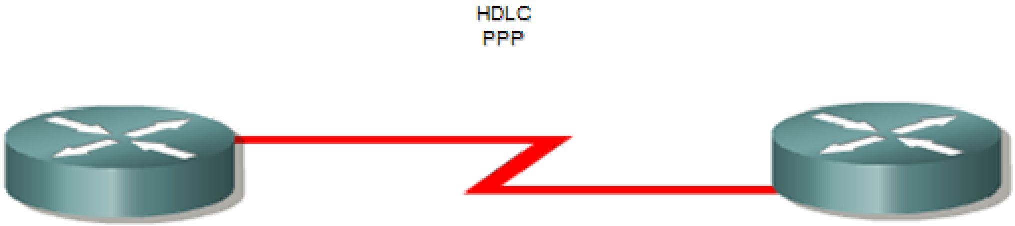
- The DR / BDR maintain these roles until they fail even when more routers with higher priorities show up on the network.
- To influence the election of DR & BDR, do one of the following:
  - Boot up the DR first, followed by the BDR, and then boot all other routers.

  OR

  - Shut down the interface on all routers, followed by a **`no shutdown`** on the DR, then the BDR, and then all other routers.

Point-to-Point

- Both routers become fully adjacent to each another.
- Usually a serial interface running either PPP or HDLC.
  - May also be a point-to-point subinterface running Frame Relay or ATM.
- No DR /BDR election required since there are only two devices.
- OSPF autodetects this type of network.
- Packets are sent to 224.0.0.5.

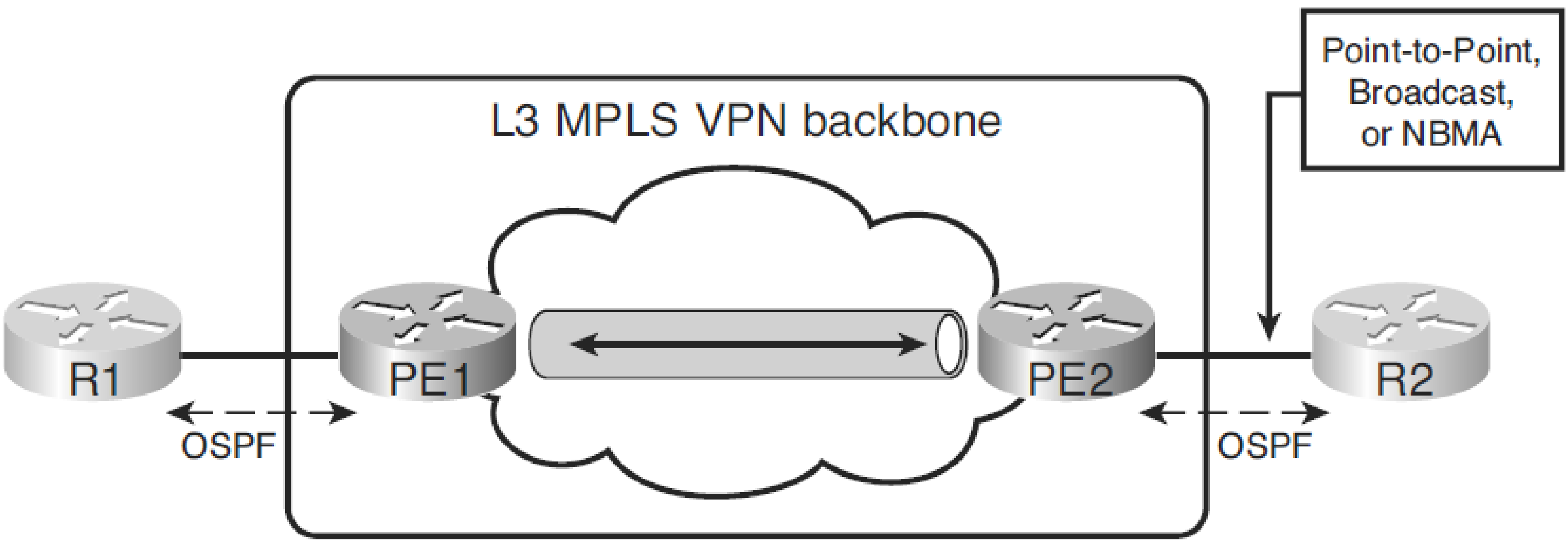


OSPF over MPLS

- Multi-Protocol Label Switching (MPLS) is an Internet Engineering Task Force (IETF) standard architecture that combines the advantages of Layer 3 routing with the benefits of Layer 2 switching.
- A unique feature of MPLS is its capability to perform label stacking, in which multiple labels can be carried in a packet.
- The top label, which is the last one in, is always processed first.
  - Label stacking enables multiple LSPs to be aggregated, thereby creating tunnels through multiple levels of an MPLS network.

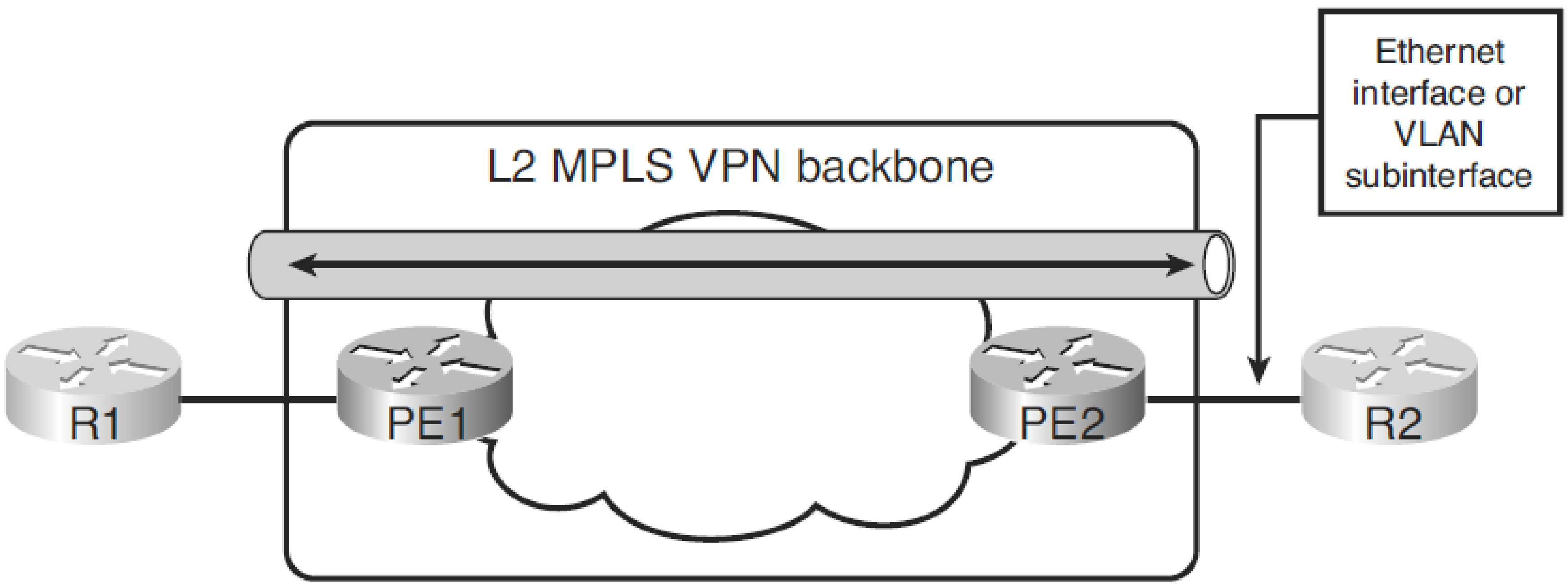
OSPF over Layer 3 MPLS VPN

- The customer and provider edge routers are running OSPF.
  - However the internal provider routers do not.
- The customer has to agree upon OSPF parameters with the service provider (SP) to ensure connectivity.
  - These parameters are often governed by the SP.



OSPF over Layer 2 MPLS VPN

- The Layer 2 MPLS VPN backbone and the provider routers are not visible to the customer routers.
  - A neighbor relationship is established directly between OSPF enabled routers over the MPLS backbone, and behaves in the same way as on an Ethernet broadcast network therefore DR and BDR routers are elected.



Nonbroadcast Multiaccess (NBMA)

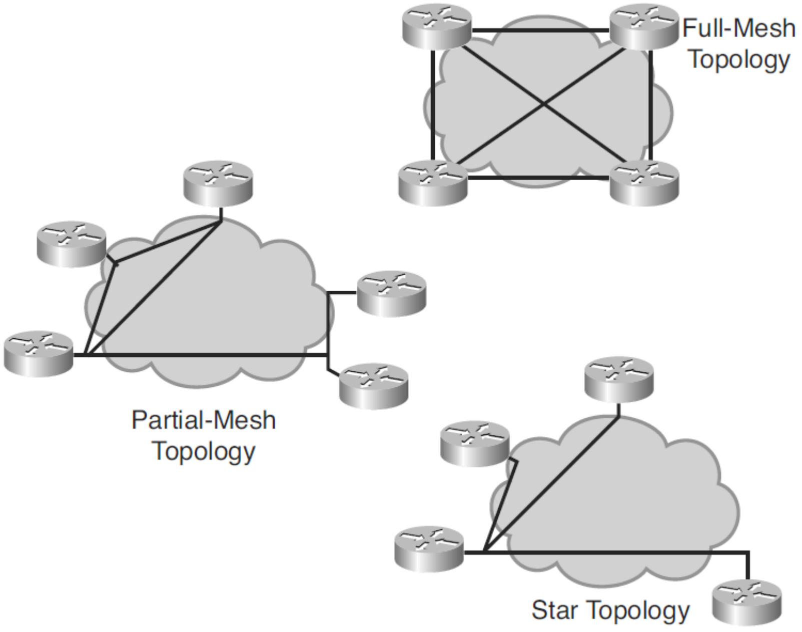
- Frame Relay, ATM, and X.25 are examples of NBMA networks.
- The default OSPF hello and dead intervals on NBMA interfaces are 30 seconds and 120 seconds, respectively.
- Although NBMA networks can support more than two routers, they have no inherent broadcast capability.
  - This can create reachability issues.
- To implement broadcasting or multicasting, the router replicates the packets to be broadcast or multicast and sends them individually on each permanent virtual circuit (PVC) to all destinations.
  - This process is CPU and bandwidth intensive.

DR Election in an NBMA Topology

- By default, OSPF cannot automatically build adjacencies with neighbor routers over NBMA interfaces.
- OSPF considers the NBMA environment to function similarly to other multiaccess media such as Ethernet.
  - However, NBMA networks are usually hub-and-spoke (star) topologies using PVCs or switched virtual circuits (SVCs).
  - In these cases, the physical topology does not provide the multiaccess capability on which OSPF relies.
- The election of the DR becomes an issue in NBMA topologies because the DR and BDR need to have full Layer 2 connectivity with all routers in the NBMA network.
- The DR and BDR also need to have a list of all the other routers so that they can establish adjacencies.

OSPF over NBMA Topology

- Depending on the network topology, several OSPF configuration choices are available for a Frame Relay network.



OSPF over NBMA Topology

- There are five NBMA topology modes of operation:
  - Two official OSPF modes described in RFCs
  - Three customized Cisco modes.
- RFC 2328-compliant modes are as follows:
  - Nonbroadcast (NBMA)
  - Point-to-multipoint
- Cisco modes are as follows:
  - Point-to-multipoint nonbroadcast
  - Broadcast
  - Point-to-point
- OSPF NBMA topology modes are configured using the **`ip ospf network`** interface configuration command.
  - Some modes require that a neighbor be manually configured using the **`neighbor`** router configuration command.

Assign an NBMA Topology Mode

- Define an OSPF network type on an interface.

```
Router(config-if)#
```

```
ip ospf network [{non-broadcast | point-to-multipoint [non-
  broadcast] | broadcast | point-to-point}]
```

- The choice of mode depends on the NBMA topology.
- The default OSPF mode on a Frame Relay:
  - Interface is **non-broadcast** mode.
  - Point-to-point subinterface is **point-to-point** mode.
  - Multipoint subinterface is **non-broadcast** mode.

NBMA Topology Modes of Operation

NBMA Modes	Description
non-broadcast (RFC-compliant)	• One IP subnet. • Neighbors must be manually configured. • DR and BDR are elected. • DR and BDR need to have full connectivity with all other routers. • Typically used in a full- or partial-mesh topology.
point-to-multipoint (RFC-compliant)	• One IP subnet. • Uses a multicast OSPF hello packet to automatically discover the neighbors. • DR and BDR are not required. The router sends additional LSAs with more information about neighboring routers. • Typically used in a partial-mesh or star topology.
point-to-multipoint nonbroadcast (Cisco proprietary)	• If multicast and broadcast are not enabled on the VCs, the RFC-compliant point-to-multipoint mode cannot be used, because the router cannot dynamically discover its neighboring routers using the hello multicast packets; this Cisco mode should be used instead. • Neighbors must be manually configured. • DR and BDR election is not required.
broadcast (Cisco proprietary)	• Makes the WAN interface appear to be a LAN. • One IP subnet. • Uses a multicast OSPF hello packet to automatically discover the neighbors. • DR and BDR are elected. • Full- or partial-mesh topology.
point-to-point (Cisco proprietary)	• Different IP subnet on each subinterface. • No DR or BDR election. • Used when only two routers need to form an adjacency on a pair of interfaces. • Interfaces can be either LAN or WAN.

Identify a Neighboring Router

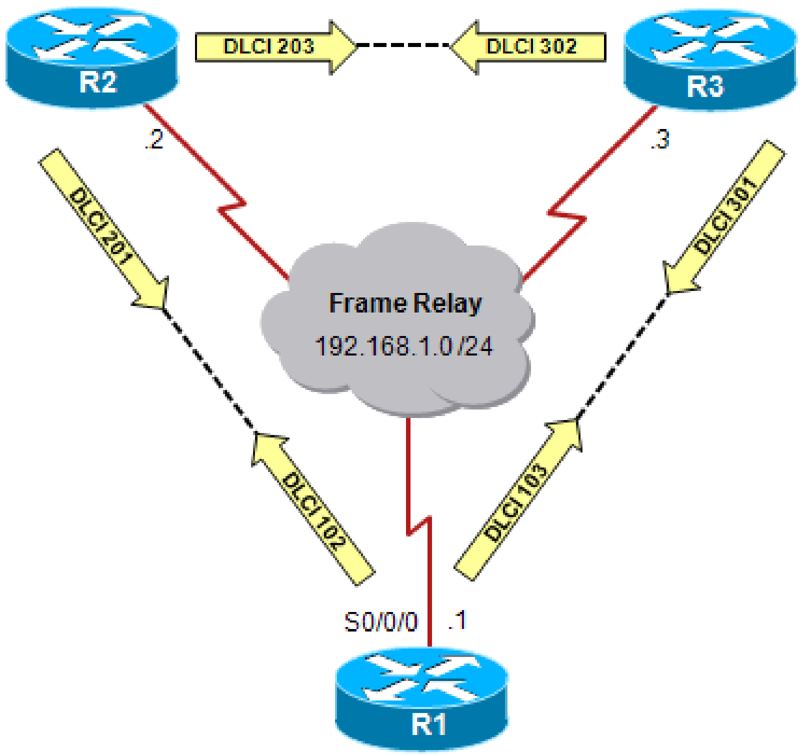
- Statically define adjacent relationships in NBMA networks.

```
Router(config-router)#
```

neighbor *ip-address* **[priority** *number***]** **[poll-interval** *number***]** **[cost** *number***]** **[database-filter all]**

Parameter	Description
ip-address	• Specifies the IP address of the neighboring router.
priority *number*	• (Optional) Specifies priority of neighbor. The default is 0, which means that the neighboring router does not become the DR or BDR.
poll-interval *number*	• (Optional) Specifies how long an NBMA interface waits before sending hellos to the neighbors even if the neighbor is inactive. The poll interval is defined in seconds.
cost *number*	• (Optional) Assigns a cost to the neighbor in the form of an integer from 1 to 65535. Neighbors with no specific cost configured assume the cost of the interface based on the **ip ospf cost** command. • For point-to-multipoint interfaces, the **cost** keyword and the *number* argument are the only options that are applicable. This keyword does not apply to nonbroadcast mode.
database-filter all	• (Optional) Filters outgoing LSAs to an OSPF neighbor.

