DATA TRANSMISSION

LAB4 – REPORT

Configuring MPLS

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1. Introduction

In this lab, the aim is to become familiarize with MPLS. At first, the IP addresses for interfaces of the routers were chosen and during the lab session the devices were configured according to those IP addresses. Figure 1 shows the IP addresses for each interface.

Router	Interface	IP Address
R1	e0/0	10.0.12.1/30
	Loopback0	1.1.1.1/32
R2	e0/0	10.0.12.2/30
	e0/1	10.0.24.1/30
	e0/2	10.0.23.1/30
	Loopback0	2.2.2.2/32
R3	e0/0	10.0.35.1/30
	e0/2	10.0.23.2/30
	e0/3	10.0.34.1/30
	Loopback0	3.3.3.3/32
R4	e0/1	10.0.24.2/30
	e0/2	10.0.45.1/30
	e0/3	10.0.34.2/30
	Loopback0	4.4.4.4/32
R5	e0/0	10.0.35.2/30
	e0/2	10.0.45.2/30
	Loopback0	5.5.5.5/32

Figure 1: IP addresses assigned to each interface

In the figure the interfaces on the routers that forms a network highlighted with the same color so that reader can see the matching interfaces.

According to this lab the neighborhoods can be shown like below:

- R1 - R2
- R2 - R1, R3, R4
- R3 - R2, R4, R5
- R4 - R2, R3, R5
- R5 - R3, R4

In addition to these, I have been requested from the professor that I should inform the reader that I do not have a lab partner, thus, I did all the lab on my own.

2. Task 3A – Address Assignment

In this task the address assignment for the interfaces was excepted according to the topology given in the lab document.

After the configuration of the interfaces of routers with the designated IP addresses the commands **show cdp neighbor** and **show cdp neighbor detail** were typed as it is requested. First one is for verifying the addressing (neighbors of each router) and the second one is to see the information about the neighbors in detail. The results of commands on each router are given below.

```
R1(config-if)#do show cdp neighbor
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           172         R S I      3640      Eth 0/0
R1(config-if)#do show cdp neighbor detail
-------------------------
Device ID: R2
Entry address(es):
  IP address: 10.0.12.2
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/0,  Port ID (outgoing port): Ethernet0/0
Holdtime : 163 sec

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advertisement version: 2
VTP Management Domain: ''
Duplex: half
```

```
R2(config-if)#do show cdp neighbor
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           140         R S I      3640      Eth 0/2
R1               Eth 0/0           129         R S I      3640      Eth 0/0
R4               Eth 0/1           177         R S I      3640      Eth 0/1
```

```
R2(config-if)#do show cdp neighbor detail
-------------------------
Device ID: R3
Entry address(es):
  IP address: 10.0.23.2
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/2,  Port ID (outgoing port): Ethernet0/2
Holdtime : 129 sec

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VTP Management Domain: ''
Duplex: half

-------------------------
Device ID: R1
Entry address(es):
  IP address: 10.0.12.1
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/0,  Port ID (outgoing port): Ethernet0/0
Holdtime : 176 sec

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Duplex: half

-------------------------
Device ID: R4
Entry address(es):
  IP address: 10.0.24.2
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/1,  Port ID (outgoing port): Ethernet0/1
Holdtime : 160 sec

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advertisement version: 2
VTP Management Domain: ''
Duplex: half
```

```
R3(config-if)#do show cdp neighbor
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            168        R S I      3640      Eth 0/2
R4               Eth 0/3            155        R S I      3640      Eth 0/3
R5               Eth 0/0            165        R S I      3640      Eth 0/0
```

```
R3(config-if)#do show cdp neighbor detail
-------------------------
Device ID: R2
Entry address(es):
  IP address: 10.0.23.1
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/2,  Port ID (outgoing port): Ethernet0/2
Holdtime : 160 sec

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advertisement version: 2
VTP Management Domain: ''
Duplex: half

-------------------------
Device ID: R4
Entry address(es):
  IP address: 10.0.34.2
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/3,  Port ID (outgoing port): Ethernet0/3
Holdtime : 145 sec

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VTP Management Domain: ''
Duplex: half

-------------------------
Device ID: R5
Entry address(es):
  IP address: 10.0.35.2
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/0,  Port ID (outgoing port): Ethernet0/0
Holdtime : 149 sec

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advertisement version: 2
VTP Management Domain: ''
Duplex: half
```

```
R4(config-if)#do show cdp neighbor
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            140        R S I      3640      Eth 0/1
R3               Eth 0/3            160        R S I      3640      Eth 0/3
R5               Eth 0/2            138        R S I      3640      Eth 0/2
```

```
R4(config-if)#do show cdp neighbor detail
-------------------------
Device ID: R2
Entry address(es):
  IP address: 10.0.24.1
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/1,  Port ID (outgoing port): Ethernet0/1
Holdtime : 134 sec

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VTP Management Domain: ''
Duplex: half

-------------------------
Device ID: R3
Entry address(es):
  IP address: 10.0.34.1
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/3,  Port ID (outgoing port): Ethernet0/3
Holdtime : 152 sec

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advertisement version: 2
VTP Management Domain: ''
Duplex: half

-------------------------
Device ID: R5
Entry address(es):
  IP address: 10.0.45.2
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/2,  Port ID (outgoing port): Ethernet0/2
Holdtime : 121 sec

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VTP Management Domain: ''
Duplex: half
```

```
R5(config-if)#do show cdp neighbor
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            139        R S I      3640      Eth 0/0
R4               Eth 0/2            167        R S I      3640      Eth 0/2
R5(config-if)#do show cdp neighbor detail
-------------------------
Device ID: R3
Entry address(es):
  IP address: 10.0.35.1
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/0,  Port ID (outgoing port): Ethernet0/0
Holdtime : 128 sec

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advertisement version: 2
VTP Management Domain: ''
Duplex: half

-------------------------
Device ID: R4
Entry address(es):
  IP address: 10.0.45.1
Platform: Cisco 3640,  Capabilities: Router Switch IGMP
Interface: Ethernet0/2,  Port ID (outgoing port): Ethernet0/2
Holdtime : 153 sec

Version :
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advertisement version: 2
VTP Management Domain: ''
Duplex: half
```

For all of the routers, the entry for **show cdp neighbor** command shows that the router that this command is typed for is now neighbors of others just like specified in the lab document and for the **show cdp neigbor detail,** the details of these neighborhoods can be seen.

3. Task 3B – Running OSPF

To be able configure MPLS, a routing protocol is needed, hence, OSPF protocol should be configured in the network at first. On each router OSPF protocol is initiated and then with the help of **ip ospf network point-to-point** command, the point-to-point mode is set for all interfaces.

