Open Shortest Path First (OSPF)

CCNA Routing and Switching

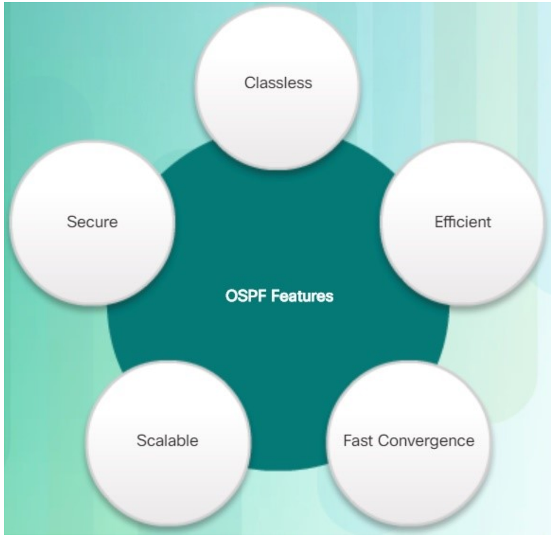
Scaling Networks v6.0

Open Shortest Path First

Features of OSPF

	Interior Gateway Protocols				Exterior Gateway Protocols
	Distance Vector		Link-State		Path Vector
IPv4	RIPv2	EIGRP	OSPFv2	IS-IS	BGP-4
IPv6	RIPng	EIGRP for IPv6	OSPFv3	IS-IS for IPv6	BGP-MP

- OSPF uses the Dijkstra shortest path first (SPF) algorithm to choose the best path.
- Administrative distance is used in determining what route gets installed in the routing table when the route is learned from multiple sources.
  - The lowest administrative distance is the one added to the routing table.



Routing changes trigger routing updates

v2 supports MD5 and SHA authentication
v3 uses IPsec for authentication

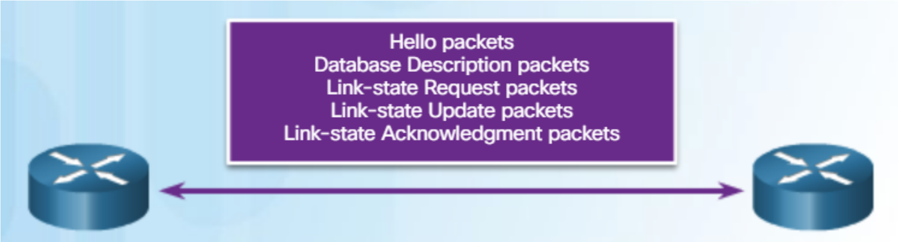
Supports a hierarchical design system through the use of areas

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

Open Shortest Path First

Components of OSPF

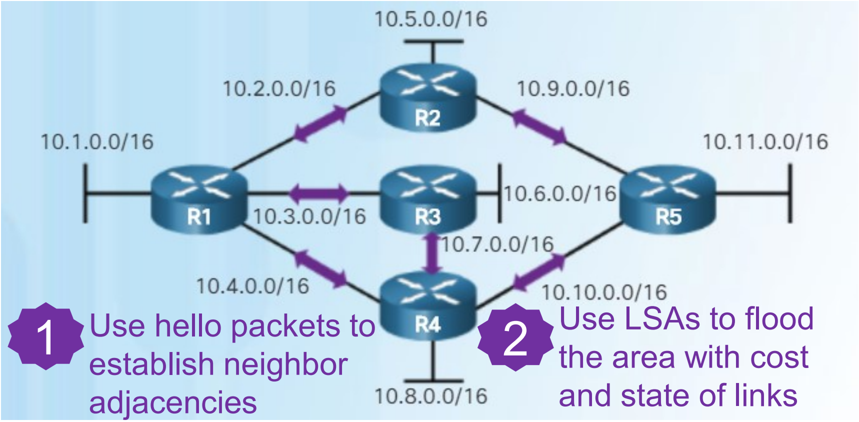
- OSPF packet types:



Database	Table	Description
Adjacency	Neighbor	• Lists all neighbor routers to which a router has established bidirectional communication • Unique for each router • View using the **show ip ospf neighbor** command
Link-state (LSDB)	Topology	• Lists information about all other routers • Represents the network topology • Contains the same LSDB as all other routers in the same area • View using the **show ip ospf database** command
Forwarding	Routing	• Lists routes generated when the SPF algorithm is run on the link-state database. • Unique to each router and contains information on how and where to send packets destined for remote networks • View using the **show ip route** command

Open Shortest Path First

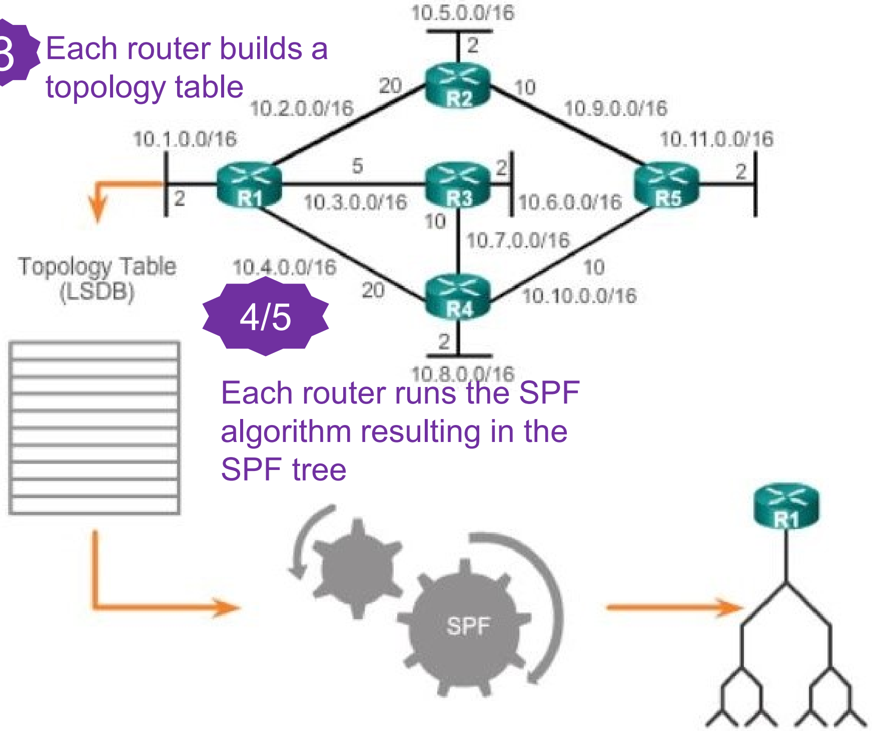
Link-State Operation



1 Use hello packets to establish neighbor adjacencies

2 Use LSAs to flood the area with cost and state of links

3 Each router builds a topology table



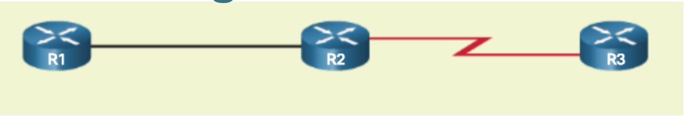
4/5 Each router runs the SPF algorithm resulting in the SPF tree

6 Each router builds a routing table that includes the path to get to the distant network and the cost to get there.

Destination	Shortest Path	Cost
10.5.0.0/16	R1→R2	22
10.6.0.0/16	R1→R3	7
10.7.0.0/16	R1→R3	15
10.8.0.0/16	R1→R3→R4	17
10.9.0.0/16	R1→R2	30
10.10.0.0/16	R1→R3→R4	25
10.11.0.0/16	R1→R3→R4→R5	27
10.5.0.0/16	R1→R2	22

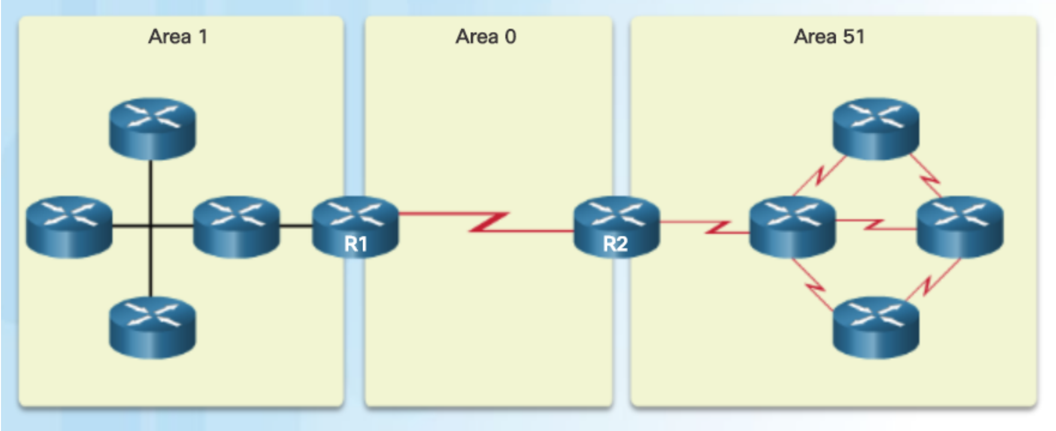
Single-Area and Multiarea OSPF

Single-Area OSPF



- All routers contained in one area
- Called the backbone area
- Known as Area 0
- Used in smaller networks with few routers

Multiarea OSPF



- Designed using a hierarchical scheme
- All areas connect to area 0
- More commonly seen with numerous areas around area 0
- Routers that connect area 0 to another area is known as an Area Border Router (ABR)
- Used in large networks
- Multiple areas reduces processing and memory overhead
- A failure in one area does not affect other areas

Encapsulating OSPF Messages

- OSPF adds its own Layer 3 header after the IP Layer 3 header.
  - The IP header contains the OSPF multicast address of either 224.0.0.5 or 224.0.0.6 and the protocol field of 89 which indicates it is an OSPF packet.
- OSPF Packet Header identifies the type of OSPF packet, the router ID, and the area ID
- OSPF Packet Type contains the specific OSPF packet type information

Data Link Frame Header	IP Packet Header	OSPF Packet Header	OSPF Packet Type-Specific Database

Data Link Frame (Ethernet Fields shown here)

