Anas Al-Selwi

Multiprotocol Label Switching Virtual Private Network

Helsinki Metropolia University of Applied Sciences

Bachelor of Engineering

Information Technology

Thesis

08 May 2013

Helsinki Metropolia University of Applied Sciences

Author(s) Title Number of Pages Date	Anas Al-Selwi Multiprotocol Label Switching Virtual Private Network 41 pages + 3 appendices 08 May 2013
Degree	Bachelor of Engineering
Degree Programme	Information Technology
Specialisation option	Computer Networks and Security
Instructor	Erik Pätynen, Senior Lecturer

A Service provider network must have the capability of facing the challenge of customer demands, especially when there are thousands or even tens of thousands of customer traffic to be carried within a single network infrastructure. Also there must be some solutions to provide new services that are not supported within the service provider network. A conventional IP lookup process and forwarding do not scale well and there must be some ways for fast lookup and packet forwarding

This thesis aimed to present and implement the technology that would allow the service provider to face this challenge and have the capability to serve new services that are not supported within his network infrastructure. In the service provider network, every customer or service is represented by an MPLS VPN and it is completely independent.

Moreover, the thesis introduced some advanced MPLS topologies, an intranet where customer sites are connected through a central site, an extranet where various customer sites are connected to each other and central services where a central server can be deployed to serve a specific customer, various customers or it can be connected to the Internet. In addition, inter-autonomous MPLS VPN, where customer sites are connected over multiple service providers, AToM and VPLS are briefly presented.

The MPLS VPN theory and implementations provided in this thesis are applied to Cisco routers only. Different vendors have different implementations, for example in MPLS, Cisco requires enabling MPLS in the interface mode. However, some vendors require enabling it in the global configuration mode even though the concept of MPLS is the same in every vendor.

Keywords	MPLS, MPLS VPN

Contents

1 Introduction

There are many topics that can be presented in MPLS such as MPLS VPN, Traffic Engineering, Any Transport over MPLS (AToM – L2 MPLS VPN), QoS and Security. However, the aim of this thesis is to present and implement MPLS VPN or L3 MPLS VPN which is actually the platform for all the services provided by a service provider since every customer or service (such as VoIP or hosting) is represented as an MPLS VPN.

Two types of MPLS VPN will be discussed and implemented in Cisco routers, MPLS VPN in a single service provider and inter-autonomous MPLS VPN (MPLS VPN over multiple service providers). In addition, some advanced MPLS VPN topologies will be discussed such as intranet, extranet, and central services. L2 MPLS VPNs (AToM and Virtual Private LAN Service VPLS) will be briefly introduced.

Communication between computers is built through layers, layer 1 to 7, as defined in the OSI model. The same methodology is applied in MPLS so that at the end we have an intelligent network. To build MPLS VPN, one of the requirements is that we need a network infrastructure which means the network must be converged. This is the underneath layer. When an MPLS VPN is built, we actually created an incomplete network that is not application-aware. So we need to continue with the MPLS model, so that in the end we will reach the application layer.

The thesis is meant for students who already have CCNP knowledge. In the beginning MPLS technology will be introduced, the reasons behind it and the basic configuration that will allow us to carry on for the implementation of MPLS VPN networks. The implementations and naming provided do not represent any company. However, they are given as examples.

Having read this thesis, a student should be able to implement his/her own MPLS VPN network and have a good knowledge of L2 MPLS VPN.

2 MPLS and Label Distribution

2.1 MPLS Basics

In traditional IP routing, packets are forwarded to destination networks based on layer 3 routing information of packet header and the routing table, and routing lookups are made independently by every router in the network. In service provider network, traditional IP routing has some issues of network scalability and routing lookups overhead. So there was a demand to a high speed packet forwarding mechanism. MPLS forwards packets based on labels (4-byte identifier) which correspond to the destination networks which reduces the overhead of traditional IP routing lookups on MPLS core routers as well as it supports protocols or services that are not supported by the service provider network.

MPLS runs on top of the IP network infrastructure which means that the network routing tables must be converged and every router must have a route to any destination network in the service provider network or MPLS domain. Any IGP routing protocol (IS-IS, OSPF, EIGRP, RIP or static) can be configured before deploying MPLS.

There are multiple applications supported by MPLS such as unicast and multicast routing, Virtual Private Network (VPN), Traffic Engineering (TE), Quality of Service (QoS) and Any Transport over MPLS (AToM). [1]

Figure 1 simplifies MPLS network infrastructure and shows the application layer, such an application as VoIP or hosting, is at the top of the hierarchy.

Application			
VPN	TE	QoS	AToM
MPLS			
IP Network Infrastructure			

Figure 1: MPLS network infrastructure

MPLS is divided into two separate components: the control plane and the data plane. The control plane is a set of protocols used to set up the data or forwarding plane which consists of routing protocols, the routing table and label distribution protocol. [2]

Basically any application such as MPLS VPN, AToM, TE or QoS that affects the forwarding of packets is within the control plane.

One of the major functions of the control plane is to exchange routing information or labels between adjacent routers and then builds the routing table which called the Routing Information Base (RIB) based on the routing protocol used, IP Forwarding Table (FIB) from RIB and Label Forwarding Information Base (LFIB) from Label Distribution Protocol (LDP) and RIB. [1]

The data plane is responsible for forwarding packets to the associated interfaces using the information in the FIB (CEF table) or the LFIB databases. [1] The routing table is not used to forward IP packets in the MPLS domain. However, it is used to set up the CEF and LFIB tables.

Figure 2 simplifies the operation of control and data planes. The information in The CEF or the LFIB databases are used to forward packets in the MPLS domain. Note that CEF table is used to forward incoming IP packets entering the MPLS domain. The output of the CEF lookup process is either an IP packet outgoing from an interface or a labelled packet. LFIB table is used to forward labelled packets only. The output of LFIB lookup process is either an IP packet (the label is removed from the labelled packet) or a labelled packet (the label is swapped with another label).

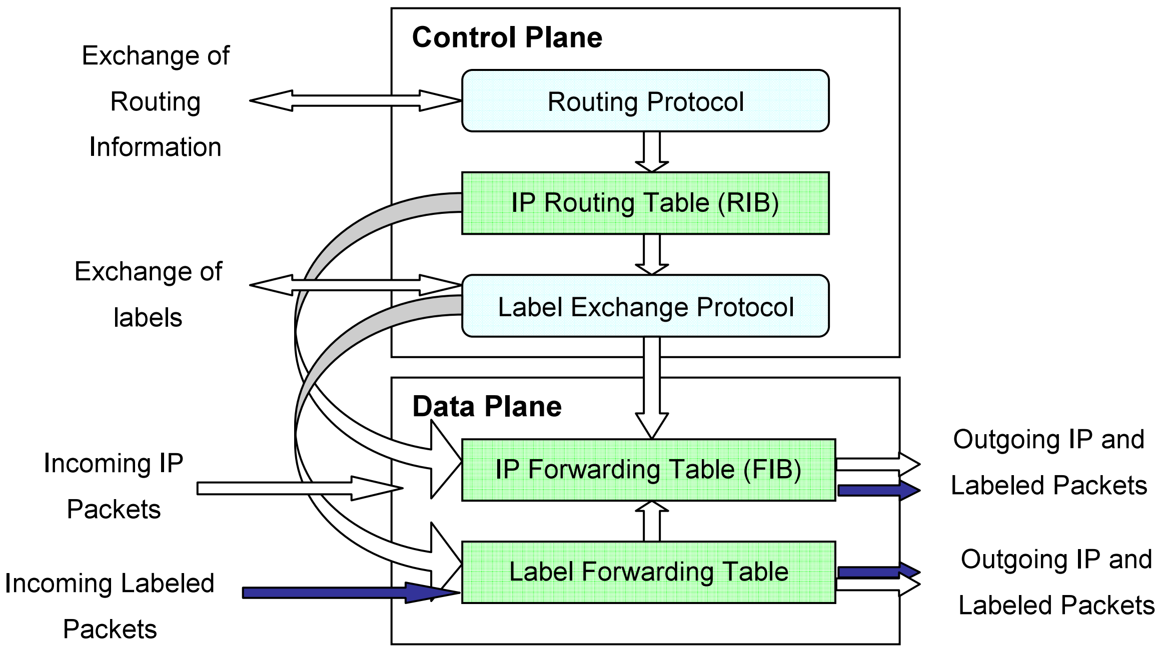

Figure 2: Control and Data Planes in the Provider Edge router. [1]

Now let us see how CEF and LFIB tables look like. At this point, there is no need to be concerned with the information provided in those tables. A global CEF table can be shown with command `show ip cef` as follows:

```
PE1#show ip cef
Prefix              Next Hop            Interface
0.0.0.0/0           drop                Null0 (default route handler entry)
0.0.0.0/32          receive
10.0.0.0/30         attached            FastEthernet0/0
10.0.0.0/32         receive
10.0.0.1/32         receive
10.0.0.2/32         10.0.0.2            FastEthernet0/0
10.0.0.3/32         receive
10.0.0.4/30         10.0.0.2            FastEthernet0/0
10.0.0.8/30         10.0.0.2            FastEthernet0/0
10.0.0.201/32       receive
10.0.0.202/32       10.0.0.2            FastEthernet0/0
224.0.0.0/4         drop
224.0.0.0/24        receive
255.255.255.255/32  receive
```

The `show ip cef` command does not show information concerning labelled packets. So we need to specify the destination network with command `show ip cef` *`destination-Ip-prefix`* {`detail`} as follows:

```
PE1#show ip cef 10.0.0.202
10.0.0.202/32, version 13, epoch 0, cached adjacency 10.0.0.2
0 packets, 0 bytes
  tag information set
    local tag: 18
    fast tag rewrite with Fa0/0, 10.0.0.2, tags imposed: {18}
  via 10.0.0.2, FastEthernet0/0, 0 dependencies
    next hop 10.0.0.2, FastEthernet0/0
    valid cached adjacency
    tag rewrite with Fa0/0, 10.0.0.2, tags imposed: {18}
```

LFIB table can be shown with command `show mpls forwarding-table` {`IP-address or destination-network`}. Using the IP-address becomes handy especially in a production network with thousands of entries either in the CEF or LFIB table. Sample of LFIB table:

```
PE1#show mpls forwarding-table
Local  Outgoing    Prefix            Bytes tag  Outgoing   Next Hop
tag    tag or VC   or Tunnel Id      switched   interface
16     Pop tag     10.0.0.4/30       0          Fa0/0      10.0.0.2
```

```
17      16           10.0.0.8/30       0           Fa0/0       10.0.0.2
18      18           10.0.0.202/32     0           Fa0/0       10.0.0.2
PE1#show mpls forwarding-table 10.0.0.202
Local   Outgoing     Prefix            Bytes tag   Outgoing    Next Hop
tag     tag or VC    or Tunnel Id      switched    interface
18      18           10.0.0.202/32     0           Fa0/0       10.0.0.2
```

The information contained in the LFIB and CEF tables will be clarified later within this chapter.

2.2 MPLS Label, Label Stack and Label Operations

MPLS label is 32 bits (4 bytes) identifier that has a similar usage as the destination IP address. Core routers in MPLS domain use the label to identify the destination node and make forwarding decisions. In addition, the label can be used to identify a service in the destination note such as a VPN. An MPLS label is equivalent to an FEC (Cisco Equivalence Class) which defined by Cisco as “a group of packets forwarded in the same manner, over the same path and with the same forwarding treatment”. An FEC defines a destination network (typically a next-hop IP address of a BGP neighbor). [1]

The label consists of four fields as shown in Figure 3:

1. Label: 20 bits number used for forwarding decisions.
2. EXP: 3 bits experimental field used to support QoS.
3. 1 bit bottom-of-stack identifier (0 indicates that there are more than one label attached to the packet, 1 indicates that this is the last label)
4. TTL: Similar to TTL value of IP header. [1]

LABEL	EXP	S	TTL
1 – 19	20 – 22	23	24 – 31

Figure 3: Label format. [1]

In an IP packet, the label is pushed between L2 and L3 headers. The L2 protocol identifier (PID) or Ethertype value is also replaced with a number as an indication of a labelled packet. [1] The label switch router LSR examines PID or Ethertype value to identify if a packet is an IP packet or a labelled packet. The label is also called a shim header. Figure 4 shows the shim header in an IP packet.

Frame Header	Label	IP Header	Payload
L2	Shim header	L3	

Figure 4: Shim Header

There are three label operations in the MPLS domain:

1. Push (or impose) label on the ingress router which insert a label or label stack to an IP packet incoming to the MPLS domain.
2. Swap label to the next-hop label in the MPLS core.
3. Pop label on the egress router outgoing from MPLS domain. [1]

Penultimate hop popping (PHP) is a mechanism to reduce one lookup process at the destination LSR by popping the label one hop before. [1] When a labelled packet is received to a destination LSR, two lookup processes take place. One lookup takes place in the LFIB table to pop the label and a second IP lookup in the routing table to forward the IP packet. PHP pops the label one hop earlier and then forwards the packet as an IP packet to the destination LSR. At the destination LSR, only an IP lookup process takes place. PHP is activated by default in Cisco routers and has an effect in the LFIB table as we are going to see later.

In MPLS, two, three or more labels can be assigned to an IP packet. This depends on the scenario being implemented. This is so-called label stack. [1] In our scenario, we want to implement MPLS VPN. So we are going to use two labels, one label (LDP label) to identify the egress LSR (the destination node) and another one (VPN label) to identify the VPN at the destination LSR. Figure 5 shows a label stack in an IP packet.

