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# Final Report

## Data Transmission, Lab3

### Configuring Basic Aspects of OSPF Routing Protocol

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### 3A. BASIC DEVICE CONFIGURATION

In this task we have decided to use 192.168.0.X as a loopback interface ip address, with ‘X’ being a natural number, denoting routers from R1 to R5. Below is the table of the loopback addresses:

Router	Loopback IP
R1	192.168.0.1
R2	192.168.0.2
R3	192.168.0.3
R4	192.168.0.4
R5	192.168.0.5

Moreover, this task required using the ip address pool 192.168.11.0/30 for routers R1- R2 and 192.168.10.0/27 for routers R2-R5 in given network topology. Therefore, we have introduced the following table:

Interface	Router Ri – Router Rj	IP Router Ri	IP Router Rj	Network
e0/0	R1 – R2	192.168.11.1	192.168.11.2	192.168.11.0/30
e0/2	R2 – R3	192.168.10.1	192.168.10.2	192.168.10.0/30
e0/1	R2 – R4	192.168.10.5	192.168.10.6	192.168.10.4/30
e0/3	R3 – R4	192.168.10.10	192.168.10.9	192.168.10.8/30
e0/2	R4 – R5	192.168.10.13	192.168.10.14	192.168.10.12/30
e0/0	R3 – R5	192.168.10.17	192.168.10.18	192.168.10.16/30

After configuring the routers using tables provided above, enabling cdp command and turning on the port, we run “show cdp neighbors” and “show ip route” commands on every router. Below is the screenshots of the result:

Router 1)

```
[R1#show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater

Device ID      Local Intrfce     Holdtme   Capability  Platform  Port ID
R2              Eth 0/0          168        R S I       3640      Eth 0/0
[R1#show 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

      192.168.11.0/30 is subnetted, 1 subnets
C        192.168.11.0 is directly connected, Ethernet0/0
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.1 is directly connected, Loopback0
```

Router 2)

```
R2#show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater

Device ID      Local Intrfce     Holdtme   Capability  Platform  Port ID
R3            Eth 0/2          171        R S I       3640      Eth 0/2
R1            Eth 0/0          121        R S I       3640      Eth 0/0
R4            Eth 0/1          150        R S I       3640      Eth 0/1

R2#show 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

      192.168.10.0/30 is subnetted, 2 subnets
C        192.168.10.0 is directly connected, Ethernet0/2
C        192.168.10.4 is directly connected, Ethernet0/1
      192.168.11.0/30 is subnetted, 1 subnets
C        192.168.11.0 is directly connected, Ethernet0/0
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.2 is directly connected, Loopback0
```

Router 3)

```
R3#show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater

Device ID      Local Intrfce     Holdtme   Capability  Platform  Port ID
R2            Eth 0/2          148        R S I       3640      Eth 0/2
R4            Eth 0/3          176        R S I       3640      Eth 0/3
R5            Eth 0/0          137        R S I       3640      Eth 0/0

R3#show 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

      192.168.10.0/30 is subnetted, 3 subnets
C        192.168.10.0 is directly connected, Ethernet0/2
C        192.168.10.8 is directly connected, Ethernet0/3
C        192.168.10.16 is directly connected, Ethernet0/0
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.3 is directly connected, Loopback0
```

Router 4)

```
R4#show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater

Device ID      Local Intrfce     Holdtme   Capability  Platform  Port ID
R2             Eth 0/1          123        R S I      3640      Eth 0/1
R3             Eth 0/3          173        R S I      3640      Eth 0/3
R5             Eth 0/2          172        R S I      3640      Eth 0/2

R4#show 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

      192.168.10.0/30 is subnetted, 3 subnets
C        192.168.10.4 is directly connected, Ethernet0/1
C        192.168.10.8 is directly connected, Ethernet0/3
C        192.168.10.12 is directly connected, Ethernet0/2
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.4 is directly connected, Loopback0
```

Router 5)

```
R5#show cdp neighbors
Capability Codes: R - Router, T - Trans Bridge, B - Source Route Bridge
                  S - Switch, H - Host, I - IGMP, r - Repeater

Device ID      Local Intrfce     Holdtme   Capability  Platform  Port ID
R3             Eth 0/0          158        R S I      3640      Eth 0/0
R4             Eth 0/2          136        R S I      3640      Eth 0/2

R5#show 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

      192.168.10.0/30 is subnetted, 2 subnets
C        192.168.10.12 is directly connected, Ethernet0/2
C        192.168.10.16 is directly connected, Ethernet0/0
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.5 is directly connected, Loopback0
```

We can see the physical connections between routers including the information about the interface of communication with devices for all the routers using “show cdp neighbors”. Having this information, we can check the proper connection between devices and use it when configuring IP addresses of physical interfaces.

After running “show ip route” command there are some observations about the outcomes of this configuration.