After configuring OSPF and point-to-point mode for it, to ensure OSPF works properly **ping** command is used to see each router can ping one to another. The results can be seen below:

```
R1#ping 2.2.2.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2.2.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/50/112 ms
R1#ping 3.3.3.3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 3.3.3.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 36/65/92 ms
R1#ping 4.4.4.4

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 4.4.4.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/60/104 ms
R1#ping 5.5.5.5

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 5.5.5.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 76/88/100 ms
R1#ping 10.0.24.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.24.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 44/56/68 ms
R1#ping 10.0.23.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.23.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 24/44/56 ms
R1#ping 10.0.35.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.35.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 64/84/96 ms
R1#ping 10.0.34.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.34.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 32/51/72 ms
R1#ping 10.0.45.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.45.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 60/92/132 ms
R1#
```

```
R2#ping 1.1.1.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 1.1.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 16/36/72 ms
R2#ping 3.3.3.3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 3.3.3.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 12/24/32 ms
R2#ping 4.4.4.4

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 4.4.4.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 16/23/36 ms
R2#ping 5.5.5.5

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 5.5.5.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 40/54/72 ms
R2#ping 10.0.35.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.35.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 24/51/84 ms
R2#ping 10.0.34.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.34.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/40/56 ms
R2#ping 10.0.45.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.45.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 48/56/68 ms
```

```
R3#ping 1.1.1.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 1.1.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 28/55/108 ms
R3#ping 2.2.2.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2.2.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 12/22/36 ms
R3#ping 4.4.4.4

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 4.4.4.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/24/28 ms
R3#ping 5.5.5.5

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 5.5.5.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/32/48 ms
R3#ping 10.0.24.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.24.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 12/41/64 ms
R3#ping 10.0.12.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 16/24/40 ms
R3#ping 10.0.35.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.35.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/29/36 ms
```

```
R4#ping 1.1.1.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 1.1.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 16/356/1420 ms
R4#ping 2.2.2.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2.2.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 12/240/460 ms
R4# ping 3.3.3.3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 3.3.3.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/128/228 ms
R4#ping 5.5.5.5

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 5.5.5.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 16/84/256 ms
R4#ping 10.0.12.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 40/242/968 ms
R4#ping 10.0.35.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.35.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/506/1664 ms
R4#
```

```
R5#ping 1.1.1.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 1.1.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 80/854/1816 ms
R5#ping 2.2.2.2

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 2.2.2.2, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 104/251/616 ms
R5#ping 3.3.3.3

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 3.3.3.3, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 20/267/920 ms
R5#ping 4.4.4.4

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 4.4.4.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 80/203/396 ms
R5#ping 10.0.12.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.12.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 136/553/1500 ms
```

To see the link costs of the links **show ip ospf interface | include protocol|Cost** command is used, and the initial costs of all links were 10 at the beginning as it can be seen below:

```
R1#show ip ospf interface | include protocol|Cost
Loopback0 is up, line protocol is up
  Process ID 1, Router ID 1.1.1.1, Network Type LOOPBACK, Cost: 1
Ethernet0/0 is up, line protocol is up
  Process ID 1, Router ID 1.1.1.1, Network Type POINT_TO_POINT, Cost: 10
R1#
```

```
R2#show ip ospf interface | include protocol|Cost
Loopback0 is up, line protocol is up
  Process ID 1, Router ID 2.2.2.2, Network Type LOOPBACK, Cost: 1
Ethernet0/2 is up, line protocol is up
  Process ID 1, Router ID 2.2.2.2, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/1 is up, line protocol is up
  Process ID 1, Router ID 2.2.2.2, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/0 is up, line protocol is up
  Process ID 1, Router ID 2.2.2.2, Network Type POINT_TO_POINT, Cost: 10
R2#
```

```
R3#show ip ospf interface | include protocol|Cost
Loopback0 is up, line protocol is up
  Process ID 1, Router ID 3.3.3.3, Network Type LOOPBACK, Cost: 1
Ethernet0/2 is up, line protocol is up
  Process ID 1, Router ID 3.3.3.3, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/3 is up, line protocol is up
  Process ID 1, Router ID 3.3.3.3, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/0 is up, line protocol is up
  Process ID 1, Router ID 3.3.3.3, Network Type POINT_TO_POINT, Cost: 10
R3#
```

```
R4#show ip ospf interface | include protocol|Cost
Loopback0 is up, line protocol is up
  Process ID 1, Router ID 4.4.4.4, Network Type LOOPBACK, Cost: 1
Ethernet0/3 is up, line protocol is up
  Process ID 1, Router ID 4.4.4.4, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/1 is up, line protocol is up
  Process ID 1, Router ID 4.4.4.4, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/2 is up, line protocol is up
  Process ID 1, Router ID 4.4.4.4, Network Type POINT_TO_POINT, Cost: 10
R4#
```

```
R5#show ip ospf interface | include protocol|Cost
Loopback0 is up, line protocol is up
  Process ID 1, Router ID 5.5.5.5, Network Type LOOPBACK, Cost: 1
Ethernet0/2 is up, line protocol is up
  Process ID 1, Router ID 5.5.5.5, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/0 is up, line protocol is up
  Process ID 1, Router ID 5.5.5.5, Network Type POINT_TO_POINT, Cost: 10
R5#
```

After checking the link costs, the link cost between R2 and R3 is changed with the **ip ospf cost 100** command to simplify the output of the traceroute as it is requested in the document.

Below the results of commands can be seen for each router:

```
R3(config-if)#do show ip ospf interface | include protocol|Cost
Loopback0 is up, line protocol is up
  Process ID 1, Router ID 3.3.3.3, Network Type LOOPBACK, Cost: 1
Ethernet0/2 is up, line protocol is up
  Process ID 1, Router ID 3.3.3.3, Network Type POINT_TO_POINT, Cost: 100
Ethernet0/3 is up, line protocol is up
  Process ID 1, Router ID 3.3.3.3, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/0 is up, line protocol is up
  Process ID 1, Router ID 3.3.3.3, Network Type POINT_TO_POINT, Cost: 10
R3(config-if)#
```

```
R2(config-if)#do show ip ospf interface | include protocol|Cost
Loopback0 is up, line protocol is up
  Process ID 1, Router ID 2.2.2.2, Network Type LOOPBACK, Cost: 1
Ethernet0/2 is up, line protocol is up
  Process ID 1, Router ID 2.2.2.2, Network Type POINT_TO_POINT, Cost: 100
Ethernet0/1 is up, line protocol is up
  Process ID 1, Router ID 2.2.2.2, Network Type POINT_TO_POINT, Cost: 10
Ethernet0/0 is up, line protocol is up
  Process ID 1, Router ID 2.2.2.2, Network Type POINT_TO_POINT, Cost: 10
R2(config-if)#
```

Then traceroute command is run on R1 and R5:

```
R1#traceroute 5.5.5.5

Type escape sequence to abort.
Tracing the route to 5.5.5.5

  1 10.0.12.2 144 msec 40 msec 24 msec
  2 10.0.24.2 52 msec 28 msec 40 msec
  3 10.0.45.2 300 msec 128 msec 76 msec
R1#
```

It is seen that from R1 to R5, the link R2-R4 is used since the link cost of R2-R4 is 10 and R2-R3 is 100. The link having lower cost is chosen. From R5 to R1 the same link is used as well, and it can be seen below:

```
R5#traceroute 1.1.1.1

Type escape sequence to abort.
Tracing the route to 1.1.1.1

  1 10.0.45.1 4 msec 104 msec 20 msec
  2 10.0.24.1 40 msec 40 msec 40 msec
  3 10.0.12.1 148 msec 80 msec 72 msec
R5#
```

4. Task 3C – Basic MPLS Configuration

In this part, it is expected to configure MPLS protocol in the network. For better performances in the global configuration mode **ip cef** is enabled and **mpls ip** command is used to enable MPLS. In addition to this, on each interface of the routers MPLS is enabled with **mpls ip** command as well. By doing so, tunnels between all routers were created automatically.

