MPLS Traffic Engineering Tunnels in IS-IS

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Contents

1 Overview

In this project we analyze, configure and test selected MPLS Traffic Engineering features which are related to IS-IS *(Intermediate System to Intermediate System)* protocol. We decided to choose three of them mentioned in table of contents above on the basis of the IS-IS role in their implementation. Each section is dedicated for one particular problem and begins with theoretical introduction including feature benefits and possible limitations. Next, sample topology is presented with proposed addressing schema, related configuration commands and expected result at the end.

2 IS-IS for basic MPLS Traffic Engineering tunnels

2.1 Introduction

Multiprotocol Label Switching (MPLS) is a lightweight tunneling technology used in many service provider networks. The contiguous set of routers in the network running MPLS software creates a tunnel, or label-switched path (LSP), by distributing a set of fixed-length 32-bit labels along a path from the network's ingress (entry point) to its egress (exit point). The ingress router appends packets that enter the LSP with a label. At each hop in the LSP, the router swaps the label; at the end of the LSP, the egress router disposes of the label and sends the packet on its way. All MPLS networks use this simple label-swap forwarding paradigm to switch packets across the network. The labels take on different meanings depending on the application or service configured over the network.

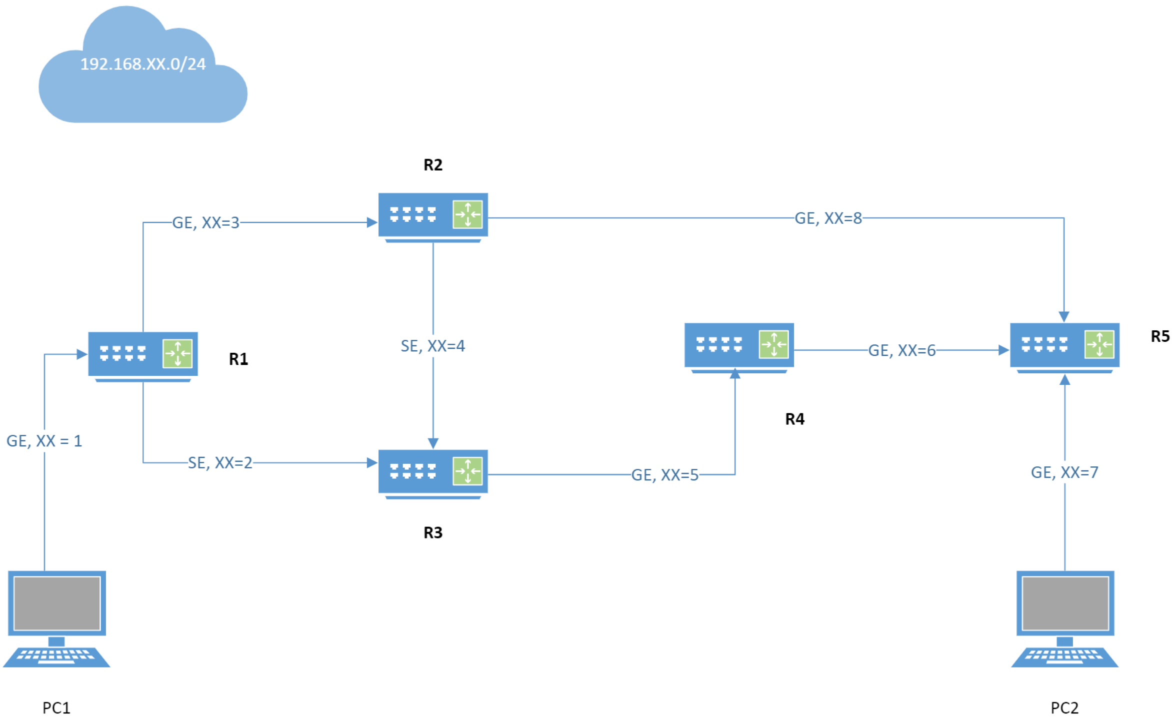
When MPLS TE is configured in a network, the IGP floods two metrics for every link: the normal IGP (OSPF or IS-IS) link metric and a TE link metric.

The IGP (in our case IS-IS) uses the IGP link metric in the normal way to compute routes for destination networks. You can specify that the path calculation for a given tunnel be based on either of the following:

- IGP link metrics.
- TE link metrics, which you can configure so that they represent the needs of a particular application.

2.2 Topology

To perform configuration for IS-IS MPLS TE tunnels we proposed this topology.



