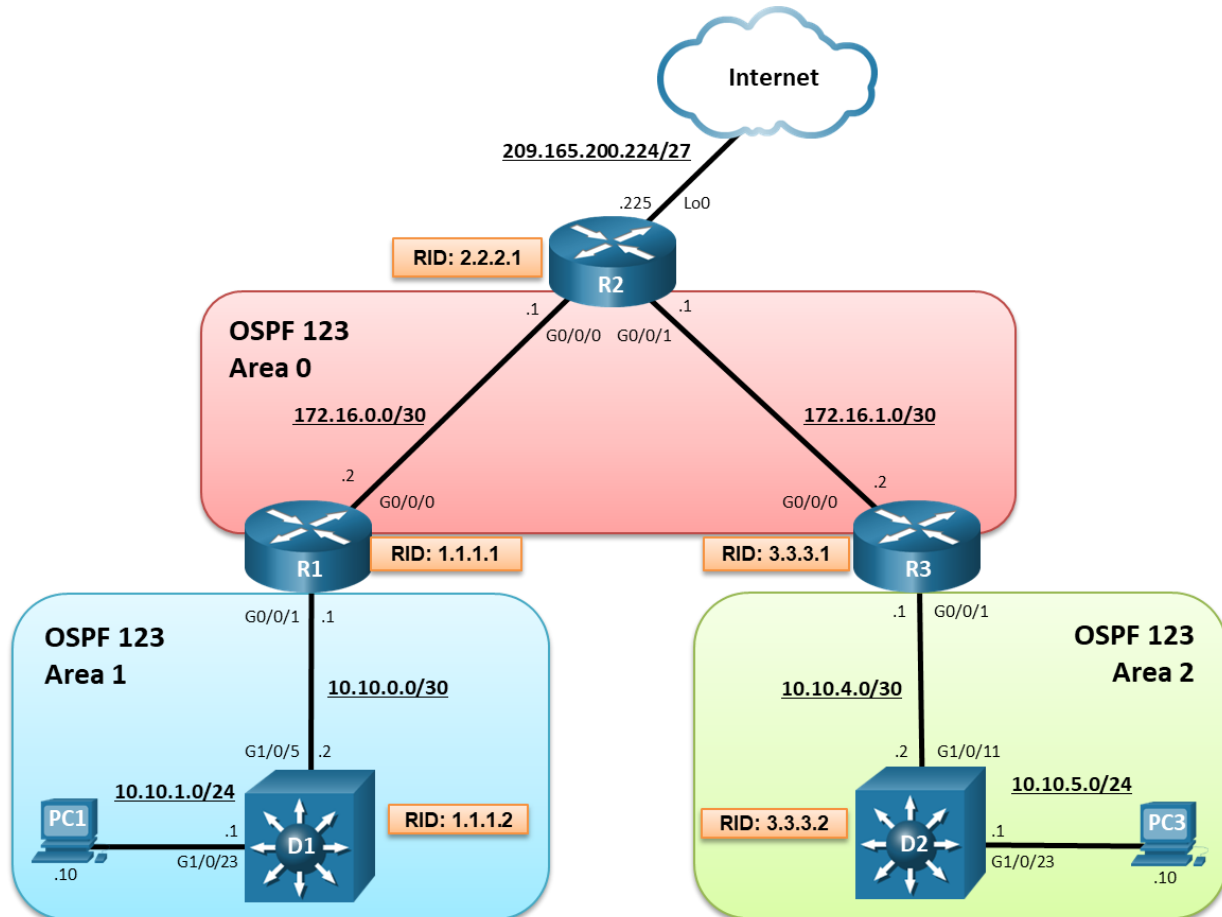# Lab - Implement Multi-Area OSPFv2 (Instructor Version)

Instructor Note: Red font color or gray highlights indicate text that appears in the instructor copy only.

Answers: 9.1.2 Lab - Implement Multi-Area OSPFv2

Topology

Addressing Table

Device	Interface	IPv4 Address
R1	G0/0/0	172.16.0.2/30
	G0/0/1	10.10.0.1/30
R2	Lo0	209.165.200.225/27
	G0/0/0	172.16.0.1/30
	G0/0/1	172.16.1.1/30

Device	Interface	IPv4 Address
R3	G0/0/0	172.16.1.2/30
	G0/0/1	10.10.4.1/30
D1	G1/0/11	10.10.0.2/30
	G1/0/23	10.10.1.1/24
D2	G1/0/11	10.10.4.2/30
	G1/0/23	10.10.5.1/24
PC1	NIC	10.10.1.10/24
PC2	NIC	10.10.5.10/24

Objectives

Part 1: Build the Network and Configure Basic Device Settings and Interface Addressing

Part 2: Configure and Verify Multiarea OSPF for IPv4 on R1, D1, and D2

Part 3: Exploring Link State Announcements

Background / Scenario

To make OSPF more efficient and scalable, OSPF supports hierarchical routing using the areas. An OSPF area is a group of routers that share the same link-state information in their link-state databases (LSDBs). When a large OSPF area is divided into smaller areas, it is called multiarea OSPF. Multi-area OSPF is useful in larger network deployments to reduce processing and memory overhead.

In this lab you will configure multiarea OSPF version 2 for IPv4. This lab was specifically designed to use three routers and two Layer 3 switches.

Note: This lab is an exercise in developing, deploying, and verifying how multiarea OSPF operates and does not reflect networking best practices.

Note: The routers used with this CCNP hands-on lab is a Cisco 4221and the two Layer 3 switches are Catalyst 3560 switches. Other routers and Layer 3 switches and Cisco IOS versions can be used. Depending on the model and Cisco IOS version, the commands available and the output produced might vary from what is shown in the labs.

Note: Ensure that the routers and switches have been erased and have no startup configurations. If you are unsure contact your instructor.

Instructor Note: Refer to the Instructor Lab Manual for the procedures to initialize and reload devices.

Required Resources

- 3 Routers (Cisco 4221 with Cisco IOS XE Release 16.9.4 universal image or comparable)
- 2 Switches (Cisco 3650 with Cisco IOS XE Release 16.9.4 universal image or comparable)
- 2 PCs (Windows with terminal emulation program, such as Tera Term)
- Console cables to configure the Cisco IOS devices via the console ports
- Ethernet cables as shown in the topology

Instructions

Part 1: Build the Network and Configure Basic Device Settings and Interface Addressing

In Part 1, you will set up the network topology and configure basic settings and interface addressing on the routers and Layer 3 switches.

Step 1: Cable the network as shown in the topology.

Attach the devices as shown in the topology diagram, and cable as necessary.

Step 2: Configure basic settings for the routers and switches.

a. Console into each router and Layer 3 switch, enter global configuration mode, and apply the basic settings and interface addressing using the following startup configurations for each device.

Router R1

```
hostname R1
no ip domain lookup
line con 0
 logging sync
 exec-time 0 0
 exit
banner motd # This is R1, Implement Multi-Area OSPFv2 Lab #
interface g0/0/0
 ip add 172.16.0.2 255.255.255.252
 no shut
 exit
interface GigabitEthernet0/0/1
 ip address 10.10.0.1 255.255.255.252
 no shut
 exit
```

Router R2

```
hostname R2
no ip domain lookup
line con 0
logging sync
exec-time 0 0
exit
banner motd # This is R2, Implement Multi-Area OSPFv2 Lab #
interface g0/0/0
 ip add 172.16.0.1 255.255.255.252
 no shut
 exit
interface GigabitEthernet0/0/1
 ip address 172.16.1.1 255.255.255.252
 no shut
```

```
 exit
interface lo0
 ip add 209.165.200.225 255.255.255.224
 exit
```

Router R3

```
hostname R3
no ip domain lookup
line con 0
 logging sync
 exec-time 0 0
 exit
banner motd # This is R3, Implement Multi-Area OSPFv2 Lab #
interface g0/0/0
 ip add 172.16.1.2 255.255.255.252
 no shut
 exit
interface GigabitEthernet0/0/1
 ip address 10.10.4.1 255.255.255.252
 no shut
 exit
```

Switch D1

```
hostname D1
no ip domain lookup
line con 0
exec-timeout 0 0
logging synchronous
exit
banner motd # This is D1, Implement Multi-Area OSPFv2 Lab #
interface g1/0/11
 no switchport
 ip address 10.10.0.2 255.255.255.252
 no shut
 exit
interface g1/0/23
 no switchport
 ip address 10.10.1.1 255.255.255.0
 no shut
 exit
```

Switch D2

```
hostname D2
no ip domain lookup
line con 0
 logging sync
 exec-time 0 0
```

```
 exit
banner motd # This is D2, Implement Multi-Area OSPFv2 Lab #
interface g1/0/11
 no switchport
 ip address 10.10.4.2 255.255.255.252
 no shut
 exit
interface g1/0/23
 no switchport
 ip address 10.10.5.1 255.255.255.0
 no shut
 exit
```

b. Save the running configuration to startup-config.

c. Verify the interface status using the **show ip interface brief** command.

```
R1# show ip interface brief | include manual
GigabitEthernet0/0/0   172.16.0.2      YES manual up                 up
GigabitEthernet0/0/1   10.10.0.1       YES manual up                 up


R2# show ip interface brief | include manual
GigabitEthernet0/0/0   172.16.0.1      YES manual up                 up
GigabitEthernet0/0/1   172.16.1.1      YES manual up                 up
Loopback0              209.165.200.225 YES manual up                 up


R3# show ip interface brief | include manual
GigabitEthernet0/0/0   172.16.1.2      YES manual up                 up
GigabitEthernet0/0/1   10.10.4.1       YES manual up                 up


D1# show ip interface brief | include manual
GigabitEthernet1/0/11  10.10.0.2       YES manual up                 up
GigabitEthernet1/0/23  10.10.1.1       YES manual up                 up


D2# show ip interface brief | include manual
GigabitEthernet1/0/11  10.10.4.2       YES manual up                 up
GigabitEthernet1/0/23  10.10.5.1       YES manual up                 up
```

d. Verify direct connectivity between all five devices. R1 is shown as an example.

```
R1# ping 10.10.0.2
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.10.0.2, timeout is 2 seconds:
..!!!
Success rate is 60 percent (3/5), round-trip min/avg/max = 2/2/2 ms


R1# ping 172.16.0.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.0.1, timeout is 2 seconds:
.!!!!
Success rate is 80 percent (4/5), round-trip min/avg/max = 1/1/1 ms
```

All five devices should be able to reach the other directly connected networks. Troubleshoot if necessary.