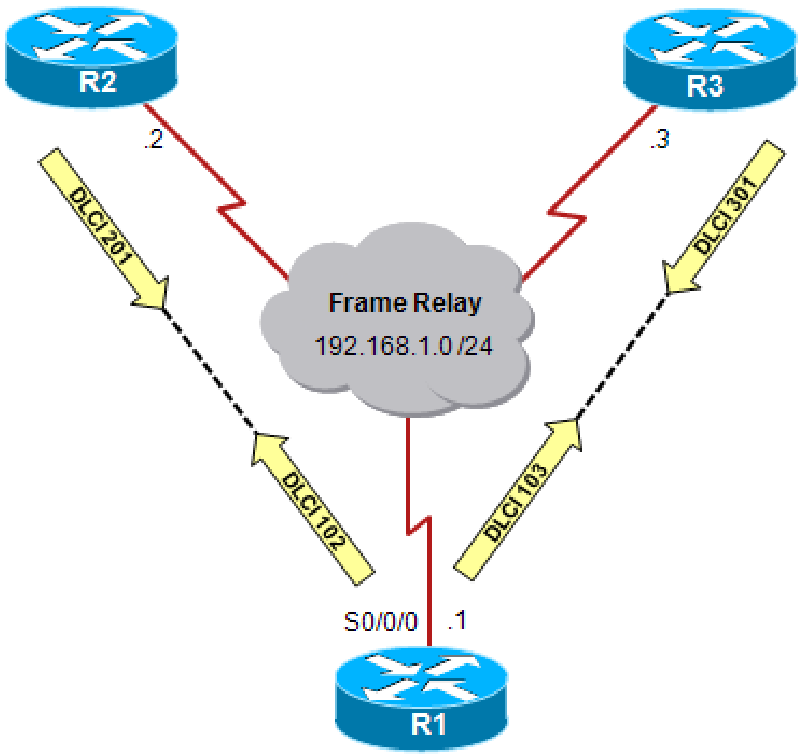
Non-Broadcast Mode Example (Full-Mesh)



- Characteristics of the RFC-compliant **non-broadcast** parameter include:
  - A full-mesh topology is typically used therefore the DR and BDR are dynamically elected.
    - DR / BDR require full connectivity with all other routers.
  - One IP subnet.
  - OSPF neighbors must be manually configured.

```
R1(config)# interface S0/0/0
R1(config-if)# ip ospf network non-broadcast
R1(config-if)# exit
R1(config)# router ospf 1
R1(config-router)# network 192.168.1.0 0.0.0.255 area 0
R1(config-router)# neighbor 192.168.1.2
R1(config-router)# neighbor 192.168.1.3
```

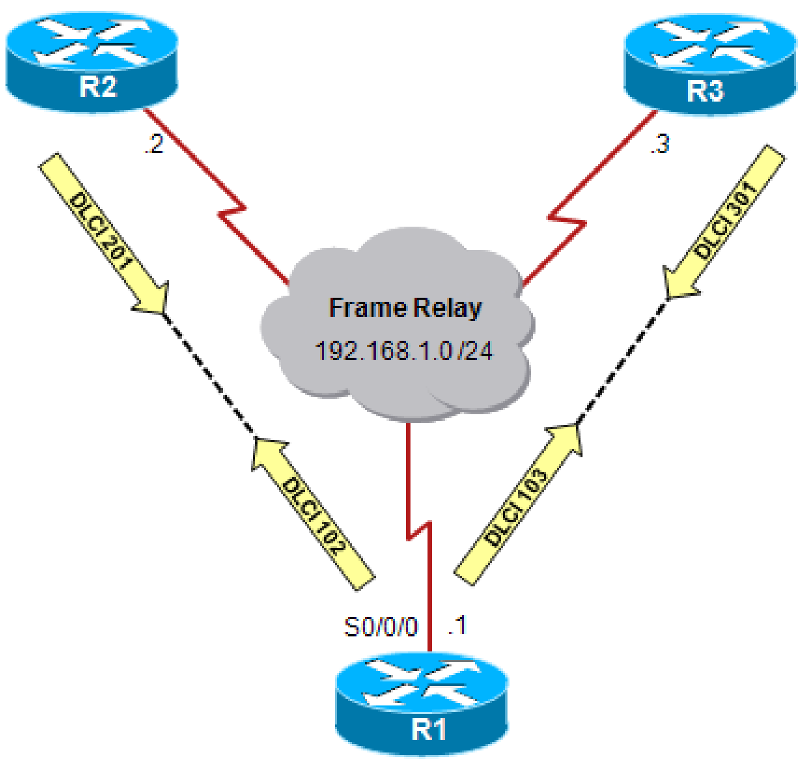
Non-Broadcast Mode Example (Partial-Mesh)



- Characteristics of the RFC-compliant **non-broadcast** parameter include:
  - If a partial-mesh topology is used then the DR and BDR are elected manually using the **priority** parameter on the hub router.
  - One IP subnet.
  - OSPF neighbors must be manually configured.

```
R1(config)# interface S0/0/0
R1(config-if)# ip ospf network non-broadcast
R1(config-if)# exit
R1(config)# router ospf 1
R1(config-router)# network 192.168.1.0 0.0.0.255 area 0
R1(config-router)# neighbor 192.168.1.2 priority 0
R1(config-router)# neighbor 192.168.1.3 priority 0
```

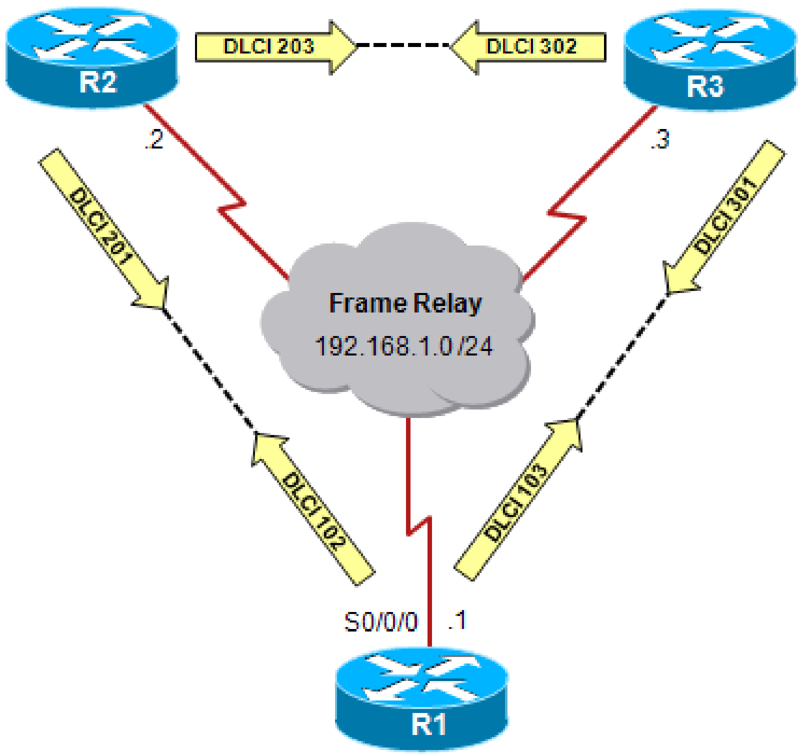
Point-to-multipoint Mode Example



- Characteristics of the RFC-compliant **`point-to-multipoint`** parameter include:
  - Used with partial-mesh or hub-and-spoke (star) topology.
  - One IP subnet.
  - DR and BDR not required.
  - Uses multicast OSPF hello packets to dynamically discover neighbors.

```
R1(config)# interface S0/0/0
R1(config-if)# ip ospf network point-to-multipoint
R1(config-if)# exit
R1(config)# router ospf 1
R1(config-router)# network 192.168.1.0 0.0.0.255 area 0
R1(config-router)#
```

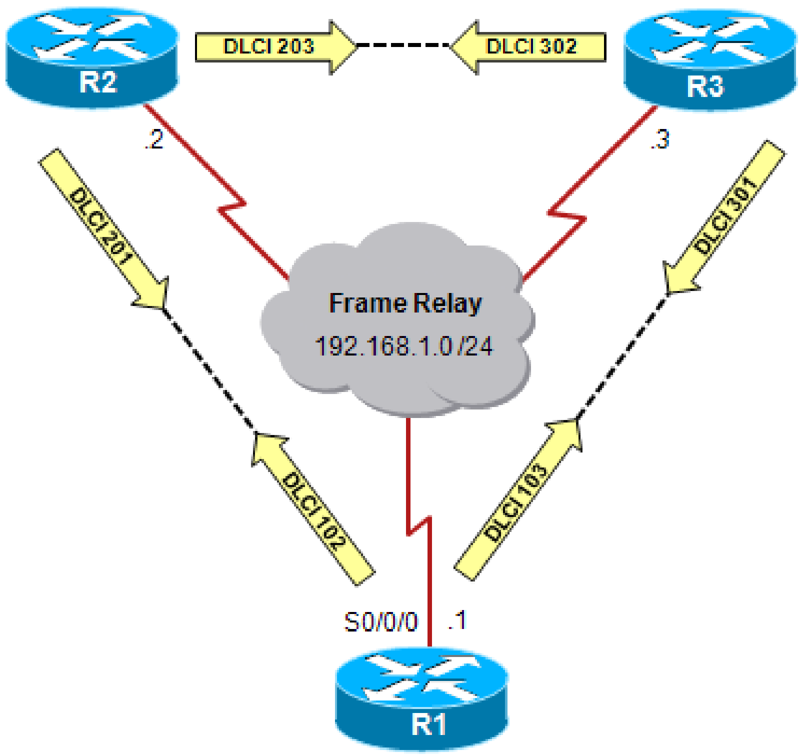
Point-to-multipoint non-broadcast Mode



- Characteristics of Cisco's **`point-to-multipoint non-broadcast`** parameter include:
  - DR and BDR not required.
  - OSPF neighbors must be manually configured.
  - Used in special cases where neighbors cannot be automatically discovered.

```
R1(config)# interface S0/0/0
R1(config-if)# ip ospf network point-to-multipoint non-broadcast
R1(config-if)# exit
R1(config)# router ospf 1
R1(config-router)# network 192.168.1.0 0.0.0.255 area 0
R1(config-router)# neighbor 192.168.1.2 cost 10
R1(config-router)# neighbor 192.168.1.3 cost 20
```

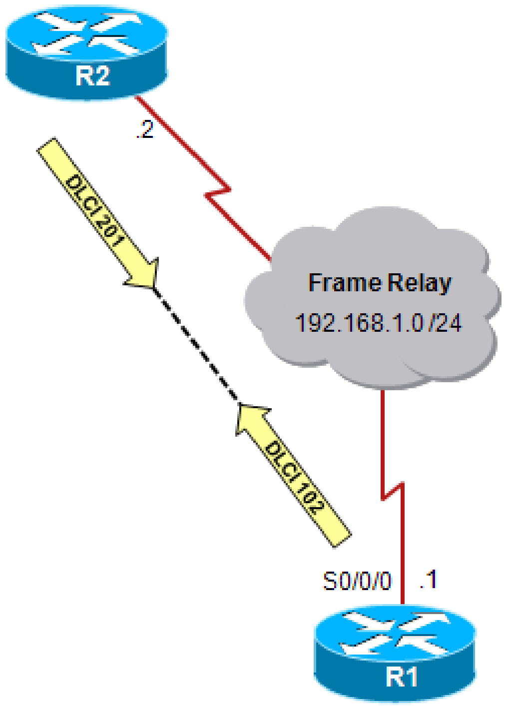
Broadcast Mode Example



- Characteristics of Cisco's **`broadcast`** parameter include:
  - DR and BDR are elected and require full connectivity with all other routers.
  - Can be configured for a full-mesh topology or a static election of the DR based on the interface priority.
  - One IP subnet.
  - Uses multicast OSPF hello packets to dynamically discover neighbors.

```
R1(config)# interface S0/0/0
R1(config-if)# ip ospf network broadcast
R1(config-if)# exit
R1(config)# router ospf 1
R1(config-router)# network 192.168.1.0 0.0.0.255 area 0
R1(config-router)#
```

Point-to-point Mode Example



- Characteristics of Cisco's **`point-to-point`** parameter include:
  - Partial mesh or star topology.
  - DR and BDR not required.
  - Only IP subnet.

```
R1(config)# interface S0/0/0
R1(config-if)# ip address 192.168.1.1 255.255.255.0
R1(config-if)# encapsulation frame-relay
R1(config-if)# ip ospf network point-to-point
R1(config-if)# exit
R1(config)# router ospf 1
R1(config-router)# network 192.168.1.0 0.0.0.255 area 0
R1(config-router)#
```

Subinterfaces

- OSPF can also be run over subinterfaces.
  - A subinterface is a physical interface that can be split into multiple logical interfaces.
  - Each subinterface requires an IP subnet.
- Subinterfaces can be defined as either a point-to-point or multipoint interface.
  - A point-to-point subinterface has similar properties to a physical point-to-point interface.
- Note:
  - The **`ip ospf network`** command is not required.

Define a Subinterface

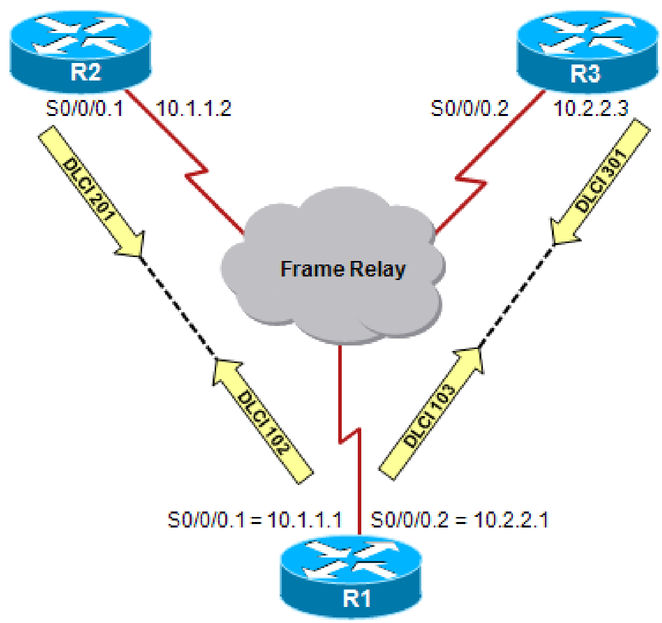
- Define a subinterface.

```
Router(config)#
```

```
interface serial number.subinterface-number {multipoint
| point-to-point}
```

Parameter	Description
number.subinterface-number	Specifies the interface number and subinterface number. The subinterface number is in the range of 1 to 4294967293. The interface number that precedes the period (.) is the interface number to which this subinterface belongs.
multipoint	Specifies that the subinterface is multipoint; on multipoint subinterfaces routing IP, all routers are in the same subnet.
point-to-point	Specifies that the subinterface is point-to-point; on point-to-point subinterfaces routing IP, each pair of point-to-point routers is in its own subnet.

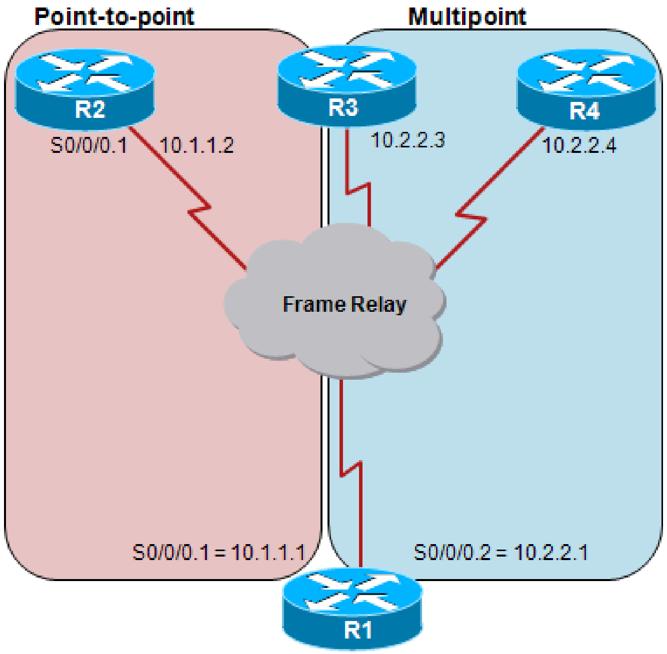
Using Point-to-point Subinterfaces



- Characteristics:
  - Same properties as any physical point-to-point physical interface
  - DR and BDR not required.
  - One IP subnet per subinterface pair.
  - Used when only 2 routers need to form an adjacency on a pair of interfaces.}

```
R1(config)# interface S0/0/0
R1(config-if)# encapsulation frame-relay
R1(config-if)# interface S0/0/0.1 point-to-point
R1(config-subif)# ip address 10.1.1.1 255.255.255.0
R1(config-subif)# interface S0/0/0.2 point-to-point
R1(config-subif)# ip address 10.2.2.1 255.255.255.0
R1(config-subif)# router ospf 1
R1(config-router)# network 10.1.1.0 0.0.0.255 area 0
R1(config-router)# network 10.2.2.0 0.0.0.255 area 0
```

Using Multipoint Subinterfaces



- The example has one point-to-point subinterface and one multipoint subinterface.
  - The multipoint subinterface supports two other routers in a single
- Multipoint Frame Relay subinterfaces default to OSPF nonbroadcast mode, which requires neighbors to be statically configured and a DR and BDR election.

```
R1(config)# interface S0/0/0
R1(config-if)# encapsulation frame-relay
R1(config-if)# interface S0/0/0.1 point-to-point
R1(config-subif)# ip address 10.1.1.1 255.255.255.0
R1(config-subif)# interface S0/0/0.2 multipoint
R1(config-subif)# ip address 10.2.2.1 255.255.255.0
R1(config-subif)# router ospf 1
R1(config-router)# network 10.0.0.0 0.255.255.255 area 0
R1(config-router)# neighbor 10.2.2.3 priority 0
R1(config-router)# neighbor 10.2.2.4 priority 0
```

OSPF over NBMA Topology Summary

OSPF Mode	NBMA Preferred Topology	Subnet Address	Hello Timer	Adjacency	RFC or Cisco	Example
Non-broadcast	Full or partial mesh	Same	30 sec	Manual configuration DR/BDR elected	RFC	Frame Relay configured on a serial interface
Point-to-multipoint	Partial mesh or star	Same	30 sec	Automatic No DR/BDR	RFC	OSPF over Frame Relay mode that eliminates the need for a DR; used when VCs support multicast and broadcast
Point-to-multipoint nonbroadcast	Partial mesh or star	Same	30 sec	Manual configuration No DR/BDR	Cisco	OSPF over Frame Relay mode that eliminates the need for a DR; used when VCs do not support multicast and broadcast
Broadcast	Full or partial mesh	Same	10 sec	Automatic DR/BDR elected	Cisco	LAN interface such as Ethernet
Point-to-point	Partial mesh or star, using subinterfaces	Different for each subinterface	10 sec	Automatic No DR/BDR	Cisco	Serial interface with point-to-point subinterfaces

Understanding OSPF LSAs

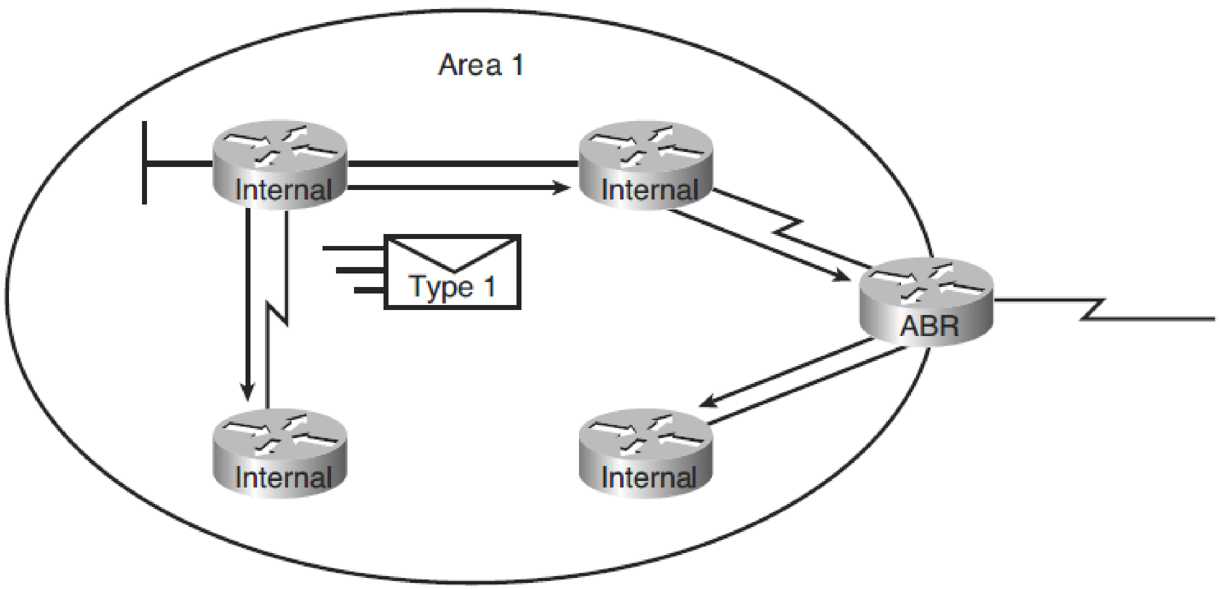
LSAs

- LSAs are the building blocks of the OSPF LSDB.
  - Individually, LSAs act as database records.
  - When combined, they describe the entire topology of an OSPF area.
- There are several types of OSPF network LSAs
  - Not all are in use.