2.3 Configuration

To configure MPLS tunnel which is based on IS-IS following steps must be done:

- Configuring a Platform to Support Traffic Engineering Tunnels (all Routers)

```
1. enable
2. configure terminal
3. ip cef distributed
4. mpls traffic-eng tunnels
5. exit
```

- Configuring IS-IS for MPLS Traffic Engineering (all Routers)

```
1. Router(config)# router isis
2. Router(config-router)# mpls traffic-eng level-1
3. Router(config-router)# mpls traffic-eng level-2
4. Router(config-router)# mpls traffic-eng router-id loopback 0
5. Router(config-router)# metric-style wide
```

```
Sample configuration at R3:

router isis
 net 49.0010.0000.0000.0003.00
 is-type level-1
 metric-style wide
 mpls traffic-eng router-id Loopback0
```

```
 mpls traffic-eng level-1
 mpls traffic-eng level-2
```

```
Sample configuration at R5:

router isis
 net 49.0010.0000.0000.0005.00
 is-type level-1
 metric-style wide
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng level-1
```

- Configuring Traffic Engineering Link Metrics

```
1. enable
2. configure terminal
3. interface type slot / subslot / port [. subinterface-number]
4. mpls traffic-eng administrative-weight weight
5. exit
6. exit
```

```
Sample configuration at R1:

interface GigabitEthernet0/0/1
 ip address 192.168.3.1 255.255.255.0
 ip router isis
 negotiation auto
 mpls traffic-eng tunnels
 mpls traffic-eng administrative-weight 1000000
 ip rsvp bandwidth 256 256
```

```
Sample configuration at R3:

interface GigabitEthernet0/0/0
 ip address 192.168.5.3 255.255.255.0
 ip router isis
 negotiation auto
 mpls traffic-eng tunnels
 mpls traffic-eng administrative-weight 20000
 ip rsvp bandwidth 256 256
```

- Configuring an MPLS Traffic Engineering Tunnel

```
1. enable
2. configure terminal
3. interface tunnel number
4. ip unnumbered type number
5. tunnel destination ip-address
6. tunnel mode mpls traffic-eng
7. tunnel mpls traffic-eng bandwidth bandwidth
8. tunnel mpls traffic-eng path-option number {dynamic |
explicit {name path-name | identifier path-number}} [lockdown]
9. exit
10. exit
```

```
Sample configuration at R1:

interface Tunnel1
 ip unnumbered Loopback0
 tunnel mode mpls traffic-eng
 tunnel destination 10.0.0.5
 tunnel mpls traffic-eng priority 1 1
 tunnel mpls traffic-eng bandwidth 100
 tunnel mpls traffic-eng path-option 1 dynamic
```

- Configuring the Metric Type for Tunnel Path Calculation

```
1. enable
2. configure terminal
3. interface tunnel number
4. tunnel mpls traffic-eng path-selection metric {igp | te}
5. exit
6. mpls traffic-eng path-selection metric {igp | te}
7. exit
```

```
Sample configuration at R1:

interface Tunnel1
 tunnel mpls traffic-eng path-selection metric te
```

