

mpls

ljm

1. MPLS introduction

MPLS is a protocol that allows fast traversal of a network by labeling the data packets. MPLS stands for Multi Protocol Label Switching. MPLS switches packets, based on a label, instead of routing data. MPLS can run IP, but also other layer 2 protocols like ATM etcetera.

Rather than trying to recreate a lab from scratch, I decided to replay an MPLS lab from Socketready (<http://socketready.com/2011/03/05/mpls-configuration-guide/>; link is dead) with some minor adjustments. Socketready is no longer available. Therefore, you can get the configs from the appendix.

MPLS is described in RFC3031. There are a number of benefits, compared to traditional WAN:

- Low cost with maximum redundancy
- Layer3-extension over the WAN
- The network is owned by the ISP however, it is logically an extension to your network.
- Packets are routed through the WAN instead of circuit switched.
- With routing comes convergence, traffic shaping (QoS and policies), and multiple routing protocols.

Some definitions:

- LSR - Label Switching Router
- PE - Provider Edge
- CE - Customer Edge

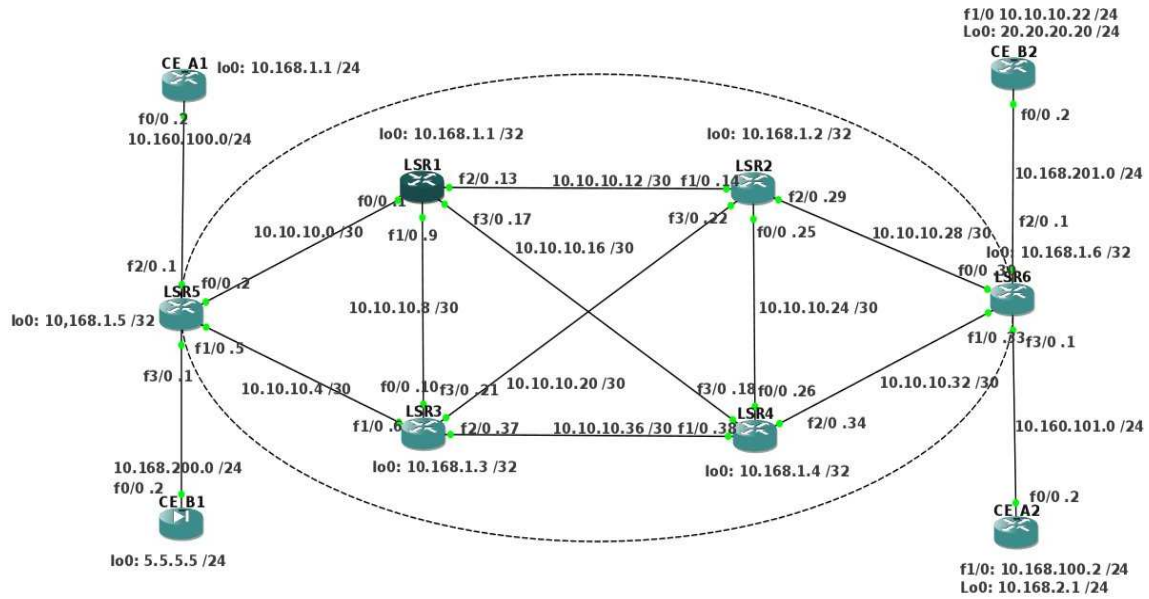
MPLS operates between layer2 and layer 3; it is sometimes called layer 2.5. Packets through the MPLS network are routed through the MPLS network, based on a label; a packet moving across the WAN can have multiple labels. Ethernet Type is 0x8847(for MPLS unicast)

3	IP
2.5	MPLS
2	Ethernet, PPP, atm etc
1	physical layer

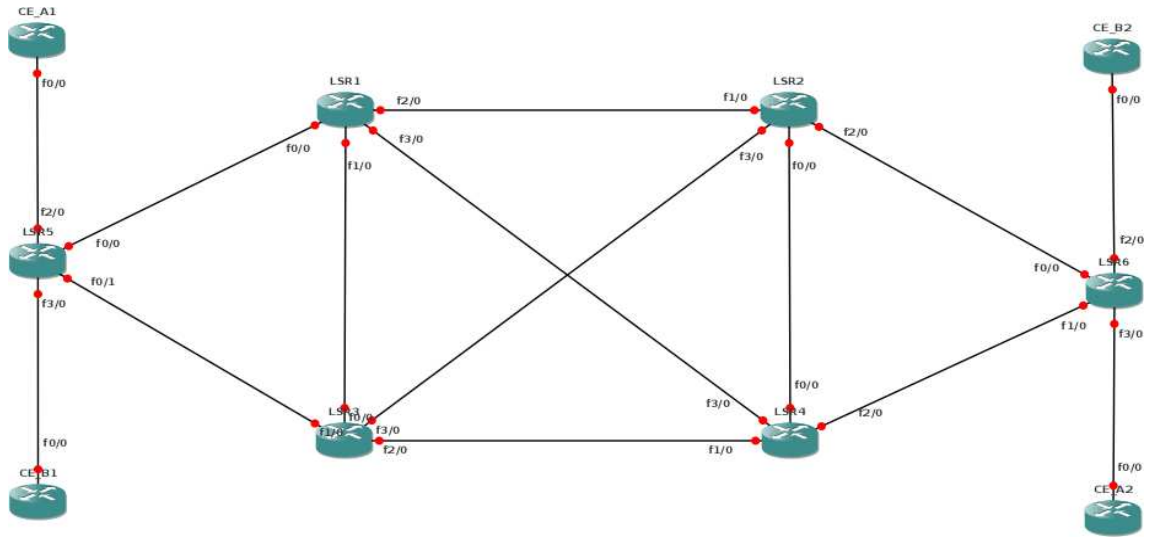
2. The network

2.1 Set-up

Because the original lab is no longer available, I added the router configs in the last chapters. The network is as depicted below.