Part 2: Configure Multiarea OSPFv2

In this part, you will implement multiarea OSPF. Multiarea OSPF defines a two-layer area hierarchy using a backbone area interconnecting regular areas. This is useful in larger network deployments to reduce processing and memory overhead.

In this topology, OSPF has the following three areas defined:

- **Area 0** – The backbone area. All regular areas should connect to the backbone area.

- **Area 1** and **Area 2** – Regular OSPF areas that connect to the backbone area.

The routers and switches in the topology are used in the following roles:

- **Internal routers** - R2 is an internal router in Area 0, D1 is internal in Area 1, and D2 is internal in Area 2.

- **Backbone routers** - R1, R2, and R3 are backbone routers as they all have interfaces in Area 0.

- **Area Border routers (ABRs)** – R1 and R3 are ABRs because they connect regular areas (i.e., Area 1 and Area 2) to the backbone Area 0.

- **Autonomous System Boundary router (ASBR)** – R2 is an ASBR because it connects to another non-OSPF network.

Recall that OSPF can be enabled using the traditional **network** router configuration command or by using the **ip ospf** *process-id* **area** *area-id* interface configuration command. Although the interface method is simpler, the OSPF routing configuration commands are applied to individual interfaces and not conveniently found in a central location. Therefore, in this lab, we will implement multiarea OSPF using wildcard masks.

You will now configure multiarea OSPF on all five devices starting with D1. You will also configure router IDs, reference bandwidths, and default route propagation.

Note: The verification output displayed in the following part assumes that the devices have been configured in the prescribed order. The output will vary if all devices are configured simultaneously.

Step 1: Implement OSPF on D1 using wildcard masks.

D1 will advertise its OSPF networks using the **network** router configuration command and wildcard masks. D1 is an internal router in Area 1. Therefore, both **network** commands will be configured for Area 1.

a. Layer 3 switches are not enabled to perform routing by default. Therefore, routing must be enabled using the **ip routing** global configuration command.

```
D1(config)# ip routing
```

b. Next, enter the OSPF router configuration mode using process ID 123, assign D1 the router ID 1.1.1.2. You will also set the reference bandwidth to distinguish between Gigabit Ethernet and FastEthernet interfaces. Changing the reference bandwidth to a higher value allows for a differentiation of cost between higher-speed interfaces.

```
D1(config)# router ospf 123
D1(config-router)# router-id 1.1.1.2
D1(config-router)# auto-cost reference-bandwidth 1000
% OSPF: Reference bandwidth is changed.
        Please ensure reference bandwidth is consistent across all routers.
```

Note: Setting the reference cost value too high may cause issues with low-bandwidth interfaces.

c. Configure D1 to advertise the FastEthernet 0/5 interface 10.10.0.0/30 network in OSPF Area 1. The wildcard mask can be calculated by deducting the subnet mask (i.e., /30 = 255.255.255.252) from 255.255.255.255, resulting in a wildcard mask of **0.0.0.3**.

```
D1(config-router)# network 10.10.0.0 0.0.0.3 area 1
```

d. Next, configure D1 to advertise its Fa0/23 interface 10.10.1.0/24 network in OSPF Area 1 and return to privileged EXEC mode.

```
D1(config-router)# network 10.10.1.0 0.0.0.255 area 1
D1(config-router)# end
```

e. Verify the OSPF configuration on D1 using the **show ip protocols** command.

```
D1# show ip protocols
*** IP Routing is NSF aware ***

Routing Protocol is "ospf 123"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 1.1.1.2
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.10.0.0 0.0.0.3 area 1
    10.10.1.0 0.0.0.255 area 1
  Routing Information Sources:
    Gateway         Distance      Last Update
  Distance: (default is 110)
```

The output confirms the router ID, and the number of areas, and the networks advertised. Notice there are no Routing Information Sources because there are no OSPF neighbors.

f. Verify the OSPF interfaces using the **show ip ospf interface brief** command.

```
D1# show ip ospf interface brief
Interface   PID   Area            IP Address/Mask   Cost  State Nbrs F/C
Gi1/0/23    123   1               10.10.1.1/24      10    DR    0/0
Gi1/0/11    123   1               10.10.0.2/30      10    DR    0/0
```

The output confirms that both G1/0/11 and G1/0/23 interfaces were correctly assigned to Area 1.

g. Finally, verify the OSPF routes in the routing table using the **show ip route ospf** command.

```
D1# show ip route ospf
```

Notice that no routes are displayed. This is because D1 does not yet have an OSPF neighbor.

Step 2: Implement OSPF on R1.

Next, configure R1. R1 is an ABR with an interface in Area 1 and the other interface in the backbone.

a. Enter the OSPF router configuration mode using process ID 123, assign R1 the router ID 1.1.1.1, and set the reference bandwidth to distinguish between Gigabit Ethernet and FastEthernet interfaces.

```
R1(config)# router ospf 123
R1(config-router)# router-id 1.1.1.1
R1(config-router)# auto-cost reference-bandwidth 1000
% OSPF: Reference bandwidth is changed.
        Please ensure reference bandwidth is consistent across all routers.
```

b. Configure R1 to advertise the G0/0/0 interface 172.16.0.0/30 network in OSPF Area 0.

```
R1(config-router)# network 172.16.0.0 0.0.0.3 area 0
```

c. Advertise the G0/0/1 interface 10.10.0.0/30 network in OSPF Area 1 and return to privileged EXEC mode.

```
R1(config-router)# network 10.10.0.0 0.0.0.3 area 1
R1(config-router)# end
*Jan  4 11:55:32.064: %OSPF-5-ADJCHG: Process 123, Nbr 1.1.1.2 on GigabitEthernet0/0/1
from LOADING to FULL, Loading Done
```

Notice the informational message stating that a neighbor adjacency has been established with D1 (i.e., 1.1.1.2).

d. Verify the OSPF configuration on R1 using the **show ip protocols** command.

```
R1# show ip protocols | begin ospf
Routing Protocol is "ospf 123"
  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
  It is an area border router
  Number of areas in this router is 2. 2 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.10.0.0 0.0.0.3 area 1
    172.16.0.0 0.0.0.3 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
    1.1.1.2              110       00:07:55
  Distance: (default is 110)
```

Like the previous output of D1, this output confirms the router ID, and the networks advertised. However, notice that it also explicitly states that R1 is an area border router (ABR), that it is in two areas, and that it has established an adjacency and exchanged routing information with D2 (i.e., 1.1.1.2).

e. Verify that the reference bandwidth has been changed using the **show ip ospf | begin Ref** command.

```
R1# show ip ospf | begin Ref
 Reference bandwidth unit is 1000 mbps
    Area BACKBONE(0) (Inactive)
        Number of interfaces in this area is 1
        Area has no authentication
        SPF algorithm last executed 00:14:41.606 ago
        SPF algorithm executed 2 times
        Area ranges are
        Number of LSA 3. Checksum Sum 0x01ABED
        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
    Area 1
        Number of interfaces in this area is 1
        Area has no authentication
        SPF algorithm last executed 00:15:07.141 ago
```

```
SPF algorithm executed 5 times
Area ranges are
Number of LSA 4. Checksum Sum 0x0292B8
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
```

The output confirms that the reference bandwidth has been changed to distinguish GigabitEthernet interfaces. The output also confirms that R1 is in two areas and has two link-state databases (LSDBs).