<table>
<tr><td rowspan="2">Frame Header</td><td>Outer</td><td>Inner</td><td rowspan="2">IP Header</td><td rowspan="2">Payload</td></tr>
<tr><td>LDP Label</td><td>VPN Label</td></tr>
<tr><td></td><td colspan="2">Label Stack</td><td></td><td></td></tr>
</table>

Figure 5: Label Stack

The label Stack introduces two more label operations:

4. Untagged: label stack is popped and then the packet is forwarded as an IP packet.
5. Aggregate: label stack is popped and then an IP lookup process is performed on the IP packet. [4]

2.3 Label Distribution Protocol and MPLS Operation

Every label switching router LSR in the MPLS domain creates its label locally and then binds it to an IPv4 prefix. The bindings are then distributed to all LDP neighbours by LDP. The neighbours then store the local and received neighbour bindings in the label information base (LIB). The LSR uses the received neighbour binding information and the routing table to build the label forwarding information base (LFIB) where the local binding is used as an incoming label and the received binding, that its route listed in the routing table, is used as an outgoing label. When LFIB is built and a labelled packet is received, the LSR is able to swap the local label that is assigned locally with the outgoing label that is assigned by the next-hop neighbour. Figure 6 simplifies label bindings and shows the local and received bindings of the IPv4 network prefix 10.0.0.0/8 redistributed by LDP. Basically, the binding is to associate the label to the IPv4 network prefix. [2] The command `show mpls ldp bindings` shows the contents of the LIB table as follows:

```
PE1#show mpls ldp bindings
  tib entry: 10.0.0.0/30, rev 2
            local binding:  tag: imp-null
            remote binding: tsr: 10.0.0.5:0, tag: imp-null
  tib entry: 10.0.0.4/30, rev 6
            local binding:  tag: 16
            remote binding: tsr: 10.0.0.5:0, tag: imp-null
  tib entry: 10.0.0.8/30, rev 8
            local binding:  tag: 17
            remote binding: tsr: 10.0.0.5:0, tag: 17
  tib entry: 10.0.0.201/32, rev 4
            local binding:  tag: imp-null
            remote binding: tsr: 10.0.0.5:0, tag: 16
  tib entry: 10.0.0.202/32, rev 10
            local binding:  tag: 18
            remote binding: tsr: 10.0.0.5:0, tag: 18
```

Figure 6 also simplifies the operation of MPLS. When an IPv4 packet is entering the MPLS domain with destination IPv4 prefix 10.0.0.0/8, the ingress LSR (It is also called Provider Edge PE) imposes or pushes a 143 label and the forwards the packet to LSR. The LSR (It is also called Provider P) swaps the incoming label 143 with the outgoing label 45 and then forwards the packet to the other LSR. The other LSR swaps incoming label 45 with the outgoing label 22 and so on. When the packet is received by egress LSR (it is also called PE), the label is popped, an IP lookup is performed and then the packet is forwarded to its destination. [2]

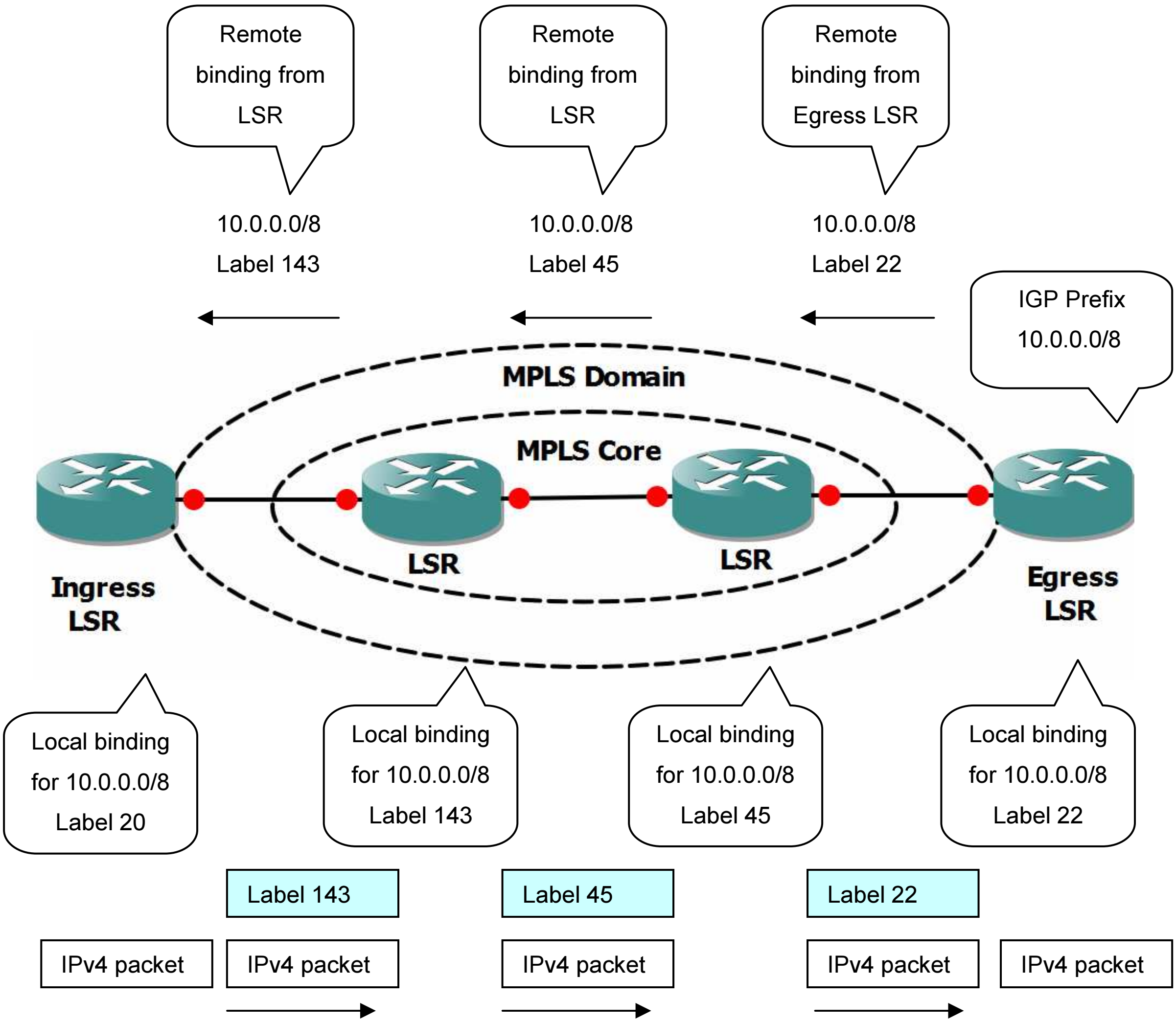

Figure 6: Label Bindings and MPLS operation. [2]

Now let us have a close look at MPLS theory in Cisco routers. At first, let us construct the LFIB entry for network 10.0.0.0/8 for all routers as shown in Figure 6 above:

Router	Local label	Remote label	MPLS Operation
Ingress LSR	20	143	20 -> 143 swap
LSR	143	45	143 -> 45 swap
LSR	45	22	45 -> 22 swap
Egress LSR	22	-	22 pop

Notice that in ingress LSR swap operation is shown in the LFIB table. However, CEF lookup process takes place to push the label 143.

Recalled that PHP is activated by default in Cisco routers and it reduces one lookup process at the egress LSR or the destination network (it does not have to be an egress LSR). PHP binds a label of 3 to an IP prefix which will be shown as imp-null (implicit null) on the router. This label tells the receiving LSR to pop the label and send the packet as an IP packet. Let us see how the LFIB table looks like when PHP is on:

Router	Local label	Remote label	MPLS Operation
Ingress LSR	20	143	20 -> 143 swap
LSR	143	45	143 -> 45 swap
LSR	45	imp-null	45 -> imp-null pop
Egress LSR	imp-null	-	No entry in LFIB table

Now let us examine the LFIB table:

```
PE1#show mpls forwarding-table
Local  Outgoing    Prefix            Bytes tag  Outgoing   Next Hop
tag    tag or VC   or Tunnel Id      switched   interface
16     Pop tag     10.0.0.4/30       0          Fa0/0      10.0.0.2
17     16          10.0.0.8/30       0          Fa0/0      10.0.0.2
18     18          10.0.0.202/32     0          Fa0/0      10.0.0.2
```

The Local tag is the local label created locally, bound to an IP prefix and then redistribute by LDP. The LSR is expecting one of these local labels to be received as an outer label. [4] If a labelled packet received with a label of 16, the label will be popped and then forwarded out of the interface Fa0/0. If a labelled packet received with a label of 17, the label will be swapped with 16 and then be forwarded out of interface Fa0/0. Notice that the local and remote labels could be the same due to the fact that the local label is locally significant. So as you can see above, swapping label 18 with 18 is pointless. However, this is how MPLS works.

Notice that there is no push operation in LFIB table. Push operation is performed in the CEF table. In case a labelled packet received from a customer, Cisco router will drop that packet. Now let us examine a CEF entry:

```
PE1#show ip cef 10.0.0.202
10.0.0.202/32, version 13, epoch 0, cached adjacency 10.0.0.2
0 packets, 0 bytes
  tag information set
    local tag: 18
    fast tag rewrite with Fa0/0, 10.0.0.2, tags imposed: {18}
```

```
  via 10.0.0.2, FastEthernet0/0, 0 dependencies
    next hop 10.0.0.2, FastEthernet0/0
    valid cached adjacency
    tag rewrite with Fa0/0, 10.0.0.2, tags imposed: {18}
```

The command shows that any IP packet destined to the destination IP address 10.0.0.202 will be imposed with a label of 18 and then be forwarded via the next hop 10.0.0.2 out of interface FastEthernet 0/0. The local label 18 is the same as the remote label in this example.

Now let us examine the LFIB table when a label stack is used:

```
PE1#show mpls forwarding-table
Local  Outgoing    Prefix            Bytes tag  Outgoing   Next Hop
tag    tag or VC   or Tunnel Id      switched   interface
16     Pop tag     192.168.0.0/30    0          Fa0/0      192.168.0.17
17     16          192.168.0.20/30   0          Fa0/0      192.168.0.17
18     17          192.168.0.4/30    0          Fa0/0      192.168.0.17
19     Pop tag     192.168.0.12/30   0          Fa0/0      192.168.0.17
20     18          192.168.0.202/32  0          Fa0/0      192.168.0.17
21     20          192.168.0.8/30    0          Fa0/0      192.168.0.17
22     21          192.168.0.24/30   0          Fa0/0      192.168.0.17
23     22          192.168.0.28/30   0          Fa0/0      192.168.0.17
24     23          192.168.0.205/32  0          Fa0/0      192.168.0.17
25     Aggregate   10.10.10.0/30[V]  0
26     Untagged    172.16.0.0/24[V]  0          Fa0/1      10.10.10.2
27     Aggregate   10.10.10.4/30[V]  5544
28     Untagged    172.16.0.0/24[V]  0          Fa1/0      10.10.10.6
```

Any labelled packet received with a label of 26, the label stack will be removed and the IP packet will be forwarded via the next hop address 10.10.10.2 out of interface Fa0/1. If a labelled packet received with a label of 25, the label stack will be removed and an IP lookup is performed. Network 10.10.10.0/30 is directly connected.

2.4 Label-Switched Path

MPLS provides connection-oriented forwarding between Provider Edge routers. Each PE has one LSP to any other PE router in the MPLS domain. The LSP is the path across the MPLS domain that labelled packets of a specific FEC traverse through. The LSP contains many FECs which basically a set of grouped-labelled packets destined to many destination networks at the egress LSR. [1]

MPLS does not change the path that has been set up by a routing protocol. Recall that MPLS binds an IP destination network to a label and then uses that label to forward labelled packets. The return labelled packets uses the reverse LSP due to the fact that routing protocols produces symmetrical routes. [1]

LDP creates a hop-by-hop LSP. So to verify the path, the CEF and LFIB entries for a specific FEC need to be checked on all LSRs along the path or we need to traceroute a destination network at the egress LSR.

Note that LDP and TE LSPs are cut one hop before the egress LSR because of PHP.

2.5 CEF Switching

2.5.1 CEF Switching Mechanisms

There are three mechanisms for switching IP packets in Cisco IOS devices:

1. Routing table driven switching: full destination network lookup process is required for every packet. In case the route contains a next-hop IP address, a recursive lookup process is required to forward the packet to the appropriate interface. This is slow and not used switching mechanism in the service provide network.
2. Cache driven switching: a cache is used to store most recent network destinations with full layer 2 header. Then, the cache is used to forward IP packets. A full lookup process is required when the destination network not found in the cache.
3. Cisco Express Class (CEF): the latest and best switching mechanisms invented by Cisco. It takes the best features from the previous switching mechanisms. A pre-build switching table, CEF is created. CEF table or Forwarding Information Base table FIB replaces the routing table. CEF supports very fast lookup, load balancing and many other features. [1]

2.5.2 CEF Configuration

CEF is enabled by default in some Cisco IOS routers such as 7200 series. It is necessary to be enabled before configuring MPLS. In case, CEF is not enabled, the following command should be issued in the global configuration mode [1]:

```
Router(config)# ip cef
```

This command enables CEF globally and creates the FIB table. In case, a CEF is required to be enabled on an interface, then CEF should be globally disabled by command `no ip cef` and the following command should be issued [1]:

```
Router(config-if)# ip route-cache cef
```

2.6 Basic MPLS and LDP Configurations

There are two compulsory configuration tasks that must be enabled before configuring MPLS on a LSR [1]:

1. CEF as shown earlier
2. LDP

To enable LDP on a LSR, the following command must be issued in the interface configuration mode [1]:

```
Router(config-if)# mpls label protocol ldp
```

This command starts LDP on the selected interface. Then, enable MPLS by command:

```
Router(config-if)# mpls ip
```

This command enables IPv4 label switching packets on the selected interface. [1]

These are the basic MPLS commands needed to demonstrate MPLS VPN. There are still optional commands that can be configured such as MPLS ID, IP TTL propagation and MTU size for labelled packets. [1]

Note that LDP and MPLS configuration commands must not be issued on the interface that is connected to the Customer Equipment (CE). These commands must be only issued within the MPLS domain.