Perhaps a simpler way to see the connected interfaces is:



Router	lo0	f0/0	f1/0	f2/0	f3/0
LSR1	10.168.1.1	10.10.10.1	10.10.10.9	10.10.10.13	10.10.10.17
LSR2	10.168.1.2	10.10.10.25	10.10.10.14	10.10.10.29	10.10.10.22
LSR3	10.168.1.3	10.10.10.10 10.10.10.16	10.10.10.37	10.10.10.21	
LSR4	10.168.1.4	10.10.10.26	10.10.10.38	10.10.10.34	10.10.10.18
LSR5	10.168.1.5	10.10.10.2	10.10.10.5	10.160.100.1	10.168.200.1
LSR6	10.168.1.6	10.10.10.30	10.10.10.33	10.168.201.1	10.160.101.1
CE_A1	10.168.1.1	10.160.100.2			
CE_A2	10.168.2.1	10.160.101.2	10.168.2.1		
CE_B1	5.5.5.5	10.168.200.2			
CE_B2	10.10.10.10	10.168.201.2	10.10.10.22		

A verification proves that it is indeed possible to ping the neighbouring routers. OSPF will route everything through the LSR-routers, so all addresses can be pinged. Another verification is `show ip route` :

```

LSR1#show ip route
Codes: C - connected, S - static, I - IGRP, 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, E - EGP
       i - IS-IS, 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
 10.0.0.0/8 is variably subnetted, 16 subnets, 2 masks
C    10.10.10.8/30 is directly connected, FastEthernet1/0
C    10.10.10.12/30 is directly connected, FastEthernet2/0
C    10.10.10.0/30 is directly connected, FastEthernet0/0
O    10.10.10.4/30 [110/2] via 10.10.10.2, 00:27:32, FastEthernet0/0
           [110/2] via 10.10.10.10, 00:27:32, FastEthernet1/0
O    10.10.10.24/30 [110/2] via 10.10.10.18, 00:27:32, FastEthernet3/0
           [110/2] via 10.10.10.14, 00:27:32, FastEthernet2/0
O    10.10.10.28/30 [110/2] via 10.10.10.14, 00:27:32, FastEthernet2/0
C    10.10.10.16/30 is directly connected, FastEthernet3/0
O    10.10.10.20/30 [110/2] via 10.10.10.10, 00:27:32, FastEthernet1/0
           [110/2] via 10.10.10.14, 00:27:32, FastEthernet2/0
O    10.10.10.32/30 [110/2] via 10.10.10.18, 00:27:32, FastEthernet3/0
O    10.10.10.36/30 [110/2] via 10.10.10.18, 00:27:46, FastEthernet3/0
           [110/2] via 10.10.10.10, 00:27:46, FastEthernet1/0
O    10.168.1.3/32 [110/2] via 10.10.10.10, 00:27:46, FastEthernet1/0
O    10.168.1.2/32 [110/2] via 10.10.10.14, 00:27:46, FastEthernet2/0
C    10.168.1.1/32 is directly connected, Loopback0
O    10.168.1.6/32 [110/3] via 10.10.10.18, 00:27:46, FastEthernet3/0
           [110/3] via 10.10.10.14, 00:27:46, FastEthernet2/0
O    10.168.1.5/32 [110/2] via 10.10.10.2, 00:27:46, FastEthernet0/0
O    10.168.1.4/32 [110/2] via 10.10.10.18, 00:27:46, FastEthernet3/0
LSR1#

```

It may be, that, when you use the configs, CEF will be enabled, but you need to start MPLS on the specific interfaces.

For LSR1, LSR2, LSR3 and LSR4, cut and paste this:

```

enable
config t
int f0/0
mpls ip
int f1/0
mpls ip
int f2/0
mpls ip
int f3/0
mpls ip

