NATIONAL UNIVERSITY
of Computer & Emerging Sciences

CY4049 - Network Protocols and Standards Fall 24BCY-5A

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Implementation of Multiprotocol Label Switching (MPLS)

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Abstract

This project aims to highlight the fundamental differences between traditional IP routing and MPLS (Multiprotocol Label Switching) through practical implementation. Using GNS3, an MPLS network was configured to highlight its efficiency improvements, including faster packet forwarding, reduced lookup times, and enhanced traffic engineering. The project also demonstrates the implementation of VRFs and OSPF to manage traffic effectively.

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1. Introduction

MPLS is a versatile solution for improving the performance of IP networks by enabling label-based switching instead of relying solely on IP lookups. This project focuses on implementing an MPLS network to demonstrate its capabilities, such as traffic engineering and efficient forwarding, in comparison to traditional IP routing.

2. Network Topology

The network topology used in this project involves Provider (P) and Provider Edge (PE) routers, along with Customer Edge (CE) routers. These routers were interconnected to form an MPLS network.

Figure 1: MPLS Network Topology

3. Policy Implementation

Policies were defined to control communication between various customer banks (Bank A, Bank B, and Bank C). The configuration's ensured traffic was routed based on predefined rules:

- Bank B cannot communicate with Bank C.
- Other communications follow the policy defined by the labels.

Figure 2: Policy Configuration Overview

4. MPLS Configuration

4.1 OSPF Configuration

OSPF was used to establish connectivity within P and PE routers. The loopback addresses of PE routers were configured to represent customer sites.

Figure 15: OSPF Connectivity Proof within P and PE Routers

4.2 MPLS Neighbor Discovery

MPLS neighbors were displayed to verify the correct setup of label-switched paths (LSPs).

Figure 17: Displaying MPLS Neighbors

4.3 Virtual Routing and Forwarding (VRFs)

VRFs were configured on PE routers to isolate customer traffic. Interfaces were assigned to VRFs based on customer-specific requirements.

Figures 20 & 21: VRF Configuration on PE Routers

5. Verification and Testing

5.1 Static Routes for Customer Edges

Static routes were defined for customer edge routers to direct traffic efficiently through the MPLS network.

Figure 26: Static Route Configuration

5.2 BGP Redistribution

BGP was implemented on PE routers and redistributed with static routes to ensure proper route propagation.
Figure 32: BGP Configuration Verification

5.3 Ping Tests

Ping tests were conducted to validate connectivity according to the defined policy.

- Figure 37: Ping Test - Bank A to All
- Figure 38: Ping Test - Bank C to Bank C
- Figure 39: Ping Test - Bank B to Bank A
- Figure 41: Communication Restriction - Bank B to Bank C

6. Conclusion

This project successfully demonstrated the configuration and operational differences between traditional IP routing and MPLS. By implementing OSPF, VRFs, and BGP within the MPLS framework, significant improvements in traffic management and forwarding efficiency were observed. The project highlights MPLS's potential to optimize network performance in modern enterprise networks.

7. References

- Figures from the provided report were directly analyzed and used for explanation.
- RFC 3031 - MPLS Architecture