3 MPLS VPN Architecture

3.1 Overview

A VPN is a network that represents a private network over the service provider network infrastructure. The VPN can be implemented in Layer 2 or 3 of the OSI model. Layer 3 MPLS VPN is called MPLS VPN and Layer 2 MPLS VPN is called Any Transport over MPLS (AToM) in Cisco. The VPN usually belongs to a customer or a company and might have several customer sites interconnected over the service provider network.

Early VPN networks connectivity was implemented using dedicated point-to-point links or leased lines which results to high cost to the customer side since the leased line can not be shared between customers and also it requires a dedicated router port resulting to high equipment cost to the service provider side. [1]

VPN was introduced to replace dedicated point-to-point links which has the capability to share a network infrastructure between customers and also being cost-effective to the customer and the service provider. [1]

There were two VPN scenarios offered by the service provider:

1. Overlay VPNs: the service provider connects the customer sites using virtual point-to-point links (virtual circuits). As more customer sites connect to the service provider network, this leads to scalability issues.
2. Peer-to-Peer VPNs: were introduced to resolve the scalability issues of overlay VPNs and also to provide fast data transport over the service provider network. The service provider participates in customer routing which results to optimum routing. As more customer sites connect to the service provider network, packet filters were introduced to distinguish customer sites and also results to huge routing tables to the service provider side which makes monitoring and troubleshooting very complex. [1]

In an MPLS VPN network, Provider Edge routers participate in customer routing and keep separate virtual forwarding table for each customer site. As a result, customers can use the same network prefix. In other words, the MPLS VPN combines the best features of the overlay VPNs and the Peer-to-Peer VPNs. [1]

MPLS VPN provides connectivity for customer sites over the MPLS domain as a VPN and also has the capability to connect different VPNs and even provide connectivity to the internet.

3.2 Simple MPLS VPN Model

It is important to be familiar with MPLS VPN functionality and terminologies used before any implementation to be introduced. In this section, we are going to present a simple model of MPLS VPN. Figure 7 shows a simple MPLS VPN model.

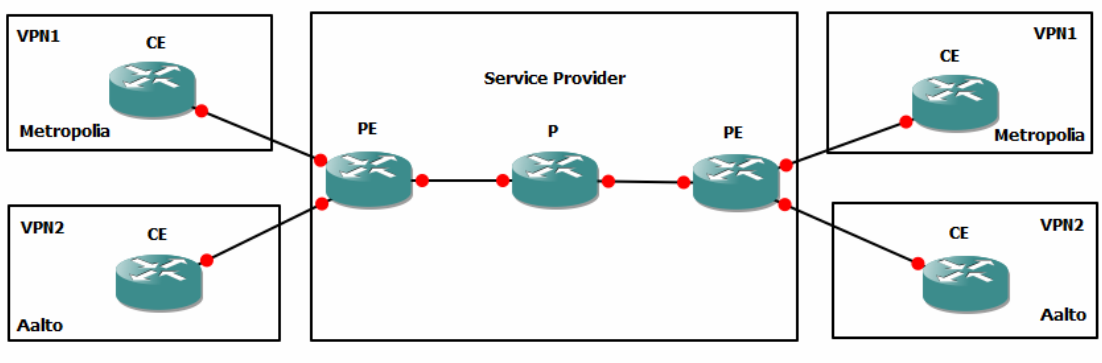

Figure 7: MPLS VPN

The service provider network infrastructure consists of two elements:

1. Provider Edge router (PE): It is connected directly to Customer Equipment CE at Layer 3. Also it runs MPLS and LDP on the interface connected to the P router so that labels are imposed and then get forwarded.
2. Provider router (P): It has no direct connection to CE and it runs MPLS and LDP. [2]

The CE is connected at Layer 3 to PE. Therefore, a routing protocol or static routing is implemented between them since there is no need to implement MPLS.
Every customer site is represented in the service provider as an MPLS VPN as shown in figure 7 above. Since it is a private network, the customer is allowed to use public or private IP addresses. The IP addresses used can be overlapping since each VPN has its own forwarding table in the service provider network. The VPN forwarding table is located only in the PE routers and it has the same format as the routing table. [2]

Multiprotocol BGP is the protocol used to carry customer routes between PE routers. P routers are unaware of the existence of VPNs. They just forward packets based on labels (swap labels).

MPLS VPN consists of some building blocks of configuration to be implemented. Those building blocks are: Virtual Routing and Forwarding table (VRF), Route Distinguisher (RD), Route Targets (RTs), route propagation through Multiprotocol BGP and forwarding of labelled packets. All configuration commands will be issued in the PE routers.

To implement MPLS VPN, there are some steps to follow:

1. Define and configure VRF
2. Define and configure RD
3. Define and configure import and export polices
4. Configure the PE-to-CE links
5. Associate the CE interfaces of the PE with the previously defined VRFs
6. Configure Multiprotocol BGP. [3]

3.3 Virtual Routing and Forwarding

VRF is a routing and forwarding table instance similar to the Cisco IOS routing table. However, VRF is associated to a single VPN or a customer and contains routes of that specific VPN due to the fact that the routing must be private and separated from other VPNs. The PE interface connected to a CE belongs to only one VPN and it is not possible to configure two VPNs in one interface. [2]

To create VRF, the command `ip vrf VPN-name` is used and it must be assigned to the PE interface associated to CE by command `ip vrf forwarding VPN-name`. Note that a VRF can be assigned to one interface. However, many interfaces can be assigned to a VRF. [2]

There are attributes that must be configured in the VRF table and we will have a close look at these attributes in section 3.4 and 3.5. However, let us present a sample configuration of VRF and how VRF looks like as shown in Example 1.

Example 1: VRF Configuration

```
!
ip vrf Metropolia
 rd 1:2
 route-target export 1:2
 route-target import 1:2
!
Interface FastEthernet0/1
 Ip vrf forwarding Metropolia
 ip address 10.10.10.1 255.255.255.252
!

PE1#show ip route vrf Metropolia

Routing Table: Metropolia
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

     172.16.0.0/24 is subnetted, 2 subnets
S       172.16.0.0 [1/0] via 10.10.10.2, FastEthernet0/1
B       172.16.1.0 [200/0] via 192.168.0.252, 00:02:19
     10.0.0.0/30 is subnetted, 2 subnets
B       10.20.20.0 [200/0] via 192.168.0.252, 00:02:19
C       10.10.10.0 is directly connected, FastEthernet0/1
```

There is also CEF table for Metropolia VRF and can be shown by command `show ip cef vrf Metropolia`.

3.4 Route Distinguisher

In an MPLS VPN network, customer routes are carried by Multiprotocol BGP. As there are thousands of customers served by the service provider network, IP addresses may overlap. If customers had overlapping IP addresses, the routing would be wrong. This problem is solved by the concept of Route Distinguisher (RD) to make IPv4 prefixes unique. The RD is just a unique identifier (64-bit) used to distinguish IP addresses from various customers. A vpnv4 prefix is created from the IPv4 prefix and the RD. MP-BGP propagates these vpnv4 prefixes between the PE routers. [2]

Note that the RD is used to make VRF IPv4 addresses unique when propagated with MP-BGP. However, RD does not indicate which VRF the IPv4 addresses belongs to. In other words, The RD does not indicate the VPN due to the fact that there are complex MPLS VPN topologies that require more than one RD per VPN. [2]

There must be at least one RD assigned to a VRF instance on the PE router. The format of RD is *ASN:nn* or *IP-address:nn*, where ANS stands for Autonomous System Number of the service provider and nn is just a number. [2]

The vpnv4 prefix is created from the combination of the IPv4 prefix (32-bits) and the RD (64-bits). The address of vpnv4 is 96-bits long. If we make a vpnv4 prefix with an IPv4 prefix 10.10.10.0/24 and a RD 1:2, the address of the vpnv4 will be 1:2:10.10.10.0/24.

The RD is configured with `rd` command after creating the VRF instance by command `ip vrf` as shown in Example 1 earlier.

3.5 Route Targets

Route Targets control the communication between VPN sites either those sites from the same customer (same VPN) or different customer (different VPN). If the communication between sites from the same customer, this is called intranet. Otherwise, if the communication between sites from different customer, this is called extranet. [2]

An RT is just a BGP extended community attribute that determines which routes to be imported from MP-BGP into VRF (remote routes from other PE routers) or which routes to be exported from VRF to be redistributed into MP-BGP in order to propagate those routes to other PE routers. When vpnv4 route is received by the PE router, the route is checked with an import extended community attribute (which is an RT) for a match. If a match is found, the route is inserted in the VRF. Otherwise, the route is rejected. [2]

The command used to configure RTs is `route target {import, export, both}` where both means import and export. In intranet case, importing should be configured in a VRF and all other PE routers should be configured with export keyword. However, in extranet case when different sites or VPNs should be connected, we need to pay more attention for the configuration. [2]

Figure 8 shows an extranet example where Cust-one sites are connected over the PE2 and PE4 routers and Cust-two sites connected over the PE1 and PE3 routers. We assume that the RD for Cust-One VRF is 1:2 and the RD for Cust-Two is 1:3. Now if Cust-One connected to PE2 router wants to communicate with Cust-Two connected to the PE1 router as noted with red oval. This can be achieved by configuring RTs on the PE1 and PE2 routers. [2]

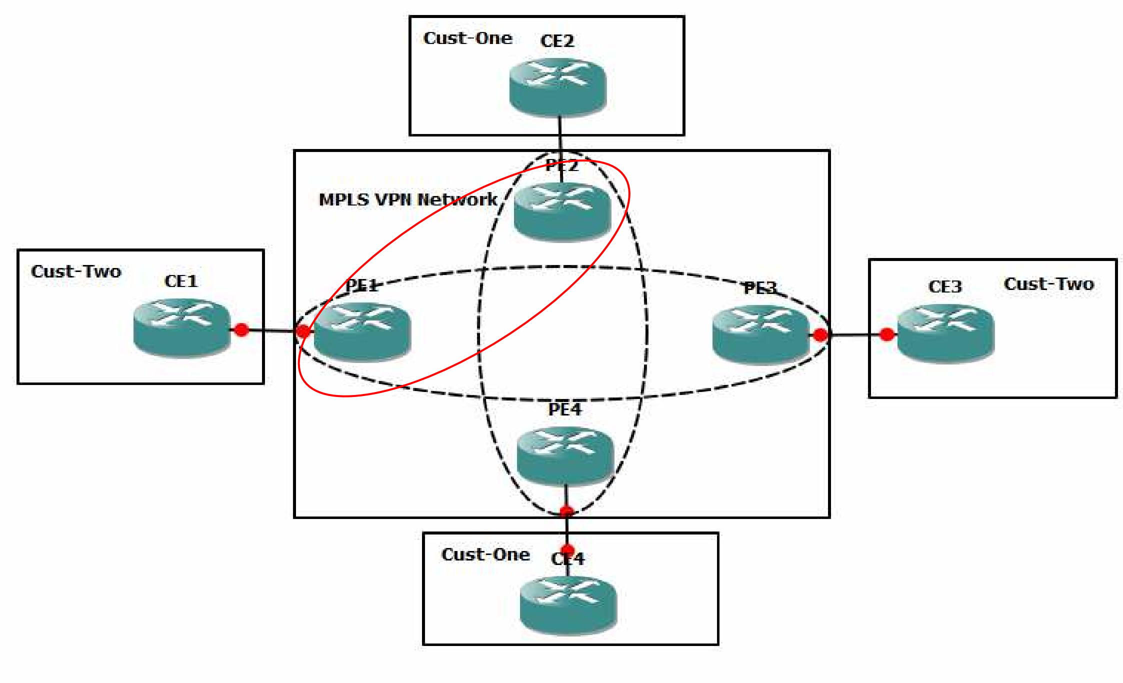

Figure 8: Extranet Case. [2]

To implement this topology, we configure RT 200:1 in Cust-One and Cust-Two VRFs on the PE1 and PE2 routers. Example 2 shows complete configuration commands for both VRFs. [2]

Example 2: Extranet Configuration. [2]

```
hostname PE1
!
ip vrf Cust-One
 rd 1:2
 route-target export 1:2
 route-target export 200:1
 route-target import 1:2
 route-target import 200:1
!
hostname PE2
!
ip vrf Cust-Two
 rd 1:3
 route-target export 1:3
 route-target export 200:1
 route-target import 1:3
 route-target import 200:1
!
```

The command `show ip bgp vpnv4 all` *`network-prefix-imported-from-other-VRF`* is used for verification.

3.6 PE-to-CE Connectivity

3.6.1 PE-to-CE Connectivity – Static Routing

In an MPLS VPN network, we have seen that each customer has its own VRF associated to an interface on the PE router that is connected to the CE router. Routes learned from that interface will be inserted in a VRF and be propagated through MP-BGP but how PE is going to learn CE routes to be propagated through MP-BGP? Actually there are many options to provide connectivity between PE and CE. Basic connectivity can be provided by static routing or RIP version 2. RIP version 1 is not supported. Other advanced connectivity options can be provided by eBGP, OSPF, ISIS or EIGRP. However, the concept is similar in every one except eBGP.