5. Task 3D – Verify MPLS/LDP Setup

To verify the configuration of MLS the various commands are run in R2:

- **show mpls interfaces, show mpls ldp neighbor:**

```
R2(config)#do show mpls interfaces
Interface              IP            Tunnel   Operational
Ethernet0/0            Yes (ldp)     No       Yes
Ethernet0/1            Yes (ldp)     No       Yes
Ethernet0/2            Yes (ldp)     No       Yes
R2(config)#do show mpls ldp neighbor
    Peer LDP Ident: 1.1.1.1:0; Local LDP Ident 2.2.2.2:0
        TCP connection: 1.1.1.1.646 - 2.2.2.2.16338
        State: Oper; Msgs sent/rcvd: 17/17; Downstream
        Up time: 00:03:14
        LDP discovery sources:
          Ethernet0/0, Src IP addr: 10.0.12.1
        Addresses bound to peer LDP Ident:
          10.0.12.1       1.1.1.1
    Peer LDP Ident: 3.3.3.3:0; Local LDP Ident 2.2.2.2:0
        TCP connection: 3.3.3.3.57640 - 2.2.2.2.646
        State: Oper; Msgs sent/rcvd: 16/16; Downstream
        Up time: 00:02:05
        LDP discovery sources:
          Ethernet0/2, Src IP addr: 10.0.23.2
        Addresses bound to peer LDP Ident:
          10.0.35.1       10.0.23.2       10.0.34.1       3.3.3.3
    Peer LDP Ident: 4.4.4.4:0; Local LDP Ident 2.2.2.2:0
        TCP connection: 4.4.4.4.13032 - 2.2.2.2.646
        State: Oper; Msgs sent/rcvd: 15/16; Downstream
        Up time: 00:01:33
        LDP discovery sources:
          Ethernet0/1, Src IP addr: 10.0.24.2
        Addresses bound to peer LDP Ident:
          10.0.24.2       10.0.45.1       10.0.34.2       4.4.4.4
```

Show mpls interfaces command is used to show all the interfaces that are added to MPLS. In here for R2 we can see that all its interfaces, R1-R2, R2-R3 and R2-R4, are added to MPLS as they should be. With **show mpls ldp neighbor** command we can see the LDP neighbors of R2 and which interfaces that are used to establish connections by using which ports. It is seen that

for the connection between R2 and R1, Ethernet0/0; between R2 and R3, Ethernet 0/2; R2 and R4, Ethernet0/1 is used. It is clearly seen that R2 became LDP neighbors with R1, R3 and R4.

- **show mpls ldp binding:**

```
R2(config)#do show mpls ldp binding
  tib entry: 1.1.1.1/32, rev 2
        local binding:  tag: 16
        remote binding: tsr: 1.1.1.1:0, tag: imp-null
        remote binding: tsr: 3.3.3.3:0, tag: 16
        remote binding: tsr: 4.4.4.4:0, tag: 16
  tib entry: 2.2.2.2/32, rev 4
        local binding:  tag: imp-null
        remote binding: tsr: 1.1.1.1:0, tag: 16
        remote binding: tsr: 3.3.3.3:0, tag: 17
        remote binding: tsr: 4.4.4.4:0, tag: 17
  tib entry: 3.3.3.3/32, rev 6
        local binding:  tag: 17
        remote binding: tsr: 1.1.1.1:0, tag: 17
        remote binding: tsr: 3.3.3.3:0, tag: imp-null
        remote binding: tsr: 4.4.4.4:0, tag: 18
  tib entry: 4.4.4.4/32, rev 8
        local binding:  tag: 18
        remote binding: tsr: 1.1.1.1:0, tag: 18
        remote binding: tsr: 3.3.3.3:0, tag: 18
        remote binding: tsr: 4.4.4.4:0, tag: imp-null
  tib entry: 5.5.5.5/32, rev 10
        local binding:  tag: 19
        remote binding: tsr: 1.1.1.1:0, tag: 19
        remote binding: tsr: 3.3.3.3:0, tag: 19
        remote binding: tsr: 4.4.4.4:0, tag: 19
  tib entry: 10.0.12.0/30, rev 12
        local binding:  tag: imp-null
        remote binding: tsr: 1.1.1.1:0, tag: imp-null
        remote binding: tsr: 3.3.3.3:0, tag: 20
        remote binding: tsr: 4.4.4.4:0, tag: 20
  tib entry: 10.0.23.0/30, rev 16
        local binding:  tag: imp-null
        remote binding: tsr: 1.1.1.1:0, tag: 21
        remote binding: tsr: 3.3.3.3:0, tag: imp-null
        remote binding: tsr: 4.4.4.4:0, tag: 21
  tib entry: 10.0.24.0/30, rev 14
        local binding:  tag: imp-null
        remote binding: tsr: 1.1.1.1:0, tag: 20
        remote binding: tsr: 3.3.3.3:0, tag: 21
        remote binding: tsr: 4.4.4.4:0, tag: imp-null
  tib entry: 10.0.34.0/30, rev 20
        local binding:  tag: 21
        remote binding: tsr: 1.1.1.1:0, tag: 23
        remote binding: tsr: 3.3.3.3:0, tag: imp-null
        remote binding: tsr: 4.4.4.4:0, tag: imp-null
  tib entry: 10.0.35.0/30, rev 22
        local binding:  tag: 22
        remote binding: tsr: 1.1.1.1:0, tag: 24
        remote binding: tsr: 3.3.3.3:0, tag: imp-null
        remote binding: tsr: 4.4.4.4:0, tag: 22
  tib entry: 10.0.45.0/30, rev 18
        local binding:  tag: 20
        remote binding: tsr: 1.1.1.1:0, tag: 22
        remote binding: tsr: 3.3.3.3:0, tag: 22
        remote binding: tsr: 4.4.4.4:0, tag: imp-null
```

This command is used to display the bindings learned from neighbors. R2 has binding with all loopback interfaces and networks between other routers with the associated tags. We see the locally bound labels and implicit-NULL tags which means that this tag is advertised when the packet will not be forwarded locally based on label but based on prefix.