Topology
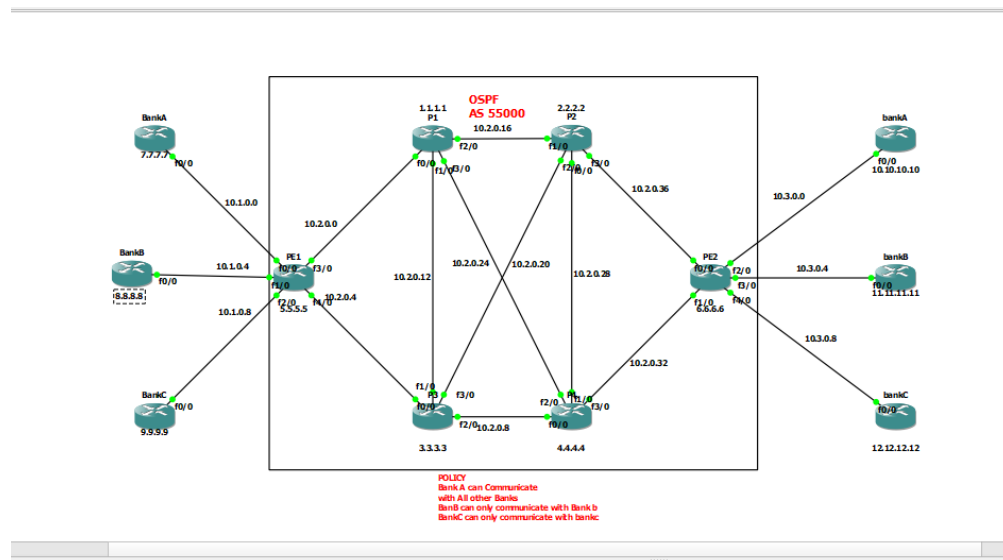
Figure 1

Policy

Figure 2

Ip-Configuration of each router

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

OSPF Connectivity Proof within P and PE Routers

Loop Back for PE2 is 6.6.6.6

```
PE2                                                              —   □   ✕

        + - replicated route, % - next hop override

Gateway of last resort is not set

      1.0.0.0/32 is subnetted, 1 subnets
O        1.1.1.1 [110/3] via 10.2.0.37, 00:01:18, FastEthernet0/0
                  [110/3] via 10.2.0.33, 00:01:42, FastEthernet1/0
      2.0.0.0/32 is subnetted, 1 subnets
O        2.2.2.2 [110/2] via 10.2.0.37, 00:01:18, FastEthernet0/0
      3.0.0.0/32 is subnetted, 1 subnets
O        3.3.3.3 [110/3] via 10.2.0.37, 00:01:18, FastEthernet0/0
                  [110/3] via 10.2.0.33, 00:01:42, FastEthernet1/0
      4.0.0.0/32 is subnetted, 1 subnets
O        4.4.4.4 [110/2] via 10.2.0.33, 00:01:42, FastEthernet1/0
      5.0.0.0/32 is subnetted, 1 subnets
O        5.5.5.5 [110/4] via 10.2.0.37, 00:01:18, FastEthernet0/0
                  [110/4] via 10.2.0.33, 00:01:42, FastEthernet1/0
      10.0.0.0/8 is variably subnetted, 21 subnets, 2 masks
O        10.1.0.0/30 [110/4] via 10.2.0.37, 00:01:18, FastEthernet0/0
                      [110/4] via 10.2.0.33, 00:01:42, FastEthernet1/0
O        10.1.0.4/30 [110/4] via 10.2.0.37, 00:01:18, FastEthernet0/0