LSA Type	Description
1	Router LSA
2	Network LSA
3	Summary LSAs
4	ASBR Summary LSAs
5	AS external LSA
6	Multicast OSPF LSA
7	Defined for NSSAs
8	External attributes LSA for Border Gateway Protocol (BGP)
9, 10, or 11	Opaque LSAs

LSA Type 1: Router LSA

- Generated by all routers in an area to describe their directly attached links (Intra-area routes).
  - Floods within its area only and cannot cross an ABR.
  - LSA includes list of directly attached links and is identified by the router ID of the originating router
  - Routing Table Entry = **O**

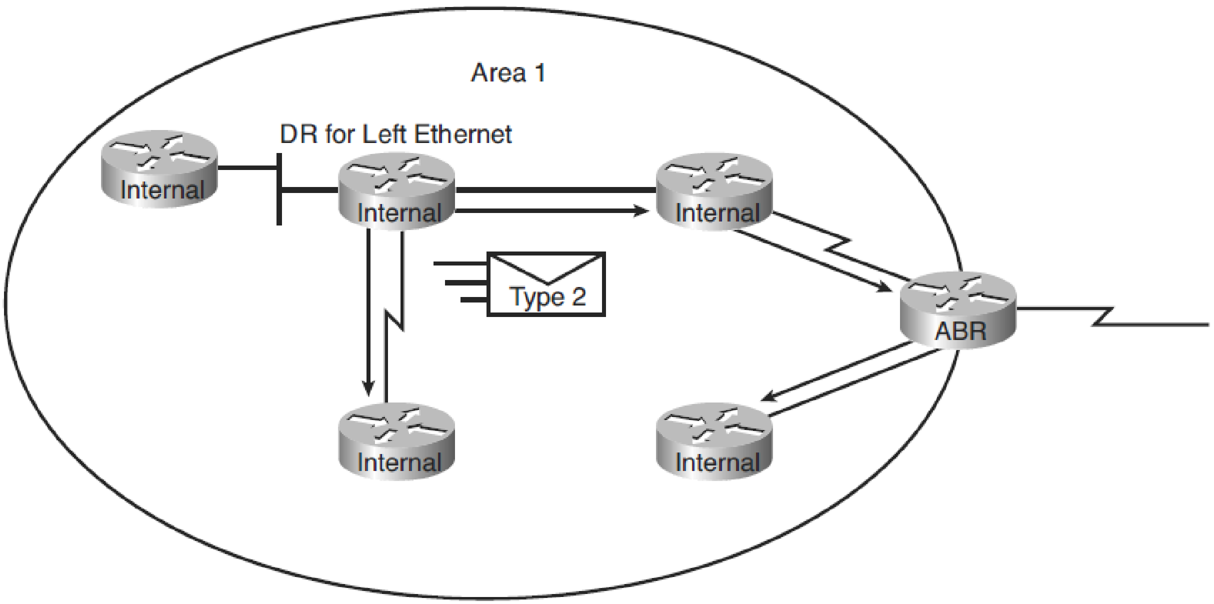


LSA Type 1: Link Types

Link Type	Description	Link-state ID
1	Point-to-point connection to another router	Neighboring router ID
2	Connection to a transit network	IP address of DR
3	Connection to a stub network	IP network/subnet number
4	Virtual link	Neighboring router ID

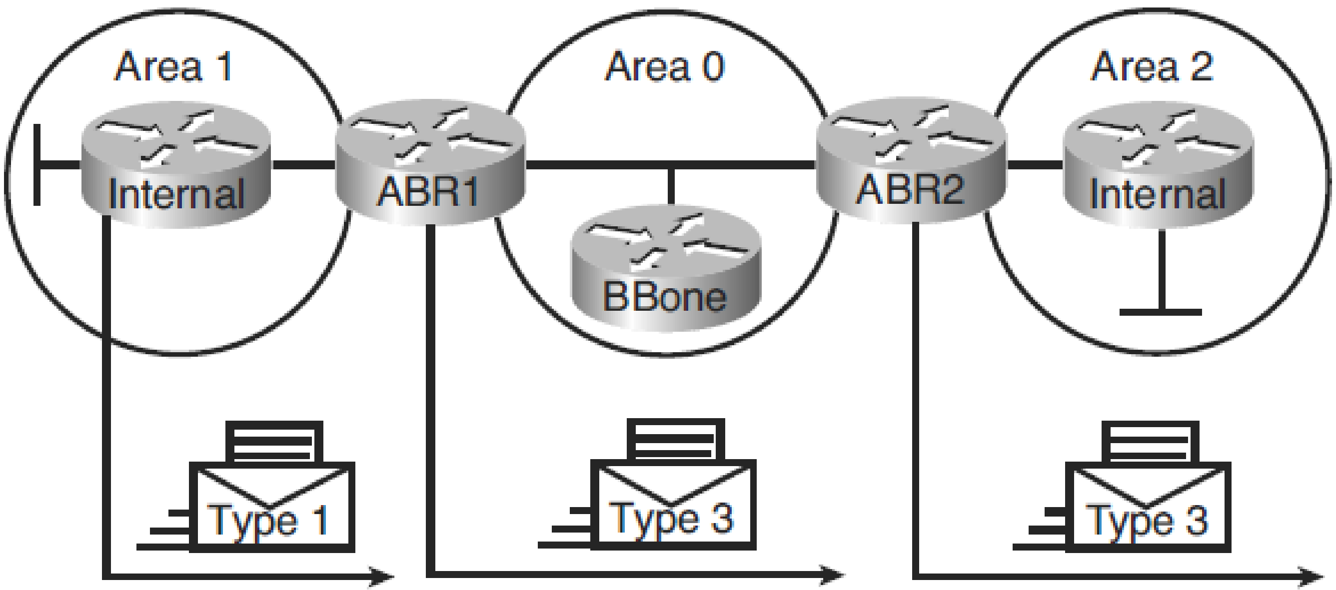
LSA Type 2: Network LSA

- Advertised by the DR of the broadcast network.
  - Floods within its area only; does not cross ABR.
  - Link-state ID is the DR.
  - Routing Table Entry = **O**



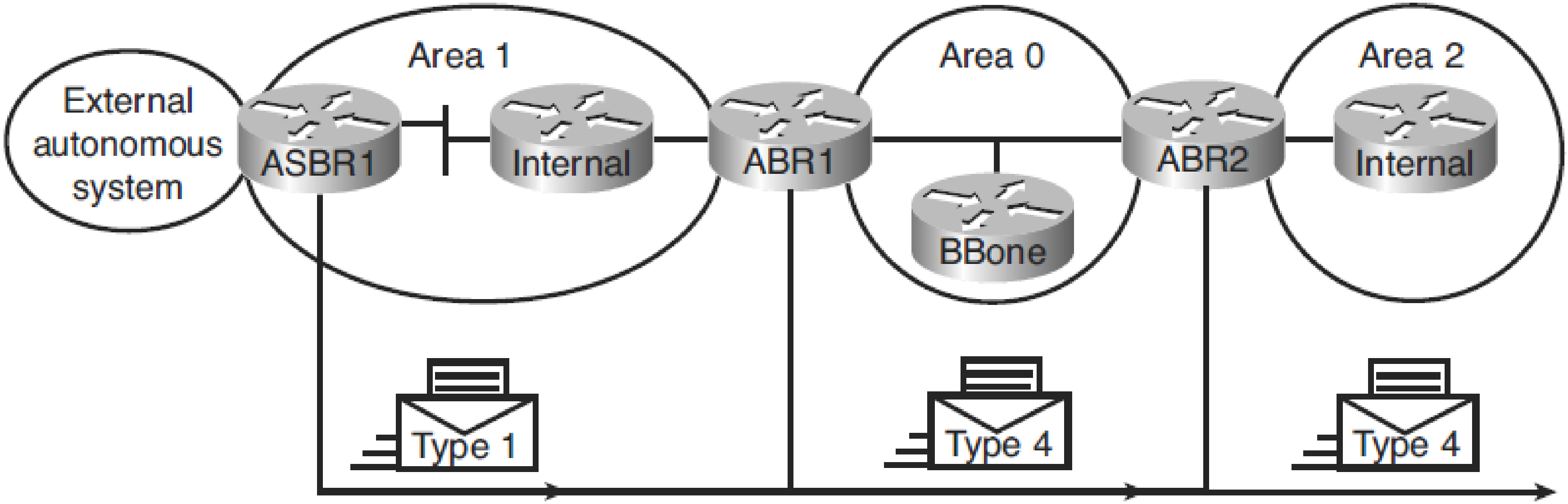
LSA Type 3: Summary LSA

- Advertised by the ABR of originating area.
  - Regenerated by subsequent ABRs to flood throughout the autonomous system.
  - By default, routes are not summarized, and type 3 LSA is advertised for every subnet.
  - Link-state ID is the network or subnet advertised in the summary LSA
  - Routing Table Entry = **O IA**



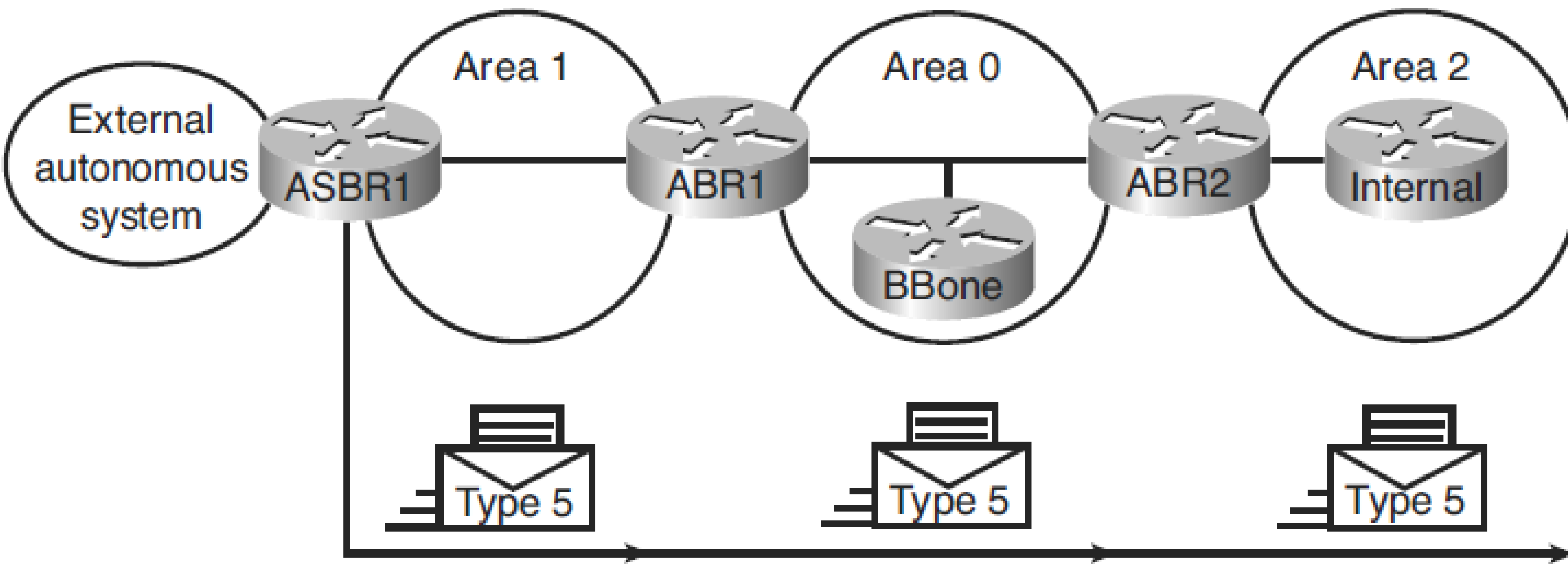
LSA Type 4: Summary LSA

- Generated by the ABR of the originating area to advertise an ASBR to all other areas in the autonomous system.
  - They are regenerated by all subsequent ABRs to flood throughout the autonomous system.
  - Link-state ID is the router ID of the ASBR.
  - Routing Table Entry = **O IA**



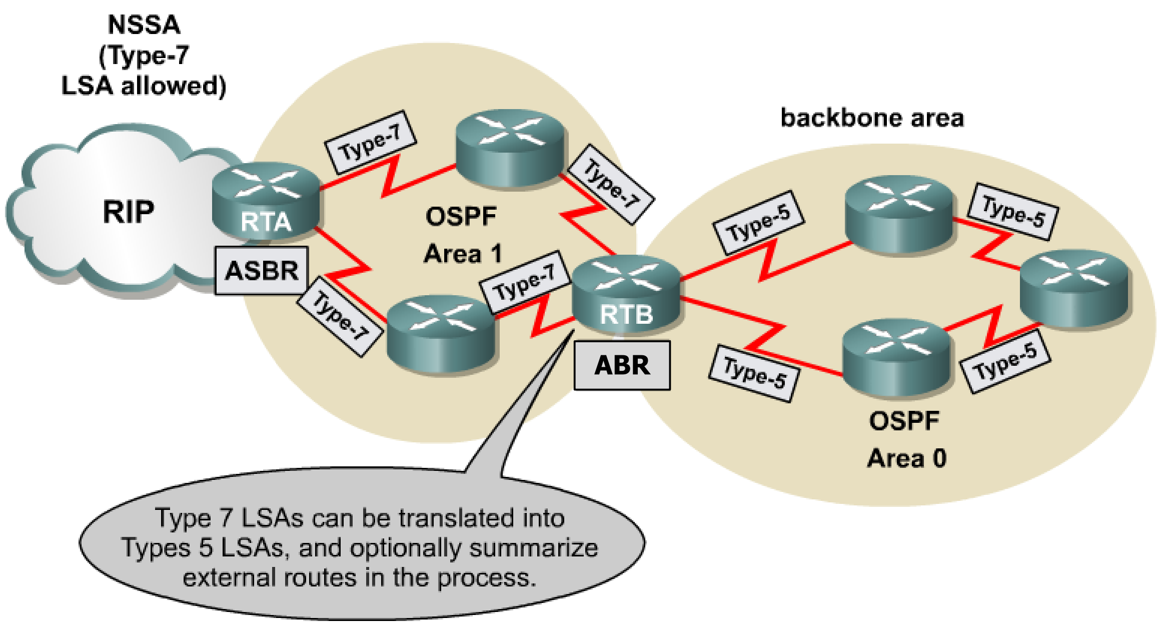
LSA Type 5: External LSA

- Used by the ASBR to advertise networks from other autonomous systems.
  - Type 5 LSAs are advertised and owned by the originating ASBR.
  - The Link-state ID is the external network number.
  - Routing Table Entry = **O E1** or **O E2**



LSA Type 7: NSSA LSA

- Generated by an ASBR inside a Not-so-stubby area (NSSA) to describe routes redistributed into the NSSA.
  - LSA 7 is translated into LSA 5 as it leaves the NSSA.
  - Routing Table Entry = **O N1** or **O N2**
  - Much like LSA 5, N2 is a static cost while N1 is a cumulative cost that includes the cost up to the ASBR.



Interpreting the OSPF LSDB and Routing Table

Interpreting the OSPF Database

Use the **show ip ospf database** command to gather link state information.

```
R1# show ip ospf database
     OSPF Router with ID (10.0.0.11) (Process ID 1)
                Router Link States (Area 0)
Link ID         ADV Router      Age         Seq#       Checksum Link count
10.0.0.11       10.0.0.11       548         0x80000002 0x00401A 1
10.0.0.12       10.0.0.12       549         0x80000004 0x003A1B 1
100.100.100.100 100.100.100.100 548         0x800002D7 0x00EEA9 2
                Net Link States (Area 0)
Link ID         ADV Router      Age         Seq#       Checksum
172.31.1.3      100.100.100.100 549         0x80000001 0x004EC9
                Summary Net Link States (Area 0)
Link ID         ADV Router      Age         Seq#       Checksum
10.1.0.0        10.0.0.11       654         0x80000001 0x00FB11
10.1.0.0        10.0.0.12       601         0x80000001 0x00F516
<output omitted>
```

LSA Sequence Numbering

- Each LSA in the LSDB maintains a sequence number.
  - The sequence numbering scheme is a 4-byte number that begins with 0x80000001 and ends with 0x7FFFFFFF.
- OSPF floods each LSA every 30 minutes to maintain proper database synchronization.
  - Each time the LSA is flooded, the sequence number is incremented by one.
- Ultimately, an LSA sequence number will wrap around to 0x80000001.
  - When this occurs, the existing LSA is prematurely aged to maxage (one hour) and flushed.
- When a router encounters two instances of an LSA, it must determine which is more recent.
  - The LSA having the newer (higher) LS sequence number is more recent.

