MULTI-AREA OSPF VIRTUAL LINK

CTS SOME
CCNP per. 1/2

Purpose

The purpose of this lab is to create a multi-area OSPF network with a minimum of 3 areas and 6 routers that bypasses an area through a virtual link. The goal was to refresh my knowledge of OSPF and learn the concept of virtual links, which allows one to bypass a backbone area in the multi-area OSPF. Through this lab, I was able to review my ability to set up multi-area OSPF, which I learned last year in CCNA.

Background Information on Lab Concepts

In OSPF (Open Shortest Path First), a link state routing protocol, all routers in the OSPF autonomous system must be physically connected to the backbone area 0 to communicate with other routers in different areas. Each router interface can only belong to one OSPF area. Multi-area OSPF involves multiple areas, with one backbone area (area 0) as the area that connects all other areas. However, if that is not possible, a virtual link can be created to connect a non-backbone area to the backbone area. The area the virtual link is bypassing is called a transit area. Once configured, area border routers not connected to the backbone area will receive information from the routers in the backbone area.

Imagine multi-area OSPF like eating at a restaurant. As a customer, you first exit your car and enter the restaurant through a door. The store door is like an area border router between your car and the business. You are in a new area inside the restaurant, and information is passed along within the restaurant as you place your order, and eat your meal. As you leave the your table to pay for your meal, you enter the payment area, with the counter serving as the border between the dining area and payment area. That is the normal flow of a multi-area OSPF network. Another method for ordering food is to call in advance and place a to-go order. In this case, you go directly from your car to the payment counter, bypassing the dining area. The same is true with a virtual link. It forms a transit area, and gives information to the payment area even though the car area is not connected to the payment area.

Lab Summary

First, I created the topology. I designated 2 routers to be in each area, with Routers 3 and 5 to be Area Border Routers. Routers 3 and 4 are in the backbone area, 1 and 2 are in area 1, and 5 and 6 are in area 2. Based on my topology, I assigned IPv4 and IPv6 addresses to each network. On routers 3 and 5, I assigned loopback addresses for the virtual link configuration.

After configuring the interfaces on the corresponding routers with the correct IP addresses, I configured OSPF on each router based on my topology. For routers 1 and 2, both interfaces are in area 1, so I configured all directly connected networks on those routers to be in area 1, with router id's 1.1.1.1 and 2.2.2.2 respectively in OSPFv2 (IPv4) and OSPFv3(IPv6). The same applies to routers 4 and 6, in areas 0 and 2 respectively (router id's 4.4.4.4 and 6.6.6.6). Since router 3 and router 5 are Area Border Routers (ABR), I configured the networks connected to R1 and R2 to area 1, and the networks connected to R4 and R6 to area 0 and area 2, respectively. For the virtual links, I used area 1 as the transit area, so on R3 and R5, I configured a virtual link over area 1 to the opposite ABR's loopback address (5.5.5.5 on R3 and 3.3.3.3 on R5).

Lab Commands

The new command required for this lab is to configure the virtual link.

```
area [transit area number] virtual-link [router-id of remote router]
```

This allows you to configure a virtual link across a multi-area OSPF network. The command must be applied on both routers before the virtual link with turn on. In addition, the command is the same in OSPFv3.

Command to verify the state of the virtual link:

```
show ip ospf virtual-link
```

This allows you to ensure the virtual link is up and running. It displays information relating to the virtual link, like the router id of the linked router, the transit area, and hello and dead timers. Below is the output from the command.

```
R5#sh ip ospf virtual-link
Virtual Link OSPF_VL0 to router 3.3.3.3 is up
Run as demand circuit
Transit area 1, via interface GigabitEthernet0/0, Cost of using 3
Transmit Delay is 1 sec, State POINT_TO_POINT,
Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
Hello due in 00:00:01
Adjacency State FULL
Index 1/2, retransmission queue length 0, number of retransmission 0
First 0x0(0)/0x0(0) Next 0x0(0)/0x0(0)
Last retransmission scan length is 0, maximum is 0
Last retransmission scan time is 0 msec, maximum is 0 msec
```

Command to verify connectivity across the network:

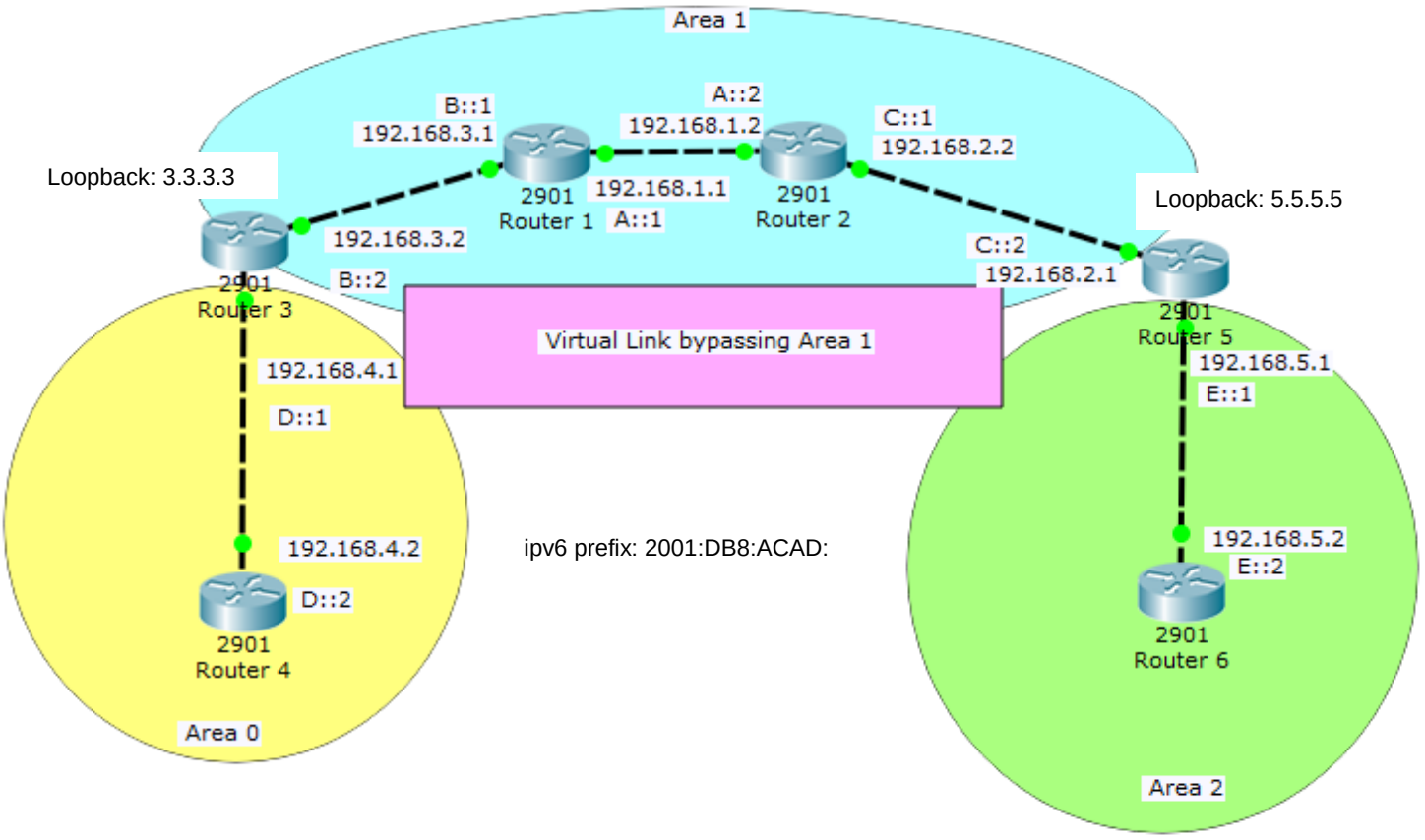
```
traceroute [ipv4 or ipv6 address]
```

In this lab, traceroute was used to verify connectivity across the whole network, as without the virtual link configured, routers in Area 0 could not send packets to routers in Area 2. Below is the output.

```
R6#traceroute 192.168.4.2
Type escape sequence to abort.
Tracing the route to 192.168.4.2

1 192.168.5.1 0 msec 0 msec 0 msec
2 192.168.2.2 0 msec 0 msec 0 msec
3 192.168.1.1 0 msec 0 msec 0 msec
4 192.168.3.2 0 msec 12 msec 0 msec
5 192.168.4.2 0 msec 13 msec 0 msec
```