MAC Destination Address = Multicast: 01-00-5E-00-00-05 or 01-00-5E-00-00-06

MAC Source Address = Address of sending interface

IP Packet

IP Source Address = Address of sending interface

IP Destination Address = Multicast: 224.0.0.5 or 224.0.0.6

Protocol Field = 89 for OSPF

OSPF Packet Header

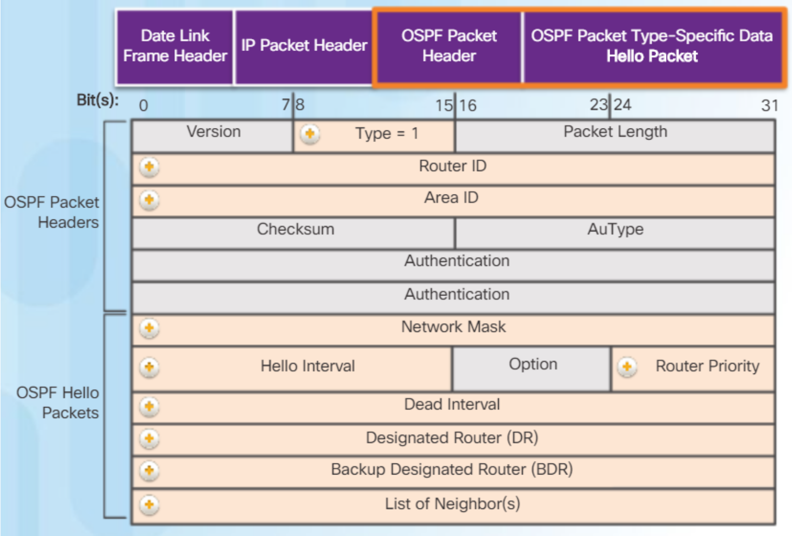
Type code for OSPF packet type

Router ID and Area ID

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

Hello Packet

- Hello packets are used to discover neighbors, establish neighbor adjacencies, advertise parameters both routers must agree upon in order to become neighbors, and elect the Designated Router (DR) and Backup Designated Router (BDR) on multi-access networks like Ethernet and Frame Relay (not serial point-to-point links).
  - Hello interval – how often a router sends hello packets
  - Dead interval – how long a router waits to hear from a neighbor router before declaring the router out of service
  - Hello and dead intervals must be the same interval setting on neighboring routers on the same link
  - Dead intervals by default are 4 times the hello interval
  - Transmitted to multicast address 224.0.0.5 in IPv4
  - Transmitted to multicast address FF02::5 in IPv6
  - Sent every 10 seconds by default on multi-access networks like Ethernet and point-to-point links
  - Sent every 30 seconds by default on non-broadcast multiple access networks (NBMA) like Frame Relay
  - *If the dead interval expires before the router receives a hello packet, OSPF removes that neighbor from its link state data base (LSDB). The router then floods the LSDB with info about the down neighbor.*



OSPF Messages

Link-State Updates

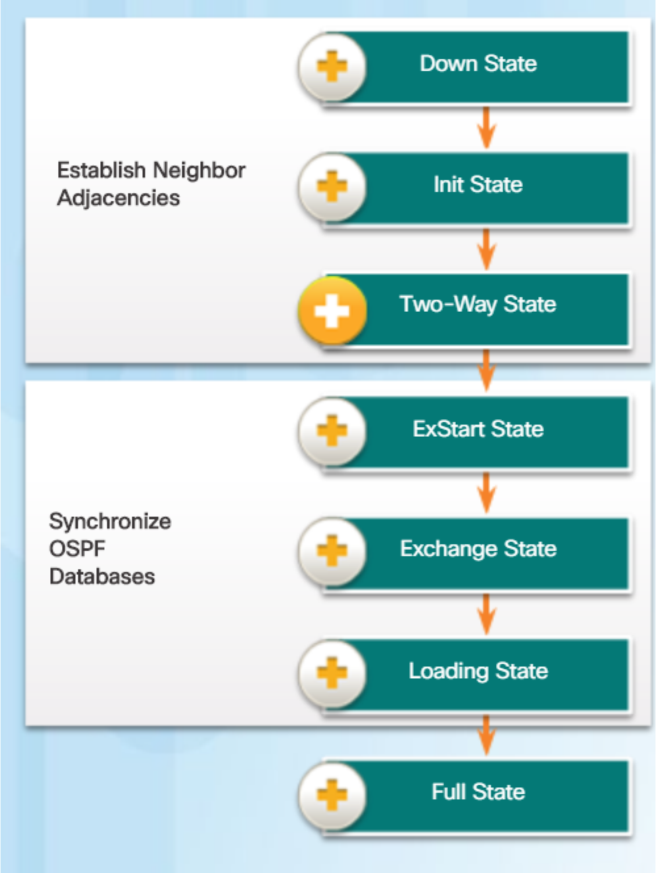
- A Link State Update (LSU) contains one or more link-state advertisements (LSAs); LSAs contain route information for destination networks
- Routers initially send Type 2 DBD packets – an abbreviated list of the sending routers LSDB
  - Receiving routers check against their own LSDB
- Type 3 LSR is used by the receiving router to request more information about an entry in the Database Description (DBD)
- Type 4 Link-state Update (LSU) is used to reply to an LSR packet

OSPF Packet Type	Packet Name	Description
1	Hello	Discovers neighbors and builds adjacencies between them
2	DBD	Checks for database synchronization between routers
3	LSR	Requests specific link-state records from router to router
4	Link-State Update (LSU)	Sends specifically requested link-state records
5	LSAck	Acknowledges the other packet types

LSA Type	Description
1	Router LSAs
2	Network LSAs
3 or 4	Summary LSAs
5	Autonomous System External LSAs
6	Multicast OSPF LSAs
7	Defined for Not-So-Stubby Areas
8	External Attributes LSA for Border Gateway Protocol (BGP)
9, 10, 11	Opaque LSAs

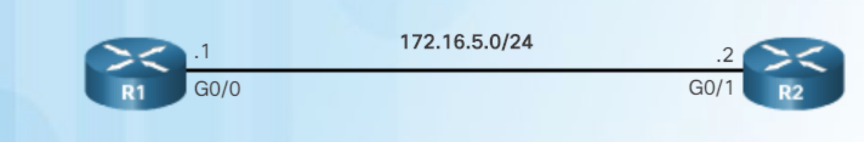
OSPF Operational States

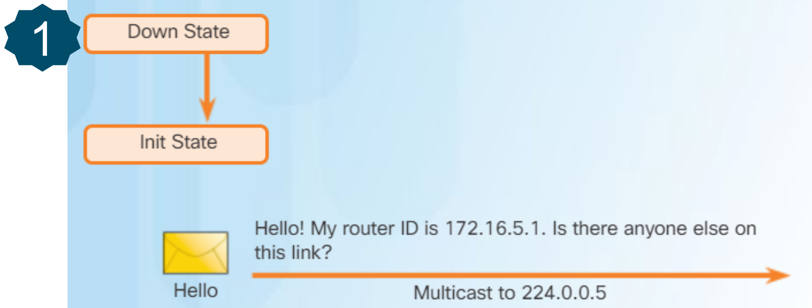
- OSPF progresses through several states while attempting to reach convergence:
  - Down – No Hello packets received; router sends Hello packets
  - Init – Hello packets are received that contain the sending router's Router ID
  - Two-Way – Used to elect a DR and BDR on an Ethernet link
  - ExStart – Negotiate master/slave relationship and DBD packet sequence number; the master initiates the DBD packet exchange
  - Exchange – Routers exchange DBD packets; if additional router information is required, then transition to the Loading State, otherwise, transition to the Full State
  - Loading – LSRs and LSUs are used to gain additional route information; routes are processed using the shortest path first (SPF) algorithm; transition to the Full State
  - Full – Routers have converged databases

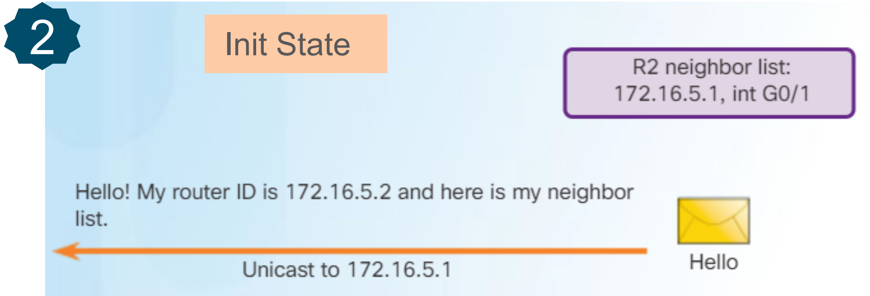


Establish Neighbor Adjacencies

- Without a pre-configured router ID (RID) or loopback addresses, R1 has a RID of 172.16.5.1 and R2 has a RID of 172.16.5.2



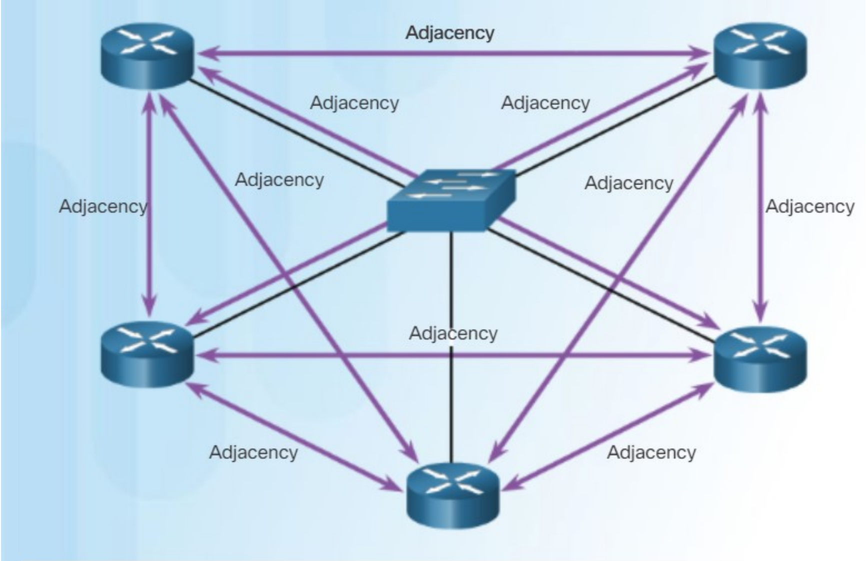




OSPF DR and BDR

- Why have a DR/BDR election?
- Reduce the number of LSAs sent – The DR is the only router used to send LSAs for the shared network
- Reduce the number of adjacencies over a multi-access network like Ethernet

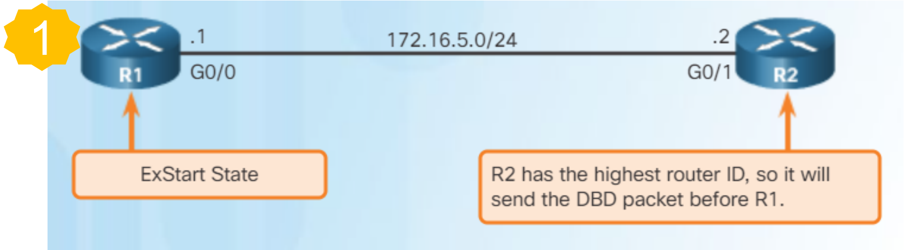
Routers	Adjacencies
n	n (n - 1) / 2
5	10
10	45
20	190
100	4,950