Route Designator in Routing Table

Route Designator	Description	
O	OSPF intra-area (router LSA) and network LSA	• Networks from within the router’s area. Advertised by way of router LSAs and network LSAs. • **LSA Type 1,2**
O IA	OSPF interarea (summary LSA)	• Networks from outside the router’s area but within the OSPF AS. Advertised by way of summary LSAs. • **LSA Type 3**
O E1	Type 1 external routes	• Networks from outside the router’s AS, advertised by way of external LSAs. • **LSA Type 5**
O E2	Type 2 external routes	• Networks from outside the router’s AS, advertised by way of external LSAs. • **LSA Type 5**
O N1	Type 1 NSSA external routes	• Networks from outside the router’s AS, advertised by way of NSSA LSAs. • **LSA Type 7**
O N2	Type 2 NSSA external routes	• Networks from outside the router’s AS, advertised by way of NSSA LSAs. • **LSA Type 7**

Route Designator in Routing Table

```
R1# show ip route
<output omitted>
Gateway of last resort is not set
172.31.0.0/24 is subnetted, 2 subnets
O IA 172.31.2.0 [110/1563] via 10.1.1.1, 00:12:35, FastEthernet0/0
O IA 172.31.1.0 [110/782] via 10.1.1.1, 00:12:35, FastEthernet0/0
10.0.0.0/8 is variably subnetted, 6 subnets, 2 masks
C 10.200.200.13/32 is directly connected, Loopback0
C 10.1.3.0/24 is directly connected, Serial0/0/0
O 10.1.2.0/24 [110/782] via 10.1.3.4, 00:12:35, Serial0/0/0
C 10.1.1.0/24 is directly connected, FastEthernet0/0
O 10.1.0.0/24 [110/782] via 10.1.1.1, 00:12:37, FastEthernet0/0
O E2 10.254.0.0/24 [110/50] via 10.1.1.1, 00:12:37, FastEthernet0/0
```

Best Path Calculation

1. All routers calculate the best paths to destinations *within their area (intra-area) and* add these entries to the routing table.
   - Includes type 1 and 2 LSAs, noted with a designator of **O**.
2. All routers calculate the best paths to the *other areas.*
   - Includes type 3 and 4 LSAs, noted with a designator of **O IA.**
3. All routers (except stub areas) calculate the best paths to the external autonomous system (type 5) destinations.
   - Includes either external type 1 (E1), indicated with an **O E1** or external type 2 (E2), indicated with an **O E2**.

ASBR – Type 1 and 2 Routes

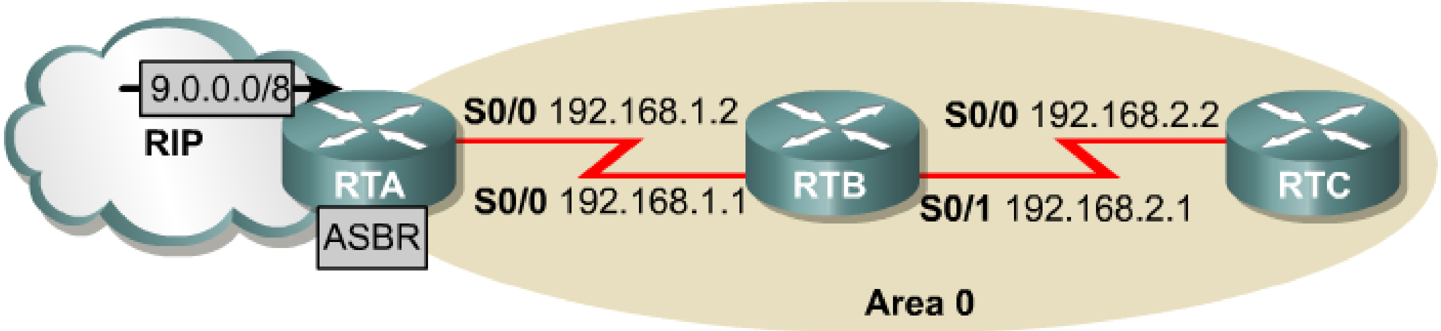
- The cost of an external route varies, depending on the external type configured on the ASBR.
- An ASBR can be configured to send out two types of external routes into OSPF.
  - Denoted in the routing table as E1 for Type 1
  - Denoted in the routing table as E2 for Type 2.
- Depending on the type, OSPF calculates the cost of external routes differently.

ASBR – Type 1 and 2 Routes

- **O E1 Routes**
  - The metric is calculated by adding the external cost to the internal cost of each link that the packet crosses.
    - Use this packet type when there are multiple ASBRs advertising a route to the same autonomous system.
- **O E2 Routes**
  - The packet will always have the external cost assigned, no matter where in the area it crosses.
    - Default setting on ASBRs.
    - Use this packet type if only one router is advertising a route to the autonomous system.
    - Type 2 routes are preferred over Type 1 routes unless two equal cost routes exist to the destination.

E2 Routes

```
RTB#show ip route
<output omitted>
O E2 9.0.0.0/8 [110/20] via 192.168.1.2, 00:00:07, Serial0/0
C    192.168.1.0/24 is directly connected, Serial0/0
C    192.168.2.0/24 is directly connected, Serial0/1
```

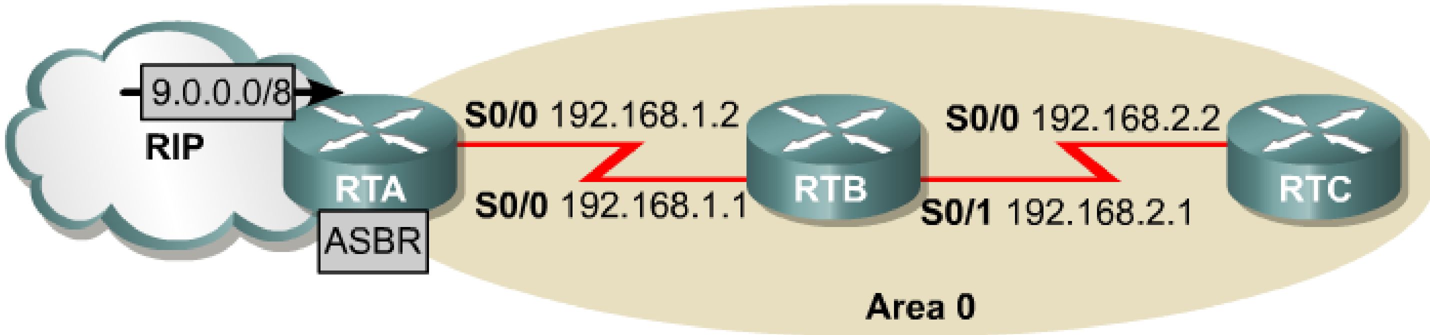



```
RTC#show ip route
<output omitted>
O E2 9.0.0.0/8 [110/20] via 192.168.2.1, 00:00:46, Serial0/0
O    192.168.1.0/24 [110/1171] via 192.168.2.1, 00:03:09, Serial0/0
C    192.168.2.0/24 is directly connected, Serial0/0
```

- By default, RTA uses a Type 2 metrics to send external routing information.
- RTB will receive the external RIP routes, including 9.0.0.0/8 from RTA.
- When RTB forwards this route, the metric for the external route remains the same (in this case, 20).

E1 Routes

```
RTB#show ip route
<output omitted>
O E1 9.0.0.0/8 [110/410] via 192.168.1.2, 00:00:05, Serial0/0
C    192.168.1.0/24 is directly connected, Serial0/0
C    192.168.2.0/24 is directly connected, Serial0/1
```




```
RTC#show ip route
<output omitted>
O E1 9.0.0.0/8 [110/1191] via 192.168.2.1, 00:00:47, Serial0/0
O    192.168.1.0/24 [110/1171] via 192.168.2.1, 00:04:50, Serial0/0
C    192.168.2.0/24 is directly connected, Serial0/0
```

- If RTA is configured to use a Type 1 metric with external routes, OSPF will increment the metric value of the external route according to its standard cost algorithm.

Configuring OSPF LSDB Overload Protection

- Limit the processing of LSAs for a defined OSPF process.

```
Router(config-router)#
```

max-lsa *maximum-number* [*threshold-percentage*] [**warning-only**] [**ignore-time** *minutes*] [**ignore-count** *count-number*] [**reset-time** *minutes*]

Parameter	Description
maximum-number	Maximum number of LSAs that the OSPF process can keep in the OSPF LSDB.
threshold-percentage	(Optional) The percentage of the maximum LSA number, as specified by the maximum-number argument, at which a warning message is logged. The default is 75 percent.
warning-only	(Optional) Specifies that only a warning message is sent when the maximum limit for LSAs is exceeded; the OSPF process never enters ignore state. Disabled by default.
ignore-time *minutes*	(Optional) Specifies the time, in minutes, to ignore all neighbors after the maximum limit of LSAs has been exceeded. The default is 5 minutes.
ignore-count *count-number*	(Optional) Specifies the number of times that the OSPF process can consecutively be placed into the ignore state. The default is five times.
reset-time *minutes*	(Optional) Specifies the time, in minutes, after which the ignore count is reset to 0. The default is 10 minutes.

Configuring and Verifying Advanced OSPF Features

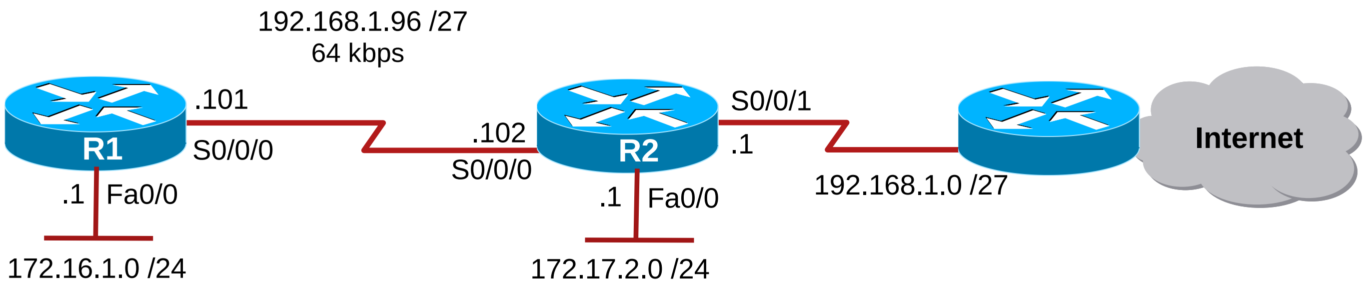
OSPF Passive-Interface

- Prevent OSPF updates out a specified router interface.

```
Router(config-router)#
passive-interface type number [default]
```

- Set a particular interface or all router interfaces to passive.
- The **default** option sets all router interfaces to passive.
- For OSPF, the command:
  - The specified interface appears as a stub network in the OSPF domain
  - The OSPF routing information is neither sent nor received through the specified router interface.
  - Prevents neighbor relationships from being established.

Passive-Interface Example




```
R1(config)# router ospf 1
R1(config-router)# passive-interface fa0/0
R1(config-router)#
```

```
R2(config)# router ospf 10
R2(config-router)# passive-interface fa0/0
R2(config-router)#
```

Alternate configuration:

```
R1(config)# router ospf 1
R1(config-router)# passive-interface default
R1(config-router)# no passive-interface S0/0/0
```

```
R2(config)# router ospf 10
R2(config-router)# passive-interface default
R2(config-router)# no passive-interface S0/0/0
R2(config-router)# no passive-interface S0/0/1
```

Propagating a Default Route

- To propagate a default route in OSPF, use the **`default-information originate`** router configuration command.
  - A default static rote also needs to be configured on the originating router
- Once configured, the default route has to be propagated into the OSPF domain.

default-information originate Command

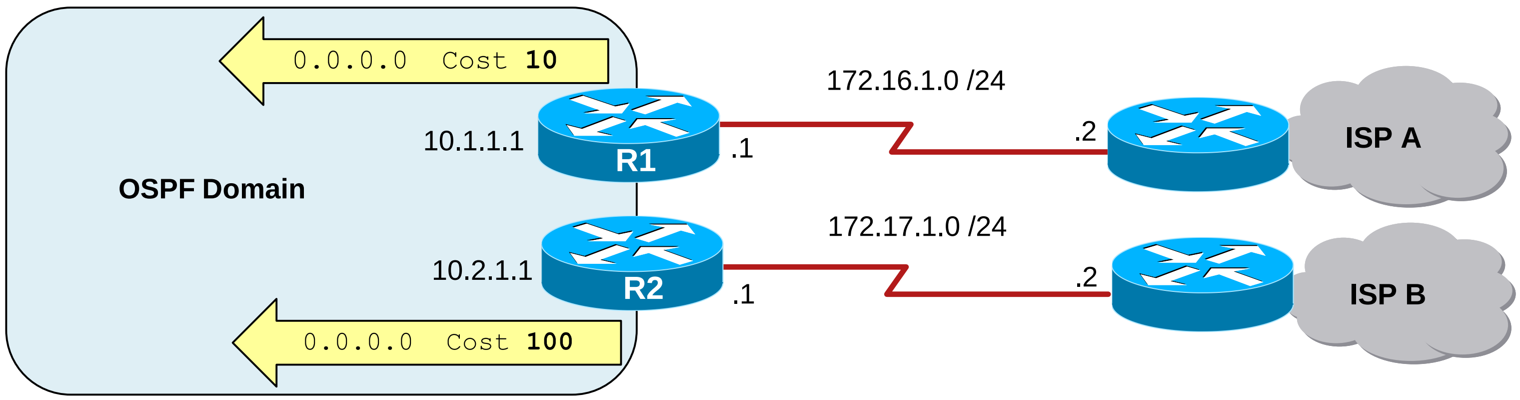
- Configures a router to generate a default external route into an OSPF routing domain.

```
Router(config-router)#
```

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

Parameter	Description
always	(Optional) Specifies that OSPF always advertises the default route regardless of whether the router has a default route in the routing table.
metric *metric-value*	(Optional) A 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. Cisco IOS Software documentation indicates that the default metric value is 10; testing shows that it is actually 1.
metric-type *type-value*	(Optional) The external link type that is associated with the default route that is 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 (indicated by O*E2 in the routing table).
route-map *map-name*	(Optional) Specifies that the routing process generates the default route if the route map is satisfied.

default-information originate Example



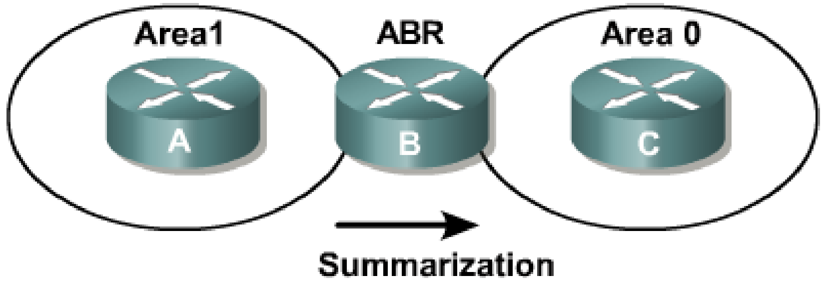

```
R1(config)# router ospf 1
R1(config-router)# network 10.1.1.1 0.0.0.0 area 0
R1(config-router)# default-information originate metric 10
R1(config-router)# exit
R1(config)# ip route 0.0.0.0 0.0.0.0 172.16.1.2
R1(config)#
```

```
R2(config)# router ospf 1
R2(config-router)# network 10.2.1.1 0.0.0.0 area 0
R2(config-router)# default-information originate metric 100
R2(config-router)# exit
R2(config)# ip route 0.0.0.0 0.0.0.0 172.17.1.2
R2(config)#
```

Route Summarization

- Route summarization involves consolidating multiple routes into a single advertisement.
- Proper route summarization directly affects the bandwidth, memory and CPU, that are consumed by the OSPF process.
  - If a network link fails or flaps, the topology change will not be propagated into the backbone or other areas.
  - It protects routers from needless routing table recalculations.
  - Because the SPF calculation places a significant demand on the router's CPU, proper summarization is an imperative part of OSPF configuration.

Using Route Summarization



Routing Table for B

```
O 172.16.8.0 255.255.255.0
O 172.16.9.0 255.255.255.0
O 172.16.10.0 255.255.255.0
O 172.16.11.0 255.255.255.0
O 172.16.12.0 255.255.255.0
O 172.16.13.0 255.255.255.0
O 172.16.14.0 255.255.255.0
O 172.16.15.0 255.255.255.0
O 172.16.16.0 255.255.255.0
O 172.16.17.0 255.255.255.0
O 172.16.18.0 255.255.255.0
O 172.16.19.0 255.255.255.0
```

LSAs Sent to Router C

```
IA 172.16.8.0 255.255.248.0
IA 172.16.16.0 255.255.252.0
```

- Interarea summary link carries mask.
- One or more entries can represent several subnets.

Types of Route Summarization

- Inter-area summarization
  - Performed at the ABR and creates Type 3 LSAs.
- External summarization
  - Performed at the ASBR and creates Type 5 LSAs.
- Both have the same fundamental requirement of contiguous addressing.
- If summarization is not configured correctly and there are multiple ASBRs, or multiple ABRs in an area, suboptimal routing is possible.
  - For example, summarizing overlapping ranges from two different routers can cause packets to be sent to the wrong destination.

Intra-Area Summarization

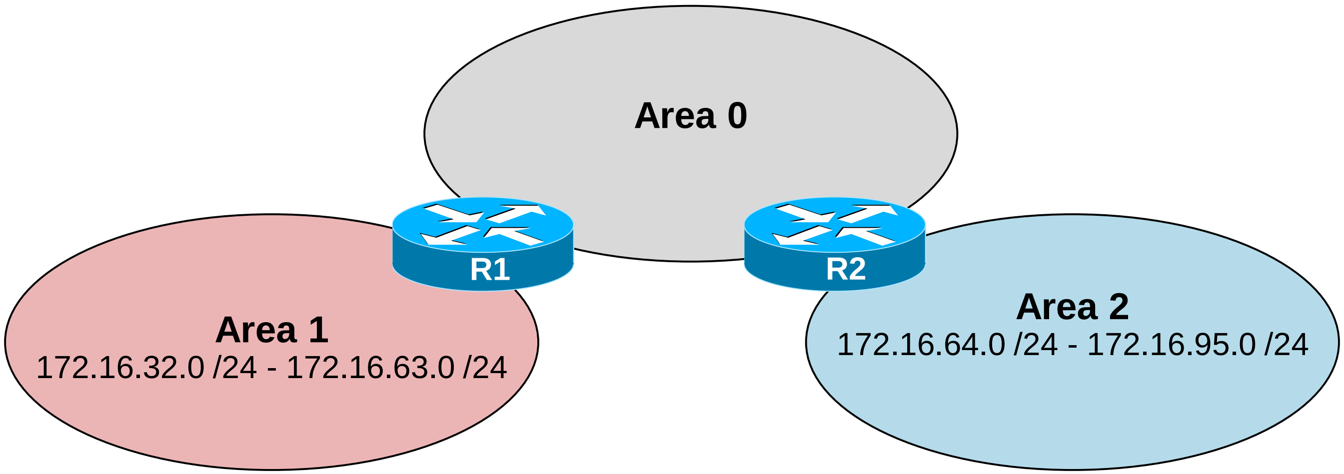
- Configure an ABR to summarize routes for a specific area.

```
Router(config-router)#
```

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

Parameter	Description
area *area-id*	Identifies the area subject to route summarization.
address	The summary address designated for a range of addresses.
mask	The IP subnet mask used for the summary route.
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 the OSPF SPF calculation to determine the shortest paths to the destination. The value can be 0 to 16777215.