Note: Area 0 is currently inactive because there are no other peers configured yet.

f. Verify the active OSPF interfaces and assigned areas using the **show ip ospf interface brief** command.

```
R1# show ip ospf interface brief
Interface    PID    Area             IP Address/Mask    Cost  State Nbrs F/C
Gi0/0/0      123    0                172.16.0.2/30      1     DR    0/0
Gi0/0/1      123    1                10.10.0.1/30       1     BDR   1/1
```

The output confirms the interfaces, areas, and IP addresses.

g. Verify which OSPF neighbors R1 has established an adjacency with using the **show ip ospf neighbor** command.

```
R1# show ip ospf neighbor


Neighbor ID     Pri   State           Dead Time   Address         Interface
1.1.1.2           1   FULL/DR         00:00:31    10.10.0.2       GigabitEthernet0/0/1
```

The output confirms that R1 has one neighbor (i.e., 1.1.1.2 = D1), they have a full adjacency established, the IP address of D1 is 10.10.0.2, and R1 can reach D1 using its G0/0/1 interface.

h. Use the **show ip ospf neighbor detail** command to get additional information about neighbor adjacencies.

```
R1# show ip ospf neighbor detail
 Neighbor 1.1.1.2, interface address 10.10.0.2, interface-id 38
    In the area 1 via interface GigabitEthernet0/0/1
    Neighbor priority is 1, State is FULL, 6 state changes
    DR is 10.10.0.2 BDR is 10.10.0.1
    Options is 0x12 in Hello (E-bit, L-bit)
    Options is 0x52 in DBD (E-bit, L-bit, O-bit)
    LLS Options is 0x1 (LR)
    Dead timer due in 00:00:34
    Neighbor is up for 00:19:09
    Index 1/1/1, retransmission queue length 0, number of retransmission 0
    First 0x0(0)/0x0(0)/0x0(0) Next 0x0(0)/0x0(0)/0x0(0)
    Last retransmission scan length is 0, maximum is 0
    Last retransmission scan time is 0 msec, maximum is 0 msec
```

As shown, the output confirms various information about the OSPF neighbor including DR and BDR status.

i. Verify the OSPF routes in the routing table using the **show ip route ospf** command.

```
R1# show ip route ospf | begin Gateway
Gateway of last resort is not set
```

```
          10.0.0.0/8 is variably subnetted, 3 subnets, 3 masks
O         10.10.1.0/24 [110/11] via 10.10.0.2, 00:24:43, GigabitEthernet0/0/1
```

The output displays an entry for the D1 LAN. The **O** designation identifies this as an OSPF internal route. Network routes learned from other OSPF routers in the same area are known as *intra-area routes* and are identified in the IP routing table with an **O**.

j. Finally, get detailed information on how R1 learned about the OSPF entry using the **show ip route ospf 10.10.1.0** command.

```
R1# show ip route 10.10.1.0
Routing entry for 10.10.1.0/24
  Known via "ospf 123", distance 110, metric 11, type intra area
  Last update from 10.10.0.2 on GigabitEthernet0/0/1, 00:25:25 ago
  Routing Descriptor Blocks:
  * 10.10.0.2, from 1.1.1.2, 00:25:25 ago, via GigabitEthernet0/0/1
      Route metric is 11, traffic share count is 1
```

The output confirms that R1 learned about the intra-area route 10.10.1.0 from 10.10.0.2 with a router ID of 1.1.1.2 in OSPF 123.

Step 3: Implement OSPF on R2.

Next, configure is R2. R2 is an internal backbone router and will become an ASBR.

a. Enter the OSPF router configuration mode using process ID 123, assign R2 the router ID 2.2.2.1, and set the reference bandwidth to distinguish between Gigabit Ethernet and FastEthernet interfaces.

```
R2(config)# router ospf 123
R2(config-router)# router-id 2.2.2.1
R2(config-router)# auto-cost reference-bandwidth 1000
% OSPF: Reference bandwidth is changed.
        Please ensure reference bandwidth is consistent across all routers.
```

b. Configure R2 to advertise its two interfaces in OSPF Area 0.

```
R2(config-router)# network 172.16.0.0 0.0.0.3 area 0
R2(config-router)# network 172.16.1.0 0.0.0.3 area 0
*Dec 28 16:22:42.530: %OSPF-5-ADJCHG: Process 123, Nbr 1.1.1.1 on GigabitEthernet0/0/0
from LOADING to FULL, Loading Done
```

The output confirms that an adjacency has been established with R1 (i.e., 1.1.1.1).

Note: Alternatively, the two **network** statements could be combined using **network 17.16.0.0 0.0.1.3 area 0**.

c. Configure R2 to propagate a default route to the internet. In our lab, the internet is represented as a loopback interface.

```
R2(config-router)# default-information originate
R2(config-router)# exit
R2(config)# ip route 0.0.0.0 0.0.0.0 lo0
%Default route without gateway, if not a point-to-point interface, may impact
performance
R2(config)# exit
```

d. Verify the OSPF configuration on R2 using the **show ip protocols** command.

```
R2# show ip protocols | begin ospf
```

```
Routing Protocol is "ospf 123"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 2.2.2.1
  It is an autonomous system boundary router
 Redistributing External Routes from,
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    172.16.0.0 0.0.0.3 area 0
    172.16.1.0 0.0.0.3 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
    1.1.1.1              110      00:24:29
  Distance: (default is 110)
```

Again, this output confirms the router ID chosen, number of areas R2 is in (i.e., 1), networks advertised, and that it has established an adjacency and exchanged routing information with R1 (i.e., 1.1.1.1). R2 does not have an adjacency with D1 because it is in another area.

Notice as well, that it explicitly states that R2 is an autonomous system boundary router (ASBR). This is because it is now propagating a default route to all other routers in the OSPF domain.

e. Verify that the reference bandwidth has been changed using the **show ip ospf | begin Ref** command as shown.

```
R2# show ip ospf | begin Ref
 Reference bandwidth unit is 1000 mbps
    Area BACKBONE(0)
        Number of interfaces in this area is 2
        Area has no authentication
        SPF algorithm last executed 00:02:27.531 ago
        SPF algorithm executed 5 times
        Area ranges are
        Number of LSA 5. Checksum Sum 0x01C25B
        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
```

The output confirms that the reference bandwidth has been changed and also confirms that R2 has two interfaces in its link-state database (LSDB).

f. Verify the active OSPF interfaces and assigned areas using the **show ip ospf interface brief** command.

```
R2# show ip ospf interface brief
```

Interface	PID	Area	IP Address/Mask	Cost	State	Nbrs F/C
Gi0/0/1	123	0	172.16.1.1/30	1	DR	0/0
Gi0/0/0	123	0	172.16.0.1/30	1	BDR	1/1

The output confirms that the two interfaces are in Area 0, their IP addresses, state, and neighbors.

g. Verify which OSPF neighbors R2 has established an adjacency using the **show ip ospf neighbor** command.

```
R2# show ip ospf neighbor
```

```
Neighbor ID     Pri   State          Dead Time   Address        Interface
1.1.1.1           1   FULL/DR        00:00:36    172.16.0.2     GigabitEthernet0/0/0
```

The output confirms that R2 has one neighbor (i.e., 1.1.1.1 = R1) and they have a full adjacency established.

h. Use the **show ip ospf neighbor detail** command to get additional information about neighbor adjacencies.

```
R2# show ip ospf neigh detail
 Neighbor 1.1.1.1, interface address 172.16.0.2, interface-id 5
    In the area 0 via interface GigabitEthernet0/0/0
    Neighbor priority is 1, State is FULL, 6 state changes
    DR is 172.16.0.2 BDR is 172.16.0.1
    Options is 0x12 in Hello (E-bit, L-bit)
    Options is 0x52 in DBD (E-bit, L-bit, O-bit)
    LLS Options is 0x1 (LR)
    Dead timer due in 00:00:34
    Neighbor is up for 00:27:48
    Index 1/1/1, retransmission queue length 0, number of retransmission 0
    First 0x0(0)/0x0(0)/0x0(0) Next 0x0(0)/0x0(0)/0x0(0)
    Last retransmission scan length is 0, maximum is 0
    Last retransmission scan time is 0 msec, maximum is 0 msec
```

As shown, the output confirms various information about the OSPF neighbor including DR and BDR status.

i. Verify the OSPF routes in the routing table using the **show ip route ospf** command.

```
R2# show ip route ospf | begin Gateway

Gateway of last resort is 0.0.0.0 to network 0.0.0.0

      10.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
O IA     10.10.0.0/30 [110/2] via 172.16.0.2, 00:28:19, GigabitEthernet0/0/0
O IA     10.10.1.0/24 [110/12] via 172.16.0.2, 00:28:19, GigabitEthernet0/0/0
```

The output displays that there is now a default gateway and two entries for the OSPF Area 1 networks. Notice how these routes are identified as **O IA** which means they are routes from another area. Network routes learned from OSPF routers in another area using an ABR are known as *interarea routes* as opposed to intra-area routes.

j. Verify the static route entry in the routing table.

```
R2# show ip route static | begin Gateway
Gateway of last resort is 0.0.0.0 to network 0.0.0.0

S*    0.0.0.0/0 is directly connected, Loopback0
```

k. Finally, get detailed information on how R2 learned about the OSPF entry using the **show ip route ospf 10.10.1.0** command.

```
R2# show ip route 10.10.1.0
Routing entry for 10.10.1.0/24
  Known via "ospf 123", distance 110, metric 12, type inter area
  Last update from 172.16.0.2 on GigabitEthernet0/0/0, 00:31:08 ago
```

```
Routing Descriptor Blocks:
* 172.16.0.2, from 1.1.1.1, 00:31:08 ago, via GigabitEthernet0/0/0
    Route metric is 12, traffic share count is 1
```

The output confirms that R2 learned about the interarea route 10.10.1.0 from OSPF 123 and specifically from R1, based on the router ID of 1.1.1.1.

Step 4: Implement OSPF on R3.