```

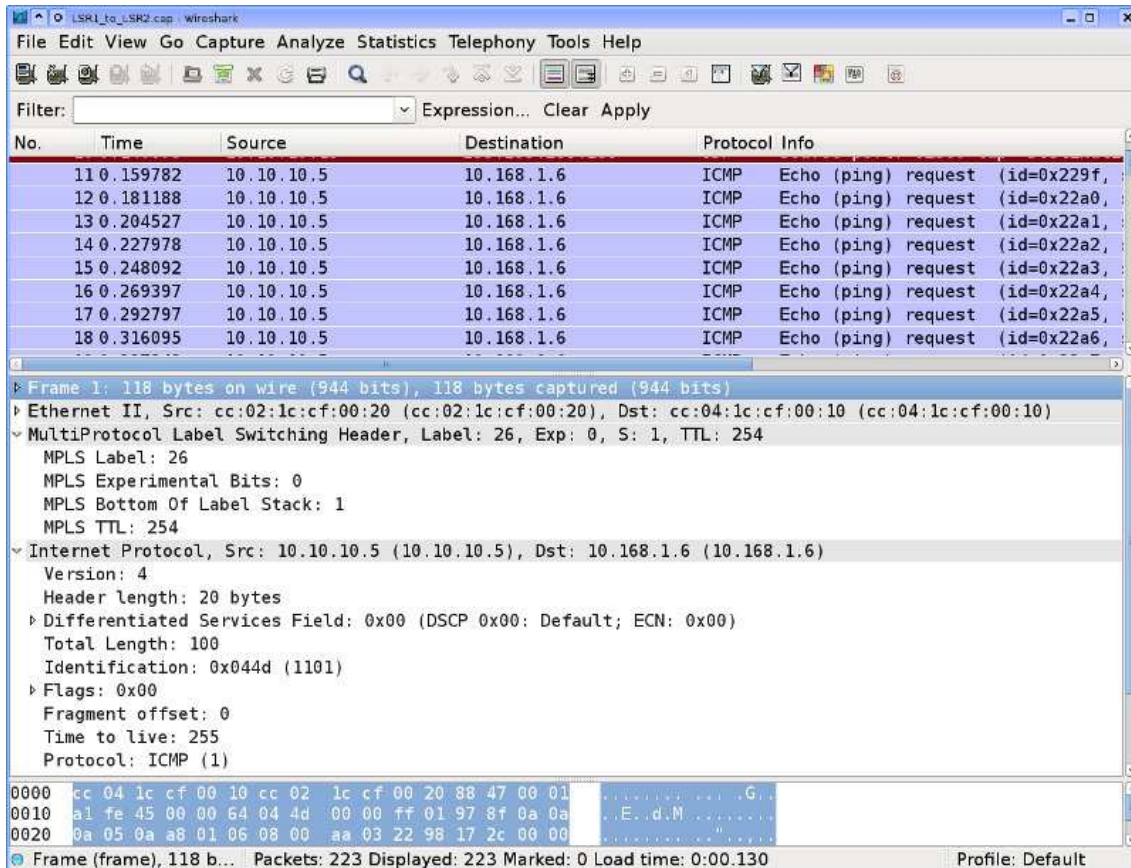
for LSR5 and LSR6:


```

enable
conf t
int f0/0
mpls ip
int f1/0
mpls ip

```

To verify that everything works, start a ping on LSR5 to the loopback address of LSR6 and start a capture on Wireshark. To make sure everything goes over the captured wire, you might want to shut-down some routers. In the trace below, you'll see only the echo requests, not the replies. The replies took another route through the MPLS cloud.



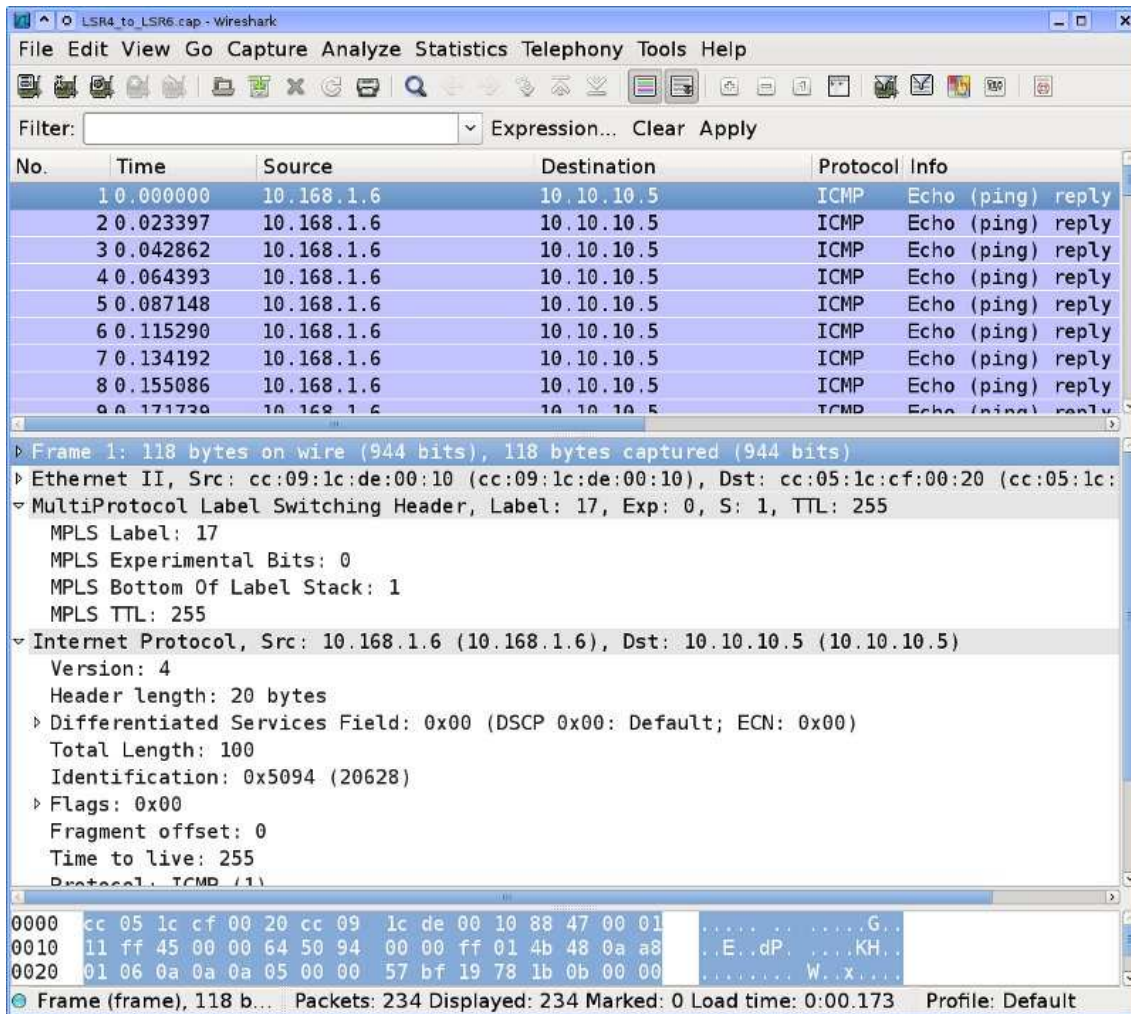
So what we see here is an echo request in MPLS. MPLS puts a header in front of the packet. This header allows faster routing through the MPLS cloud.