## 3B. INITIAL OSPF PROTOCOL CONFIGURATION

After completing the initial device configuration we proceeded to setting up the OSPF protocol for all routers. In the first stage all routers were in the same area - default backbone area. Here is an example of the commands used for router R5:

```
R5#config terminal
Enter configuration commands, one per line. End with CNTL/Z.
R5(config)#router ospf 5
R5(config-router)#network 192.168.10.12 0.0.0.3 area 0
R5(config-router)#network 192.168.10.16 0.0.0.3 area 0
[R5(config-router)#end
R5#
*Mar 1 02:43:49.387: %SYS-5-CONFIG_I: Configured from console by console
```

We checked the OSPF configuration and routing tables of all routers, by running the commands “show ip route” and “show ip ospf” to ensure if the setting was correct. Here is the output:

Router 1)

```
R1#show ip ospf
Routing Process "ospf 1" with ID 192.168.0.1
Start time: 02:43:56.080, Time elapsed: 00:02:47.392
Supports only single TOS(TOS0) routes
Supports opaque LSA
Supports Link-local Signaling (LLS)
Supports area transit capability
Router is not originating router-LSAs with maximum metric
Initial SPF schedule delay 5000 msec
Minimum hold time between two consecutive SPFs 10000 msec
Maximum wait time between two consecutive SPFs 10000 msec
Incremental-SPF disabled
Minimum LSA interval 5 secs
Minimum LSA arrival 1000 msec
LSA group pacing timer 240 secs
Interface flood pacing timer 33 msec
Retransmission pacing timer 66 msec
Number of external LSA 0. Checksum Sum 0x000000
Number of opaque AS LSA 0. Checksum Sum 0x000000
Number of DCbitless external and opaque AS LSA 0
Number of DoNotAge external and opaque AS LSA 0
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Number of areas transit capable is 0
External flood list length 0

R1#show ip route
^
% Invalid input detected at '^' marker.

R1#show 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

      192.168.10.0/30 is subnetted, 5 subnets
O        192.168.10.0 [110/20] via 192.168.11.2, 00:00:37, Ethernet0/0
O        192.168.10.4 [110/20] via 192.168.11.2, 00:00:37, Ethernet0/0
O        192.168.10.8 [110/30] via 192.168.11.2, 00:00:37, Ethernet0/0
O        192.168.10.12 [110/30] via 192.168.11.2, 00:00:37, Ethernet0/0
O        192.168.10.16 [110/30] via 192.168.11.2, 00:00:37, Ethernet0/0
      192.168.11.0/30 is subnetted, 1 subnets
C        192.168.11.0 is directly connected, Ethernet0/0
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.1 is directly connected, Loopback0
```

Router 2)

```
[R2#show ip ospf
Routing Process "ospf 2" with ID 192.168.0.2
Start time: 02:42:51.036, Time elapsed: 00:02:42.724
Supports only single TOS(TOS0) routes
Supports opaque LSA
Supports Link-local Signaling (LLS)
Supports area transit capability
Router is not originating router-LSAs with maximum metric
Initial SPF schedule delay 5000 msec
Minimum hold time between two consecutive SPFs 10000 msec
Maximum wait time between two consecutive SPFs 10000 msec
Incremental-SPF disabled
Minimum LSA interval 5 secs
Minimum LSA arrival 1000 msec
LSA group pacing timer 240 secs
Interface flood pacing timer 33 msec
Retransmission pacing timer 66 msec
Number of external LSA 0. Checksum Sum 0x000000
Number of opaque AS LSA 0. Checksum Sum 0x000000
Number of DCbitless external and opaque AS LSA 0
Number of DoNotAge external and opaque AS LSA 0
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Number of areas transit capable is 0
External flood list length 0

[R2#show 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

      192.168.10.0/30 is subnetted, 5 subnets
C        192.168.10.0 is directly connected, Ethernet0/2
C        192.168.10.4 is directly connected, Ethernet0/1
O        192.168.10.8 [110/20] via 192.168.10.6, 00:00:55, Ethernet0/1
                  [110/20] via 192.168.10.2, 00:00:55, Ethernet0/2
O        192.168.10.12 [110/20] via 192.168.10.6, 00:00:55, Ethernet0/1
O        192.168.10.16 [110/20] via 192.168.10.2, 00:00:55, Ethernet0/2
      192.168.11.0/30 is subnetted, 1 subnets
C        192.168.11.0 is directly connected, Ethernet0/0
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.2 is directly connected, Loopback0
```