Next to configure is R3. Like R1, R3 is an ABR with an interface in Area 0 and one in Area 2.

a. Enter the OSPF router configuration mode using process ID 123, assign R3 the router ID 3.3.3.1, and set the reference bandwidth to distinguish between Gigabit Ethernet and FastEthernet interfaces.

```
R3(config)# router ospf 123
R3(config-router)# router-id 3.3.3.1
R3(config-router)# auto-cost reference-bandwidth 1000
% OSPF: Reference bandwidth is changed.
```

Note: Please ensure reference bandwidth is consistent across all routers.

b. Configure R3 to advertise its interfaces in OSPF Area 0 and Area 2 accordingly and then return to privileged EXEC mode.

```
R3(config-router)# network 172.16.1.0 0.0.0.3 area 0
R3(config-router)# network 10.10.4.0 0.0.0.3 area 2
R3(config-router)# end
R3#
*Jan  5 19:28:25.146: %OSPF-5-ADJCHG: Process 123, Nbr 2.2.2.1 on GigabitEthernet0/0/0
from LOADING to FULL, Loading Done
```

c. Verify the OSPF configuration on R3 using the **show ip protocols** command.

```
R3# show ip protocols | begin ospf
Routing Protocol is "ospf 123"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 3.3.3.1
  It is an area border router
  Number of areas in this router is 2. 2 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.10.4.0 0.0.0.3 area 2
    172.16.1.0 0.0.0.3 area 0
  Routing Information Sources:
    Gateway         Distance      Last Update
    1.1.1.1              110      00:01:43
    2.2.2.1              110      00:01:43
  Distance: (default is 110)
```

The output confirms the router ID, and that R3 is an ABR, it has interfaces in two areas, the networks it is advertising, and that R3 has R1 (i.e., 1.1.1.1) and R2 (i.e., 2.2.2.1) as sources of routing information.

d. Verify that the reference bandwidth has been changed using the **show ip ospf | begin Ref** command as shown.

```
R3# show ip ospf | begin Ref
```

```
Reference bandwidth unit is 1000 mbps
   Area BACKBONE(0)
       Number of interfaces in this area is 1
       Area has no authentication
       SPF algorithm last executed 00:10:38.256 ago
       SPF algorithm executed 4 times
       Area ranges are
       Number of LSA 8. Checksum Sum 0x0396BA
       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
   Area 2
       Number of interfaces in this area is 1
       Area has no authentication
       SPF algorithm last executed 00:10:13.755 ago
       SPF algorithm executed 2 times
       Area ranges are
       Number of LSA 6. Checksum Sum 0x0362CF
       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
```

The output confirms that the reference bandwidth has been changed and also confirms that R2 has area information for Area 0 and Area 2.

e. Verify the active OSPF interfaces and assigned areas using the **show ip ospf interface brief** command.

```
R3# show ip ospf interface brief
Interface    PID   Area              IP Address/Mask    Cost  State  Nbrs F/C
Gi0/0/0      123   0                 172.16.1.2/30      1     BDR    1/1
Gi0/0/1      123   2                 10.10.4.1/30       1     DR     0/0
```

The output confirms the interfaces, process ID, areas, IP addresses, cost, state, and neighbors.

f. Verify which OSPF neighbors R2 has established an adjacency with using the **show ip ospf neighbor** command.

```
R3# show ip ospf neighbor
Neighbor ID    Pri   State      Dead Time   Address      Interface
2.2.2.1          1   FULL/DR    00:00:31    172.16.1.1   GigabitEthernet0/0/0
```

The output confirms that R3 has one neighbor (i.e., 2.2.2.1= R2) and they have a full adjacency established.

g. Use the **show ip ospf neighbor detail** command to get additional information about neighbor adjacencies.

```
R3# show ip ospf neighbor detail
 Neighbor 2.2.2.1, interface address 172.16.1.1, interface-id 6
    In the area 0 via interface GigabitEthernet0/0/0
    Neighbor priority is 1, State is FULL, 6 state changes
    DR is 172.16.1.1 BDR is 172.16.1.2
```

```
      Options is 0x12 in Hello (E-bit, L-bit)
      Options is 0x52 in DBD (E-bit, L-bit, O-bit)
      LLS Options is 0x1 (LR)
      Dead timer due in 00:00:37
      Neighbor is up for 00:21:50
      Index 1/1/1, retransmission queue length 0, number of retransmission 0
      First 0x0(0)/0x0(0)/0x0(0) Next 0x0(0)/0x0(0)/0x0(0)
      Last retransmission scan length is 0, maximum is 0
      Last retransmission scan time is 0 msec, maximum is 0 msec
```

As shown, the output confirms various information about the OSPF neighbor including DR and BDR status.

h. Verify the OSPF routes in the routing table using the **show ip route ospf** command.

```
R3# show ip route ospf | begin Gateway
Gateway of last resort is 172.16.1.1 to network 0.0.0.0

O*E2  0.0.0.0/0 [110/1] via 172.16.1.1, 00:26:08, GigabitEthernet0/0/0
      10.0.0.0/8 is variably subnetted, 4 subnets, 3 masks
O IA     10.10.0.0/30 [110/3] via 172.16.1.1, 00:26:08, GigabitEthernet0/0/0
O IA     10.10.1.0/24 [110/13] via 172.16.1.1, 00:26:08, GigabitEthernet0/0/0
      172.16.0.0/16 is variably subnetted, 3 subnets, 2 masks
O        172.16.0.0/30 [110/2] via 172.16.1.1, 00:26:08, GigabitEthernet0/0/0
```

The output verifies that R3 has received a default route from R2, two interarea routes (i.e., O IA routes) and one intra-area OSPF route (i.e., O routes). The O*E2 route indicates that this is an external route that did not originate in OSPF. The asterisk identifies this as a candidate default route.

i. Now get detailed information on how R3 learned about the O E2 and O IA routes.

```
R3# show ip route 0.0.0.0
Routing entry for 0.0.0.0/0, supernet
  Known via "ospf 123", distance 110, metric 1, candidate default path
  Tag 123, type extern 2, forward metric 1
  Last update from 172.16.1.1 on GigabitEthernet0/0/0, 00:28:41 ago
  Routing Descriptor Blocks:
  * 172.16.1.1, from 2.2.2.1, 00:28:41 ago, via GigabitEthernet0/0/0
     Route metric is 1, traffic share count is 1
     Route tag 123

R3# show ip route 10.10.1.0
Routing entry for 10.10.1.0/24
  Known via "ospf 123", distance 110, metric 13, type inter area
  Last update from 172.16.1.1 on GigabitEthernet0/0/0, 00:29:10 ago
  Routing Descriptor Blocks:
  * 172.16.1.1, from 1.1.1.1, 00:29:10 ago, via GigabitEthernet0/0/0
     Route metric is 13, traffic share count is 1
```

The output confirms that R3 learned about the default route from R2 (2.2.2.1) and interarea routes from R1 (1.1.1.1) via OSPF.

Step 5: Implement OSPF on D2.

Last to configure is D2. Like D1, D2 is an internal router in Area 2.

a. Layer 3 switches are not enabled to perform routing by default. Therefore, routing must be enabled using the **ip routing** global configuration command.

```
D2(config)# ip routing
```

b. Next, enter the OSPF router configuration mode using process ID 123, assign the D2 the router ID 3.3.3.2, and set the reference bandwidth to distinguish between Gigabit Ethernet and FastEthernet interfaces.

```
D2(config)# router ospf 123
D2(config-router)# router-id 3.3.3.2
D2(config-router)# auto-cost reference-bandwidth 1000
% OSPF: Reference bandwidth is changed.
        Please ensure reference bandwidth is consistent across all routers.
```

c. Configure D2 to advertise its interfaces in OSPF Area 2 and return to privileged EXEC mode.

```
D2(config-router)# network 10.10.4.0 0.0.0.3 area 2
D2(config-router)# network 10.10.5.0 0.0.0.255 area 2
D2(config-router)# end
D2#
*Mar  1 01:52:03.888: %OSPF-5-ADJCHG: Process 123, Nbr 3.3.3.1 on
GigabitEthernet1/0/11 from LOADING to FULL, Loading Done
```

d. Verify the OSPF configuration on D2 using the **show ip protocols** command.

```
D2# show ip protocols
Routing Protocol is "ospf 123"
  Outgoing update filter list for all interfaces is not set
  Incoming update filter list for all interfaces is not set
  Router ID 3.3.3.2
  Number of areas in this router is 1. 1 normal 0 stub 0 nssa
  Maximum path: 4
  Routing for Networks:
    10.10.4.0 0.0.0.3 area 2
    10.10.5.0 0.0.0.255 area 2
  Routing Information Sources:
    Gateway         Distance      Last Update
    3.3.3.1              110       00:09:35
    2.2.2.1              110       00:04:38
  Distance: (default is 110)
```

As expected, we can verify the router ID, number of areas, networks being advertised, and routing sources. It may be surprising that R2 (i.e., 2.2.2.1) is displayed as a routing source. The reason is because it is the source of the default route.