2.2 MPLS tests

So now MPLS works. Socketready now goes on to configuring the customer VPNs. But first, some exploration of the MPLS needs to be done.

2.2.1 Where did our ping go?

Earlier, we saw that the echo request from LSR5 to LSR6 went over the link between LSR1 and LSR2, but we did not see any replies. So, the replies must follow another route. And indeed: the replies go over LSR4.



The image shows a Wireshark capture window titled "LSR4_to_LSR6.cap - Wireshark". The main pane displays a list of captured packets. The selected packet (No. 1) is an ICMP Echo (ping) reply from 10.168.1.6 to 10.10.10.5. The packet details pane shows the following structure:

- Ethernet II, Src: cc:09:1c:de:00:10 (cc:09:1c:de:00:10), Dst: cc:05:1c:cf:00:20 (cc:05:1c:cf:00:20)
- MultiProtocol Label Switching Header, Label: 17, Exp: 0, S: 1, TTL: 255
 - MPLS Label: 17
 - MPLS Experimental Bits: 0
 - MPLS Bottom Of Label Stack: 1
 - MPLS TTL: 255
- Internet Protocol, Src: 10.168.1.6 (10.168.1.6), Dst: 10.10.10.5 (10.10.10.5)
 - Version: 4
 - Header length: 20 bytes
 - Differentiated Services Field: 0x00 (DSCP 0x00: Default; ECN: 0x00)
 - Total Length: 100
 - Identification: 0x5094 (20628)
 - Flags: 0x00
 - Fragment offset: 0
 - Time to live: 255
 - Protocol: ICMP (1)

The packet bytes pane shows the raw data in hexadecimal and ASCII:

```
0000 cc 05 1c cf 00 20 cc 09 1c de 00 10 88 47 00 01  . . . . .G . .
0010 11 ff 45 00 00 64 50 94 00 00 ff 01 4b 48 0a a8  . . .dP . . .KH .
0020 01 06 0a 0a 0a 05 00 00 57 bf 19 78 1b 0b 00 00  . . . . .W .x . .
```

The status bar at the bottom indicates: "Frame (frame), 118 b... Packets: 234 Displayed: 234 Marked: 0 Load time: 0:00.173 Profile: Default".

Notice, that the MPLS label is different. This is exactly what we expect.

2.2.2 Remove label at the last hop

Apparently, MPLS removes the MPLS label for the last hop.

The image shows a Wireshark capture of network traffic. The main pane displays a list of 9 ICMP Echo (ping) requests. The details pane for the first frame shows the following structure:

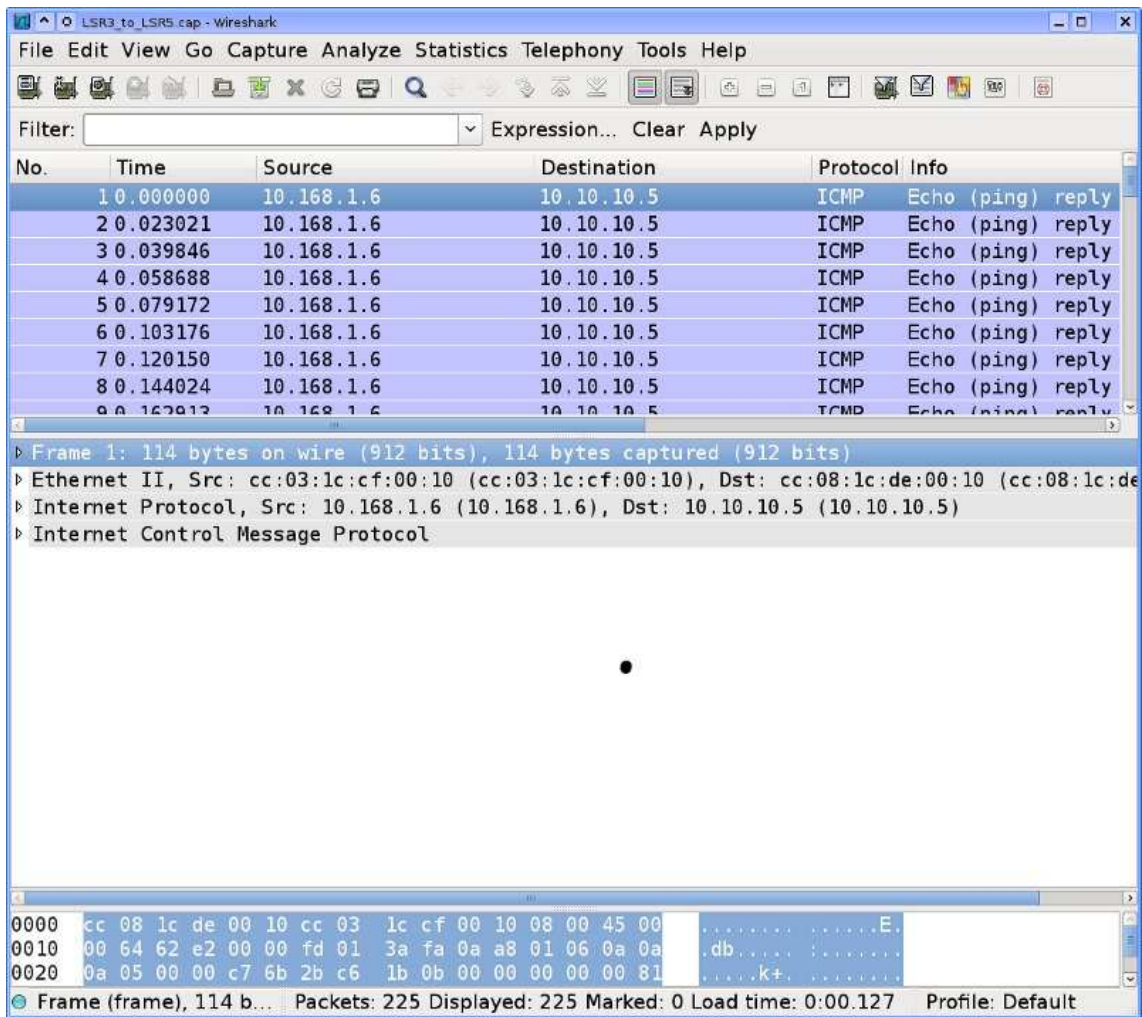
- Frame 1: 114 bytes on wire (912 bits), 114 bytes captured (912 bits)
- Ethernet II, Src: cc:04:1c:cf:00:20 (cc:04:1c:cf:00:20), Dst: cc:09:1c:de:00:00 (cc:09:1c:de:00:00)
- Internet Protocol, Src: 10.10.10.5 (10.10.10.5), Dst: 10.168.1.6 (10.168.1.6)
- Internet Control Message Protocol