- Verifying the Tunnel Path Metric Configuration

```
1. enable
2. show mpls traffic-eng topolog y
3. show mpls traffic-eng tunnels
4. exit
```

```
R1#show mpls traffic-eng tunnels

P2P TUNNELS/LSPs:

Name: R1_t1                    (Tunnel1) Destination: 10.0.0.5
  Status:
    Admin: up  Oper: up  Path: valid   Signalling: connected
    path option 1, type dynamic
    (Basis for Setup, path weight 30)

  Config Parameters:
    Bandwidth: 100      kbps (Global)  Priority: 1  1
    Affinity: 0x0/0xFFFF
    Metric Type: TE (interface)
    Path-selection Tiebreaker:
      Global: not set   Tunnel Specific: not set
      Effective: min-fill (default)
    Hop Limit: disabled
    Cost Limit: disabled
    Path-invalidation timeout: 10000 msec (default),
    Action: Tear
    AutoRoute: disabled LockDown: disabled
    Loadshare: 100 [20000000] bw-based
    auto-bw: disabled
    Fault-OAM: disabled, Wrap-Protection: disabled,
    Wrap-Capable: No
  Active Path Option Parameters:
    State: dynamic path option 1 is active
    BandwidthOverride: disabled  LockDown: disabled
    Verbatim: disabled
  Node Hop Count: 3

  InLabel  :  -
  OutLabel : Serial0/1/0, 18
  Next Hop : 192.168.2.3
  RSVP Signalling Info:
       Src 10.0.0.1, Dst 10.0.0.5, Tun_Id 1, Tun_Instance 12
    RSVP Path Info:
      My Address: 192.168.2.1
      Explicit Route: 192.168.2.3 192.168.4.2 192.168.8.2
                      192.168.8.5 10.0.0.5
      Record   Route:   NONE
      Tspec: ave rate=100 kbits, burst=1000 bytes,
      peak rate=100 kbits
    RSVP Resv Info:
      Record   Route:   NONE
      Fspec: ave rate=100 kbits, burst=1000 bytes,
      peak rate=100 kbits

  History:
    Tunnel:
      Time since created: 21 minutes, 7 seconds
      Time since path change: 2 minutes, 38 seconds
      Number of LSP IDs (Tun_Instances) used: 12
```

```
      Current LSP: [ID: 12]
        Uptime: 2 minutes, 41 seconds
        Selection: reoptimization
      Prior LSP: [ID: 10]
        ID: path option unknown
        Removal Trigger: reoptimization completed

  P2MP TUNNELS:

  P2MP SUB-LSPS:
```

```
  Check IS-IS configuration:
  Sample configuration at R2:

  R2#show isis nei

  System Id        Type Interface      IP Address      State Holdtime
  R1               L1   Gi0/0/1        192.168.3.1     UP    23
  R3               L1   Se0/1/0        192.168.4.3     UP    28
  R5               L1   Gi0/0/0        192.168.8.5     UP    28

  Circuit Id
  R2.02
  03
  R2.01

  R2#show isis topology

  IS-IS TID 0 paths to level-1 routers
  System Id             Metric     Next-Hop               Interface
  SNPA
  R1                    10         R1                     Gi0/0/1
  6c5e.3b79.6261
  R2                    --
  R3                    10         R3                     Se0/1/0
  *HDLC*
  R4                    20         R3                     Se0/1/0
  *HDLC*
                                   R5                     Gi0/0/0
  6c5e.3bab.5690
  R5                    10         R5                     Gi0/0/0
  6c5e.3bab.5690

  IS-IS TID 0 paths to level-2 routers
  System Id             Metric     Next-Hop               Interface
  SNPA
  R2
```

3 MPLS Traffic Engineering Interarea Tunnels in IS-IS

3.1 Introduction

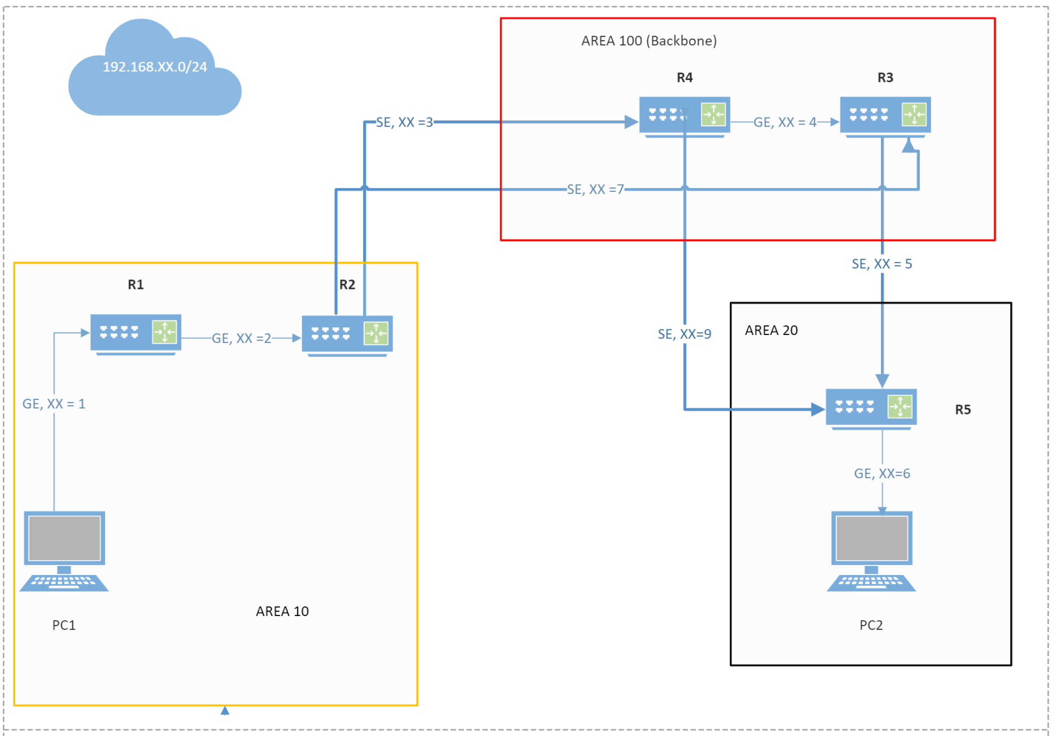
The MPLS Traffic Engineering: Interarea Tunnels feature allows you to establish Multiprotocol Label Switching (MPLS) traffic engineering (TE) tunnels that span multiple Interior Gateway