Network Diagram



Configurations

Router 1:

```
Current configuration : 1675 bytes
version 12.4
no service password-encryption
hostname R1
no aaa new-model
ip cef
ipv6 unicast-routing
interface FastEthernet0/0
 ip address 192.168.1.1
255.255.255.252
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:A::1/64
 ipv6 ospf 1 area 1
interface FastEthernet0/1
 ip address 192.168.3.1
255.255.255.252
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:B::1/64
 ipv6 ospf 1 area 1
router ospf 1
 router-id 1.1.1.1
 log-adjacency-changes
 network 192.168.1.0 0.0.0.3 area 1
 network 192.168.3.0 0.0.0.3 area 1
ip http server
no ip http secure-server
ipv6 router ospf 1
 router-id 1.1.1.1
 log-adjacency-changes
control-plane
banner motd ^CAUTHORIZED ACCESS
ONLY Configured by Sonya Lao^C
line con 0
line aux 0
line vty 0 4
 login
scheduler allocate 20000 1000
end
```

Router 2:

```
Current configuration : 1509 bytes
version 12.4
no service password-encryption
hostname R2
ip cef
ipv6 unicast-routing
ipv6 cef
interface FastEthernet0/0
 ip address 192.168.1.2
255.255.255.252
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:C::1/64
 ipv6 ospf 1 area 1
interface FastEthernet0/1
 ip address 192.168.2.2
255.255.255.252
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:A::1/64
 ipv6 ospf 1 area 1
router ospf 1
 router-id 2.2.2.2
 log-adjacency-changes
 network 192.168.1.0 0.0.0.3 area 1
 network 192.168.2.0 0.0.0.3 area 1
ip forward-protocol nd
no ip http server
no ip http secure-server
ipv6 router ospf 1
 router-id 2.2.2.2
 log-adjacency-changes
control-plane
banner motd ^CAUTHORIZED ACCESS
ONLY Configured by Sonya Lao^C
line con 0
line aux 0
line vty 0 4
 login
```

```
scheduler allocate 20000 1000
end
```

Router 3:

```
Current configuration: 1969 bytes
Last configuration change at
15:08:51 UTC Thu Sep 15 2016
version 15.2
no service password-encryption
hostname R3
ip cef
ipv6 unicast-routing
ipv6 cef
interface Loopback0
 ip address 3.3.3.3 255.0.0.0
 ipv6 address FE0:2::2/64
 ipv6 ospf 1 area 1
interface GigabitEthernet0/0
 ip address 192.168.3.2
255.255.255.252
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:B::2/64
 ipv6 ospf 1 area 1
interface GigabitEthernet0/1
 ip address 192.168.4.1
255.255.255.0
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:D::1/64
 ipv6 ospf 1 area 0
router ospf 1
 router-id 3.3.3.3
 area 1 virtual-link 5.5.5.5
 network 3.0.0.0 0.255.255.255 area
1
 network 192.168.3.0 0.0.0.3 area 1
 network 192.168.4.0 0.0.0.255 area
0
no ip http server
no ip http secure-server
ipv6 router ospf 1
 router-id 3.3.3.3
 area 1 virtual-link 5.5.5.5
banner motd ^CAUTHORIZED ACCESS
ONLY Configured by Sonya Lao^C
line con 0
line aux 0
line vty 0 4
 login
 transport input all
scheduler allocate 20000 1000
end
```