- **show mpls forwarding-table, show mpls forwarding-table detail:**

```
R2(config)#do show mpls forwarding-table
Local  Outgoing    Prefix           Bytes tag  Outgoing   Next Hop
tag    tag or VC   or Tunnel Id     switched   interface
16     Pop tag     1.1.1.1/32       0          Et0/0      10.0.12.1
17     18          3.3.3.3/32       0          Et0/1      10.0.24.2
18     Pop tag     4.4.4.4/32       0          Et0/1      10.0.24.2
19     19          5.5.5.5/32       0          Et0/1      10.0.24.2
20     Pop tag     10.0.45.0/30     0          Et0/1      10.0.24.2
21     Pop tag     10.0.34.0/30     0          Et0/1      10.0.24.2
22     22          10.0.35.0/30     0          Et0/1      10.0.24.2
R2(config)#do show mpls forwarding-table detail
Local  Outgoing    Prefix           Bytes tag  Outgoing   Next Hop
tag    tag or VC   or Tunnel Id     switched   interface
16     Pop tag     1.1.1.1/32       0          Et0/0      10.0.12.1
       MAC/Encaps=14/14, MRU=1504, Tag Stack{}
       CC025ED50000CC035ED500008847
       No output feature configured
    Per-packet load-sharing
17     18          3.3.3.3/32       0          Et0/1      10.0.24.2
       MAC/Encaps=14/18, MRU=1500, Tag Stack{18}
       CC005ED50001CC035ED500018847 00012000
       No output feature configured
    Per-packet load-sharing
18     Pop tag     4.4.4.4/32       0          Et0/1      10.0.24.2
       MAC/Encaps=14/14, MRU=1504, Tag Stack{}
       CC005ED50001CC035ED500018847
       No output feature configured
    Per-packet load-sharing
19     19          5.5.5.5/32       0          Et0/1      10.0.24.2
       MAC/Encaps=14/18, MRU=1500, Tag Stack{19}
       CC005ED50001CC035ED500018847 00013000
       No output feature configured
    Per-packet load-sharing
20     Pop tag     10.0.45.0/30     0          Et0/1      10.0.24.2
       MAC/Encaps=14/14, MRU=1504, Tag Stack{}
       CC005ED50001CC035ED500018847
       No output feature configured
    Per-packet load-sharing
21     Pop tag     10.0.34.0/30     0          Et0/1      10.0.24.2
       MAC/Encaps=14/14, MRU=1504, Tag Stack{}
       CC005ED50001CC035ED500018847
       No output feature configured
    Per-packet load-sharing
22     22          10.0.35.0/30     0          Et0/1      10.0.24.2
       MAC/Encaps=14/18, MRU=1500, Tag Stack{22}
       CC005ED50001CC035ED500018847 00016000
       No output feature configured
    Per-packet load-sharing
```

In the forwarding table and the details of it:

- Local tags can be found. These are put to the MPLS header by other routers for R2 to learn where to forward the packet.

- Outgoing tag or VC information can be seen, and this information is used by R2 to decide if it should forward the packet with MPLS header with the tag or popping it and not use MPLS. In here, popping tag happens when router has direct connection to the interface of the destination, or the destination address is a loopback interface and the router that will forward the packet has a direct connection to the router having this loopback address. For example, we can see that in the details of table of R2, pop tag option is used for loopback of R1.
- Outgoing interface shows the interface which connects the router with the next one which will forward the packet.
- Next hop shows the address of the next router that is going to forward the packet.

LDP is using the shortest paths for creating the connections and this can be seen for R2 with the provided tables above with the information of IP addresses of the links used for generated paths.

6. Task 3E – Check Paths

```
R1#traceroute 5.5.5.5

Type escape sequence to abort.
Tracing the route to 5.5.5.5

  1 10.0.12.2 [MPLS: Label 19 Exp 0] 104 msec 56 msec 76 msec
  2 10.0.24.2 [MPLS: Label 19 Exp 0] 60 msec 68 msec 76 msec
  3 10.0.45.2 60 msec 44 msec 76 msec
R1#
```

When traceroute command is used on R1 it is seen that packets use MPLS tunnels having label 19 while going through R2 and R4 and after R4 the label for MPLS is popped since the next router is R5 and the destination is its loopback, so the forwarding is done via the direct connection from R4 to R5. This information can be foreseen by looking at the forwarding tables of the inner routers along the path. The tables are shown below:

```
R1(config)#do show mpls forwarding-table
Local  Outgoing    Prefix           Bytes tag  Outgoing    Next Hop
tag    tag or VC   or Tunnel Id     switched   interface
16     Pop tag     2.2.2.2/32       0          Et0/0       10.0.12.2
17     17          3.3.3.3/32       0          Et0/0       10.0.12.2
18     18          4.4.4.4/32       0          Et0/0       10.0.12.2
19     19          5.5.5.5/32       0          Et0/0       10.0.12.2
20     Pop tag     10.0.24.0/30     0          Et0/0       10.0.12.2
21     Pop tag     10.0.23.0/30     0          Et0/0       10.0.12.2
22     20          10.0.45.0/30     0          Et0/0       10.0.12.2
23     21          10.0.34.0/30     0          Et0/0       10.0.12.2
24     22          10.0.35.0/30     0          Et0/0       10.0.12.2
R1(config)#
```

From R1's table we can see that the packets will be packet with the label 19 as shown in 4th entry of the table and the next hop is the interface Et0/0 of R2.

```
R2(config)#do show mpls forwarding-table
Local  Outgoing    Prefix           Bytes tag  Outgoing    Next Hop
tag    tag or VC   or Tunnel Id     switched   interface
16     Pop tag     1.1.1.1/32       0          Et0/0       10.0.12.1
17     18          3.3.3.3/32       0          Et0/1       10.0.24.2
18     Pop tag     4.4.4.4/32       0          Et0/1       10.0.24.2
19     19          5.5.5.5/32       360        Et0/1       10.0.24.2
20     Pop tag     10.0.45.0/30     0          Et0/1       10.0.24.2
21     Pop tag     10.0.34.0/30     0          Et0/1       10.0.24.2
22     22          10.0.35.0/30     0          Et0/1       10.0.24.2
R2(config)#
```

From R2's table we see that the packets will be labeled as 19 again but the next hop will be the interface Et0/1 of R4.

```
R4(config)#do show mpls forwarding-table
Local  Outgoing    Prefix           Bytes tag  Outgoing    Next Hop
tag    tag or VC   or Tunnel Id     switched   interface
16     16          1.1.1.1/32       0          Et0/1       10.0.24.1
17     Pop tag     2.2.2.2/32       1260       Et0/1       10.0.24.1
18     Pop tag     3.3.3.3/32       1242       Et0/3       10.0.34.1
19     Pop tag     5.5.5.5/32       672        Et0/2       10.0.45.2
20     Pop tag     10.0.12.0/30     1302       Et0/1       10.0.24.1
21     Pop tag     10.0.23.0/30     0          Et0/3       10.0.34.1
       Pop tag     10.0.23.0/30     0          Et0/1       10.0.24.1
22     Pop tag     10.0.35.0/30     0          Et0/2       10.0.45.2
       Pop tag     10.0.35.0/30     0          Et0/3       10.0.34.1
R4(config)#
```

From the table of R4 we see that the tag 19 is popped for the destination 5.5.5.5 and the direct connection having address 10.0.45.2 is used.