This section provides connectivity between the PE and CE routers using static routing. Then, we will redistribute those static routes into BGP to be propagated to the other PE routes through MP-iBGP. Static routing option is a good choice when the customer has only one entry point to the service provider network. [3]

Note that in MPLS VPN, there must be full-mesh BGP sessions between all the PE routers. We will provide a configuration sample for BGP sessions later in this chapter. At first, we need to configure each network beyond the CE router on the PE router with a static route. If we assume that the network prefix of the CE router is 172.16.0.0/24, the configuration command will be as follows:

```
PE1(config)# ip route vrf Metropolia 172.16.0.0 255.255.255.0
serial0 10.10.10.2
```

Then we need to redistribute this static route into BGP. To do this, we have to use the redistribute command within `address-family` sub-mode of the VRF as follows:

```
router bgp 1
!
address-family ipv4 vrf Metropolia
 redistribute connected
 redistribute static
exit address-family
!
```

Using `address-family` sub-mode makes the router redistribute the routes to only interfaces associated with the address-family. [3]

Note that the command `redistribute connected` is added to propagate the network prefix that is directly connected to the PE. Otherwise, the communication of the VPN sites would fail.

3.6.2 PE-to-CE Connectivity – RIP Version 2

This section provides connectivity between the PE and CE routers using RIP version 2. The routes learned through RIP form a CE router is placed into the VRF associated to the interface connected to the CE router. Then, these routes are propagated through MP-iBGP to other PE routers.

As we already know, RIP routing updates consist of all RIP routes in the routing table plus the RIP-enabled directly connected interfaces. These routing updates are sent out to all interfaces that belong to the address range of the `network` command. In an MPLS VPN network, there is another way to overcome this operation, since it is clearly not desirable. [3]

Using the `address-family` sub-mode within the RIP process configuration makes the router interprets any configuration commands in between as belonging to the specified VRF. Routes learned through RIP are advertised to only interfaces associated with the address-family. [3] RIP configuration commands for Aalto VRF as follows:

```
router rip
!
address-family ipv4 vrf Aalto
 version 2
 redistribute bgp 1 metric 2
 network 10.0.0.0
 no auto-summary
exit-address-family
!
```

This configuration gets the RIP routes propagated through MP-BGP into Aalto VRF. However, it does not advertise routes leaned through the CE router to other PE routers. [3] To do this, we should issue the following commands:

```
router bgp 1
!
address-family ipv4 vrf Aalto
 redistribute connected
 redistribute rip
exit address-family
!
```

3.6.3 PE-to-CE Connectivity – eBGP

eBGP can be used as the routing protocol between the PE and CE routers. We just need to create an eBGP session and activate it under the `address family ipv4` `vrf` of the router bgp process on the PE router. [2] A Sample of configuration commands is as follows:

```
router bgp 1
!
address-family ipv4 vrf Helsinki
 redistribute connected
 neighbor 10.30.30.6 remote-as 2
 neighbor 10.30.30.6 activate
 exit-address-family
!
```

3.7 Interface Association to a VRF

As mentioned earlier in 3.3 section that after defining a VRF, we must associate it with an interface that is connected to the CE router. This is done by `ip vrf forwarding` interface-mode command. Following is a configuration sample:

```
interface serial0
 ip vrf forwarding Aalto
 ip address 10.10.10.5 255.255.255.252
```

When associating an interface to a VRF, the IP address of the interface is removed from the routing table and also from the interface. Therefore, issuing `ip address` command is mandatory after `ip vrf forwarding` command. [3]

3.8 Route Propagation in an MPLS VPN Network

This section aims to show how customer routes propagate over the MPLS VPN network. The route propagation occurs as follows:

1. Customer IPv4 routes are learnt by the PE router through IGP or eBGP
2. Learnt IPv4 routes are then inserted into a particular VRF routing table associated to the CE.
3. IPv4 routes are then redistributed into MP-BGP. A VPNv4 route is made by adding the RD to the IPv4 route. RTs are also added.
4. MP-iBGP propagates VPNv4 routes with MPLS label and RTs.

5. RTs indicate to which VRF the route is imported and RD is removed from the VPNv4 route.
6. IPv4 routes are inserted into the VRF routing table on the other PE router
7. IGP or eBGP advertises IPv4 routes to the CE at the other site. [2]

3.9 Multiprotocol BGP

3.9.1 Overview of MP-BGP

MP-BGP will be introduced in this section since it is the only routing protocol used to propagate customer routes between the PE routers.

BGP is a standard protocol used for interdomain routing that makes up the internet. Service providers run BGP between them as the routing protocol. BGP is a powerful protocol that has the capability to carry out thousands of IPv4 or IPv6 routes and allows polices to be implemented. A service provider peers with other service provider through eBGP and runs iBGP internally.

Multiprotocol extension of BGP (RFC 2858) was developed to carry other routing information than IPv4. When IPv6 was developed, Multiprotocol BGP has the capability to carry IPv6 prefixes. This feature of Multiprotocol BGP allows us to carry the label to identify the MPLS VPN (or Virtual Routing and Forwarding table VRF). Basically MP-BGP has the capability to carry any routing protocol information.

3.9.2 Multiprotocol BGP Configuration

The first step of MP-BGP configuration is to create BGP sessions between the PE routers in the MPLS VPN network. A full-mesh topology of BGP sessions must be created for all the PE routers. Sample configuration commands as follows:

```
router bgp 1
 neighbor 192.168.0.205 remote as 1
 neighbor 192.168.0.205 update-source loopback0
 neighbor 192.168.0.205 activate
!
```

Note that the IP address of the loopback0 interface was used to peer the PE routers. This configuration is recommended especially in the service provider network.

The other configuration step is to activate the MP-iBGP session in order to exchange VPN-IPv4 prefixes using address-family sub-mode in the BGP process configuration. This configuration must be applied for each VRF configured in the PE router. The usage of address-family allows MP-BGP to carry protocols other than IPv4. The configuration commands as follows:

```
router bgp 1
!
address-family vpnv4
 neighbor 192.168.0.205 activate
 neighbor 192.168.0.205 send-community extended
exit address-family
```

When issuing the command `neighbor 192.168.0.205 activate`, there is no need to issue the command `neighbor 192.168.0.205 send community extended` because it is added by default. [3]

RD and RTs are called extended community attributes that have been added to the standard BGP to create MP-BGP. In order to MP-BGP to propagate these extended community attributes, the command `neighbor 192.168.0.205 send community extended` must be added as shown above.

3.10 MPLS VPN Site Expansion

Imagine a VPN customer who has two sites interconnected over a service provider network is requesting a connectivity for a third site, how this site is connected over the service provider network? In an MPLS VPN network, connecting third site is like plug and play. The customer VPN needs to be added on the PE router associated to the third site CE with same configuration of VRF, RD and RTs. In addition, we need to activate MP-BGP in order to propagate VPNv4 routes over the PE routers connected to customer sites. If the third customer site is added to the same PE router which is connected to the first or second customer site, the third site router interface needs only to be associated to the customer VRF.

3.11 MPLS VPN Example

Figure 9 shows an MPLS VPN network which consists of 4 P routers in the core, 4 PE routers and 3 customers (Metropolia, Aalto and Helsinki). The objective of the MPLS VPN network is to connect customer sites with each other (Metropolia customer has two sites, Aalto has 3 sites and Helsinki has 2 sites). For PE-to-CE connectivity, we will implement static routing for Metropolia, RIP for Aalto and eBGP for Helsinki.
Let us assume that one of the requirements of the customers Metropolia and Helsinki is to make an extranet between them on the PE2 and PE3 routers.

In this MPLS VPN example, we are going to present the configuration commands of the MPLS VPN network to create connectivity between customer sites, network infrastructure and MPLS configuration commands will also be shown. Full configuration commands are listed in Appendix 1.

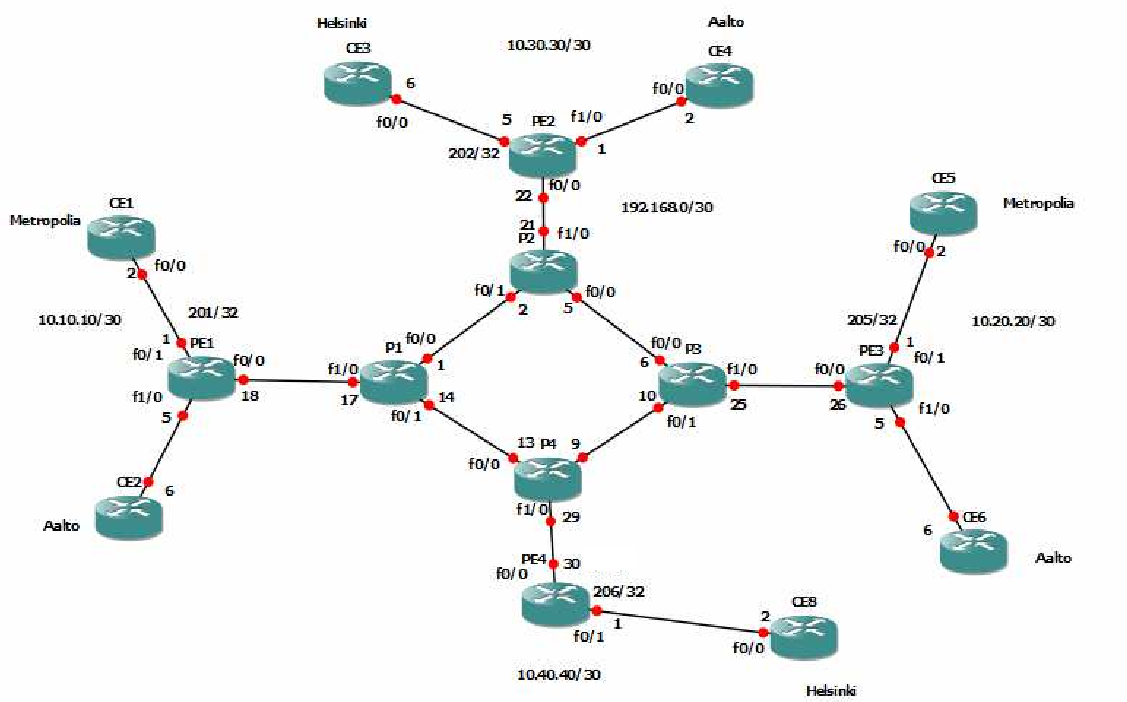

Figure 9: MPLS VPN Sample

There are certain commands that allow us to access and troubleshoot VRF tables within the MPLS VPN network. These commands are ping, traceroute, telnet and show ip route as follows:

```
PE1# ping vrf Metropolia 172.16.0.1
PE1# telnet 172.16.1.1 /vrf Helsinki
PE1# traceroute vrf Aalto 172.16.2.1
PE1# show ip route vrf Metropolia
```

In the MPLS VPN configuration sample, we will notice that every site has a route to every destination network on the other site(s). This is not always desirable due to the fact that an organization contains HQ and braches. Braches should not have all network routes to the HQ. There is a way that we could control the routes advertised through MP-BGP using route map. This solution will not be discussed in here.

3.12 Testing an MPLS VPN Network

The command `show ip route vrf` *`VPN-name`* determines the starting point of testing for a customer VPN in case remote routes are propagated from other site(s) through MP-BGP. Otherwise, we should troubleshoot the customer VPN.

In the MPLS VPN example implemented in Appendix 1, let us test Aalto VPN (every VPN is completely independent). Recall that Aalto VPN consists of 3 sites (on PE1, PE2 and PE3 routers) and it uses RIP as the routing protocol for PE-to-CE connectivity. In the beginning, we have to show the sample configuration of all CE routers of Aalto VPN (As a service provider, access to CE routers is not possible). Example 3 shows a sample configuration of all Aalto CE routers.

hostname CE2	hostname CE4	hostname CE6
!	!	!
interface Loopback0	interface Loopback0	interface Loopback0
ip address 172.16.0.1 255.255.255.0	ip address 172.16.2.1 255.255.255.0	ip address 172.16.1.1 255.255.255.0
!	!	!
interface FastEthernet0/0	interface FastEthernet0/0	interface FastEthernet0/0
ip address 10.10.10.6 255.255.255.252	ip address 10.30.30.2 255.255.255.252	ip address 10.20.20.6 255.255.255.252
!	!	!
router rip	router rip	router rip
version 2	version 2	version 2
network 10.0.0.0	network 10.0.0.0	network 10.0.0.0
network 172.16.0.0	network 172.16.0.0	network 172.16.0.0
no auto-summary	no auto-summary	no auto-summary
!	!	!

Example 3: Sample Configuration of Aalto CE routers

Now let us see the output of command `show ip route vrf Aalto` on the PE1 router:

```
PE1#show ip route vrf Aalto

Routing Table: Aalto
……
     172.16.0.0/24 is subnetted, 3 subnets
R       172.16.0.0 [120/1] via 10.10.10.6, 00:00:17, FastEthernet1/0
B       172.16.1.0 [200/1] via 192.168.0.205, 00:20:13
B       172.16.2.0 [200/1] via 192.168.0.202, 00:20:13
     10.0.0.0/30 is subnetted, 3 subnets
B       10.30.30.0 [200/0] via 192.168.0.202, 00:22:59
B       10.20.20.4 [200/0] via 192.168.0.205, 00:22:59
C       10.10.10.4 is directly connected, FastEthernet1/0
```

Notice that four networks are propagated through MP-BGB and one network learned from the CE1 router through RIP.