e. Verify that the reference bandwidth has been changed using the **show ip ospf | begin Ref** command as shown.

```
D2# show ip ospf | begin Ref
 Reference bandwidth unit is 1000 mbps
    Area 2
        Number of interfaces in this area is 2
        Area has no authentication
        SPF algorithm last executed 00:13:01.877 ago
        SPF algorithm executed 3 times
```

```
<output omitted>
```

f. Verify the active OSPF interfaces and assigned areas using the **show ip ospf interface brief** command.

```
D2# show ip ospf interface brief
Interface    PID   Area            IP Address/Mask    Cost  State Nbrs F/C
Gi1/0/23      123   2               10.10.5.1/24       10    DR    0/0
G11/0/11      123   2               10.10.4.2/30       1     BDR   1/1
```

The output confirms that the two interfaces are in Area 2 and their IP addresses are correct.

g. Verify which OSPF neighbors D2 has established an adjacency with using the **show ip ospf neighbor** command.

```
D2# show ip ospf neighbor
Neighbor ID    Pri   State        Dead Time   Address      Interface
3.3.3.1         1    FULL/BDR     00:00:33    10.10.4.1    GigabitEthernet1/0/11
```

The output confirms that D2 has one neighbor (i.e., 3.3.3.1= R3) and they have a full adjacency established.

h. Verify the OSPF routes in the routing table using the **show ip route ospf | begin Gateway** command.

```
D2# show ip route ospf | begin Gateway
Gateway of last resort is 10.10.4.1 to network 0.0.0.0

O*E2  0.0.0.0/0 [110/1] via 10.10.4.1, 00:09:25, Gigabitthernet1/0/11
      10.0.0.0/8 is variably subnetted, 6 subnets, 3 masks
O IA     10.10.0.0/30 [110/4] via 10.10.4.1, 00:09:00, GigabitEthernet1/0/11
O IA     10.10.1.0/24 [110/14] via 10.10.4.1, 00:09:00, GigabitEthernet1/0/11
      172.16.0.0/30 is subnetted, 2 subnets
O IA     172.16.0.0 [110/3] via 10.10.4.1, 00:09:00, GigabitEthernet1/0/11
O IA     172.16.1.0 [110/2] via 10.10.4.1, 00:09:00, GigabitEthernet1/0/11
```

The output displays four interarea routes (i.e., O IA routes) and the OSPF external route from 2.2.2.1(R2).

```
D2# show ip route 0.0.0.0
Routing entry for 0.0.0.0/0, supernet
  Known via "ospf 123", distance 110, metric 1, candidate default path
  Tag 123, type extern 2, forward metric 2
  Last update from 10.10.4.1 on GigabitEthernet1/0/11, 00:18:31 ago
  Routing Descriptor Blocks:
  * 10.10.4.1, from 2.2.2.1, 00:18:31 ago, via GigabitEthernet1/0/11
      Route metric is 1, traffic share count is 1
      Route tag 123
```

As we can see, the routing source for the default route is R2 (i.e., 2.2.2.1).

Step 6: Verify end-to-end connectivity.

The multiarea OSPF network is now completely configured. We now need to verify the operation of OSPF.

a. From PC1, verify that it has been assigned the correct IP address as listed in the Addressing Table using the **ipconfig** Windows command.

```
C:\Users\Student> ipconfig

Windows IP Configuration
```

```
Ethernet adapter Ethernet0:

    Connection-specific DNS Suffix  . :
    Link-local IPv6 Address . . . . . : fe80::7853:120b:ecdf:d718%6
    IPv4 Address. . . . . . . . . . . : 10.10.1.10
    Subnet Mask . . . . . . . . . . . : 255.255.255.0
    Default Gateway . . . . . . . . . : 10.10.1.1
```

b. Verify end-to-end connectivity by pinging PC3.

```
C:\Users\Student> ping 10.10.5.10

Pinging 10.10.5.10 with 32 bytes of data:

Pinging 10.10.5.10 with 32 bytes of data:
Reply from 10.10.5.10: bytes=32 time=1ms TTL=123
Reply from 10.10.5.10: bytes=32 time=1ms TTL=123
Reply from 10.10.5.10: bytes=32 time=1ms TTL=123
Reply from 10.10.5.10: bytes=32 time=1ms TTL=123

Ping statistics for 10.10.5.10:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 0ms, Maximum = 1ms, Average = 0ms
```

c. Verify the route taken by doing a traceroute to PC3.

```
C:\Users\Student> tracert 10.10.5.10

Tracing route to DESKTOP-3FR7RKA [10.10.5.10]
over a maximum of 30 hops:

  1     1 ms     1 ms     1 ms  10.10.1.1
  2    <1 ms    <1 ms    <1 ms  10.10.0.1
  3     1 ms    <1 ms    <1 ms  172.16.0.1
  4     1 ms     1 ms    <1 ms  172.16.1.2
  5     1 ms     2 ms     2 ms  10.10.4.2
  6     1 ms    <1 ms    <1 ms  DESKTOP-3RF7RKA [10.10.5.10]

Trace complete.
```

This confirms end-to-end connectivity.

Part 3: Exploring Link State Announcements

In this part, you will verify that the network has converged and explore how link-state advertisements (LSAs) are used as the building blocks for the OSPF link-state database (LSDB).

OSPF routers create LSAs for every directly connected OSPF-enabled interface. It then sends those LSAs to OSPF peers to form adjacencies. Individually, LSAs are database records providing specific OSPF network details. Combined, they describe the entire topology of an OSPF area.

OSPF routers uses six LSA types for IPv4 routing:

- **Type 1, router LSA** – All OSPF-enabled routers create and send type 1 LSAs. The LSAs are immediately propagated within the area. An ABR does not forward the LSA outside the area.

- **Type 2, network LSA** - Only a DR generates and advertises a type 2 LSA. The type 2 network LSA lists each of the attached routers that make up the transit network, including the DR itself, and the subnet mask that is used on the link. The DR floods the LSA to all OSPF routers (i.e., 224.0.0.5) on the multiaccess network. The content of the displayed type 2 LSA describes the network segment listing the DR address, the attached routers, and the used subnet mask. This information is used by each router participating in OSPF to build the exact picture of the described multiaccess segment, which cannot be fully described with just type 1 LSAs.

- **Type 3, summary LSA** - ABRs do not forward type 1 or type 2 LSAs into other areas. ABRs flood type 3 LSAs to propagate network information to other areas. Type 3 summary LSAs describe networks that are in an area to the rest of the areas in the OSPF autonomous system.

- **Type 4, ASBR summary LSA** – When there is an ASBR in the OSPF domain, it advertises itself using a special type 1 LSA. When an ABR receives this type 1 LSA, it builds a type 4 LSA to advertise the existence of the ASBR and floods it to other areas. Subsequent ABRs regenerate a type 4 LSA and flood it into their areas.

- **Type 5, AS external LSA** – ASBRs generate a type 5 external LSAs to advertise external OSPF routes to the OSPF domain. Type 5 LSAs are originated by the ASBR and are flooded to the entire autonomous system.

- **Type 7, NSSA external LSA** – This is a special LSA generated by a not-so-stubby (NSSA) ASBR to advertise external OSPF networks to an OSPF domain. The ABR converts the type 7 LSA to a type 5 LSA and propagates it to other areas. An NSSA network is a special-case area type used to reduce the amount of flooding, the LSDB size, and the routing table size in routers within the area.

Note: Other LSAs also exist but are out of scope of this lab.

The focus of this section will be on LSA types 1, 2, and 3 which are used to identify intra-area and interarea routes.

Step 1: Verifying OSPF and Exploring LSAs on D1.

D1 is an internal router and generates type 1 LSAs. It is also the DR on the link connecting to R1 and therefore generates type 2 LSAs.

a. On D1, display the list of neighbors using the **show ip ospf neighbors** command.

```
D1# show ip ospf neighbor


Neighbor ID     Pri   State          Dead Time   Address        Interface
1.1.1.1           1   FULL/BDR       00:00:32    10.10.0.1      GigabitEthernet1/0/11
```

The output confirms that R1 (i.e., 1.1.1.1) is a neighbor and is the BDR on the link. Therefore, D1 must be the DR.

b. Verify the OSPF routing table using the **show ip router ospf | begin Gateway** command.

```
D1# show ip route ospf | begin Gateway


Gateway of last resort is 10.10.0.1 to network 0.0.0.0


O*E2  0.0.0.0/0 [110/1] via 10.10.0.1, 01:15:48, GigabitEthernet1/0/11
      10.0.0.0/8 is variably subnetted, 6 subnets, 3 masks
O IA    10.10.4.0/30 [110/4] via 10.10.0.1, 00:52:50, GigabitEthernet1/0/11
O IA    10.10.5.0/24 [110/14] via 10.10.0.1, 00:24:49, GigabitEthernet1/0/11
      172.16.0.0/30 is subnetted, 2 subnets
```

```
O IA      172.16.0.0 [110/2] via 10.10.0.1, 02:05:06, GigabitEthernet1/0/11
O IA      172.16.1.0 [110/3] via 10.10.0.1, 01:18:11, GigabitEthernet1/0/11
```

The routing table lists the four interarea networks and one external OSPF network.