7. Task 3F – Configure Basic Traffic Engineering

For this part of the lab, RSVP-TE (Resource Reservation Protocol – Traffic Engineering), which is an extension of RSVP that allows setting properties of tunnels and defining explicit paths, configuration is expected. The configuration steps are:

I. Enabling MPLS TE for routing protocol (in our case OSPF) and setting loopback interface as MPLS router id. Using the commands given in the lab document Traffic engineering is enabled for each router.
II. In the global configuration mode, MLPS traffic engineering capabilities are enabled for each router and this process is done for each concerned interface of each router.
III. Then b setting the bandwidths of the interfaces RSVP is enabled for all interfaces of routers. All the bandwidths are set to 512 except the link between R2 and R4, it is set as 64.

IV. On R1 and R5 a tunnel1 interface is defined as MPLS tunnel and it is set as dynamic tunnel. After typing the commands on the document, a tunnel from R1 to Loopback0 of R5 and from R5 to Loopback0 of R1 is created. This tunnel has bandwidth of 256 kbps since it is a dynamic tunnel which chooses the paths based on bandwidths and by setting as 256, we will make sue that the link R2-R4 will not be used.

To confirm that tunnel works properly the output of the command **show mpls traffic-eng tunnels** can be seen:

```
Name: R1_t1                               (Tunnel1) Destination: 5.5.5.5
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected

    path option 2, type dynamic (Basis for Setup, path weight 120)

  Config Parameters:
    Bandwidth: 256      kbps (Global)  Priority: 5  5   Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    AutoRoute:  enabled   LockDown: disabled  Loadshare: 256      bw-based
    auto-bw: disabled

  InLabel  :  -
  OutLabel : Ethernet0/0, 23
  RSVP Signalling Info:
       Src 1.1.1.1, Dst 5.5.5.5, Tun_Id 1, Tun_Instance 3
    RSVP Path Info:
      My Address: 1.1.1.1
      Explicit Route: 10.0.12.2 10.0.23.2 10.0.35.2 5.5.5.5
      Record Route:  NONE
      Tspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
    RSVP Resv Info:
      Record Route:  NONE
      Fspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
  History:
    Tunnel:
      Time since created: 3 minutes, 23 seconds
      Time since path change: 2 minutes, 19 seconds
    Current LSP:
      Uptime: 2 minutes, 20 seconds
    Prior LSP:
      ID: path option 2 [2]
      Removal Trigger: router ID changed

LSP Tunnel R5_t1 is signalled, connection is up
  InLabel  : Ethernet0/0, implicit-null
  OutLabel :  -
  RSVP Signalling Info:
       Src 5.5.5.5, Dst 1.1.1.1, Tun_Id 1, Tun_Instance 3
    RSVP Path Info:
      My Address: 1.1.1.1
      Explicit Route:  NONE
      Record Route:  NONE
      Tspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
    RSVP Resv Info:
      Record Route:  NONE
      Fspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
```

In the above picture the tunnels created from R1 to R5 and from R5 to R1 can be seen. For R1_t1 the source is 1.1.1.1 and the destination is 5.5.5.5. The path that is dynamically assigned can be seen in Explicit Route part which can be derived as R1-R2-R3-R5.

The result of the same command on R5:

```
R5(config-if)#do show mpls traffic-eng tunnels
Name: R5_t1                           (Tunnel1) Destination: 1.1.1.1
  Status:
    Admin: up        Oper: up     Path: valid       Signalling: connected
    path option 2, type dynamic (Basis for Setup, path weight 120)

  Config Parameters:
    Bandwidth: 256      kbps (Global)  Priority: 5  5   Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    AutoRoute:  enabled   LockDown: disabled  Loadshare: 256      bw-based
    auto-bw: disabled

  InLabel  :  -
  OutLabel : Ethernet0/0, 24
  RSVP Signalling Info:
       Src 5.5.5.5, Dst 1.1.1.1, Tun_Id 1, Tun_Instance 3
    RSVP Path Info:
      My Address: 5.5.5.5
      Explicit Route: 10.0.35.1 10.0.23.1 10.0.12.1 1.1.1.1
      Record Route:  NONE
      Tspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
    RSVP Resv Info:
      Record Route:  NONE
      Fspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
  History:
    Tunnel:
      Time since created: 4 minutes, 33 seconds
      Time since path change: 3 minutes, 49 seconds
    Current LSP:
      Uptime: 3 minutes, 49 seconds
    Prior LSP:
      ID: path option 2 [2]
      Removal Trigger: router ID changed

LSP Tunnel R1_t1 is signalled, connection is up
  InLabel  : Ethernet0/0, implicit-null
  OutLabel :  -
  RSVP Signalling Info:
       Src 1.1.1.1, Dst 5.5.5.5, Tun_Id 1, Tun_Instance 3
    RSVP Path Info:
      My Address: 5.5.5.5
```

```
    Explicit Route:  NONE
    Record Route:  NONE
    Tspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
  RSVP Resv Info:
    Record Route:  NONE
    Fspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
```

For R5 the path can be found with the way as it was found for R1. The created tunnel can be seen in the OSPF interfaces:

```
Loopback0 is up, line protocol is up
  Internet Address 1.1.1.1/32, Area 0
  Process ID 1, Router ID 1.1.1.1, Network Type LOOPBACK, Cost: 1
  Loopback interface is treated as a stub Host
Tunnel1 is up, line protocol is up
  Interface is unnumbered. Using address of Loopback0 (1.1.1.1), Area 0
  Process ID 1, Router ID 1.1.1.1, Network Type POINT_TO_POINT, Cost: 11111
  Transmit Delay is 1 sec, State POINT_TO_POINT
  Timer intervals configured, Hello 10, Dead 40, Wait 40, Retransmit 5
    oob-resync timeout 40
    No Hellos (Passive interface)
  Supports Link-local Signaling (LLS)
  Index 3/3, flood queue length 0
  Next 0x0(0)/0x0(0)
  Last flood scan length is 0, maximum is 0
  Last flood scan time is 0 msec, maximum is 0 msec
  Neighbor Count is 0, Adjacent neighbor count is 0
  Suppress hello for 0 neighbor(s)
Ethernet0/0 is up, line protocol is up
```