                      [110/4] via 10.2.0.33, 00:01:42, FastEthernet1/0
O        10.1.0.8/30 [110/4] via 10.2.0.37, 00:01:18, FastEthernet0/0
                      [110/4] via 10.2.0.33, 00:01:42, FastEthernet1/0
O        10.2.0.0/30 [110/3] via 10.2.0.37, 00:01:18, FastEthernet0/0
                      [110/3] via 10.2.0.33, 00:01:42, FastEthernet1/0
O        10.2.0.4/30 [110/3] via 10.2.0.37, 00:01:18, FastEthernet0/0
                      [110/3] via 10.2.0.33, 00:01:42, FastEthernet1/0
O        10.2.0.8/30 [110/2] via 10.2.0.33, 00:01:42, FastEthernet1/0
O        10.2.0.12/30 [110/3] via 10.2.0.37, 00:01:18, FastEthernet0/0
                       [110/3] via 10.2.0.33, 00:01:42, FastEthernet1/0
O        10.2.0.16/30 [110/2] via 10.2.0.37, 00:01:18, FastEthernet0/0
O        10.2.0.20/30 [110/2] via 10.2.0.37, 00:01:18, FastEthernet0/0
O        10.2.0.24/30 [110/2] via 10.2.0.33, 00:01:42, FastEthernet1/0
O        10.2.0.28/30 [110/2] via 10.2.0.37, 00:01:18, FastEthernet0/0
                       [110/2] via 10.2.0.33, 00:01:42, FastEthernet1/0
PE2(config-router)#
```
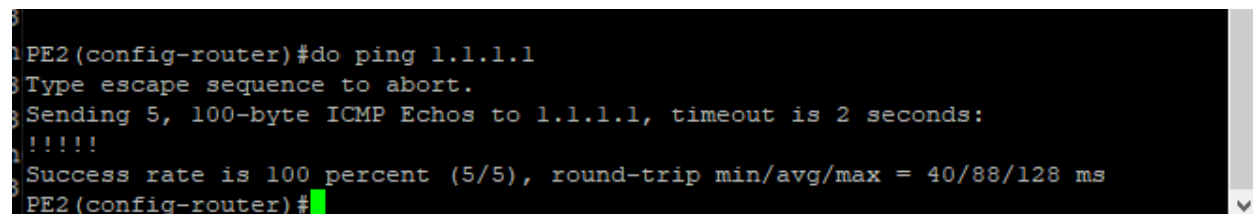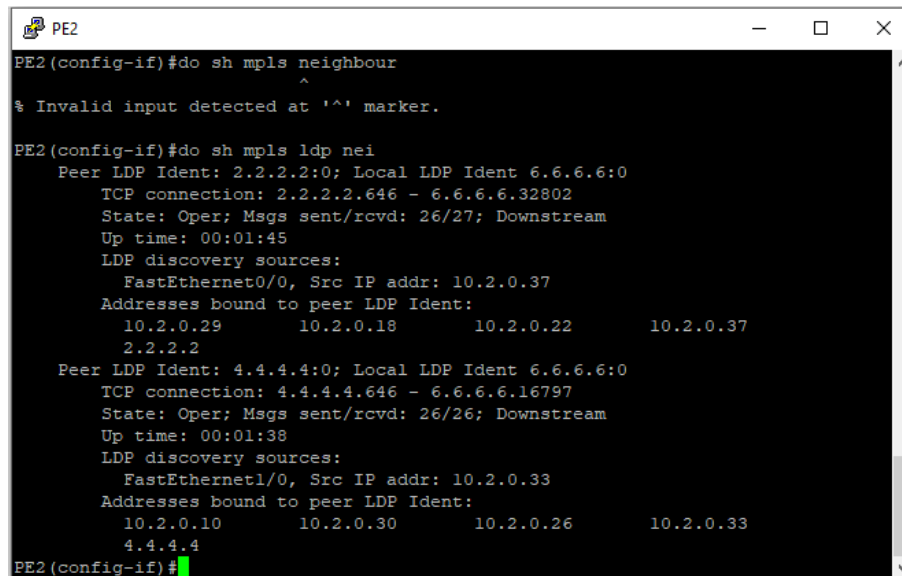
Figure 15

```
PE2(config-router)#do ping 1.1.1.1
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 1.1.1.1, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 40/88/128 ms
PE2(config-router)#
```
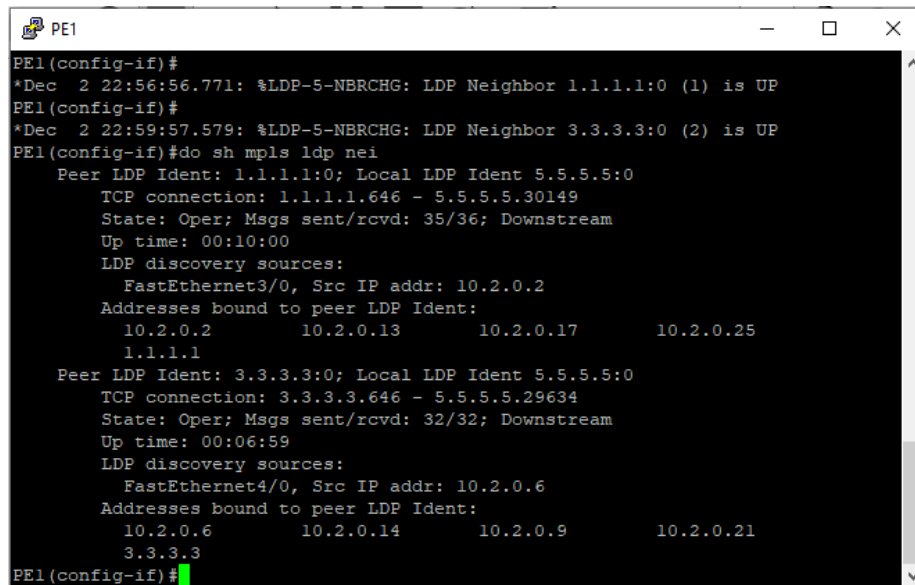
Figure 16