c. D1 learned about these networks from LSAs. A router maintains a LSDB for each area it has interfaces in. Because D1 is an internal OSPF router, it will only have entries for Area 1. To display the contents of the LSDB of D1, use the **show ip ospf database** command.

```
D1# show ip ospf database


            OSPF Router with ID (1.1.1.2) (Process ID 123)


                Router Link States (Area 1)

Link ID         ADV Router      Age         Seq#        Checksum Link count
1.1.1.1         1.1.1.1         1806        0x80000005 0x00DC15 1
1.1.1.2         1.1.1.2         167         0x80000005 0x001AA6 2


                Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#        Checksum
10.10.0.2       1.1.1.2         167         0x80000003 0x00B462


                Summary Net Link States (Area 1)

Link ID         ADV Router      Age         Seq#        Checksum
10.10.4.0       1.1.1.1         1806        0x80000002 0x00A86E
10.10.5.0       1.1.1.1         1807        0x80000002 0x0014F4
172.16.0.0      1.1.1.1         1807        0x80000002 0x00DBA1
172.16.1.0      1.1.1.1         1807        0x80000002 0x00DAA0


                Summary ASB Link States (Area 1)

Link ID         ADV Router      Age         Seq#        Checksum
2.2.2.1         1.1.1.1         1807        0x80000002 0x00131C


                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#        Checksum Tag
0.0.0.0         2.2.2.1         1939        0x80000002 0x009F90 123
```

Notice how the command output is divided into the following five sections:

o **Router Link States** – These are the type 1 LSAs received by D1 and they identify the routers (i.e., 1.1.1.1 = R1, 1.1.1.2 = D1) in Area 1 that sent them, and the number of links that the routers have in the area. Therefore, R1 only has one interface in Area 1 and D1 has 2 interfaces in Area 1.

o **Net Link States** – These are the type 2 LSAs generated by the DR. In our example, the DR is 1.1.1.2 (i.e., D1) on the link 10.10.0.2.

o **Summary Net Link States –** These are the type 3 LSAs describing remote networks (i.e., our O IA networks or interarea routes) and the router that advertised them to D1.

- o **Summary ASB Link States –** This is a type 4 LSA sent by the ABR (i.e., 1.1.1.1 = R1) advertising that there is an ASBR in the network (i.e., 2.2.2.1).

- o **Type-5 AS External Link States** – This is a type 5 LSA advertising a default route (i.e., 0.0.0.0) and the router that is advertising it (i.e., 2.2.2.1).

d. Additional information about the Router Link States type 1 LSA can be gathered using the **show ip ospf database router** command.

```
D1# show ip ospf database router

            OSPF Router with ID (1.1.1.2) (Process ID 123)

               Router Link States (Area 1)

  Routing Bit Set on this LSA in topology Base with MTID 0
  LS age: 843
  Options: (No TOS-capability, DC)
  LS Type: Router Links
  Link State ID: 1.1.1.1
  Advertising Router: 1.1.1.1
  LS Seq Number: 80000007
  Checksum: 0xD817
  Length: 36
  Area Border Router
  Number of Links: 1

    Link connected to: a Transit Network
     (Link ID) Designated Router address: 10.10.0.2
     (Link Data) Router Interface address: 10.10.0.1
      Number of TOS metrics: 0
       TOS 0 Metrics: 1



  LS age: 1196
   Options: (No TOS-capability, DC)
   LS Type: Router Links
   Link State ID: 1.1.1.2
   Advertising Router: 1.1.1.2
   LS Seq Number: 80000006
   Checksum: 0x18A7
   Length: 48
   Number of Links: 2

  Link connected to: a Transit Network
      (Link ID) Designated Router address: 10.10.0.2
      (Link Data) Router Interface address: 10.10.0.2
       Number of MTID metrics: 0
        TOS 0 Metrics: 1

    Link connected to: a Stub Network
```

```
(Link ID) Network/subnet number: 10.10.1.0
(Link Data) Network Mask: 255.255.255.0
 Number of MTID metrics: 0
  TOS 0 Metrics: 10
```

The output provides more information about the type 1 LSAs. The first router link (i.e., type 1) LSA is from R1 (i.e., 1.1.1.1). It is an ABR with only 1 link in Area 1 which is the transit network connecting to D1. The second router link portion identifies the transit network connecting to R1 and the stub network of D1 (i.e., 10.10.1.0/24).

An OSPF link can be connected to a stub, to another router (point-to-point), or to a transit network. The transit network usually describes an Ethernet segment which can include two or more routers. If the link is connected to a transit network, the LSA also includes the IP address of the DR.

e. To learn more about type 2 network LSAs, use **show ip ospf database network** command.

D1# **show ip ospf database network**

```
            OSPF Router with ID (1.1.1.2) (Process ID 123)


                Net Link States (Area 1)


  LS age: 845
  Options: (No TOS-capability, DC)
  LS Type: Network Links
  Link State ID: 10.10.0.2 (address of Designated Router)
  Advertising Router: 1.1.1.2
  LS Seq Number: 80000005
  Checksum: 0xB064
  Length: 32
  Network Mask: /30
        Attached Router: 1.1.1.2
        Attached Router: 1.1.1.1
```

The content of the type 2 LSA describes the network segment listing the DR address, the attached routers, and subnet mask using CIDR notation. This information is used by each router in the area to build the exact picture of the described multiaccess segment, which cannot be fully described with just type 1 LSAs.

f. To learn more about type 3 summary LSAs, use **show ip ospf database summary** command.

D1# **show ip ospf database summary**

```
            OSPF Router with ID (1.1.1.2) (Process ID 123)


                Summary Net Link States (Area 1)


  LS age: 987
  Options: (No TOS-capability, DC, Upward)
  LS Type: Summary Links(Network)
  Link State ID: 10.10.4.0 (summary Network Number)
  Advertising Router: 1.1.1.1
  LS Seq Number: 80000005
```

```
Checksum: 0xA271
Length: 28
Network Mask: /30
      MTID: 0        Metric: 3


LS age: 987
Options: (No TOS-capability, DC, Upward)
LS Type: Summary Links(Network)
Link State ID: 10.10.5.0 (summary Network Number)
Advertising Router: 1.1.1.1
LS Seq Number: 80000005
Checksum: 0xEF7
Length: 28
Network Mask: /24
      MTID: 0        Metric: 13


LS age: 988
Options: (No TOS-capability, DC, Upward)
LS Type: Summary Links(Network)
Link State ID: 172.16.0.0 (summary Network Number)
Advertising Router: 1.1.1.1
LS Seq Number: 80000005
Checksum: 0xD5A4
Length: 28
Network Mask: /30
      MTID: 0        Metric: 1


LS age: 989
Options: (No TOS-capability, DC, Upward)
LS Type: Summary Links(Network)
Link State ID: 172.16.1.0 (summary Network Number)
Advertising Router: 1.1.1.1
LS Seq Number: 80000005
Checksum: 0xD4A3
Length: 28
Network Mask: /30
      MTID: 0        Metric: 2
```

The output lists four type 3 LSAs. The LSAs identify the interarea networks, which ABR advertised, and the network mask using CIDR notation.

g. To learn more about type 4 summary LSAs, use **show ip ospf database asbr-summary** command.

```
D1# show ip ospf database asbr-summary


          OSPF Router with ID (1.1.1.2) (Process ID 123)


              Summary ASB Link States (Area 1)


LS age: 591
Options: (No TOS-capability, DC, Upward)
```

```
LS Type: Summary Links(AS Boundary Router)
Link State ID: 2.2.2.1 (AS Boundary Router address)
Advertising Router: 1.1.1.1
LS Seq Number: 80000006
Checksum: 0xB20
Length: 28
Network Mask: /0
      MTID: 0        Metric: 1
```

The output lists one type 4 LSA advertised by R1 identifying 2.2.2.1 as an ASBR.

h. Finally, to learn more about type 5 AS external link LSAs, use **show ip ospf database external** command.

```
D1# show ip ospf database external

            OSPF Router with ID (1.1.1.2) (Process ID 123)

                Type-5 AS External Link States

   LS age: 1024
   Options: (No TOS-capability, DC, Upward)
   LS Type: AS External Link
   Link State ID: 0.0.0.0 (External Network Number )
   Advertising Router: 2.2.2.1
   LS Seq Number: 80000006
   Checksum: 0x9794
   Length: 36
   Network Mask: /0
        Metric Type: 2 (Larger than any link state path)
        TOS: 0
        Metric: 1
        Forward Address: 0.0.0.0
        External Route Tag: 123
```

The output lists one type 5 LSA identifying that 0.0.0.0/0 is available from 2.2.2.1 (i.e., R2).

Step 2: Verifying OSPF and exploring LSAs on an ABR R1.

R1 is an ABR with interfaces in Area 1 and Area 0. Therefore, R1 will have two LSDBs.