To prove that tunnel is used we can check the MPLS forwarding tables of R1 and R5 and we will see that there is a slight difference comparing to what we have in the section E. This time we will have [T] in the Outgoing tag or VC section as can be seen below:

```
R1(config-if)#do show mpls forwarding-table
Local  Outgoing    Prefix           Bytes tag  Outgoing   Next Hop
tag    tag or VC   or Tunnel Id     switched   interface
16     Pop tag     2.2.2.2/32       0          Et0/0      10.0.12.2
17     17          3.3.3.3/32       0          Et0/0      10.0.12.2
18     18          4.4.4.4/32       0          Et0/0      10.0.12.2
19     Pop tag [T] 5.5.5.5/32       0          Tu1        point2point
20     Pop tag     10.0.24.0/30     0          Et0/0      10.0.12.2
21     Pop tag     10.0.23.0/30     0          Et0/0      10.0.12.2
22     20          10.0.45.0/30     0          Et0/0      10.0.12.2
23     21          10.0.34.0/30     0          Et0/0      10.0.12.2
24     22          10.0.35.0/30     0          Et0/0      10.0.12.2
       Pop tag [T] 10.0.35.0/30     0          Tu1        point2point

[T]     Forwarding through a TSP tunnel.
        View additional tagging info with the 'detail' option
R1(config-if)#
```

Here we see that the packet is forwarded through TSP tunnel as it written in the picture. This is the same for R5 as well:

```
R5(config-if)#do show mpls forwarding-table
Local  Outgoing    Prefix           Bytes tag  Outgoing   Next Hop
tag    tag or VC   or Tunnel Id     switched   interface
16     Pop tag [T] 1.1.1.1/32       0          Tu1        point2point
17     17          2.2.2.2/32       0          Et0/2      10.0.45.1
18     Pop tag     3.3.3.3/32       0          Et0/0      10.0.35.1
19     Pop tag     4.4.4.4/32       0          Et0/2      10.0.45.1
20     20          10.0.12.0/30     0          Et0/2      10.0.45.1
21     Pop tag     10.0.24.0/30     0          Et0/2      10.0.45.1
22     Pop tag     10.0.23.0/30     0          Et0/0      10.0.35.1
23     Pop tag     10.0.34.0/30     0          Et0/2      10.0.45.1
       Pop tag     10.0.34.0/30     0          Et0/0      10.0.35.1

[T]     Forwarding through a TSP tunnel.
        View additional tagging info with the 'detail' option
```

These tables in section E have changed slightly because of the tunnel. We can also see the routes of R1 and realize that there is a new route between R3-R5 which is using the tunnel and the connection to 5.5.5.5 is using this tunnel:

```
R1(config-if)#do 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

     1.0.0.0/32 is subnetted, 1 subnets
C       1.1.1.1 is directly connected, Loopback0
     2.0.0.0/32 is subnetted, 1 subnets
O       2.2.2.2 [110/11] via 10.0.12.2, 00:03:37, Ethernet0/0
     3.0.0.0/32 is subnetted, 1 subnets
O       3.3.3.3 [110/31] via 10.0.12.2, 00:03:37, Ethernet0/0
     4.0.0.0/32 is subnetted, 1 subnets
O       4.4.4.4 [110/21] via 10.0.12.2, 00:03:37, Ethernet0/0
     5.0.0.0/32 is subnetted, 1 subnets
O       5.5.5.5 [110/31] via 5.5.5.5, 00:03:37, Tunnel1
     10.0.0.0/30 is subnetted, 6 subnets
C       10.0.12.0 is directly connected, Ethernet0/0
O       10.0.24.0 [110/20] via 10.0.12.2, 00:03:38, Ethernet0/0
O       10.0.23.0 [110/110] via 10.0.12.2, 00:03:40, Ethernet0/0
O       10.0.45.0 [110/30] via 10.0.12.2, 00:03:40, Ethernet0/0
O       10.0.34.0 [110/30] via 10.0.12.2, 00:03:41, Ethernet0/0
O       10.0.35.0 [110/40] via 10.0.12.2, 00:03:41, Ethernet0/0
                  [110/40] via 5.5.5.5, 00:03:41, Tunnel1
```

The result of traceroute command on R1 is:

```
R1#traceroute 5.5.5.5

Type escape sequence to abort.
Tracing the route to 5.5.5.5

  1 10.0.12.2 [MPLS: Label 23 Exp 0] 52 msec 40 msec 60 msec
  2 10.0.23.2 [MPLS: Label 23 Exp 0] 80 msec 44 msec 76 msec
  3 10.0.35.2 64 msec 48 msec 72 msec
R1#
```

This is also a proof that the path R2-R3-R5 is used.

As a next step the bandwidths are restored as 512 except this time the link between R2-R3, it is set 64 and then traceroute command is once again run on R1 to see if there will be any changes:

```
R1#traceroute 5.5.5.5

Type escape sequence to abort.
Tracing the route to 5.5.5.5

  1 10.0.12.2 [MPLS: Label 23 Exp 0] 40 msec 60 msec 64 msec
  2 10.0.24.2 [MPLS: Label 23 Exp 0] 72 msec 48 msec 68 msec
  3 10.0.45.2 64 msec 48 msec 72 msec
R1#
```

As it can be seen the path is now set as R1-R2-R4-R5 since we increased the bandwidth of this link and decreased the link of R2-R3, so tunnel has chosen the path with higher bandwidth. We can deduce this information from the forwarding-tables of routers as well.

V. In this phase the bandwidths of all links are set to 512 and tunnel 1 is shutdown and traceroute command is run once again:

```
R1#traceroute 5.5.5.5

Type escape sequence to abort.
Tracing the route to 5.5.5.5

  1 10.0.12.2 144 msec 40 msec 24 msec
  2 10.0.24.2 52 msec 28 msec 40 msec
  3 10.0.45.2 300 msec 128 msec 76 msec
R1#
```

After disabling tunnel, the route became the same as it was at first (in OSPF part) because this route is depended on the costs of the links, not on bandwidth. Now a new tunnel named tunnel2 is defined and an explicit path is given from R1 to R5 traversing the R2, R3 and R4 respectively. After defining tunnel on both R1 and R5 traceroute command is run on them:

```
R1#traceroute 5.5.5.5

Type escape sequence to abort.
Tracing the route to 5.5.5.5

  1 10.0.12.2 [MPLS: Label 23 Exp 0] 72 msec 56 msec 76 msec
  2 10.0.23.2 [MPLS: Label 23 Exp 0] 56 msec 84 msec 52 msec
  3 10.0.34.2 [MPLS: Label 23 Exp 0] 88 msec 60 msec 72 msec
  4 10.0.45.2 60 msec 68 msec 72 msec
R1#
```