Protocol (IGP) areas and levels, removing the restriction that had required the tunnel headend and tailend routers both be in the same area. The IGP can be either Intermediate System-to-Intermediate System (IS-IS) or Open Shortest Path First (OSPF). Due to the fact that we examine IS-IS in our project we will use it to test its performance in interarea tunneling. Before we begin, we must be aware of some limitations in the interarea MPLS tunneling in IS-IS:

- The dynamic path option feature for TE tunnels (which is specified in the tunnel mpls traffic-eng path-option number dynamic command) is not supported.
- Tunnel affinity (the tunnel mpls traffic-eng affinity command) is not supported for interarea tunnels
- The reoptimization of tunnel paths is not supported for interarea tunnels.
- MPLS traffic engineering supports only a single IGP process/instance.

Existance of interarea tunnels in MPLS results in many benefits which are used to simplify the process of setting up tunnels between routers. For example, when it is desirable for the traffic from one router to another router in a different IGP area to travel over TE LSPs, the MPLS Traffic Engineering Interarea Tunnels feature allows you to configure a tunnel that runs from the source router to the destination router. The alternative would be to configure a sequence of tunnels, each crossing one of the areas between source and destination routers such that the traffic arriving on one such tunnel is forwarded into the next such tunnel.

3.2 Topology



3.3 Configuration

To configure MPLS interarea tunnel configuration we follow these steps:

- Configuring IS-IS for Interarea Tunnels (all Routers except R1)

```
1. enable
2. configure terminal
3. router isis
4. metric-style wide
```

```
5. net 49.0XXX.0000.0000.0YYY.00
where XXX - area_number, YYY - Router number
6. mpls traffic-eng router-id Loopback0
7. mpls traffic-eng level-1
8. mpls traffic-eng level-2
9. end
```

- Configuring IS-IS for Nonbackbone Routers (only R1)

```
1. enable
2. configure terminal
3. router isis
4. metric-style wide
5. net 49.0XXX.0000.0000.0YYY.00
where XXX - area_number, YYY - Router number
6. mpls traffic-eng router-id Loopback0
7. mpls traffic-eng level-1
8. end
```

- Configuring IS-IS for Interfaces (all Routers)

```
1. enable
2. configure terminal
3. router isis
4. metric-style wide
5. net 49.0XXX.0000.0000.0YYY.00
 where XXX - area_number, YYY - Router number
6. mpls traffic-eng router-id Loopback0
7. interface <interface_name> [FOR ALL ACTIVE INTERFACES]
8. ip router isis
9. end
```

- Configuring MPLS and RSVP to Support Traffic Engineering (all Routers)

```
1. enable
2. configure terminal
3. mpls traffic-eng tunnels
4. interface <interface_name> [FOR ALL ACTIVE INTERFACES]
5. mpls traffic-eng tunnels
6. ip rsvp bandwidth 256 256
7. ip address <ip-address> <mask>
8. end
```

- Configuring an MPLS Traffic Engineering Interarea Tunnel (on R1)

```
1. enable
2. configure terminal
3. interface Tunnel1
```

```
4. ip unnumbered Loopback0
5. tunnel mode mpls traffic-eng
6. tunnel destination 10.0.0.5
7. tunnel mpls traffic-eng priority 1 1
8. tunnel mpls traffic-eng bandwidth 100
9. tunnel mpls traffic-eng path-option 1 explicit name pathsth
10. end
```

- Configuring Explicit Path (on R1)

```
1. enable
2. configure terminal
3. ip explicit-path name pathsth enable
4. next-address loose 10.0.0.2
5. next-address loose 10.0.0.3
6. next-address loose 10.0.0.5
7. end
```

- Configuring an MPLS Traffic Engineering Tunnel with Autoroute Destination (NOT SUPPORTED)

```
As it occured, these features are not available in LAB routers
therefore we setup static route to allow router
to forward the traffic to the tunnel
and to the destination.

 R1(config)# ip route 192.168.6.0 255.255.255.0 Tunnel1
```