Router 3)

```
[R3#show ip ospf
Routing Process "ospf 3" with ID 192.168.0.3
Start time: 02:43:04.908, Time elapsed: 00:02:38.308
Supports only single TOS(TOS0) routes
Supports opaque LSA
Supports Link-local Signaling (LLS)
Supports area transit capability
Router is not originating router-LSAs with maximum metric
Initial SPF schedule delay 5000 msec
Minimum hold time between two consecutive SPFs 10000 msec
Maximum wait time between two consecutive SPFs 10000 msec
Incremental-SPF disabled
Minimum LSA interval 5 secs
Minimum LSA arrival 1000 msec
LSA group pacing timer 240 secs
Interface flood pacing timer 33 msec
Retransmission pacing timer 66 msec
Number of external LSA 0. Checksum Sum 0x0000000
Number of opaque AS LSA 0. Checksum Sum 0x0000000
Number of DCbitless external and opaque AS LSA 0
Number of DoNotAge external and opaque AS LSA 0
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Number of areas transit capable is 0
External flood list length 0
[ Area BACKBONE(0)
[ Number of interfaces in this area is 3
[ Area has no authentication
[ SPF algorithm last executed 00:01:13.256 ago
[ SPF algorithm executed 5 times
[ Area ranges are
[ Number of LSA 11. Checksum Sum 0x053AE5
[ Number of opaque link LSA 0. Checksum Sum 0x0000000
[ Number of DCbitless LSA 0
[ Number of indication LSA 0
[ Number of DoNotAge LSA 0
[ Flood list length 0
[

[R3#
[R3#
[R3#
[R3#show 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

      192.168.10.0/30 is subnetted, 5 subnets
C        192.168.10.0 is directly connected, Ethernet0/2
O        192.168.10.4 [110/20] via 192.168.10.9, 00:01:22, Ethernet0/3
                  [110/20] via 192.168.10.1, 00:01:22, Ethernet0/2
C        192.168.10.8 is directly connected, Ethernet0/3
O        192.168.10.12 [110/20] via 192.168.10.18, 00:01:22, Ethernet0/0
                  [110/20] via 192.168.10.9, 00:01:22, Ethernet0/3
C        192.168.10.16 is directly connected, Ethernet0/0
      192.168.11.0/30 is subnetted, 1 subnets
O        192.168.11.0 [110/20] via 192.168.10.1, 00:01:23, Ethernet0/2
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.3 is directly connected, Loopback0
```

Router 4)

```
[R4#show ip ospf
Routing Process "ospf 4" with ID 192.168.0.4
Start time: 02:43:29.220, Time elapsed: 00:03:12.988
Supports only single TOS(TOS0) routes
Supports opaque LSA
Supports Link-local Signaling (LLS)
Supports area transit capability
Router is not originating router-LSAs with maximum metric
Initial SPF schedule delay 5000 msecs
Minimum hold time between two consecutive SPFs 10000 msecs
Maximum wait time between two consecutive SPFs 10000 msecs
Incremental-SPF disabled
Minimum LSA interval 5 secs
Minimum LSA arrival 1000 msecs
LSA group pacing timer 240 secs
Interface flood pacing timer 33 msecs
Retransmission pacing timer 66 msecs
Number of external LSA 0. Checksum Sum 0x000000
Number of opaque AS LSA 0. Checksum Sum 0x000000
Number of DCbitless external and opaque AS LSA 0
Number of DoNotAge external and opaque AS LSA 0
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Number of areas transit capable is 0
External flood list length 0
[ Area BACKBONE(0)
[ Number of interfaces in this area is 3
[ Area has no authentication
[ SPF algorithm last executed 00:02:11.552 ago
[ SPF algorithm executed 6 times
Area ranges are
[ Number of LSA 11. Checksum Sum 0x053AE5
[ 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
[

[R4#
[R4#show 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

      192.168.10.0/30 is subnetted, 5 subnets
O        192.168.10.0 [110/20] via 192.168.10.10, 00:02:17, Ethernet0/3
                  [110/20] via 192.168.10.5, 00:02:17, Ethernet0/1
C        192.168.10.4 is directly connected, Ethernet0/1
C        192.168.10.8 is directly connected, Ethernet0/3
C        192.168.10.12 is directly connected, Ethernet0/2
O        192.168.10.16 [110/20] via 192.168.10.14, 00:02:17, Ethernet0/2
                  [110/20] via 192.168.10.10, 00:02:17, Ethernet0/3
      192.168.11.0/30 is subnetted, 1 subnets
O        192.168.11.0 [110/20] via 192.168.10.5, 00:02:18, Ethernet0/1
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.4 is directly connected, Loopback0
```