Now the testing process is started on the PE1 using ping and traceroute commands. We need to ping and traceroute remote networks propagated through MB-BGP as follows:

```
PE1#ping vrf Aalto 10.30.30.1

Type escape sequence to abort.
```

```
Sending 5, 100-byte ICMP Echos to 10.30.30.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 144/215/308 ms
PE1#ping vrf Aalto 10.20.20.5

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.20.20.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 248/343/424 ms
PE1#ping vrf Aalto 172.16.1.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 296/348/432 ms


PE1#ping vrf Aalto 172.16.2.1

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 172.16.2.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 248/296/356 ms

PE1#traceroute vrf Aalto 172.16.1.1

Type escape sequence to abort.
Tracing the route to 172.16.1.1

  1 192.168.0.17 [MPLS: Labels 23/28 Exp 0] 40 msec 64 msec 32 msec
  2 192.168.0.2 [MPLS: Labels 23/28 Exp 0] 48 msec 36 msec 32 msec
  3 192.168.0.6 [MPLS: Labels 23/28 Exp 0] 44 msec 28 msec 36 msec
  4 10.20.20.5 [MPLS: Label 28 Exp 0] 36 msec 24 msec 28 msec
  5 10.20.20.6 28 msec *  48 msec
PE1#traceroute vrf Aalto 172.16.2.1

Type escape sequence to abort.
Tracing the route to 172.16.2.1

  1 192.168.0.17 [MPLS: Labels 18/26 Exp 0] 40 msec 52 msec 44 msec
  2 192.168.0.2 [MPLS: Labels 16/26 Exp 0] 44 msec 40 msec 68 msec
  3 10.30.30.1 [MPLS: Label 26 Exp 0] 32 msec 32 msec 16 msec
  4 10.30.30.2 36 msec *  56 msec
```

Then we should continue testing other PE routers using ping and traceroute commands as shown above. The Aalto customer can also test his own sites using the normal ping and traceroute commands.

In the following there are some useful commands which can be used to verify MPLS and MPLS VPN:

```
PE1#show mpls forwarding-table
Local  Outgoing    Prefix            Bytes tag  Outgoing    Next Hop
tag    tag or VC   or Tunnel Id      switched   interface
16     Pop tag     192.168.0.0/30    0          Fa0/0       192.168.0.17
17     16          192.168.0.20/30   0          Fa0/0       192.168.0.17
18     17          192.168.0.4/30    0          Fa0/0       192.168.0.17
19     Pop tag     192.168.0.12/30   0          Fa0/0       192.168.0.17
20     18          192.168.0.202/32  0          Fa0/0       192.168.0.17
21     20          192.168.0.8/30    0          Fa0/0       192.168.0.17
22     21          192.168.0.24/30   0          Fa0/0       192.168.0.17
23     22          192.168.0.28/30   0          Fa0/0       192.168.0.17
24     23          192.168.0.205/32  0          Fa0/0       192.168.0.17
25     Aggregate   10.10.10.0/30[V]  0
26     Untagged    172.16.0.0/24[V]  0          Fa0/1       10.10.10.2
27     Aggregate   10.10.10.4/30[V]  5544
28     Untagged    172.16.0.0/24[V]  0          Fa1/0       10.10.10.6

PE1#show mpls forwarding-table vrf Aalto
Local  Outgoing    Prefix            Bytes tag  Outgoing    Next Hop
tag    tag or VC   or Tunnel Id      switched   interface
27     Aggregate   10.10.10.4/30[V]  0
28     Untagged    172.16.0.0/24[V]  0          Fa1/0       10.10.10.6

PE1#show ip cef vrf Aalto
Prefix              Next Hop            Interface
0.0.0.0/0           drop                Null0 (default route handler entry)
0.0.0.0/32          receive
10.10.10.4/30       attached            FastEthernet1/0
10.10.10.4/32       receive
10.10.10.5/32       receive
10.10.10.7/32       receive
10.20.20.4/30       192.168.0.17        FastEthernet0/0
10.30.30.0/30       192.168.0.17        FastEthernet0/0
172.16.0.0/24       10.10.10.6          FastEthernet1/0
172.16.1.0/24       192.168.0.17        FastEthernet0/0
172.16.2.0/24       192.168.0.17        FastEthernet0/0
224.0.0.0/4         drop
224.0.0.0/24        receive
255.255.255.255/32  receive

PE1#show ip cef vrf Aalto 172.16.1.0
172.16.1.0/24, version 13, epoch 0, cached adjacency 192.168.0.17
0 packets, 0 bytes
  tag information set
    local tag: VPN-route-head
    fast tag rewrite with Fa0/0, 192.168.0.17, tags imposed: {23 28}
  via 192.168.0.205, 0 dependencies, recursive
```

```
    next hop 192.168.0.17, FastEthernet0/0 via 192.168.0.205/32
    valid cached adjacency
    tag rewrite with Fa0/0, 192.168.0.17, tags imposed: {23 28
```

```
PE1#show mpls ldp neighbor
    Peer LDP Ident: 192.168.0.17:0; Local LDP Ident 192.168.0.201:0
            TCP connection: 192.168.0.17.646 - 192.168.0.201.57001
            State: Oper; Msgs sent/rcvd: 29/28; Downstream
            Up time: 00:12:47
            LDP discovery sources:
              FastEthernet0/0, Src IP addr: 192.168.0.17
        Addresses bound to peer LDP Ident:
          192.168.0.1     192.168.0.14    192.168.0.17
```

```
PE1#show mpls ldp discovery
 Local LDP Identifier:
    192.168.0.201:0
    Discovery Sources:
    Interfaces:
            FastEthernet0/0 (ldp): xmit/recv
                LDP Id: 192.168.0.17:0; no host route
```

```
PE1#show ip bgp vpnv4 rd 1:3
BGP table version is 23, local router ID is 192.168.0.201
Status codes: s suppressed, d damped, h history, * valid, > best, i - inter-
nal,
              r RIB-failure, S Stale
Origin codes: i - IGP, e - EGP, ? - incomplete

   Network          Next Hop            Metric LocPrf Weight Path
Route Distinguisher: 1:3 (default for vrf Aalto)
*> 10.10.10.4/30    0.0.0.0                  0         32768 ?
*>i10.20.20.4/30    192.168.0.205            0    100      0 ?
*>i10.30.30.0/30    192.168.0.202            0    100      0 ?
*> 172.16.0.0/24    10.10.10.6               1         32768 ?
*>i172.16.1.0/24    192.168.0.205            1    100      0 ?
*>i172.16.2.0/24    192.168.0.202            1    100      0 ?
```

All these verification commands have been issued on the PE1 router only. Verifying other PE routers (PE2 and PE3) should be continued.

3.13 Advanced MPLS VPN Topologies

3.13.1 Intranet and Extranet Example

Intranet and extranet topologies were briefly discussed earlier in section 3.5. The idea of implementing these topologies is to configure route target BGP extended community attributes to export and import routes within a site or various sites. Depending on how these attributes are configured, it clearly identifies the implemented topology. In this section, we will discuss only two topologies:

1. Intranet and Extranet Topologies
2. Central Services Topology

Intranet and extranet are the most common topologies implemented in the service provider network. The statements of route targets BGP extended community attributes control the behaviour of the VRF communications. [3]

Figure 10 shows an extranet connectivity with central site access where the customer 2 central site on the PE2 router exports its own routes with a value of 1:15. In addition, it imports routes from customer 2 sites with a value of 1:4. Routes from the central site are imported to the other customer 2 sites. This configuration lets the other customer 2 sites to access the central site but not the customer 1 sites. The customer 1 sites are able to access the other customer 2 sites and the customer 2 sites are also able to access the customer 1 sites as you can see the import and export values below.

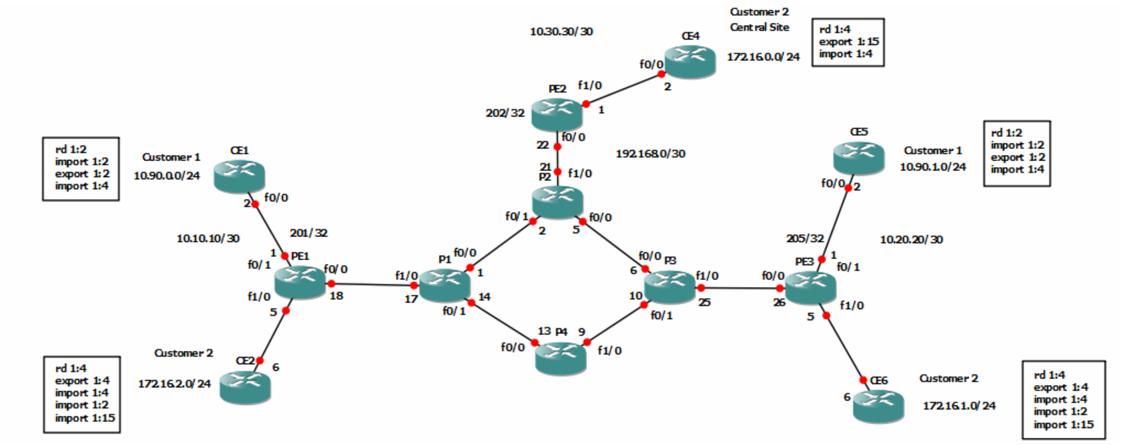

Figure 10: Extranet Connectivity with Central Site Access. [3]

Note that in an extranet case where different customers are interconnected, every customer routes must be unique. In other words, there must not be overlapping IP prefixes. Otherwise, the communication would be broken.

3.13.2 Central Services Topology

Organizations provide services to clients on central servers located on one or more central sites such as application hosting or access to shared resources. Client sites must not be able to communicate with each other. This is one of the requirements of implementing Central Services Topology. [3]

To implement this topology, we need to do the following:

1. Create a separate VRF for each client site so that clients can not communicate with each other
2. Configure each VRF with a different RD. [3]

Server sites must be able to communicate with each other. They should be configured with the same VRF if connected to the same PE. Otherwise, we can use the same RD. Concerning RTs, we need to do the following:

1. Server routes should be exported to clients with a route target such as Server_RT
2. Clients should import server routes into their own VRFs
3. Clients routes should be exported with a common route target such as Client_RT
4. Severs should import clients routes into their own VRFs
5. Client routes should not be imported to other clients. [3]

Using the same MPLS VPN network implemented in the previous chapter, we assume that Metropolia customer requires deploying a server (called MetroServer) on the PE4 router and it serves Metropolia and Helsinki clients as shown in figure 11 below. Helsinki clients should not be able to communicate with Metropolia clients.

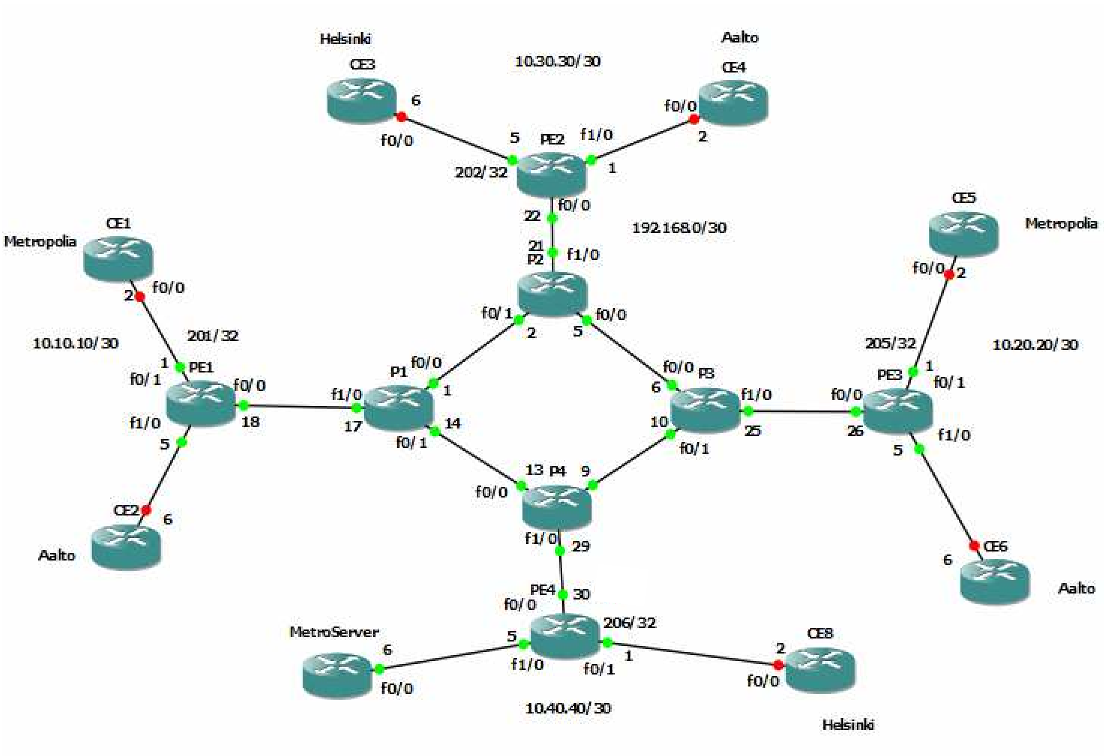

Figure 11: Central Services Topology

At first, we should create and configure MetroServer VRF as follows:

```
ip vrf MetroServer
 rd 1:10
 route-target both 1:20 ! Server_RT
 route-target import 1:40 ! Client_RT
!
```

On the client side (Metropolia and Helsinki), we should import the server route target and export their own route targets as shown below:

```
ip vrf Metropolia
 rd 1:2
 route-target import 1:20 ! Server_RT
 route-target export 1:40 ! Client_RT
!

ip vrf Helsinki
 rd 1:4
 route-target import 1:20 ! Server_RT
 route-target export 1:40 ! Client_RT
!
```

Then we have to configure the interface associated to MetroServer on the PE4 router, routing protocol and redistribution of routes from MetroServer VRF into MP-BGP. Full configuration commands are listed in Appendix 2.

3.14 Inter-autonomous MPLS VPN

So far, we have seen some MPLS VPN topologies in one service provider network infrastructure. Inter-autonomous MPLS VPN is a VPN service provided over various service providers. Customer traffic is carried out over multiple service providers due to geography or a customer preference (the customer is using more than one service provider network). [3] Figure 12 shows an example of inter-autonomous MPLS VPN. As shown below, there are two service providers (Saba and teleYemen) and one customer Qutaiba. The objective is to connect the two Qutaiba sites over Saba and teleYemen service providers.