- Verifying the Tunnel configuration- various configurations

```
 R1#show mpls traffic-eng tunnels

P2P TUNNELS/LSPs:

Name: R1_t1          (Tunnel1) Destination: 10.0.0.5
  Status:
    Admin: up     Oper: up   Path: valid Signalling: connected
    path option 1,
    type explicit pathsth (Basis for Setup, path weight 10)

  Config Parameters:
    Bandwidth: 100kbps (Global)  Priority: 1  1
    Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    Path-selection Tiebreaker:
      Global: not set    Tunnel Specific: not set
      Effective: min-fill (default)
    Hop Limit: disabled
    Cost Limit: disabled
    Path-invalidation timeout: 10000 msec (default),
```

```
      Action: Tear
      AutoRoute: disabled
      LockDown: disabled Loadshare: 100 [20000000] bw-based
      auto-bw: disabled
      Fault-OAM: disabled, Wrap-Protection: disabled,
      Wrap-Capable: No
    Active Path Option Parameters:
      State: explicit path option 1 is active
      BandwidthOverride: disabled
      LockDown: disabled  Verbatim: disabled
    Node Hop Count: 1

    InLabel  :  -
    OutLabel : GigabitEthernet0/0/0, 17
    Next Hop : 192.168.2.2
    RSVP Signalling Info:
         Src 10.0.0.1, Dst 10.0.0.5, Tun_Id 1, Tun_Instance 49
      RSVP Path Info:
        My Address: 192.168.2.1
        Explicit Route: 192.168.2.2 10.0.0.2 10.0.0.3* 10.0.0.5*
        Record   Route:
        Tspec: ave rate=100 kbits, burst=1000 bytes,
        peak rate=100 kbits
      RSVP Resv Info:
        Record   Route:  192.168.7.2 192.168.5.2 192.168.5.5
        Fspec: ave rate=100 kbits, burst=1000 bytes,
        peak rate=100 kbits

    History:
      Tunnel:
        Time since created: 42 minutes, 4 seconds
        Time since path change: 22 minutes, 37 seconds
        Number of LSP IDs (Tun_Instances) used: 49
      Current LSP: [ID: 49]
        Uptime: 19 minutes, 7 seconds
        Selection: reoptimization
      Prior LSP: [ID: 47]
        ID: path option 1 [47]
        Removal Trigger: reoptimization completed
        Last Error: RSVP::
        Path Error from 192.168.2.2:
        Notify: Better path exists (flags 0)

P2MP TUNNELS:

P2MP SUB-LSPS:
```

```
Check IS-IS configuration:
Sample configuration at R3:

R3#show isis topology
IS-IS TID 0 paths to level-1 routers
System Id            Metric     Next-Hop    Interface
R3                   --
```

```
R4                      10          R4          Gi0/0/0

IS-IS TID 0 paths to level-2 routers
System Id               Metric      Next-Hop    Interface
R2                      10          R2          Se0/1/1
R3                      --
R4                      10          R4          Gi0/0/0
R5                      10          R5          Se0/1/0
```

```
Check IS-IS configuration:
Sample configuration at R3:

R3#show isis nei
System Id          Type Interface      IP Address      State  Holdtime
R2                 L2   Se0/1/1        192.168.7.2     UP     23
R4                 L1   Gi0/0/0        192.168.4.4     UP     9
R4                 L2   Gi0/0/0        192.168.4.4     UP     8
R5                 L2   Se0/1/0        192.168.5.5     UP     28
```

```
R1#show ip route
L1   0.0.0.0/0 [115/10] via 192.168.2.2, GigabitEthernet0/0/0
        10.0.0.0/32 is subnetted, 2 subnets
C    10.0.0.1 is directly connected, Loopback0
L1   10.0.0.2 [115/20] via 192.168.2.2, GigabitEthernet0/0/0
     192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C    192.168.1.0/24 is directly connected, GigabitEthernet0/0/1
L    192.168.1.1/32 is directly connected, GigabitEthernet0/0/1
     192.168.2.0/24 is variably subnetted, 2 subnets, 2 masks
C    192.168.2.0/24 is directly connected, GigabitEthernet0/0/0
L    192.168.2.1/32 is directly connected, GigabitEthernet0/0/0
L1   192.168.3.0/24 [115/20] via 192.168.2.2,GigabitEthernet0/0/0
 S      192.168.6.0/24 is directly connected, Tunnel1
L1   192.168.7.0/24 [115/20] via 192.168.2.2,GigabitEthernet0/0/0
```

```
Check IS-IS configuration:
Sample configuration at R3:

 R3#show isis nei

System Id          Type Interface     IP Address      State  Holdtime
R2                 L2   Se0/1/1       192.168.7.2      UP    23
R4                 L1   Gi0/0/0       192.168.4.4      UP    9
R4                 L2   Gi0/0/0       192.168.4.4      UP    8
R5                 L2   Se0/1/0       192.168.5.5      UP    28
```

```
From PC–1 to PC–2:
tracert 192.168.6.1


Tracing route to 192.168.6.1 over a maximum of 30 hops

  1     <1 ms    <1 ms    <1 ms   192.168.1.1
  2      4 ms     5 ms     5 ms   192.168.2.2
  3      4 ms     4 ms     4 ms   192.168.7.3
  4      3 ms     3 ms     3 ms   192.168.5.5
  5      4 ms     4 ms     3 ms   192.168.6.1

Trace complete.
```