MPLS Implementation
displaying MPLS neighbors.


```
PE2
PE2(config-if)#do sh mpls neighbour
                         ^
% Invalid input detected at '^' marker.

PE2(config-if)#do sh mpls ldp nei
    Peer LDP Ident: 2.2.2.2:0; Local LDP Ident 6.6.6.6:0
        TCP connection: 2.2.2.2.646 - 6.6.6.6.32802
        State: Oper; Msgs sent/rcvd: 26/27; Downstream
        Up time: 00:01:45
        LDP discovery sources:
          FastEthernet0/0, Src IP addr: 10.2.0.37
        Addresses bound to peer LDP Ident:
          10.2.0.29      10.2.0.18      10.2.0.22      10.2.0.37
          2.2.2.2
    Peer LDP Ident: 4.4.4.4:0; Local LDP Ident 6.6.6.6:0
        TCP connection: 4.4.4.4.646 - 6.6.6.6.16797
        State: Oper; Msgs sent/rcvd: 26/26; Downstream
        Up time: 00:01:38
        LDP discovery sources:
          FastEthernet1/0, Src IP addr: 10.2.0.33
        Addresses bound to peer LDP Ident:
          10.2.0.10      10.2.0.30      10.2.0.26      10.2.0.33
          4.4.4.4
PE2(config-if)#
```

Figure 17


```
PE1
PE1(config-if)#
*Dec  2 22:56:56.771: %LDP-5-NBRCHG: LDP Neighbor 1.1.1.1:0 (1) is UP
PE1(config-if)#
*Dec  2 22:59:57.579: %LDP-5-NBRCHG: LDP Neighbor 3.3.3.3:0 (2) is UP
PE1(config-if)#do sh mpls ldp nei
    Peer LDP Ident: 1.1.1.1:0; Local LDP Ident 5.5.5.5:0
        TCP connection: 1.1.1.1.646 - 5.5.5.5.30149
        State: Oper; Msgs sent/rcvd: 35/36; Downstream
        Up time: 00:10:00
        LDP discovery sources:
          FastEthernet3/0, Src IP addr: 10.2.0.2
        Addresses bound to peer LDP Ident:
          10.2.0.2       10.2.0.13      10.2.0.17      10.2.0.25
          1.1.1.1
    Peer LDP Ident: 3.3.3.3:0; Local LDP Ident 5.5.5.5:0
        TCP connection: 3.3.3.3.646 - 5.5.5.5.29634
        State: Oper; Msgs sent/rcvd: 32/32; Downstream
        Up time: 00:06:59
        LDP discovery sources:
          FastEthernet4/0, Src IP addr: 10.2.0.6
        Addresses bound to peer LDP Ident:
          10.2.0.6       10.2.0.14      10.2.0.9       10.2.0.21
          3.3.3.3
PE1(config-if)#
```

