AN MPLS VPN NETWORK DESIGNED FOR THE EDMONTON CAPITAL REGION: Theory, Case study and Lab Implementation

PROJECT REPORT

Submitted By:

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Contents

1.0 Executive Summary

The technology of MPLS has been around for many years and has taken the world by storm. It has become extremely popular in a relatively short period of time. The major benefits of using an MPLS framework in your network are the ability to use one unified networking core, better IP over ATM integration, a BGP free core, Traffic engineering among other things.

Another technology that has been around for a few years is that of Virtual Private Networks (VPN's).The technology involves using a public network, usually that of an ISP (Internet Service Provider) to simulate a private network or a feeling of a private network for the customer. VPN's have changed the networking world and the way the world operates in the late 20th Century. They have created not only economic benefits for the companies by making it cost effective for them to link their different offices spread out across diverse geographical regions without the need for dedicated T1 or leased lines that were extremely expensive to purchase, but have also created the phenomenon of the "Home Worker". More and more employees can work from home by connecting via a VPN to their office servers, and work from home saving both the company and themselves resources.

While these two technologies may not have been developed at the same time, MPLS and VPN are a perfect fit with each other and the MPLS VPN solution has become an ubiquitous technology to adopt in a 21st century corporation that seeks to adopt a unified network structure for the enterprise as a whole and is looking for a scalable solution as the Company looks toward the future with expansion and growth ahead.

Given the brief context of the MPLS VPN solution being a cornerstone of any modern company, this project was envisioned to look at the application of this technology to a huge and aspiring city of the 21st century that is looking to unify all the city services provided to the citizens and tax payers so that they may avail smart services in the 21st century.

It is keeping this in mind that I set out to study the Edmonton Capital Region that consists of the capital city of the province of Alberta, Edmonton and its surrounding satellite cities

and suburbs. Thorough research was conducted on all the various areas in and around the city, and locations of around 170 government service centres. These service centres have been divided logically by function such as Schools, Police Stations, Universities, hospitals, fire stations and Libraries.

 For all these government services their relative location and distances from each other and within the city was mapped out in detail using Google Maps My Maps feature and detailed data was compiled. Based on these distances, and keeping in mind Fiber Optic limitations and noise and interference, an MPLS VPN network was designed between all the areas, the details of which will be described later on in this report.

Once the network was designed theoretically after reading lots of literature and keeping best design practices in mind, I implemented the MPLS VPN network in a lab environment to show the validity of the design and a practical implementation of the same.

This project shows that it is a good concept to unify the various departments and government services such as schools, hospitals, universities, police stations, fire stations and libraries in the city of Edmonton to create one unified VPN network. This will provide better quality of service to the citizens and tax payers, at a cheaper cost to the city. This technology is scalable, so it also ensures that the city of Edmonton would be well poised to grow rapidly into the 21st century.

2.0 Introduction

The Edmonton Capital Region (ECR), also commonly referred to as the Alberta Capital Region, Greater Edmonton or Metro Edmonton, is a conglomeration of municipalities centred on Alberta's provincial capital of Edmonton. [1][27]

The ECR consists of 2 major satellite cities, St. Albert and Sherwood Park along with the City of Edmonton itself and the population of the ECR is around 1.2 million people as per the latest census.

The region has experienced rapid growth as a result of the resource boom particularly in the oil sector. This has led to a population boom in the region and the need to provide

better services for its increasing number of citizens is of paramount importance in the future going forward.

The first step in designing a unified network for the ECR was to conduct a design/ case study of the entire region. This study was conducted using real world distances and metrics using the My Maps feature on google maps. [2]

An interactive version of the ECR government services map created can be accessed by clicking the link here.
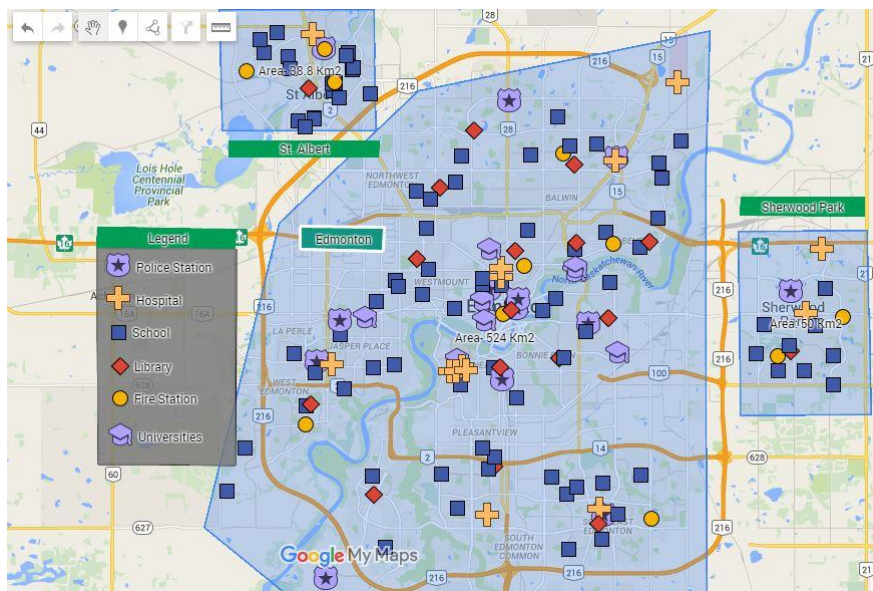
The map created is as shown below:

Figure 1: Edmonton Capital Region Government Services

Some features found in the map include:

- A total of 20 schools from St Albert, 9 Schools from Sherwood Park (SWP), and 62 schools from Edmonton were considered in the map.
- A total of 1 police station from St. Albert, 1 from SWP and 11 from Edmonton were placed on the map.
- Three fire stations from St. Albert, 3 from SWP and 6 from Edmonton were considered on the map.
- A library each from St. Albert and SWP and 16 libraries from Edmonton were placed on the map.

- One hospital from St Albert, three from SWP and 13 from Edmonton were considered.
- 8 Universities from the city of Edmonton were considered to be placed on the map.
- In Total 160 government services across the ECR were grouped by function and placed on the map according to their exact latitude and longitude of location.
- The area of St. Albert is roughly 40 km^2, SWP is around 48 Km^2 while the city of Edmonton extends an area of 524 Km^2. It is important to note here that this area refers to the maximum range of government services that span from one end to another of the respective region. For example, in St. Albert, it means that all government services that have to be served as part of the network must lie in an area not more than 40 km^2.

After the detailed map was created, the next step was to design a framework, technology and topology that was to be used to create a network that spans all these different government services buildings across the three regions of the ECR.

The technology I chose to use was that of an MPLS VPN solution that would create one network for all the service buildings. In the next sections, we shall look at some theory behind MPLS, VPN's and how they are intended to be used in the ECR to create the network that we desire.

3.0 Theory and Concepts

3.1 Multiprotocol Label Switching (MPLS)

3.1.1 Need for MPLS

The story of MPLS began in the 1990's when a group from Ipsilon networks proposed a "flow management protocol". [3] They wanted to create an IP switching technique that worked over ATM networks but it never took off.

While this particular initiative did not work, there was a need for a protocol such as MPLS because in those days, VLSI IP packets could not be switched through hardware and overall, the switching of IP packets through software was slow. Hence the primary reason for the creation of MPLS was to facilitate the switching of IP packets in hardware using a label switching paradigm and hence speed up the layer 3 routing process.

However, the present use of MPLS is far different than what it was originally designed for. We shall look at some of the uses of MPLS in the sections coming below.

3.1.2 Place of MPLS in the OSI model

The Open Systems Interconnection model (OSI model) is a conceptual model that characterizes and standardizes the communication functions of a telecommunication or computing system without regard to their underlying internal structure and technology. Its goal is the interoperability of diverse communication systems with standard protocols. The model partitions a communication system into abstraction layers. The original version of the model defined seven layers. [4]

A layer serves the layer above it and is served by the layer below it. For example, a layer that provides error-free communications across a network provides the path needed by applications above it, while it calls the next lower layer to send and receive packets that comprise the contents of that path. Two instances at the same layer are visualized as connected by a horizontal connection in that layer. [4]

The model is a product of the Open Systems Interconnection project at the International Organization for Standardization (ISO), maintained by the identification ISO/IEC 7498-1. [4]

The seven layers that the OSI model contains is as shown in the diagram below:
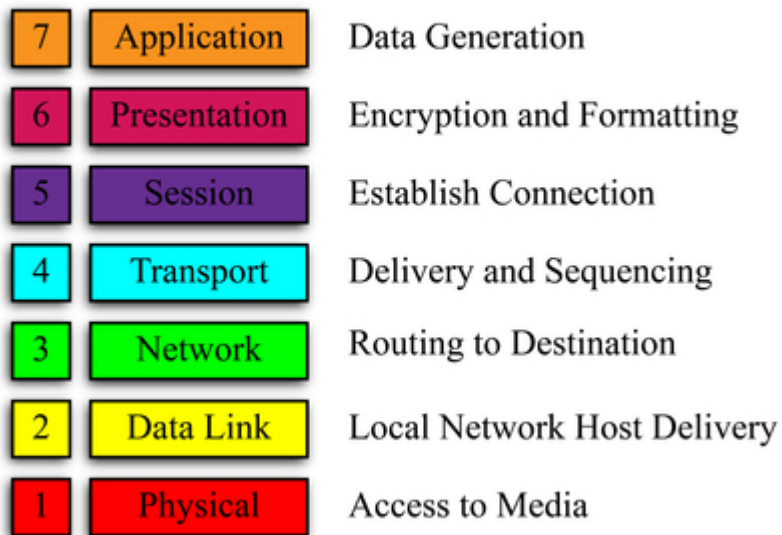
OSI Model

7	Application	Data Generation
6	Presentation	Encryption and Formatting
5	Session	Establish Connection
4	Transport	Delivery and Sequencing
3	Network	Routing to Destination
2	Data Link	Local Network Host Delivery
1	Physical	Access to Media

Figure 2: OSI Model

Ref: https://sites.google.com/site/cis105portfolios/internet/7-layers

The layer 3 or network layer deals with the IP protocol and routing of packets with IP addresses, while the layer 2 or data link layer deals with layer 2 protocols such as Ethernet, HDLC, PPP, frame relay and basically consists of switching using hardware addresses.

MPLS is unique in the sense that it neither functions strictly at a layer 3 level, nor at a layer 2 level. It functions in between layers 2 and 3 and does not strictly fall into the OSI model. Thus it is sometimes known as a layer 2.5 protocol.

It uses MPLS labels that are sandwiched almost into a packet after the data link layer header but before the IP network header.

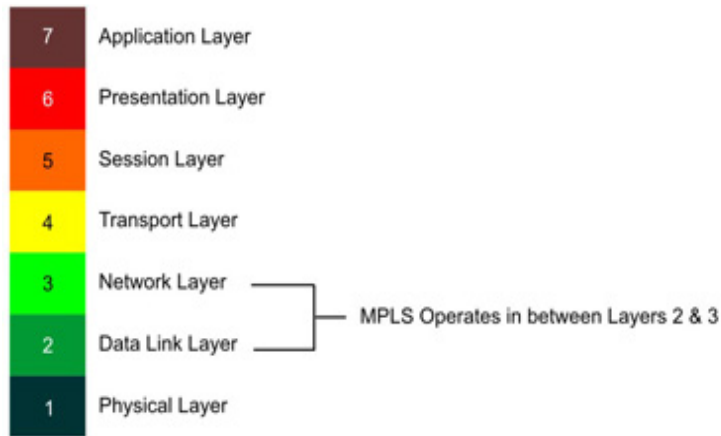Thus MPLS can be envisioned as a layer 2.5 protocol as shown in the diagram below.

Figure 3: MPLS in OSI Model

Ref: http://MPLSinfo.org/images/MPLS-osi-model.jpg

3.1.3 Uses of MPLS Today

The original purpose for which MPLS was built is not as important anymore. However, MPLS has grown to become of the most pervasive technologies of our time and it has found many uses especially for service providers in providing WAN technologies to various customers.

Some benefits are listed below [5]:

Benefits of one unified network

- Since MPLS operates over layer 2.5, it provides the ability to carry any layer 3 protocol other than IP. Only the Ingress and Egress routers would need to perform more computations but the entire core of the network could route packets based solely on the MPLS label that is attached.
- Before what could be done through layer 2 protocols like HDLC and PP can now be performed by MPLS at layer 2 as well. This feature is called Any Transport over MPLS (AToM).

BGP free core

- The ISP generally provide WAN and internet services to their customers and large enterprises.
- The ISP routers generally look at the IP prefixes of the destination IP networks and if the destination prefix is not within their network, they must have routes to reach destinations

outside their network. This information is generally propagated by the BGP protocol, which is the de facto protocol of the internet.

- However, the resulting routing table of the Internet is extremely large and the burden on the resources of routers running this protocol is very large. Before the advent of MPLS, many ISP's had a network topology where many or most routers in the core ran the BGP protocol. Thus it was expensive to operate and maintain. With the advent of MPLS, it was possible to a BGP free core and route packets on the basis of the label that was placed.
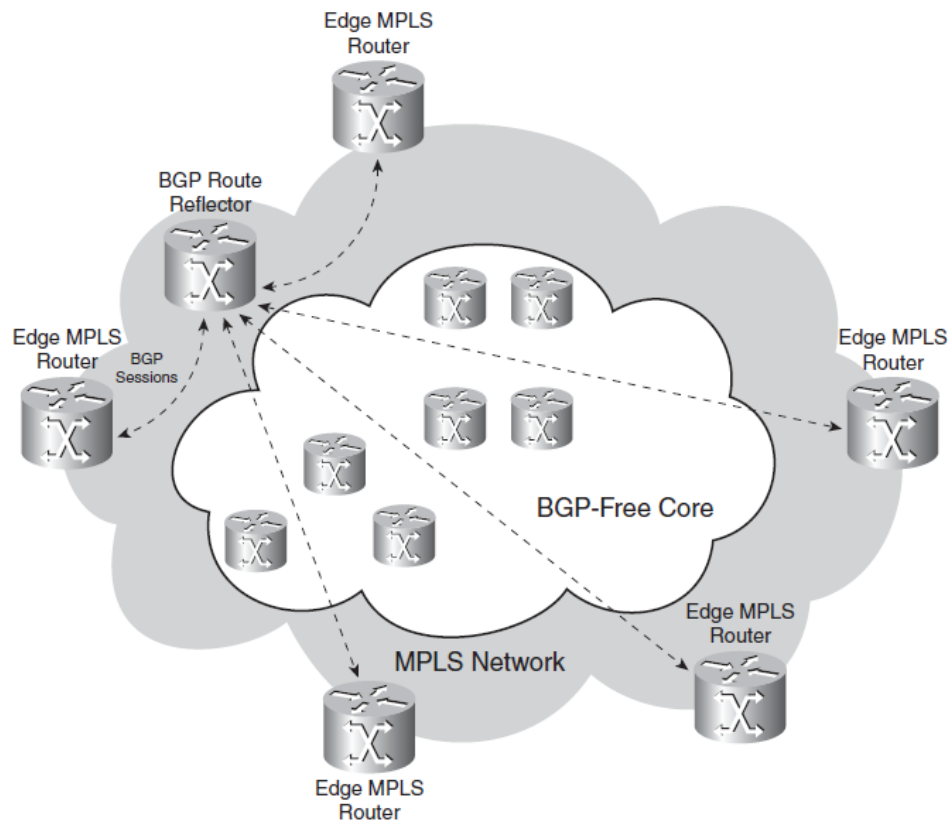

Figure 4: BGP free core with MPLS

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

MPLS VPN

- The MPLS VPN technology is one of the most used technologies with MPLS.
- There is an entire section in the following sections dedicated to describing details of this technology.

3.1.4 Operation of MPLS

<u>Terms and Components of MPLS</u> [5]

Below are defined a few common terms and definitions that will be useful in understanding the operation of MPLS and MPLS VPN's.

MPLS LABEL:

- The label is the heart of the MPLS protocol. As the very name suggests, label switching is what MPLS is all about.

- The label is a 32 bit value that is stacked at Layer 2.5 of the OSI model. This label is used by all the MPLS enabled routers to route the packet. It is through using this label that MPLS can carry variety of protocols through it, both layer 2 and layer 3.
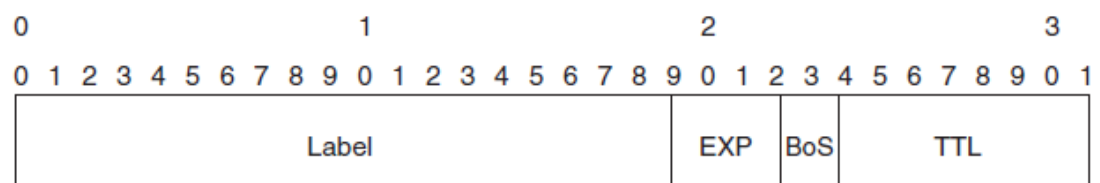
```
0                             1                       2                           3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
┌─────────────────────────────────────┬───────┬─────┬───────────┐
│                Label                 │  EXP  │ BoS │    TTL    │
└─────────────────────────────────────┴───────┴─────┴───────────┘
```

Figure 5: Structure of one MPLS label

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

- The label itself consists of the first 20 bits, while the EXP bits are used for mainly Qos purposes. The bottom of stack or BoS bit refers to whether the label is the last label or there are other labels below it. It is important to note that there can be more than one label stacked on top of another in MPLS and hence this bit tells the router which label is the last one.

- The TTL or Time to Live bits function in a manner similar to the IP packet TTL field and prevent any MPLS label from living on forever in the network. It is reduced at each hop count and if it goes below 0 or has a value that is higher than the corresponding IP header value, it is corrected accordingly.

LABEL SWITCHED ROUTER (LSR):

- A router that supports MPLS is known as a LSR. The feature can be enabled by using the appropriate commands on the router based on the manufacturer.

- There can be thought of three categories of LSR routers in a MPLS enabled network.

  - Ingress LSR:

    - This router refers to the LSR router that exists at the edge of an MPLS enabled network with respect to an IP packet or any packet that is entering the MPLS network. Thus any router which receives packets from an external network into the MPLS network is known as the Ingress LSR.

    - The resources of the Ingress LSR must be large enough to handle the complexity required to translate the incoming IP packet based on the destination prefix to a label value that needs to be used to transport the packet to the correct egress router.

    - The decision on what label to use for what prefix can be based on FEC classes that determine the quality of service that the packet warrants. It could also be based on other factors such as based solely on the IP prefix, bandwidth allocation for each client etc.

  - Egress LSR

    - This router refers to the LSR router that exists at the edge of an MPLS enabled network with respect to an IP packet or any packet that is leaving the MPLS network. Thus any router which receives packets from an internal MPLS network and is about to leave the network to an external one is known as the Egress LSR.

    - The resources of the Egress LSR must be large enough to handle the complexity required to translate the incoming MPLS packet based on the label value to the correct ip address that needs to be used to transport the packet to the correct router or end host.

o Intermediate LSR

- These routers are the MPLS routers that are present in the core of the MPLS network. They receive packets to and from other MPLS enabled routers.

- These routers need the least resources and do not need to be aware of the underlying packets or protocols such as BGP to route packets. They only look at the label that is attached at the top and make a decision as to what to do with the packet.

- A successful label swap operation will include swapping the incoming label with the appropriate label that has been sent to it by the downstream router and it send the label out its interface.

LABEL SWITCHED PATH (LSP)

- LSP refers to the path or part of the path that a packet takes within the MPLS network from the ingress to the egress router.

- It is important to note that an LSP is unidirectional in nature. Therefore we need two LSP's, that can either traverse the network through a single path or multiple paths to ensure that a packet travels out of and into the network back to the originator of the packet.
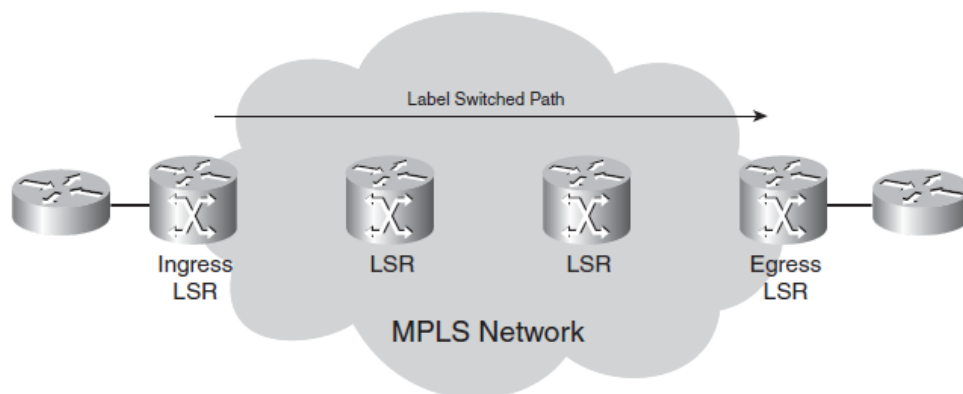

Figure 6: LSP path

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

FORWARD EQUIVALENCE CLASS (FEC)

- FEC refers to the class or group of packets that are given the same treatment in the network.

- All members of the same FEC have the same label, although the converse needn't be necessarily true.

- The factors for choosing an FEC might be based on a few parameters such as same layer 3 ip prefix, same BGP next hop address, packets that need the same Qos service or bandwidth reservations by link in the MPLS network of the ISP.

LABEL DISTRIBUTION

Now that we have seen what an MPLS label is and the different components of a network, there comes a need to distribute labels across the network.

As described, a label is something that is of local significance that is chosen by the router. However to distribute this to other routers, a new protocol was devised called Label Distribution Protocol or LDP. Other existing protocols such as RSVP or BGP also are used in networks to distribute labels through an MPLS network.

We shall look at LDP and BGP and how they distribute labels across the MPLS based network.

LDP:

- The LDP protocol creates a binding for every IGP prefix that a router has. Once this prefix is created, either independent or ordered approach of label distribution can be employed.

- In an independent approach, every router sends the chosen label for the IGP prefixes it has out all its interfaces that are running LDP. In an ordered approach, the head end or upstream router will send a label that it has chosen for a particular prefix. This then triggers a chain reaction in the downstream router that sends the label that it has chosen for the corresponding prefix and so on until the entire LSP is formed.