Router 4:

```
Current configuration : 1706 bytes
Last configuration change at
15:17:44 UTC Thu Sep 15 2016
version 15.2
no service password-encryption
hostname R4
ip cef
ipv6 unicast-routing
ipv6 cef
interface GigabitEthernet0/0
 ip address 192.168.4.2
255.255.255.0
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:D::2/64
 ipv6 ospf 1 area 0
interface GigabitEthernet0/1
 no ip address
 shutdown
 duplex auto
 speed auto
router ospf 1
 router-id 4.4.4.4
 network 192.168.4.0 0.0.0.255 area
0
ipv6 router ospf 1
 router-id 4.4.4.4
control-plane
mgcp profile default
gatekeeper
 shutdown
banner motd ^CAUTHORIZED ACCESS
ONLY Configured by Sonya Lao^C
line con 0
line aux 0
line 2
 no activation-character
 no exec
 transport preferred none
 transport output lat pad telnet
rlogin lapb-ta mop udptn v120 ssh
 stopbits 1
line vty 0 4
```

```
 login
 transport input all
scheduler allocate 20000 1000
end
```

Router 5:

```
Last configuration change at
15:11:53 UTC Thu Sep 15 2016
version 15.2
no service password-encryption
hostname R5
ip cef
ipv6 unicast-routing
ipv6 cef
interface Loopback0
 ip address 5.5.5.5 255.0.0.0
 ip broadcast-address 5.0.0.0
 ipv6 address FE01:3::3/64
 ipv6 ospf 1 area 1
interface GigabitEthernet0/0
 ip address 192.168.2.1
255.255.255.252
 ip broadcast-address 192.168.2.0
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:C::2/64
 ipv6 ospf 1 area 1
interface GigabitEthernet0/1
 ip address 192.168.5.1
255.255.255.0
 ip broadcast-address 192.168.5.0
 ip ospf cost 10
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:E::1/64
 ipv6 ospf 1 area 2
router ospf 1
 router-id 5.5.5.5
 area 1 virtual-link 3.3.3.3
 network 5.0.0.0 0.255.255.255 area
1
 network 192.168.2.0 0.0.0.3 area 1
 network 192.168.5.0 0.0.0.255 area
2
ipv6 router ospf 1
 router-id 5.5.5.5
 area 1 virtual-link 3.3.3.3
banner motd ^CAUTHORIZED ACCESS
ONLY Configured by Sonya Lao^C
line con 0
line vty 0 4
 login
 transport input all
scheduler allocate 20000 1000
end
```

Router 6:

```
Current configuration: 1845 bytes
Last configuration change at
15:48:21 UTC Thu Sep 15 2016
version 15.2
no service password-encryption
hostname R6
ip cef
ipv6 unicast-routing
ipv6 cef
interface GigabitEthernet0/0
 ip address 192.168.5.2
255.255.255.0
 duplex auto
 speed auto
 ipv6 address 2001:DB8:ACAD:E::2/64
 ipv6 ospf 1 area 2
router ospf 1
 router-id 6.6.6.6
 network 192.168.5.0 0.0.0.255 area
2
ipv6 router ospf 1
 router-id 6.6.6.6
control-plane
banner motd ^CAUTHORIZED ACCESS
ONLY Configured by Sonya Lao^C
line con 0
line aux 0
line 2

line vty 0 4
 login
 transport input all
scheduler allocate 20000 1000
end
```

Router_1 show ip route:

```
R1#sh ip route

Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route
Gateway of last resort is not set
     3.0.0.0/32 is subnetted, 1 subnets
O       3.3.3.3 [110/2] via 192.168.3.2, 00:26:56, FastEthernet0/1
     5.0.0.0/32 is subnetted, 1 subnets
O       5.5.5.5 [110/3] via 192.168.1.2, 00:26:56, FastEthernet0/0
O IA 192.168.4.0/24 [110/2] via 192.168.3.2, 00:26:56, FastEthernet0/1
O IA 192.168.5.0/24 [110/12] via 192.168.1.2, 00:26:56, FastEthernet0/0
     192.168.1.0/30 is subnetted, 1 subnets
C       192.168.1.0 is directly connected, FastEthernet0/0
     192.168.2.0/30 is subnetted, 1 subnets
O       192.168.2.0 [110/2] via 192.168.1.2, 00:26:57, FastEthernet0/0
     192.168.3.0/30 is subnetted, 1 subnets
C       192.168.3.0 is directly connected, FastEthernet0/1
```