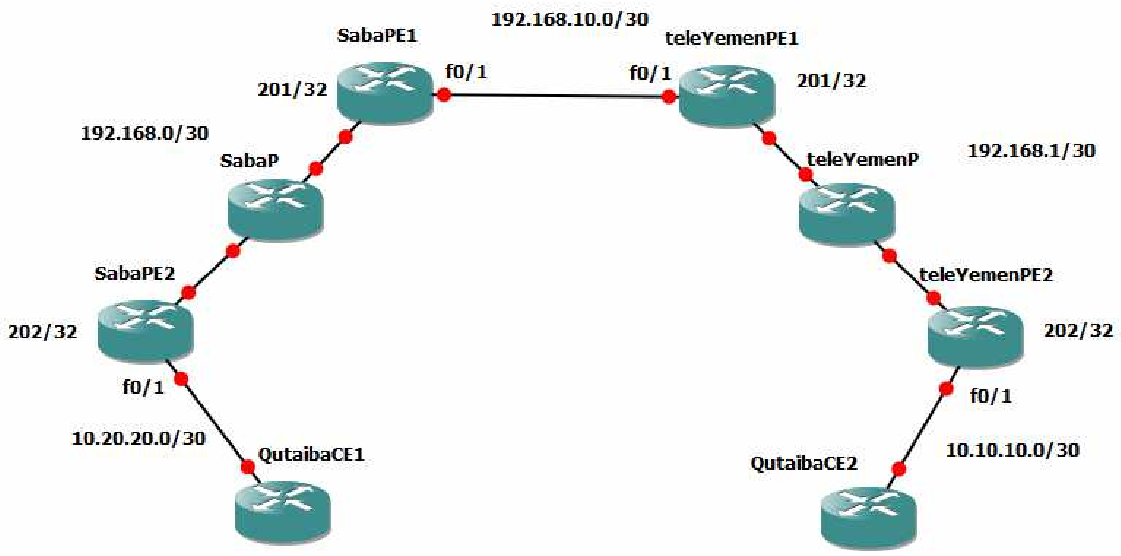

Figure 12: Inter-autonomous MPLS VPN

This type of MPLS VPN can not be implemented with the information we have seen so far. A new mechanism is needed to exchange VPNv4 prefixes and labels. One option to implement such topology is to exchange VPNv4 prefixes across MPLS domain boundaries. Figure 13 shows how IPv4 and VPNv4 prefixes are exchanged.

As shown in Figure 13, a direct MP-eBGP session is created between PE1 of SP1 and PE1 of SP2. This MP-eBGP session allows the exchange of VPNv4 prefixes. There is no label distribution over the link between the two service providers. Each service provider is totally independent which means that there is no exchange of internal prefixes or MPLS labels. [3] The functionality of each service provider MPLS VPN is similar to what we have seen so far.

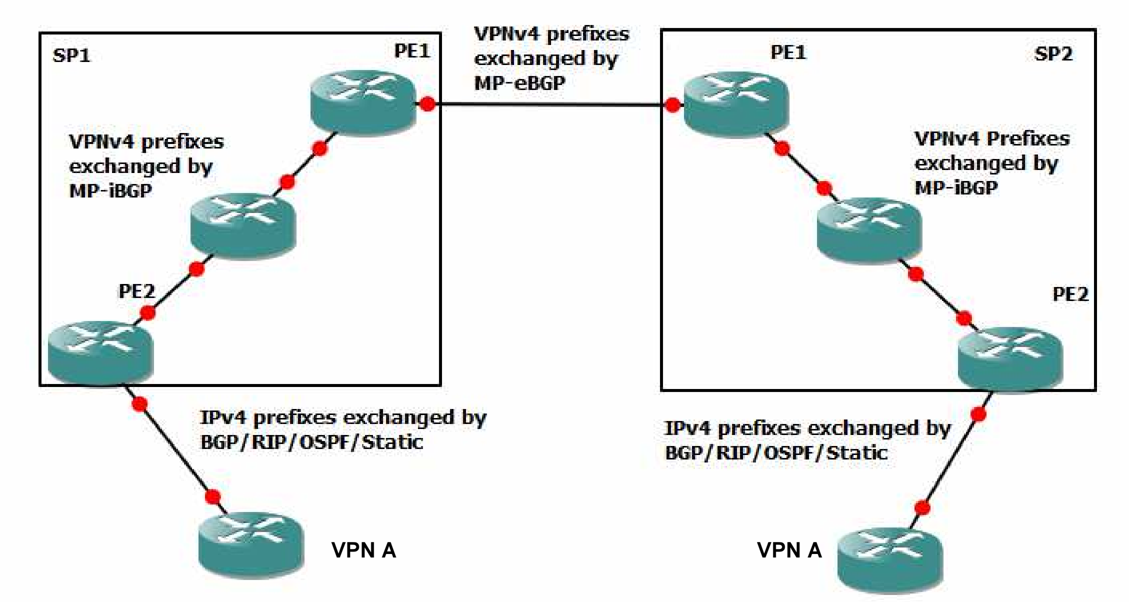

Figure 13: Exchange of IPv4 and VPNv4 prefixes between two service providers

The configuration of this type of MPLS VPN is similar to what we have seen so far except for two aspects:

1. We need to disable automatic router filtering feature of MP-BGP on the border PE routers by command `no bgp default route-target filter`. This MP-BGP default feature discards any undesirable VPNv4 using a route target extended community. If the route target extended community received with VPNv4 prefixes does not match with any of the PE's configured VRFs, the VPNv4 prefixes are dropped. Therefore, we do not need to configure any VRFs on the border PE routers. [3]

2. As shown in Figure 13, when an IPv4 packet is forwarded from the PE1 router of SP1 to the PE1 router of SP2 through MP-eBGP, The PE1 router of SP2 does not know how to forward the packet because it did not allocate the label for it. So there is a need for the PE1 router of SP2 to allocate a new label to forward the

packet. This is achieved by `next-hop-self` command. [3] Full configuration commands of Figure 12 are listed in Appendix 3.

4 Introduction to AToM and VPLS

4.1 Any Transport over MPLS

4.1.1 Overview of AToM

Any Transport over MPLS represents L2 MPLS VPN or L2VPN in Cisco and provides a L2 point-to-point VPN service. This technology was introduced years later after the deployment of MPLS VPN in order to carry the L2 traffic between customer sites since MPLS VPN has no support for L2 protocols. There are many L2 protocols supported by AToM such as Ethernet, HLDC, PPP, ATM or Frame Relay. [2]

Before the deployment of AToM, other network infrastructure was carrying L2 traffic besides the MPLS network. So there were two network infrastructures. AToM was integrated to the MPLS network so that L2 or L3 traffic is transported over the same MPLS network infrastructure. [2] AToM works in a similar way as MPLS VPN where popping and pushing the label are made in the PE routers and the P routers are not aware of the existence of VPNs; they just forward packets by swapping the outer label. However, the label stack location depends on the L2 protocol used. PHP is also applied.

One slight difference between MPLS VPN and AToM is the control word which is 4 byte identifier added when pushing the label stack and it contains control information such as protocol control information and a sequence number which is used to carry L2 frames over the MPLS domain. Figure 14 shows the location of the control word and label stack. [2]

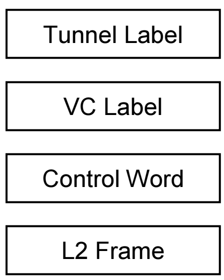

Figure 14: The Control Word and Label Stack. [2]

In AToM, the label stack consists of two labels: the outer label (tunnel label) and inner label (Virtual Circuit VC label or Pseudowire PW label). The tunnel label determines the path (LSP) across the MPLS domain towards the egress LSR and the VC label determines the Attachment Circuit AC on the egress LSR which connects PE to CE. The AC could be either a VC such as a Frame Relay VC or a physical circuit such as an Ethernet port. Figure 15 clarifies AToM. [5]

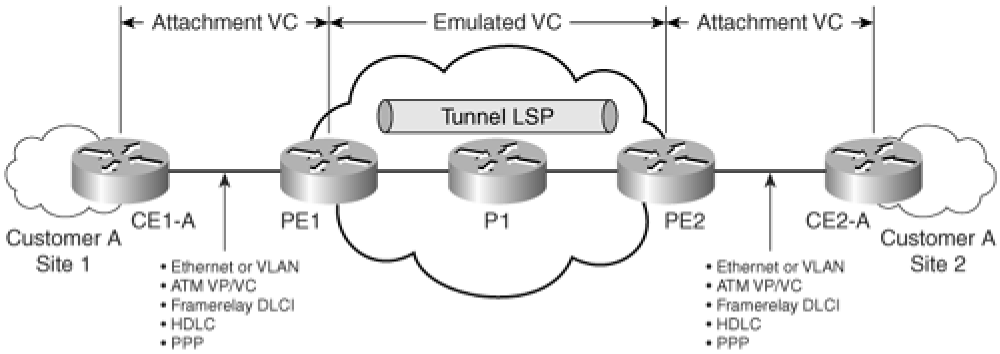

Figure 15: AToM [5]

In the MPLS domain, customer traffic is transported over a pseudowire or an emulated VC which is a logical line or tunnel within the LSP. A pseudowire transports traffic in one way. So to connect customer sites, a reversed pseudowire or VC must exist. A targeted LDP session (LDP session with non-adjacent routers) between PE routers is required. However, the targeted LDP session is activated automatically as soon as the VC is up. Figure 16 clarifies pseudowires. [5]

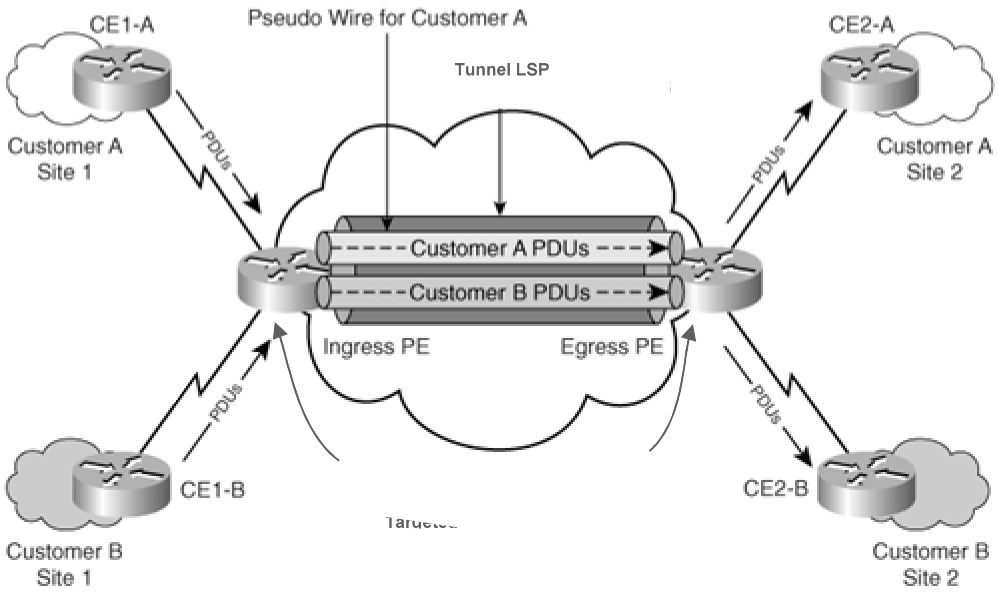

Figure 16: Pseudowires. [5]

Note that customer sites are connected over the MPLS network at L2. So there is no routing participation with the service provider network as we have seen in MPLS VPN. If a routing protocol being configured on CE routers, the rouging protocol establish adjacency between them. So the customer has privacy to his own routes. In the MPLS network, no need to carry customer routes over the MPLS domain and also there is no need to tie up security at the PE routers.

Configuring and deploying AToM or VPLS is quite simple. However, there are two issues; the Cisco router must have the hardware capabilities of supporting AToM or VPLS and the right configuration commands should be used for the Cisco IOS. The issue is that old Cisco IOS versions have different configuration commands.

4.1.2 Ethernet over MPLS (EoMPLS)

EoMPLS transports traffic over the MPLS domain through pseudowires. The Ethernet AC could be either an Ethernet port or an 802.1Q VLAN. In Ethernet mode, Ethernet frames or 802.1Q trunk can be transported over the MPLS network. However, in VLAN mode, a VLAN or VLANs or VLANs inside a VLAN (Dot1q Tunnelling) can be transported over the MPLS network. Each VLAN has its own pseudowire or VC. [2]

4.2 VPLS

Virtual Private LAN Service (VPLS) is a L2 point-to-multipoint VPN service where the MPLS network emulates a virtual Ethernet switch which has the same characteristics as the Ethernet switch. Even though VPLS provides a point-to-multipoint VPN service, it works in similar way as L2 point-to-point VPN service. VPLS creates a full-mesh topology of pseudowires for each customer site. The label stack also consists of two labels, the tunnel label and VC or PW label. [2]

VPLS behaves the same way as the Ethernet switch where frames are replicated and then transported over the MPLS domain to all customer sites. VPLS supports EoMPLS and the AC can be different at each site. Figure 17 clarifies VPLS.