- Irrespective of which method is chosen for label distribution, LDP ensures that every router has a label for an incoming packet into the ingress router.
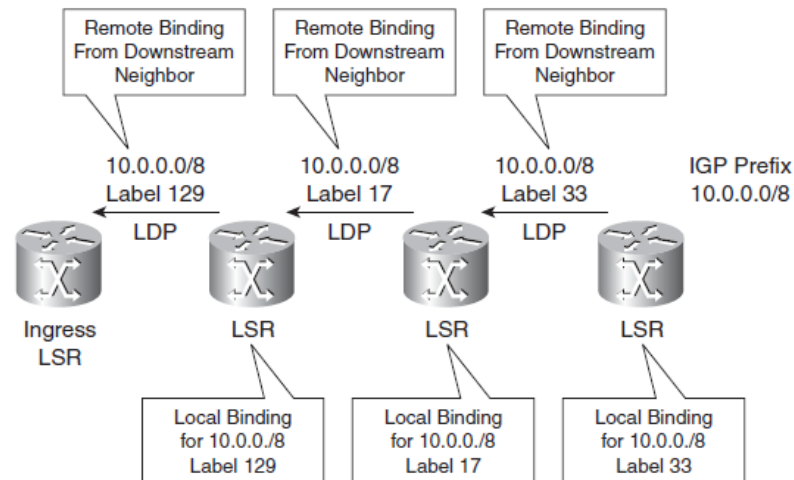
Figure 7: Label propagation in LDP

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

LABEL FORWARDING INSTANCE BASE (LFIB)

- All the labels that are chosen by a local router and those that are received from neighbors are populated by each router in a database known as LFIB.

- This acts as the forwarding plane of the MPLS protocol. When any label is received by the router, it first checks the LFIB to see if the label is known.

- For each label, a corresponding rule is mentioned and these could range from swapping the label with another, adding a new label on top of the old, popping an existing label and even removing all labels and sending out a plain IP packet. Whatever the case may be, if a label does not exist in the LFIB, the router most likely drops the packet, unless the destination IP has a route in the routing table of the router.

- The **Label Information Base (LIB)** stores the locally bound labels for each router and the best route is copied into the LFIB.

BGP:

- Border Gateway Protocol (BGP) is the existing de-facto protocol of the internet.

- It is an application layer protocol which is reliable and uses TCP for its reliability. Since this protocol is already so flexible it is used to transport labels in MPLS. A slightly tweaked version of this protocol known as Multi-Protocol BGP is used to transport labels. Its primary use in in MPLS VPN networks and we shall look at it in detail in the VPN section.

Operation of MPLS:

Now that we have looked at all the building blocks of MPLS, we shall see a sample MPLS network in operation so that we can better visualize how it works.
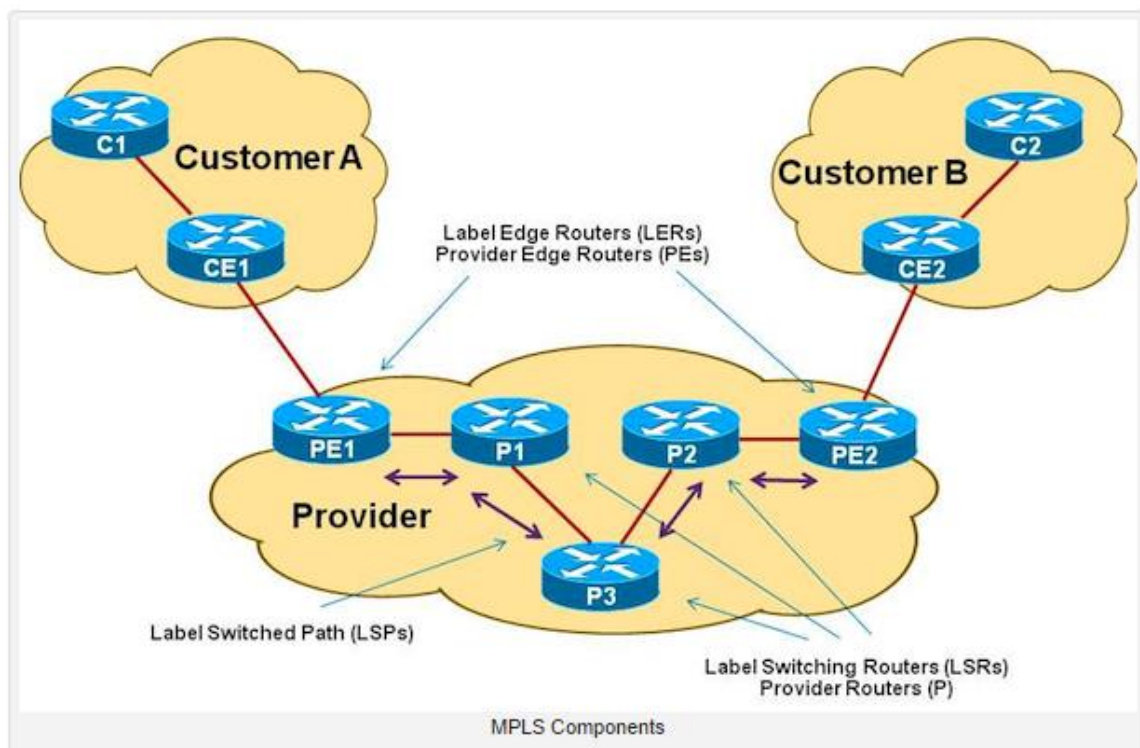
Figure 8: Sample MPLS network in operation

Ref: http://blog.ine.com/2010/06/28/MPLS-components-part-2/

The above diagram shows a sample scenario where two customers A and B with two Customer Equipment (CE) routers CE1 and CE2 connect to an ISP provider.

Two Ingress routers and two Egress routers exist for the ISP. PE1 acts as the Ingress router for Customer A and egress for Customer B. PE2 acts as Ingress router for customer B and Egress router for customer A.

In common terminology, the ingress and egress routers are known as Label Edge Routers (LER's).

Based on this sample diagram, let us see how the basic operation of MPLS can be described.

- Every Router in the network that wishes to run the protocols enables MPLS locally using the MPLS ip command in the global config mode.
- The routers in the core network must be running an Internal Gateway Protocol (IGP) in order to connect to all other routers in the network.
- The locally significant labels per router are distributed to other routers through a label distribution protocol such as LDP or RSVP, or through a slightly tweaked version of BGP known as MBGP in the case of use in VPN's.
- Each of these labels that is created by a router is associated with a prefix that a router knows through an IGP. These labels are then passed on from the downstream router to the router upstream to it.
- Thus once labels are distributed and all core routers are running MPLS, the customer router CE1 peers with the PE1 router and CE2 peers with the PE2 router.
- We shall describe what happens when a packet from CE1 enters the network but the same is true in the other direction as well.
- The IP packet received from CE1 is looked into by PE1. The destination prefix is examined in the LFIB and the corresponding label that the downstream router expects in the LSP is pushed on top of the IP header and is sent out the appropriate interface.
- The Intermediate LSR routers are known as Provider or (P) routers. These routers only look at the existing label at top of the packet and route the packet along the LSP to the next downstream router.
- When the packet arrives at the egress router of at PE2, and in this case we assume that customer A wants to communicate with customer B, the egress router strips the labels off the packet and send the packet as a regular IP packet to CE2 and the host receives the packet, totally unaware of MPLS running in the background.

3.2 Virtual Private Networks (VPN's)

3.2.1 Introduction to VPN

Virtual private networks or VPN's have changed the way networking and business operate ever since their commercialization. A VPN refers to simulating a private network for a company over a public infrastructure like that of an ISP.

Before the world of VPN, companies used to pay for dedicated T1 or T3 lines to link their different offices together. However, while they served the purpose, they created a lot of wastage as the line was unused when the company did not operate after hours for example. Also, it was very expensive as the costs were not shared.

3.2.2 Two types of VPN that existed before MPLS

There were two paradigms of VPN models that existed prior to the advent of MPLS. [5][20][21][23]

The Two types of VPN models were:

- **Overlay VPN model**

    o   In this model, a service provider provides virtual circuits via point to point links between one of the edge of the customers network to another. The customer routers peer directly with each other through the point to point links. The service provider does not take part in the routing process and never sees the customer's routes.

    o   The most common layer 2 protocols used in the overlay model of connection was with PPP, HDLC and Frame relay.
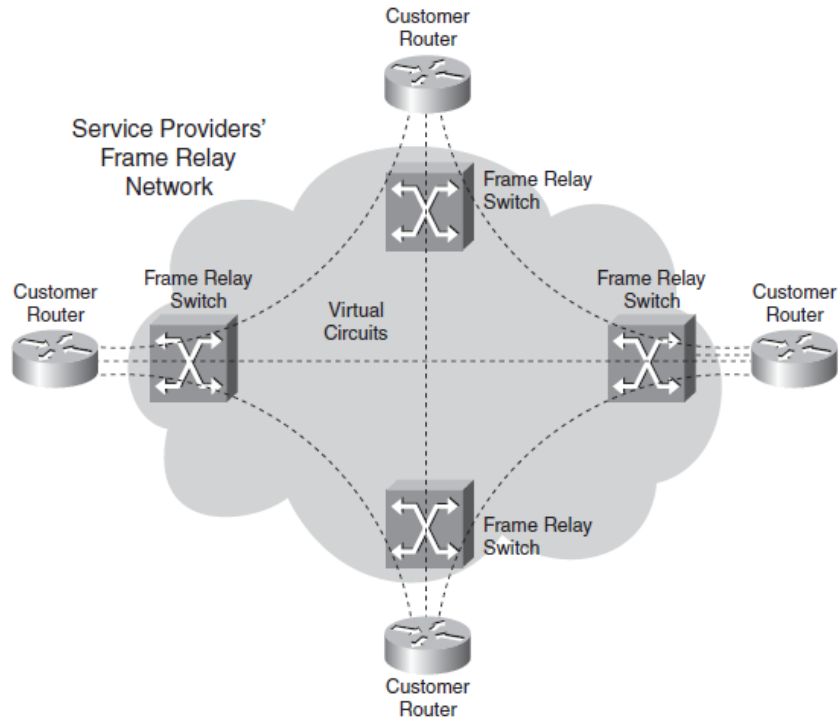
Figure 9: Overlay VPN example- Frame Relay

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

From a layer 3 perspective, the customer routes would peer with each other as shown below, completely oblivious to the virtual circuit that was connecting them.
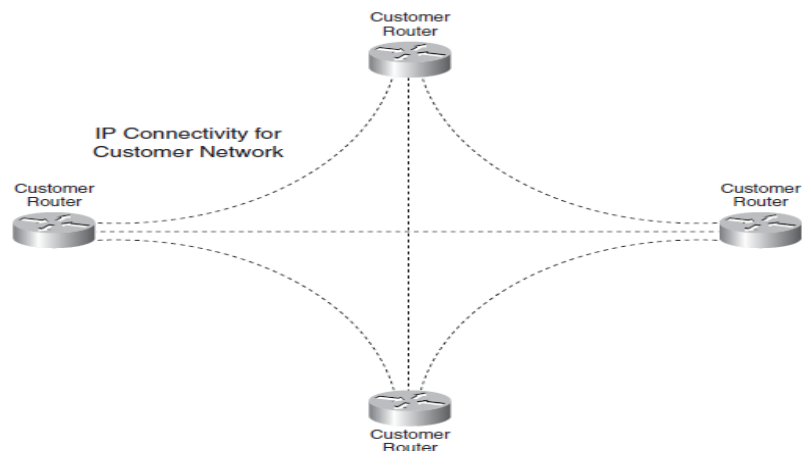

Figure 10: Overlay VPN example- Layer 3 Logical Diagram

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

Some of the advantages of the overlay peering model was that the customer routes had total privacy. However, this also had some disadvantages since the ISP routers did not peer with the customer routers. Thus there was not much flexibility and all the virtual point to point links had to be maintained manually. Also the customers had no control or knowledge of how the path would be through the ISP network.

- **Peer to Peer VPN model**

  o The peer to peer model involves carrying the customer routes through the provider network. The customers take part in the peering process of their routes by peering with a provider router and exchanging routes.
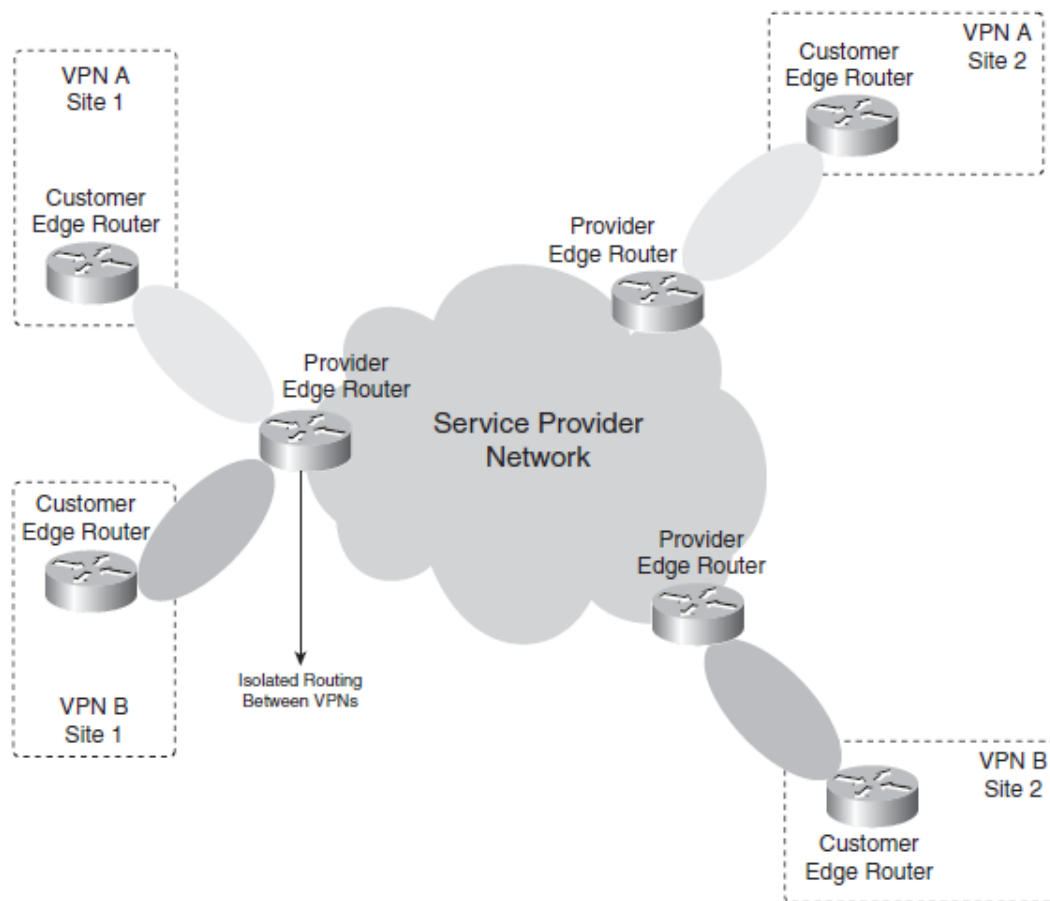
Figure 11: Peer to Peer VPN example

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

- The VPN still requires that privacy and isolation exists for each customer and this was achieved with the help of access and filter lists that filtered out the list of routes that each customer would see.

- While this model had its own advantage of flexibility and customer peering, it was hard to maintain as each customer had to have unique routes within the network. Thus it proved harder to implement on a larger scale.

- **MPLS VPN Model : The best of both worlds**

  - The MPLS technology was extremely well suited to be used to create a VPN technology that combined the best of the features of both overlay and peer to peer VPN's.

  - In this methodology, a customer router peers with a provider router. Thus it takes part in the routing process just as a router would in a peer to peer model.

  - However, the privacy and isolation of each customer is maintained with the help of what is known as **Virtual Routing/forwarding (VRF).** The VRF acts just the same as how Vlans would act at layer 2 but in this case at layer 3.

  - The VRF ensures that each customer has a separate routing table maintained for each of them. This ensures that the routes of one customer remain within its very own routing table and does not affect another.

  - Thus the MPLS VPN provides the best of both worlds, the privacy and isolation of overlay VPN's with the peering and customer participation of peer- peer methodology.

  - We shall look at the details and specifics of certain components that make up the MPLS VPN and how it works in a separate section below.
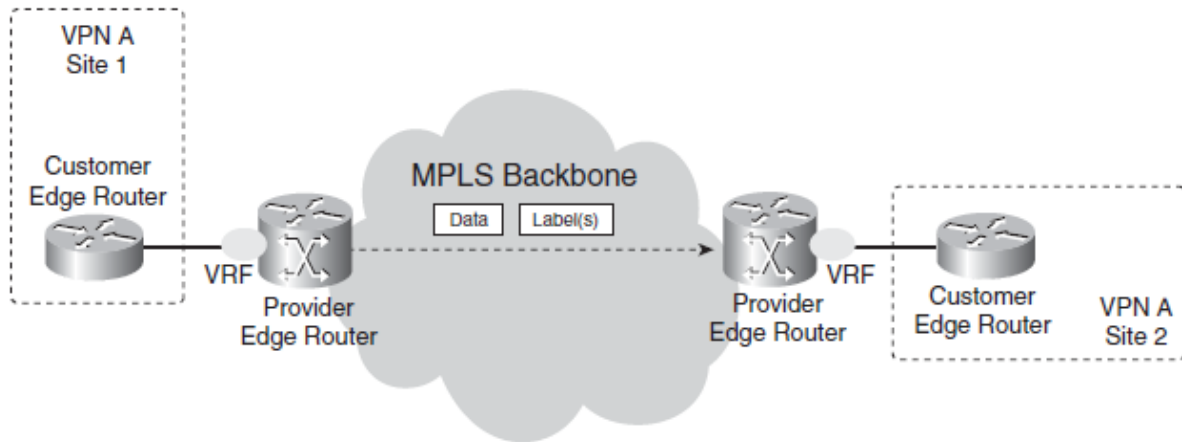
Figure 12: VRF formed for each customer

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

To get a working MPLS VPN network however, it is important that we know a few other components that are used in creating one.

They are first, to understand the common internal gateway protocols that are used within the core of the network and why they may be used. The second would be to understand the concept of multiprotocol BGP as it is used to transport labels between the PE routers.

3.3 Internal Gateway Protocols (IGP's)

An interior gateway protocol (IGP) is a type of protocol used for exchanging routing information between gateways (commonly routers) within an autonomous system (for example, a system of corporate local area networks). This routing information can then be used to route network-layer protocols like IP. [6][11][12][13][14][15]

The two types of IGP's are Distance Vector and Linked State Algorithms.

Distance Vector:

- The distance vector protocols use distance based metric as the name suggests to find the best route to other indirectly connected routers.
- Hop counts are a common metric to figure out which is the best path to a destination Ip Prefix.
- While distance vector protocols are easy to set up and configure, they possess serious disadvantages such as their propensity to get into routing loops, slow convergence time and most importantly lack of scalability.

- The RIP protocol, which was one of the first distance vector protocols cannot scale more than 50 devices on average before getting into issues.
- The main problem with them is that the hop count does not include factors such as congestion and bandwidth by default and each router does not have a view of the entire topology and cannot make decisions based on the entire picture.
- It is for this reason that in large scale ISP's, link state routing protocols are more preferred.

Link state:

- As mentioned, in the link state protocol, each router possesses the topology information present in the area and makes a routing table consisting of best hops based on the entire routing table.
- The routers send periodic updates to each other only when there is a change in the routing topology, rather than periodically every few seconds. This is the primary reason link state protocols are much more scalable and reliable than distant vector protocols and are the main choice for ISP's to use as their internal protocol of choice.
- The two commercial link state protocols available are
  - OSPF
    - It stands for open shortest path first protocol.
    - An OSPF network divides the network into logical areas. The areas in OSPF spans between links and interfaces and a router may have one interface in one area and another interface in another area. This type of router is known as an ABR or area border router.
    - It is not necessary to have ABR's in the topology, but if there is more than one area, it is important to have a base or default area called area 0.
    - Every router needs to have a connection back to area 0 throughout the network, and this is a necessity as the area 0 forms a backbone that stretches across the entire network. This is one of the main drawbacks of OSPF. The need to have a connection throughout the internal network to area 0 makes it hard to extend the network without making too many changes and that is why ISP's prefer ISIS as their link state IGP of choice.
  - ISIS
    - IS-IS stands for Intermediate Systems- Intermediate Systems and was originally developed for the OSI protocol rather than IP.
    - IS-IS is also a link state protocol similar to OSPF, but however has some significant advantages that make it more popular.
    - The main advantage being that there is no need to maintain an area 0 and a connection to that area throughout the network.

- In IS-IS, the areas are divided not by links, but the entire router is placed into a single area by itself.
- There are three types of areas, L1, L2 and L1/L2. By default all routers are L1/L2 routers and this is equivalent to the backbone area 0 of OSPF. L1 refers to the local area and L2 refers to only the backbone routes. The only requirement in IS-IS is that there must be a continuous presence of at least one L2 or L1/L2 router in each area of the topology. This acts as an ABR router in OSPF and is used to get out of the network.
- Some other advantages of IS-IS area :
  - With partial route calculation (PRC), IS-IS offers the ability to have more routers in area 0/Level 2 than OSPF.
  - IS-IS does not require the presence of an area 0 and thus can be scaled more efficiently than OSPF.
  - Is easy to transition into IpV6 in the future if required.
  - More flexible protocol overall as compared to OSPF.

3.4 Border Gateway Protocol (BGP)

The Border Gateway Protocol (BGP) is an application layer protocol that uses TCP for providing a reliable way of transporting the routing tables of the internet and today it is the only protocol that makes the internet work. [7][8][9][10][5]

Since BGP is already designed to carry many protocols at the lower layers, it was slightly tweaked to be used in MPLS VPN networks to carry VRF routes from one PE to another PE using what is called M-BGP or multiprotocol BGP.

Thus the MBGP ensures that all the VRF routes that a PE router has to all the CE routers that peer with it are carried over to the other PE routers that have M-BGP peering relationship with it.

In the next section, we shall tie all these concepts together and look at the components of an MPLS VPN network and then look at an example to see how it works.

3.5 MPLS VPN in Action

We shall look at few of the terms that are commonly used in an MPLS VPN network, followed by looking at a process flow chart that describes how the various protocols are tied together in making it work.
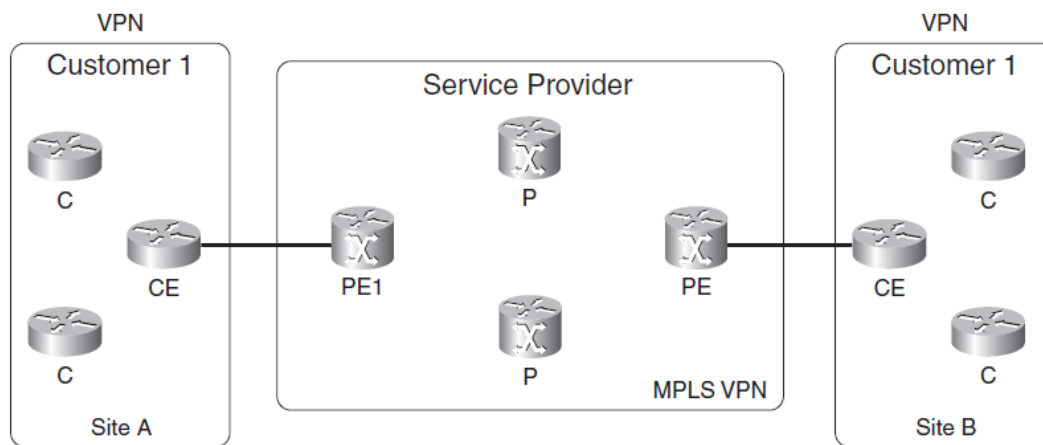
Figure 13: MPLS VPN Schematic diagram

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

- PE stands for Provider Equipment, CE stands for Customer Equipment and C and P stand for Customer and provider and are independently present in their own network without peering with another router from another network.