Router_1 show ipv6 route:

```
R1#sh ipv6 route
IPv6 Routing Table - 11 entries
Codes: C - Connected, L - Local, S - Static, R - RIP, B - BGP
       U - Per-user Static route
       I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary
       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   FE0:2::2/128 [110/1]
     via FE80::26E9:B3FF:FE3C:1C60, FastEthernet0/1
C   2001:DB8:ACAD:A::/64 [0/0]
     via ::, FastEthernet0/0
L   2001:DB8:ACAD:A::1/128 [0/0]
     via ::, FastEthernet0/0
C   2001:DB8:ACAD:B::/64 [0/0]
     via ::, FastEthernet0/1
L   2001:DB8:ACAD:B::1/128 [0/0]
     via ::, FastEthernet0/1
O   2001:DB8:ACAD:C::/64 [110/1]
     via ::, FastEthernet0/0
OI  2001:DB8:ACAD:D::/64 [110/2]
     via FE80::26E9:B3FF:FE3C:1C60, FastEthernet0/1
OI  2001:DB8:ACAD:E::/64 [110/3]
     via FE80::215:C6FF:FE78:D5A0, FastEthernet0/0
O   FE01:3::3/128 [110/2]
     via FE80::215:C6FF:FE78:D5A0, FastEthernet0/0
```

```
L   FE80::/10 [0/0]
     via ::, Null0
L   FF00::/8 [0/0]
     via ::, Null0
```

Router 2 show ip route:

```
R2>sh ip route
Codes: C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     3.0.0.0/32 is subnetted, 1 subnets
O       3.3.3.3 [110/3] via 192.168.1.1, 00:36:52, FastEthernet0/0
     5.0.0.0/32 is subnetted, 1 subnets
O       5.5.5.5 [110/2] via 192.168.2.1, 00:36:29, FastEthernet0/1
O IA 192.168.4.0/24 [110/3] via 192.168.1.1, 00:36:52, FastEthernet0/0
O IA 192.168.5.0/24 [110/11] via 192.168.2.1, 00:36:19, FastEthernet0/1
     192.168.1.0/30 is subnetted, 1 subnets
C       192.168.1.0 is directly connected, FastEthernet0/0
     192.168.2.0/30 is subnetted, 1 subnets
C       192.168.2.0 is directly connected, FastEthernet0/1
     192.168.3.0/30 is subnetted, 1 subnets
O       192.168.3.0 [110/2] via 192.168.1.1, 00:36:53, FastEthernet0/0
```

Router 2 show ipv6 route:

```
R2>sh ipv6 route
IPv6 Routing Table - Default - 10 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, M - MIPv6, R - RIP, I1 - ISIS L1
       I2 - ISIS L2, IA - ISIS interarea, IS - ISIS summary, D - EIGRP
       EX - EIGRP external
       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   FE0:2::2/128 [110/2]
     via FE80::21B:D4FF:FE95:DE20, FastEthernet0/0
C   2001:DB8:ACAD:A::/64 [0/0]
     via FastEthernet0/1, directly connected
L   2001:DB8:ACAD:A::1/128 [0/0]
     via FastEthernet0/1, receive
O   2001:DB8:ACAD:B::/64 [110/2]
     via FE80::21B:D4FF:FE95:DE20, FastEthernet0/0
C   2001:DB8:ACAD:C::/64 [0/0]
     via FastEthernet0/0, directly connected
L   2001:DB8:ACAD:C::1/128 [0/0]
     via FastEthernet0/0, receive
OI  2001:DB8:ACAD:D::/64 [110/3]
     via FE80::21B:D4FF:FE95:DE20, FastEthernet0/0
OI  2001:DB8:ACAD:E::/64 [110/2]
     via FE80::32E4:DBFF:FE67:1778, FastEthernet0/1
```

```
O   FE01:3::3/128 [110/1]
     via FE80::32E4:DBFF:FE67:1778, FastEthernet0/1
L   FF00::/8 [0/0]
     via Null0, receive
```