The packet bytes pane shows the following hex and ASCII data:

```
0000 cc 09 1c de 00 00 cc 04 1c cf 00 20 08 00 45 00 .....E.
0010 00 64 5b 86 00 00 fd 01 42 56 0a 0a 0a 05 0a a8 .d[.....BV.....
0020 01 06 08 00 60 cc 24 6a 1b 0b 00 00 00 00 00 80 .....$]
```

At the bottom, the status bar indicates: Frame (frame), 114 b... Packets: 233 Displayed: 233 Marked: 0 Load time: 0:00.070 Profile: Default

This is consistent behaviour, as you can see for the replies:



Apparently, this is the result of a feature called PHP (Penultimate Hop Popping). If I understand it correctly, the last hop would be the one in LSR6 from f0/0 to the loopback interface.

If you ping between two CE routers, everything in the MPLS-cloud will have an MPLS header.

A. Router configurations

A.1 configs/CE_A1.cfg

```
hostname CE_A1
ip subnet-zero
call rsvp-sync
interface Loopback0
  ip address 10.168.1.1 255.255.255.0
interface FastEthernet0/0
  ip address 10.160.100.2 255.255.255.0
  duplex auto
  speed auto
interface FastEthernet1/0
  no ip address
  shutdown
  duplex auto
  speed auto
interface FastEthernet2/0
  no ip address
  shutdown
  duplex auto
  speed auto
interface FastEthernet3/0
  no ip address
  shutdown
  duplex auto
  speed auto
router bgp 65111
  bgp log-neighbor-changes
  redistribute connected
  neighbor 10.160.100.1 remote-as 100
  neighbor 10.160.100.1 update-source Loopback0
ip classless
ip route 0.0.0.0 0.0.0.0 FastEthernet0/0
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```

A.2 configs/CE_A2.cfg

```
hostname CE_A2
ip subnet-zero
call rsvp-sync
interface Loopback0
  ip address 10.168.2.1 255.255.255.0
interface FastEthernet0/0
  ip address 10.160.101.2 255.255.255.0
  duplex auto
  speed auto
interface FastEthernet1/0
  ip address 10.168.100.2 255.255.255.0
  duplex auto
  speed auto
interface FastEthernet2/0
  no ip address
  shutdown
  duplex auto
  speed auto
interface FastEthernet3/0
  no ip address
  shutdown
  duplex auto
  speed auto
router bgp 65111
  bgp log-neighbor-changes
  redistribute connected
  neighbor 10.160.101.1 remote-as 100
  neighbor 10.160.101.1 update-source Loopback0
ip classless
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```

A.3 configs/CE_B1.cfg

```
hostname CE_B1
ip subnet-zero
call rsvp-sync
interface Loopback0
  ip address 10.168.22.1 255.255.255.0
interface FastEthernet0/0
  ip address 10.168.200.2 255.255.255.0
  duplex auto
  speed auto
interface FastEthernet1/0
  no ip address
  shutdown
  duplex auto
  speed auto
interface FastEthernet2/0
  no ip address
  shutdown
  duplex auto
  speed auto
interface FastEthernet3/0
  no ip address
  shutdown
  duplex auto
  speed auto
router bgp 65222
  bgp log-neighbor-changes
  redistribute connected
  neighbor 10.168.200.1 remote-as 100
  neighbor 10.168.200.1 update-source Loopback0
ip classless
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```


A.4 configs/CE_B2.cfg