- A CE has a direct layer 3 connection with a PE. The principles of operation are similar to that of a VPN described earlier, where the CE peers with the PE and exchanges its internal routes and topology. The customer A is connected from site A to site B simulating a private network through a public network.

- We shall see how this is achieved. As mentioned, before the MPLS network ensures isolation and privacy of each customer through the concept of VRF. In order to achieve this there are two concepts to keep in mind.

Route Distinguisher (RD)

- The VPN prefixes are transferred across the MPLS VPN network with the help of M-BGP.

- However, to avoid the problems faced by traditional peer to peer VPN model, it was necessary to ensure that customer routes are all unique. To make every customer route unique, a route distinguisher concept was developed.

- An RD is a 64 bit field that is put in front of the prefix to make each VRF unique when the M-BGP carries the routes.

- There may be more than one RD that may assigned to each VPN in certain scenarios. However, it is necessary that each VRF has at least one VPN.

- There can be two common formats for an RD, either ASN: nn where ASN stands for autonomous system number and nn stands for number or ip address: nn. It is common in ISP's to have ASN: nn format.

Route Target (RT)

- While RD's help distinguish traffic from one VPN to another, there needs to be a way for the VPN of one network to communicate with another in certain cases, known as extranet VPN communication.

- This is achieved with the concept of an extended BGP community attribute known as RT. It allows importing and exporting routes from the VRF to M-BGP and vice versa. This allows the flexibility to decide which VRF routes are advertised in both directions and the communication and isolation can be controlled.
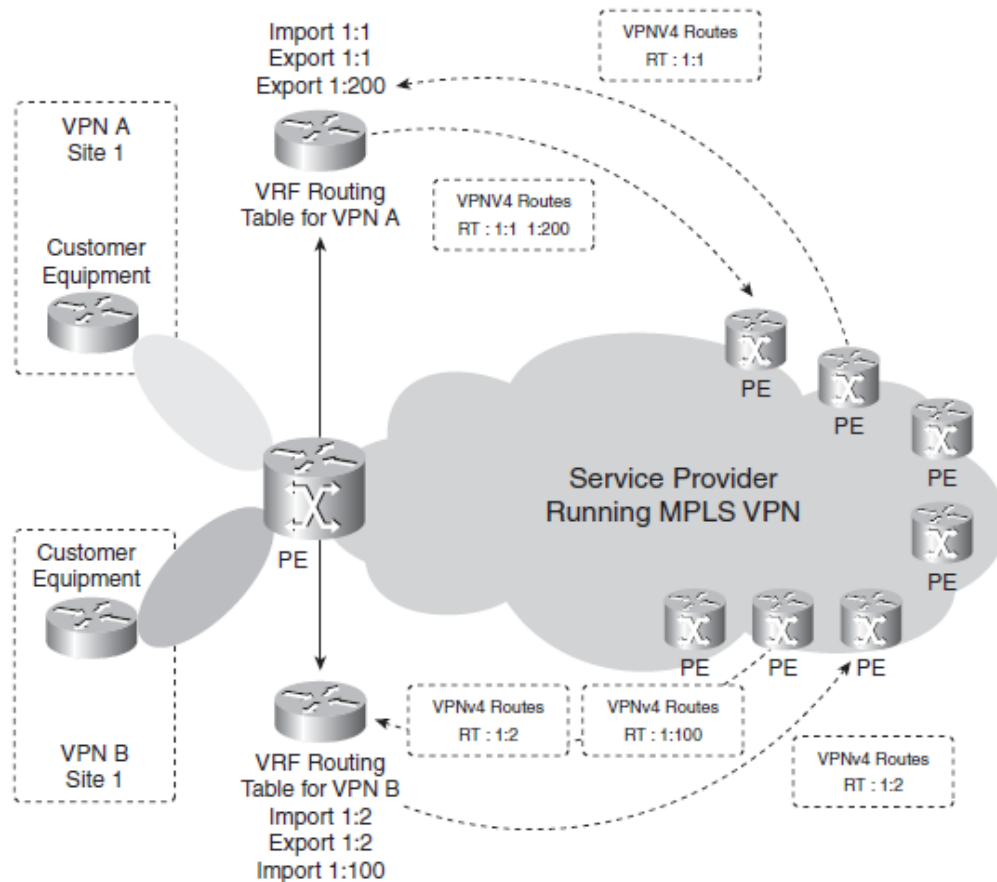
Figure 14: MPLS VPN RT diagram

Ref: MPLS Fundamentals Book; Author: Luc De Ghein, CCIE number: 1897

<u>Route Propagation in an MPLS VPN network: VPNv4 address Family</u> [5]

The RD and RT explained above, when added before an ipv4 address becomes what is known as a VPNv4 address and is usually of the format 1:10.0.0.1/08 for example.

The BGP protocol that carries these VPNv4 addresses becomes the multi-protocol BGP.

The steps that are needed to be configured to make this network work are as follows:

▪ The CE and the PE peer generally using an IGP that is configured to work with a VRF or through an e-bgp relationship.

- The ipv4 route received by the PE is added to the corresponding VRF routing table.

- The ipv4 route is added to the MP-BGP. A RD and RT are added to convert this into a VPNv4 address.

- The ingress core PE routes communicate this VPNv4 addresses with each other with the help of RD and RT's using MPLS running between them.

- The egress core PE looks at the RT's to understand which VRF to import the routes into and removes the RD.

- The ipv4 route is added into the corresponding VRF table.

- IGP or e-bgp relationship between the egress PE and the CE sends the routes to the customer as normal ipV4 routes.

The entire process above can be visualized using the diagram shown below:
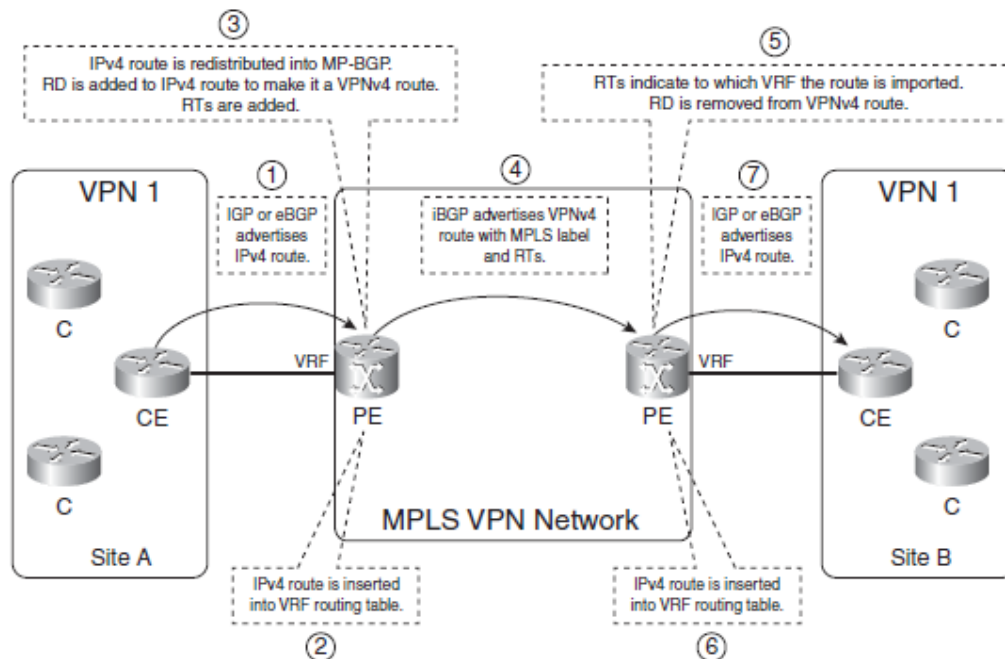
Figure 15: MPLS VPN step by step operation

4.0 MPLS VPN Design in Edmonton Capital Region (ECR)

4.1 Introduction

Since we have seen all the theory and concepts behind the protocols and network design, we shall now look into the story of how the MPLS VPN network was conceived for the ECR region.

The first step as mentioned earlier was to create a real world map based on latitude and longitude of the exact location of the various government services present in the city, whether they be in the form of hospitals, universities, schools, police stations, fire stations and libraries.

Once this task was undertaken a map was created (as shown earlier but for the purposes of ease of reading the report has been published below one again for reference).
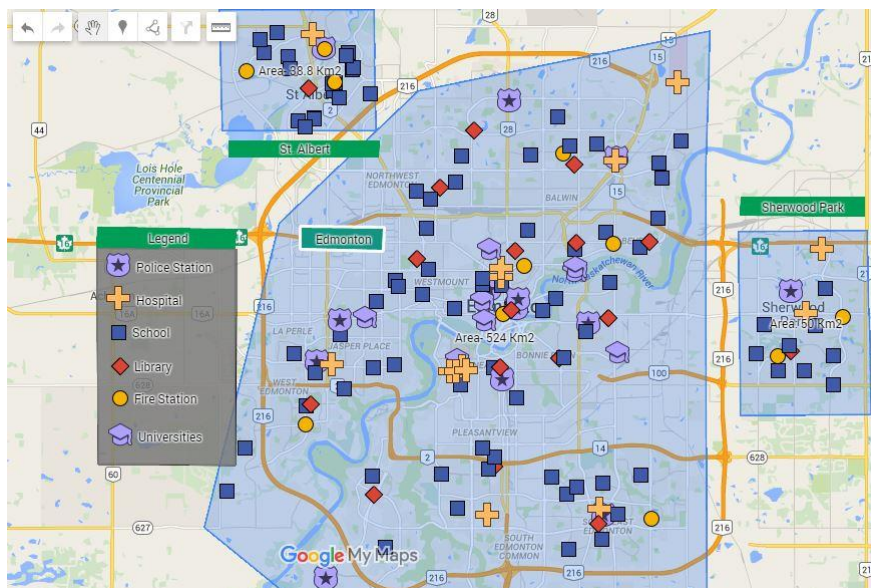
Figure 1: Edmonton Capital Region Government Services

The statistics or features of this map can be referred to in the introductory section.

We shall now look at the factors considered from this map that determined the placement of the PE and CE routers and also the network topology that was designed for the ECR.

4.2 Factors considered while designing network

- The first thing that I did was to create a database of each and every government service building recorded on the map.

- After this step, I split the ECR into roughly 6 sub regions as shown below:

  - St. Albert

  - Sherwood Park

  - Edmonton North

  - Edmonton South

  - Edmonton West Central

  - Edmonton East Central

- The splitting of the one huge ECR region into sub regions was done not only to create logical separation of the different areas into different administrative regions but also to maintain a fiber optic network limitations of roughly 9km per standard single mode connection after which attenuation and interference would occur.

- For each of these sub regions, which were chosen with real world measurement distances as conducted on google maps, I assigned a primary PE router to each area.

- The primary PE router peers with all the CE routers in its region. The PE routers are additionally placed at a distance from each other such that the distance from any CE router in one region is not more than 9km away from a PE router located in another region.

- This careful positioning of the PE routers not only within each region from all the CE's but from one CE to at least one other PE router has made a network design possible that is inherently capable of redundancy and failure protection mechanisms.

- Any CE that is considered to be important can just peer with another PE device that is assigned as its backup PE device so that it can peer with that. This ensures that every region is protected inherently in the case of failure on the part of its primary PE. The backup PE is always there to ensure the entire region and CE's do not get lost.

- Below is shown a table of information that was created as part of the research work done to ensure a correct understanding is reached on which PE is placed where, how many PE's and regions we need and also the average distance between each CE to its corresponding primary PE and its assigned backup PE in the case of failure of its primary PE.

ID	Name of Government Service	Type of Government Service	Primary Region/ Location	Link speed Required for CE	Primary PE serving the CE	Average distance of CE equipment to primary PE (KM)	Designated backup PE for the corresponding CE	Average distance of CE equipment to designated backup PE (KM)
1	Muriel Martin Elementary School	School	St. Albert	10	PE St Albert	2.2	PE Edmonton North	9.13
2	Elmer S Gish School	School	St. Albert	10	PE St Albert	2.8	PE Edmonton North	4.72
3	Bellerose Composite High School	School	St. Albert	10	PE St Albert	2.2	PE Edmonton North	9.35
4	St Albert Public School District #5565	School	St. Albert	10	PE St Albert	1.25	PE Edmonton North	6.19
5	Paul Kane High School	School	St. Albert	10	PE St Albert	1.48	PE Edmonton North	6.6
6	Keenooshayo Elementary School	School	St. Albert	10	PE St Albert	1.69	PE Edmonton North	5.78
7	Leo Nickerson Elementary School	School	St. Albert	10	PE St Albert	1.79	PE Edmonton North	8.21
8	École Secondaire Sainte Marguerite D'Youvi	School	St. Albert	10	PE St Albert	1.62	PE Edmonton North	5.41
9	Wild Rose Elementary School	School	St. Albert	10	PE St Albert	2.5	PE Edmonton North	8
10	Sir Alexander Mackenzie School	School	St. Albert	10	PE St Albert	1.1	PE Edmonton North	6.27
11	J. J. Nearing Catholic	School	St. Albert	10	PE St Albert	2.79	PE Edmonton North	9.72

#	Name	Type	City		PE		Backup	
	Elementary School							
12	Robert Rundle Elementary	School	St. Albert	10	PE St Albert	2.34	PE Edmonton North	8.14
13	Sir George Simpson Junior High	School	St. Albert	10	PE St Albert	2.45	PE Edmonton North	7.59
14	Bertha Kennedy Catholic Community School	School	St. Albert	10	PE St Albert	1.23	PE Edmonton North	8.35
15	Albert Lacombe Catholic Elementary School	School	St. Albert	10	PE St Albert	2.84	PE Edmonton North	7.83
16	École Marie Poburan	School	St. Albert	10	PE St Albert	1.82	PE Edmonton North	5.45
17	Preschool	School	St. Albert	10	PE St Albert	1.21	PE Edmonton North	7.16
18	Outreach High School	School	St. Albert	10	PE St Albert	1.25	PE Edmonton North	6.3
19	Neil M Ross Catholic School	School	St. Albert	10	PE St Albert	1.63	PE Edmonton North	5.71
20	Ronald Harvey Elementary	School	St. Albert	10	PE St Albert	1	PE Edmonton North	8.25
21	St Albert Public Library	Library	St. Albert	1	PE St Albert	0.871	PE Edmonton North	9.92
22	RCMP	Police Station	St. Albert	1	PE St Albert	1	PE Edmonton North	6.76
23	Fire Station No. 3	Fire Station	St. Albert	1	PE St Albert	3	PE Edmonton North	9.96
24	St. Albert Fire Station No. 2	Fire Station	St. Albert	1	PE St Albert	0.971	PE Edmonton North	6.85
25	St Albert Fire Station 1	Fire Station	St. Albert	1	PE St Albert	1.26	PE Edmonton North	7.8
26	Sturgeon Community Hospital	Hospital	St. Albert	1	PE St Albert	1.35	PE Edmonton North	7.62
27	Madonna Catholic School	School	Sherwood Park	10	PE Sherwood Park	1.5	Backup PE-E,N & SWP	3.85
28	Bev Facey Community High School	School	Sherwood Park	10	PE Sherwood Park	2.08	Backup PE-E,N & SWP	7.28
29	Holy Spirit Catholic School	School	Sherwood Park	10	PE Sherwood Park	1.95	Backup PE-E,N & SWP	6.31

30	Brentwood Elementary	School	Sherwood Park	10	PE Sherwood Park	2.16	Backup PE-E,N & SWP	6.54
31	Strathcona Christian Academy Secondary	School	Sherwood Park	10	PE Sherwood Park	3.25	Backup PE-E,N & SWP	8.13
32	Glen Allan Elementary School	School	Sherwood Park	10	PE Sherwood Park	0.8	Backup PE-E,N & SWP	6.09
33	St. Theresa Catholic Middle School	School	Sherwood Park	10	PE Sherwood Park	1.2	Backup PE-E,N & SWP	5.31
34	Sherwood Heights Junior High	School	Sherwood Park	10	PE Sherwood Park	2.37	Backup PE-E,N & SWP	5.66
35	Westboro Elementary School	School	Sherwood Park	10	PE Sherwood Park	2.35	Backup PE-E,N & SWP	4.44
36	Strathcona County Library	Library	Sherwood Park	1	PE Sherwood Park	1.4	Backup PE-E,N & SWP	5.57
37	Royal Canadian Mounted Police	Police Station	Sherwood Park	1	PE Sherwood Park	1.39	Backup PE-E,N & SWP	4.73
38	Strathcona Community Hospital	Hospital	Sherwood Park	1	PE Sherwood Park	3.2	Backup PE-E,N & SWP	6.24
39	Strathcona County Health Centre	Hospital	Sherwood Park	1	PE Sherwood Park	0.9	Backup PE-E,N & SWP	5.55
40	Alberta Health Services	Hospital	Sherwood Park	1	PE Sherwood Park	0.9	Backup PE-E,N & SWP	5.45
41	Strathcona County Fire Station	Fire Station	Sherwood Park	1	PE Sherwood Park	2	Backup PE-E,N & SWP	7.12
42	Strathcona County Emergency Services	Fire Station	Sherwood Park	1	PE Sherwood Park	1.96	Backup PE-E,N & SWP	5.25
43	Strathcona County Fire Hall #6	Fire Station	Sherwood Park	1	PE Sherwood Park	1.21	Backup PE-E,N & SWP	4.61
44	Edmonton Public Schools	School	Edmonton	10	PE Edmonton East Central	6.3	Backup PE-E,N & SWP	8.3
45	J.H. Picard	School	Edmonton	10	PE Edmonton	4.7	Backup PE-E,N & SWP	9.6

					East Central			
46	Patricia Heights Elementary School	School	Edmonton	10	PE Edmonton West Central	3.58	PE Edmonton South	4.4
47	Edmonton Christian West School	School	Edmonton	10	PE Edmonton West Central	8.9	PE Edmonton South	7.2
48	Victoria School of the Arts	School	Edmonton	10	PE Edmonton East Central	6.5	Backup PE-E,N & SWP	8.54
49	Millwoods Christian School	School	Edmonton	10	PE Edmonton South	5.57	PE Edmonton East Central	5.8
50	St. Joseph High School	School	Edmonton	10	PE Edmonton east Central	6.8	Backup PE-E,N & SWP	9.12
51	Athlone School	School	Edmonton	10	PE Edmonton North	6.47	PE St Albert	8.26
52	Rideau Park School	School	Edmonton	10	PE Edmonton South	3.3	PE Edmonton West Central	8.6
53	The Waldorf Independent School of Edmonton	School	Edmonton	10	PE Edmonton East Central	2.2	Backup PE-E,N & SWP	5.2
54	St. Elizabeth Catholic School	School	Edmonton	10	PE Edmonton South	6.5	PE Edmonton East Central	6.3
55	Aurora School	School	Edmonton	10	PE Edmonton North	6.7	PE St Albert	9.04
56	St. Bonaventure Elementary School	School	Edmonton	10	PE Edmonton North	9.2	Backup PE-E,N & SWP	5.38
57	Lee Ridge School	School	Edmonton	10	PE Edmonton North	9.14	Backup PE-E,N & SWP	5.4
58	Overlanders School	School	Edmonton	10	PE Edmonton North	9.95	Backup PE-E,N & SWP	3.14
59	Fresh Start	School	Edmonton	10	PE Edmonton North	9.88	Backup PE-E,N & SWP	4.8
60	Progressive Academy	School	Edmonton	10	PE Edmonton	8.6	PE Edmonton South	5.7

					West Central			
61	Edmonton Public Schools	School	Edmonton	10	PE Edmonton East Central	6.7	Backup PE-E,N & SWP	8.45
62	St. Mary Catholic School	School	Edmonton	10	PE Edmonton South	3.9	PE Edmonton West Central	3.2
63	McLeod School	School	Edmonton	10	PE Edmonton North	6.49	Backup PE-E,N & SWP	7.47
64	St. Timothy Catholic School	School	Edmonton	10	PE Edmonton North	3.9	PE St Albert	8.02
65	R.J. Scott School	School	Edmonton	10	PE Edmonton East Central	5.6	Backup PE-E,N & SWP	2.7
66	McNally High School	School	Edmonton	10	PE Edmonton East Central	4.3	Backup PE-E,N & SWP	6.03
67	McKernan School	School	Edmonton	10	PE Edmonton West Central	7.6	PE Edmonton South	1.8
68	Edmonton Academy	School	Edmonton	10	PE Edmonton West Central	9.3	PE Edmonton South	5.15
69	Archbishop MacDonald Catholic School	School	Edmonton	10	PE Edmonton West Central	8.83	PE Edmonton South	7.33
70	St. John Bosco Catholic School	School	Edmonton	10	PE Edmonton North	4.3	Backup PE-E,N & SWP	9.3
71	Sweet Grass School	School	Edmonton	10	PE Edmonton South	3.97	PE Edmonton West Central	7.48
72	Weinlos School	School	Edmonton	10	PE Edmonton South	9.3	PE Edmonton East Central	6.6
73	L.Y. Cairns School	School	Edmonton	10	PE Edmonton South	2.49	PE Edmonton West Central	8.83
74	McKee School	School	Edmonton	10	PE Edmonton South	2.21	PE Edmonton East Central	7.12

75	Eastglen School	School	Edmonton	10	PE Edmonton East Central	5.61	Backup PE-E,N & SWP	5.4
76	Monsignor Fee Otterson School	School	Edmonton	10	PE Edmonton South	9.15	PE Edmonton West Central	9.97
77	Fraser School	School	Edmonton	10	PE Edmonton North	9.89	Backup PE-E,N & SWP	5.8
78	Stratford School	School	Edmonton	10	PE Edmonton West Central	5.2	PE Edmonton South	4.07
79	Kensington School	School	Edmonton	10	PE Edmonton North	5.28	PE St Albert	8.71
80	Delton Elementary School	School	Edmonton	10	PE Edmonton East Central	7.18	Backup PE-E,N & SWP	7.43
81	Sir John Thompson	School	Edmonton	10	PE Edmonton North	6.06	PE St Albert	7.8
82	Saint Thomas More Junior High School	School	Edmonton	10	PE Edmonton West Central	5.6	PE Edmonton South	5.8
83	Cardinal Leger Junior High School	School	Edmonton	10	PE Edmonton North	4.6	Backup PE-E,N & SWP	8.9
84	Bessie Nichols School	School	Edmonton	10	PE Edmonton West Central	2.7	PE Edmonton South	8.7
85	Old Scona Academic High School	School	Edmonton	10	PE Edmonton East Central	5.7	Backup PE-E,N & SWP	9.9
86	St. Kateri Catholic School	School	Edmonton	10	PE Edmonton South	9.4	PE Edmonton East Central	5.2
87	Parkland Immanuel Christian School	School	Edmonton	10	PE Edmonton West Central	3.8	PE Edmonton South	9.97
88	Greenview School	School	Edmonton	10	PE Edmonton South	7.8	PE Edmonton East Central	5.22
89	St. Rose Junior High School	School	Edmonton	10	PE Edmonton	5.63	PE Edmonton South	3.87