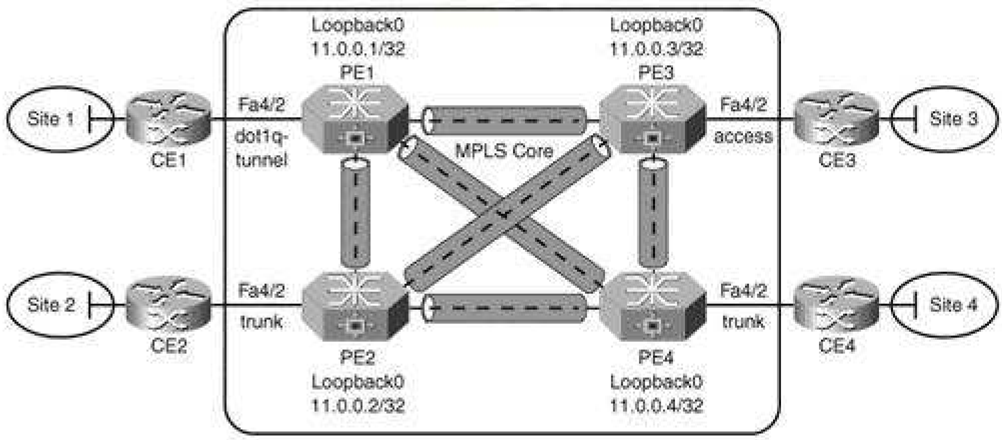

Figure 17: VPLS. [6]

As shown above, the AC on PE1 is a dot1q VLAN and the AC on PE2, PE3 and PE4 is an Ethernet port. In Ethernet mode, the Ethernet connection between PE and CE routers is already a trunk line.

5 Conclusion

To sum up, the thesis clarified and implemented MPLS VPN over a single service provider or multiple service providers as well as presented some advanced MPLS VPN topologies such as intranet, extranet and central services. In addition, AToM and VPLS technologies were briefly introduced.

MPLS is a powerful forwarding technology used to resolve the scalability issue as a result of separating the control and data planes as well as to reduce the lookup process overheard in the service provider network. In the core of the MPLS network, IPv4 packets get forwarded based on labels (a 4-byte identifier) which correspond to the destination networks.

MPLS VPN is the platform of all services provided in the service provider network. It takes the best features of overlay VPNs and the Peer-to-Peer VPNs. Every customer or service is represented as an MPLS VPN, and it contains a Virtual and Forwarding table (VRF) which is used in a similar way as the global routing table but for that specific VPN. RD makes the VPN routes unique and RTs control the communication between customer sites. MB-BGP propagates VPNv4 routes between the PE routers or between service providers (inter-autonomous MPLS VPN).

There are many options for PE-to-CE connectivity, static routes, RIP, eBGP, OSPF, ISIS and EIGRP. Static routes are a good choice when there is a single entry point to the service provider network. The usage of PE-to-CE connectivity routing protocol depends on the routing protocol used by the customer.

Intranet is created when connecting several sites to a central site but for the same MPLS VPN and extranet is created when various sites are connected to each other. Intranet and extranet topologies can be integrated with each other. In addition, a server can be deployed within the service provider network to provide services to a customer, several customers or it can be connected to the Internet. Inter-autonomous MPLS VPN is a VPN service over multiple service providers. Service providers exchange VPNv4 routes using MP-eBGP.

AToM is an L2 point-to-point VPN service which connects customer sites at L2 through pseudowires. The AC at each site could be different, Ehternet port, 802.1Q VLAN, PPP connection or HDLC link. VPLS is an L2 point-to-multipoint VPN service which emulates a virtual Ethernet switch.

References

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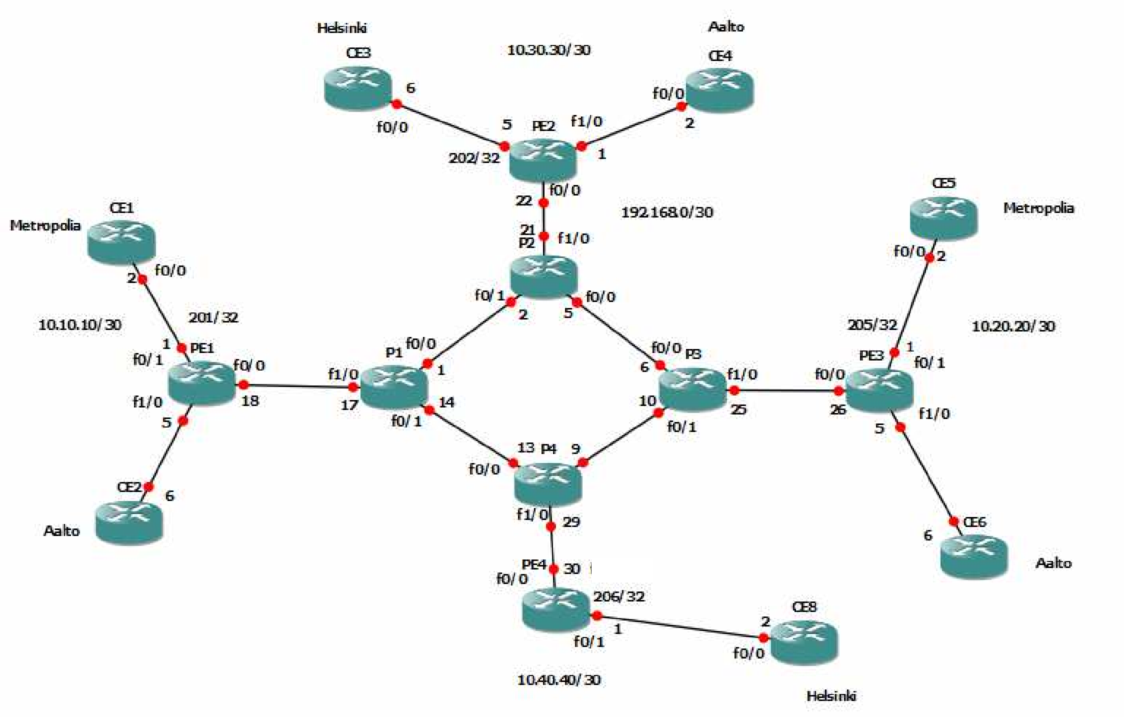
URL: http://mpls-configuration-on-cisco-ios-software.org.ua/1587051990/ch11lev1sec1.html.
Access date 19 April 2013

6. MPLS: The Core [online]
URL: http://chetanress.blogspot.fi/2010/07/vpls-implementation.html.
Access date 20 April 2013

Appendix 1: MPLS VPN Example

The MPLS VPN network topology to be implemented:



Router	Interface	IP Address	Subnet Mask
PE1	F0/0	192.168.0.18	255.255.255.252
	F0/1	10.10.10.1	255.255.255.252
	F1/0	10.10.10.5	255.255.255.252
	Loopback0	192.168.0.201	255.255.255.255
PE2	F0/0	192.168.0.22	255.255.255.252
	F0/1	10.30.30.5	255.255.255.252
	F1/0	10.30.30.1	255.255.255.252
	Loopback0	192.168.0.202	255.255.255.255
PE3	F0/0	192.168.0.26	255.255.255.252
	F0/1	10.20.20.1	255.255.255.252
	F1/0	10.20.20.5	255.255.255.252
	Loopback0	192.168.0.205	255.255.255.255
PE4	F0/0	192.168.0.30	255.255.255.252
	F0/1	10.40.40.1	255.255.255.252
	Loopback0	192.168.0.206	255.255.255.255
P1	F0/0	192.168.0.1	255.255.255.252
	F0/1	192.168.0.14	255.255.255.252
	F1/0	192.168.0.17	255.255.255.252
P2	F0/0	192.168.0.5	255.255.255.252
	F0/1	192.168.0.2	255.255.255.252
	F1/0	192.168.0.21	255.255.255.252
P3	F0/0	192.168.0.6	255.255.255.252

	F0/1	192.168.0.10	255.255.255.252
	F1/0	192.168.0.25	255.255.255.252
P4	F0/0	192.168.0.13	255.255.255.252
	F0/1	192.168.0.9	255.255.255.252
	F1/0	192.168.0.29	255.255.255.252

Configuration Commands:

```
hostname PE1
!
ip cef
!
ip vrf Aalto
 rd 1:3
 route-target export 1:3
 route-target import 1:3
!
ip vrf Metropolia
 rd 1:2
 route-target export 1:2
 route-target export 200:4
 route-target import 1:2
 route-target import 200:4
!
interface Loopback0
 ip address 192.168.0.201 255.255.255.255
!
interface FastEthernet0/0
 ip address 192.168.0.18 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip vrf forwarding Metropolia
 ip address 10.10.10.1 255.255.255.252
!
interface FastEthernet1/0
 ip vrf forwarding Aalto
 ip address 10.10.10.5 255.255.255.252
!
```

```
router ospf 1
 network 192.168.0.0 0.0.0.255 area 0
!
router rip
 !
 address-family ipv4 vrf Aalto
 redistribute bgp 1 metric 2
 network 10.0.0.0
 no auto-summary
 version 2
 exit-address-family
!
router bgp 1
 neighbor 192.168.0.202 remote-as 1
 neighbor 192.168.0.202 update-source Loopback0
 neighbor 192.168.0.202 activate
 neighbor 192.168.0.205 remote-as 1
 neighbor 192.168.0.205 update-source Loopback0
 neighbor 192.168.0.206 remote-as 1
 neighbor 192.168.0.206 update-source Loopback0
!
 address-family vpnv4
 neighbor 192.168.0.202 activate
 neighbor 192.168.0.202 send-community extended
 neighbor 192.168.0.205 activate
 neighbor 192.168.0.205 send-community extended
 exit-address-family
 !
 address-family ipv4 vrf Metropolia
 redistribute connected
 redistribute static
 exit-address-family
 !
 address-family ipv4 vrf Aalto
 redistribute connected
 redistribute rip
 exit-address-family
!
ip route vrf Metropolia 172.16.0.0 255.255.255.0 FastEthernet0/1
10.10.10.2
```

```
hostname PE2
!
ip cef
!
ip vrf Aalto
 rd 1:3
 route-target export 1:3
 route-target import 1:3
!
ip vrf Helsinki
 rd 1:4
 route-target export 1:4
 route-target export 200:4
 route-target import 1:4
 route-target import 200:4
!
interface Loopback0
 ip address 192.168.0.202 255.255.255.255
!
interface FastEthernet0/0
 ip address 192.168.0.22 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip vrf forwarding Helsinki
 ip address 10.30.30.5 255.255.255.252
!
interface FastEthernet1/0
 ip vrf forwarding Aalto
 ip address 10.30.30.1 255.255.255.252
!
router ospf 1
 network 192.168.0.0 0.0.0.255 area 0
!
router rip
 !
 address-family ipv4 vrf Aalto
 redistribute bgp 1 metric 2
 network 10.0.0.0
 no auto-summary
```

```
 version 2
 exit-address-family
!
router bgp 1
 neighbor 192.168.0.201 remote-as 1
 neighbor 192.168.0.201 update-source Loopback0
 neighbor 192.168.0.201 activate
 neighbor 192.168.0.205 remote-as 1
 neighbor 192.168.0.205 update-source Loopback0
 neighbor 192.168.0.206 remote-as 1
 neighbor 192.168.0.206 update-source Loopback0
 !
 address-family vpnv4
 neighbor 192.168.0.201 activate
 neighbor 192.168.0.201 send-community extended
 neighbor 192.168.0.205 activate
 neighbor 192.168.0.205 send-community extended
 neighbor 192.168.0.206 activate
 neighbor 192.168.0.206 send-community extended
 exit-address-family
 !
 address-family ipv4 vrf Helsinki
 redistribute connected
 neighbor 10.30.30.6 remote-as 2
 neighbor 10.30.30.6 activate
 exit-address-family
 !
 address-family ipv4 vrf Aalto
 redistribute connected
 redistribute rip
 exit-address-family
!

hostname PE3
!
ip cef
!
ip vrf Aalto
 rd 1:3
 route-target export 1:3
 route-target import 1:3
```

```
!
ip vrf Metropolia
 rd 1:2
 route-target export 1:2
 route-target import 1:2
!
interface Loopback0
 ip address 192.168.0.205 255.255.255.255
!
interface FastEthernet0/0
 ip address 192.168.0.26 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip vrf forwarding Metropolia
 ip address 10.20.20.1 255.255.255.252
!
interface FastEthernet1/0
 ip vrf forwarding Aalto
 ip address 10.20.20.5 255.255.255.252
!
router ospf 1
 network 192.168.0.0 0.0.0.255 area 0
!
router rip
 !
 address-family ipv4 vrf Aalto
 redistribute bgp 1 metric 2
 network 10.0.0.0
 no auto-summary
 version 2
 exit-address-family
!
router bgp 1
 neighbor 192.168.0.201 remote-as 1
 neighbor 192.168.0.201 update-source Loopback0
 neighbor 192.168.0.201 activate
 neighbor 192.168.0.202 remote-as 1
 neighbor 192.168.0.202 update-source Loopback0
 neighbor 192.168.0.206 remote-as 1
```

```
 neighbor 192.168.0.206 update-source Loopback0
 !
 address-family vpnv4
 neighbor 192.168.0.201 activate
 neighbor 192.168.0.201 send-community extended
 neighbor 192.168.0.202 activate
 neighbor 192.168.0.202 send-community extended
 exit-address-family
 !
 address-family ipv4 vrf Metropolia
 redistribute connected
 redistribute static
 exit-address-family
 !
 address-family ipv4 vrf Aalto
 redistribute connected
 redistribute rip
 exit-address-family
!
ip route vrf Metropolia 172.16.1.0 255.255.255.0 FastEthernet0/1
10.20.20.2

hostname PE4
!
ip vrf Helsinki
 rd 1:4
 route-target export 1:4
 route-target import 1:4
!
interface Loopback0
 ip address 192.168.0.206 255.255.255.255
!
interface FastEthernet0/0
 ip address 192.168.0.30 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip vrf forwarding Helsinki
 ip address 10.40.40.1 255.255.255.252
```