From the above picture we can see that the route goes through the defined path.

```
R1#show mpls traffic-eng tunnels

Name: R1_t1                               (Tunnel1) Destination: 5.5.5.5
  Status:
    Admin: admin-down Oper: down   Path: not valid   Signalling: Down
    path option 2, type dynamic

  Config Parameters:
    Bandwidth: 256      kbps (Global)  Priority: 5  5   Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    AutoRoute:  enabled   LockDown: disabled  Loadshare: 256      bw-based
    auto-bw: disabled

  History:
    Tunnel:
      Time since created: 41 minutes, 14 seconds
      Time since path change: 13 minutes, 40 seconds
    Prior LSP:
      ID: path option 2 [4]
      Removal Trigger: tunnel shutdown

Name: R1_t2                               (Tunnel2) Destination: 5.5.5.5
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected

    path option 1, type explicit MyPath (Basis for Setup, path weight 130)

  Config Parameters:
    Bandwidth: 256      kbps (Global)  Priority: 2  2   Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    AutoRoute:  enabled   LockDown: disabled  Loadshare: 256      bw-based
    auto-bw: disabled

  InLabel  :  -
  OutLabel : Ethernet0/0, 23
  RSVP Signalling Info:
       Src 1.1.1.1, Dst 5.5.5.5, Tun_Id 2, Tun_Instance 12
    RSVP Path Info:
      My Address: 1.1.1.1
      Explicit Route: 10.0.12.2 10.0.23.2 10.0.34.2 10.0.45.2
                      5.5.5.5
      Record Route:  NONE
      Tspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
    RSVP Resv Info:
      Record Route:  NONE
      Fspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
  History:
    Tunnel:
      Time since created: 12 minutes, 32 seconds
      Time since path change: 2 minutes, 44 seconds
    Current LSP:
      Uptime: 2 minutes, 44 seconds
R1#
```

With the show mpls traffic-eng tunnels command we can see the tunnels on R1, and we can also see that explicit route is the same as the route in traceroute command. The same results can also be seen in R5 as shown below:

```
R5#traceroute 1.1.1.1

Type escape sequence to abort.
Tracing the route to 1.1.1.1

  1 10.0.45.1 [MPLS: Label 24 Exp 0] 72 msec 80 msec 80 msec
  2 10.0.34.1 [MPLS: Label 24 Exp 0] 84 msec 56 msec 104 msec
  3 10.0.23.1 [MPLS: Label 24 Exp 0] 80 msec 60 msec 100 msec
  4 10.0.12.1 80 msec 68 msec 92 msec
R5#
```

```
R5#show mpls traffic-eng tunnels

Name: R5_t1                               (Tunnel1) Destination: 1.1.1.1
  Status:
    Admin: admin-down Oper: down   Path: not valid   Signalling: Down
    path option 2, type dynamic

  Config Parameters:
    Bandwidth: 256      kbps (Global)  Priority: 5  5   Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    AutoRoute:  enabled   LockDown: disabled  Loadshare: 256      bw-based
    auto-bw: disabled

  History:
    Tunnel:
      Time since created: 42 minutes, 31 seconds
      Time since path change: 16 minutes, 47 seconds
    Prior LSP:
      ID: path option 2 [4]
      Removal Trigger: tunnel shutdown

Name: R5_t2                               (Tunnel2) Destination: 1.1.1.1
  Status:
    Admin: up         Oper: up     Path: valid       Signalling: connected

    path option 1, type explicit MyPath (Basis for Setup, path weight 130)

  Config Parameters:
    Bandwidth: 256      kbps (Global)  Priority: 2  2   Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    AutoRoute:  enabled   LockDown: disabled  Loadshare: 256      bw-based
    auto-bw: disabled

  InLabel  :  -
  OutLabel : Ethernet0/2, 24
  RSVP Signalling Info:
       Src 5.5.5.5, Dst 1.1.1.1, Tun_Id 2, Tun_Instance 10
    RSVP Path Info:
      My Address: 5.5.5.5
      Explicit Route: 10.0.45.1 10.0.34.1 10.0.23.1 10.0.12.1
                      1.1.1.1
      Record Route:  NONE
      Tspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
    RSVP Resv Info:
      Record Route:  NONE
      Fspec: ave rate=256 kbits, burst=1000 bytes, peak rate=256 kbits
  History:
    Tunnel:
      Time since created: 14 minutes, 18 seconds
      Time since path change: 1 minutes, 47 seconds
    Current LSP:
      Uptime: 1 minutes, 49 seconds
```

VI. **show ip ospf mpls traffic-eng link** command is run on R2 and the results:

```
R2(config-if)#do show ip ospf mpls traffic-eng link

           OSPF Router with ID (2.2.2.2) (Process ID 1)

  Area 0 has 3 MPLS TE links. Area instance is 19.

  Links in hash bucket 8.
    Link is associated with fragment 1. Link instance is 19
      Link connected to Point-to-Point network
      Link ID : 3.3.3.3
      Interface Address : 10.0.23.1
      Neighbor Address : 10.0.23.2
      Admin Metric te: 100 igp: 100
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
      Affinity Bit : 0x0

  Links in hash bucket 9.
    Link is associated with fragment 2. Link instance is 19
      Link connected to Point-to-Point network
      Link ID : 4.4.4.4
      Interface Address : 10.0.24.1
      Neighbor Address : 10.0.24.2
      Admin Metric te: 10 igp: 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 64000       Priority 3 : 64000
      Priority 4 : 64000       Priority 5 : 64000
      Priority 6 : 64000       Priority 7 : 64000
      Affinity Bit : 0x0

  Links in hash bucket 16.
    Link is associated with fragment 0. Link instance is 19
      Link connected to Point-to-Point network
      Link ID : 1.1.1.1
      Interface Address : 10.0.12.2
      Neighbor Address : 10.0.12.1
      Admin Metric te: 10 igp: 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
      Affinity Bit : 0x0
```

It is seen that area 0 has 3 MPLS TE links and we can see priorities of each as well as their instances, associated fragments. It also seen that each link is connected to point-to-point

network as it is set at the beginning. This table shows what will be advertised by OSPF and we can see all neighbors of R2, which are R1, R3 and R4, in it. This means R2 is advertising these and we can also see the information of which networks R2 is connected to its neighbors and through which interfaces. We can also see the metrics, bandwidths of each link as well.