					West Central			
90	Holy Cross	School	Edmonton	10	PE Edmonton West Central	7.6	PE Edmonton South	6.24
91	St. Leo Catholic School	School	Edmonton	10	PE Edmonton East Central	5.6	Backup PE-E,N & SWP	3.7
92	St. Boniface Catholic School	School	Edmonton	10	PE Edmonton South	2	PE Edmonton West Central	6.27
93	Suzuki Charter School	School	Edmonton	10	PE Edmonton East Central	4	PE Edmonton South	3.8
94	Monsignor William Irwin Catholic School	School	Edmonton	10	PE Edmonton South	6.18	PE Edmonton West Central	5.84
95	St. Clement Elementary/Junior High School	School	Edmonton	10	PE Edmonton South	8.2	PE Edmonton East Central	8.8
96	St. Catherine Catholic School	School	Edmonton	10	PE Edmonton East Central	7.3	Backup PE-E,N & SWP	9.45
97	Vimy Ridge Academy	School	Edmonton	10	PE Edmonton East Central	2.6	Backup PE-E,N & SWP	6.76
98	Riverdale School	School	Edmonton	10	PE Edmonton East Central	4.06	Backup PE-E,N & SWP	6.54
99	St. Justin Catholic School	School	Edmonton	10	PE Edmonton West Central	3.8	PE Edmonton South	5.9
100	H.E. Beriault Catholic School	School	Edmonton	10	PE Edmonton East Central	4.03	Backup PE-E,N & SWP	5.24
101	Johnny Bright Elementary-Junior High School	School	Edmonton	10	PE Edmonton South	8.43	PE Edmonton West Central	9.33
102	Meyokumin School	School	Edmonton	10	PE Edmonton South	8.9	PE Edmonton East Central	7.7

103	John Barnett School	School	Edmonton	10	PE Edmonton North	5.59	Backup PE-E,N & SWP	8.08
104	Belmead School	School	Edmonton	10	PE Edmonton West Central	4.6	PE Edmonton South	7.13
105	Blessed Oscar Romero High School	School	Edmonton	10	PE Edmonton West Central	2.4	PE Edmonton South	5.8
106	MacEwan University - Centre for the Arts and Communications	University	Edmonton	100	PE Edmonton West Central	6.7	PE Edmonton South	6.3
107	Concordia University of Edmonton	University	Edmonton	100	PE Edmonton East Central	5.18	Backup PE-E,N & SWP	5.29
108	MacEwan - University Service Centre	University	Edmonton	100	PE Edmonton East Central	6.8	Backup PE-E,N & SWP	9.25
109	The King's University	University	Edmonton	100	PE Edmonton East Central	1	Backup PE-E,N & SWP	4.4
110	University Of Lethbridge	University	Edmonton	100	PE Edmonton East Central	4.8	Backup PE-E,N & SWP	5
111	University of Alberta	University	Edmonton	100	PE Edmonton West Central	8.16	PE Edmonton East Central	2.87
112	Athabasca University, Edmonton	University	Edmonton	100	PE Edmonton East Central	6.5	Backup PE-E,N & SWP	9.2
113	Nait	University	Edmonton	100	PE Edmonton East Central	8.19	Backup PE-E,N & SWP	9
114	University of Alberta Hospital	Hospital	Edmonton	1	PE Edmonton West Central	8.16	PE Edmonton South	2.87
115	Royal Alexandra Hospital	Hospital	Edmonton	1	PE Edmonton East Central	7.16	Backup PE-E,N & SWP	8.42

116	Misericordia Community Hospital	Hospital	Edmonton	1	PE Edmonton West Central	4.07	PE Edmonton South	5.27
117	Grey Nuns Community Hospital	Hospital	Edmonton	1	PE Edmonton South	8.4	PE Edmonton East Central	6.76
118	Alberta Hospital Edmonton	Hospital	Edmonton	1	PE Edmonton North	9.06	Backup PE-E,N & SWP	8.86
119	St. Joseph's Auxiliary Hospital	Hospital	Edmonton	1	PE Edmonton South	4.89	PE Edmonton East Central	9.25
120	Cross Cancer Institute	Hospital	Edmonton	1	PE Edmonton West Central	7.57	PE Edmonton South	2.69
121	Hospital & Community Day Care	Hospital	Edmonton	1	PE Edmonton West Central	7.6	PE Edmonton South	2.7
122	Stollery Children's Hospital	Hospital	Edmonton	1	PE Edmonton West Central	7.6	PE Edmonton South	2.7
123	University Hospital Foundation	Hospital	Edmonton	1	PE Edmonton West Central	7.6	PE Edmonton South	2.7
124	Misericordia Community Hospital	Hospital	Edmonton	1	PE Edmonton West Central	4.52	PE Edmonton South	5.6
125	Glenrose Rehabilitation Hospital	Hospital	Edmonton	1	PE Edmonton East Central	7.08	Backup PE-E,N & SWP	6.81
126	Northeast Community Health Centre	Hospital	Edmonton	1	PE Edmonton North	7.48	Backup PE-E,N & SWP	6.47
127	Edmonton Police Service - Headquarters	Police Station	Edmonton	1	PE Edmonton East Central	5.6	Backup PE-E,N & SWP	7.7
128	Edmonton Police Service - McDougall Station	Police Station	Edmonton	1	PE Edmonton East Central	6.75	Backup PE-E,N & SWP	8.8
129	Edmonton Police Service -	Police Station	Edmonton	1	PE Edmonton North	7.48	Backup PE-E,N & SWP	6.34

	Northeast Division							
130	West Edmonton Mall Community Police Station	Police Station	Edmonton	1	PE Edmonton West Central	4.4	PE Edmonton South	6.05
131	Old Strathcona Station	Police Station	Edmonton	1	PE Edmonton East Central	5.6	Backup PE-E,N & SWP	9.6
132	Edmonton Police Service Recruiting Centre	Police Station	Edmonton	1	PE Edmonton East Central	5.2	Backup PE-E,N & SWP	7.9
133	Namao Station	Police Station	Edmonton	1	PE Edmonton North	2.09	PE St Albert	9.18
134	Edmonton Police Service - Southeast Division	Police Station	Edmonton	1	PE Edmonton South	8.5	PE Edmonton East Central	6.9
135	Edmonton Police Service - West Division	Police Station	Edmonton	1	PE Edmonton West Central	6.2	PE Edmonton South	6.3
136	Edmonton Police Service - Ottewell Station	Police Station	Edmonton	1	PE Edmonton East Central	2.68	Backup PE-E,N & SWP	4.76
137	Edmonton Police Service - Southwest Division	Police Station	Edmonton	1	PE Edmonton South	8.3	PE Edmonton West Central	5.4
138	Edmonton Fire Department 14	Fire Station	Edmonton	1	PE Edmonton North	5.5	Backup PE-E,N & SWP	8.15
139	Fire Station 5	Fire Station	Edmonton	1	PE Edmonton East Central	6.19	Backup PE-E,N & SWP	7.25
140	Alberta Fire Commissioner's	Fire Station	Edmonton	1	PE Edmonton East Central	5.7	Backup PE-E,N & SWP	8.7
141	Meadows Fire Station #26	Fire Station	Edmonton	1	PE Edmonton South	9.9	PE Edmonton East Central	7
142	Highlands Firestation #7	Fire Station	Edmonton	1	PE Edmonton East Central	5.56	Backup PE-E,N & SWP	3.57

143	Fire Station #19 - Callingwood	Fire Station	Edmonton	1	PE Edmonton West Central	1.59	PE Edmonton South	5.69
144	Edmonton Public Library - Stanley A. Milner Library	Library	Edmonton	1	PE Edmonton East Central	5.45	Backup PE-E,N & SWP	8.26
145	Edmonton Public Library - Sprucewood Branch	Library	Edmonton	1	PE Edmonton East Central	6.98	Backup PE-E,N & SWP	7.97
146	Edmonton Public Library - Whitemud Crossing Branch	Library	Edmonton	1	PE Edmonton South	3.12	PE Edmonton West Central	8.55
147	Edmonton Public Library - Strathcona Branch	Library	Edmonton	1	PE Edmonton East Central	5.38	Backup PE-E,N & SWP	9.24
148	Edmonton Public Library - Abbottsfield Branch	Library	Edmonton	1	PE Edmonton East Central	5.8	Backup PE-E,N & SWP	2.6
149	Edmonton Public Library - Woodcroft Branch	Library	Edmonton	1	PE Edmonton North	8.83	PE St Albert	9.96
150	Edmonton Public Library - Riverbend Branch	Library	Edmonton	1	PE Edmonton South	4.12	PE Edmonton West Central	3.6
151	Edmonton Public Library - Idylwylde Branch	Library	Edmonton	1	PE Edmonton East Central	2.76	Backup PE-E,N & SWP	6.77
152	Edmonton Public Library - Londonderry Branch	Library	Edmonton	1	PE Edmonton North	6.11	Backup PE-E,N & SWP	7.56
153	Edmonton Public Library - Mill Woods Branch	Library	Edmonton	1	PE Edmonton South	8.39	PE Edmonton East Central	6.88
154	Edmonton Public Library - Lois Hole Library	Library	Edmonton	1	PE Edmonton West Central	2.59	PE Edmonton South	5.55
155	Edmonton Public Library - Capilano Branch	Library	Edmonton	1	PE Edmonton East Central	2.2	Backup PE-E,N & SWP	4.16

					PE Edmonton East Central	6.15	Backup PE- E,N & SWP	5.43
156	Edmonton Public Library - Highlands Branch	Library	Edmonton	1				
157	Edmonton Public Library - Calder Branch	Library	Edmonton	1	PE Edmonton North	5.42	PE St Albert	8.04
158	Edmonton Public Library - Castle Downs Branch	Library	Edmonton	1	PE Edmonton North	2.82	PE St Albert	7.83
159	Alberta Library The	Library	Edmonton	1	PE Edmonton East Central	5.14	Backup PE- E,N & SWP	7.76

Figure 16: Data Table showing detailed Information of government service buildings, PE and CE routers in the Edmonton Capital Region

- The sub regions created, along with their primary PE and designated backup PE's are shown in the table below:

PRIMARY PE ROUTER NAME	Primary Service Region	Comments
PE St Albert	St Albert	Serves as backup PE router to Edmonton North Region
PE Edmonton North	North Central-East Edmonton	Serves as backup PE router to St Albert Region
PE Edmonton West Central	West Central Edmonton	Serves as backup PE router to Western Half of Edmonton South
PE Edmonton East Central	East-Central Edmonton	Serves as backup PE router to Eastern half of Edmonton South Region and Sherwood Region
PE Edmonton South	South Edmonton	Serves as Backup PE Router to Edmonton West Central Region
PE Sherwood	Sherwood	Serves as Primary PE router to Sherwood Park Region
Backup PE- E,N & SWP	North, East Central and Sherwood	Serves as backup PE for Edmonton North, East Central and Sherwood

Figure 17: Data Table showing primary PE per region, with backup designated PE

The same information shown in the table above can be viewed through the diagram shown below
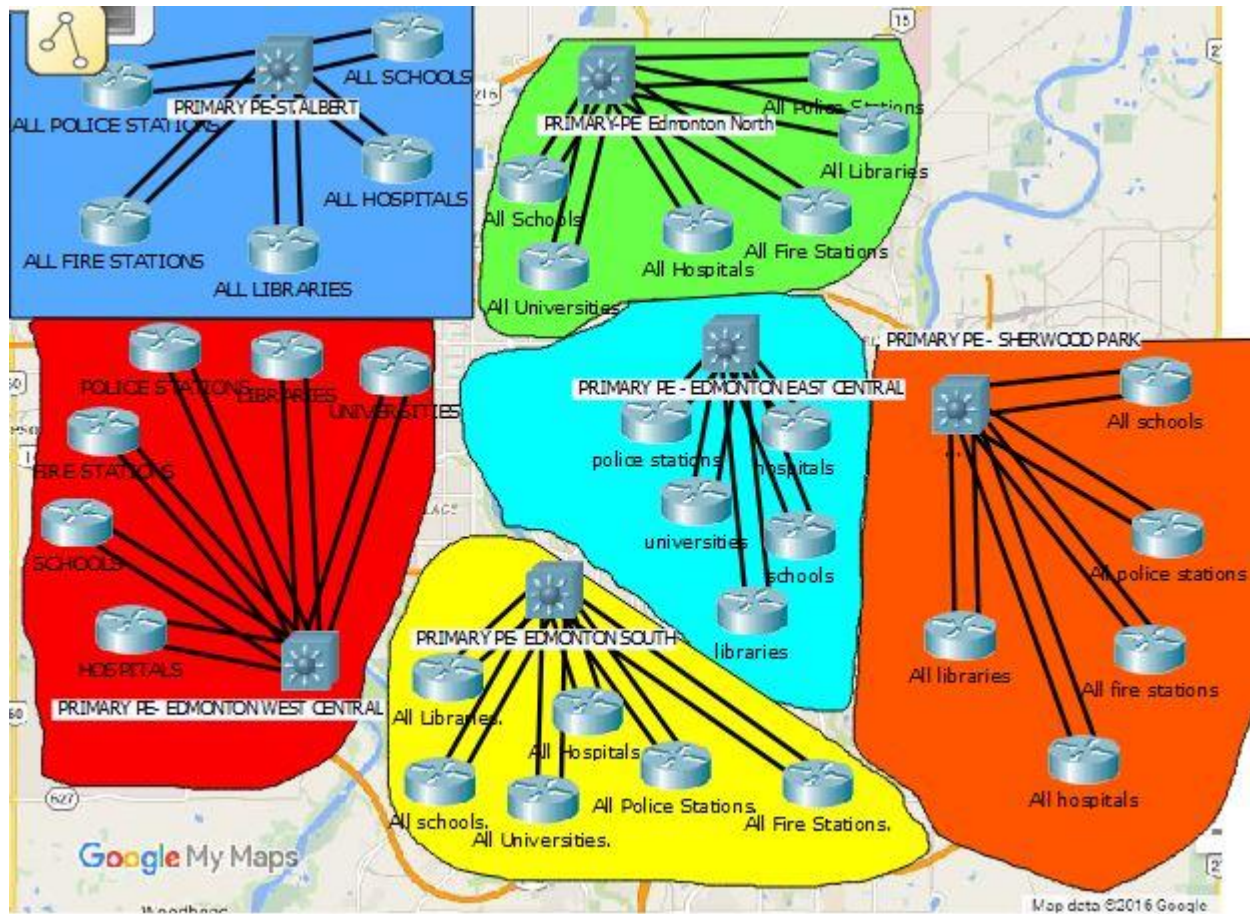
Figure 18: Sub Regions and their primary CE's in the ECR

4.3 Design Topology

Thus far we have seen the factors considered into how the different CE devices and PE devices were chosen and the rational for placing the PE routers the way I did along with the number of PE routers.

The next step was to come up with a network topology to achieve this. In order to do this, first I visualized each CE router being connected to its corresponding primary PE router within its region.

While this may not have been necessary as it is not practical to get into such level of detail, I did so anyway because it gave a good platform for me to visualize the entire network as a whole when I finally developed it.

- The diagram below shows the network topology that would arise at the St. Albert area when the CE devices connect to their primary PE device.
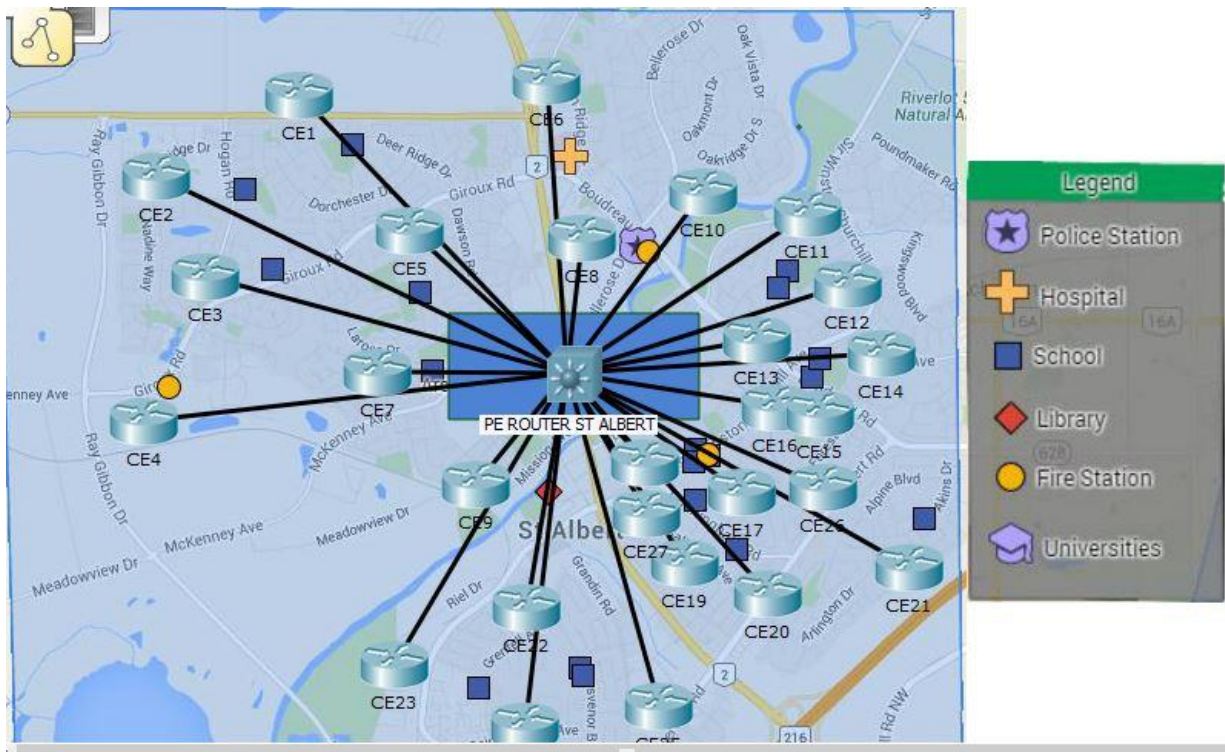
Figure 19: Sub Region St Albert and the CE's connecting to the ST Albert Primary PE router

- The diagram below shows the network topology that would arise at the Sherwood Park (SWP) area when the CE devices connect to their primary PE device.
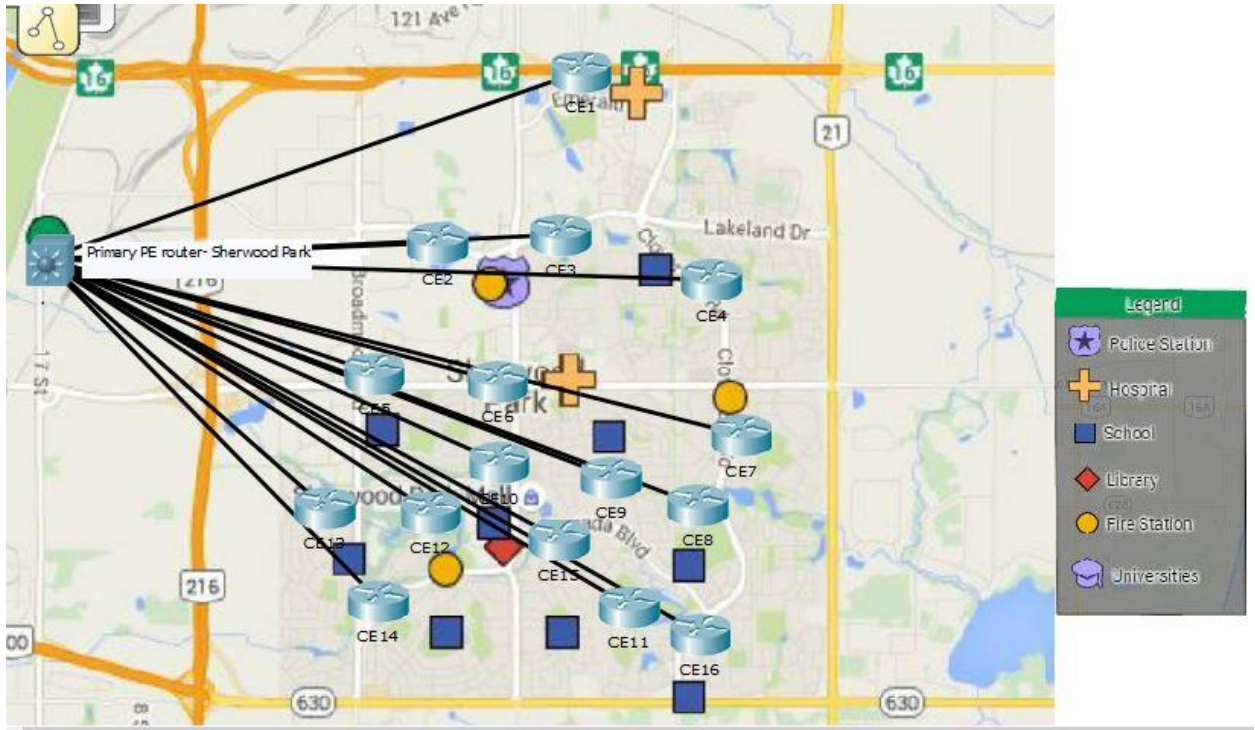
Figure 20: Sub Region SWP and the CE's connecting to the SWP Primary PE router

▪ The diagram below shows the network topology that would arise at the Edmonton North area when the CE devices connect to their primary PE device.
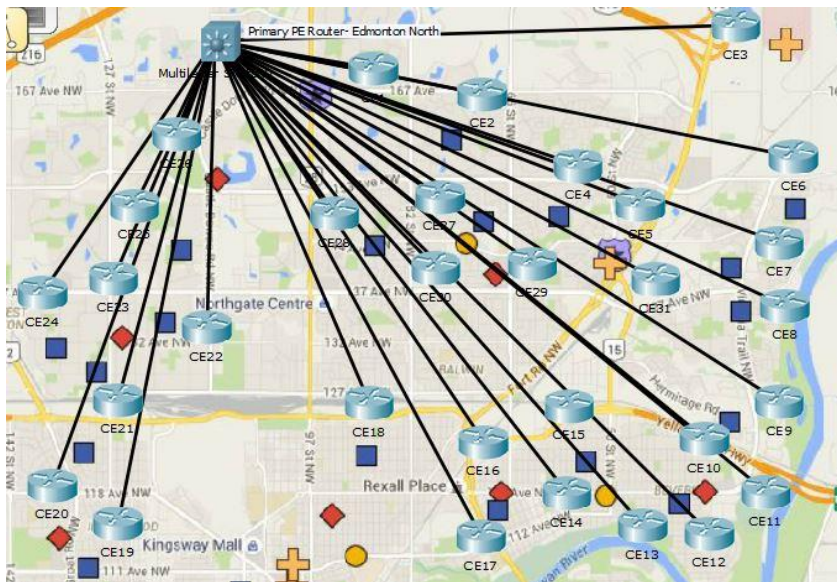
Figure 21: Sub Region Edmonton North and the CE's connecting to the Edmonton North Primary PE router