Display the LSDB on R1.

```
R1# show ip ospf database

            OSPF Router with ID (1.1.1.1) (Process ID 123)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#       Checksum Link count
1.1.1.1         1.1.1.1         1250        0x80000009 0x001E87 1
2.2.2.1         2.2.2.1         1284        0x8000000C 0x00A06E 2
3.3.3.1         3.3.3.1         1220        0x80000008 0x00BDDA 1
```

```
                    Net Link States (Area 0)

Link ID          ADV Router       Age          Seq#        Checksum
172.16.0.2       1.1.1.1          1284         0x80000006 0x002A3E
172.16.1.1       2.2.2.1          1284         0x80000006 0x0067F9


                    Summary Net Link States (Area 0)

Link ID          ADV Router       Age          Seq#        Checksum
10.10.0.0        1.1.1.1          1250         0x80000008 0x00B462
10.10.1.0        1.1.1.1          1250         0x80000006 0x0024E6
10.10.4.0        3.3.3.1          1220         0x80000008 0x0058B4
10.10.5.0        3.3.3.1          1220         0x80000006 0x00C739


                    Router Link States (Area 1)

Link ID          ADV Router       Age          Seq#        Checksum Link count
1.1.1.1          1.1.1.1          1250         0x80000009 0x00D419 1
1.1.1.2          1.1.1.2          1632         0x80000008 0x0014A9 2


                    Net Link States (Area 1)

Link ID          ADV Router       Age          Seq#        Checksum
10.10.0.2        1.1.1.2          1632         0x80000006 0x00AE65


                    Summary Net Link States (Area 1)

Link ID          ADV Router       Age          Seq#        Checksum
10.10.4.0        1.1.1.1          1250         0x80000006 0x00A072
10.10.5.0        1.1.1.1          1250         0x80000006 0x000CF8
172.16.0.0       1.1.1.1          1250         0x80000006 0x00D3A5
172.16.1.0       1.1.1.1          1250         0x80000006 0x00D2A4


                    Summary ASB Link States (Area 1)

Link ID          ADV Router       Age          Seq#        Checksum
2.2.2.1          1.1.1.1          1250         0x80000006 0x000B20


                    Type-5 AS External Link States

Link ID          ADV Router       Age          Seq#        Checksum Tag
0.0.0.0          2.2.2.1          1284         0x80000006 0x009794 123
```

The output displays the type 1, 2, and 3 LSAs in Area 0, and then lists the type 1, 2, 3, and 4 LSAs in Area 1. The last section displays the type 5 LSAs.

To learn more about each LSA type, use the following commands:

o   **show ip ospf database router**

o   **show ip ospf database network**

o   **show ip ospf database summary**

    o   **show ip ospf database asbr-summary**

    o   **show ip ospf database external**

Step 3: Verifying OSPF and exploring LSAs on the ASBR R2.

R2 is an ASBR with interfaces in Area 0 and an external non-OSPF network.

Display the LSDB on R2.

```
R2# show ip ospf database

                OSPF Router with ID (2.2.2.1) (Process ID 123)

                Router Link States (Area 0)

Link ID         ADV Router      Age         Seq#        Checksum Link count
1.1.1.1         1.1.1.1         1790        0x80000009 0x001E87 1
2.2.2.1         2.2.2.1         1822        0x8000000C 0x00A06E 2
3.3.3.1         3.3.3.1         1759        0x80000008 0x00BDDA 1

                Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#        Checksum
172.16.0.2      1.1.1.1         1822        0x80000006 0x002A3E
172.16.1.1      2.2.2.1         1822        0x80000006 0x0067F9

                Summary Net Link States (Area 0)

Link ID         ADV Router      Age         Seq#        Checksum
10.10.0.0       1.1.1.1         1790        0x80000008 0x00B462
10.10.1.0       1.1.1.1         1790        0x80000006 0x0024E6
10.10.4.0       3.3.3.1         1759        0x80000008 0x0058B4
10.10.5.0       3.3.3.1         1759        0x80000006 0x00C739

                Type-5 AS External Link States

Link ID         ADV Router      Age         Seq#        Checksum Tag
0.0.0.0         2.2.2.1         1822        0x80000006 0x009794 123
```

The output displays the type 1, 2, 3 and 5 LSAs in Area 0. Notice that there is no type 4 LSA because R2 is the ASBR and only an ABR can generate an LSA4.

Router Interface Summary Table

Router Model	Ethernet Interface #1	Ethernet Interface #2	Serial Interface #1	Serial Interface #2
1800	Fast Ethernet 0/0 (F0/0)	Fast Ethernet 0/1 (F0/1)	Serial 0/0/0 (S0/0/0)	Serial 0/0/1 (S0/0/1)
1900	Gigabit Ethernet 0/0 (G0/0)	Gigabit Ethernet 0/1 (G0/1)	Serial 0/0/0 (S0/0/0)	Serial 0/0/1 (S0/0/1)

Router Model	Ethernet Interface #1	Ethernet Interface #2	Serial Interface #1	Serial Interface #2
2801	Fast Ethernet 0/0 (F0/0)	Fast Ethernet 0/1 (F0/1)	Serial 0/1/0 (S0/1/0)	Serial 0/1/1 (S0/1/1)
2811	Fast Ethernet 0/0 (F0/0)	Fast Ethernet 0/1 (F0/1)	Serial 0/0/0 (S0/0/0)	Serial 0/0/1 (S0/0/1)
2900	Gigabit Ethernet 0/0 (G0/0)	Gigabit Ethernet 0/1 (G0/1)	Serial 0/0/0 (S0/0/0)	Serial 0/0/1 (S0/0/1)
4221	Gigabit Ethernet 0/0/0 (G0/0/0)	Gigabit Ethernet 0/0/1 (G0/0/1)	Serial 0/1/0 (S0/1/0)	Serial 0/1/1 (S0/1/1)
4300	Gigabit Ethernet 0/0/0 (G0/0/0)	Gigabit Ethernet 0/0/1 (G0/0/1)	Serial 0/1/0 (S0/1/0)	Serial 0/1/1 (S0/1/1)

Note: To find out how the router is configured, look at the interfaces to identify the type of router and how many interfaces the router has. There is no way to effectively list all the combinations of configurations for each router class. This table includes identifiers for the possible combinations of Ethernet and Serial interfaces in the device. The table does not include any other type of interface, even though a specific router may contain one. An example of this might be an ISDN BRI interface. The string in parenthesis is the legal abbreviation that can be used in Cisco IOS commands to represent the interface.

Device Configs - Final

Router R1

```
R1# show run
Building configuration...

Current configuration : 1360 bytes
!
version 16.9
service timestamps debug datetime msec
service timestamps log datetime msec
platform qfp utilization monitor load 80
no platform punt-keepalive disable-kernel-core
!
hostname R1
!
boot-start-marker
boot-end-marker
!
no aaa new-model
!
no ip domain lookup
!
login on-success log
!
subscriber templating
!
multilink bundle-name authenticated
```

```
!
diagnostic bootup level minimal
!
spanning-tree extend system-id
!
redundancy
 mode none
!
interface GigabitEthernet0/0/0
 ip address 172.16.0.2 255.255.255.252
 negotiation auto
!
interface GigabitEthernet0/0/1
 ip address 10.10.0.1 255.255.255.252
 negotiation auto
!
router ospf 123
 router-id 1.1.1.1
 auto-cost reference-bandwidth 1000
 network 10.10.0.0 0.0.0.3 area 1
 network 172.16.0.0 0.0.0.3 area 0
!
ip forward-protocol nd
no ip http server
ip http secure-server
!
control-plane
!
banner motd ^CCC This is R1, Implement Multi-Area OSPFv2 Lab ^C
!
line con 0
 exec-timeout 0 0
 logging synchronous
 transport input none
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
end
```

Router R2

```
R2# show run
Building configuration...


Current configuration : 1416 bytes
!
version 16.9
```

```
service timestamps debug datetime msec
service timestamps log datetime msec
platform qfp utilization monitor load 80
no platform punt-keepalive disable-kernel-core
!
hostname R2
!
boot-start-marker
boot-end-marker
!
no aaa new-model
!
no ip domain lookup
!
login on-success log
!
subscriber templating
!
multilink bundle-name authenticated
!
spanning-tree extend system-id
!
redundancy
 mode none
!
interface Loopback0
 ip address 209.165.200.225 255.255.255.224
!
interface GigabitEthernet0/0/0
 ip address 172.16.0.1 255.255.255.252
 negotiation auto
!
interface GigabitEthernet0/0/1
 ip address 172.16.1.1 255.255.255.252
 negotiation auto
!
router ospf 123
 router-id 2.2.2.1
 auto-cost reference-bandwidth 1000
 network 172.16.0.0 0.0.0.3 area 0
 network 172.16.1.0 0.0.0.3 area 0
 default-information originate
!
ip forward-protocol nd
no ip http server
ip http secure-server
ip route 0.0.0.0 0.0.0.0 Loopback0
!
control-plane
!
```

```
banner motd ^CCC This is R2, Implement Multi-Area OSPFv2 Lab ^C
!
line con 0
 exec-timeout 0 0
 logging synchronous
 transport input none
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
!
end
```

Router R3

R3# **show run**
```
Building configuration...


Current configuration : 3583 bytes
!
version 16.9
service timestamps debug datetime msec
service timestamps log datetime msec
platform qfp utilization monitor load 80
no platform punt-keepalive disable-kernel-core
!
hostname R3
!
boot-start-marker
boot-end-marker
!
no aaa new-model
!
no ip domain lookup
!
login on-success log
!
subscriber templating
!
multilink bundle-name authenticated
!
spanning-tree extend system-id
!
redundancy
 mode none
!
interface GigabitEthernet0/0/0
 ip address 172.16.1.2 255.255.255.252
```

```
 negotiation auto
!
interface GigabitEthernet0/0/1
 ip address 10.10.4.1 255.255.255.252
 negotiation auto
!
interface Serial0/1/0
 no ip address
!
interface Serial0/1/1
 no ip address
!
router ospf 123
 router-id 3.3.3.1
 auto-cost reference-bandwidth 1000
 network 10.10.4.0 0.0.0.3 area 2
 network 172.16.1.0 0.0.0.3 area 0
!
ip forward-protocol nd
no ip http server
ip http secure-server
!
control-plane
!
banner motd ^CCC This is R3, Implement Multi-Area OSPFv2 Lab ^C
!
line con 0
 exec-timeout 0 0
 logging synchronous
 transport input none
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
!
end
```