4 MPLS Traffic Engineering - Forwarding Traffic

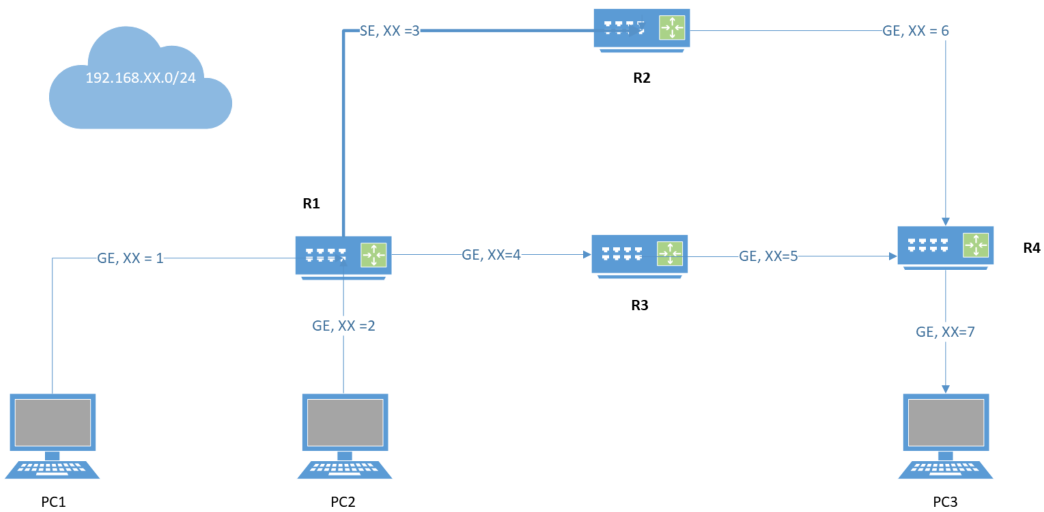
4.1 Introduction

When we have already created a MPLS tunnel, we need to define, which traffic should be forwarded through it. There are several ways to achieve this:

- Static routing
- Policy-based routing
- Forwarding adjacency
- Autoroute announce

With basic configuration we will prepare IS-IS to work with MPLS and create MPLS tunnel with explicit route. In our scenerio all traffic from PC1 to PC3 is forwarded through R3 because of higher IS-IS cost on serial interface. With help of forwarding methods we will cause traffic from PC1 to PC3 to come through R2 via MPLS tunnel.

4.2 Topology



4.3 Basic Configuration

To configure IS-IS, MPLS TE and tunnel, we follow these steps:

- Configuring IS-IS for MPLS TE

```
1. enable
2. configure terminal
3. router isis
4. metric-style wide
5. net 49.0001.0000.0000.000Y.00
where Y - Router number
6. is-type level-1
7. mpls traffic-eng router-id Loopback0
8. mpls traffic-eng level-1
9. interface <interface_name> [FOR ALL ACTIVE INTERFACES]
10. ip address <ip-address> <mask>
11. ip router isis
12. end
```

- Configuring MPLS and RSVP to Support Traffic Engineering

```
1. enable
2. configure terminal
3. mpls traffic-eng tunnels
4. interface <interface_name> [FOR ALL ACTIVE INTERFACES]
5. mpls traffic-eng tunnels
6. ip rsvp bandwidth 256 256
7. end
```

- Configuring an MPLS Traffic Engineering Tunnel

```
1. enable
2. configure terminal
3. interface Tunnel1
4. ip unnumbered Loopback0
5. tunnel mode mpls traffic-eng
6. tunnel destination <destination-IP>
7. tunnel mpls traffic-eng priority 1 1
8. tunnel mpls traffic-eng bandwidth 100
9. tunnel mpls traffic-eng path-option 1 explicit name toR4
10. ip explicit-path name toR4
11. next-address 10.0.0.2
12. next-address 10.0.0.4
13. end
```

- Set IS-IS cost on R1 (on serial interface)

```
1. interface Serial0/1/0
2. isis metric 20
```