- The diagram below shows the network topology that would arise at the Edmonton South area when the CE devices connect to their primary PE device.
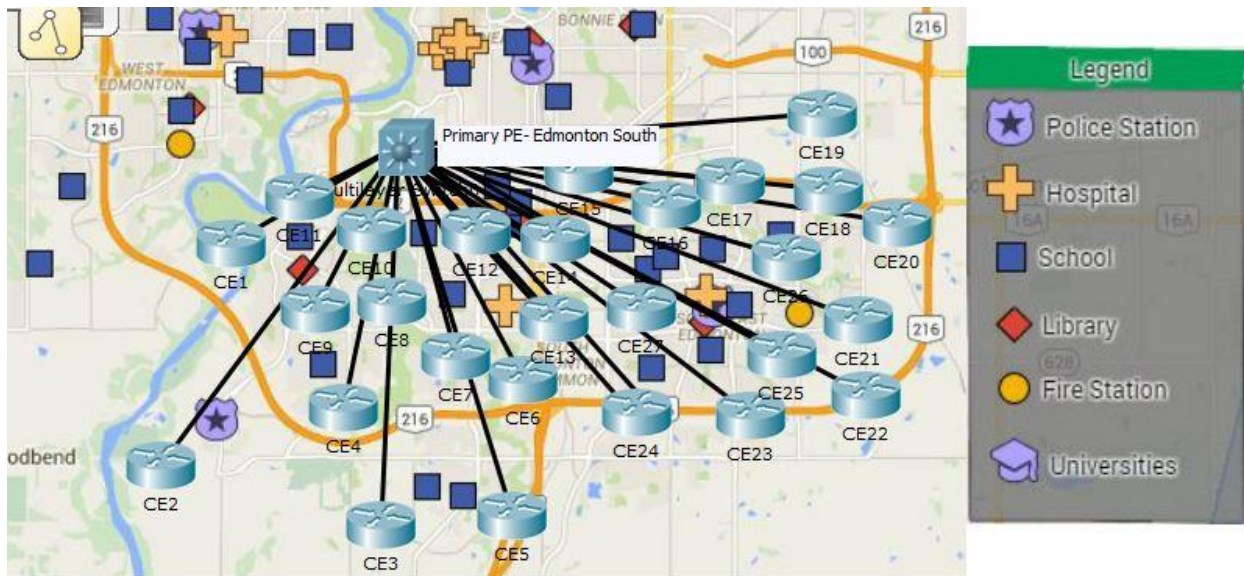
Figure 22: Sub Region Edmonton South and the CE's connecting to the Edmonton South Primary PE router

- The diagram below shows the network topology that would arise at the Edmonton West Central area when the CE devices connect to their primary PE device.
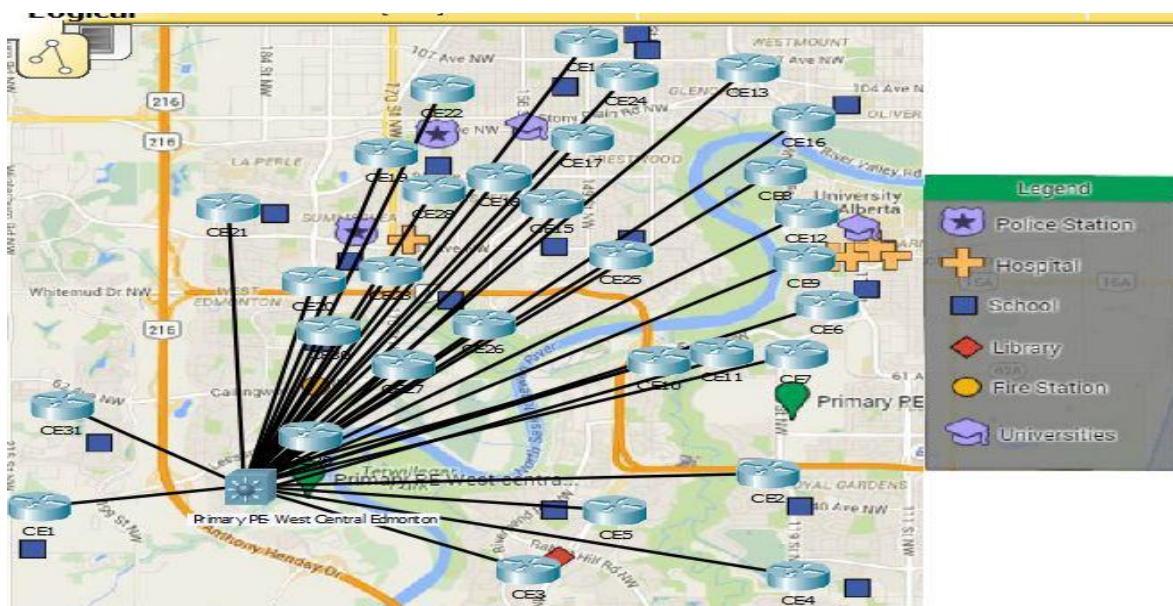
Figure 23: Sub Region Edmonton West Central and the CE's connecting to the Edmonton West Primary PE router

- The diagram below shows the network topology that would arise at the Edmonton East Central area when the CE devices connect to their primary PE device.
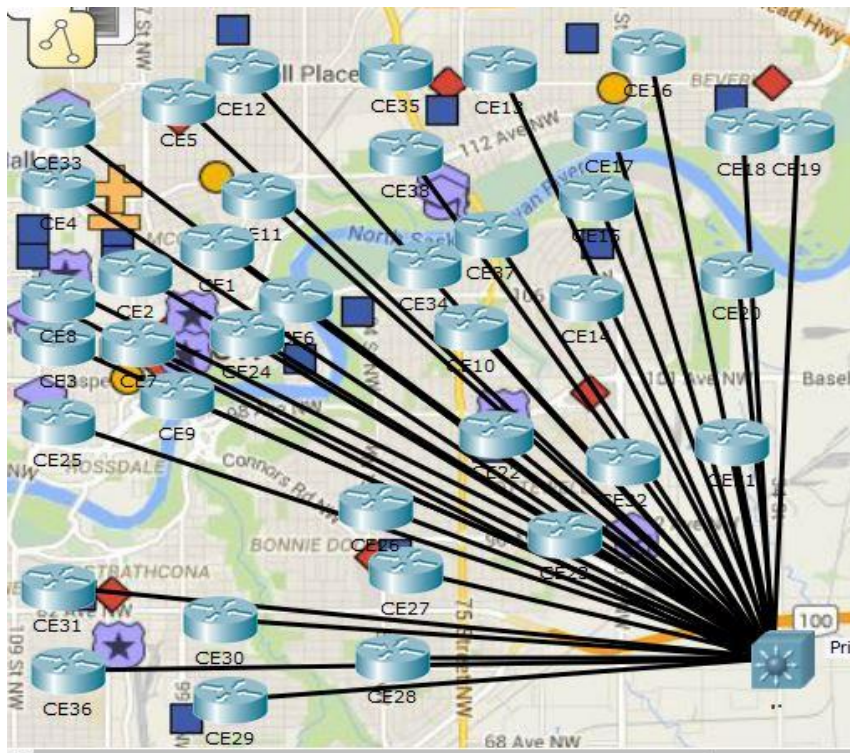
Figure 24: Sub Region Edmonton East Central and the CE's connecting to the Edmonton East Primary PE router

To the design above, it was also decided that two core routers would be added, Core_R1 and Core_R2 somewhere near the downtown area in the center of the city of Edmonton.

The intention is that these two routers would serve as P routers or core routers in the network that would only run MPLS on them and be ignorant to all other protocols, thus providing a BGP free core.

So putting together the various PE's and core P routers that would also act as gateways to the internet, a design topology of the following ensued.

All Loopbacks have /32 subnet
All PE-CE links run ebgp and have
an ip address 172.16.0.0., subnet /30
All Core links run ibgp with ip address of
192.168.0.0 , subnet mask of /30
All Sites have same RD 65000: 1 and belong to a
single VPN with VRF called: customer_gov

Figure 25: MPLS VPN network topology with the various PE routers peered with the CE routers and the two core routers

4.4 Dashboard/ Statistics of design

Before we proceed to the lab implementation of the MPLS network shown above, I would like to put up a few charts of interesting statistics that I compiled from the network and raw data collected during the research conducted.

Figure 26: Workload by primary PE per area
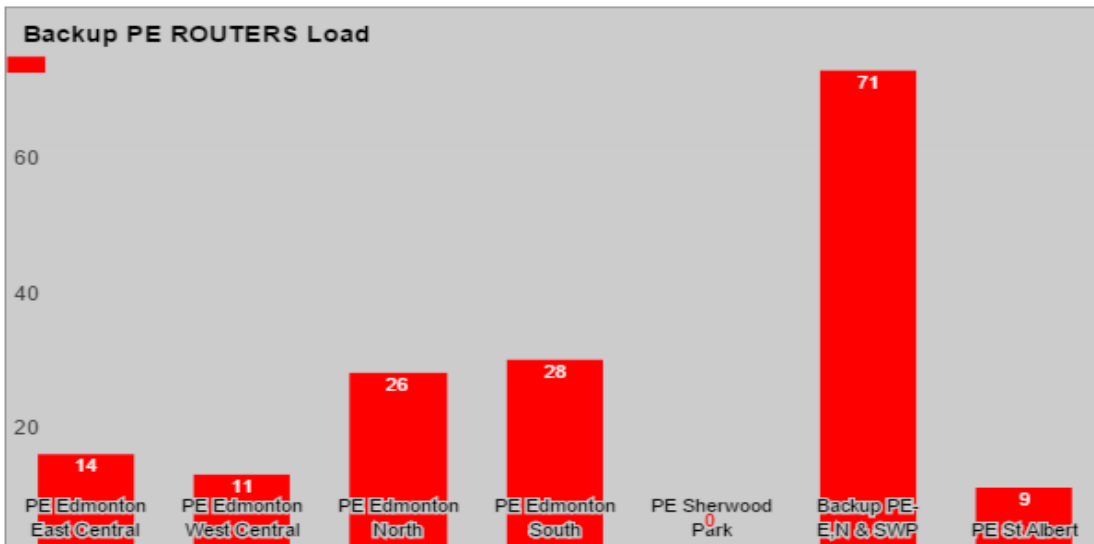
Figure 27: Workload by backup PE per area if used
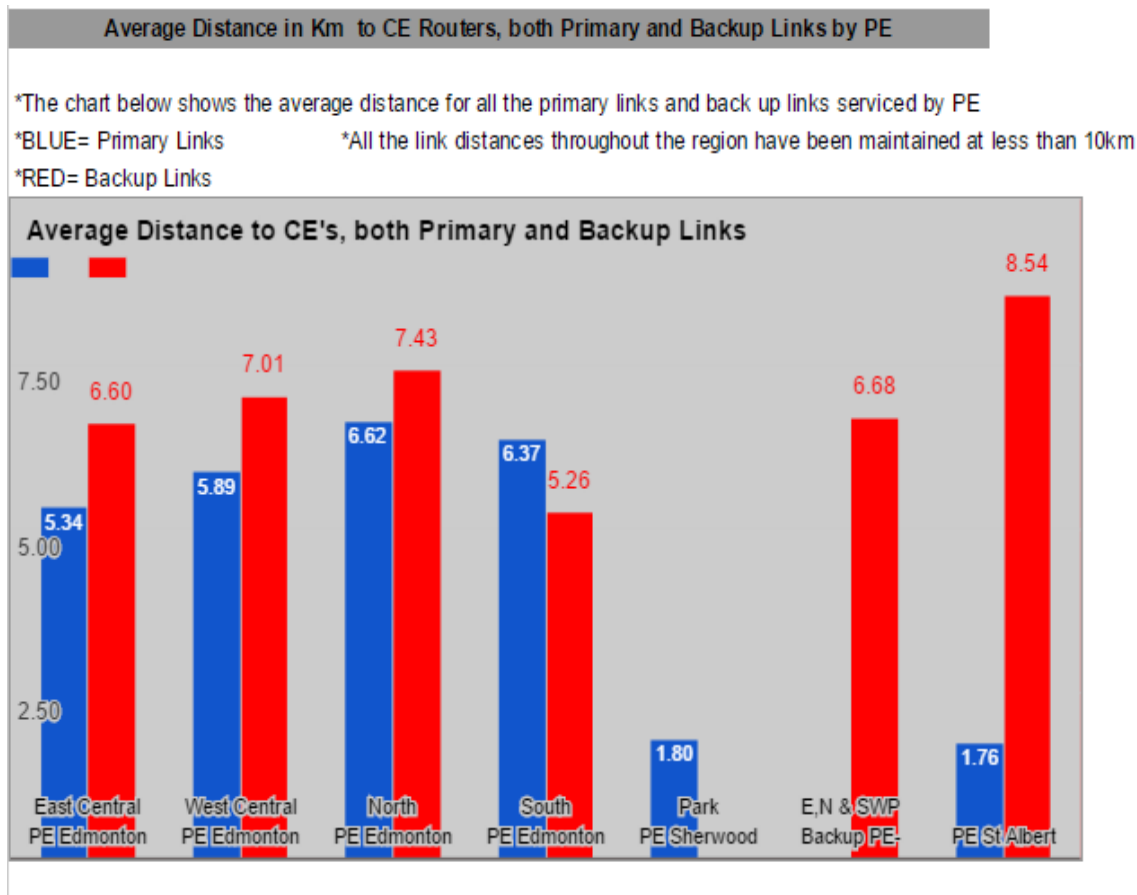
Figure 28: Average distance from CE to both primary and secondary PE's in km

5.0 Lab Implementation

5.1 Ip Addressing Schema and Topology

The IP Addresses were selected carefully based on requirements that existed per type of link and region. [16][17][30][31]

It was not feasible to simulate 160 CE devices in total and 8 PE and P routers.

So a scaled down approach was taken where two network ID's per region were taken as loopbacks per CE that connected to its primary PE. The loopbacks are intended to simulate two customer devices that function as CE's peering with the PE.

A separate IP address space was given to the core ISP links and network.

A separate address space was given to the peering links between the ISP and the CE devices across the Edmonton Capital Region.

The details of the ip addresses selected and the rationale behind them are summarized in the table given below.

Factors for Loopback Links that simluate devices in areas	Area	Number of CE devices	Total number of ip addresses for hosts required	Subnet mask: Gives 1 Network and 1 Host each	IP Address Network	IP Address Range	Broadcast Address(BA)	Available Hosts per ip address/subnet mask
	St Albert	26	52	255.255.255.255 (/32)	10.0.1.0	10.0.0.1 11.0.0.1 Where each Ip address refers to one host	BA Same as ip Address	1
	Sherwood Park	17	34	255.255.255.255 (/32)	10.0.2.0	10.0.0.6 11.0.0.6 Where each Ip address refers to one host	BA Same as ip Address	1
	Edmonton	116	232	255.255.255.255 (/32)	10.0.3.0	10.0.0.2 10.0.0.3 10.0.0.4 10.0.0.7 11.0.0.2 11.0.0.3 11.0.0.4 11.0.0.7 Where each Ip address refers to one host	BA Same as ip Address	1

Figure 29: Table for selecting Loopback Addresses on CE devices

	Router Name/ Area Served	Number of Links to other Routers	Subnet mask: Gives 64 Networks and 2 Hosts per Network	IP Address Range	Broadcast Address(BA)	Available Hosts per ip address/subnet mask
Factors for ISP core links	PE St Albert	3	255.255.255.252 (/30)	Link with Edmonton North: 192.168.0.1 - 192.168.0.2 Link with Downtown Core Router 1: 192.168.0.9-192.168.0.10 Link with Downtown Core Router 2:192.168.0.5-192.168.0.6	Link with Edmonton North: 192.168.0.3 Link with Downtown Core Router 1: 192.168.0.11 Link with Downtown Core Router 2:192.168.0.7	2
	PE Edmonton North	3	255.255.255.252 (/30)	Link with Edmonton North: 192.168.0.2 - 192.168.0.1 Link with Downtown Core Router 1: 192.168.0.37-192.168.0.38 Link with Downtown Core Router 2:192.168.0.13-192.168.0.14	Link with Edmonton North: 192.168.0.3 Link with Downtown Core Router 1: 192.168.0.38 Link with Downtown Core Router 2:192.168.0.15	2
	Downtown Core Router 1	5	255.255.255.252 (/30)	Link with Edmonton North: 192.168.0.37-192.168.0.38 Link with Downtown Core Router 2:192.168.0.17-192.168.0.18 Link with St.Albert: 192.168.0.10-192.168.0.9 Link with Edmonton West Central:192.168.0.41-192.168.0.42 Link with Edmonton South: 192.168.0.21-192.168.0.22	Link with Edmonton North: 192.168.0.39 Link with Downtown Core Router 2:192.168.0.19 Link with St.Albert: 192.168.0.11 Link with Edmonton West Central:192.168.0.43 Link with Edmonton South: 192.168.0.23	2
	Downtown Core Router 2	6	255.255.255.252 (/30)	Link with Edmonton North: 192.168.0.14-192.168.0.13 Link with Downtown Core Router	Link with Edmonton North: 192.168.0.15 Link with Downtown Core Router 1:192.168.0.19 Link with St.Albert:	2

			1:192.168.0.18-192.168.0.17 Link with St.Albert: 192.168.0.10-192.168.0.9 Link with Edmonton East Central:192.168.0.25-192.168.0.26 Link with Sherwood Park: 192.168.0.33-192.168.0.34 Link with Backup Router:192.168.0.29-192.168.0.30	192.168.0.11 Link with Edmonton East Central:192.168.0.27 Link with Sherwood Park: 192.168.0.35 Link with Backup Router:192.168.0.21	
PE Sherwood Park	1	255.255.255.252 (/30)	Link with Downtown Core Router 2:192.168.0.34-192.168.0.33	Link with Downtown Core Router 2:192.168.0.35	2
PE Edmonton West Central	1	255.255.255.252 (/30)	Link with Downtown Core Router 1:192.168.0.42-192.168.0.41	Link with Downtown Core Router 1:192.168.0.18-192.168.0.17	2
PE Edmonton East Central	1	255.255.255.252 (/30)	Link with Downtown Core Router 2:192.168.0.26-192.168.0.25	Link with Downtown Core Router 2:192.168.0.27	2
Backup Router	1	255.255.255.252 (/30)	Link with Downtown Core Router 2:192.168.0.18-192.168.0.17	Link with Downtown Core Router 2:192.168.0.19	2
PE Edmonton South	1	255.255.255.252 (/30)	Link with Downtown Core Router 1:192.168.0.22-192.168.0.21	Link with Downtown Core Router 1:192.168.0.23	2

Figure 30: Table for selecting IP Addresses on PE-P devices or Core ISP network

Factors for PE-CE Links by Area	Router Name/ Area Served	Primary Link to CE	Minimum number of networks required	Subnet mask: Gives 16384 Networks and 2 Hosts each	IP Address Network	IP Address Range	Broadcast Address(BA)	Available Hosts per ip address/subnet mask
	St Albert	St Albert	104	255.255.255.252 (/30)	172.16.0.0	172.16.0.1 - 172.16.0.2	172.16.0.3	2
	Edmonton North	Edmonton North	92	255.255.255.252 (/30)	172.16.0.20	172.16.0.21- 172.16.0.22	172.16.0.23	2
	Sherwood Park	Sherwood Park	68	255.255.255.252 (/30)	172.16.0.16	172.16.0.17- 172.16.0.18	172.16.0.19	2
	Edmonton West Central	Edmonton West Central	112	255.255.255.252 (/30)	172.16.0.4	172.16.0.5 - 172.16.0.6	172.16.0.7	2
	Edmonton East Central	Edmonton East Central	164	255.255.255.252 (/30)	172.16.0.12	172.16.0.13- 172.16.0.14	172.16.0.15	2
	Edmonton South	Edmonton South	96	255.255.255.252 (/30)	172.16.0.8	172.16.0.9 - 172.16.0.10	172.16.0.11	2

Figure 31: Table for selecting IP Addresses on PE-CE devices for peering between customers and the provider edge

After the IP Addresses were chosen, the topology was built as shown earlier.

All Loopbacks have /32 subnet
All PE-CE links run ebgp and have an ip address 172.16.0.0., subnet /30
All Core links run ibgp with ip address of 192.168.0.0 , subnet mask of /30
All Sites have same RD 65000: 1 and belong to a single VPN with VRF called: customer_gov

PE_EDMONTON_NORTH
(192.168.0.2) (172.16.0.21)
Lo: 3.3.3.3 f2/1 (172.16.0.22)

Lo1: 10.0.0.4
Lo2: 11.0.0.4
CE_EDM_NORTH
AS 65533

Lo1: 10.0.0.5
Lo2: 11.0.0.5

PE_ST_ALBERT
(172.16.0.1)
(192.168.0.1)
(192.168.0.37)

f2/0 f1/0
INTERNET
BACKUP_R
f0/0

CE_ST_ALBERT
AS-65531 (172.16.0.2)
ebgp
f0/0

Lo:1.1.1.1
f0/0
f2/1
f1/0 (192.168.0.5)
(192.168.0.9)

(192.168.0.13)
nio_gen_eth: Ethernet
(192.168.0.30) Lo: 9.9.9.9
g3/0

Lo1: 10.0.0.1
Lo2: 11.0.0.1

(192.168.0.10)
(192.168.0.38)

(192.168.0.6)
(192.168.0.14)
(192.168.0.49)
(192.168.0.50) (192.168.0.29)
f0/0 f5/0 g3/0

PE_EDMONTON_WEST_CENTRAL
(192.168.0.42)
Lo: 2.2.2.2 f0/0
(172.16.0.5) f1/0

(192.168.0.41)
f2/0
(192.168.0.17)
f0/0 f1/0

(192.168.0.18)
f1/0
Lo: 5.5.5.5 g4/0
(192.168.0.33) (192.168.0.34)
CORE_R_2

PE_SWP
b4/0
Lo: 6.6.6.6
f0/0
(172.16.0.17)

ebgp
(172.16.0.6)
f0/0

INTERNET
12.0.0.1 /30

Lo: 4.4.4.4 g3/0
CORE_R_1
12.0.0.2 /30
f2/1
g4/0
(192.168.0.21)

f2/0
f2/1
(192.168.0.25)

(172.16.0.18)

AS-65532

nio_gen_eth: Loopback
AS 65501

CE_EDM_WEST

CE_EDM_SOUTH
(172.16.0.10)
f0/0
ebgp

(192.168.0.22)
f0/0
(172.16.0.9)
Lo: 7.7.7.7
f1/0
PE_EDMONTON_SOUTH

(192.168.0.26)
f0/0
CE_SWP

(172.16.0.13)
ebgp

f0/0
AS 65502

Lo1: 10.0.0.6
Lo2: 11.0.0.6

AS 65503
CE_EDM_EAST
f0/0

Lo: 8.8.8.8
f1/0
PE_EDMONTON_EAST_CENTRAL
(172.16.0.14)

Lo1: 10.0.0.2
Lo2: 11.0.0.2

Lo1: 10.0.0.3
Lo2: 11.0.0.3

Lo1: 10.0.0.7
Lo2: 11.0.0.7

Figure 25: MPLS VPN network topology with the various PE routers peered with the CE routers and the two core routers

5.2 Screenshots

- The network was built using one VPN network through a VRF called customer_gov that spanned all the regions of the Edmonton Capital Region. [23][24][25][26]

- The various ip addresses were assigned for each device as per the IP Addressing scheme shown in the previous section.