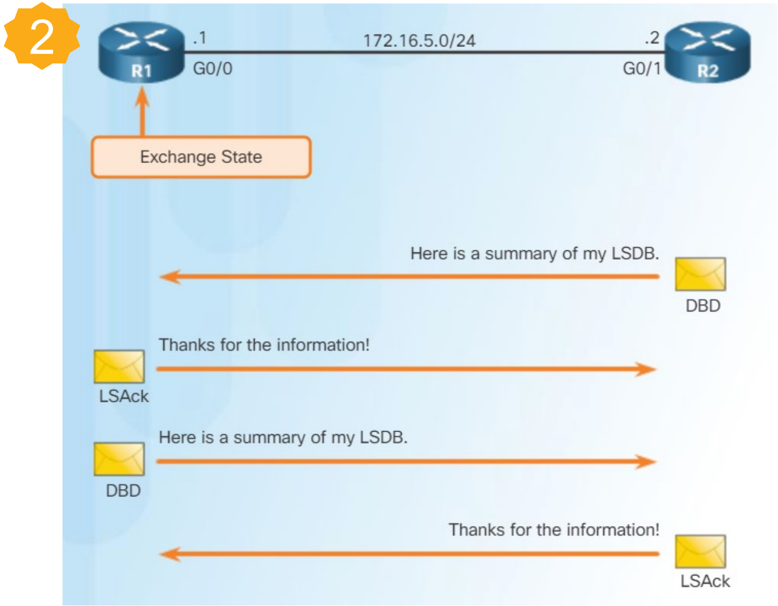


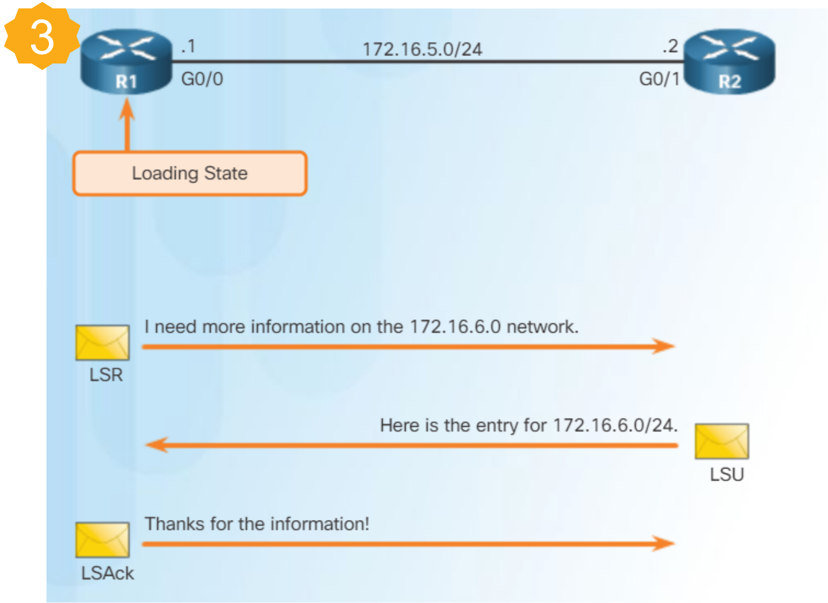
Number of Adjacencies = n (n - 1) / 2
n = number of routers
Example: 5 (5 - 1) / 2 = 10 adjacencies

Synchronizing OSPF Databases

- After the Two-Way state, routers need to synchronize their databases and use the other four types of OSPF packets to exchange information.







8.2 Single-Area OSPFv2

Router OSPF Configuration Mode

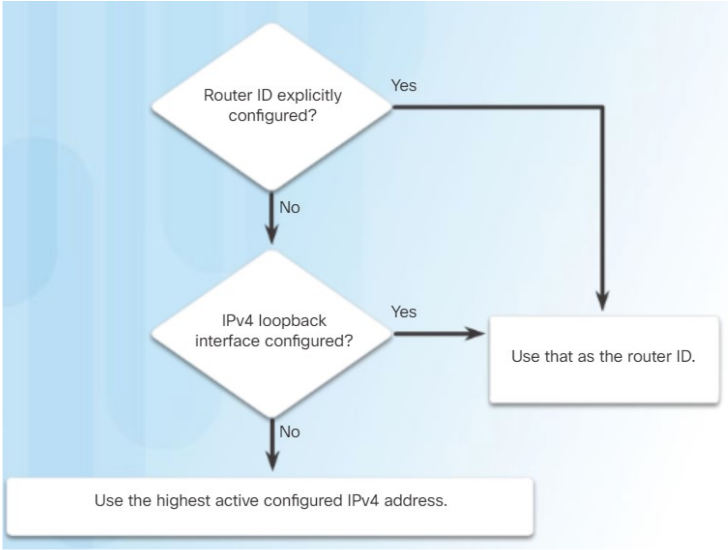
- OSPFv2 configuration uses the router ospf configuration mode
  - From global configuration mode, type **router ospf** *process-id* to enter commands

```
R1(config)# router ospf 10
R1(config-router)# ?
Router configuration commands:
 auto-cost              Calculate OSPF interface cost according to
                        bandwidth
 network                Enable routing on an IP network
 no                     Negate a command or set its defaults
 passive-interface      Suppress routing updates on an interface
 priority               OSPF topology priority
 router-id              router-id for this OSPF process
```

Note there are other commands used in this mode.

Router IDs

- Router IDs are used to uniquely identify an OSPF router
- Router IDs are 32 bits long in both OSPFv2 (IPv4) and OSPFv3 (IPv6)
- Used in the election of the DR if a priority number is not configured
- Ways a router gets a router ID
  1. Configured using the **router-id *rid*** OSPF router configuration mode command
  2. If a router ID is not configured, the highest configured loopback interface is used
  3. If there are no configured loopback interfaces, then the highest active IPv4 address is used (not recommended because if the interface with the highest IPv4 address goes down, the router ID selection process starts over)



If a loopback address is used, do not route this network using a network statement!

Configuring an OSPF Router ID

- Use the **router-id** *x.x.x.x* command to configure a router ID.
- Use the **show ip protocols** command to verify the router ID.
- Use the **clear ip ospf process** command after changing the router ID to make the change effective.

```
R1(config)# router ospf 10
R1(config-router)# router-id 1.1.1.1
R1(config-router)# end
R1#
*Mar 25 19:50:36.595: %SYS-5-CONFIG_I: Configured from console
R1#
R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 10"
   Outgoing update filter list for all interfaces is not set
   Incoming update filter list for all interfaces is not set
   Router ID 1.1.1.1
   Number of areas in this router is 0. 0 normal 0 stub 0 nssa
   Maximum path: 4
   Routing for Networks:
   Routing Information Sources:
   Gateway         Distance      Last Update
   Distance: (default is 110)
```

```
R1# clear ip ospf process
Reset ALL OSPF processes? [no]: y
R1#
*Mar 25 19:46:22.423: %OSPF-5-ADJCHG: Process 10, Nbr
3.3.3.3 on Serial0/0/1 from FULL to DOWN, Neighbor Down:
 Interface down or detached
*Mar 25 19:46:22.423: %OSPF-5-ADJCHG: Process 10, Nbr
2.2.2.2 on Serial0/0/0 from FULL to DOWN, Neighbor Down:
 Interface down or detached
*Mar 25 19:46:22.475: %OSPF-5-ADJCHG: Process 10, Nbr
3.3.3.3 on Serial0/0/1 from LOADING to FULL, Loading Done
*Mar 25 19:46:22.475: %OSPF-5-ADJCHG: Process 10, Nbr
2.2.2.2 on Serial0/0/0 from LOADING to FULL, Loading Done
R1#
R1# show ip protocols | section Router ID
  Router ID 1.1.1.1
```

Enabling OSPF on Interfaces

- Use the **network** command to specify which interface(s) participate in the OSPFv2 area.
  - (config)# **router ospf** *x*
  - (config-router)# **network** *x.x.x.x wildcard_mask* **area** *area-id*
- Two ways to use the **network** command
  - Advertise the particular network, calculating the wildcard mask

```
R1(config)# router ospf 10
R1(config-router)# network 172.16.1.0 0.0.0.255 area 0
R1(config-router)# network 172.16.3.0 0.0.0.3 area 0
R1(config-router)# network 192.168.10.4 0.0.0.3 area 0
```

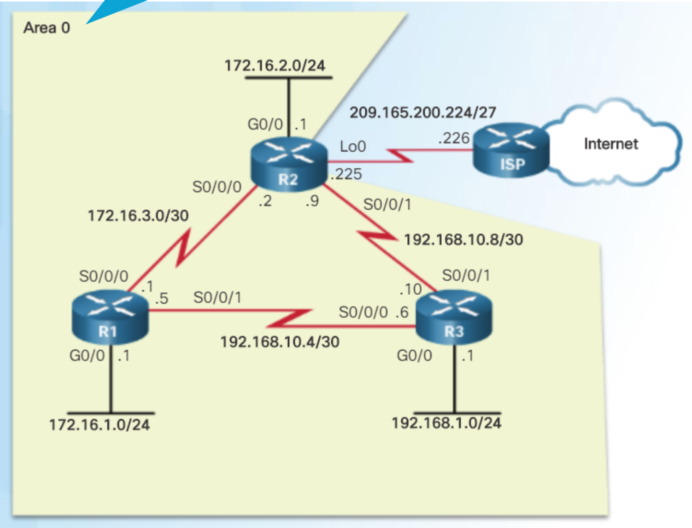
  - Advertise the IP address on the router interface with a 0.0.0.0 wildcard mask

```
R1(config)# router ospf 10
R1(config-router)# network 172.16.1.1 0.0.0.0 area 0
R1(config-router)# network 172.16.3.1 0.0.0.0 area 0
R1(config-router)# network 192.168.10.5 0.0.0.0 area 0
```

Common misconception!

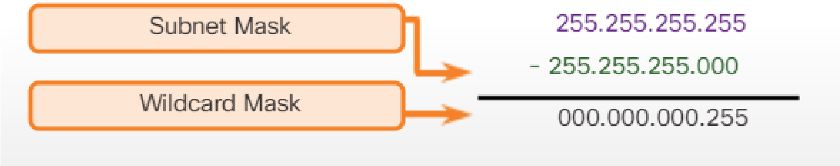
R2 has 3 interfaces in Area 0 so three network statements are used (not 6 network statements for all 6 networks in the entire area)

If a single-area topology is used, it is best to use Area 0

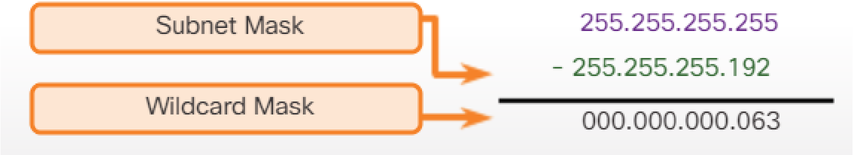


Wildcard Mask

- To determine the wildcard mask, subtract the normal mask from 255.255.255.255
- A wildcard mask bit of 0 – match the bit
- A wildcard mask bit of 1 – ignore the bit
- A wildcard mask is a series of 0s with the rest 1s (the 0s and 1s are not alternating like an IP address)