Figure 18

Figure 19

Ip Vrfs on Router PE1 and on PE2

Figure 20

PE2


```
PE2(config-vrf)#do sh ip vrf
  Name                            Default RD          Interfaces
  Bank-A                          55000:100
  Bank-B                          55000:200
  Bank-C                          55000:300
PE2(config-vrf)#do sh ip vrf detail
VRF Bank-A (VRF Id = 1); default RD 55000:100; default VPNID <not set>
  No interfaces
VRF Table ID = 1
  Export VPN route-target communities
    RT:55000:100
  Import VPN route-target communities
    RT:55000:100
  No import route-map
  No export route-map
  VRF label distribution protocol: not configured
  VRF label allocation mode: per-prefix

VRF Bank-B (VRF Id = 2); default RD 55000:200; default VPNID <not set>
  No interfaces
VRF Table ID = 2
  Export VPN route-target communities
    RT:55000:200
  Import VPN route-target communities
    RT:55000:200
  No import route-map
  No export route-map
  VRF label distribution protocol: not configured
  VRF label allocation mode: per-prefix

VRF Bank-C (VRF Id = 3); default RD 55000:300; default VPNID <not set>
  No interfaces
VRF Table ID = 3
  Export VPN route-target communities
    RT:55000:300
  Import VPN route-target communities
```
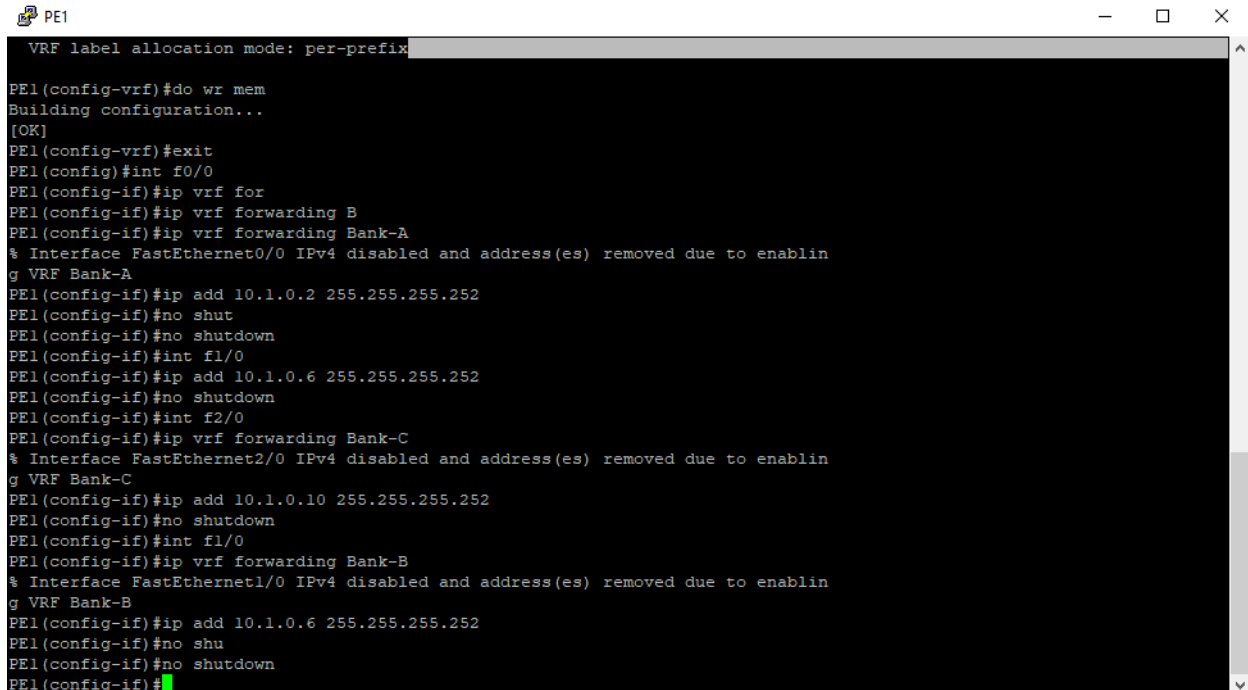
Figure 21