```
hostname CE_B2
ip subnet-zero
call rsvp-sync
interface Loopback0
  ip address 10.140.20.20 255.255.255.0
interface FastEthernet0/0
  ip address 10.168.201.2 255.255.255.0
  duplex auto
  speed auto
interface FastEthernet1/0
  ip address 10.10.10.22 255.255.255.0
  duplex auto
  speed auto
interface FastEthernet2/0
  no ip address
  shutdown
  duplex auto
  speed auto
interface FastEthernet3/0
  no ip address
  shutdown
  duplex auto
  speed auto
router bgp 65222
  bgp log-neighbor-changes
  redistribute connected
  neighbor 10.168.201.1 remote-as 100
  neighbor 10.168.201.1 update-source Loopback0
ip classless
ip route 0.0.0.0 0.0.0.0 FastEthernet0/0
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```

A.5 configs/LSR1.cfg

```
hostname "LSR1"
ip subnet-zero
ip cef
call rsvp-sync
interface Loopback0
  ip address 10.168.1.1 255.255.255.255
interface FastEthernet0/0
  ip address 10.10.10.1 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet1/0
  ip address 10.10.10.9 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet2/0
  ip address 10.10.10.13 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet3/0
  ip address 10.10.10.17 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
router ospf 10
  log-adjacency-changes
  network 10.10.10.0 0.0.0.3 area 1
  network 10.10.10.8 0.0.0.3 area 1
  network 10.10.10.12 0.0.0.3 area 1
  network 10.10.10.16 0.0.0.3 area 1
  network 10.168.1.1 0.0.0.0 area 1
router bgp 100
  no bgp default ipv4-unicast
  bgp log-neighbor-changes
  neighbor 10.160.100.1 remote-as 100
  neighbor 10.160.100.1 update-source Loopback0
  neighbor 10.160.100.1 activate
  neighbor 10.168.1.2 remote-as 100
  neighbor 10.168.1.2 update-source Loopback0
  neighbor 10.168.1.2 activate
  neighbor 10.168.1.3 remote-as 100
  neighbor 10.168.1.3 update-source Loopback0
  neighbor 10.168.1.3 activate
  neighbor 10.168.1.4 remote-as 100
  neighbor 10.168.1.4 update-source Loopback0
  neighbor 10.168.1.4 activate
  neighbor 10.168.1.5 remote-as 100
  neighbor 10.168.1.5 update-source Loopback0
```

```
neighbor 10.168.1.5 activate
!
address-family vpnv4
neighbor 10.160.100.1 activate
neighbor 10.160.100.1 route-reflector-client
neighbor 10.160.100.1 send-community extended
neighbor 10.168.1.2 activate
neighbor 10.168.1.2 route-reflector-client
neighbor 10.168.1.2 send-community extended
neighbor 10.168.1.3 activate
neighbor 10.168.1.3 route-reflector-client
neighbor 10.168.1.3 send-community extended
neighbor 10.168.1.4 activate
neighbor 10.168.1.4 route-reflector-client
neighbor 10.168.1.4 send-community extended
neighbor 10.168.1.5 activate
neighbor 10.168.1.5 route-reflector-client
neighbor 10.168.1.5 send-community extended
exit-address-family
ip classless
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```

A.6 configs/LSR2.cfg

```
hostname "LSR2"
ip subnet-zero
ip cef
call rsvp-sync
interface Loopback0
  ip address 10.168.1.2 255.255.255.255
interface FastEthernet0/0
  ip address 10.10.10.25 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet1/0
  ip address 10.10.10.14 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet2/0
  ip address 10.10.10.29 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet3/0
  ip address 10.10.10.22 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
router ospf 10
  log-adjacency-changes
  network 10.10.10.12 0.0.0.3 area 1
  network 10.10.10.20 0.0.0.3 area 1
  network 10.10.10.24 0.0.0.3 area 1
  network 10.10.10.28 0.0.0.3 area 1
  network 10.168.1.2 0.0.0.0 area 1
router bgp 100
  no bgp default ipv4-unicast
  bgp log-neighbor-changes
  neighbor 10.160.101.1 remote-as 100
  neighbor 10.160.101.1 update-source Loopback0
  neighbor 10.160.101.1 activate
  neighbor 10.168.1.1 remote-as 100
  neighbor 10.168.1.1 update-source Loopback0
  neighbor 10.168.1.1 activate
  neighbor 10.168.1.3 remote-as 100
  neighbor 10.168.1.3 update-source Loopback0
  neighbor 10.168.1.3 activate
  neighbor 10.168.1.4 remote-as 100
  neighbor 10.168.1.4 update-source Loopback0
  neighbor 10.168.1.4 activate
  neighbor 10.168.1.6 remote-as 100
  neighbor 10.168.1.6 update-source Loopback0
```

```
neighbor 10.168.1.6 activate
!
address-family vpnv4
neighbor 10.160.101.1 activate
neighbor 10.160.101.1 route-reflector-client
neighbor 10.160.101.1 send-community extended
neighbor 10.168.1.1 activate
neighbor 10.168.1.1 route-reflector-client
neighbor 10.168.1.1 send-community extended
neighbor 10.168.1.3 activate
neighbor 10.168.1.3 route-reflector-client
neighbor 10.168.1.3 send-community extended
neighbor 10.168.1.4 activate
neighbor 10.168.1.4 route-reflector-client
neighbor 10.168.1.4 send-community extended
neighbor 10.168.1.6 activate
neighbor 10.168.1.6 route-reflector-client
neighbor 10.168.1.6 send-community extended
exit-address-family
ip classless
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```