/24 mask



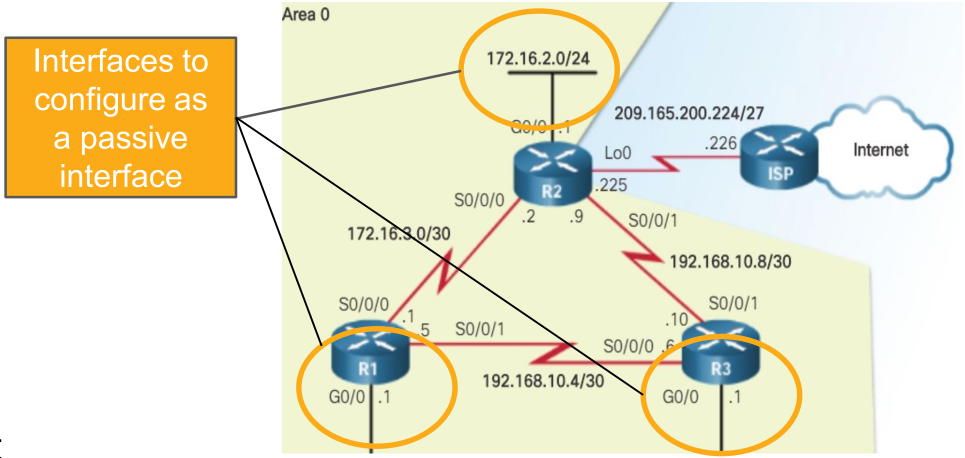
/26 mask

Configuring Single-Area OSPFv2

Passive Interface

- An interface configured as a passive interface does not **SEND** OSPF messages.
- Best practice for interfaces that have users attached (security)
- Doesn't waste bandwidth sending messages out OSPF-enabled interfaces that don't have another router attached.
- Use the **passive-interface** command to configure
- Use the **show ip protocols** to verify

```
R1(config)# router ospf 10
R1(config-router)# passive-interface GigabitEthernet 0/0
```

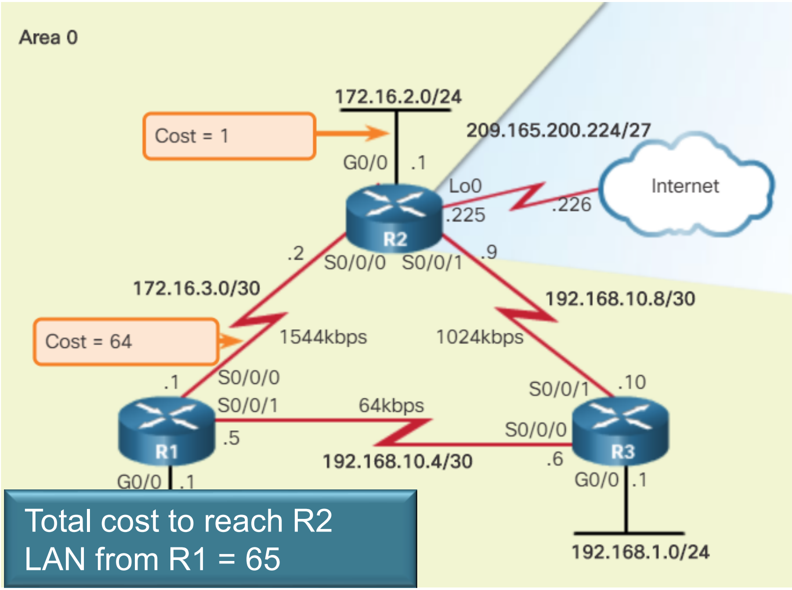



```
R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 10"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 1.1.1.1
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    172.16.1.1 0.0.0.0 area 0
    172.16.3.1 0.0.0.0 area 0
    192.168.10.5 0.0.0.0 area 0
  Passive Interface(s):
    GigabitEthernet0/0
  Routing Information Sources:
    Gateway         Distance      Last Update
    3.3.3.3              110      00:08:35
    2.2.2.2              110      00:08:35
  Distance: (default is 110)
```

OSPF Accumulates Costs

- The “cost” for a destination network is an accumulation of all cost values from source to destination.
- The cost metric can be seen in the routing table as the second number within the brackets.




```
R1# show ip route | include 172.16.2.0
O        172.16.2.0/24 [110/65] via 172.16.3       39:07,
         Serial0/0/0
R1#
R1# show ip route 172.16.2.0
Routing entry for 172.16.2.0/24
  Known via "ospf 10", distance 110, metric 65, type intra
  area
  Last update from 172.16.3.2 on Serial0/0/0, 03:39:15 ago
  Routing Descriptor Blocks:
  * 172.16.3.2, from 2.2.2.2, 03:39:15 ago, via Serial0/0/0
      Route metric is 65, traffic share count is 1
```

Cost metric to destination network 172.16.2.0 from R1

OSPF Metric = Cost

- OSPF uses the metric of cost to determine the best path used to reach a destination network (Cost = reference bandwidth / interface bandwidth)
- Lowest cost is a better path
- The interface bandwidth influences the cost assigned
  - A lower bandwidth interface has a higher cost
- Changing the OSPF reference bandwidth affects only the OSPF calculation used to determine the metric, not the bandwidth of the interface.
- Use the **auto-cost reference-bandwidth** command to change the OSPF reference bandwidth.
- Default reference bandwidth is 100 Mbps.

Interface Type	Reference Bandwidth in bps		Default Bandwidth in bps	Cost
10 Gbps Ethernet	100,000,000	÷	10,000,000,000	1
1 Gbps Ethernet	100,000,000	÷	1,000,000,000	1
100 Mbps Ethernet	100,000,000	÷	100,000,000	1
10 Mbps Ethernet	100,000,000	÷	10,000,000	10
1.544 Mbps Serial	100,000,000	÷	1,544,000	64
128 kbps Serial	100,000,000	÷	128,000	781
64 kbps Serial	100,000,000	÷	64,000	1562

This is an issue because it is the same cost due to the default reference bandwidth. Needs to be adjusted!

With the default reference bandwidth applied makes 100Mbps Ethernet, 1 Gbps Ethernet, and 10 Gbps Ethernet appear to be the same bandwidth within the best path calculations.

Adjusting the Reference Bandwidth

- To adjust to distinguish between 100 Mbps Ethernet and Gigabit Ethernet, use the **auto-cost reference-bandwidth 1000** command.
- To adjust to distinguish between 100 Mbps Ethernet and Gigabit Ethernet, use the **auto-cost reference-bandwidth 10000** command.

Interface Type	Reference Bandwidth in bps		Default Bandwidth in bps	Cost
10 Gbps Ethernet	1,000,000,000	÷	10,000,000,000	1
1 Gbps Ethernet	1,000,000,000	÷	1,000,000,000	1
100 Mbps Ethernet	1,000,000,000	÷	100,000,000	10
10 Mbps Ethernet	1,000,000,000	÷	10,000,000	100
1.544 Mbps Serial	1,000,000,000	÷	1,544,000	647
128 kbps Serial	1,000,000,000	÷	128,000	7812
64 kbps Serial	1,000,000,000	÷	64,000	15625

auto-cost reference-bandwidth 1000 command applied

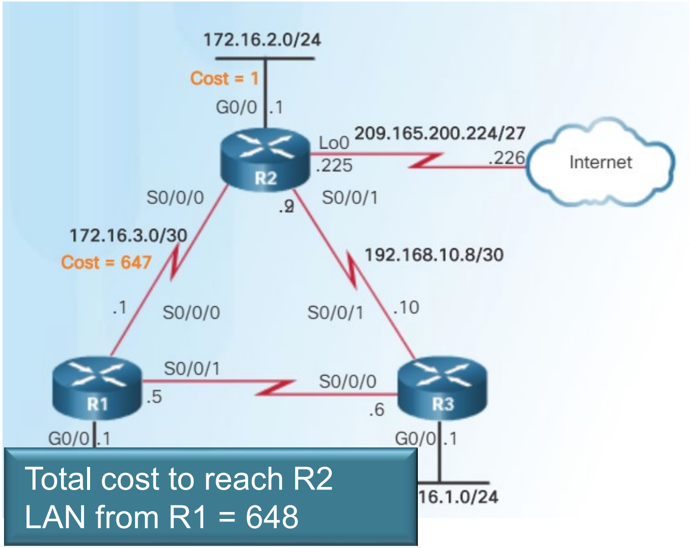
Interface Type	Reference Bandwidth in bps		Default Bandwidth in bps	Cost
10 Gbps Ethernet	10,000,000,000	÷	10,000,000,000	1
1 Gbps Ethernet	10,000,000,000	÷	1,000,000,000	10
100 Mbps Ethernet	10,000,000,000	÷	100,000,000	100
10 Mbps Ethernet	10,000,000,000	÷	10,000,000	1000
1.544 Mbps Serial	10,000,000,000	÷	1,544,000	6477
128 kbps Serial	10,000,000,000	÷	128,000	78126
64 kbps Serial	10,000,000,000	÷	64,000	156250

auto-cost reference-bandwidth 10000 command applied

OSPF Cost

Adjusting the Reference Bandwidth (Cont.)

- If the routers in the topology are adjusted to accommodate Gigabit links, the cost of the serial link is now 647 instead of 64. The total cost from R1 to the R2 LAN is now 648 instead of 65.
- If there were FastEthernet links in the topology, OSPF would make better choices.

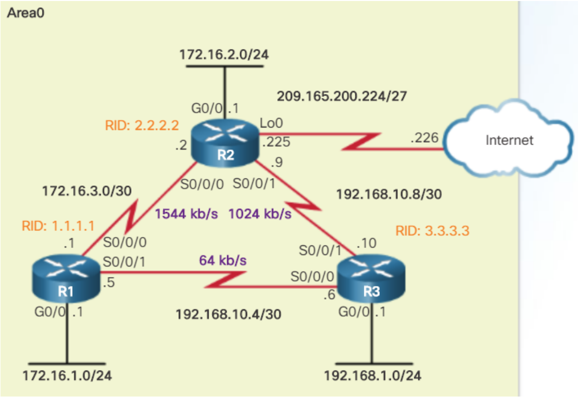



```
R1# show ip ospf interface serial 0/0/0
Serial0/0/0 is up, line protocol is up
  Internet Address 172.16.3.1/30,Area 0,Attached via Network Statement
  Process ID 10,Router ID 1.1.1.1,Network Type POINT_TO_POINT,Cost:647
  Topology-MTID    Cost    Disabled    Shutdown      Topology Name
        0          647       no          no             Base
```

```
R1# show ip route | include 172.16.2.0
O        172.16.2.0/24 [110/648] via 172.16.3.2, 00:06:03, Serial0/0/0
R1#
R1# show ip route 172.16.2.0
Routing entry for 172.16.2.0/24
  Known via "ospf 10", distance 110, metric 648, type intra area
  Last update from 172.16.3.2 on Serial0/0/0, 00:06:17 ago
  Routing Descriptor Blocks:
  * 172.16.3.2, from 2.2.2.2, 00:06:17 ago, via Serial0/0/0
      Route metric is 648, traffic share count is 1
```

Default Interface Bandwidth

- Bandwidth values defined on an interface do not change the capacity of the interface.
- Bandwidth values defined on an interface are used by the EIGRP and OSPF routing protocols to compute the metric.
- Serial links default to 1.544 Mbps and that might not be an accurate bandwidth for the transmission rate.
- Use the **show interfaces** command to see the interface bandwidth..




```
R1# show interfaces serial 0/0/0
Serial0/0/0 is up, line protocol is up
    Hardware is WIC MBRD Serial
    Description: Link to R2
    Internet address is 172.16.3.1/30
    MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
       reliability 255/255, txload 1/255, rxload 1/255
```