## Router 5)

```
[R5#show ip ospf
Routing Process "ospf 5" with ID 192.168.0.5
Start time: 02:43:48.072, Time elapsed: 00:03:24.000
Supports only single TOS(TOS0) routes
Supports opaque LSA
Supports Link-local Signaling (LLS)
Supports area transit capability
Router is not originating router-LSAs with maximum metric
Initial SPF schedule delay 5000 msec
Minimum hold time between two consecutive SPFs 10000 msec
Maximum wait time between two consecutive SPFs 10000 msec
Incremental-SPF disabled
Minimum LSA interval 5 secs
Minimum LSA arrival 1000 msec
LSA group pacing timer 240 secs
Interface flood pacing timer 33 msec
Retransmission pacing timer 66 msec
Number of external LSA 0. Checksum Sum 0x000000
Number of opaque AS LSA 0. Checksum Sum 0x000000
Number of DCbitless external and opaque AS LSA 0
Number of DoNotAge external and opaque AS LSA 0
Number of areas in this router is 1. 1 normal 0 stub 0 nssa
Number of areas transit capable is 0
External flood list length 0
[   Area BACKBONE(0)
[     Number of interfaces in this area is 2
[     Area has no authentication
[     SPF algorithm last executed 00:02:41.276 ago
      SPF algorithm executed 4 times
[     Area ranges are
[       Number of LSA 11. Checksum Sum 0x053AE5
       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
[

R5#
[R5#show 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

      192.168.10.0/30 is subnetted, 5 subnets
0        192.168.10.0 [110/20] via 192.168.10.17, 00:02:49, Ethernet0/0
0        192.168.10.4 [110/20] via 192.168.10.13, 00:02:49, Ethernet0/2
0        192.168.10.8 [110/20] via 192.168.10.17, 00:02:49, Ethernet0/0
                  [110/20] via 192.168.10.13, 00:02:49, Ethernet0/2
C        192.168.10.12 is directly connected, Ethernet0/2
C        192.168.10.16 is directly connected, Ethernet0/0
      192.168.11.0/30 is subnetted, 1 subnets
0        192.168.11.0 [110/30] via 192.168.10.17, 00:02:50, Ethernet0/0
                  [110/30] via 192.168.10.13, 00:02:50, Ethernet0/2
      192.168.0.0/32 is subnetted, 1 subnets
C        192.168.0.5 is directly connected, Loopback0
R5#
```

### 3C. OSPF DATABASE

We've switched the kind of links between routers R2-R4, R2-R3, R3-R5, and R4-R5 from broadcast to point-to-point at this point. As a result, each router announces its router LSA because all routers are in the same region, but only routers R2 and R4 send network LSAs because the type of 192.168.11.0 and 192.168.10.4 links is set to broadcast and they are the designated routers for those subnetworks (as perceived by R5). Below is the example of a change on the R4 router:

```
R4#config terminal
Enter configuration commands, one per line. End with CNTL/Z.
R4(config)#interface e0/1
R4(config-if)#ip ospf network point-to-point
R4(config-if)#interface e0/2
R4(config-if)#ip ospf network point-to-point
[R4(config-if)#end
R4#
```

We ran the command “show ip ospf database” on router R5 to check the routing information and got the following output:

```
[R5#show ip ospf database

        OSPF Router with ID (192.168.0.5) (Process ID 5)

        Router Link States (Area 0)

Link ID      ADV Router      Age      Seq#      Checksum Link count
192.168.0.1  192.168.0.1  498      0x80000002 0x008ED9 1
192.168.0.2  192.168.0.2  62       0x80000005 0x0081D0 5
192.168.0.3  192.168.0.3  50       0x80000005 0x00A485 5
192.168.0.4  192.168.0.4  30       0x80000006 0x008D9A 5
192.168.0.5  192.168.0.5  16       0x80000006 0x00C35B 4

        Net Link States (Area 0)

Link ID      ADV Router      Age      Seq#      Checksum
192.168.10.9 192.168.0.4  450      0x80000001 0x00FB7D
192.168.11.2 192.168.0.2  497      0x80000001 0x001372
```

After that we analyse the output, which shows us type 1 LSAs.

We can see information about the age of the LSA (how long ago the router R5 received the LSA), the type and ID of the link state, the router that announced the LSA (router R3), information for checking the validity of the LSA, and the number of links the router announces (5 in case of R3) by focusing on the LSA sent by router R3 (identified by the loopback address - 192.168.0.3).