Intra-Area Summarization Example




```
R1(config)# router ospf 100
R1(config-router)# network 172.16.32.1 0.0.0.0 area 1
R1(config-router)# network 172.16.96.1 0.0.0.0 area 0
R1(config-router)# area 1 range 172.16.32.0 255.255.224.0
R1(config-router)#
```

```
R2(config)# router ospf 100
R2(config-router)# network 172.16.64.1 0.0.0.0 area 2
R2(config-router)# network 172.16.127.1 0.0.0.0 area 0
R2(config-router)# area 2 range 172.16.64.0 255.255.224.0
R2(config-router)#
```

External Summarization

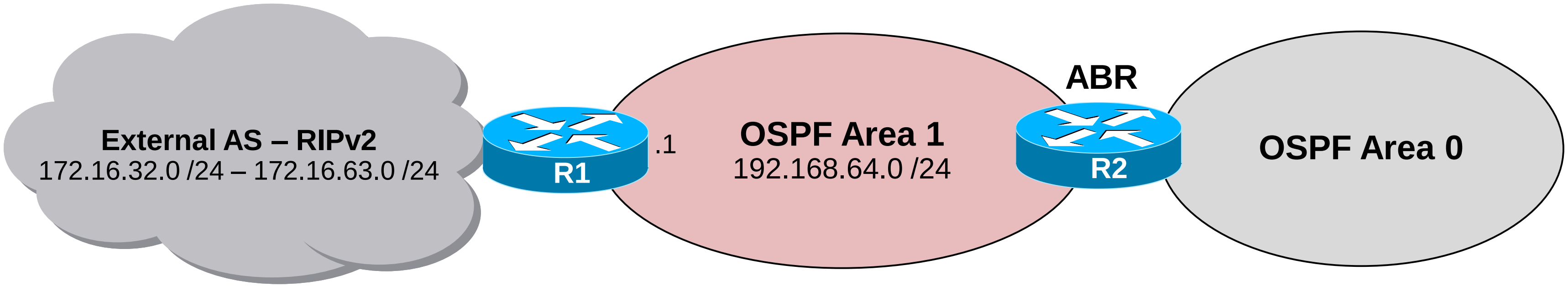
- Configure an ASBR to summarize external routes.

```
Router(config-router)#
```

```
summary-address ip-address mask [not-advertise] [tag tag]
```

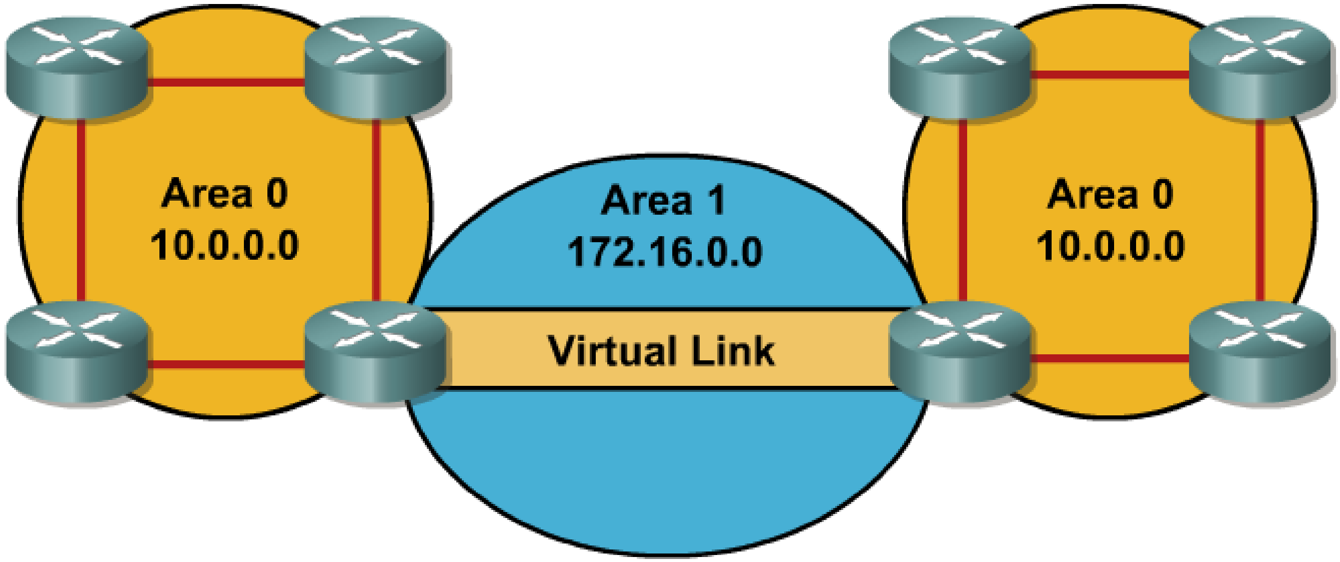
Parameter	Description
ip-address	The summary address designated for a range of addresses.
mask	The IP subnet mask used for the summary route.
not-advertise	(Optional) Used to suppress routes that match the address/mask pair.
tag *tag*	(Optional) A tag value that can be used as a "match" value to control redistribution via route maps.

External Summarization



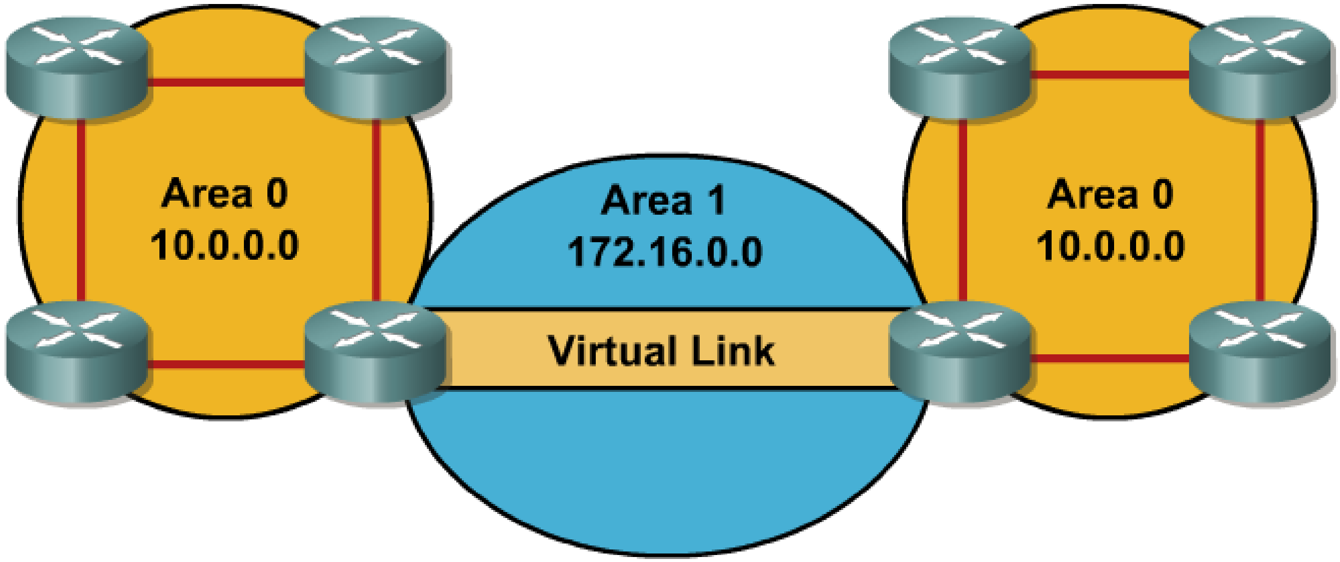

```
R1(config)# router ospf 100
R1(config-router)# network 192.168.64.1 0.0.0.0 area 1
R1(config-router)# summary-address 172.16.32.0 255.255.224.0
R1(config-router)#
```

Virtual Links



- Virtual links are used to connect a discontiguous area to area 0.
- A logical connection is built between router A and router B.
- Virtual links are recommended for backup or temporary connections.

LSAs on Virtual Links



- LSAs usually age out after 30 minutes.
  - However, LSAs learned across virtual links have the DoNotAge (DNA) option set.
  - Required to prevent excessive flooding over virtual links.
- To identify an area as a virtual link, use the **area** *area-id* **virtual-link** router configuration command.

Configuring Virtual Links

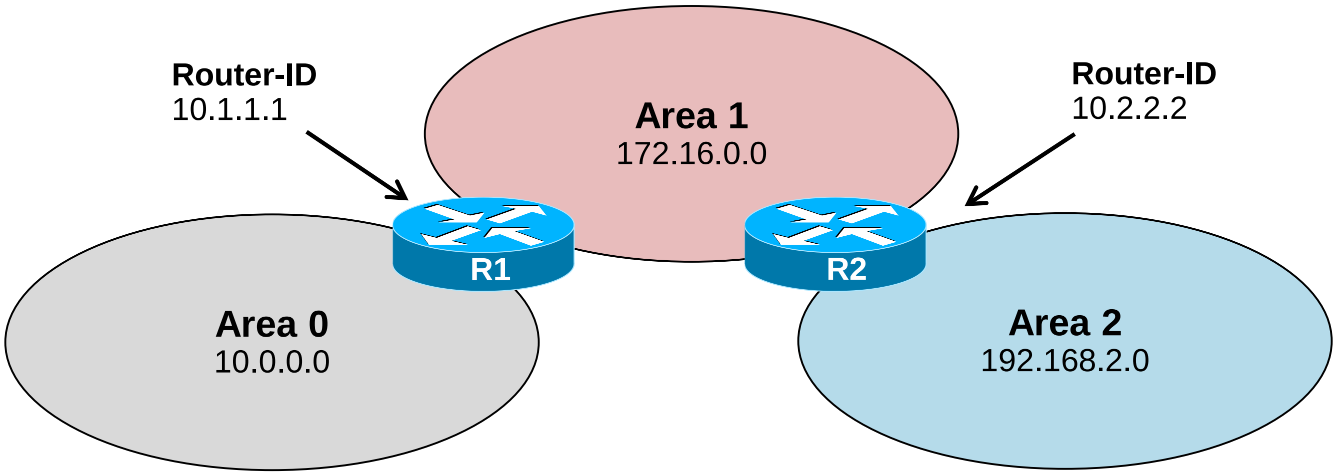
- Define an OSPF virtual link.

```
Router(config-router)#
```

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

Parameter	Description
area-id	Specifies the area ID of the transit area for the virtual link.
router-id	Specifies the router ID of the virtual link neighbor.
authentication	(Optional) Specifies an authentication type.
message-digest	(Optional) Specifies the use of MD5 authentication.
null	(Optional) Overrides authentication if configured.
hello-interval *seconds*	(Optional) Specifies the time between the hello packets (default 10).
retransmit-interval *seconds*	(Optional) Specifies the time between LSA retransmissions (default 5).
transmit-delay *seconds*	(Optional) Specifies the time to send an LSU packet (default 1).
dead-interval *seconds*	(Optional) Specifies the dead-interval time (default 40).
authentication-key *key*	(Optional) Specifies the password for simple password authentication.
message-digest-key *key-id* **md5** *key*	(Optional) Identifies the key ID and key for MD5 authentication.

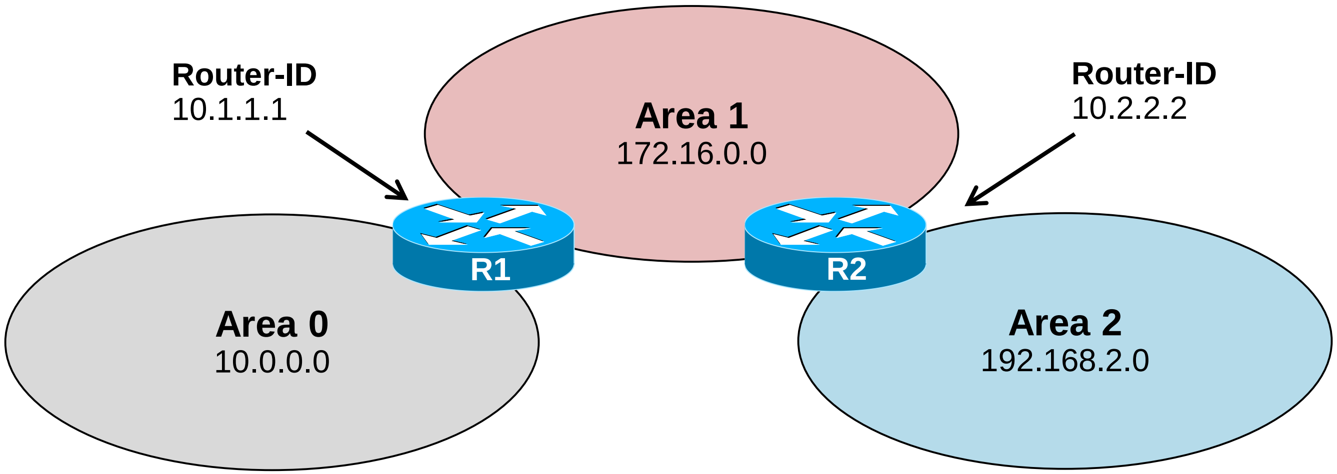
Virtual-Link Example




```
R1(config)# router ospf 100
R1(config-router)# network 172.16.0.0 0.0.255.255 area 1
R1(config-router)# network 10.0.0.0 0.0.255.255 area 0
R1(config-router)# area 1 virtual-link 10.2.2.2
R1(config-router)#
```

```
R2(config)# router ospf 100
R2(config-router)# network 172.16.0.0 0.0.255.255 area 1
R2(config-router)# network 192.168.2.0 0.0.0.255 area 0
R2(config-router)# area 1 virtual-link 10.1.1.1
R2(config-router)#
```

Verifying a Virtual-Link Example




```
R1# show ip ospf virtual-links
Virtual Link OSPF_VL0 to router 10.2.2.2 is up
  Run as demand circuit
  DoNotAge LSA allowed.
  Transit area 1, via interface Serial0/0/1, Cost of using 781
  Transmit Delay is 1 sec, State POINT_TO_POINT,
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    Hello due in 00:00:07
    Adjacency State FULL (Hello suppressed)
    Index 1/2, retransmission queue length 0, number of retransmission 1
    First 0x0(0)/0x0(0) Next 0x0(0)/0x0(0)
    Last retransmission scan length is 1, maximum is 1
    Last retransmission scan time is 0 msec, maximum is 0 msec
R1#
```

Changing the Reference Bandwidth

Interface Type	10^8/bps = Cost
Fast Ethernet and faster	10^8/100,000,000 bps = 1
Ethernet	10^8/10,000,000 bps = 10
E1	10^8/2,048,000 bps = 48
T1	10^8/1,544,000 bps = 64
128 kbps	10^8/128,000 bps = 781
64 kbps	10^8/64,000 bps = 1562
56 kbps	10^8/56,000 bps = 1785

- The reference bandwidth defaults to 10^8 (100,000,000 bps or 100 Mbps).
  - This can be a problem when using interfaces faster than 100 Mbps and higher since they would all have the same OSPF cost of 1.
- The reference bandwidth can be modified using the **`auto-cost reference-bandwidth`** router configuration command.

Changing the Reference Bandwidth

- Change the reference bandwidth for faster interfaces.

```
Router(config-router)#
```

```
auto-cost reference-bandwidth ref-bw
```

- The *ref-bw* parameter is the reference bandwidth in megabits per second.
  - The range is from 1 to 4,294,967.
  - The default is 100.
- Use this command if interfaces are faster than 100 Mbps.
  - The command must be configured on all OSPF routers to ensure accurate route calculations.

Modifying the Cost of a Link

- The cost of a link can be modified using either the:
  - **`bandwidth`** interface command
  - **`ip ospf cost`** interface command
- The configured **`bandwidth`** *`value`* is used by the SPF algorithm to calculate the cost.
  - For example, configuring the **`bandwidth 128`** command on a serial interface would generate a cost of 1,562.
    - Cost = 100,000,000 / 128,000 = 1,562.
- Using the **`ip ospf cost`** interface command achieves the same result without the calculation.
  - For example, the interface cost could be statically configured using the **`ip ospf cost 1562`** command.

Override the Default Interface Cost

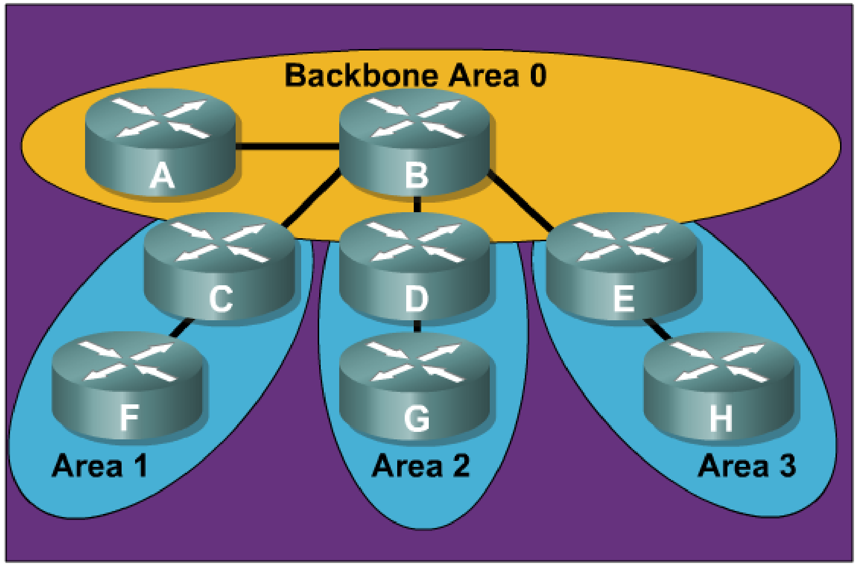
- Manually define the cost of an interface.

```
Router(config-if)#
```

`ip ospf cost` *`interface-cost`*

- The *`interface-cost`* is an integer from 1 to 65,535.
  - The lower the number, the better (and more preferred) the link.
- Can be used as an alternative to the **`bandwidth`** command.