- An internal gateway protocol, IS-IS was enabled on all the core routers throughout the ISP network.

- Multiprotocol BGP (MBGP) was implemented on each PE device and peering was built in a full mesh from each PE router to every other PE router.

- E-BGP peering was built between the CE devices and the PE device in its region.

- MPLS was enabled with the help of targeted hellos and targeted LDP was employed between the P and PE routers on the core.

- Thus with the IGP running on the core, CE and PE routers peering through e-BGP relationships, MPLS running within the core that helps propagate the VPNv4 routes that are carried across the network by the MP-BGP protocol, the MPLS VPN network is complete.

- All the CE routers can reach the other CE routers through the MPLS network.

We shall see a few screenshots of the network in operation so that we can see in practice how it is working.

Pings from one CE in a location or Region to Another

- St Albert to Edmonton East

```
CE_ST_ALBERT#ping 11.0.0.7

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 11.0.0.7, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 68/98/136 ms
CE_ST_ALBERT#
```

Figure 32: Ping - CE St Albert to CE Edmonton East

- Edmonton West to Edmonton North

```
*Feb 26 21:19:02.747: %SYS-5-RESTART: System restarted --
Cisco IOS Software, 7200 Software (C7200-SPSERVICESK9-M), Version 12.4(15)T7, RELEASE SOFTWARE (fc3)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2008 by Cisco Systems, Inc.
Compiled Thu 14-Aug-08 03:05 by prod_rel_team
*Feb 26 21:19:02.807: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa1/0 Physical Port Administrative State Down
*Feb 26 21:19:02.815: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa2/0 Physical Port Administrative State Down
*Feb 26 21:19:02.819: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa2/1 Physical Port Administrative State Down
*Feb 26 21:19:02.835: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi3/0 Physical Port Administrative State Down
*Feb 26 21:19:02.847: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi4/0 Physical Port Administrative State Down
*Feb 26 21:19:02.855: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa5/0 Physical Port Administrative State Down
*Feb 26 21:19:02.863: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa6/0 Physical Port Administrative State Down
*Feb 26 21:19:02.867: %SNMP-5-COLDSTART: SNMP agent on host CE_EDM_WEST is undergoing a cold start
*Feb 26 21:19:24.327: %BGP-5-ADJCHANGE: neighbor 172.16.0.5 Up
CE_EDM_WEST>en
CE_EDM_WEST#ping 10.0.0.4

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.0.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 72/92/120 ms
CE_EDM_WEST#
```

Figure 33: Ping - CE Edmonton East to CE Edmonton North

- St Albert to Sherwood Park

Figure 34: Ping - CE St Albert to CE SWP

- Edmonton South to Edmonton North

Figure 35: Ping - CE Edmonton South to CE Edmonton North

- Edmonton West to Edmonton East


```
CE_EDM_WEST                                                                    —    □    ×
*Feb 26 21:19:02.819: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa2/1 Physical Port Administrative State Down
*Feb 26 21:19:02.835: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi3/0 Physical Port Administrative State Down
*Feb 26 21:19:02.847: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi4/0 Physical Port Administrative State Down
*Feb 26 21:19:02.855: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa5/0 Physical Port Administrative State Down
*Feb 26 21:19:02.863: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa6/0 Physical Port Administrative State Down
*Feb 26 21:19:02.867: %SNMP-5-COLDSTART: SNMP agent on host CE_EDM_WEST is undergoing a cold start
*Feb 26 21:19:24.327: %BGP-5-ADJCHANGE: neighbor 172.16.0.5 Up
CE_EDM_WEST>en
CE_EDM_WEST#ping 10.0.0.4

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.0.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 72/92/120 ms
CE_EDM_WEST#E{M'}T
CE_EDM_WEST#p}
CE_EDM_WEST#
CE_EDM_WEST#ping 11.0.0.7

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 11.0.0.7, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 100/132/164 ms
CE_EDM_WEST#
```

Figure 36: Ping - CE Edmonton West to CE Edmonton East

- Sherwood Park to Edmonton North


```
CE_SWP                                                                         —    □    ×
*Feb 26 21:18:43.803: %LINK-5-CHANGED: Interface FastEthernet5/0, changed state to administratively down
*Feb 26 21:18:49.991: %SYS-5-RESTART: System restarted --
Cisco IOS Software, 7200 Software (C7200-SPSERVICESK9-M), Version 12.4(15)T7, RELEASE SOFTWARE (fc3)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2008 by Cisco Systems, Inc.
Compiled Thu 14-Aug-08 03:05 by prod_rel_team
*Feb 26 21:18:50.047: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa1/0 Physical Port Administrative State Down
*Feb 26 21:18:50.055: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa2/0 Physical Port Administrative State Down
*Feb 26 21:18:50.063: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa2/1 Physical Port Administrative State Down
*Feb 26 21:18:50.075: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi3/0 Physical Port Administrative State Down
*Feb 26 21:18:50.087: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi4/0 Physical Port Administrative State Down
*Feb 26 21:18:50.095: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa5/0 Physical Port Administrative State Down
*Feb 26 21:18:50.107: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa6/0 Physical Port Administrative State Down
*Feb 26 21:18:50.107: %SNMP-5-COLDSTART: SNMP agent on host CE_SWP is undergoing a cold start
*Feb 26 21:19:15.739: %BGP-5-ADJCHANGE: neighbor 172.16.0.17 Up
CE_SWP>en
CE_SWP#pin
CE_SWP#ping 11.0.0.4

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 11.0.0.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 80/117/144 ms
CE_SWP#
```

Figure 37: Ping - CE SWP to CE Edmonton North

Traceroutes of Pings from one CE in a location or Region to Another

We shall look at the Traceroutes of the same pings shown above in the same order so that you can see the label swapping process that happens as the packet is leaving the CE in one AS and going to another CE located in another AS.

- St Albert to Edmonton East


```
CE_ST_ALBERT                                                          —    □    ×
CE_ST_ALBERT#
CE_ST_ALBERT#
CE_ST_ALBERT#
CE_ST_ALBERT#
CE_ST_ALBERT#ping 11.0.0.6

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 11.0.0.6, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 72/78/96 ms
CE_ST_ALBERT#trac
CE_ST_ALBERT#traceroute pin
CE_ST_ALBERT#traceroute pi
CE_ST_ALBERT#traceroute pi
CE_ST_ALBERT#traceroute 11.0.0.7

Type escape sequence to abort.
Tracing the route to 11.0.0.7

  1 172.16.0.1 40 msec 28 msec 52 msec
  2 192.168.0.6 [MPLS: Labels 25/36 Exp 0] 128 msec 108 msec 104 msec
  3 172.16.0.13 [AS 65503] [MPLS: Label 36 Exp 0] 112 msec 84 msec 100 msec
  4 172.16.0.14 [AS 65503] 120 msec 96 msec *
CE_ST_ALBERT#
```
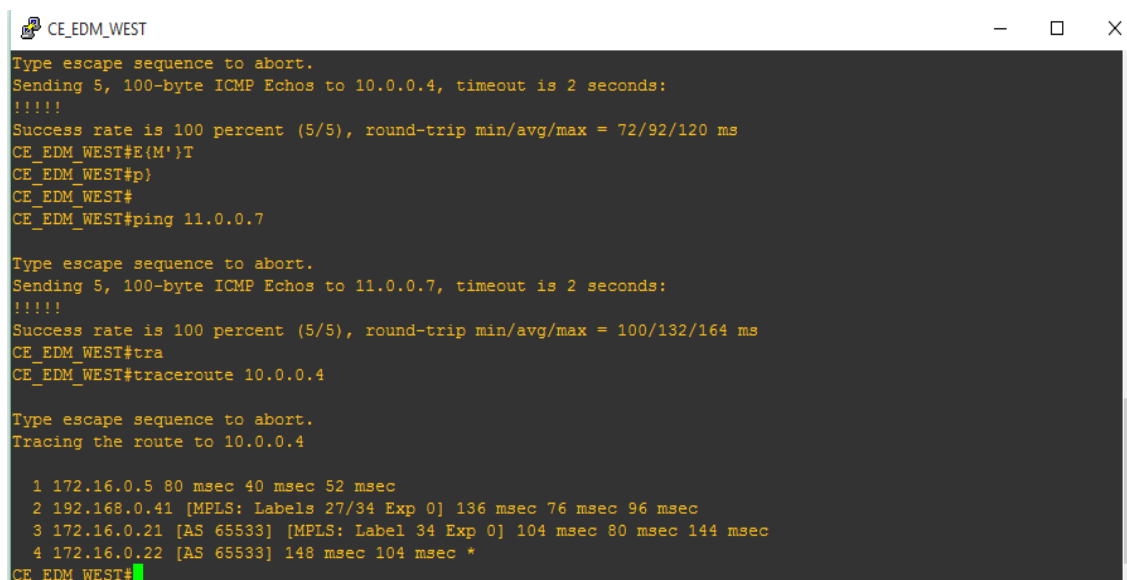
Figure 38: Trace Route - CE St Albert to CE Edmonton East

- Edmonton West to Edmonton North


```
CE_EDM_WEST                                                           —    □    ×
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 10.0.0.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 72/92/120 ms
CE_EDM_WEST#E{M'}T
CE_EDM_WEST#p}
CE_EDM_WEST#
CE_EDM_WEST#ping 11.0.0.7

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 11.0.0.7, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 100/132/164 ms
CE_EDM_WEST#tra
CE_EDM_WEST#traceroute 10.0.0.4

Type escape sequence to abort.
Tracing the route to 10.0.0.4

  1 172.16.0.5 80 msec 40 msec 52 msec
  2 192.168.0.41 [MPLS: Labels 27/34 Exp 0] 136 msec 76 msec 96 msec
  3 172.16.0.21 [AS 65533] [MPLS: Label 34 Exp 0] 104 msec 80 msec 144 msec
  4 172.16.0.22 [AS 65533] 148 msec 104 msec *
CE_EDM_WEST#
```

Figure 39: Trace Route - CE Edmonton West to CE Edmonton North

- St Albert to Sherwood Park


```
CE_ST_ALBERT                                                        —    □    ×

CE_ST_ALBERT#trac
CE_ST_ALBERT#traceroute pin
CE_ST_ALBERT#traceroute pi
CE_ST_ALBERT#traceroute pi
CE_ST_ALBERT#traceroute 11.0.0.7

Type escape sequence to abort.
Tracing the route to 11.0.0.7

  1 172.16.0.1 40 msec 28 msec 52 msec
  2 192.168.0.6 [MPLS: Labels 25/36 Exp 0] 128 msec 108 msec 104 msec
  3 172.16.0.13 [AS 65503] [MPLS: Label 36 Exp 0] 112 msec 84 msec 100 msec
  4 172.16.0.14 [AS 65503] 120 msec 96 msec *
CE_ST_ALBERT#tr
CE_ST_ALBERT#traceroute 11.0.0.6

Type escape sequence to abort.
Tracing the route to 11.0.0.6

  1 172.16.0.1 36 msec 12 msec 52 msec
  2 192.168.0.6 [MPLS: Labels 24/36 Exp 0] 124 msec 128 msec 148 msec
  3 172.16.0.17 [AS 65502] [MPLS: Label 36 Exp 0] 124 msec 84 msec 100 msec
  4 172.16.0.18 [AS 65502] 144 msec 112 msec *
CE_ST_ALBERT#
```

Figure 40: Trace Route - CE St Albert to CE Sherwood Park

- Edmonton South to Edmonton North


```
CE_EDM_SOUTH                                                        —    □    ×

*Feb 26 21:18:31.975: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet2/1, changed state to down
*Feb 26 21:18:32.191: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet3/0, changed state to dow
n
*Feb 26 21:18:32.195: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet4/0, changed state to dow
n
*Feb 26 21:18:54.235: %BGP-5-ADJCHANGE: neighbor 172.16.0.9 Up
CE_EDM_SOUTH>en
CE_EDM_SOUTH#ping 11.0.0.4

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 11.0.0.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 108/133/152 ms
CE_EDM_SOUTH#tra
CE_EDM_SOUTH#traceroute 11.0.0.4

Type escape sequence to abort.
Tracing the route to 11.0.0.4

  1 172.16.0.9 44 msec 44 msec 48 msec
  2 192.168.0.21 [MPLS: Labels 27/35 Exp 0] 192 msec 96 msec 108 msec
  3 172.16.0.21 [AS 65533] [MPLS: Label 35 Exp 0] 100 msec 84 msec 100 msec
  4 172.16.0.22 [AS 65533] 128 msec 96 msec *
CE_EDM_SOUTH#
```
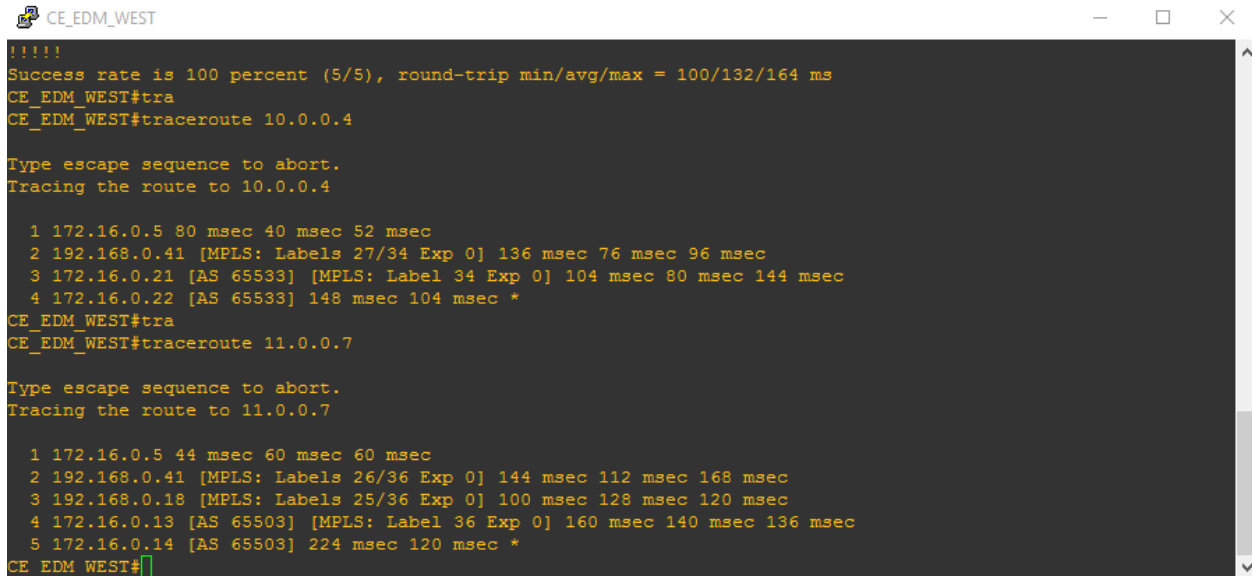
Figure 41: Trace Route - CE Edmonton South to CE Edmonton North

- Edmonton West to Edmonton East


```
CE_EDM_WEST                                                              —  □  ✕

!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 100/132/164 ms
CE_EDM_WEST#tra
CE_EDM_WEST#traceroute 10.0.0.4

Type escape sequence to abort.
Tracing the route to 10.0.0.4

  1 172.16.0.5 80 msec 40 msec 52 msec
  2 192.168.0.41 [MPLS: Labels 27/34 Exp 0] 136 msec 76 msec 96 msec
  3 172.16.0.21 [AS 65533] [MPLS: Label 34 Exp 0] 104 msec 80 msec 144 msec
  4 172.16.0.22 [AS 65533] 148 msec 104 msec *
CE_EDM_WEST#tra
CE_EDM_WEST#traceroute 11.0.0.7

Type escape sequence to abort.
Tracing the route to 11.0.0.7

  1 172.16.0.5 44 msec 60 msec 60 msec
  2 192.168.0.41 [MPLS: Labels 26/36 Exp 0] 144 msec 112 msec 168 msec
  3 192.168.0.18 [MPLS: Labels 25/36 Exp 0] 100 msec 128 msec 120 msec
  4 172.16.0.13 [AS 65503] [MPLS: Label 36 Exp 0] 160 msec 140 msec 136 msec
  5 172.16.0.14 [AS 65503] 224 msec 120 msec *
CE_EDM_WEST#
```
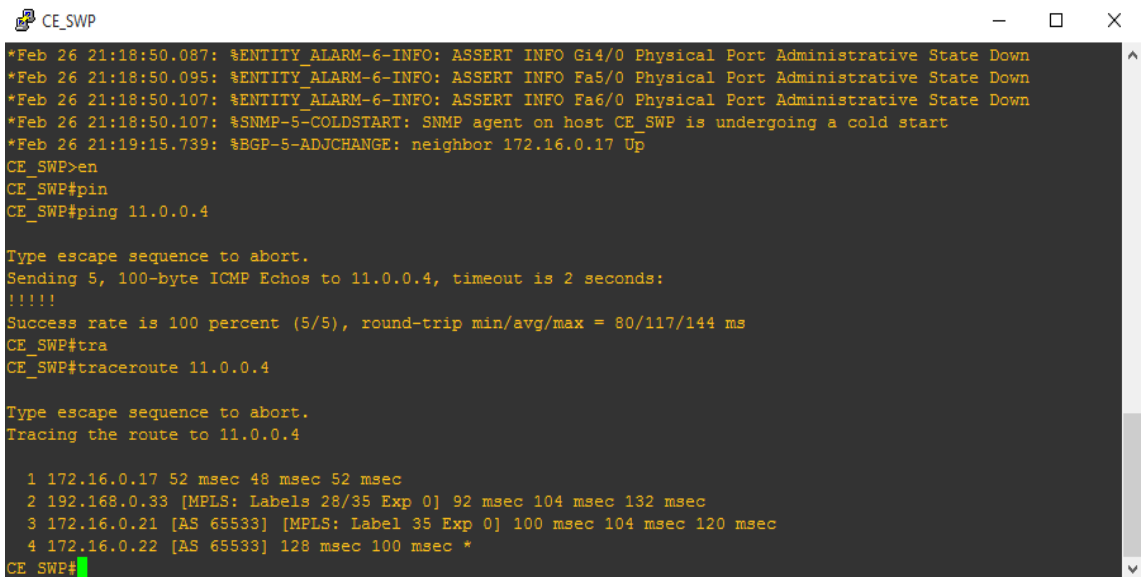
Figure 42: Trace Route - CE Edmonton West to CE Edmonton East

- Sherwood Park to Edmonton North


```
CE_SWP                                                                   —  □  ✕

*Feb 26 21:18:50.087: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi4/0 Physical Port Administrative State Down
*Feb 26 21:18:50.095: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa5/0 Physical Port Administrative State Down
*Feb 26 21:18:50.107: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa6/0 Physical Port Administrative State Down
*Feb 26 21:18:50.107: %SNMP-5-COLDSTART: SNMP agent on host CE_SWP is undergoing a cold start
*Feb 26 21:19:15.739: %BGP-5-ADJCHANGE: neighbor 172.16.0.17 Up
CE_SWP>en
CE_SWP#pin
CE_SWP#ping 11.0.0.4

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 11.0.0.4, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 80/117/144 ms
CE_SWP#tra
CE_SWP#traceroute 11.0.0.4

Type escape sequence to abort.
Tracing the route to 11.0.0.4

  1 172.16.0.17 52 msec 48 msec 52 msec
  2 192.168.0.33 [MPLS: Labels 28/35 Exp 0] 92 msec 104 msec 132 msec
  3 172.16.0.21 [AS 65533] [MPLS: Label 35 Exp 0] 100 msec 104 msec 120 msec
  4 172.16.0.22 [AS 65533] 128 msec 100 msec *
CE_SWP#
```

Figure 43: Trace Route - SWP to CE Edmonton North

MPLS Configuration

- **Sh MPLS ldp neighbor** –PE St Albert

Figure 44: Sh MPLS ldp neighbor- PE St Albert

- **Sh MPLS ldp neighbor** –PE Edmonton North

Figure 45: Sh MPLS ldp neighbor- PE Edmonton North

- **Sh MPLS ldp neighbor** –PE Edmonton West Central


```
PE_EDMONTON_WEST_CENTRAL                                                                                    —  □  ×
*Feb 26 21:19:02.779: %LINK-5-CHANGED: Interface GigabitEthernet4/0, changed state to administratively down
*Feb 26 21:19:02.783: %LINK-5-CHANGED: Interface FastEthernet5/0, changed state to administratively down
*Feb 26 21:19:02.991: %LINK-5-CHANGED: Interface FastEthernet6/0, changed state to administratively down
*Feb 26 21:19:03.199: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet2/0, changed state to down
*Feb 26 21:19:03.535: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet2/1, changed state to down
*Feb 26 21:19:03.735: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet3/0, changed state to dow
n
*Feb 26 21:19:03.791: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet4/0, changed state to dow
n
*Feb 26 21:19:04.903: %SYS-5-CONFIG_I: Configured from memory by console
*Feb 26 21:19:08.939: %SYS-5-RESTART: System restarted --
Cisco IOS Software, 7200 Software (C7200-SPSERVICESK9-M), Version 12.4(15)T7, RELEASE SOFTWARE (fc3)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2008 by Cisco Systems, Inc.
Compiled Thu 14-Aug-08 03:05 by prod_rel_team
*Feb 26 21:19:09.007: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa2/0 Physical Port Administrative State Down
*Feb 26 21:19:09.011: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa2/1 Physical Port Administrative State Down
*Feb 26 21:19:09.023: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi3/0 Physical Port Administrative State Down
*Feb 26 21:19:09.039: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi4/0 Physical Port Administrative State Down
*Feb 26 21:19:09.047: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa5/0 Physical Port Administrative State Down
*Feb 26 21:19:09.055: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa6/0 Physical Port Administrative State Down
*Feb 26 21:19:09.059: %SNMP-5-COLDSTART: SNMP agent on host PE_EDM_WEST is undergoing a cold start
*Feb 26 21:19:18.059: %LDP-5-NBRCHG: LDP Neighbor 4.4.4.4:0 (1) is UP
*Feb 26 21:19:27.531: %BGP-5-ADJCHANGE: neighbor 7.7.7.7 Up
*Feb 26 21:19:37.351: %BGP-5-ADJCHANGE: neighbor 3.3.3.3 Up
*Feb 26 21:19:38.567: %BGP-5-ADJCHANGE: neighbor 1.1.1.1 Up
*Feb 26 21:19:38.631: %BGP-5-ADJCHANGE: neighbor 6.6.6.6 Up
*Feb 26 21:19:39.519: %BGP-5-ADJCHANGE: neighbor 8.8.8.8 Up
*Feb 26 21:19:44.783: %BGP-5-ADJCHANGE: neighbor 172.16.0.6 vpn vrf customer_gov Up
PE_EDM_WEST>en
PE_EDM_WEST#sh mpls ld
PE_EDM_WEST#sh mpls ldp ne
PE_EDM_WEST#sh mpls ldp neighbor
    Peer LDP Ident: 4.4.4.4:0; Local LDP Ident 2.2.2.2:0
        TCP connection: 4.4.4.4.37167 - 2.2.2.2.646
        State: Oper; Msgs sent/rcvd: 54/56; Downstream
        Up time: 00:59:07
        LDP discovery sources:
          FastEthernet0/0, Src IP addr: 192.168.0.41
          Targeted Hello 2.2.2.2 -> 4.4.4.4, active
        Addresses bound to peer LDP Ident:
          4.4.4.4         192.168.0.10    192.168.0.38    192.168.0.41
          12.0.0.2        192.168.0.17    192.168.0.21
PE_EDM_WEST#
```