Next, we ran the command “show ip ospf database router” on router R5 and got the following output:

```
[R5#show ip ospf database router

    OSPF Router with ID (192.168.0.5) (Process ID 5)

        Router Link States (Area 0)

LS age: 558
Options: (No TOS-capability, DC)
LS Type: Router Links
Link State ID: 192.168.0.1
Advertising Router: 192.168.0.1
LS Seq Number: 80000002
Checksum: 0x8ED9
Length: 36
Number of Links: 1

Link connected to: a Transit Network
(Link ID) Designated Router address: 192.168.11.2
(Link Data) Router Interface address: 192.168.11.1
Number of TOS metrics: 0
TOS 0 Metrics: 10

[ LS age: 123
[ Options: (No TOS-capability, DC)
[ LS Type: Router Links
Link State ID: 192.168.0.2
Advertising Router: 192.168.0.2
LS Seq Number: 80000005
Checksum: 0x81D0
Length: 84
Number of Links: 5

[ Link connected to: another Router (point-to-point)
(Link ID) Neighboring Router ID: 192.168.0.4
(Link Data) Router Interface address: 192.168.10.5
Number of TOS metrics: 0
TOS 0 Metrics: 10

[ Link connected to: a Stub Network
(Link ID) Network/subnet number: 192.168.10.4
(Link Data) Network Mask: 255.255.255.252
Number of TOS metrics: 0
TOS 0 Metrics: 10

[ Link connected to: another Router (point-to-point)
(Link ID) Neighboring Router ID: 192.168.0.3
(Link Data) Router Interface address: 192.168.10.1
Number of TOS metrics: 0
TOS 0 Metrics: 10

[ Link connected to: a Stub Network
(Link ID) Network/subnet number: 192.168.10.0
(Link Data) Network Mask: 255.255.255.252
Number of TOS metrics: 0
TOS 0 Metrics: 10

[ Link connected to: a Transit Network
(Link ID) Designated Router address: 192.168.11.2
(Link Data) Router Interface address: 192.168.11.2
Number of TOS metrics: 0
TOS 0 Metrics: 10

[ LS age: 118
[ Options: (No TOS-capability, DC)
[ LS Type: Router Links
[ Link State ID: 192.168.0.3
[ Advertising Router: 192.168.0.3
```

```
[ LS Seq Number: 80000005
[ Checksum: 0xA485
[ Length: 84
[ Number of Links: 5
[
[   Link connected to: another Router (point-to-point)
[     (Link ID) Neighboring Router ID: 192.168.0.5
[     (Link Data) Router Interface address: 192.168.10.17
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[   Link connected to: a Stub Network
[     (Link ID) Network/subnet number: 192.168.10.16
[     (Link Data) Network Mask: 255.255.255.252
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[   Link connected to: a Transit Network
[     (Link ID) Designated Router address: 192.168.10.9
[     (Link Data) Router Interface address: 192.168.10.10
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[   Link connected to: another Router (point-to-point)
[     (Link ID) Neighboring Router ID: 192.168.0.2
[     (Link Data) Router Interface address: 192.168.10.2
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[   Link connected to: a Stub Network
[     (Link ID) Network/subnet number: 192.168.10.0
[     (Link Data) Network Mask: 255.255.255.252
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[ LS age: 106
[ Options: (No TOS-capability, DC)
[ LS Type: Router Links
[ Link State ID: 192.168.0.4
[ Advertising Router: 192.168.0.4
[ LS Seq Number: 80000006
[ Checksum: 0x8D9A
[ Length: 84
[ Number of Links: 5
[
[   Link connected to: another Router (point-to-point)
[     (Link ID) Neighboring Router ID: 192.168.0.5
[     (Link Data) Router Interface address: 192.168.10.13
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[   Link connected to: a Stub Network
[     (Link ID) Network/subnet number: 192.168.10.12
[     (Link Data) Network Mask: 255.255.255.252
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[   Link connected to: a Transit Network
[     (Link ID) Designated Router address: 192.168.10.9
[     (Link Data) Router Interface address: 192.168.10.9
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[   Link connected to: another Router (point-to-point)
[     (Link ID) Neighboring Router ID: 192.168.0.2
[     (Link Data) Router Interface address: 192.168.10.6
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[   Link connected to: a Stub Network
[     (Link ID) Network/subnet number: 192.168.10.4
[     (Link Data) Network Mask: 255.255.255.252
[       Number of TOS metrics: 0
[       TOS 0 Metrics: 10
[
[ LS age: 99
[ Options: (No TOS-capability, DC)
[ LS Type: Router Links
[ Link State ID: 192.168.0.5
[ Advertising Router: 192.168.0.5
[ LS Seq Number: 80000006
[ Checksum: 0xC35B
[ Length: 72
[ Number of Links: 4
[
[   Link connected to: another Router (point-to-point)
[     (Link ID) Neighboring Router ID: 192.168.0.3
```

```
[ (Link Data) Router Interface address: 192.168.10.9
[   Number of TOS metrics: 0
[     TOS 0 Metrics: 10
[

[ Link connected to: another Router (point-to-point)
[ (Link ID) Neighboring Router ID: 192.168.0.2
[ (Link Data) Router Interface address: 192.168.10.6
[   Number of TOS metrics: 0
[     TOS 0 Metrics: 10
[

[ Link connected to: a Stub Network
[ (Link ID) Network/subnet number: 192.168.10.4
[ (Link Data) Network Mask: 255.255.255.252
[   Number of TOS metrics: 0
[     TOS 0 Metrics: 10
[

[ LS age: 99
[ Options: (No TOS-capability, DC)
[ LS Type: Router Links
[ Link State ID: 192.168.0.5
[ Advertising Router: 192.168.0.5
[ LS Seq Number: 80000006
[ Checksum: 0xC35B
[ Length: 72
[ Number of Links: 4
[

[ Link connected to: another Router (point-to-point)
[ (Link ID) Neighboring Router ID: 192.168.0.3
[ (Link Data) Router Interface address: 192.168.10.18
[   Number of TOS metrics: 0
[     TOS 0 Metrics: 10
[

[ Link connected to: a Stub Network
[ (Link ID) Network/subnet number: 192.168.10.16
[ (Link Data) Network Mask: 255.255.255.252
[   Number of TOS metrics: 0
[     TOS 0 Metrics: 10
[

[ Link connected to: another Router (point-to-point)
[ (Link ID) Neighboring Router ID: 192.168.0.4
[ (Link Data) Router Interface address: 192.168.10.14
[   Number of TOS metrics: 0
[     TOS 0 Metrics: 10
[

[ Link connected to: a Stub Network
[ (Link ID) Network/subnet number: 192.168.10.12
[ (Link Data) Network Mask: 255.255.255.252
[   Number of TOS metrics: 0
[     TOS 0 Metrics: 10
```