Assigning interface vrfs


```
  VRF label allocation mode: per-prefix

PE1(config-vrf)#do wr mem
Building configuration...
[OK]
PE1(config-vrf)#exit
PE1(config)#int f0/0
PE1(config-if)#ip vrf for
PE1(config-if)#ip vrf forwarding B
PE1(config-if)#ip vrf forwarding Bank-A
% Interface FastEthernet0/0 IPv4 disabled and address(es) removed due to enablin
g VRF Bank-A
PE1(config-if)#ip add 10.1.0.2 255.255.255.252
PE1(config-if)#no shut
PE1(config-if)#no shutdown
PE1(config-if)#int f1/0
PE1(config-if)#ip add 10.1.0.6 255.255.255.252
PE1(config-if)#no shutdown
PE1(config-if)#int f2/0
PE1(config-if)#ip vrf forwarding Bank-C
% Interface FastEthernet2/0 IPv4 disabled and address(es) removed due to enablin
g VRF Bank-C
PE1(config-if)#ip add 10.1.0.10 255.255.255.252
PE1(config-if)#no shutdown
PE1(config-if)#int f1/0
PE1(config-if)#ip vrf forwarding Bank-B
% Interface FastEthernet1/0 IPv4 disabled and address(es) removed due to enablin
g VRF Bank-B
PE1(config-if)#ip add 10.1.0.6 255.255.255.252
PE1(config-if)#no shu
PE1(config-if)#no shutdown
PE1(config-if)#
```
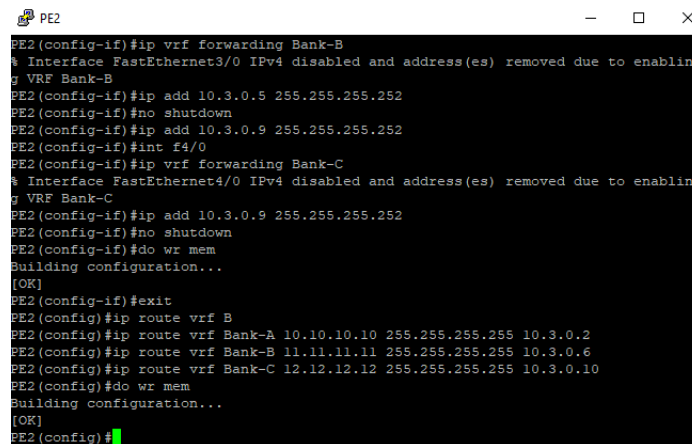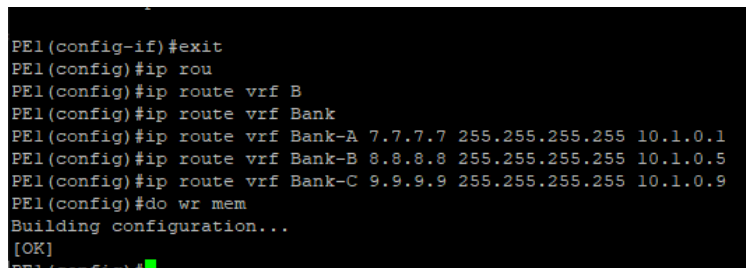
Figure 22

Figure 23

Defining Routes for Costumer Edges to travel in Vrfs

Figure 24

Figure 25

Defining Static Routes for Costumer Edges
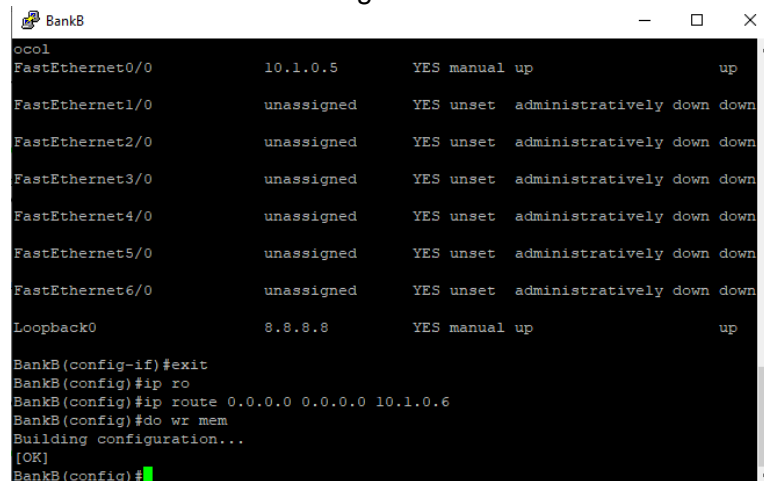
Figure 26