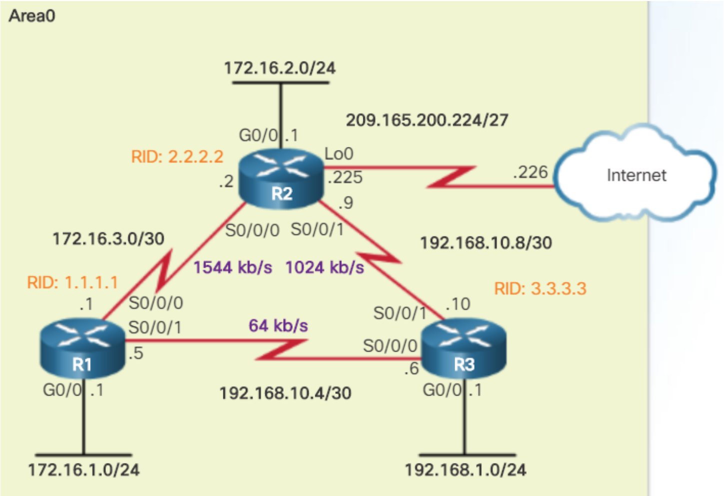
```
R1# show ip ospf interface serial 0/0/1
Serial0/0/1 is up, line protocol is up
    Internet Address 192.168.10.5/30, Area 0, Attached via
    Network Statement
    Process ID 10, Router ID 1.1.1.1, Network Type
    POINT_TO_POINT, Cost: 647
    Topology-MTID    Cost    Disabled    Shutdown    Topology Name
          0           647       no          no           Base
```

```
R1# show interfaces serial 0/0/1 | include BW
    MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
```

```
R1# show ip ospf interface serial 0/0/1 | include Cost:
    Process ID 10, Router ID 1.1.1.1, Network Type
POINT_TO_POINT, Cost: 647
```

OSPF Cost

Adjusting the Interface Bandwidth




```
R1(config)# int s0/0/1
R1(config-if)# bandwidth 64
R1(config-if)# end
R1#
*Mar 27 10:10:07.735: %SYS-5-CONFIG_I: Configured from console by c
R1#
R1#  show interfaces serial 0/0/1 | include BW
  MTU 1500 bytes, BW 64 Kbit/sec, DLY 20000 usec,
R1#
R1#  show ip ospf interface serial 0/0/1 | include Cost:
  Process ID 10, Router ID 1.1.1.1, Network Type
  POINT_TO_POINT, Cost: 15625
R1#
```

- The bandwidth must be adjusted at each end of the serial links, therefore:
  - R2 requires its S0/0/1 interface to be adjusted to 1,024 kb/s.
  - R3 requires its serial 0/0/0 to be adjusted to 64 kb/s and its serial 0/0/1 to be adjusted to 1,024 kb/s.
- Note: Command only modifies OSPF bandwidth metric. Does not modify the actual link bandwidth.

OSPF Cost

Manually Setting the OSPF Cost

- Instead of manually setting the interface bandwidth, the OSPF cost can be manually configured using the **ip ospf cost** *value* interface configuration mode command.

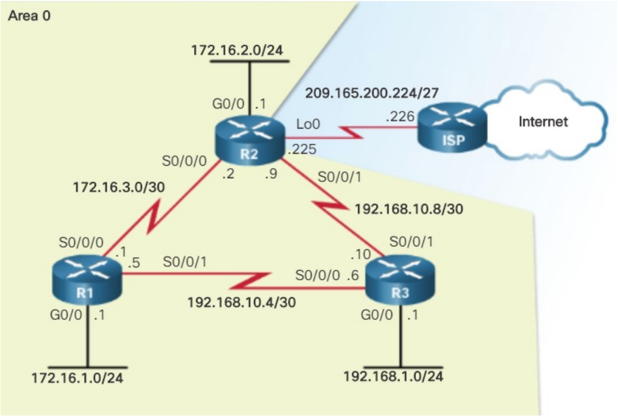
The **no bandwidth 64** is used to remove the command that was previously applied and reset the bandwidth back to the default.

```
R1(config)# int s0/0/1
R1(config-if)# no bandwidth 64
R1(config-if)# ip ospf cost 15625
R1(config-if)# end
R1#
R1# show interface serial 0/0/1 | include BW
    MTU 1500 bytes, BW 1544 Kbit/sec, DLY 20000 usec,
R1#
R1# show ip ospf interface serial 0/0/1 | include Cost:
    Process ID 10, Router ID 1.1.1.1, Network Type POINT_TO_POINT,
    Cost: 15625
```

Adjusting the Interface Bandwidth		Manually Setting the OSPF Cost
R1(config)# **interface S0/0/1** R1(config-if)# **bandwidth 64**	=	R1(config)# **interface S0/0/1** R1(config-if)# **ip ospf cost 15625**
R2(config)# **interface S0/0/1** R2(config-if)# **bandwidth 1024**	=	R2(config)# **interface S0/0/1** R2(config-if)# **ip ospf cost 976**
R3(config)# **interface S0/0/0** R3(config-if)# **bandwidth 64**	=	R3(config)# **interface S0/0/0** R3(config-if)# **ip ospf cost 15625**
R3(config)# **interface S0/0/1** R3(config-if)# **bandwidth 1024**	=	R3(config)# **interface S0/0/1** R3(config-if)# **ip ospf cost 976**

Verify OSPF Neighbors

- Use the **show ip ospf neighbor** to verify the router has formed an adjacency with a directly-connected router.



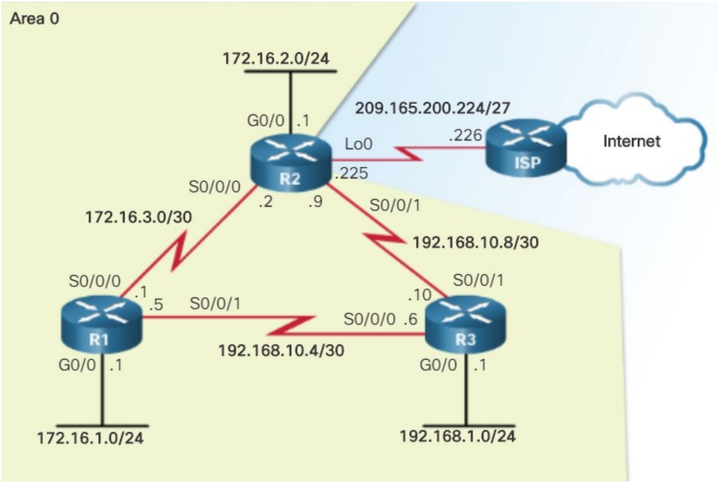

```
R1# show ip ospf neighbor

Neighbor ID  Pri State   Dead Time   Address        Interface
3.3.3.3        0 FULL/-  00:00:37    192.168.10.6   Serial0/0/1
2.2.2.2        0 FULL/-  00:00:30    172.16.3.2     Serial0/0/0
```

Output	Description
Neighbor ID	The router ID of the neighbor router
Pri	The OSPFv2 priority of the interface used in the DR/BDR election process
State	The OSPFv2 state – Full means that the link-state database has had the algorithm executed and the neighbor router and R1 have identical LSDBs. Ethernet multi-access interfaces may show as 2WAY. The dash indicates that no DR/BDR is required.
Dead time	Amount of time remaining before expecting to receive a hello packet from the neighbor before declaring the neighbor down. This value is reset when a hello packet is received.
Address	The address of the neighbor's directly-connected interface
Interface	The interface on R1 used to form an adjacency with the neighbor router

Verify OSPF Protocol Settings

- The **show ip protocols** command is used to verify the OSPFv2 process ID, router ID, networks being advertised by the router, neighbors that are sending OSPF updates, and the administrative distance (110 by default).




```
R1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 10"
  Outgoing update filter list for all interfaces is not
  set
  Incoming update filter list for all interfaces is not
  set
  Router ID 1.1.1.1
  Number of areas in this router is 1. 1 normal 0 stub 0
  nssa
  Maximum path: 4
  Routing for Networks:
    172.16.1.0 0.0.0.255 area 0
    172.16.3.0 0.0.0.3 area 0
    192.168.10.4 0.0.0.3 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
    2.2.2.2              110      00:17:18
    3.3.3.3              110      00:14:49
  Distance: (default is 110)
```

Verify OSPF Process Information

- The **show ip ospf** command is another way to see the OSPFv2 process ID and router ID.

```
R1# show ip ospf
Routing Process "ospf 10" with ID 1.1.1.1
Start time: 01:37:15.156, Time elapsed: 01:32:57.776
Supports only single TOS(TOS0) routes
Supports opaque LSA
Supports Link-local Signaling (LLS)
Supports area transit capability
Supports NSSA (compatible with RFC 3101)
Event-log enabled, Maximum number of events: 1000, Mode:
cyclic
Router is not originating router-LSAs with maximum metric
Initial SPF schedule delay 5000 msecs
Minimum hold time between two consecutive SPFs 10000 msecs
Maximum wait time between two consecutive SPFs 10000 msecs
Incremental-SPF disabled
Minimum LSA interval 5 secs
Minimum LSA arrival 1000 msecs
LSA group pacing timer 240 secs
Interface flood pacing timer 33 msecs
Retransmission pacing timer 66 msecs
Number of external LSA 0. Checksum Sum 0x000000
Number of opaque AS LSA 0. Checksum Sum 0x000000
Number of DCbitless external and opaque AS LSA 0
Number of DoNotAge external and opaque AS LSA 0
Number of areas in this router is 1. 1 normal 0 stub 0
nssa
```

```
Number of areas transit capable is 0
External flood list length 0
IETF NSF helper support enabled
Cisco NSF helper support enabled
Reference bandwidth unit is 1000 mbps
       Area BACKBONE(0)
       Number of interfaces in this area is 3
       Area has no authentication
       SPF algorithm last executed 01:30:45.364 ago
       SPF algorithm executed 3 times
       Area ranges are
       Number of LSA 3. Checksum Sum 0x02033A
       Number of opaque link LSA 0. Checksum Sum 0x000000
       Number of DCbitless LSA 0
       Number of indication LSA 0
       Number of DoNotAge LSA 0
       Flood list length 0
```