Finally, we ran “show ip ospf database network”, which displays LSAs of type 2 that announce transit networks. As for router LSA we observe the advertising router, age, link state type, and validating information. The link state ID is the designated router’s ID for the transit network (the router which is responsible for announcing the network). The subnetwork mask and all routers in that network are also visible (identified by the loopback addresses). Below is the output of R5 router:

```
[R5#show ip ospf database network

    OSPF Router with ID (192.168.0.5) (Process ID 5)

        Net Link States (Area 0)

    Routing Bit Set on this LSA
    LS age: 544
    Options: (No TOS-capability, DC)
    LS Type: Network Links
    Link State ID: 192.168.10.9 (address of Designated Router)
    Advertising Router: 192.168.0.4
    LS Seq Number: 80000001
    Checksum: 0xFB7D
    Length: 32
    Network Mask: /30
    [
        Attached Router: 192.168.0.4
        Attached Router: 192.168.0.3

    Routing Bit Set on this LSA
    [
        LS age: 591
        Options: (No TOS-capability, DC)
        LS Type: Network Links
        Link State ID: 192.168.11.2 (address of Designated Router)
        Advertising Router: 192.168.0.2
        LS Seq Number: 80000001
        Checksum: 0x1372
        Length: 32
        Network Mask: /30
        Attached Router: 192.168.0.2
        Attached Router: 192.168.0.1
    ]]
```

### 3D. MULTI-AREA OSPF

We now have succeeded in establishing OSPF in a single area (area 0). At this stage, we must move R1-R2 interface into area 1. By this, we split the network into two separate areas (area 1 and area 0) making R2 an Area Boundary Router. Below is the example of configuration:

```
R1#config terminal
Enter configuration commands, one per line. End with CNTL/Z.
R1(config)#router ospf 1
R1(config-router)#network 192.168.11.0 0.0.0.3 area 1
R1(config-router)#end
*Mar 1 02:56:21.359: %OSPF-5-ADJCHG: Process 1, Nbr 192.168.0.2 on Ethernet0/0 from FULL to DOWN, Neighbor Down: Interface down or detached
*Mar 1 02:56:21.359: %OSPF-6-AREACHG: 192.168.11.0/30 changed from area 0 to area 1
R1(config-router)#end
```

Now we ran “show ip ospf database” command for routers R1 and R5 and see the output:

Router R1)

```
[R1#show ip ospf database

    OSPF Router with ID (192.168.0.1) (Process ID 1)

        Router Link States (Area 1)

Link ID      ADV Router      Age      Seq#      Checksum Link count
192.168.0.1  192.168.0.1   3        0x80000002 0x008ED9 1
192.168.0.2  192.168.0.2   4        0x80000002 0x008FD4 1

        Net Link States (Area 1)

Link ID      ADV Router      Age      Seq#      Checksum
192.168.11.2 192.168.0.2   4        0x80000001 0x001372

        Summary Net Link States (Area 1)

Link ID      ADV Router      Age      Seq#      Checksum
192.168.10.0 192.168.0.2   44       0x80000001 0x00A3B3
192.168.10.4 192.168.0.2   44       0x80000001 0x007BD7
192.168.10.8 192.168.0.2   44       0x80000001 0x00B78D
192.168.10.12 192.168.0.2   44       0x80000001 0x008FB1
192.168.10.16 192.168.0.2   44       0x80000001 0x0067D5
```

Router R5)

```
R5#show ip ospf database

    OSPF Router with ID (192.168.0.5) (Process ID 5)

        Router Link States (Area 0)

Link ID      ADV Router      Age      Seq#      Checksum Link count
192.168.0.1  192.168.0.1   786      0x80000002 0x008ED9 1
192.168.0.2  192.168.0.2   95       0x80000006 0x000551 4
192.168.0.3  192.168.0.3   338      0x80000005 0x00A485 5
192.168.0.4  192.168.0.4   319      0x80000006 0x008D9A 5
192.168.0.5  192.168.0.5   304      0x80000006 0x00C35B 4

        Net Link States (Area 0)

Link ID      ADV Router      Age      Seq#      Checksum
192.168.10.9 192.168.0.4   738      0x80000001 0x00FB7D

        Summary Net Link States (Area 0)

Link ID      ADV Router      Age      Seq#      Checksum
192.168.11.0 192.168.0.2   91       0x80000001 0x0098BD
```