- Verification

```
On R1:
 1. show ip route
R1(config)#do show ip route

10.0.0.0/32 is subnetted, 4 subnets
C     10.0.0.1 is directly connected, Loopback0
i L1 10.0.0.2 [115/30] via 192.168.3.2,  Serial0/1/0
i L1 10.0.0.3 [115/20] via 192.168.4.3,  GigabitEthernet0/0/1
i L1 10.0.0.4 [115/30] via 192.168.4.3,  GigabitEthernet0/0/1
    192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C   192.168.1.0/24 is directly connected, GigabitEthernet0/0/0
L   192.168.1.1/32 is directly connected, GigabitEthernet0/0/0
     192.168.3.0/24 is variably subnetted, 2 subnets, 2 masks
C   192.168.3.0/24 is directly connected, Serial0/1/0
L   192.168.3.1/32 is directly connected, Serial0/1/0
    192.168.4.0/24 is variably subnetted, 2 subnets, 2 masks
C   192.168.4.0/24 is directly connected, GigabitEthernet0/0/1
L   192.168.4.1/32 is directly connected, GigabitEthernet0/0/1
L1 192.168.5.0/24 [115/20] via 192.168.4.3, GigabitEthernet0/0/1
L1 192.168.6.0/24 [115/30] via 192.168.4.3, GigabitEthernet0/0/1
                  [115/30] via 192.168.3.2, Serial0/1/0

L1 192.168.7.0/24 [115/30] via 192.168.4.3,GigabitEthernet0/0/1

 2. show mpls traffic-eng tunnels

R1#show mpls traffic-eng tunnels

P2P TUNNELS/LSPs:

Name: R1_t1          (Tunnel1) Destination: 10.0.0.4
  Status:
    Admin: up    Oper: up      Path: valid
    Signalling: connected
    path option 1, type explicit toR4
    (Basis for Setup, path weight 30)

  Config Parameters:
    Bandwidth: 100 kbps (Global)  Priority: 1  1
    Affinity: 0x0/0xFFFF
    Metric Type: TE (default)
    Path-selection Tiebreaker:
      Global: not set    Tunnel Specific: not set
      Effective: min-fill (default)
    Hop Limit: disabled
    [ignore: Explicit Path Option with all Strict Hops]
```

```
    Cost Limit: disabled
    Path-invalidation timeout: 10000 msec (default)
    , Action: Tear
    AutoRoute: disabled LockDown: disabled
    Loadshare: 100 [20000000] bw-based
    auto-bw: disabled
    Fault-OAM: disabled,
    Wrap-Protection: disabled, Wrap-Capable: No
  Active Path Option Parameters:
    State: explicit path option 1 is active
    BandwidthOverride: disabled
    LockDown: disabled  Verbatim: disabled
  Node Hop Count: 2

  InLabel  :  -
  OutLabel : Serial0/1/0, 17
  Next Hop : 192.168.3.2
  RSVP Signalling Info:
       Src 10.0.0.1, Dst 10.0.0.4,
       Tun_Id 1, Tun_Instance 3
    RSVP Path Info:
      My Address: 192.168.3.1
      Explicit Route: 192.168.3.2
      192.168.6.2 192.168.6.4 10.0.0.4
      Record   Route:   NONE
      Tspec: ave rate=100 kbits,
      burst=1000 bytes, peak rate=100 kbits
    RSVP Resv Info:
      Record   Route:   NONE
      Fspec: ave rate=100 kbits, burst=1000 bytes,
      peak rate=100 kbits

  History:
    Tunnel:
      Time since created: 3 minutes, 50 seconds
      Time since path change: 1 minutes, 53 seconds
      Number of LSP IDs (Tun_Instances) used: 3
    Current LSP: [ID: 3]
      Uptime: 1 minutes, 53 seconds
      Selection: reoptimization
    Prior LSP: [ID: 2]
      ID: path option unknown
      Removal Trigger: configuration changed (severe)


On PC1:
 1. tracert 192.168.7.1
where 192.168.7.1 is an IP of PC3

Tracing route to 192.168.7.1 over a maximum of 30 hops

1   <1ms     <1ms    <1ms     192.168.1.1
2   <1ms     <1ms    <1ms     192.168.4.3
3   <1ms     <1ms    <1ms     192.168.5.4
4    1ms      1ms    <1ms     192.168.7.1
```

4.4 Static routing

This is the simplest way to traffic packets through MPLS tunnel. We just need to create a static route on tunnel head end router.