Switch D1

```
D1# show run
Building configuration...

Current configuration : 6501 bytes
!
version 16.9
no service pad
service timestamps debug datetime msec
service timestamps log datetime msec
! Call-home is enabled by Smart-Licensing.
```

```
service call-home
no platform punt-keepalive disable-kernel-core
!
hostname D1
!
vrf definition Mgmt-vrf
 !
 address-family ipv4
 exit-address-family
 !
 address-family ipv6
 exit-address-family
!
!
no aaa new-model
switch 1 provision ws-c3650-24ps!
!
ip routing
!
no ip domain lookup
!
login on-success log
!
license boot level ipservicesk9
!
diagnostic bootup level minimal
!
spanning-tree mode rapid-pvst
spanning-tree extend system-id
!
redundancy
 mode sso
!
transceiver type all
 monitoring
!
class-map match-any system-cpp-police-topology-control
  description Topology control
class-map match-any system-cpp-police-sw-forward
  description Sw forwarding, L2 LVX data, LOGGING
class-map match-any system-cpp-default
  description Inter FED, EWLC control, EWLC data
class-map match-any system-cpp-police-sys-data
  description Learning cache ovfl, High Rate App, Exception, EGR Exception,
NFLSAMPLED DATA, RPF Failed
class-map match-any system-cpp-police-punt-webauth
  description Punt Webauth
class-map match-any system-cpp-police-l2lvx-control
  description L2 LVX control packets
class-map match-any system-cpp-police-forus
```

```
   description Forus Address resolution and Forus traffic
class-map match-any system-cpp-police-multicast-end-station
   description MCAST END STATION
class-map match-any system-cpp-police-multicast
   description Transit Traffic and MCAST Data
class-map match-any system-cpp-police-l2-control
   description L2 control
class-map match-any system-cpp-police-dot1x-auth
   description DOT1X Auth
class-map match-any system-cpp-police-data
   description ICMP redirect, ICMP_GEN and BROADCAST
class-map match-any system-cpp-police-stackwise-virt-control
   description Stackwise Virtual
class-map match-any non-client-nrt-class
class-map match-any system-cpp-police-routing-control
   description Routing control and Low Latency
class-map match-any system-cpp-police-protocol-snooping
   description Protocol snooping
class-map match-any system-cpp-police-dhcp-snooping
   description DHCP snooping
class-map match-any system-cpp-police-system-critical
   description System Critical and Gold Pkt
!
policy-map system-cpp-policy
!
interface GigabitEthernet0/0
 vrf forwarding Mgmt-vrf
 no ip address
 negotiation auto
!
interface GigabitEthernet1/0/1
!
interface GigabitEthernet1/0/2
!
interface GigabitEthernet1/0/3
!
interface GigabitEthernet1/0/4
!
interface GigabitEthernet1/0/5
!
interface GigabitEthernet1/0/6
!
interface GigabitEthernet1/0/7
!
interface GigabitEthernet1/0/8
!
interface GigabitEthernet1/0/9
!
interface GigabitEthernet1/0/10
!
```

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```
interface GigabitEthernet1/0/11
 no switchport
 ip address 10.10.0.2 255.255.255.252
!
interface GigabitEthernet1/0/12
!
interface GigabitEthernet1/0/13
!
interface GigabitEthernet1/0/14
!
interface GigabitEthernet1/0/15
!
interface GigabitEthernet1/0/16
!
interface GigabitEthernet1/0/17
!
interface GigabitEthernet1/0/18
!
interface GigabitEthernet1/0/19
!
interface GigabitEthernet1/0/20
!
interface GigabitEthernet1/0/21
!
interface GigabitEthernet1/0/22
!
interface GigabitEthernet1/0/23
 no switchport
 ip address 10.10.1.1 255.255.255.0
!
interface GigabitEthernet1/0/24
!
interface GigabitEthernet1/1/1
!
interface GigabitEthernet1/1/2
!
interface GigabitEthernet1/1/3
!
interface GigabitEthernet1/1/4
!
interface Vlan1
 no ip address
!
router ospf 123
 router-id 1.1.1.2
 auto-cost reference-bandwidth 1000
 network 10.10.0.0 0.0.0.3 area 1
 network 10.10.1.0 0.0.0.255 area 1
!
ip forward-protocol nd
```

```
ip http server
ip http secure-server
!
control-plane
 service-policy input system-cpp-policy
!
banner motd ^C This is D1, Implement Multi-Area OSPFv2 Lab ^C
!
line con 0
 exec-timeout 0 0
 logging synchronous
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
line vty 5 15
 login
!
end
```

Switch D2

```
D2# show run
Building configuration...

Current configuration : 6501 bytes
!
version 16.9
no service pad
service timestamps debug datetime msec
service timestamps log datetime msec
! Call-home is enabled by Smart-Licensing.
service call-home
no platform punt-keepalive disable-kernel-core
!
hostname D2
!
vrf definition Mgmt-vrf
 !
 address-family ipv4
 exit-address-family
 !
 address-family ipv6
 exit-address-family
!
no aaa new-model
switch 1 provision ws-c3650-24ps
!
ip routing
```

```
!
no ip domain lookup
!
login on-success log
!
license boot level ipservicesk9
!
!
diagnostic bootup level minimal
!
spanning-tree mode rapid-pvst
spanning-tree extend system-id
!
redundancy
 mode sso
!
transceiver type all
 monitoring
!
class-map match-any system-cpp-police-topology-control
  description Topology control
class-map match-any system-cpp-police-sw-forward
  description Sw forwarding, L2 LVX data, LOGGING
class-map match-any system-cpp-default
  description Inter FED, EWLC control, EWLC data
class-map match-any system-cpp-police-sys-data
  description Learning cache ovfl, High Rate App, Exception, EGR Exception,
NFLSAMPLED DATA, RPF Failed
class-map match-any system-cpp-police-punt-webauth
  description Punt Webauth
class-map match-any system-cpp-police-l2lvx-control
  description L2 LVX control packets
class-map match-any system-cpp-police-forus
  description Forus Address resolution and Forus traffic
class-map match-any system-cpp-police-multicast-end-station
  description MCAST END STATION
class-map match-any system-cpp-police-multicast
  description Transit Traffic and MCAST Data
class-map match-any system-cpp-police-l2-control
  description L2 control
class-map match-any system-cpp-police-dot1x-auth
  description DOT1X Auth
class-map match-any system-cpp-police-data
  description ICMP redirect, ICMP_GEN and BROADCAST
class-map match-any system-cpp-police-stackwise-virt-control
  description Stackwise Virtual
class-map match-any non-client-nrt-class
class-map match-any system-cpp-police-routing-control
  description Routing control and Low Latency
class-map match-any system-cpp-police-protocol-snooping
```

```
  description Protocol snooping
class-map match-any system-cpp-police-dhcp-snooping
  description DHCP snooping
class-map match-any system-cpp-police-system-critical
  description System Critical and Gold Pkt
!
policy-map system-cpp-policy
!
interface GigabitEthernet0/0
 vrf forwarding Mgmt-vrf
 no ip address
 negotiation auto
!
interface GigabitEthernet1/0/1
!
interface GigabitEthernet1/0/2
!
interface GigabitEthernet1/0/3
!
interface GigabitEthernet1/0/4
!
interface GigabitEthernet1/0/5
!
interface GigabitEthernet1/0/6
!
interface GigabitEthernet1/0/7
!
interface GigabitEthernet1/0/8
!
interface GigabitEthernet1/0/9
!
interface GigabitEthernet1/0/10
!
interface GigabitEthernet1/0/11
 no switchport
 ip address 10.10.4.2 255.255.255.252
!
interface GigabitEthernet1/0/12
!
interface GigabitEthernet1/0/13
!
interface GigabitEthernet1/0/14
!
interface GigabitEthernet1/0/15
!
interface GigabitEthernet1/0/16
!
interface GigabitEthernet1/0/17
!
interface GigabitEthernet1/0/18
```

```
!
interface GigabitEthernet1/0/19
!
interface GigabitEthernet1/0/20
!
interface GigabitEthernet1/0/21
!
interface GigabitEthernet1/0/22
!
interface GigabitEthernet1/0/23
 no switchport
 ip address 10.10.5.1 255.255.255.0
!
interface GigabitEthernet1/0/24
!
interface GigabitEthernet1/1/1
!
interface GigabitEthernet1/1/2
!
interface GigabitEthernet1/1/3
!
interface GigabitEthernet1/1/4
!
interface Vlan1
 no ip address
!
router ospf 123
 router-id 3.3.3.2
 auto-cost reference-bandwidth 1000
 network 10.10.4.0 0.0.0.3 area 2
 network 10.10.5.0 0.0.0.255 area 2
!
ip forward-protocol nd
ip http server
ip http secure-server
!
control-plane
 service-policy input system-cpp-policy
!
banner motd ^C This is D2, Implement Multi-Area OSPFv2 Lab ^C
!
line con 0
 exec-timeout 0 0
 logging synchronous
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
line vty 5 15
```

```
 login
!
end
```