Next, we ran “show ip ospf database summary” command for routers R1 and R5 and see the output:

Router R1)

```
R1#show ip ospf database summary

    OSPF Router with ID (192.168.0.1) (Process ID 1)

        Summary Net Link States (Area 1)

    Routing Bit Set on this LSA
    LS age: 77
    Options: (No TOS-capability, DC, Upward)
    LS Type: Summary Links(Network)
    Link State ID: 192.168.10.0 (summary Network Number)
    Advertising Router: 192.168.0.2
    LS Seq Number: 80000001
    Checksum: 0xA3B3
    Length: 28
    Network Mask: /30
        TOS: 0 Metric: 10

    [ Routing Bit Set on this LSA
    LS age: 77
    [ Options: (No TOS-capability, DC, Upward)
    [ LS Type: Summary Links(Network)
    [ Link State ID: 192.168.10.4 (summary Network Number)
    [ Advertising Router: 192.168.0.2
    [ LS Seq Number: 80000001
    [ Checksum: 0x7BD7
    [ Length: 28
    Network Mask: /30
        TOS: 0 Metric: 10
    [
    [
        Routing Bit Set on this LSA
        LS age: 80
        Options: (No TOS-capability, DC, Upward)
        LS Type: Summary Links(Network)
        Link State ID: 192.168.10.8 (summary Network Number)
        Advertising Router: 192.168.0.2
        LS Seq Number: 80000001
        Checksum: 0xB78D
        Length: 28
        Network Mask: /30
            TOS: 0 Metric: 20
    [
    [
        Routing Bit Set on this LSA
        LS age: 82
        Options: (No TOS-capability, DC, Upward)
        LS Type: Summary Links(Network)
        Link State ID: 192.168.10.12 (summary Network Number)
        Advertising Router: 192.168.0.2
        LS Seq Number: 80000001
        Checksum: 0x8FB1
        Length: 28
        Network Mask: /30
            TOS: 0 Metric: 20
    [
    [
        Routing Bit Set on this LSA
        LS age: 83
        Options: (No TOS-capability, DC, Upward)
        LS Type: Summary Links(Network)
        Link State ID: 192.168.10.16 (summary Network Number)
        Advertising Router: 192.168.0.2
        LS Seq Number: 80000001
        Checksum: 0x67D5
        Length: 28
        Network Mask: /30
            TOS: 0 Metric: 20
    ]]
```

Router R5)

```
R5#show ip ospf database summary

    OSPF Router with ID (192.168.0.5) (Process ID 5)

        Summary Net Link States (Area 0)

    Routing Bit Set on this LSA
    LS age: 98
    Options: (No TOS-capability, DC, Upward)
    LS Type: Summary Links(Network)
    Link State ID: 192.168.11.0 (summary Network Number)
    Advertising Router: 192.168.0.2
    LS Seq Number: 80000001
    Checksum: 0x98BD
    Length: 28
    Network Mask: /30
    TOS: 0 Metric: 10
```

The result of the “show ip ospf database summary” command on R1 and R5 differs noticeably, which is due to the fact that router R2, as the border router, announces the topology of area 1 to all routers in area 0, and vice versa. Because the R1-R2 interface is the sole one in area 1 in our network, router R5 receives this data and stores it in its OSPF link state database. R2, on the other hand, receives information on the topology of area 0, therefore R2 announces all interfaces R2-R3, R2-R4, R3-R5, R4-R5, and R3-R4 to R1, which records the information in its OSPF database.

### 3E. OSPF LINK COST

Before applying changes on link costs, we have decided to run “ping” and “traceroute” commands from R4 to R1 on interface e0/0. The results were successful, and we were able to communicate between those two routers: all the packets were delivered using ping command and traceroute command showed us the shortest path.

```
R4#ping 192.168.11.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.11.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/47/72 ms
R4#traceroute 192.168.11.1

Type escape sequence to abort.
Tracing the route to 192.168.11.1

 1 192.168.10.5 28 msec 16 msec 28 msec
 2 192.168.11.1 36 msec 40 msec 36 msec
```

Then we ran “show ip route” command that displays a router's routing table, which includes the router to which traffic should be directed in order to deliver a package and the total cost of transportation. The routing table for router R1 is as follows:

```

R1#show 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

      192.168.10.0/30 is subnetted, 5 subnets
O IA    192.168.10.0 [110/20] via 192.168.11.2, 00:03:20, Ethernet0/0
O IA    192.168.10.4 [110/20] via 192.168.11.2, 00:03:20, Ethernet0/0
O IA    192.168.10.8 [110/30] via 192.168.11.2, 00:03:20, Ethernet0/0
O IA    192.168.10.12 [110/30] via 192.168.11.2, 00:03:20, Ethernet0/0
O IA    192.168.10.16 [110/30] via 192.168.11.2, 00:03:20, Ethernet0/0
      192.168.11.0/30 is subnetted, 1 subnets
C      192.168.11.0 is directly connected, Ethernet0/0
      192.168.0.0/32 is subnetted, 1 subnets
C      192.168.0.1 is directly connected, Loopback0

```

Because the cost of each hop is set to 10 by default and has not been altered, the cost (second value in square brackets) is equal to the length of the shortest path multiplied by 10. It's worth noting that the route cost includes the cost of the last link as well.