Figure 46: Sh MPLS ldp neighbor- PE Edmonton West

- **Sh MPLS ldp neighbor** –PE Edmonton East Central


```
PE_EDMONTON_EAST_CENTRAL                                                                                    —  □  ×
*Feb 26 21:19:03.543: %LINEPROTO-5-UPDOWN: Line protocol on Interface FastEthernet2/1, changed state to down
*Feb 26 21:19:03.747: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet3/0, changed state to dow
n
*Feb 26 21:19:03.747: %LINEPROTO-5-UPDOWN: Line protocol on Interface GigabitEthernet4/0, changed state to dow
n
*Feb 26 21:19:04.887: %SYS-5-CONFIG_I: Configured from memory by console
*Feb 26 21:19:08.903: %SYS-5-RESTART: System restarted --
Cisco IOS Software, 7200 Software (C7200-SPSERVICESK9-M), Version 12.4(15)T7, RELEASE SOFTWARE (fc3)
Technical Support: http://www.cisco.com/techsupport
Copyright (c) 1986-2008 by Cisco Systems, Inc.
Compiled Thu 14-Aug-08 03:05 by prod_rel_team
*Feb 26 21:19:08.967: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa2/0 Physical Port Administrative State Down
*Feb 26 21:19:08.975: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa2/1 Physical Port Administrative State Down
*Feb 26 21:19:08.987: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi3/0 Physical Port Administrative State Down
*Feb 26 21:19:08.999: %ENTITY_ALARM-6-INFO: ASSERT INFO Gi4/0 Physical Port Administrative State Down
*Feb 26 21:19:09.007: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa5/0 Physical Port Administrative State Down
*Feb 26 21:19:09.019: %ENTITY_ALARM-6-INFO: ASSERT INFO Fa6/0 Physical Port Administrative State Down
*Feb 26 21:19:09.023: %SNMP-5-COLDSTART: SNMP agent on host PE_EDM_EAST is undergoing a cold start
*Feb 26 21:19:17.363: %LDP-5-NBRCHG: LDP Neighbor 5.5.5.5:0 (1) is UP
*Feb 26 21:19:25.863: %BGP-5-ADJCHANGE: neighbor 7.7.7.7 Up
*Feb 26 21:19:36.387: %BGP-5-ADJCHANGE: neighbor 6.6.6.6 Up
*Feb 26 21:19:37.403: %BGP-5-ADJCHANGE: neighbor 3.3.3.3 Up
*Feb 26 21:19:39.467: %BGP-5-ADJCHANGE: neighbor 1.1.1.1 Up
*Feb 26 21:19:40.843: %BGP-5-ADJCHANGE: neighbor 2.2.2.2 Up
*Feb 26 21:19:42.691: %BGP-5-ADJCHANGE: neighbor 172.16.0.14 vpn vrf customer_gov Up
PE_EDM_EAST>en
PE_EDM_EAST#
PE_EDM_EAST#
PE_EDM_EAST#sh mpls
PE_EDM_EAST#sh mpls ne
PE_EDM_EAST#sh mpls ld
PE_EDM_EAST#sh mpls ldp ne
PE_EDM_EAST#sh mpls ldp neighbor
    Peer LDP Ident: 5.5.5.5:0; Local LDP Ident 8.8.8.8:0
        TCP connection: 5.5.5.5.646 - 8.8.8.8.39073
        State: Oper; Msgs sent/rcvd: 54/56; Downstream
        Up time: 01:01:00
        LDP discovery sources:
          FastEthernet0/0, Src IP addr: 192.168.0.25
          Targeted Hello 8.8.8.8 -> 5.5.5.5, active
        Addresses bound to peer LDP Ident:
          5.5.5.5         192.168.0.14    192.168.0.6     192.168.0.18
          192.168.0.25    192.168.0.29    192.168.0.33    192.168.0.50
PE_EDM_EAST#
```

Figure 47: Sh MPLS ldp neighbor- PE Edmonton East

- **Sh MPLS ldp neighbor** –PE Edmonton South

Figure 48: Sh MPLS ldp neighbor- PE Edmonton South

- **Sh MPLS ldp neighbor** –PE SWP

Figure 49: Sh MPLS ldp neighbor- PE SWP

- **Sh MPLS ldp neighbor** –PE Core Router 1

Figure 50: Sh MPLS ldp neighbor- PE Core Router 1

- **Sh MPLS ldp neighbor** –PE Core Router 2

Figure 51: Sh MPLS ldp neighbor- PE Core Router 2

A few Routing tables and other things:

- show bgp VPNv4 unicast all summary: PE Edmonton South

Figure 52: show bgp VPNv4 unicast all summary: PE Edmonton South

- show bgp VPNv4 unicast all summary: PE St Albert

Figure 53: show bgp VPNv4 unicast all summary: PE St Albert

- Bgp routing table CE Edmonton West

```
CE_EDM_WEST#sh ip bgp
BGP table version is 37, local router ID is 11.0.0.2
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale
Origin codes: i - IGP, e - EGP, ? - incomplete

   Network          Next Hop           Metric LocPrf Weight Path
*> 10.0.0.1/32      172.16.0.5                            0 65000 65531 ?
*> 10.0.0.2/32      0.0.0.0                0        32768 ?
*> 10.0.0.3/32      172.16.0.5                            0 65000 65501 ?
*> 10.0.0.4/32      172.16.0.5                            0 65000 65533 ?
*> 10.0.0.6/32      172.16.0.5                            0 65000 65502 ?
*> 10.0.0.7/32      172.16.0.5                            0 65000 65503 ?
*> 11.0.0.1/32      172.16.0.5                            0 65000 65531 ?
*> 11.0.0.2/32      0.0.0.0                0        32768 ?
*> 11.0.0.3/32      172.16.0.5                            0 65000 65501 ?
*> 11.0.0.4/32      172.16.0.5                            0 65000 65533 ?
*> 11.0.0.6/32      172.16.0.5                            0 65000 65502 ?
*> 11.0.0.7/32      172.16.0.5                            0 65000 65503 ?
*> 172.16.0.0/30    172.16.0.5                            0 65000 65531 ?
*> 172.16.0.4/30    0.0.0.0                0        32768 ?
*> 172.16.0.8/30    172.16.0.5                            0 65000 65501 ?
*> 172.16.0.12/30   172.16.0.5                            0 65000 65503 ?
*> 172.16.0.16/30   172.16.0.5                            0 65000 65502 ?
   Network          Next Hop           Metric LocPrf Weight Path
*> 172.16.0.20/30   172.16.0.5                            0 65000 65533 ?
CE_EDM_WEST#
```

Figure 54: show ip bgp: CE Edmonton West

- Bgp VRF routing table: St Albert

```
PE_ST_ALBERT                                                                    —  □  ×
0 BGP route-map cache entries using 0 bytes of memory
0 BGP filter-list cache entries using 0 bytes of memory
Bitfield cache entries: current 2 (at peak 3) using 64 bytes of memory
BGP using 5172 total bytes of memory
3 received paths for inbound soft reconfiguration
BGP activity 21/3 prefixes, 39/18 paths, scan interval 15 secs

Neighbor        V    AS MsgRcvd MsgSent   TblVer  InQ OutQ Up/Down  State/PfxRcd
2.2.2.2         4 65000     76      83       56    0    0 01:13:49        3
3.3.3.3         4 65000     77      83       56    0    0 01:13:48        3
6.6.6.6         4 65000     77      83       56    0    0 01:13:48        3
7.7.7.7         4 65000     75      84       56    0    0 01:14:02        3
8.8.8.8         4 65000     76      83       56    0    0 01:13:50        3
172.16.0.2      4 65531     49     109       56    0    0 00:24:07        3
PE_ST_ALBERT#sh ip bgp vpn
PE_ST_ALBERT#sh ip bgp vpnv4 vr
PE_ST_ALBERT#sh ip bgp vpnv4 vrf customer_gov
BGP table version is 56, local router ID is 1.1.1.1
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
              r RIB-failure, S Stale
Origin codes: i - IGP, e - EGP, ? - incomplete

   Network          Next Hop           Metric LocPrf Weight Path
Route Distinguisher: 65000:1 (default for vrf customer_gov)
*> 10.0.0.1/32      172.16.0.2            0              0 65531 ?
*>i10.0.0.2/32      2.2.2.2              0   100        0 65532 ?
*>i10.0.0.3/32      7.7.7.7              0   100        0 65501 ?
*>i10.0.0.4/32      3.3.3.3              0   100        0 65533 ?
*>i10.0.0.6/32      6.6.6.6              0   100        0 65502 ?
*>i10.0.0.7/32      8.8.8.8              0   100        0 65503 ?
*> 11.0.0.1/32      172.16.0.2            0              0 65531 ?
*>i11.0.0.2/32      2.2.2.2              0   100        0 65532 ?
*>i11.0.0.3/32      7.7.7.7              0   100        0 65501 ?
*>i11.0.0.4/32      3.3.3.3              0   100        0 65533 ?
*>i11.0.0.6/32      6.6.6.6              0   100        0 65502 ?
*>i11.0.0.7/32      8.8.8.8              0   100        0 65503 ?
r> 172.16.0.0/30    172.16.0.2            0              0 65531 ?
*>i172.16.0.4/30    2.2.2.2              0   100        0 65532 ?
*>i172.16.0.8/30    7.7.7.7              0   100        0 65501 ?
*>i172.16.0.12/30   8.8.8.8              0   100        0 65503 ?
   Network          Next Hop           Metric LocPrf Weight Path
*>i172.16.0.16/30   6.6.6.6              0   100        0 65502 ?
*>i172.16.0.20/30   3.3.3.3              0   100        0 65533 ?
PE_ST_ALBERT#
```

Figure 55: show ip bgp VPNv4 vrf customer_gov – PE St Albert

- Bgp VRF routing table: PE SWP

Figure 56: show ip bgp VPNv4 vrf customer_gov – PE SWP

- ip routing table: PE Edmonton West

Figure 57: show ip route – PE Edmonton West

- ip routing table: PE Edmonton North

Figure 58: show ip route – PE Edmonton North

- ip routing table: CE Edmonton East

Figure 59: show ip route – CE Edmonton East

5.3 Running Configurations of Devices

- PE Routers Running Configurations

ST Albert:

PE_ST_ALBERT>en

PE_ST_ALBERT#sh run

Building configuration...

Current configuration : 2890 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname PE_ST_ALBERT

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

!

!

!

ip vrf customer_gov

rd 65000:1

route-target export 65000:1

route-target import 65000:1

!

multilink bundle-name authenticated

MPLS label protocol ldp

MPLS ldp neighbor 3.3.3.3 targeted

MPLS ldp neighbor 4.4.4.4 targeted

MPLS ldp neighbor 5.5.5.5 targeted

MPLS ldp holdtime 400

MPLS ldp discovery targeted-hello accept

!

!

!

!

!

!

!

!

!

!

!

!

!

archive

 log config

  hidekeys

!

!

!

!

!

interface Loopback1

 ip address 1.1.1.1 255.255.255.255

 ip router isis

!

interface FastEthernet0/0

 ip vrf forwarding customer_gov

 ip address 172.16.0.1 255.255.255.252

 duplex full

!

```
interface FastEthernet1/0
 ip address 192.168.0.9 255.255.255.252
 ip router isis
 duplex full
 MPLS ip
!
interface FastEthernet2/0
 ip address 192.168.0.1 255.255.255.252
 ip router isis
 duplex full
 speed auto
!
interface FastEthernet2/1
 ip address 192.168.0.5 255.255.255.252
 ip router isis
 duplex full
 speed auto
 MPLS ip
 isis metric 7
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
 shutdown
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
```

```
 duplex half
!
router isis
 net 49.0001.1111.1111.1111.00
!
router bgp 65000
 no synchronization
 bgp log-neighbor-changes
 neighbor 2.2.2.2 remote-as 65000
 neighbor 2.2.2.2 update-source Loopback1
 neighbor 3.3.3.3 remote-as 65000
 neighbor 3.3.3.3 update-source Loopback1
 neighbor 6.6.6.6 remote-as 65000
 neighbor 6.6.6.6 update-source Loopback1
 neighbor 7.7.7.7 remote-as 65000
 neighbor 7.7.7.7 update-source Loopback1
 neighbor 8.8.8.8 remote-as 65000
 neighbor 8.8.8.8 update-source Loopback1
 neighbor 172.16.0.2 remote-as 65531
 no auto-summary
!
address-family VPNv4
 neighbor 2.2.2.2 activate
 neighbor 2.2.2.2 send-community extended
 neighbor 3.3.3.3 activate
 neighbor 3.3.3.3 send-community extended
 neighbor 6.6.6.6 activate
 neighbor 6.6.6.6 send-community extended
 neighbor 7.7.7.7 activate
 neighbor 7.7.7.7 send-community extended
 neighbor 8.8.8.8 activate
 neighbor 8.8.8.8 send-community extended
exit-address-family
!
address-family ipv4 vrf customer_gov
 neighbor 172.16.0.2 remote-as 65531
 neighbor 172.16.0.2 activate
 neighbor 172.16.0.2 as-override
```

```
  neighbor 172.16.0.2 soft-reconfiguration inbound
 no synchronization
 exit-address-family
!
ip forward-protocol nd
no ip http server
no ip http secure-server
!
!
!
logging alarm informational
!
!
MPLS ldp router-id Loopback1
!
control-plane
!
!
!
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
!
!
end
```

PE_ST_ALBERT#

Edmonton North:

PE_EDM_NORTH#sh run

Building configuration...

Current configuration : 2810 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname PE_EDM_NORTH

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

!

!

!

ip vrf customer_gov

 rd 65000:1

 route-target export 65000:1

 route-target import 65000:1

!

multilink bundle-name authenticated

MPLS label protocol ldp

MPLS ldp neighbor 4.4.4.4 targeted

MPLS ldp neighbor 5.5.5.5 targeted

MPLS ldp holdtime 400

MPLS ldp discovery targeted-hello accept

!

!

!

!

!

!

!

!

!

!

!

!

!

!

archive

 log config

  hidekeys

!

!

!

!

!

!

interface Loopback1

 ip address 3.3.3.3 255.255.255.255

 ip router isis

!

interface FastEthernet0/0

 ip address 192.168.0.2 255.255.255.252

 ip router isis

 duplex full

!

interface FastEthernet1/0

 ip address 192.168.0.13 255.255.255.252

 ip router isis

```
 duplex full
 MPLS ip
!
interface FastEthernet2/0
 ip address 192.168.0.37 255.255.255.252
 ip router isis
 duplex full
 speed auto
 MPLS ip
!
interface FastEthernet2/1
 ip vrf forwarding customer_gov
 ip address 172.16.0.21 255.255.255.252
 duplex full
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
 shutdown
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router isis
 net 49.0001.2222.2222.2222.00
```

```
!
router bgp 65000
 no synchronization
 bgp log-neighbor-changes
 neighbor 1.1.1.1 remote-as 65000
 neighbor 1.1.1.1 update-source Loopback1
 neighbor 2.2.2.2 remote-as 65000
 neighbor 2.2.2.2 update-source Loopback1
 neighbor 6.6.6.6 remote-as 65000
 neighbor 6.6.6.6 update-source Loopback1
 neighbor 7.7.7.7 remote-as 65000
 neighbor 7.7.7.7 update-source Loopback1
 neighbor 8.8.8.8 remote-as 65000
 neighbor 8.8.8.8 update-source Loopback1
 no auto-summary
 !
 address-family VPNv4
  neighbor 1.1.1.1 activate
  neighbor 1.1.1.1 send-community extended
  neighbor 2.2.2.2 activate
  neighbor 2.2.2.2 send-community extended
  neighbor 6.6.6.6 activate
  neighbor 6.6.6.6 send-community extended
  neighbor 7.7.7.7 activate
  neighbor 7.7.7.7 send-community extended
  neighbor 8.8.8.8 activate
  neighbor 8.8.8.8 send-community extended
 exit-address-family
 !
 address-family ipv4 vrf customer_gov
  neighbor 172.16.0.22 remote-as 65533
  neighbor 172.16.0.22 activate
  neighbor 172.16.0.22 as-override
  neighbor 172.16.0.22 soft-reconfiguration inbound
  no synchronization
 exit-address-family
 !
ip forward-protocol nd
```

```
no ip http server

no ip http secure-server

!

!

!

logging alarm informational

!

!

MPLS ldp router-id Loopback1

!

control-plane

!

!

!

!

!

!

!

gatekeeper

 shutdown

!

!

line con 0

 stopbits 1

line aux 0

 stopbits 1

line vty 0 4

 login

!

!

end


PE_EDM_NORTH#
```

Edmonton West Central:

PE_EDM_WEST#sh run

Building configuration...

Current configuration : 2671 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname PE_EDM_WEST

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

!

!

!

ip vrf customer_gov

 rd 65000:1

 route-target export 65000:1

 route-target import 65000:1

!

multilink bundle-name authenticated

MPLS ldp neighbor 4.4.4.4 targeted

MPLS ldp holdtime 400

MPLS ldp discovery targeted-hello accept

!

!

!

!

```
!
!
!
!
!
!
!
!
!
!
archive
 log config
  hidekeys
!
!
!
!
!
!
interface Loopback1
 ip address 2.2.2.2 255.255.255.255
 ip router isis
!
interface FastEthernet0/0
 ip address 192.168.0.42 255.255.255.252
 ip router isis
 duplex full
 MPLS ip
!
interface FastEthernet1/0
 ip vrf forwarding customer_gov
 ip address 172.16.0.5 255.255.255.252
 duplex full
!
interface FastEthernet2/0
 no ip address
 shutdown
 duplex auto
```

```
 speed auto
!
interface FastEthernet2/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
 shutdown
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router isis
 net 49.0001.6666.6666.6666.00
!
router bgp 65000
 no synchronization
 bgp log-neighbor-changes
 neighbor 1.1.1.1 remote-as 65000
 neighbor 1.1.1.1 update-source Loopback1
 neighbor 3.3.3.3 remote-as 65000
 neighbor 3.3.3.3 update-source Loopback1
```

```
neighbor 6.6.6.6 remote-as 65000

neighbor 6.6.6.6 update-source Loopback1

neighbor 7.7.7.7 remote-as 65000

neighbor 7.7.7.7 update-source Loopback1

neighbor 8.8.8.8 remote-as 65000

neighbor 8.8.8.8 update-source Loopback1

no auto-summary

!

address-family VPNv4

 neighbor 1.1.1.1 activate

 neighbor 1.1.1.1 send-community extended

 neighbor 3.3.3.3 activate

 neighbor 3.3.3.3 send-community extended

 neighbor 6.6.6.6 activate

 neighbor 6.6.6.6 send-community extended

 neighbor 7.7.7.7 activate

 neighbor 7.7.7.7 send-community extended

 neighbor 8.8.8.8 activate

 neighbor 8.8.8.8 send-community extended

exit-address-family

!

address-family ipv4 vrf customer_gov

 neighbor 172.16.0.6 remote-as 65532

 neighbor 172.16.0.6 activate

 neighbor 172.16.0.6 as-override

 neighbor 172.16.0.6 soft-reconfiguration inbound

 no synchronization

exit-address-family

!

ip forward-protocol nd

no ip http server

no ip http secure-server

!

!

!

logging alarm informational

!

!
```

MPLS ldp router-id Loopback1

!

control-plane

!

!

!

!

!

!

!

gatekeeper

 shutdown

!

!

line con 0

 stopbits 1

line aux 0

 stopbits 1

line vty 0 4

 login

!

!

end

PE_EDM_WEST#

PE EDMONTON SOUTH

PE_EDM_SOUTH#sh run

Building configuration...