Figure 27

Figure 28

Figure 29

Figure 30

Figure 31

Implementing BGP on pe routers And Re distributing them with static routes

```
PE1
PE1(config)#ip route vrf Bank-A 7.7.7.7 255.255.255.255 10.1.0.1
PE1(config)#ip route vrf Bank-B 8.8.8.8 255.255.255.255 10.1.0.5
PE1(config)#ip route vrf Bank-C 9.9.9.9 255.255.255.255 10.1.0.9
PE1(config)#do wr mem
Building configuration...
[OK]
PE1(config)#router bgp 55000
PE1(config-router)#
PE1(config-router)#nei
PE1(config-router)#neighbor 6.6.6.6 rem
PE1(config-router)#neighbor 6.6.6.6 remo
PE1(config-router)#neighbor 6.6.6.6 remote-as 55000
PE1(config-router)#nei 6.6.6.6 upd
PE1(config-router)#nei 6.6.6.6 update-source loo
PE1(config-router)#nei 6.6.6.6 update-source loopback 0
PE1(config-router)#add
PE1(config-router)#address-family vpnv4
PE1(config-router-af)#nei
PE1(config-router-af)#neighbor 6.6.6.6 ac
PE1(config-router-af)#neighbor 6.6.6.6 activate
PE1(config-router-af)#neighbor 6.6.6.6 next
PE1(config-router-af)#neighbor 6.6.6.6 next-hop-
PE1(config-router-af)#neighbor 6.6.6.6 next-hop-s
PE1(config-router-af)#neighbor 6.6.6.6 next-hop-self
PE1(config-router-af)#neighbor 6.6.6.6 sen
PE1(config-router-af)#neighbor 6.6.6.6 send-community b
PE1(config-router-af)#neighbor 6.6.6.6 send-community both
PE1(config-router-af)#add
PE1(config-router-af)#exit
PE1(config-router)#add
PE1(config-router)#address-family ipv4 vrf B
PE1(config-router)#address-family ipv4 vrf Bank-A
PE1(config-router-af)#red
PE1(config-router-af)#redistribute st
PE1(config-router-af)#redistribute static
PE1(config-router-af)#redistribute conn
PE1(config-router-af)#redistribute connected
PE1(config-router-af)#address-family ipv4 vrf Bank-B
PE1(config-router-af)#redistribute static
PE1(config-router-af)#redistribute connected
PE1(config-router-af)#address-family ipv4 vrf Bank-C
PE1(config-router-af)#redistribute static
PE1(config-router-af)#redistribute connected
PE1(config-router-af)#
```
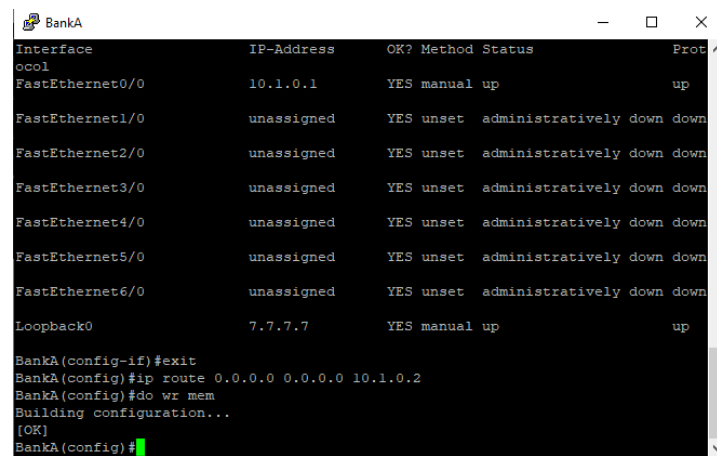
Figure 32

```
PE2(config)#router bgp 55000
PE2(config-router)#ne
PE2(config-router)#nei
PE2(config-router)#neighbor 5.5.5.5 remote-as 55000
PE2(config-router)#neighbor 5.5.5.5 upd
PE2(config-router)#neighbor 5.5.5.5 update-source
*Dec  2 23:52:50.083: %BGP-5-ADJCHANGE: neighbor 5.5.5.5 Up
PE2(config-router)#neighbor 5.5.5.5 update-source lo
PE2(config-router)#neighbor 5.5.5.5 update-source loo
PE2(config-router)#neighbor 5.5.5.5 update-source loopback 0
PE2(config-router)#add
PE2(config-router)#address-family vpnv4
PE2(config-router-af)#nei 5.5.5.5 act
PE2(config-router-af)#nei 5.5.5.5 activate
PE2(config-router-af)#nei 5.5.5.5 activate
*Dec  2 23:53:54.391: %BGP-5-ADJCHANGE: neighbor 5.5.5.5 Down Capability changed
*Dec  2 23:53:54.395: %BGP_SESSION-5-ADJCHANGE: neighbor 5.5.5.5 IPv4 Unicast to
pology base removed from session  Capability changed
PE2(config-router-af)#nei 5.5.5.5 activate
*Dec  2 23:53:55.447: %BGP-5-ADJCHANGE: neighbor 5.5.5.5 Up
PE2(config-router-af)#nei 5.5.5.5 nei
PE2(config-router-af)#nei 5.5.5.5 ne
PE2(config-router-af)#nei 5.5.5.5 next-hop-s
PE2(config-router-af)#nei 5.5.5.5 next-hop-self
PE2(config-router-af)#nei 5.5.5.5 sen
PE2(config-router-af)#nei 5.5.5.5 send-community both
PE2(config-router-af)#exit
PE2(config-router)#add
PE2(config-router)#address-family ipv4 vrf Bank-A
PE2(config-router-af)#red
PE2(config-router-af)#redistribute st
PE2(config-router-af)#redistribute static
PE2(config-router-af)#redistribute con
PE2(config-router-af)#redistribute connected
PE2(config-router-af)#address-family ipv4 vrf Bank-B
PE2(config-router-af)#redistribute static
PE2(config-router-af)#redistribute connected
PE2(config-router-af)#address-family ipv4 vrf Bank-C
PE2(config-router-af)#redistribute static
PE2(config-router-af)#redistribute connected
PE2(config-router-af)#do wr mem
Building configuration...
[OK]
PE2(config-router-af)#
```