4.4.1 Configuration and verification

```
Sample configuration at R1:
R1(config)# ip route 192.168.7.0 255.255.255.0 tunnel 1

 Verification:

R1#show ip route
     10.0.0.0/32 is subnetted, 4 subnets
C    10.0.0.1 is directly connected, Loopback0
i L1 10.0.0.2 [115/30] via 192.168.3.2, Serial0/1/0
i L1 10.0.0.3 [115/20] via 192.168.4.3, GigabitEthernet0/0/1
i L1 10.0.0.4 [115/30] via 192.168.4.3, GigabitEthernet0/0/1
      192.168.1.0/24 is variably subnetted, 2 subnets, 2 masks
C    192.168.1.0/24 is directly connected, GigabitEthernet0/0/0
L   192.168.1.1/32 is directly connected,GigabitEthernet0/0/0
      192.168.3.0/24 is variably subnetted, 2 subnets, 2 masks
C        192.168.3.0/24 is directly connected, Serial0/1/0
L        192.168.3.1/32 is directly connected, Serial0/1/0
      192.168.4.0/24 is variably subnetted, 2 subnets, 2 masks
C    192.168.4.0/24 is directly connected,GigabitEthernet0/0/1
L    192.168.4.1/32 is directly connected,GigabitEthernet0/0/1
L1 192.168.5.0/24 [115/20] via 192.168.4.3, GigabitEthernet0/0/1
L1 192.168.6.0/24 [115/30] via 192.168.4.3,GigabitEthernet0/0/1
                     [115/30] via 192.168.3.2,  Serial0/1/0
 S     192.168.7.0/24 is directly connected, Tunnel1
```

4.5 Policy-based routing

Policy-based routing (PBR) uses a configured policy on the incoming interface to send traffic to a specific next hop. It can be configured using route-maps and ACLs, which gives a wider choice of criteria to route traffic through a tunnel. Additionally we can manipulate matched packets, for example changing IP precedence.

4.5.1 Configuration and verification

To perform further configuration we must delete previously configured static route.

```
On R1:

interface g0/0/0
    ip policy route-map pbr

route-map pbr permit 10
    match ip address 100
    set interface Tunnel1
    set ip precedence flash
```

```
access-list 100 permit ip host 192.168.1.10 host 192.168.7.1


Verification:

show route-map pbr

R1#show route-map pbr
route-map pbr, permit, sequence 10
  Match clauses:
    ip address (access-lists): 100
  Set clauses:
    ip precedence flash
    interface Tunnel1
  Policy routing matches: 36 packets, 3542 bytes

On PC1:

1. tracert 192.168.7.1

where 192.168.7.1 is an IP of PC3

Tracing route to 192.168.7.1 over a maximum of 30 hops

1    <1ms      <1ms     <1ms     192.168.1.1
2     3ms       2ms      3ms     192.168.3.2
3     2ms       1ms      2ms     192.168.6.4
4     3ms       2ms      2ms     192.168.7.1
```

4.6 Forwarding adjacency

The MPLS Traffic Engineering Forwarding Adjacency feature allows a network administrator to handle a traffic engineering (TE) label switched path (LSP) tunnel as a link in an Interior Gateway Protocol (IGP) network based on the Shortest Path First (SPF) algorithm.

Both Intermediate System-to-Intermediate System (IS-IS) and Open Shortest Path First (OSPF) are supported. However, we study only IS-IS protocol in our project.

Before studying the Forwarding Adjacency feature we must be aware of the following limitations that are present in this feature:

- Using the MPLS Traffic Engineering Forwarding Adjacency feature increases the size of the IGP database by advertising a TE tunnel as a link.
- You must configure MPLS TE forwarding adjacency tunnels bidirectionally.

Additionally, when forwarding adjacency is used, all routers under IGP can see the tunnel as link and including it in SPF calculations, even they are not running MPLS TE. As an optional parameter we can define holdtime, which specify the time in milliseconds that the router must wait to flood, after the TE LSP has gone down.

4.6.1 Configuration and verification

To perform further configuration we must delete previously configured route-map on interface G0/0/0 on R1. We have to create a MPLS tunnel from R4 to R1.

```
We need to enable forwarding adjacency
on both router's tunnel interfaces (R1 and R4):

    tunnel mpls traffic-eng forwarding-adjacency
    isis metric 1 level-1

Verification:

On R1:


1. show ip route isis

R1#show ip route isis

Gateway of last resort is not set

i L1      10.0.0.2 [115/21] via 10.0.0.4,  Tunnel1
i L1      10.0.0.3 [115/20] via 192.168.4.3,  GigabitEthernet0/0/1
i L1      10.0.0.4 [115/11] via 10.0.0.4, Tunnel1
i L1  192.168.5.0/24 [115/11] via 10.0.0.4,  Tunnel1
i L1  192.168.6.0/24 [115/11] via 10.0.0.4, Tunnel1
i L1  192.168.7.0/24 [115/11] via 10.0.0.4,  Tunnel1




On PC1:

1. tracert 192.168.7.1

where 192.168.7.1 is an IP of PC3
Tracing route to 192.168.7.1 over a maximum of 30 hops

1    <1ms     <1ms    <1ms    192.168.1.1
2     2ms      2ms     2ms    192.168.3.2
3     2ms      2ms     1ms    192.168.6.4
4     3ms      3ms     2ms    192.168.7.1
```

5 Bibliography

MPLS Cisco Configuration Guides