The result of **show ip ospf database opaque area** command can be seen below:

```
R2(config-if)#do show ip ospf database opaque-area
            OSPF Router with ID (2.2.2.2) (Process ID 1)
                Type-10 Opaque Link Area Link States (Area 0)

  LS age: 472
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.0
  Opaque Type: 1
  Opaque ID: 0
  Advertising Router: 1.1.1.1
  LS Seq Number: 80000007
  Checksum: 0x370B
  Length: 140
  Fragment number : 0

    MPLS TE router ID : 1.1.1.1

    Link connected to Point-to-Point network
      Link ID : 2.2.2.2
      Interface Address : 10.0.12.1
      Neighbor Address : 10.0.12.2
      Admin Metric : 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
      Affinity Bit : 0x0
      IGP Metric : 10

    Number of Links : 1

  LS age: 224
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.0
  Opaque Type: 1
  Opaque ID: 0
  Advertising Router: 2.2.2.2
  LS Seq Number: 80000007
  Checksum: 0xC07D
  Length: 140
  Fragment number : 0
```

```
    MPLS TE router ID : 2.2.2.2

    Link connected to Point-to-Point network
      Link ID : 1.1.1.1
      Interface Address : 10.0.12.2
      Neighbor Address : 10.0.12.1
      Admin Metric : 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
      Affinity Bit : 0x0
      IGP Metric : 10

    Number of Links : 1

  LS age: 165
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.0
  Opaque Type: 1
  Opaque ID: 0
  Advertising Router: 3.3.3.3
  LS Seq Number: 80000005
  Checksum: 0x15E1
  Length: 140
  Fragment number : 0

    MPLS TE router ID : 3.3.3.3

    Link connected to Point-to-Point network
      Link ID : 5.5.5.5
      Interface Address : 10.0.35.1
      Neighbor Address : 10.0.35.2
      Admin Metric : 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 64000       Priority 3 : 64000
      Priority 4 : 64000       Priority 5 : 64000
      Priority 6 : 64000       Priority 7 : 64000
      Affinity Bit : 0x0
      IGP Metric : 10

    Number of Links : 1

  LS age: 1136
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.0
  Opaque Type: 1
```

```
  Opaque ID: 0
  Advertising Router: 4.4.4.4
  LS Seq Number: 80000005
  Checksum: 0x30E0
  Length: 140
  Fragment number : 0

    MPLS TE router ID : 4.4.4.4

    Link connected to Point-to-Point network
      Link ID : 2.2.2.2
      Interface Address : 10.0.24.2
      Neighbor Address : 10.0.24.1
      Admin Metric : 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 64000       Priority 3 : 64000
      Priority 4 : 64000       Priority 5 : 64000
      Priority 6 : 64000       Priority 7 : 64000
      Affinity Bit : 0x0
      IGP Metric : 10

    Number of Links : 1

  LS age: 14
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.0
  Opaque Type: 1
  Opaque ID: 0
  Advertising Router: 5.5.5.5
  LS Seq Number: 80000005
  Checksum: 0x30BE
  Length: 140
  Fragment number : 0

    MPLS TE router ID : 5.5.5.5

    Link connected to Point-to-Point network
      Link ID : 3.3.3.3
      Interface Address : 10.0.35.2
      Neighbor Address : 10.0.35.1
      Admin Metric : 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 64000       Priority 3 : 64000
      Priority 4 : 64000       Priority 5 : 64000
      Priority 6 : 64000       Priority 7 : 64000
      Affinity Bit : 0x0
      IGP Metric : 10
```

```
    Number of Links : 1

  LS age: 485
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.1
  Opaque Type: 1
  Opaque ID: 1
  Advertising Router: 2.2.2.2
  LS Seq Number: 80000006
  Checksum: 0xDAA5
  Length: 132
  Fragment number : 1

    Link connected to Point-to-Point network
      Link ID : 3.3.3.3
      Interface Address : 10.0.23.1
      Neighbor Address : 10.0.23.2
      Admin Metric : 100
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
      Affinity Bit : 0x0
      IGP Metric : 100

    Number of Links : 1

  LS age: 240
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.1
  Opaque Type: 1
  Opaque ID: 1
  Advertising Router: 3.3.3.3
  LS Seq Number: 80000006
  Checksum: 0x621E
  Length: 132
  Fragment number : 1

    Link connected to Point-to-Point network
      Link ID : 2.2.2.2
      Interface Address : 10.0.23.2
      Neighbor Address : 10.0.23.1
      Admin Metric : 100
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
```

```
      Affinity Bit : 0x0
      IGP Metric : 100

    Number of Links : 1

  LS age: 525
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.1
  Opaque Type: 1
  Opaque ID: 1
  Advertising Router: 4.4.4.4
  LS Seq Number: 80000005
  Checksum: 0x7E7B
  Length: 132
  Fragment number : 1

    Link connected to Point-to-Point network
      Link ID : 5.5.5.5
      Interface Address : 10.0.45.1
      Neighbor Address : 10.0.45.2
      Admin Metric : 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
      Affinity Bit : 0x0
      IGP Metric : 10

    Number of Links : 1

  LS age: 280
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.1
  Opaque Type: 1
  Opaque ID: 1
  Advertising Router: 5.5.5.5
  LS Seq Number: 80000005
  Checksum: 0x6F3
  Length: 132
  Fragment number : 1

    Link connected to Point-to-Point network
      Link ID : 4.4.4.4
      Interface Address : 10.0.45.2
      Neighbor Address : 10.0.45.1
      Admin Metric : 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
```

```
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
      Affinity Bit : 0x0
      IGP Metric : 10

    Number of Links : 1

  LS age: 1194
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.2
  Opaque Type: 1
  Opaque ID: 2
  Advertising Router: 2.2.2.2
  LS Seq Number: 80000005
  Checksum: 0xEB40
  Length: 132
  Fragment number : 2

    Link connected to Point-to-Point network
      Link ID : 4.4.4.4
      Interface Address : 10.0.24.1
      Neighbor Address : 10.0.24.2
      Admin Metric : 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 64000       Priority 3 : 64000
      Priority 4 : 64000       Priority 5 : 64000
      Priority 6 : 64000       Priority 7 : 64000
      Affinity Bit : 0x0
      IGP Metric : 10

    Number of Links : 1

  LS age: 534
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.2
  Opaque Type: 1
  Opaque ID: 2
  Advertising Router: 3.3.3.3
  LS Seq Number: 80000004
  Checksum: 0x69AE
  Length: 132
  Fragment number : 2

    Link connected to Point-to-Point network
      Link ID : 4.4.4.4
      Interface Address : 10.0.34.1
      Neighbor Address : 10.0.34.2
      Admin Metric : 10
      Maximum bandwidth : 1250000
```

```
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
      Affinity Bit : 0x0
      IGP Metric : 10

    Number of Links : 1

  LS age: 287
  Options: (No TOS-capability, DC)
  LS Type: Opaque Area Link
  Link State ID: 1.0.0.2
  Opaque Type: 1
  Opaque ID: 2
  Advertising Router: 4.4.4.4
  LS Seq Number: 80000004
  Checksum: 0xF027
  Length: 132
  Fragment number : 2

    Link connected to Point-to-Point network
      Link ID : 3.3.3.3
      Interface Address : 10.0.34.2
      Neighbor Address : 10.0.34.1
      Admin Metric : 10
      Maximum bandwidth : 1250000
      Maximum reservable bandwidth : 64000
      Number of Priority : 8
      Priority 0 : 64000       Priority 1 : 64000
      Priority 2 : 32000       Priority 3 : 32000
      Priority 4 : 32000       Priority 5 : 32000
      Priority 6 : 32000       Priority 7 : 32000
      Affinity Bit : 0x0
      IGP Metric : 10

    Number of Links : 1
```