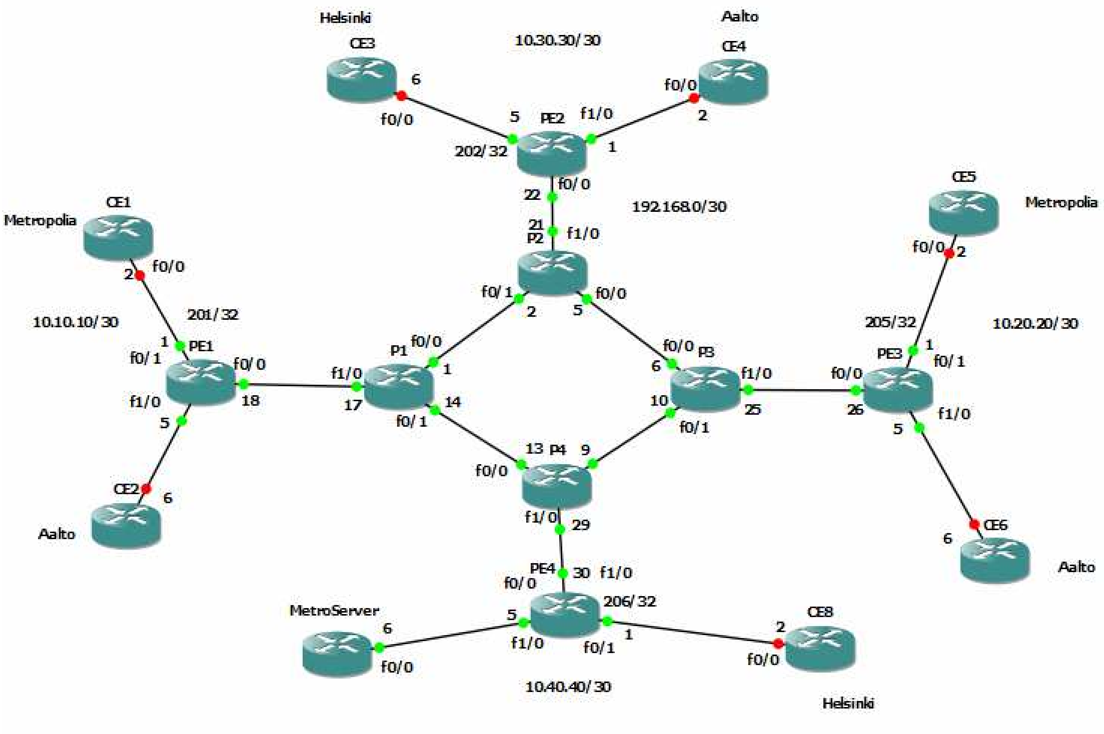
```
!
router ospf 1
 network 192.168.0.0 0.0.0.255 area 0
!
router bgp 1
 bgp log-neighbor-changes
 neighbor 192.168.0.201 remote-as 1
 neighbor 192.168.0.201 update-source Loopback0
 neighbor 192.168.0.201 activate
 neighbor 192.168.0.202 remote-as 1
 neighbor 192.168.0.202 update-source Loopback0
 neighbor 192.168.0.205 remote-as 1
 neighbor 192.168.0.205 update-source Loopback0
 !
 address-family vpnv4
 neighbor 192.168.0.202 activate
 neighbor 192.168.0.202 send-community extended
 exit-address-family
 !
 address-family ipv4 vrf Helsinki
 redistribute connected
 neighbor 10.40.40.2 remote-as 2
 neighbor 10.40.40.2 activate
 exit-address-family
!

hostname P1
!
ip cef
!
interface FastEthernet0/0
 ip address 192.168.0.1 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip address 192.168.0.14 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet1/0
```

```
 ip address 192.168.0.17 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
router ospf 1
 network 0.0.0.0 255.255.255.255 area 0
!

hostname P2
!
ip cef
!
interface FastEthernet0/0
 ip address 192.168.0.5 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip address 192.168.0.2 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet1/0
 ip address 192.168.0.21 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
router ospf 1
 network 0.0.0.0 255.255.255.255 area 0
!

hostname P3
!
ip cef
!
interface FastEthernet0/0
 ip address 192.168.0.6 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
```

```
 ip address 192.168.0.10 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet1/0
 ip address 192.168.0.25 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
router ospf 1
 network 0.0.0.0 255.255.255.255 area 0
!

hostname P4
!
ip cef
!
interface FastEthernet0/0
 ip address 192.168.0.13 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip address 192.168.0.9 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet1/0
 ip address 192.168.0.29 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
router ospf 1
 network 0.0.0.0 255.255.255.255 area 0
```

Appendix 2: Central Services Topology - Example

We are going to use the same MPLS VPN network implemented in Appendix 1 with its full configuration commands. In this appendix, we will only present the configuration commands needed to implement Central Services Topology.



Router	Interface	IP Address	Subnet Mask
PE4	F1/0	10.40.40.5	255.255.255.252

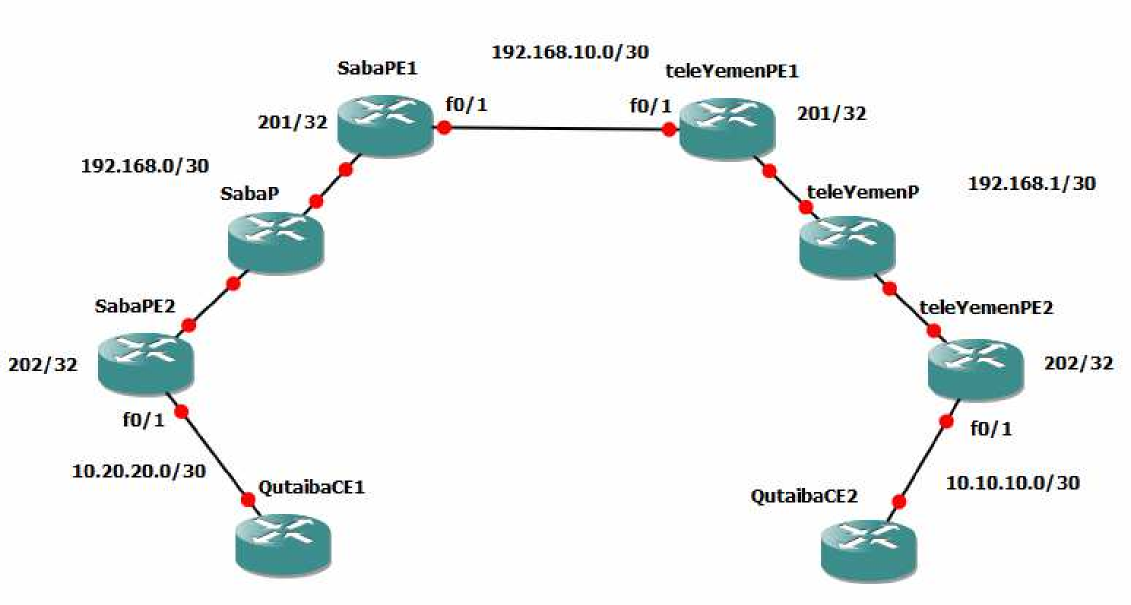
Configuration Commands:

```
hostname PE4
!
ip vrf MetroServer
 rd 1:10
 route-target both 1:20 ! Server_RT
 route-target import 1:40 ! Client_RT
!
ip vrf Helsinki
 route-target import 1:20 ! Server_RT
 route-target export 1:40 ! Client_RT
!
interface FastEthernet1/0
```

```
 ip vrf forwarding MetroServer
 ip address 10.40.40.5 255.255.255.252
!
router bgp 1
 !
 address-family vpnv4
  neighbor 192.168.0.201 activate
  neighbor 192.168.0.201 send-community extended
  neighbor 192.168.0.205 activate
  neighbor 192.168.0.205 send-community extended
 exit-address-family
 !
 address-family ipv4 vrf MetroServer
  redistribute connected
 exit-address-family
 !

hostname PE1
!
ip vrf Metropolia
 route-target import 1:20 ! Server_RT
 route-target export 1:40 ! Client_RT
!
router bgp 1
 !
 address-family vpnv4
  neighbor 192.168.0.206 activate
  neighbor 192.168.0.206 send-community extended
 exit-address-family
 !

hostname PE2
!
ip vrf Metropolia
 route-target import 1:20 ! Server_RT
 route-target export 1:40 ! Client_RT
!

hostname PE3
!
```

```
ip vrf Metropolia
 route-target import 1:20 ! Server_RT
 route-target export 1:40 ! Client_RT
!
router bgp 1
 !
 address-family vpnv4
  neighbor 192.168.0.206 activate
  neighbor 192.168.0.206 send-community extended
 exit-address-family
 !
```

Appendix 3: Inter-autonomous MPLS VPN Example



Router	Interface	IP Address	Subnet Mask
SabaPE1	F0/0	192.168.0.2	255.255.255.252
	F0/1	192.168.10.2	255.255.255.252
	Loopback0	192.168.0.201	255.255.255.255
SabaP	F0/0	192.168.0.1	255.255.255.252
	F0/1	192.168.0.5	255.255.255.252
SabaPE2	F0/0	192.168.0.6	255.255.255.252
	F0/1	10.20.20.1	255.255.255.252
	Loopback0	192.168.0.202	255.255.255.255
teleYemenPE1	F0/0	192.168.1.2	255.255.255.252
	F1/0	192.168.10.1	255.255.255.252
	Loopback0	192.168.1.201	255.255.255.255
teleYemenP	F0/0	192.168.1.1	255.255.255.252
	F0/1	192.168.1.5	255.255.255.252
teleYemenPE2	F0/0	192.168.1.6	255.255.255.252
	F0/1	10.10.10.1	255.255.255.252
	Loopback0	192.168.1.202	255.255.255.255

Configuration Commands:

```
hostname SabaPE1
!
ip cef
!
interface Loopback0
 ip address 192.168.0.201 255.255.255.255
!
```

```
interface FastEthernet0/0
 ip address 192.168.0.2 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip address 192.168.10.2 255.255.255.252
!
router ospf 1
 network 192.168.0.0 0.0.0.255 area 0
!
router bgp 2
 no bgp default ipv4-unicast
 no bgp default route-target filter
 neighbor 192.168.0.202 remote-as 2
 neighbor 192.168.0.202 update-source Loopback0
 neighbor 192.168.10.1 remote-as 1
 !
address-family vpnv4
 neighbor 192.168.0.202 activate
 neighbor 192.168.0.202 send-community extended
 neighbor 192.168.0.202 next-hop-self
 neighbor 192.168.10.1 activate
 neighbor 192.168.10.1 send-community extended
 exit-address-family
!

hostname SabaP
!
ip cef
!
interface FastEthernet0/0
 ip address 192.168.0.1 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip address 192.168.0.5 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
```

```
router ospf 1
 log-adjacency-changes
 network 0.0.0.0 255.255.255.255 area 0
!

hostname SabaPE2
!
ip cef
!
ip vrf Qutaiba
 rd 1:2
 route-target export 100:2
 route-target import 100:2
!
interface Loopback0
 ip address 192.168.0.202 255.255.255.255
!
interface FastEthernet0/0
 ip address 192.168.0.6 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip vrf forwarding Qutaiba
 ip address 10.20.20.1 255.255.255.252
!
router ospf 1
 network 192.168.0.0 0.0.0.255 area 0
!
router bgp 2
 neighbor 192.168.0.201 remote-as 2
 neighbor 192.168.0.201 update-source Loopback0
 !
address-family vpnv4
 neighbor 192.168.0.201 activate
 neighbor 192.168.0.201 send-community extended
 exit-address-family
 !
 address-family ipv4 vrf Qutaiba
 redistribute connected
 redistribute static
```

```
exit-address-family
!
ip route vrf Qutaiba 172.16.0.0 255.255.255.0 FastEthernet0/1
10.20.20.2

hostname teleYemenPE1
!
ip cef
!
interface Loopback0
 ip address 192.168.1.201 255.255.255.252
!
interface FastEthernet0/0
 ip address 192.168.1.2 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip address 192.168.10.1 255.255.255.252
!
router ospf 1
 network 192.168.1.0 0.0.0.255 area 0
!
router bgp 1
 no bgp default ipv4-unicast
 no bgp default route-target filter
 neighbor 192.168.1.202 remote-as 1
 neighbor 192.168.1.202 update-source Loopback0
 neighbor 192.168.10.2 remote-as 2
 !
address-family vpnv4
 neighbor 192.168.1.202 activate
 neighbor 192.168.1.202 send-community extended
 neighbor 192.168.1.202 next-hop-self
 neighbor 192.168.10.2 activate
 neighbor 192.168.10.2 send-community extended
 exit-address-family
!

hostname teleYemenP
!
```

```
ip cef
!
interface FastEthernet0/0
 ip address 192.168.1.1 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip address 192.168.1.5 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
router ospf 1
 network 0.0.0.0 255.255.255.255 area 0
!

hostname teleYemenPE2
!
ip cef
!
ip vrf Qutaiba
 rd 1:2
 route-target export 100:2
 route-target import 100:2
!
interface Loopback0
 ip address 192.168.1.202 255.255.255.255
!
interface FastEthernet0/0
 ip address 192.168.1.6 255.255.255.252
 mpls label protocol ldp
 mpls ip
!
interface FastEthernet0/1
 ip vrf forwarding Qutaiba
 ip address 10.10.10.1 255.255.255.252
!
router ospf 1
 network 192.168.1.0 0.0.0.255 area 0
!
router bgp 1
```

```
 bgp log-neighbor-changes
 neighbor 192.168.1.201 remote-as 1
 neighbor 192.168.1.201 update-source Loopback0
!
 address-family vpnv4
  neighbor 192.168.1.201 activate
  neighbor 192.168.1.201 send-community extended
 exit-address-family
 !
 address-family ipv4 vrf Qutaiba
  redistribute connected
  redistribute static
 exit-address-family
!
ip route vrf Qutaiba 172.16.1.0 255.255.255.0 FastEthernet0/1
10.10.10.2
!
```