A.7 configs/LSR3.cfg

```
hostname "LSR3"
ip subnet-zero
ip cef
call rsvp-sync
interface Loopback0
  ip address 10.168.1.3 255.255.255.255
interface FastEthernet0/0
  ip address 10.10.10.10 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet1/0
  ip address 10.10.10.6 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet2/0
  ip address 10.10.10.37 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet3/0
  ip address 10.10.10.21 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
router ospf 10
  log-adjacency-changes
  network 10.10.10.4 0.0.0.3 area 1
  network 10.10.10.8 0.0.0.3 area 1
  network 10.10.10.20 0.0.0.3 area 1
  network 10.10.10.36 0.0.0.3 area 1
  network 10.168.1.3 0.0.0.0 area 1
router bgp 100
  no bgp default ipv4-unicast
  bgp log-neighbor-changes
  neighbor 10.168.1.1 remote-as 100
  neighbor 10.168.1.1 update-source Loopback0
  neighbor 10.168.1.1 activate
  neighbor 10.168.1.2 remote-as 100
  neighbor 10.168.1.2 update-source Loopback0
  neighbor 10.168.1.2 activate
  neighbor 10.168.1.4 remote-as 100
  neighbor 10.168.1.4 update-source Loopback0
  neighbor 10.168.1.4 activate
  neighbor 10.168.1.5 remote-as 100
  neighbor 10.168.1.5 update-source Loopback0
  neighbor 10.168.1.5 activate
  !
  address-family vpnv4
```

```
neighbor 10.168.1.1 activate
neighbor 10.168.1.1 route-reflector-client
neighbor 10.168.1.1 send-community both
neighbor 10.168.1.2 activate
neighbor 10.168.1.2 route-reflector-client
neighbor 10.168.1.2 send-community extended
neighbor 10.168.1.4 activate
neighbor 10.168.1.4 route-reflector-client
neighbor 10.168.1.4 send-community extended
neighbor 10.168.1.5 activate
neighbor 10.168.1.5 route-reflector-client
neighbor 10.168.1.5 send-community extended
exit-address-family
ip classless
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```

A.8 configs/LSR4.cfg

```
hostname "LSR4"
ip subnet-zero
ip cef
call rsvp-sync
interface Loopback0
  ip address 10.168.1.4 255.255.255.255
interface FastEthernet0/0
  ip address 10.10.10.26 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet1/0
  ip address 10.10.10.38 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet2/0
  ip address 10.10.10.34 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet3/0
  ip address 10.10.10.18 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
router ospf 10
  log-adjacency-changes
  network 10.10.10.16 0.0.0.3 area 1
  network 10.10.10.24 0.0.0.3 area 1
  network 10.10.10.32 0.0.0.3 area 1
  network 10.10.10.36 0.0.0.3 area 1
  network 10.168.1.4 0.0.0.0 area 1
router bgp 100
  no bgp default ipv4-unicast
  bgp log-neighbor-changes
  neighbor 10.160.101.1 remote-as 100
  neighbor 10.160.101.1 update-source Loopback0
  neighbor 10.160.101.1 activate
  neighbor 10.168.1.1 remote-as 100
  neighbor 10.168.1.1 update-source Loopback0
  neighbor 10.168.1.1 activate
  neighbor 10.168.1.2 remote-as 100
  neighbor 10.168.1.2 update-source Loopback0
  neighbor 10.168.1.2 activate
  neighbor 10.168.1.3 remote-as 100
  neighbor 10.168.1.3 update-source Loopback0
  neighbor 10.168.1.3 activate
  neighbor 10.168.1.6 remote-as 100
  neighbor 10.168.1.6 update-source Loopback0
```



```
neighbor 10.168.1.6 activate
!
address-family vpnv4
neighbor 10.160.101.1 activate
neighbor 10.160.101.1 route-reflector-client
neighbor 10.160.101.1 send-community extended
neighbor 10.168.1.1 activate
neighbor 10.168.1.1 route-reflector-client
neighbor 10.168.1.1 send-community extended
neighbor 10.168.1.2 activate
neighbor 10.168.1.2 route-reflector-client
neighbor 10.168.1.2 send-community extended
neighbor 10.168.1.3 activate
neighbor 10.168.1.3 route-reflector-client
neighbor 10.168.1.3 send-community extended
neighbor 10.168.1.6 activate
neighbor 10.168.1.6 route-reflector-client
neighbor 10.168.1.6 send-community extended
exit-address-family
ip classless
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```