Router 3 show ip route:

```
R3>sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      3.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C        3.0.0.0/8 is directly connected, Loopback0
L        3.3.3.3/32 is directly connected, Loopback0
      5.0.0.0/32 is subnetted, 1 subnets
O        5.5.5.5 [110/4] via 192.168.3.1, 00:40:11, GigabitEthernet0/0
      192.168.1.0/30 is subnetted, 1 subnets
O        192.168.1.0 [110/2] via 192.168.3.1, 00:40:38, GigabitEthernet0/0
      192.168.2.0/30 is subnetted, 1 subnets
O        192.168.2.0 [110/3] via 192.168.3.1, 00:40:11, GigabitEthernet0/0
      192.168.3.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.3.0/30 is directly connected, GigabitEthernet0/0
L        192.168.3.2/32 is directly connected, GigabitEthernet0/0
      192.168.4.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.4.0/24 is directly connected, GigabitEthernet0/1
L        192.168.4.1/32 is directly connected, GigabitEthernet0/1
O IA  192.168.5.0/24 [110/13] via 192.168.3.1, 00:39:56, GigabitEthernet0/0
```

Router 3 show ipv6 route:

```
R3>sh ipv6 route
IPv6 Routing Table - default - 11 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       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, l - LISP
C   FE0:2::/64 [0/0]
     via Loopback0, directly connected
L   FE0:2::2/128 [0/0]
     via Loopback0, receive
O   2001:DB8:ACAD:A::/64 [110/2]
     via FE80::21B:D4FF:FE95:DE21, GigabitEthernet0/0
C   2001:DB8:ACAD:B::/64 [0/0]
     via GigabitEthernet0/0, directly connected
L   2001:DB8:ACAD:B::2/128 [0/0]
     via GigabitEthernet0/0, receive
O   2001:DB8:ACAD:C::/64 [110/2]
     via FE80::21B:D4FF:FE95:DE21, GigabitEthernet0/0
C   2001:DB8:ACAD:D::/64 [0/0]
     via GigabitEthernet0/1, directly connected
L   2001:DB8:ACAD:D::1/128 [0/0]
     via GigabitEthernet0/1, receive
OI  2001:DB8:ACAD:E::/64 [110/4]
     via FE80::21B:D4FF:FE95:DE21, GigabitEthernet0/0
O   FE01:3::3/128 [110/3]
     via FE80::21B:D4FF:FE95:DE21, GigabitEthernet0/0
L   FF00::/8 [0/0]
     via Null0, receive
```

Router 4 show ip route:

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

Gateway of last resort is not set

      3.0.0.0/32 is subnetted, 1 subnets
O IA     3.3.3.3 [110/2] via 192.168.4.1, 00:42:45, GigabitEthernet0/0
      5.0.0.0/32 is subnetted, 1 subnets
O IA     5.5.5.5 [110/5] via 192.168.4.1, 00:42:19, GigabitEthernet0/0
      192.168.1.0/30 is subnetted, 1 subnets
O IA     192.168.1.0 [110/3] via 192.168.4.1, 00:42:45, GigabitEthernet0/0
      192.168.2.0/30 is subnetted, 1 subnets
O IA     192.168.2.0 [110/4] via 192.168.4.1, 00:42:45, GigabitEthernet0/0
      192.168.3.0/30 is subnetted, 1 subnets
O IA     192.168.3.0 [110/2] via 192.168.4.1, 00:42:45, GigabitEthernet0/0
      192.168.4.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.4.0/24 is directly connected, GigabitEthernet0/0
L        192.168.4.2/32 is directly connected, GigabitEthernet0/0
O IA  192.168.5.0/24 [110/14] via 192.168.4.1, 00:42:19, GigabitEthernet0/0
```

Router 4 show ipv6 route:

```
R4#sh ipv6 route
IPv6 Routing Table - default - 9 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       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, l - LISP
OI  FE0:2::2/128 [110/1]
     via FE80::26E9:B3FF:FE3C:1C61, GigabitEthernet0/0
OI  2001:DB8:ACAD:A::/64 [110/3]
     via FE80::26E9:B3FF:FE3C:1C61, GigabitEthernet0/0
OI  2001:DB8:ACAD:B::/64 [110/2]
     via FE80::26E9:B3FF:FE3C:1C61, GigabitEthernet0/0
OI  2001:DB8:ACAD:C::/64 [110/3]
     via FE80::26E9:B3FF:FE3C:1C61, GigabitEthernet0/0
C   2001:DB8:ACAD:D::/64 [0/0]
     via GigabitEthernet0/0, directly connected
L   2001:DB8:ACAD:D::2/128 [0/0]
     via GigabitEthernet0/0, receive
OI  2001:DB8:ACAD:E::/64 [110/5]
     via FE80::26E9:B3FF:FE3C:1C61, GigabitEthernet0/0
OI  FE01:3::3/128 [110/4]
     via FE80::26E9:B3FF:FE3C:1C61, GigabitEthernet0/0
L   FF00::/8 [0/0]
     via Null0, receive
```

Router 5 show ip route:

```
R5#sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      3.0.0.0/32 is subnetted, 1 subnets
O        3.3.3.3 [110/4] via 192.168.2.2, 00:44:36, GigabitEthernet0/0
      5.0.0.0/8 is variably subnetted, 2 subnets, 2 masks
C        5.0.0.0/8 is directly connected, Loopback0
L        5.5.5.5/32 is directly connected, Loopback0
      192.168.1.0/30 is subnetted, 1 subnets

O        192.168.1.0 [110/2] via 192.168.2.2, 00:44:36, GigabitEthernet0/0
      192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.2.0/30 is directly connected, GigabitEthernet0/0
L        192.168.2.1/32 is directly connected, GigabitEthernet0/0
      192.168.3.0/30 is subnetted, 1 subnets
O        192.168.3.0 [110/3] via 192.168.2.2, 00:44:36, GigabitEthernet0/0
O     192.168.4.0/24 [110/4] via 192.168.2.2, 00:44:16, GigabitEthernet0/0
      192.168.5.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.5.0/24 is directly connected, GigabitEthernet0/1
```

Router 5 show ipv6 route:

```
R5#sh ipv6 route
IPv6 Routing Table - default - 11 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       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, l - LISP
O   FE0:2::2/128 [110/3]
     via FE80::215:C6FF:FE78:D5A1, GigabitEthernet0/0
O   2001:DB8:ACAD:A::/64 [110/1]
     via GigabitEthernet0/0, directly connected
O   2001:DB8:ACAD:B::/64 [110/3]
     via FE80::215:C6FF:FE78:D5A1, GigabitEthernet0/0
C   2001:DB8:ACAD:C::/64 [0/0]
     via GigabitEthernet0/0, directly connected
L   2001:DB8:ACAD:C::2/128 [0/0]
     via GigabitEthernet0/0, receive
O   2001:DB8:ACAD:D::/64 [110/4]
     via FE80::215:C6FF:FE78:D5A1, GigabitEthernet0/0
C   2001:DB8:ACAD:E::/64 [0/0]
     via GigabitEthernet0/1, directly connected
L   2001:DB8:ACAD:E::1/128 [0/0]
     via GigabitEthernet0/1, receive
C   FE01:3::/64 [0/0]
     via Loopback0, directly connected
L   FE01:3::3/128 [0/0]
     via Loopback0, receive
L   FF00::/8 [0/0]
     via Null0, receive
```

Router 6 show ip route:

```
R6>sh ip route
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      3.0.0.0/32 is subnetted, 1 subnets
O IA     3.3.3.3 [110/5] via 192.168.5.1, 00:46:24, GigabitEthernet0/0
      5.0.0.0/32 is subnetted, 1 subnets
O IA     5.5.5.5 [110/2] via 192.168.5.1, 00:46:24, GigabitEthernet0/0
      192.168.1.0/30 is subnetted, 1 subnets
O IA     192.168.1.0 [110/3] via 192.168.5.1, 00:46:24, GigabitEthernet0/0
      192.168.2.0/30 is subnetted, 1 subnets
O IA     192.168.2.0 [110/2] via 192.168.5.1, 00:46:24, GigabitEthernet0/0
      192.168.3.0/30 is subnetted, 1 subnets
O IA     192.168.3.0 [110/4] via 192.168.5.1, 00:46:24, GigabitEthernet0/0
O IA  192.168.4.0/24 [110/5] via 192.168.5.1, 00:46:18, GigabitEthernet0/0
      192.168.5.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.5.0/24 is directly connected, GigabitEthernet0/0
L        192.168.5.2/32 is directly connected, GigabitEthernet0/0
```

Router 6 show ipv6 route:

```
R6>sh ipv6 route
IPv6 Routing Table - default - 9 entries
Codes: C - Connected, L - Local, S - Static, U - Per-user Static route
       B - BGP, HA - Home Agent, MR - Mobile Router, R - RIP
       H - NHRP, I1 - ISIS L1, I2 - ISIS L2, IA - ISIS interarea
       IS - ISIS summary, D - EIGRP, EX - EIGRP external, NM - NEMO
       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, l - LISP
OI  FE0:2::2/128 [110/4]
     via FE80::32E4:DBFF:FE67:1779, GigabitEthernet0/0
OI  2001:DB8:ACAD:A::/64 [110/2]
     via FE80::32E4:DBFF:FE67:1779, GigabitEthernet0/0
OI  2001:DB8:ACAD:B::/64 [110/4]
     via FE80::32E4:DBFF:FE67:1779, GigabitEthernet0/0
OI  2001:DB8:ACAD:C::/64 [110/2]
     via FE80::32E4:DBFF:FE67:1779, GigabitEthernet0/0
OI  2001:DB8:ACAD:D::/64 [110/5]
     via FE80::32E4:DBFF:FE67:1779, GigabitEthernet0/0
C   2001:DB8:ACAD:E::/64 [0/0]
     via GigabitEthernet0/0, directly connected
L   2001:DB8:ACAD:E::2/128 [0/0]
     via GigabitEthernet0/0, receive
OI  FE01:3::3/128 [110/1]
     via FE80::32E4:DBFF:FE67:1779, GigabitEthernet0/0
L   FF00::/8 [0/0]
     via Null0, receive
```

Router 5 show ip ospf neighbor:

```
R5#sh ip ospf neigh

Neighbor ID Pri State Dead Time Address Interface
2.2.2.2 1 FULL/BDR 00:00:31 192.168.2.2 GigabitEthernet0/0
6.6.6.6 1 FULL/DR 00:00:30 192.168.5.2 GigabitEthernet0/1
3.3.3.3 0 FULL/ - 00:00:34 192.168.3.2 OSPF_VL0

R5#sh ipv6 ospf neigh

Neighbor ID Pri State Dead Time Interface ID Interface
2.2.2.2 1 FULL/BDR 00:00:36 2 GigabitEthernet0/0
6.6.6.6 1 FULL/DR 00:00:36 1 GigabitEthernet0/1
3.3.3.3 0 FULL/ - 00:00:34 1 OSPFv3_VL0
```

Router 3 show ip ospf neighbor:

```
R3#sh ip ospf neigh
Neighbor ID Pri State Dead Time Address Interface
1.1.1.1 1 FULL/BDR 00:00:36 192.168.3.1 GigabitEthernet0/0
5.5.5.5 0 EXCHANGE/ - 00:00:35 192.168.2.1 OSPF_VL0
4.4.4.4 1 FULL/DR 00:00:35 192.168.4.2 GigabitEthernet0/1

R3#sh ipv6 ospf neigh
Neighbor ID Pri State Dead Time Interface ID Interface
1.1.1.1 1 FULL/BDR 00:00:39 2 GigabitEthernet0/0
4.4.4.4 1 FULL/DR 00:00:39 1 GigabitEthernet0/1
5.5.5.5 0 FULL/ - 00:00:34 1 OSPFv3_VL0
```

Problems

When I first started the lab, I researched how to configure a virtual link online, and tried to emulate a similar configuration, but I didn't realize that the example topology was different in that there were only three routers. I decided to take the information that I learned and apply it to my own topology, leading me to create a more detailed routing table and network diagram to help myself understand the network better. Even though I knew the correct command to use, I had trouble identifying the correct address to use for the destination router when configuring the virtual link. At first, I used the router id, but did not configure a loopback address, so the virtual link stayed down. Next I tried the IP address of the interface in the transit area, but the virtual link was not even created. Finally, I added loopback addresses to the area border routers that corresponded to the router ids, and that was successful.

Conclusion

In general, the lab was accomplished favorably. Because the virtual link was the only new concept, I was able to configure multi-area OSPF and interface addressing smoothly. In return, my only main troubleshooting area was the virtual link. I also had to adapt to the new lab and learn how to operate the rack, and I think I am fully comfortable working in the lab now.