Verify OSPF Interface Settings

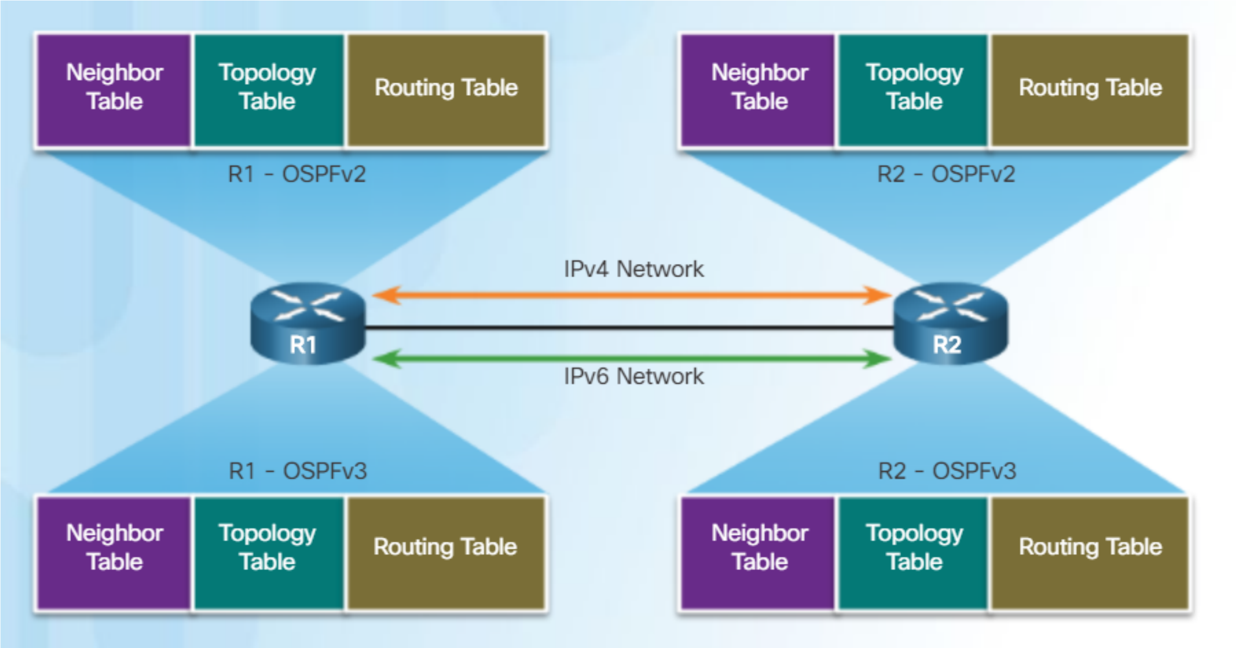
- Use the **show ip ospf interface** command to see details for every OSPFv2-enabled interface especially to see if the network statements were correctly composed.
- Use the **show ip ospf interface brief** command to see key information about OSPFv2-enabled interfaces on a particular router.

```
R1# show ip ospf interface brief
Interface   PID   Area   IP Address/Mask   Cost  State   Nbrs F/C
Se0/0/1     10    0      192.168.10.5/30   15625 P2P     1/1
Se0/0/0     10    0      172.16.3.1/30     647   P2P     1/1
Gi0/0       10    0      172.16.1.1/24     1     DR      0/0
```

8.3 Single-Area OSPFv3

OSPFv3

- OSPFv3 is used to exchange IPv6 prefixes and build an IPv6 routing table.
- OSPFv3 builds three OSPF tables – neighbor table, topology table, and routing table.



Similarities Between OSPFv2 and OSPFv3

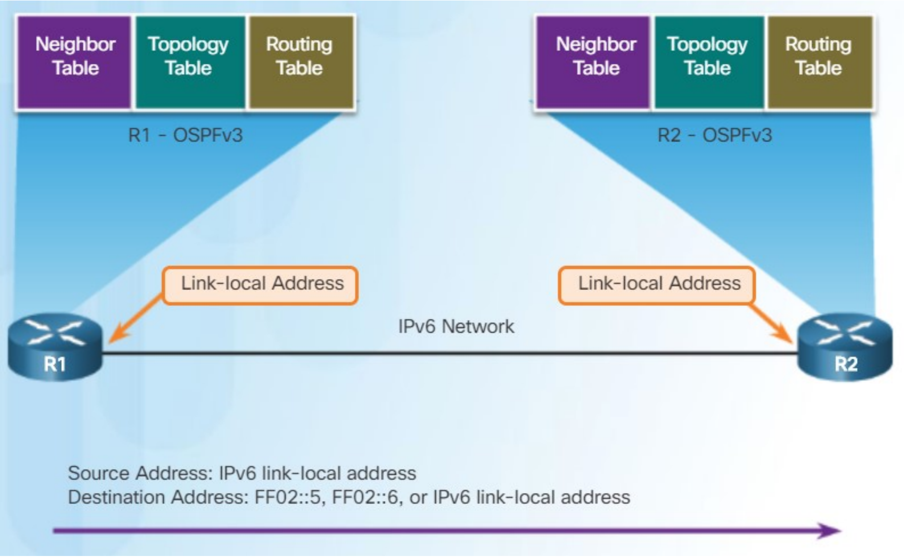
Feature	Comments
Link-State	Both are this type of routing protocol
Routing algorithm	Shortest Path First (SPF)
Metric	Cost
Areas	Both use and support a two-level hierarchy with areas connecting to Area 0
Packet types	Both use the same Hello, DBD, LSR, LSU, and LSAck packets
Neighbor discovery	Transitions through the same states using Hello packets
DR/BDR	Function and election process is the same
Router ID	Both use a 32-bit router ID; determined by the same process

Differences Between OSPFv2 and OSPFv3

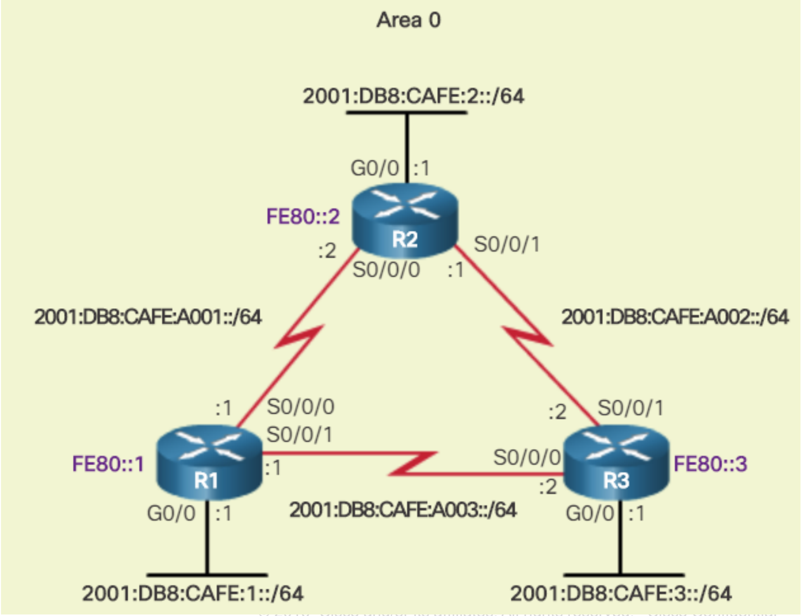
Feature	OSPFv2	OSPFv3
Advertisements	IPv4 networks	IPv6 prefixes
Source address	IPv4 source address	IPv6 link-local address
Destination address	Choice of: • Neighbor IPv4 unicast address • 224.0.0.5 all-OSPF-routers multicast address • 224.0.0.6 DR/BDR multicast address	Choice of: • Neighbor IPv6 link-local address • FF02::5 all-OSPF-routers multicast address • FF02::6 DR/BDR multicast address
Advertise networks	Configured using the **network** router configuration command	Configured using the **ipv6 ospf** *process-id* **area** *area-id* interface configuration command
IP unicast routing	IPv4 unicast routing is enabled by default	IPv6 unicast forwarding is not enabled by default. Use the **ipv6 unicast-routing** global configuration command to enable.
Authentication	Plain text and MD5	IPv6 authentication (IPsec)

Link-Local Addresses

- An IPv6-link-local address enables a device to communicate with other IPv6-enabled devices on the same link and only on that link (subnet).
  - Packets with a source or destination link-local address cannot be routed beyond the link from where the packet originated.
- IPv6 link-local address are used to exchange OSPFv3 messages



The FE80 address on each router represents the link-local address assigned to each router.



Configuring OSPFv3

Link-Local Addresses

- Verify IPv6 addresses on interfaces.
- Remember that link-local addresses are automatically created when an IPv6 global unicast address is assigned to an interface. However, IPv6 global unicast addresses are not required. Link-local addresses are required for OSPFv3.
- Unless configured manually, Cisco routers create a link-local address using FE80::/10 prefix and the EUI-64 process by manipulating the 48-bit Ethernet MAC address.
- Manually configuring link-local addresses make it easier to manage and verify OSPFv3 configurations.
  - Use the **ipv6 address link-local** interface command to apply.
  - Use the **show ipv6 interface brief** command to verify.

```
R1# show ipv6 interface brief
Em0/0                      [administratively down/down]
    unassigned
GigabitEthernet0/0         [up/up]
    FE80::32F7:DFF:FEA3:DA0
    2001:DB8:CAFE:1::1
GigabitEthernet0/1         [administratively down/down]
    unassigned
Serial0/0/0                [up/up]
    FE80::32F7:DFF:FEA3:DA0
    2001:DB8:CAFE:A001::1
Serial0/0/1                [up/up]
    FE80::32F7:DFF:FEA3:DA0
    2001:DB8:CAFE:A003::1
```

```
R1(config)# interface GigabitEthernet 0/0
R1(config-if)# ipv6 address fe80::1 link-local
R1(config-if)# exit
R1(config)# interface Serial0/0/0
R1(config-if)# ipv6 address fe80::1 link-local
R1(config-if)# exit
R1(config)# interface Serial0/0/1
R1(config-if)# ipv6 address fe80::1 link-local
```

```
R1# show ipv6 interface brief
Em0/0                      [administratively down/down]
    unassigned
GigabitEthernet0/0         [up/up]
    FE80::1
    2001:DB8:CAFE:1::1
GigabitEthernet0/1         [administratively down/down]
    unassigned
Serial0/0/0                [up/up]
    FE80::1
    2001:DB8:CAFE:A001::1
Serial0/0/1                [up/up]
```

OSPFv3 Network Topology

Steps to Configure OSPFv3

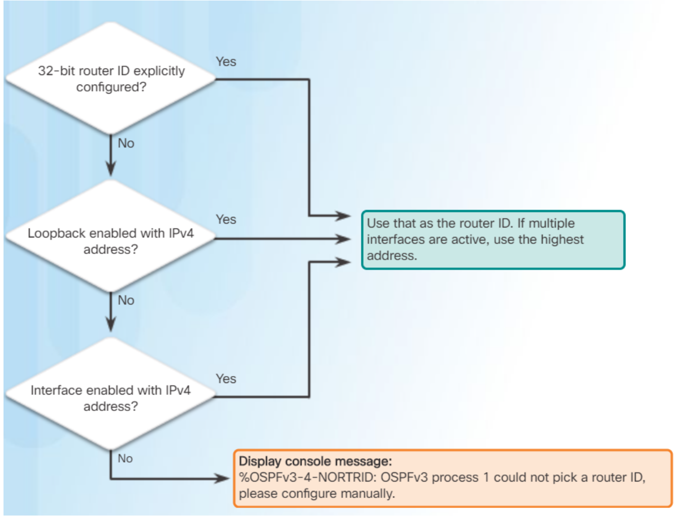
1. Enable IPv6 unicast routing in global configuration mode – **ipv6 unicast-routing**
2. (Optional) Configure link-local addresses.
3. Configure a 32-bit router ID in OSPFv3 router configuration mode – **router-id** *rid*
4. Configure optional routing specifics such as adjusting the reference bandwidth.
5. (Optional, but optimum) Configure OSPFv3 interface specific settings such as setting the interface bandwidth on serial links.
6. Enable OSPFv3 routing in interface configuration mode – **ipv6 ospf area**

Be sure to turn on IPv6 routing and assign IPv6 addresses to interfaces before enabling OSPFv3.

```
R1(config)# ipv6 unicast-routing
R1(config)#
R1(config)# interface GigabitEthernet 0/0
R1(config-if)# description R1 LAN
R1(config-if)# ipv6 address 2001:DB8:CAFE:1::1/64
R1(config-if)# no shut
R1(config-if)#
R1(config-if)# interface Serial0/0/0
R1(config-if)# description Link to R2
R1(config-if)# ipv6 address 2001:DB8:CAFE:A001::1/64
R1(config-if)# clock rate 128000
R1(config-if)# no shut
R1(config-if)#
R1(config-if)# interface Serial0/0/1
R1(config-if)# description Link to R3
R1(config-if)# ipv6 address 2001:DB8:CAFE:A003::1/64
R1(config-if)# no shut
```

Configuring the OSPFv3 Router ID

- Use the **ipv6 router ospf** *process-id* global configuration command to enter router configuration mode.
- Use the **router-id** *rid* command in router configuration mode to assign a router ID and use the **show ipv6 protocols** command to verify.