When we use the amount of bandwidth in MB to compare the value of default bandwidth (10MB) of an interface to link cost (10), we observe that they are identical. Below is the example of routers R2 and R4 (interface e0/1) that shows it. The information about the bandwidth and the cost is symmetric.

Router R2)

```

R2#show ip ospf interface brief
Interface   PID   Area           IP Address/Mask   Cost   State Nbrs F/C
Et0/1       2     0              192.168.10.5/30   10     P2P   1/1
Et0/2       2     0              192.168.10.1/30   10     P2P   1/1
Et0/0       2     1              192.168.11.2/30   10     DR    1/1
R2#show ip ospf interface | include protocol | Cost
Ethernet0/1 is up, line protocol is up
  Process ID 2, Router ID 192.168.0.2, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/2 is up, line protocol is up
  Process ID 2, Router ID 192.168.0.2, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/0 is up, line protocol is up
  Process ID 2, Router ID 192.168.0.2, Network Type BROADCAST, Cost: 10
R2#show interface | include protocol | BW
Ethernet0/0 is up, line protocol is up
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
  0 unknown protocol drops
Ethernet0/1 is up, line protocol is up
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
  0 unknown protocol drops
Ethernet0/2 is up, line protocol is up
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
  0 unknown protocol drops
Ethernet0/3 is administratively down, line protocol is down
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
  0 unknown protocol drops
Loopback0 is up, line protocol is up
  MTU 1514 bytes, BW 8000000 Kbit/sec, DLY 5000 usec,
  0 unknown protocol drops

```

Router R4)

```
R4#show ip ospf interface brief
Interface    PID   Area          IP Address/Mask   Cost   State Nbrs F/C
Et0/2        4     0             192.168.10.13/30  10     P2P   1/1
Et0/3        4     0             192.168.10.9/30   10     DR    1/1
Et0/1        4     0             192.168.10.6/30   10     P2P   1/1
R4#show ip ospf interface | include protocol | Cost
Ethernet0/2 is up, line protocol is up
  Process ID 4, Router ID 192.168.0.4, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/3 is up, line protocol is up
  Process ID 4, Router ID 192.168.0.4, Network Type BROADCAST, Cost: 10
Ethernet0/1 is up, line protocol is up
  Process ID 4, Router ID 192.168.0.4, Network Type POINT_TO_POINT, Cost: 10
R4#show interface | include protocol | BW
Ethernet0/0 is administratively down, line protocol is down
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
    0 unknown protocol drops
Ethernet0/1 is up, line protocol is up
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
    0 unknown protocol drops
Ethernet0/2 is up, line protocol is up
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
    0 unknown protocol drops
Ethernet0/3 is up, line protocol is up
  MTU 1500 bytes, BW 10000 Kbit/sec, DLY 1000 usec,
    0 unknown protocol drops
Loopback0 is up, line protocol is up
  MTU 1514 bytes, BW 8000000 Kbit/sec, DLY 5000 usec,
    0 unknown protocol drops
```

After, we increased the cost between R2-R4 connection. Below are the commands we ran to do that:

```
R2#config terminal
Enter configuration commands, one per line.  End with CNTL/Z.
R2(config)#interface e0/1
R2(config-if)#ip ospf cost 100
[R2(config-if)#end]
```

We can notice some changes in the network after increasing the cost of the R2-R4 connection, because routers chose the way with the lowest cost, therefore it is cheaper to skip the R2-R4 interface. Below is the output of “show ip ospf interface | include protocol | cost” command of router R4, which proves the above statement:

```
R4#show ip ospf interface | include protocol | Cost
Ethernet0/2 is up, line protocol is up
  Process ID 4, Router ID 192.168.0.4, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/3 is up, line protocol is up
  Process ID 4, Router ID 192.168.0.4, Network Type BROADCAST, Cost: 10
Ethernet0/1 is up, line protocol is up
  Process ID 4, Router ID 192.168.0.4, Network Type POINT_TO_POINT, Cost: 100
```

Now, we try to send the packets from R4 to R1 using ping command and trace its path. As we see, packets were successfully delivered, but the previous path has been changed. This is the consequence of increasing the connection cost:

```
R4#ping 192.168.11.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 192.168.11.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 40/56/72 ms
R4#traceroute 192.168.11.1

Type escape sequence to abort.
Tracing the route to 192.168.11.1

 1 192.168.10.10 8 msec 16 msec 20 msec
 2 192.168.10.1 32 msec 36 msec 44 msec
 3 192.168.11.1 60 msec 56 msec 76 msec
```