Current configuration : 2549 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

```
!
hostname PE_EDM_SOUTH
!
boot-start-marker
boot-end-marker
!
!
no aaa new-model
ip cef
!
!
!
!
ip vrf customer_gov
 rd 65000:1
 route-target export 65000:1
 route-target import 65000:1
!
multilink bundle-name authenticated
!
!
!
!
!
!
!
!
!
!
!
!
!
!
archive
 log config
  hidekeys
!
!
```

```
!
!
!
!
interface Loopback1
 ip address 7.7.7.7 255.255.255.255
 ip router isis
!
interface FastEthernet0/0
 ip address 192.168.0.22 255.255.255.252
 ip router isis
 duplex full
 MPLS ip
!
interface FastEthernet1/0
 ip vrf forwarding customer_gov
 ip address 172.16.0.9 255.255.255.252
 duplex full
!
interface FastEthernet2/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet2/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
```

```
 shutdown
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router isis
 net 49.0001.7777.7777.7777.00
!
router bgp 65000
 no synchronization
 bgp log-neighbor-changes
 neighbor 1.1.1.1 remote-as 65000
 neighbor 1.1.1.1 update-source Loopback1
 neighbor 2.2.2.2 remote-as 65000
 neighbor 2.2.2.2 update-source Loopback1
 neighbor 3.3.3.3 remote-as 65000
 neighbor 3.3.3.3 update-source Loopback1
 neighbor 6.6.6.6 remote-as 65000
 neighbor 6.6.6.6 update-source Loopback1
 neighbor 8.8.8.8 remote-as 65000
 neighbor 8.8.8.8 update-source Loopback1
 no auto-summary
!
address-family VPNv4
 neighbor 1.1.1.1 activate
 neighbor 1.1.1.1 send-community extended
 neighbor 2.2.2.2 activate
 neighbor 2.2.2.2 send-community extended
 neighbor 3.3.3.3 activate
 neighbor 3.3.3.3 send-community extended
```

```
  neighbor 6.6.6.6 activate

  neighbor 6.6.6.6 send-community extended

  neighbor 8.8.8.8 activate

  neighbor 8.8.8.8 send-community extended

 exit-address-family

 !

 address-family ipv4 vrf customer_gov

  neighbor 172.16.0.10 remote-as 65501

  neighbor 172.16.0.10 activate

  neighbor 172.16.0.10 as-override

  neighbor 172.16.0.10 soft-reconfiguration inbound

  no synchronization

 exit-address-family

 !

ip forward-protocol nd

no ip http server

no ip http secure-server

 !

 !

 !

logging alarm informational

 !

 !

 !

control-plane

 !

 !

 !

 !

 !

 !

 !

gatekeeper

 shutdown

 !

 !

line con 0

 stopbits 1
```

```
line aux 0
 stopbits 1
line vty 0 4
 login
!
!
end


PE_EDM_SOUTH#
```

PE EDMONTON EAST CENTRAL

```
PE_EDM_EAST#sh run
Building configuration...

Current configuration : 2676 bytes
!
upgrade fpd auto
version 12.4
service timestamps debug datetime msec
service timestamps log datetime msec
no service password-encryption
!
hostname PE_EDM_EAST
!
boot-start-marker
boot-end-marker
!
!
no aaa new-model
ip cef
!
!
!
!
ip vrf customer_gov
 rd 65000:1
```

```
  route-target export 65000:1
  route-target import 65000:1
 !
multilink bundle-name authenticated
MPLS ldp neighbor 5.5.5.5 targeted
MPLS ldp holdtime 400
MPLS ldp discovery targeted-hello accept
 !
 !
 !
 !
 !
 !
 !
 !
 !
 !
 !
 !
 !
 !
archive
 log config
  hidekeys
 !
 !
 !
 !
 !
 !
interface Loopback1
 ip address 8.8.8.8 255.255.255.255
 ip router isis
 !
interface FastEthernet0/0
 ip address 192.168.0.26 255.255.255.252
 ip router isis
 duplex full
```

```
MPLS ip
!
interface FastEthernet1/0
 ip vrf forwarding customer_gov
 ip address 172.16.0.13 255.255.255.252
 duplex full
!
interface FastEthernet2/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet2/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
 shutdown
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
```

```
!
router isis
 net 49.0001.5555.5555.5555.00
!
router bgp 65000
 no synchronization
 bgp log-neighbor-changes
 neighbor 1.1.1.1 remote-as 65000
 neighbor 1.1.1.1 update-source Loopback1
 neighbor 2.2.2.2 remote-as 65000
 neighbor 2.2.2.2 update-source Loopback1
 neighbor 3.3.3.3 remote-as 65000
 neighbor 3.3.3.3 update-source Loopback1
 neighbor 6.6.6.6 remote-as 65000
 neighbor 6.6.6.6 update-source Loopback1
 neighbor 7.7.7.7 remote-as 65000
 neighbor 7.7.7.7 update-source Loopback1
 no auto-summary
!
address-family VPNv4
 neighbor 1.1.1.1 activate
 neighbor 1.1.1.1 send-community extended
 neighbor 2.2.2.2 activate
 neighbor 2.2.2.2 send-community extended
 neighbor 3.3.3.3 activate
 neighbor 3.3.3.3 send-community extended
 neighbor 6.6.6.6 activate
 neighbor 6.6.6.6 send-community extended
 neighbor 7.7.7.7 activate
 neighbor 7.7.7.7 send-community extended
exit-address-family
!
address-family ipv4 vrf customer_gov
 neighbor 172.16.0.14 remote-as 65503
 neighbor 172.16.0.14 activate
 neighbor 172.16.0.14 as-override
 neighbor 172.16.0.14 soft-reconfiguration inbound
 no synchronization
```

exit-address-family

!

ip forward-protocol nd

no ip http server

no ip http secure-server

!

!

!

logging alarm informational

!

!

MPLS ldp router-id Loopback1

!

control-plane

!

!

!

!

!

!

!

gatekeeper

 shutdown

!

!

line con 0

 stopbits 1

line aux 0

 stopbits 1

line vty 0 4

 login

!

!

end

PE_EDM_EAST#

PE SWP

PE_SWP#sh run

Building configuration...

Current configuration : 2671 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname PE_SWP

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

!

!

!

ip vrf customer_gov

 rd 65000:1

 route-target export 65000:1

 route-target import 65000:1

!

multilink bundle-name authenticated

MPLS ldp neighbor 5.5.5.5 targeted

MPLS ldp holdtime 400

MPLS ldp discovery targeted-hello accept

!

!

!

!

```
!
!
!
!
!
!
!
!
!
!
archive
 log config
  hidekeys
!
!
!
!
!
!
interface Loopback1
 ip address 6.6.6.6 255.255.255.255
 ip router isis
!
interface FastEthernet0/0
 ip vrf forwarding customer_gov
 ip address 172.16.0.17 255.255.255.252
 duplex full
!
interface FastEthernet1/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet2/0
 no ip address
 shutdown
 duplex auto
 speed auto
```

```
!
interface FastEthernet2/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 ip address 192.168.0.34 255.255.255.252
 ip router isis
 negotiation auto
 MPLS ip
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router isis
 net 49.0001.8888.8888.8888.00
!
router bgp 65000
 no synchronization
 bgp log-neighbor-changes
 neighbor 1.1.1.1 remote-as 65000
 neighbor 1.1.1.1 update-source Loopback1
 neighbor 2.2.2.2 remote-as 65000
 neighbor 2.2.2.2 update-source Loopback1
```

```
neighbor 3.3.3.3 remote-as 65000

neighbor 3.3.3.3 update-source Loopback1

neighbor 7.7.7.7 remote-as 65000

neighbor 7.7.7.7 update-source Loopback1

neighbor 8.8.8.8 remote-as 65000

neighbor 8.8.8.8 update-source Loopback1

no auto-summary

!

address-family VPNv4

 neighbor 1.1.1.1 activate

 neighbor 1.1.1.1 send-community extended

 neighbor 2.2.2.2 activate

 neighbor 2.2.2.2 send-community extended

 neighbor 3.3.3.3 activate

 neighbor 3.3.3.3 send-community extended

 neighbor 7.7.7.7 activate

 neighbor 7.7.7.7 send-community extended

 neighbor 8.8.8.8 activate

 neighbor 8.8.8.8 send-community extended

exit-address-family

!

address-family ipv4 vrf customer_gov

 neighbor 172.16.0.18 remote-as 65502

 neighbor 172.16.0.18 activate

 neighbor 172.16.0.18 as-override

 neighbor 172.16.0.18 soft-reconfiguration inbound

 no synchronization

exit-address-family

!

ip forward-protocol nd

no ip http server

no ip http secure-server

!

!

!

logging alarm informational

!

!
```

MPLS ldp router-id Loopback1

!

control-plane

!

!

!

!

!

!

!

gatekeeper

 shutdown

!

!

line con 0

 stopbits 1

line aux 0

 stopbits 1

line vty 0 4

 login

!

!

end

PE_SWP#

Core Router 1

CORE_R_1#sh run

Building configuration...

Current configuration : 1726 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

```
!
hostname CORE_R_1
!
boot-start-marker
boot-end-marker
!
!
no aaa new-model
ip cef
!
!
!
!
ip name-server 8.8.4.4
multilink bundle-name authenticated
MPLS ldp neighbor 5.5.5.5 targeted
MPLS ldp neighbor 7.7.7.7 targeted
MPLS ldp holdtime 400
MPLS ldp discovery targeted-hello accept
!
!
!
!
!
!
!
!
!
!
!
!
!
!
archive
 log config
  hidekeys
!
!
```

```
!
!
!
!
interface Loopback1
 ip address 4.4.4.4 255.255.255.255
 ip router isis
!
interface FastEthernet0/0
 ip address 192.168.0.10 255.255.255.252
 ip router isis
 duplex full
 MPLS ip
!
interface FastEthernet1/0
 ip address 192.168.0.38 255.255.255.252
 ip router isis
 duplex full
 MPLS ip
!
interface FastEthernet2/0
 ip address 192.168.0.41 255.255.255.252
 ip router isis
 duplex full
 speed auto
 MPLS ip
!
interface FastEthernet2/1
 ip address 12.0.0.2 255.255.255.252
 duplex auto
 speed auto
!
interface GigabitEthernet3/0
 ip address 192.168.0.17 255.255.255.252
 ip router isis
 negotiation auto
 MPLS ip
!
```

interface GigabitEthernet4/0

 ip address 192.168.0.21 255.255.255.252

 ip router isis

 negotiation auto

 MPLS ip

!

interface FastEthernet5/0

 no ip address

 shutdown

 duplex half

!

interface FastEthernet6/0

 no ip address

 shutdown

 duplex half

!

router isis

 net 49.0001.3333.3333.3333.00

 redistribute connected

!

ip forward-protocol nd

ip route 0.0.0.0 0.0.0.0 12.0.0.1

no ip http server

no ip http secure-server

!

!

!

logging alarm informational

!

!

MPLS ldp router-id Loopback1

!

control-plane

!

!

!

!

!

!

!

gatekeeper

 shutdown

!

!

line con 0

 stopbits 1

line aux 0

 stopbits 1

line vty 0 4

 login

!

!

end

CORE_R_1#

CORE ROUTER 2

CORE_R2#sh run

Building configuration...

Current configuration : 1619 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname CORE_R2

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

!

!

!

multilink bundle-name authenticated

MPLS ldp holdtime 400

MPLS ldp discovery targeted-hello accept

!

!

!

!

!

!

!

!

!

!

!

!

!

archive

 log config

  hidekeys

!

!

!

!

!

!

interface Loopback1

 ip address 5.5.5.5 255.255.255.255

 ip router isis

!

interface FastEthernet0/0

 ip address 192.168.0.14 255.255.255.252

 ip router isis

 duplex full

MPLS ip

!

interface FastEthernet1/0

 ip address 192.168.0.6 255.255.255.252

 ip router isis

 duplex full

 MPLS ip

!

interface FastEthernet2/0

 ip address 192.168.0.18 255.255.255.252

 ip router isis

 duplex full

 speed auto

 MPLS ip

!

interface FastEthernet2/1

 ip address 192.168.0.25 255.255.255.252

 ip router isis

 duplex full

 speed auto

 MPLS ip

!

interface GigabitEthernet3/0

 ip address 192.168.0.29 255.255.255.252

 ip router isis

 negotiation auto

 MPLS ip

!

interface GigabitEthernet4/0

 ip address 192.168.0.33 255.255.255.252

 ip router isis

 negotiation auto

 MPLS ip

!

interface FastEthernet5/0

 ip address 192.168.0.50 255.255.255.252

 duplex full

!

```
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router isis
 net 49.0001.4444.4444.4444.00
!
ip forward-protocol nd
no ip http server
no ip http secure-server
!
!
!
logging alarm informational
!
!
MPLS ldp router-id Loopback1
!
control-plane
!
!
!
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
!
```

!

end

CORE_R2#

Customer Equipment or CE Routers Configuration

CE ST Albert

CE_ST_ALBERT#sh run

Building configuration...

Current configuration : 1490 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname CE_ST_ALBERT

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

!

!

!

multilink bundle-name authenticated

!

!

!

!

!

!

```
!
!
!
!
!
!
!
!
archive
 log config
  hidekeys
!
!
!
!
!
!
interface Loopback1
 ip address 10.0.0.1 255.255.255.255
!
interface Loopback2
 ip address 11.0.0.1 255.255.255.255
!
interface FastEthernet0/0
 ip address 172.16.0.2 255.255.255.252
 duplex full
!
interface FastEthernet1/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet2/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
```

```
interface FastEthernet2/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
 shutdown
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router bgp 65531
 no synchronization
 bgp log-neighbor-changes
 redistribute connected
 redistribute static
 neighbor 172.16.0.1 remote-as 65000
 neighbor 172.16.0.1 soft-reconfiguration inbound
 no auto-summary
!
ip forward-protocol nd
no ip http server
no ip http secure-server
```

!

!

!

logging alarm informational

!

!

!

control-plane

!

!

!

!

!

!

!

gatekeeper

 shutdown

!

!

line con 0

 stopbits 1

line aux 0

 stopbits 1

line vty 0 4

 login

!

!

end

CE_ST_ALBERT#

CE Edmonton West

CE_EDM_WEST#sh run

Building configuration...

Current configuration : 1489 bytes

!

upgrade fpd auto

```
version 12.4
service timestamps debug datetime msec
service timestamps log datetime msec
no service password-encryption
!
hostname CE_EDM_WEST
!
boot-start-marker
boot-end-marker
!
!
no aaa new-model
ip cef
!
!
!
!
multilink bundle-name authenticated
!
!
!
!
!
!
!
!
!
!
!
!
!
!
archive
 log config
  hidekeys
!
!
!
```

```
!
!
!
interface Loopback1
 ip address 10.0.0.2 255.255.255.255
!
interface Loopback2
 ip address 11.0.0.2 255.255.255.255
!
interface FastEthernet0/0
 ip address 172.16.0.6 255.255.255.252
 duplex full
!
interface FastEthernet1/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet2/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet2/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
 shutdown
```

```
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router bgp 65532
 no synchronization
 bgp log-neighbor-changes
 redistribute connected
 redistribute static
 neighbor 172.16.0.5 remote-as 65000
 neighbor 172.16.0.5 soft-reconfiguration inbound
 no auto-summary
!
ip forward-protocol nd
no ip http server
no ip http secure-server
!
!
!
logging alarm informational
!
!
!
control-plane
!
!
!
!
!
!
```

!

gatekeeper

 shutdown

!

!

line con 0

 stopbits 1

line aux 0

 stopbits 1

line vty 0 4

 login

!

!

end

CE_EDM_WEST#

CE Edmonton South

CE_EDM_SOUTH#sh run

Building configuration...

Current configuration : 1491 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname CE_EDM_SOUTH

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

```
!
!
!
multilink bundle-name authenticated
!
!
!
!
!
!
!
!
!
!
!
!
!
archive
 log config
  hidekeys
!
!
!
!
!
!
interface Loopback1
 ip address 10.0.0.3 255.255.255.255
!
interface Loopback2
 ip address 11.0.0.3 255.255.255.255
!
interface FastEthernet0/0
 ip address 172.16.0.10 255.255.255.252
 duplex full
!
interface FastEthernet1/0
```

```
 no ip address
 shutdown
 duplex half
!
interface FastEthernet2/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet2/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
 shutdown
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router bgp 65501
 no synchronization
```

```
 bgp log-neighbor-changes
 redistribute connected
 redistribute static
 neighbor 172.16.0.9 remote-as 65000
 neighbor 172.16.0.9 soft-reconfiguration inbound
 no auto-summary
!
ip forward-protocol nd
no ip http server
no ip http secure-server
!
!
!
logging alarm informational
!
!
!
control-plane
!
!
!
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
!
!
end
```

CE_EDM_SOUTH#

CE Edmonton East

CE_EDM_EAST#sh run

Building configuration...

Current configuration : 1492 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname CE_EDM_EAST

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

!

!

!

multilink bundle-name authenticated

!

!

!

!

!

!

!

!

!

!

```
!
!
!
!
archive
 log config
  hidekeys
!
!
!
!
!
!
interface Loopback1
 ip address 10.0.0.7 255.255.255.255
!
interface Loopback2
 ip address 11.0.0.7 255.255.255.255
!
interface FastEthernet0/0
 ip address 172.16.0.14 255.255.255.252
 duplex full
!
interface FastEthernet1/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet2/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet2/1
 no ip address
 shutdown
 duplex auto
```

```
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
 shutdown
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router bgp 65503
 no synchronization
 bgp log-neighbor-changes
 redistribute connected
 redistribute static
 neighbor 172.16.0.13 remote-as 65000
 neighbor 172.16.0.13 soft-reconfiguration inbound
 no auto-summary
!
ip forward-protocol nd
no ip http server
no ip http secure-server
!
!
!
logging alarm informational
```

!

!

!

control-plane

!

!

!

!

!

!

!

gatekeeper

 shutdown

!

!

line con 0

 stopbits 1

line aux 0

 stopbits 1

line vty 0 4

 login

!

!

end

CE_EDM_EAST#

CE SWP

CE_SWP#sh run

Building configuration...

Current configuration : 1487 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname CE_SWP

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

!

!

!

multilink bundle-name authenticated

!

!

!

!

!

!

!

!

!

!

!

!

!

archive

 log config

  hidekeys

!

!

!

!

!

!

interface Loopback1

ip address 10.0.0.6 255.255.255.255

!

interface Loopback2

ip address 11.0.0.6 255.255.255.255

!

interface FastEthernet0/0

ip address 172.16.0.18 255.255.255.252

duplex full

!

interface FastEthernet1/0

no ip address

shutdown

duplex half

!

interface FastEthernet2/0

no ip address

shutdown

duplex auto

speed auto

!

interface FastEthernet2/1

no ip address

shutdown

duplex auto

speed auto

!

interface GigabitEthernet3/0

no ip address

shutdown

negotiation auto

!

interface GigabitEthernet4/0

no ip address

shutdown

negotiation auto

!

interface FastEthernet5/0

```
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router bgp 65502
 no synchronization
 bgp log-neighbor-changes
 redistribute connected
 redistribute static
 neighbor 172.16.0.17 remote-as 65000
 neighbor 172.16.0.17 soft-reconfiguration inbound
 no auto-summary
!
ip forward-protocol nd
no ip http server
no ip http secure-server
!
!
!
logging alarm informational
!
!
!
control-plane
!
!
!
!
!
!
!
gatekeeper
 shutdown
```

!

!

line con 0

 stopbits 1

line aux 0

 stopbits 1

line vty 0 4

 login

!

!

end

CE_SWP#

CE Edmonton North

CE_EDM_NORTH#sh run

Building configuration...

Current configuration : 1493 bytes

!

upgrade fpd auto

version 12.4

service timestamps debug datetime msec

service timestamps log datetime msec

no service password-encryption

!

hostname CE_EDM_NORTH

!

boot-start-marker

boot-end-marker

!

!

no aaa new-model

ip cef

!

!

!

!

multilink bundle-name authenticated

!

!

!

!

!

!

!

!

!

!

!

!

!

archive

 log config

  hidekeys

!

!

!

!

!

!

interface Loopback1

 ip address 10.0.0.4 255.255.255.255

!

interface Loopback2

 ip address 11.0.0.4 255.255.255.255

!

interface FastEthernet0/0

 ip address 172.16.0.22 255.255.255.252

 duplex full

!

interface FastEthernet1/0

```
 no ip address
 shutdown
 duplex half
!
interface FastEthernet2/0
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface FastEthernet2/1
 no ip address
 shutdown
 duplex auto
 speed auto
!
interface GigabitEthernet3/0
 no ip address
 shutdown
 negotiation auto
!
interface GigabitEthernet4/0
 no ip address
 shutdown
 negotiation auto
!
interface FastEthernet5/0
 no ip address
 shutdown
 duplex half
!
interface FastEthernet6/0
 no ip address
 shutdown
 duplex half
!
router bgp 65533
 no synchronization
```

```
 bgp log-neighbor-changes
 redistribute connected
 redistribute static
 neighbor 172.16.0.21 remote-as 65000
 neighbor 172.16.0.21 soft-reconfiguration inbound
 no auto-summary
!
ip forward-protocol nd
no ip http server
no ip http secure-server
!
!
!
logging alarm informational
!
!
!
control-plane
!
!
!
!
!
!
!
gatekeeper
 shutdown
!
!
line con 0
 stopbits 1
line aux 0
 stopbits 1
line vty 0 4
 login
!
!
end
```

Conclusion

The project looked at the theoretical aspects of building an MPLS VPN network that spanned the entire Edmonton Capital Region consisting of the city of Edmonton as well as the satellite cities surrounding it.

Thorough research was conducted with respect to the real world positions of government service buildings based on latitude and longitude on google maps and a map was created that placed different services on different areas of the map. Once this was done, distance and spatial analysis was considered for each and every area and the city was subdivided into various sub regions and each region was assigned a primary PE router and an optional backup PE router. The distances of the PE routers that were placed from each other as well as the various CE's in their region was carefully measured using real world measurements and care was taken that no distance was more than 9- 10 km apart from a CE to either its primary PE or a designated backup PE.

Once the placement of the various core network was decided, work was done to place two core routers that served as P routers in the MPLS VPN network that only ran MPLS on them thus providing a BGP free core to the network.

After the network topology was decided, IP addresses were allocated to different aspects of the network such as core network, the links for the PE-CE peering as well as the loopbacks that were employed on the various CE routers to simulate multiple CE routers that are peering with the selected primary PE router.

Once the network was built logically, it was implemented in the lab on a smaller scale validating the network design and the proof of concept.

The project concluded that all the work conducted theoretically shows that it is indeed feasible to build an MPLS VPN network that unifies all government services in the city of Edmonton. The design of the city makes it easy to do so, as even though it is spread out, it has a grid based layout and is divided into sectors, which ensure that designing and placing routers according to area becomes a relatively easy task. Thus with a few number of primary PE routers (~6), the entire city was able to have been covered and serviced by an MPLS network. This was a very useful study conducted into the real world distances of the various government service buildings

and real world distances between the various areas that the ECR is split into. I would hope that this work proves very useful in the future for anyone who is looking for real world information about the structure of the city of Edmonton, the distances between the various areas and a template that looks into the theoretical construction of such a network within the Edmonton Capital Region.

Appendix

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4	4	BGP free Core with MPLS	
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59	59	show ip route – CE Edmonton East	

List of Abbreviations

IP	Internet Protocol
MPLS	Multi-Protocol Label Switching
QoS	Quality of Service
LER	Label Edge Router
PER	Provider Edge router
LSR	Label switching routers
LSP	Label Switched paths
FEC	Forward Equivalence Class
CER	Customer Edge Routers
LIB	Label information Base
FIB	Forwarding information Base
LFIB	Label forwarding base
TDP	Tag Distribution Protocol
BGP	Border Gateway Protocol
RSVP	Resource reservation Protocol
VPN	Virtual Private Network
ATM	Asynchronous Transfer Mode
IGP	Interior Gateway Protocol
EGP	Exterior Gateway Protocol
OSPF	Open shortest path first
AS	Autonomous system
ABR	Area Border Router
RR	Route Reflector
ISIS	Intermediate system- Intermediate System
DU	Downstream Unsolicited
DoD	Downstream on Demand
Vlan	Virtual LAN
ECR	Edmonton Capital Region
VPN	Virtual Private Network
M-BGP	Multiprotocol BGP
MP-BGP	Multiprotocol BGP
SWP	Sherwood Park

References

Below specified are some references to books and websites that I have used during the course of the project.

I would also like to thank Mr. Juned Noonari, who provided me with some extremely useful and valuable study material and information in the form of PowerPoint presentations and short pdf documents on various networking concepts such as ISIS, BGP, MPLS VPN's, OSPF etc.

The guidance he also provided to me while we had our project progress discussions was very valuable and I would like to mention his contribution here.

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