Same process as OSPFv2

```
R1(config)# ipv6 router ospf 10
R1(config-rtr)#
*Mar 29 11:21:53.739: %OSPFv3-4-NORTRID: Process OSPFv3-1-
IPv6 could not pick a router-id, please configure manually
R1(config-rtr)#
R1(config-rtr)# router-id 1.1.1.1
R1(config-rtr)#
R1(config-rtr)# auto-cost reference-bandwidth 1000
% OSPFv3-1-IPv6:  Reference bandwidth is changed. Please
ensure reference bandwidth is consistent across all routers.
R1(config-rtr)#
R1(config-rtr)# end
R1#
R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "ospf 10"
  Router ID 1.1.1.1
  Number of areas: 0 normal, 0 stub, 0 nssa
  Redistribution:
    None
```

Notice the message

Modifying an OSPFv3 Router ID

- Use the **clear ipv6 ospf process** privileged EXEC mode command after changing the router ID to complete the router ID change and force a router to renegotiate neighbor adjacencies using the new router ID.

Commonly forgotten step

```
R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "ospf 10"
  Router ID 10.1.1.1
  Number of areas: 0 normal, 0 stub, 0 nssa
  Redistribution:
   None
```

Original router ID

```
R1(config)# ipv6 router ospf 10
R1(config-rtr)# router-id 1.1.1.1
R1(config-rtr)# end
R1#
```

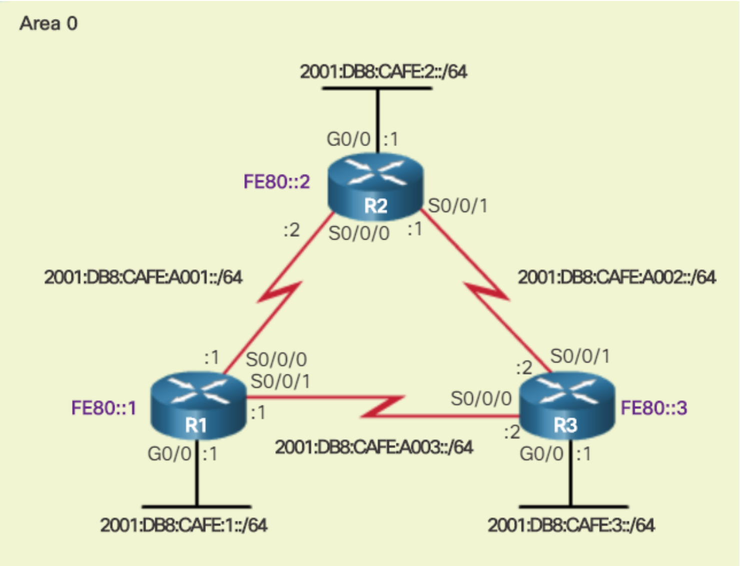
Change the router ID.

```
R1# clear ipv6 ospf process
Reset selected OSPFv3 processes? [no]: y
R1#
R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "ospf 10"
  Router ID 1.1.1.1
  Number of areas: 0 normal, 0 stub, 0 nssa
  Redistribution:
    None
```

Complete the router ID change.

Enabling OSPFv3 on Interfaces

- Use the **ipv6 ospf area** interface configuration mode command to enable OSPFv3 on a specific interface. Ensure the interface is within an OSPF area.
- Use the **show ipv6 ospf interfaces brief** command to verify.




```
R1(config)# interface GigabitEthernet 0/0
R1(config-if)# ipv6 ospf 10 area 0
R1(config-if)#
R1(config-if)# interface Serial0/0/0
R1(config-if)# ipv6 ospf 10 area 0
R1(config-if)#
R1(config-if)# interface Serial0/0/1
R1(config-if)# ipv6 ospf 10 area 0
R1(config-if)#
R1(config-if)# end
R1#
R1# show ipv6 ospf interfaces brief
Interface   PID   Area     Intf ID   Cost    State   Nbrs F/C
Se0/0/1     10     0          7      15625   P2P     0/0
Se0/0/0     10     0          6      647     P2P     0/0
Gi0/0       10     0          3        1     WAIT    0/0
R1#
```

Verifying OSPFv3

- Use the **show ipv6 ospf neighbor** command to verify neighbor connectivity with directly-connected routers.

```
R1# show ipv6 ospf neighbor

OSPFv3 Router with ID (1.1.1.1) (Process ID 10)

Neighbor ID     Pri   State      Dead Time    Interface ID Interface
3.3.3.3           0   FULL/  -   00:00:39     6            Serial0/0/1
2.2.2.2           0   FULL/  -   00:00:36     6            Serial0/0/0
```

- Use the **show ipv6 protocols** command to verify vital OSPFv3 configuration information.

```
R1# show ipv6 protocols
IPv6 Routing Protocol is "connected"
IPv6 Routing Protocol is "ND"
IPv6 Routing Protocol is "ospf 10"
 Router ID 1.1.1.1
 Number of areas: 1 normal, 0 stub, 0 nssa
 Interfaces (Area 0):
   Serial0/0/1
   Serial0/0/0
   GigabitEthernet0/0
```

- Use the **show ipv6 ospf interface** command to display a detailed list for every OSPFv3-enabled interface.
- The **show ipv6 ospf interface brief** command is an easier output to verify which interfaces are being used with OSPFv3.

```
R1# show ipv6 ospf interface brief
Interface    PID   Area            Intf ID    Cost  State Nbrs F/C
Se0/0/1      10    0               7          15625 P2P   1/1
Se0/0/0      10    0               6          647   P2P   1/1
Gi0/0        10    0               3          1     DR    0/0
```

Verify The IPv6 Routing Table

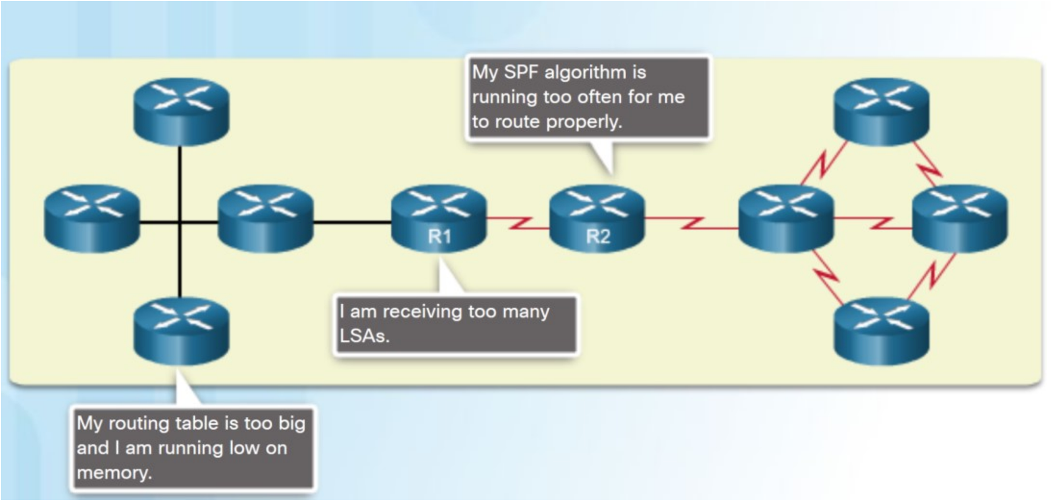
- Use the **show ipv6 route** command to see an IPv6 routing table.
- Use the **show ipv6 route ospf** command to see just the OSPFv3 routes.

```
R1# show ipv6 route ospf
IPv6 Routing Table - default - 10 entries
Codes:C - Connected, L - Local, S - Static, U - Per-user Static route
      B - BGP, R - RIP, H - NHRP, I1 - ISIS L1
      I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary, D - EIGRP
      EX - EIGRP external, ND - ND Default, NDp - ND Prefix, DCE - Destination
      NDr - Redirect, O - OSPF Intra, OI - OSPF Inter, OE1 - OSPF ext 1
     OE2 - OSPF ext 2, ON1 - OSPF NSSA ext 1, ON2 - OSPF NSSA ext 2
 O   2001:DB8:CAFE:2::/64 [110/657]
     via FE80::2, Serial0/0/0
 O   2001:DB8:CAFE:3::/64 [110/1304]
     via FE80::2, Serial0/0/0
 O   2001:DB8:CAFE:A002::/64 [110/1294]
     via FE80::2, Serial0/0/0
```

9.1 Multiarea OSPF

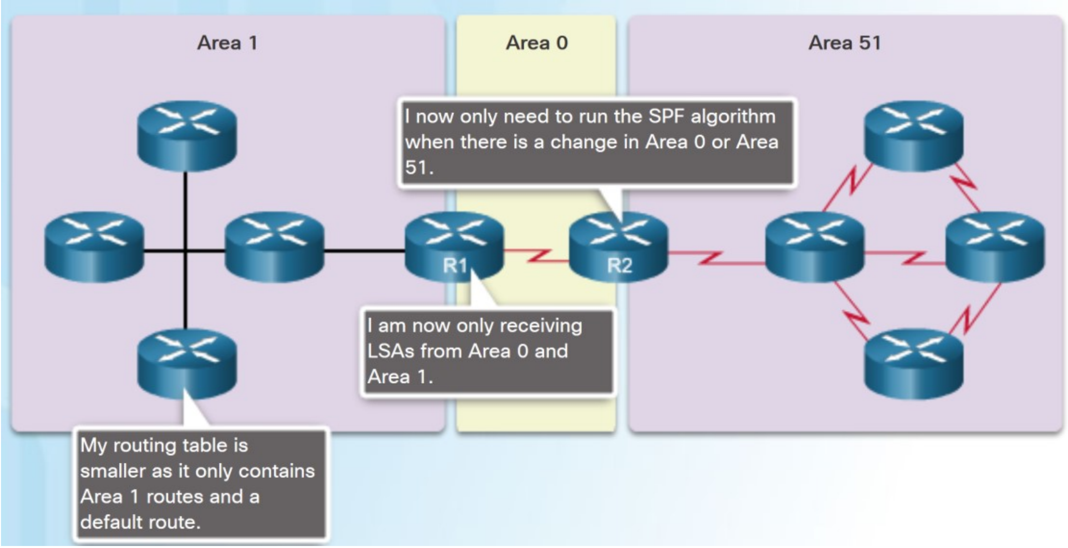
Single-Area OSPF

- Issues in a large single area OSPF:
  - Large routing table
  - Large link-state database (LSDB)
  - Frequent SPF algorithm calculations
- To make OSPF more efficient and scalable, OSPF supports hierarchical routing using areas.