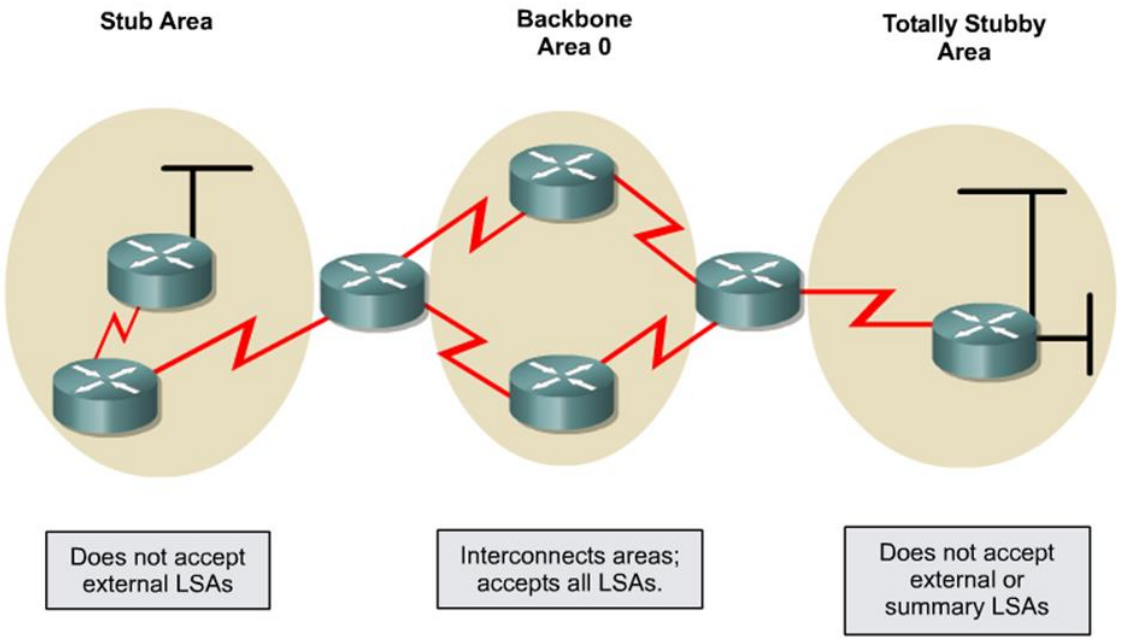
OSPF Two-Layer Hierarchy - Review



- **Backbone Area**
  - Referred to as Area 0
  - Also known as the Transit Area.
- **Regular (Standard) Areas**
  - Also known as a nonbackbone areas.
  - All regular areas must connect to the backbone area.

OSPF Special Area Types

- The OSPF standard area can be further divided into four types of stub areas:
  - Stub area
  - Totally stubby area
  - NSSA
  - Totally stubby NSSA



OSPF Area Types

Area Type	Accepts routes within area (O) *LSA Type 1,2*	Accepts routes from other areas (O IA) *LSA Type 3*	Accepts external routes (O E1 and O E2) *LSA Type 4,5*	Allows ASBR	Cisco proprietary
Standard	Yes	Yes	Yes	Yes	No
Backbone	Yes	Yes	Yes	Yes	No
Stub	Yes	Yes	No (uses default route)	No	No
Totally stubby	Yes	No (uses default route)	No (uses default route)	No	Yes
NSSA	Yes	Yes	No (uses default route)	Yes	No
Totally stubby NSSA	Yes	No (uses default route)	No (uses default route)	Yes	Yes

Stub and Totally Stub Area Characteristics

- An area qualifies as stub or totally stubby area if it has the following characteristics:
  - The area is not the backbone area (area 0).
  - There is a single exit point from that area.
    - If there are multiple exits, one or more ABRs should inject a default route into the stub area however suboptimal routing paths might occur.
  - There is no ASBR inside the area.
  - The area is not used as a transit area for virtual links.

Stub and Totally Stub Area Characteristics

- All OSPF routers inside the stub area, including ABRs, are configured as stub routers using the **area** *area-id* **stub** router configuration command.
- By default, the ABR of a stubby or totally stubby area advertises a default route with a cost of 1.
  - To change the cost of the default route, use the **area** *area-id* **default-cost** *cost* router configuration command.

Configure a Stub Area

- Identify an area as a stub network.

```
Router(config-router)#
```

```
area area-id stub
```

- The *area-id* parameter is the identifier for the stub area and can be either a decimal value or a value in dotted-decimal format, like an IP address.

Change the Default Cost

- Define the cost of the default route injected into the stub stubby area.

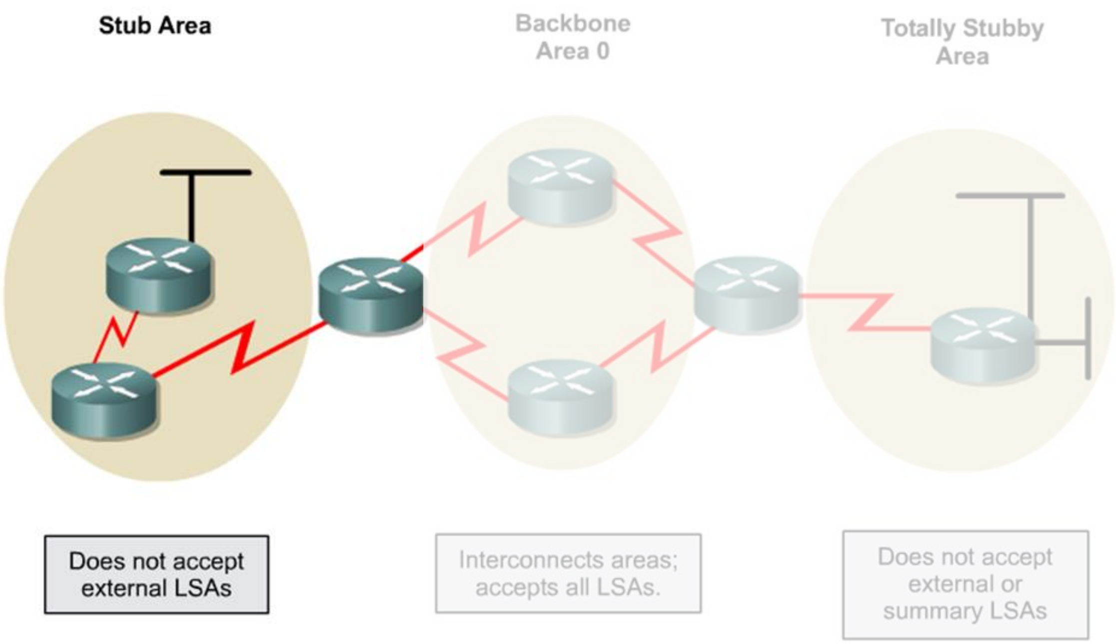
```
Router(config-router)#
```

```
area area-id default-cost cost
```

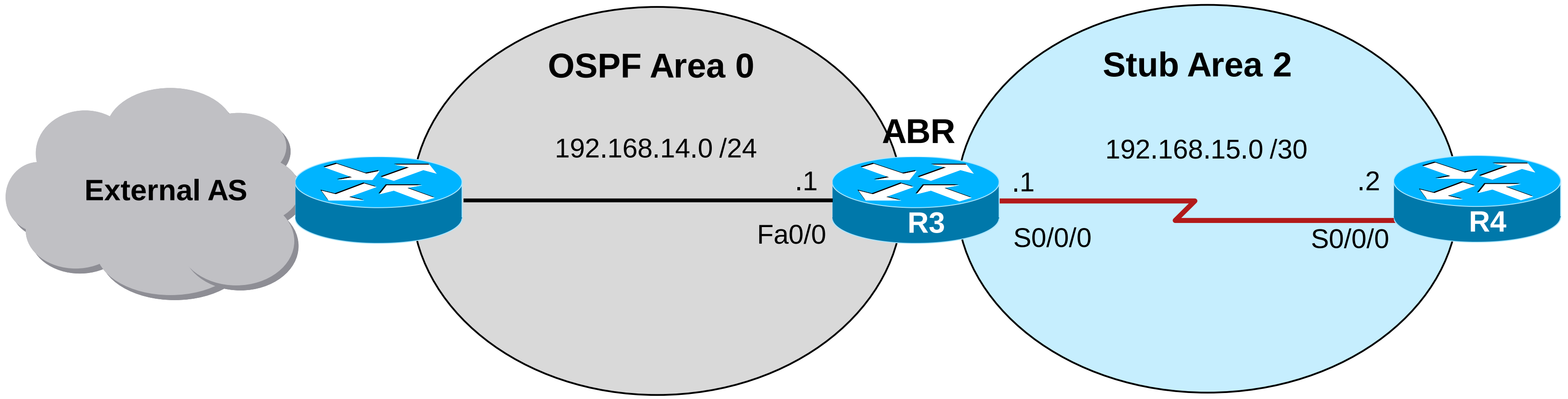
- The *cost* parameter is for the default summary route.
  - The acceptable values are 0 through 16777215.
  - The default is 1.
- If this command has not been configured, the ABR will advertise 0.0.0.0 with a default cost metric of 1 plus any internal costs.

Stub Area

- Typically used in a hub-and-spoke network.
- Area does not accept external summary routes from non-OSPF sources (e.g., RIP, EIGRP).
  - Specifically, it does not accept Types 4 and 5 LSAs.
  - A default route (0.0.0.0) is propagated throughout the area to send a packet to an external network.



Configuring a Stub Area

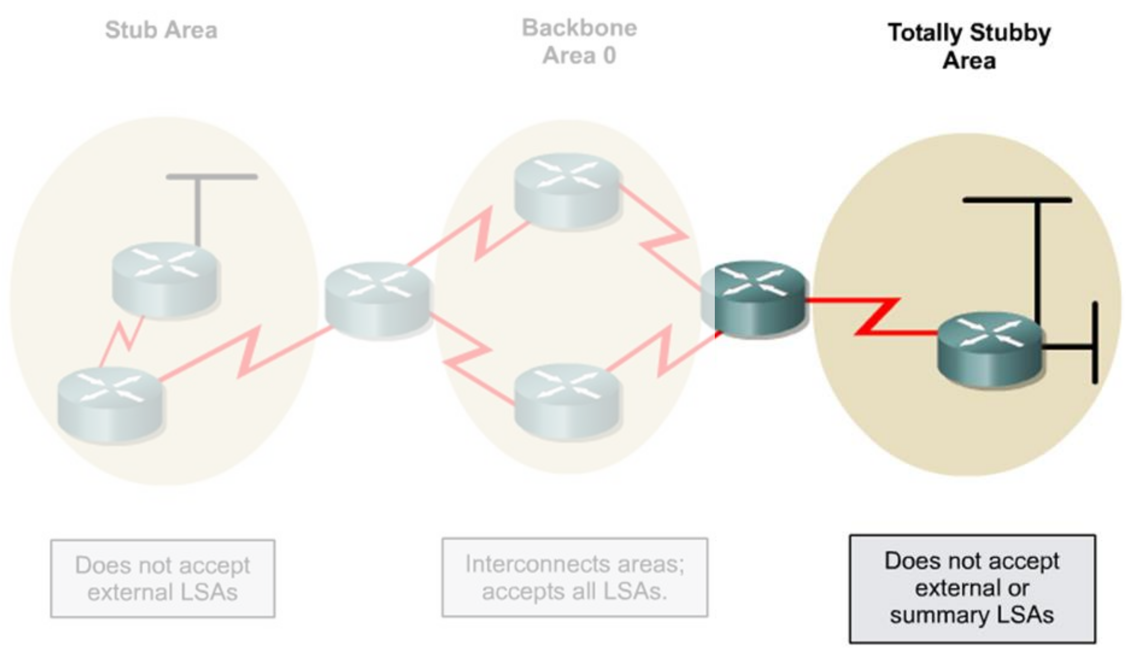



```
R3(config)# interface FastEthernet0/0
R3(config-if)# ip address 192.168.14.1 255.255.255.0
R3(config-if)# interface Serial 0/0/0
R3(config-if)# ip address 192.168.15.1 255.255.255.252
R3(config-if)# router ospf 100
R3(config-router)# network 192.168.14.0 0.0.0.255 area 0
R3(config-router)# network 192.168.15.0 0.0.0.255 area 2
R3(config-router)# area 2 stub
R3(config-router)#
```

```
R4(config-if)# interface Serial 0/0/0
R4(config-if)# ip address 192.168.15.2 255.255.255.252
R4(config-if)# router ospf 100
R4(config-router)# network 192.168.15.0 0.0.0.255 area 2
R4(config-router)# area 2 stub
R4(config-router)#
```

Totally Stubby Area

- Cisco proprietary solution that is better than stub area.
- Area does not accept external AS routes or inter-area routes.
  - Specifically, it does not accept Types 3, 4 and 5 LSAs.
  - It recognizes only intra-area routes and the default route 0.0.0.0.
  - A default route (0.0.0.0) is propagated throughout the area.



Configure a Totally Stubby Area

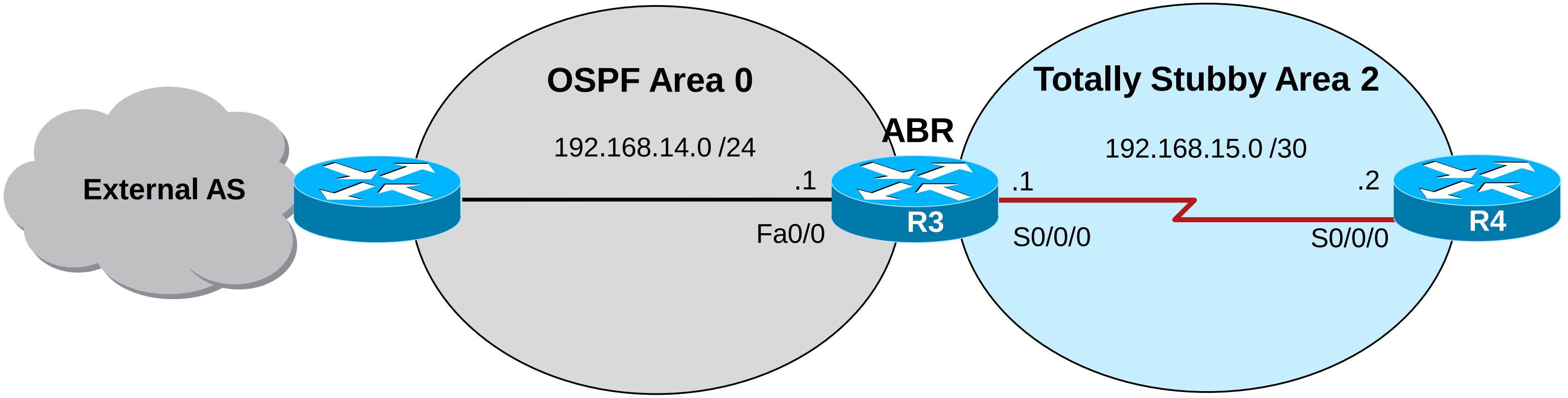
- Identify an ABR as a totally stubby network.

```
Router(config-router)#
```

```
area area-id stub no-summary
```

- Command is only configured on the ABR.
  - All other routers in the totally stubby area are configured as stub routers.
- The *`area-id`* parameter is the identifier for the stub area and can be either a decimal value or a value in dotted-decimal format, like an IP address.
- The **`no-summary`** parameter stops summary LSAs, in addition to external LSAs, from flooding into the totally stubby area.

Configuring a Totally Stubby Area

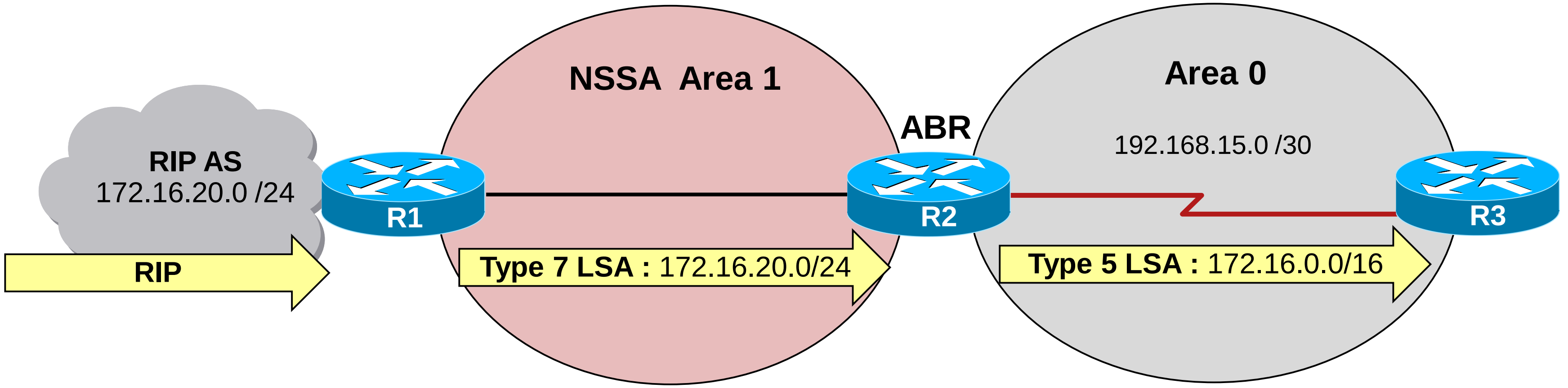



```
R3(config)# interface FastEthernet0/0
R3(config-if)# ip address 192.168.14.1 255.255.255.0
R3(config-if)# interface Serial 0/0/0
R3(config-if)# ip address 192.168.15.1 255.255.255.252
R3(config-if)# router ospf 100
R3(config-router)# network 192.168.14.0 0.0.0.255 area 0
R3(config-router)# network 192.168.15.0 0.0.0.255 area 2
R3(config-router)# area 2 stub no-summary
R3(config-router)#
```

```
R4(config-if)# interface Serial 0/0/0
R4(config-if)# ip address 192.168.15.2 255.255.255.252
R4(config-if)# router ospf 100
R4(config-router)# network 192.168.15.0 0.0.0.255 area 2
R4(config-router)# area 2 stub
R4(config-router)#
```

Not-So-Stubby Area (NSSA)

- Similar to a Stub Area, except that it is primarily used to connect to ISPs, or when redistribution is required.
  - Specifically, it does not accept Types 4 and 5 LSAs.
  - Allows the importing of external routes as Type 7 LSAs and converts them to Type 5 LSAs on the ABR.
  - Better than creating stub areas and also useful for spokes.