A.9 configs/LSR5.cfg

```
hostname LSR5
ip subnet-zero
ip vrf CustomerA1
  rd 65000:1
  route-target export 65000:1
  route-target import 65000:1
ip vrf CustomerB1
  rd 65000:2
  route-target export 65000:2
  route-target import 65000:2
ip cef
call rsvp-sync
interface Loopback0
  ip address 10.168.1.5 255.255.255.255
interface FastEthernet0/0
  ip address 10.10.10.2 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet1/0
  ip address 10.10.10.5 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet2/0
  ip vrf forwarding CustomerA1
  ip address 10.160.100.1 255.255.255.0
  duplex auto
  speed auto
interface FastEthernet3/0
  ip vrf forwarding CustomerB1
  ip address 10.168.200.1 255.255.255.0
  duplex auto
  speed auto
router ospf 10
  log-adjacency-changes
  network 10.10.10.0 0.0.0.3 area 1
  network 10.10.10.4 0.0.0.3 area 1
  network 10.168.1.5 0.0.0.0 area 1
router bgp 100
  no bgp default ipv4-unicast
  bgp log-neighbor-changes
  neighbor 10.160.100.2 remote-as 65111
  neighbor 10.160.100.2 update-source Loopback0
  neighbor 10.160.100.2 activate
  neighbor 10.160.101.1 remote-as 100
  neighbor 10.160.101.1 update-source Loopback0
  neighbor 10.160.101.1 activate
  neighbor 10.168.1.1 remote-as 100
  neighbor 10.168.1.1 update-source Loopback0
```

```
neighbor 10.168.1.1 activate
neighbor 10.168.1.3 remote-as 100
neighbor 10.168.1.3 update-source Loopback0
neighbor 10.168.1.3 activate
neighbor 10.168.200.2 remote-as 65222
neighbor 10.168.200.2 update-source Loopback0
neighbor 10.168.200.2 activate
neighbor 10.168.201.1 remote-as 100
neighbor 10.168.201.1 update-source Loopback0
neighbor 10.168.201.1 activate
!
address-family ipv4 vrf CustomerB1
redistribute connected
neighbor 10.168.200.2 remote-as 65222
neighbor 10.168.200.2 activate
no auto-summary
no synchronization
exit-address-family
!
address-family ipv4 vrf CustomerA1
redistribute connected
neighbor 10.160.100.2 remote-as 65111
neighbor 10.160.100.2 activate
no auto-summary
no synchronization
exit-address-family
!
address-family vpnv4
neighbor 10.160.101.1 activate
neighbor 10.160.101.1 send-community extended
neighbor 10.168.1.1 activate
neighbor 10.168.1.1 send-community extended
neighbor 10.168.1.3 activate
neighbor 10.168.1.3 send-community extended
neighbor 10.168.201.1 activate
neighbor 10.168.201.1 send-community extended
exit-address-family
ip classless
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```

A.10 configs/LSR6.cfg

```
hostname LSR6
ip subnet-zero
ip vrf CustomerA2
  rd 65000:1
  route-target export 65000:1
  route-target import 65000:1
ip vrf CustomerB2
  rd 2:2
  route-target export 65000:2
  route-target import 65000:2
ip cef
call rsvp-sync
interface Loopback0
  ip address 10.168.1.6 255.255.255.255
interface FastEthernet0/0
  ip address 10.10.10.30 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet1/0
  ip address 10.10.10.33 255.255.255.252
  duplex auto
  speed auto
  tag-switching ip
interface FastEthernet2/0
  ip vrf forwarding CustomerB2
  ip address 10.168.201.1 255.255.255.0
  duplex auto
  speed auto
interface FastEthernet3/0
  ip vrf forwarding CustomerA2
  ip address 10.160.101.1 255.255.255.0
  duplex auto
  speed auto
router ospf 10
  log-adjacency-changes
  network 10.10.10.28 0.0.0.3 area 1
  network 10.10.10.32 0.0.0.3 area 1
  network 10.168.1.6 0.0.0.0 area 1
router bgp 100
  no bgp default ipv4-unicast
  bgp log-neighbor-changes
  neighbor 10.160.100.1 remote-as 100
  neighbor 10.160.100.1 update-source Loopback0
  neighbor 10.160.100.1 activate
  neighbor 10.160.201.2 remote-as 65111
  neighbor 10.160.201.2 update-source Loopback0
  neighbor 10.160.201.2 activate
  neighbor 10.168.1.2 remote-as 100
  neighbor 10.168.1.2 update-source Loopback0
```

```
neighbor 10.168.1.2 activate
neighbor 10.168.1.4 remote-as 100
neighbor 10.168.1.4 update-source Loopback0
neighbor 10.168.1.4 activate
neighbor 10.168.200.1 remote-as 100
neighbor 10.168.200.1 update-source Loopback0
neighbor 10.168.200.1 activate
neighbor 10.168.201.2 remote-as 65222
neighbor 10.168.201.2 update-source Loopback0
neighbor 10.168.201.2 activate
!
address-family ipv4 vrf CustomerB2
redistribute connected
neighbor 10.168.201.2 remote-as 65222
neighbor 10.168.201.2 activate
no auto-summary
no synchronization
exit-address-family
!
address-family ipv4 vrf CustomerA2
redistribute connected
neighbor 10.160.101.2 remote-as 65111
neighbor 10.160.101.2 activate
no auto-summary
no synchronization
exit-address-family
!
address-family vpnv4
neighbor 10.160.100.1 activate
neighbor 10.160.100.1 send-community extended
neighbor 10.168.1.2 activate
neighbor 10.168.1.2 send-community extended
neighbor 10.168.1.4 activate
neighbor 10.168.1.4 send-community extended
neighbor 10.168.200.1 activate
neighbor 10.168.200.1 send-community extended
exit-address-family
ip classless
ip http server
dial-peer cor custom
line con 0
line aux 0
line vty 0 4
  login
end
```

CONTENTS

1. MPLS introduction	0
2. The network	1
2.1 Set-up	2
2.2 MPLS tests	6
A. Router configurations	9
A.1 configs/CE_A1.cfg	10
A.2 configs/CE_A2.cfg	11
A.3 configs/CE_B1.cfg	12
A.4 configs/CE_B2.cfg	13
A.5 configs/LSR1.cfg	14
A.6 configs/LSR2.cfg	16
A.7 configs/LSR3.cfg	18
A.8 configs/LSR4.cfg	20
A.9 configs/LSR5.cfg	22
A.10 configs/LSR6.cfg	24