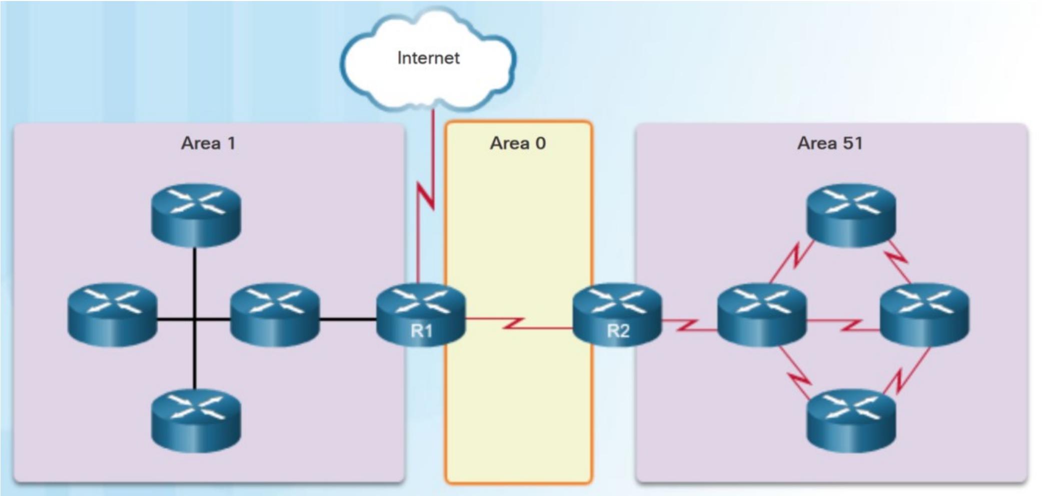


Multiarea OSPF

- Multiarea OSPF:
  - Large OSPF area is divided into smaller areas.
  - Reduces processing and memory overhead.
  - Requires a hierarchical network design.
  - The main area is the backbone area (area 0) and all other areas connect to it.
- Advantages of Multiarea OSPF:
  - Smaller routing tables - Fewer routing table entries as network addresses can be summarized between areas.
  - Reduced link-state update overhead.
  - Reduced frequency of SPF calculations.

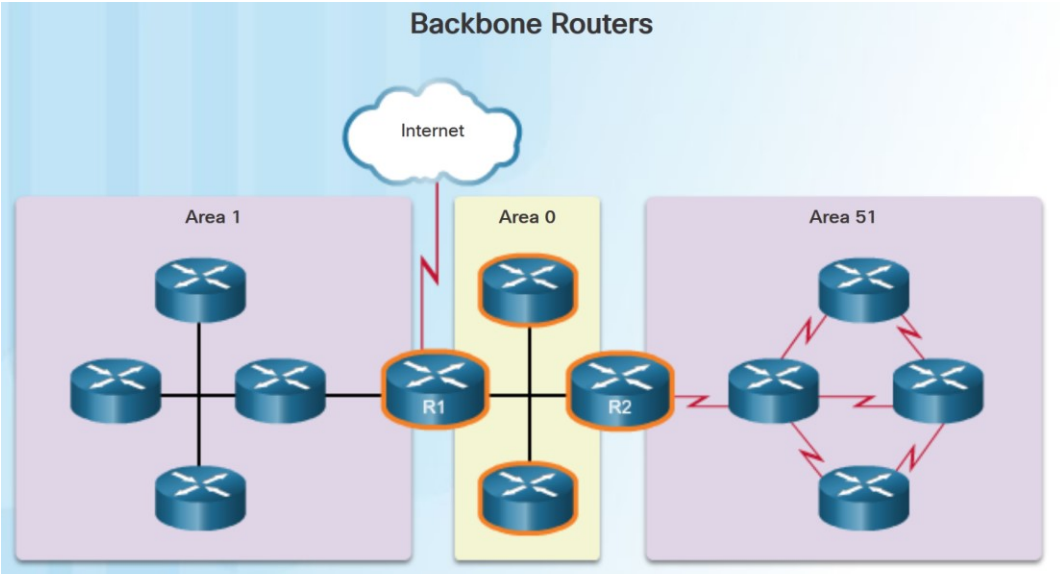


OSPF Two-Layer Area Hierarchy



- Multiarea OSPF is implemented in a two-layer area hierarchy.
- Backbone (Transit) area - An OSPF area whose primary function is the fast and efficient movement of IP packets:
  - Interconnects with other OSPF area types.
  - Also called OSPF area 0.
- Regular (nonbackbone) area - Connects users and resources:
  - Usually set up along functional or geographical groupings
  - All traffic from other areas must cross a transit area.

Types of OSPF Routers

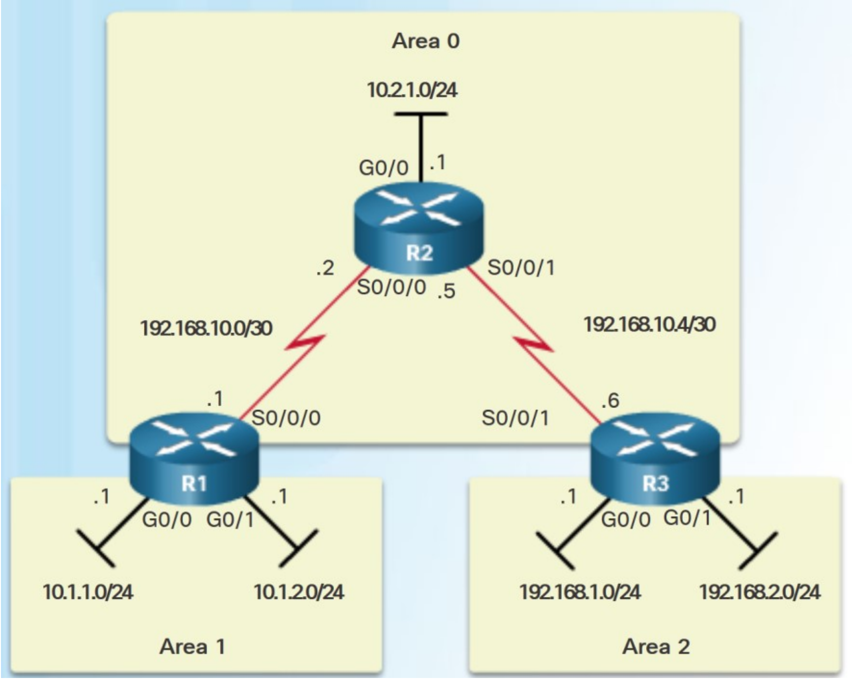


- There are four different types of OSPF routers:
  - Internal router –A router that has all of its interfaces in the same area.
  - Backbone router - A router in the backbone area. The backbone area is set to area 0
  - Area Border Router (ABR) – A router that has interfaces attached to multiple areas.
  - Autonomous System Boundary Router (ASBR) – A router that has at least one interface attached to an external internetwork.
- A router can be classified as more than one router type.

Implementing Multiarea OSPF

- There are 4 steps to implementing multiarea OSPF:
  - Step 1. Gather the network requirements and parameters
  - Step 2. Define the OSPF parameters
    - Single area or multiarea OSPF?
    - IP addressing plan
    - OSPF areas
    - Network topology
  - Step 3. Configure the multiarea OSPF implementation based on the parameters.
  - Step 4. Verify the multiarea OSPF implementation

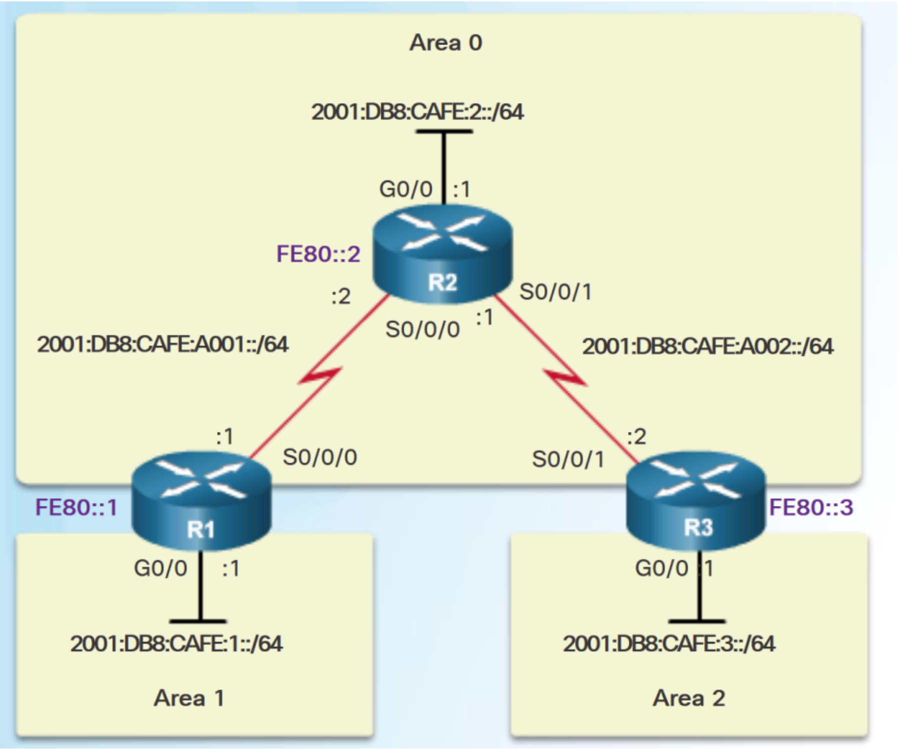
Configuring Multiarea OSPFv2




```
R1(config)# router ospf 10
R1(config-router)# router-id 1.1.1.1
R1(config-router)# network 10.1.1.1 0.0.0.0 area 1
R1(config-router)# network 10.1.2.1 0.0.0.0 area 1
R1(config-router)# network 192.168.10.1 0.0.0.0 area 0
R1(config-router)# end
R1#
```

- There are no special commands to implement multiarea OSPFv2.
- A router becomes an ABR when it has two network statements in different areas.
- R1 is an ABR because it has interfaces in area 1 and an interface in area 0.

Configuring Multiarea OSPFv3




```
R1(config)# ipv6 router ospf 10
R1(config-rtr)# router-id 1.1.1.1
R1(config-rtr)# exit
R1(config)#
R1(config)# interface GigabitEthernet 0/0
R1(config-if)# ipv6 ospf 10 area 1
R1(config-if)#
R1(config-if)# interface Serial0/0/0
R1(config-if)# ipv6 ospf 10 area 0
R1(config-if)# end
R1#
```

- There are no special commands required to implement multiarea OSPFv3.
- A router becomes an ABR when it has two interfaces in different areas.