Configure an NSSA

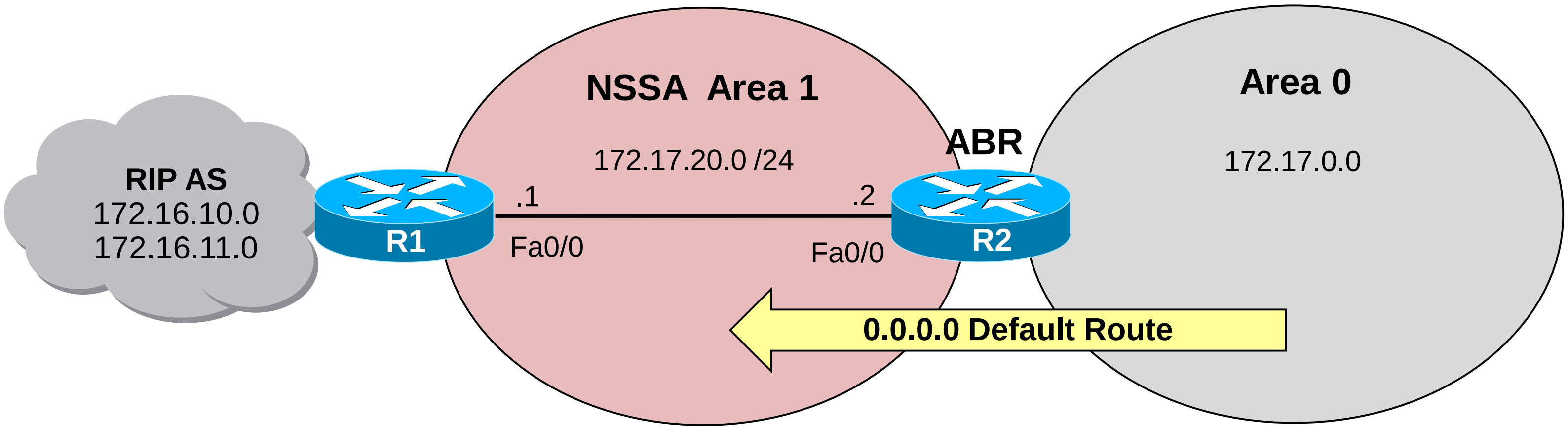
- Define an NSSA area.

```
Router(config-router)#
```

```
area area-id nssa no-redistribution] [default-information-
  originate] [metric metric-value] [metric-type type-value] [no-
  summary]
```

Parameter	Description
area-id	The identifier for the NSSA.
no-redistribution	(Optional) Used when the router is an NSSA ABR and you want the redistribute command to import routes only into the standard areas, but not into the NSSA area.
default-information-originate	(Optional) Used to generate a type 7 default LSA into the NSSA area. This keyword takes effect only on an NSSA ABR or an NSSA ASBR.
metric *metric-value*	(Optional) Metric that is used for generating the default route. Acceptable values are 0 through 16777214.
metric-type *type-value*	(Optional) OSPF metric type for default routes. It can be one of the following values: type 1 external route or 2: type 2 external route
no-summary	(Optional) Allows an area to be a totally stubby NSSA, which is like an NSSA but does not have summary routes injected into it.

Configuring a NSSA Area



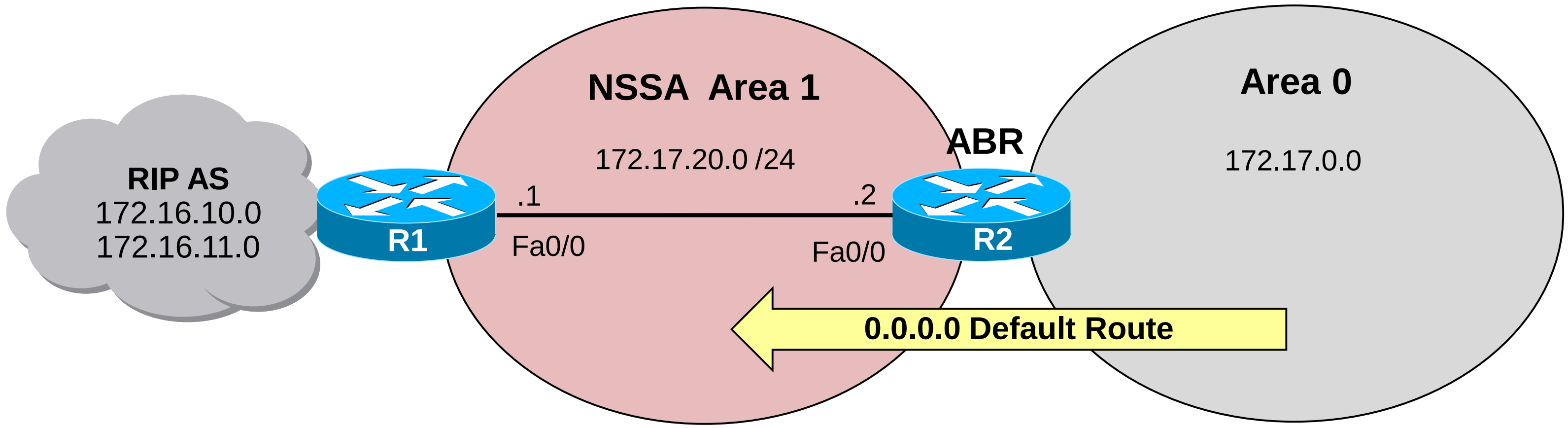

```
R1(config)# router ospf 10
R1(config-router)# redistribute rip subnets
R1(config-router)# default metric 150
R1(config-router)# network 172.17.0.0 0.0.255.255 area 1
R1(config-router)# area 1 nssa
R1(config-router)#
```

```
R2(config)# router ospf 10
R2(config-router)# summary-address 172.16.0.0 255.255.0.0
R2(config-router)# network 172.17.20.0 0.0.0.255 area 1
R2(config-router)# network 172.17.0.0 0.0.255.255 area 0
R2(config-router)# area 1 nssa default-information-originate
R2(config-router)#
```

Totally Stubby NSSA

- Cisco proprietary solution to NSSA.
- Area does not accept external AS routes or inter-area routes.
  - Specifically, it does not accept Types 3, 4 and 5 LSAs.
  - It recognizes only intra-area routes and the default route 0.0.0.0.
  - A default route (0.0.0.0) is propagated throughout the area.
- The ABR of a totally stubby NSSA must be configured with the **`no-summary`** keyword to prevent the flooding of summary routes for other areas into the NSSA area.

Configuring a Totally Stubby NSSA Area




```
R1(config)# router ospf 10
R1(config-router)# redistribute rip subnets
R1(config-router)# default metric 150
R1(config-router)# network 172.17.0.0 0.0.255.255 area 1
R1(config-router)# area 1 nssa
R1(config-router)#
```

```
R2(config)# router ospf 10
R2(config-router)# summary-address 172.16.0.0 255.255.0.0
R2(config-router)# network 172.17.20.0 0.0.0.255 area 1
R2(config-router)# network 172.17.0.0 0.0.255.255 area 0
R2(config-router)# area 1 nssa no-summary
R2(config-router)#
```

OSPF STUB Areas

Area Type	TYPE 1 LSA	TYPE 2 LSA	TYPE 3 LSA	TYPE 4 LSA	TYPE 5 LSA	TYPE 7 LSA
Stub	Yes	Yes	Yes	No *(uses default route)*	No *(uses default route)*	N/A
Totally stubby	Yes	Yes	No (uses default route)	No *(uses default route)*	No *(uses default route)*	N/A
NSSA	Yes	Yes	Yes	No *(uses default route)*	No *(uses default route)*	Yes
Totally NSSA	Yes	Yes	No (uses default route)	No *(uses default route)*	No *(uses default route)*	Yes

How Does OSPF Generate Default Routes?

- In a standard area:
  - Routers do not automatically generate default routes.
  - The **`default-information originate`** command must be used.
  - This is not true if the router does not have a default route. **`[always]`** required.

- In a stub and totally stubby area:
  - The ABR automatically generates a summary LSA with the link-state ID 0.0.0.0
  - The **`default-information originate`** command is not required.
  - This is true even if the ABR does not have a default route.

- In an NSSA area:
  - The ABR generates the default route, but not by default.
  - To force the ABR to generate the default route, use the: **area** *area-id* **nssa default-information-originate** command.

- In a totally stubby NSSA:
  - The ABR automatically generates a default route.

Standard Area <*database*>

```
R2(config-router)#do show ip ospf database

            OSPF Router with ID (99.99.99.99) (Process ID 1)

                Router Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum Link count
3.3.3.33        3.3.3.33        2010        0x80000067 0x007250 5
99.99.99.99     99.99.99.99     262         0x80000066 0x00DB96 2

                Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.23.3    3.3.3.33        246         0x80000002 0x00BD16

                Summary Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.34.0    3.3.3.33        246         0x80000039 0x00EA63
192.168.40.0    3.3.3.33        246         0x80000019 0x00CA86

                Summary ASB Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
4.4.4.33        3.3.3.33        246         0x80000002 0x00984A

                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#       Checksum Tag
2.2.2.2         99.99.99.99     262         0x80000003 0x00E127 0
2.2.2.11        99.99.99.99     268         0x80000003 0x008778 0
2.2.2.22        99.99.99.99     268         0x80000003 0x0019DB 0
4.4.4.3         4.4.4.33        662         0x80000003 0x000E54 0
4.4.4.11        4.4.4.33        662         0x80000003 0x00BD9C 0
4.4.4.22        4.4.4.33        662         0x80000003 0x004FFF 0
192.168.102.0   99.99.99.99     268         0x80000003 0x00261B 0
R2(config-router)#
```

Stub Area <*database*>

```
R2(config-router)# do show ip ospf database

            OSPF Router with ID (99.99.99.99) (Process ID 1)

                Router Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum Link count
3.3.3.33        3.3.3.33        49          0x8000006A 0x005072 5
99.99.99.99     99.99.99.99     48          0x80000068 0x00D99B 2

                Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.23.2    99.99.99.99     48          0x80000001 0x00C3B0

                Summary Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
0.0.0.0         3.3.3.33        58          0x80000001 0x00A271
192.168.34.0    3.3.3.33        58          0x8000003A 0x000748
192.168.40.0    3.3.3.33        58          0x80000019 0x00CA86
R2(config-router)#
```

Totally Stub Area <*database*>

```
R2(config-router)# do show ip ospf database

            OSPF Router with ID (99.99.99.99) (Process ID 1)

                Router Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum Link count
3.3.3.33        3.3.3.33        99          0x8000006A 0x005072 5
99.99.99.99     99.99.99.99     98          0x80000068 0x00D99B 2

                Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.23.2    99.99.99.99     97          0x80000001 0x00C3B0

                Summary Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
0.0.0.0         3.3.3.33        17          0x80000002 0x00A072
R2(config-router)#
```

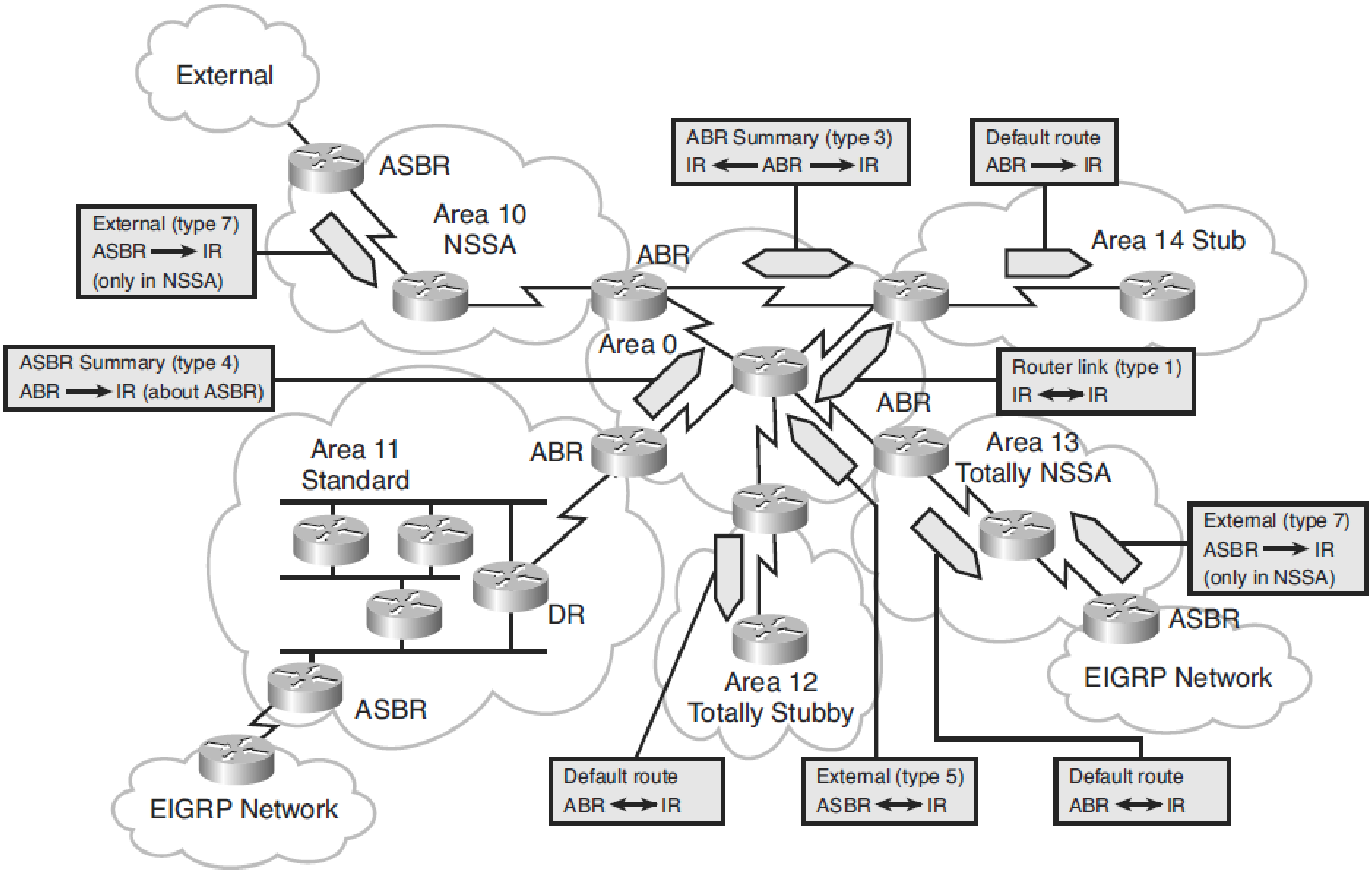
NSSA Area <*database*>

```
R2(config-router)# do show ip ospf database

            OSPF Router with ID (99.99.99.99) (Process ID 1)

                Router Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum Link count
3.3.3.33        3.3.3.33        41          0x8000006D 0x00D7DD 5
99.99.99.99     99.99.99.99     45          0x8000006A 0x006306 2

                Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.23.2    99.99.99.99     40          0x80000003 0x004723

                Summary Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.34.0    3.3.3.33        43          0x80000003 0x00FC81
192.168.40.0    3.3.3.33        43          0x80000019 0x00CA86


                Type-7 AS External Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum Tag
2.2.2.2         99.99.99.99     52          0x80000001 0x006970 0
2.2.2.11        99.99.99.99     52          0x80000001 0x000FC1 0
2.2.2.22        99.99.99.99     54          0x80000001 0x00A025 0
192.168.102.0   99.99.99.99     54          0x80000001 0x00AD64 0
R2(config-router)#
```

Totally Stubby NSSA Area <*database*>

```
R2(config-router)# do show ip ospf database

            OSPF Router with ID (99.99.99.99) (Process ID 1)

                Router Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum Link count
3.3.3.33        3.3.3.33        96          0x8000006D 0x00D7DD 5
99.99.99.99     99.99.99.99     99          0x8000006A 0x006306 2

                Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
192.168.23.2    99.99.99.99     95          0x80000003 0x004723

                Summary Net Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum
0.0.0.0         3.3.3.33        11          0x80000001 0x002AE1

                Type-7 AS External Link States (Area 305)

Link ID         ADV Router      Age         Seq#       Checksum Tag
2.2.2.2         99.99.99.99     106         0x80000001 0x006970 0
2.2.2.11        99.99.99.99     106         0x80000001 0x000FC1 0
2.2.2.22        99.99.99.99     108         0x80000001 0x00A025 0
192.168.102.0   99.99.99.99     108         0x80000001 0x00AD64 0
R2(config-router)#
```

Example OSPF Area Types in a Network

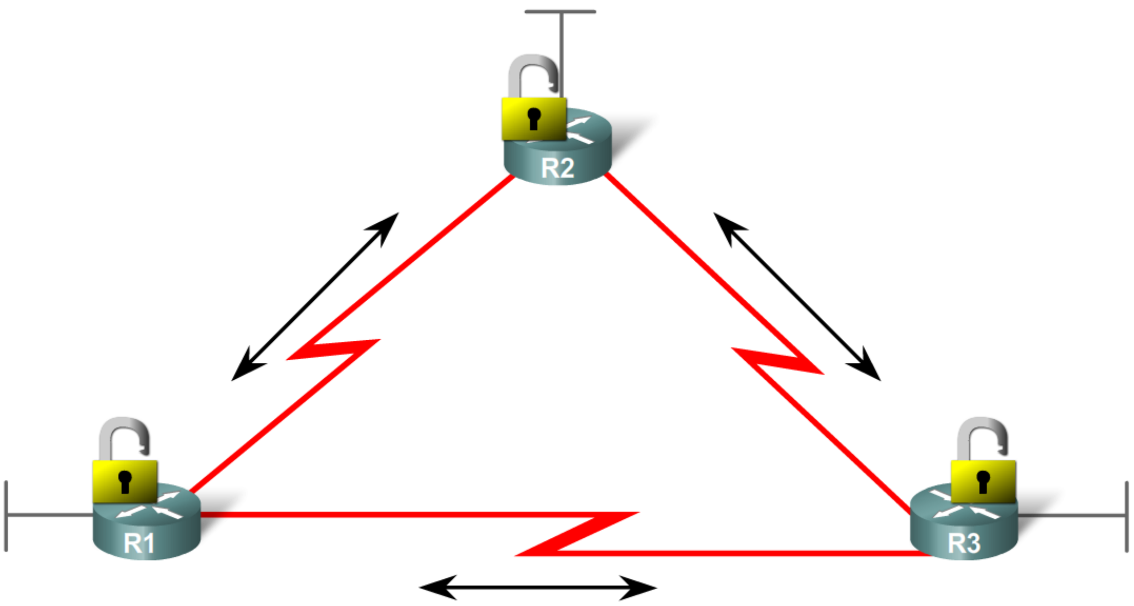


Configuring and Verifying Advanced OSPF Authentication

OSPF Authentication

- Purpose is to authenticate routing information.
  - This is an interface specific configuration.
  - Routers will only accept routing information from other routers that have been configured with the same authentication information.

Authentication



OSPF Authentication Types

- Router generates and checks each packet and authenticates the source of each update packet it receives

- Requires a pre-defined “key” (password)
  - Note: All participating neighbors must have the same key configured

- OSPF supports 2 types of authentication:
  - Simple password authentication (plain text)
    - Less secure
  - MD5 authentication
    - More secure and recommended

Planning for OSPF

- The following key parameters must be defined in enough detail before configuring OSPF authentication:
  - The authentication mode (simple password versus MD5)
  - The definition of one or more keys to authenticate OSPF packets, according to the network security plan.

- Once defined, the following steps may be implemented:
  1. Assign a password (key) to be used.
     - The actual command varies depending on the authentication mode used.
  2. Specify the authentication mode (simple password or MD5).

Configure A Key for Simple Authentication

- Define a password to use for simple password authentication.

```
Router(config-if)#
```

```
ip ospf authentication-key password
```

- The *password* parameter can be entered up to 8 bytes in length.
- This command is used in conjunction with the **ip ospf authentication** command.

Configure the MD5 Key-ID and Key

- Define a password to use for MD5 authentication.

```
Router(config-if)#
```

```
ip ospf message-digest-key key-id md5 key
```

- The *key-id* parameter is an identifier in the range from 1 to 255.
- The *key* parameter can be entered up to 16 bytes in length.
- All neighboring routers on the same network must have the same *key-id* and the same *key* value.
- This command is used in conjunction with the **ip ospf authentication message-digest** command.

Configure the Authentication Mode for OSPF

- Specify the authentication type.

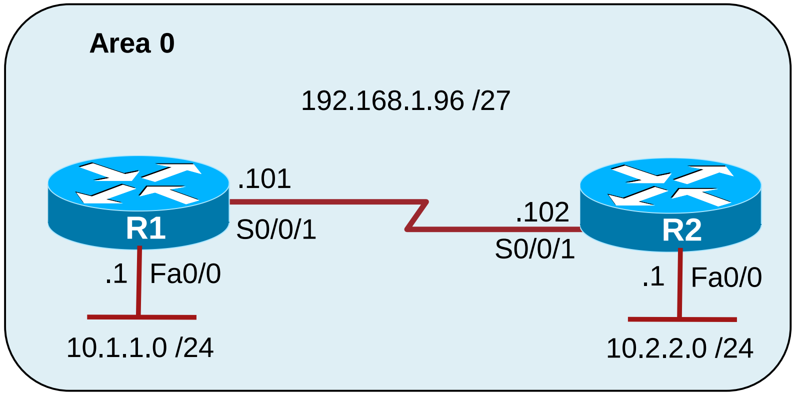
```
Router(config-if)#
```

```
ip ospf authentication [message-digest | null]
```

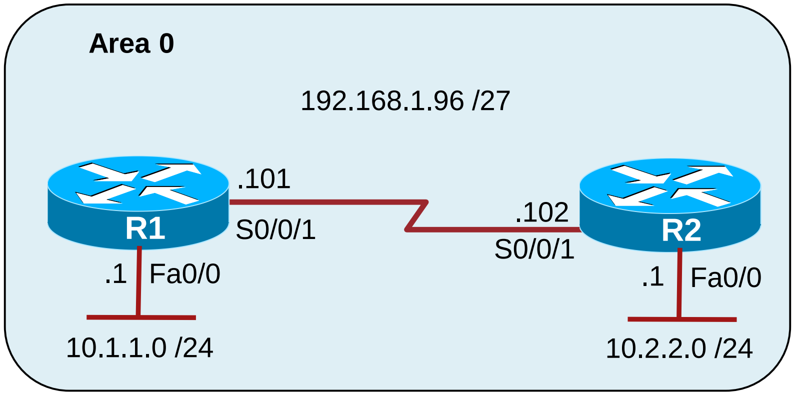
- Before using this command, configure a password.
- The command without any parameters specifies that simple password authentication will be used.
- The **`message-digest`** parameter specifies that MD5 authentication will be used.
- The **`null`** parameter specifies that no authentication is used.
  - This can be useful for overriding simple password or MD5 authentication.

Configuring Simple Password Authentication

```
R1# show running-config
!
<output omitted>
!
interface Fa0/0
 ip address 10.1.1.1 255.255.255.0
!
<output omitted>
!
interface Serial0/0/1
 ip address 192.168.1.101 255.255.255.224
 ip ospf authentication
 ip ospf authentication-key PLAINPAS
!
<output omitted>
!
router ospf 10
 log-adjacency-changes
 network 10.1.1.1 0.0.0.0 area 0
 network 192.168.1.0 0.0.0.255 area 0
!
<output omitted>
```



Configuring Simple Password Authentication




```
R2# show running-config
!
<output omitted>
!
interface Fa0/0
 ip address 10.2.2.1 255.255.255.0
!
<output omitted>
!
interface Serial0/0/1
 ip address 192.168.1.102 255.255.255.224
 ip ospf authentication
 ip ospf authentication-key PLAINPAS
!
<output omitted>
!
router ospf 10
 log-adjacency-changes
 network 10.2.2.1 0.0.0.0 area 0
 network 192.168.1.0 0.0.0.255 area 0
!
<output omitted>
```

Verifying Simple Password Authentication

Displays adjacency-related events of a successful connection.

```
R1# debug ip ospf adj
OSPF adjacency events debugging is on
R1#
<output omitted>

*Feb 17 18:42:01.250: OSPF: 2 Way Communication to 10.2.2.1 on Serial0/0/1,
state 2WAY
*Feb 17 18:42:01.250: OSPF: Send DBD to 10.2.2.1 on Serial0/0/1 seq 0x9B6 opt
0x52 flag 0x7 len 32
*Feb 17 18:42:01.262: OSPF: Rcv DBD from 10.2.2.1 on Serial0/0/1 seq 0x23ED
opt0x52 flag 0x7 len 32  mtu 1500 state EXSTART
*Feb 17 18:42:01.262: OSPF: NBR Negotiation Done. We are the SLAVE
*Feb 17 18:42:01.262: OSPF: Send DBD to 10.2.2.1 on Serial0/0/1 seq 0x23ED opt
0x52 flag 0x2 len 72
<output omitted>

R1# show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.2.2.1          0   FULL/  -        00:00:34    192.168.1.102   Serial0/0/1
```

Troubleshooting Simple Password Problems

- Simple authentication on R1, no authentication on R2:

```
R1#
*Feb 17 18:51:31.242: OSPF: Rcv pkt from 192.168.1.102, Serial0/0/1
: Mismatch Authentication type. Input packet specified type 0, we
use type 1

R2#
*Feb 17 18:50:43.046: OSPF: Rcv pkt from 192.168.1.101, Serial0/0/1
: Mismatch Authentication type. Input packet specified type 1, we
use type 0
```

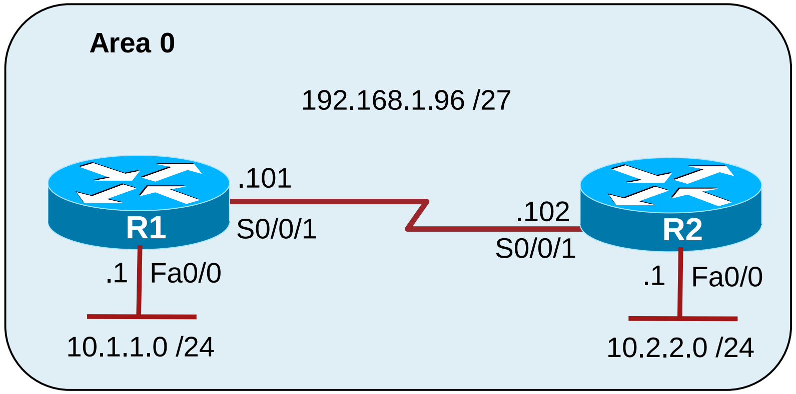
Troubleshooting Simple Password Problems

- Simple authentication on R1 and R2, but different passwords.

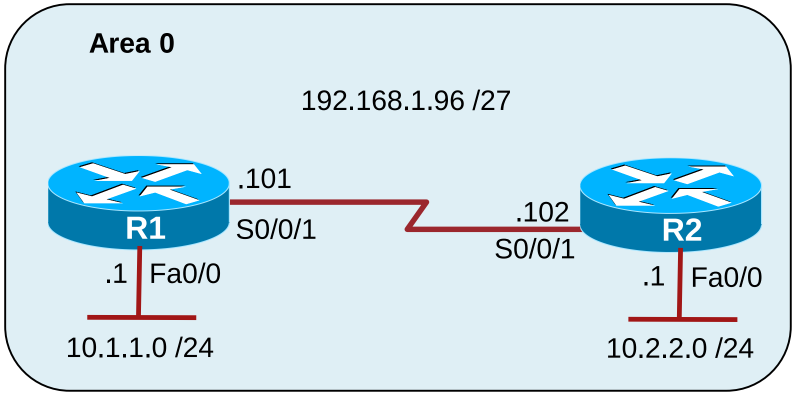
```
R1#
*Feb 17 18:54:01.238: OSPF: Rcv pkt from 192.168.1.102, Serial0/0/1
: Mismatch Authentication Key - Clear Text

R2#
*Feb 17 18:53:13.050: OSPF: Rcv pkt from 192.168.1.101, Serial0/0/1
: Mismatch Authentication Key - Clear Text
```

Configuring MD5 Authentication

```
R1# show running-config
!
<output omitted>
!
interface Fa0/0
 ip address 10.1.1.1 255.255.255.0
!
<output omitted>
!
interface Serial0/0/1
 ip address 192.168.1.101 255.255.255.224
 ip ospf authentication message-digest
 ip ospf message-digest-key 1 md5 SECRETPASS
!
<output omitted>
!
router ospf 10
 log-adjacency-changes
 network 10.1.1.1 0.0.0.0 area 0
 network 192.168.1.0 0.0.0.255 area 0
!
<output omitted>
```



Configuring MD5 Authentication




```
R2# show running-config
!
<output omitted>
!
interface Fa0/0
 ip address 10.2.2.1 255.255.255.0
!
<output omitted>
!
interface Serial0/0/1
 ip address 192.168.1.102 255.255.255.224
 ip ospf authentication message-digest
 ip ospf message-digest-key 1 md5 SECRETPASS
!
<output omitted>
!
router ospf 10
 log-adjacency-changes
 network 10.2.2.1 0.0.0.0 area 0
 network 192.168.1.0 0.0.0.255 area 0
!
<output omitted>
```

Verifying MD5 Authentication

```
R1# show ip ospf interface
Serial0/0/1 is up, line protocol is up
  Internet Address 192.168.1.101/27, Area 0
  Process ID 10, Router ID 10.1.1.1, Network Type POINT_TO_POINT, Cost: 64
  Transmit Delay is 1 sec, State POINT_TO_POINT
<output omitted>
  Neighbor Count is 1, Adjacent neighbor count is 1
    Adjacent with neighbor 10.2.2.1
  Suppress hello for 0 neighbor(s)
  Message digest authentication enabled
    Youngest key id is 1
<output omitted>
R1#
R1# show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.2.2.1          0   FULL/  -        00:00:31    192.168.1.102   Serial0/0/1

R1#
```

Verifying MD5 Authentication

```
R1# debug ip ospf adj
OSPF adjacency events debugging is on
<output omitted>
*Feb 17 17:14:06.530: OSPF: Send with youngest Key 1
*Feb 17 17:14:06.546: OSPF: 2 Way Communication to 10.2.2.2 on Serial0/0/1,
state 2WAY
*Feb 17 17:14:06.546: OSPF: Send DBD to 10.2.2.2 on Serial0/0/1 seq 0xB37 opt
0x52 flag 0x7 len 32
*Feb 17 17:14:06.546: OSPF: Send with youngest Key 1
*Feb 17 17:14:06.562: OSPF: Rcv DBD from 10.2.2.2 on Serial0/0/1 seq 0x32F
opt 0x52 flag 0x7 len 32  mtu 1500 state EXSTART
*Feb 17 17:14:06.562: OSPF: NBR Negotiation Done. We are the SLAVE
*Feb 17 17:14:06.562: OSPF: Send DBD to 10.2.2.2 on Serial0/0/1 seq 0x32F opt
0x52 flag 0x2 len 72
*Feb 17 17:14:06.562: OSPF: Send with youngest Key 1
<output omitted>

R1# show ip ospf neighbor
Neighbor ID     Pri   State           Dead Time   Address         Interface
10.2.2.2          0   FULL/  -        00:00:35    192.168.1.102   Serial0/0/1
```

Troubleshooting MD5 Authentication

MD5 authentication on both R1 and R2, but R1 has key 1 and R2 has key 2, both with the same passwords:

```
R1#
*Feb 17 17:56:16.530: OSPF: Send with youngest Key 1
*Feb 17 17:56:26.502: OSPF: Rcv pkt from 192.168.1.102, Serial0/0/1 : Mismatch
Authentication Key - No message digest key 2 on interface
*Feb 17 17:56:26.530: OSPF: Send with youngest Key 1

R2#
*Feb 17 17:55:28.226: OSPF: Send with youngest Key 2
*Feb 17 17:55:28.286: OSPF: Rcv pkt from 192.168.1.101, Serial0/0/1 : Mismatch
Authentication Key - No message digest key 1 on interface
*Feb 17 17:55:38.226: OSPF: Send with youngest Key 2
```

Chapter 3 Summary

The chapter focused on the following topics:

- Characteristics of link-state routing protocols.
- OSPF's two-tier hierarchical area structure, with a backbone area 0 and regular areas.
- How OSPF routers use the Hello protocol to build adjacencies.
- The OSPF metric calculation, which is based on the link bandwidth.
- The five types of OSPF packets—hello, DBD, LSR, LSU, and LSAck.
- The neighbor states that OSPF interfaces may pass through: down, init, two-way, exstart, exchange, loading, and full.

Chapter 3 Summary (cont.)

- The five fields in the hello packet must match on neighboring routers: hello interval, dead interval, area id, authentication password, and stub area flag.
- Planning OSPF implementations, including the IP addressing, network topology, and OSPF areas.
- Basic OSPF configuration commands including:
  - **router ospf** *process-id* global configuration command
  - **network** *ip-address wildcard-mask* **area** *area-id* interface configuration command
  - **ip ospf** *process-id* **area** *area-id* [**secondaries none**] interface configuration command
  - **bandwidth** *kilobits* interface configuration command
  - **router-id** *ip-address* router configuration command

Chapter 3 Summary (cont.)

- Commands for verifying OSPF operation:
  - **`show ip protocols`**
  - **`show ip ospf neighbor`**
  - **`show ip route`**
  - **`show ip route ospf`**
  - **`show ip ospf interface`**
  - **`show ip ospf database`**
  - **`show ip ospf`**

  - **`debug ip ospf events`**
  - **`debug ip ospf adj`**
  - **`debug ip ospf packet`**

Chapter 3 Summary (cont.)

- How the OSPF router ID is selected with the **`router-id`** *`ip-address`* router configuration command, the highest IP address on any active loopback interface, or the highest IP address of any active physical interface when OSPF starts.
- The three types of networks defined by OSPF: point-to-point, broadcast, and NBMA.
- How a DR and BDR are selected.
- The five modes of OSPF operation available for NBMA networks: nonbroadcast and point-to-multipoint RFC modes; and broadcast, point-to-multipoint nonbroadcast, and point-to-point Cisco modes.
- The different types of OSPF routers: internal routers, backbone routers, ABRs, and ASBRs.
- The 11 different OSPF LSA types.
- The three kinds of OSPF routes: intra-area (O), interarea (O IA), and external (either O E1 or O E2).
- Configuring OSPF LSDB overload protection using the **`max-lsa`** router configuration command.

Chapter 3 Summary (cont.)

- Using the **passive-interface type number [default]** router configuration command.
- Propagate an OSPF default route using the **default-information originate [always]** router configuration command.
- OSPF summarization can be configured on an ABR using the **area** *area-id range address mask* **[advertise | not-advertise] [cost** *cost***]** router configuration command, and on an ASBR using the **summary-address** *ip-address mask* **[not-advertise] [tag** *tag***]** router configuration command.
- Virtual links are configured with the **area** *area-id* **virtual-link** *router-id* router configuration command, and verified with the **show ip ospf virtual-links** command.
- The several area types defined in OSPF: standard areas, backbone (transit) areas, stub areas, totally stubby areas, NSSAs, and totally stubby NSSAs.

Chapter 3 Summary (cont.)

- The types of OSPF authentication: null, simple password authentication (also called plain-text authentication), and MD5 authentication.
- The commands to configure OSPF simple password authentication:
  - **ip ospf authentication-key** *password* interface configuration command
  - **ip ospf authentication** interface configuration command or the **area area-id authentication** router configuration command
- The commands to configure OSPF MD5 authentication:
  - **ip ospf message-digest-key key-id md5 key** interface configuration command
  - **ip ospf authentication message-digest** interface configuration command or the **area area-id authentication message-digest** router configuration command

Chapter 3 Labs

- **IGP-LAB-3.1 OSPF Multi Area**
- **IGP-LAB-3.2 OSPF Virtual Link**
- **IGP-LAB-3.3 OSPF Stub**
- **IGP-LAB-3.4 OSPF NSSA**

Q&A