Figure 33

Confirmation Of Routes Successfully Vpn has been implemented.


```
 PE1
PE1(config-router-af)#
*Dec  3 00:09:25.163: %BGP-5-ADJCHANGE: neighbor 6.6.6.6 Down Peer closed the session
*Dec  3 00:09:25.167: %BGP_SESSION-5-ADJCHANGE: neighbor 6.6.6.6 IPv4 Unicast topology base remov
*Dec  3 00:09:26.167: %BGP-5-ADJCHANGE: neighbor 6.6.6.6 Up
PE1(config-router-af)#do wr mem
Building configuration...
[OK]
PE1(config-router-af)#end
PE1#sh
*Dec  3 00:12:24.019: %SYS-5-CONFIG_I: Configured from console by console
PE1#sh ip route vrf B
PE1#sh ip route vrf Bank-A

Routing Table: Bank-A
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      7.0.0.0/32 is subnetted, 1 subnets
S        7.7.7.7 [1/0] via 10.1.0.1
      8.0.0.0/32 is subnetted, 1 subnets
B        8.8.8.8 [20/0] via 10.1.0.5 (Bank-B), 00:07:01
      9.0.0.0/32 is subnetted, 1 subnets
B        9.9.9.9 [20/0] via 10.1.0.9 (Bank-C), 00:06:52
      10.0.0.0/8 is variably subnetted, 9 subnets, 2 masks
C        10.1.0.0/30 is directly connected, FastEthernet0/0
L        10.1.0.2/32 is directly connected, FastEthernet0/0
B        10.1.0.4/30 is directly connected (Bank-B), 00:06:59, FastEthernet1/0
L        10.1.0.6/32 is directly connected, FastEthernet1/0
B        10.1.0.8/30 is directly connected (Bank-C), 00:06:50, FastEthernet2/0
L        10.1.0.10/32 is directly connected, FastEthernet2/0
B        10.3.0.0/30 [200/0] via 6.6.6.6, 00:01:38
B        10.3.0.8/30 [200/0] via 6.6.6.6, 00:01:28
B        10.10.10.10/32 [200/0] via 6.6.6.6, 00:01:43
      12.0.0.0/32 is subnetted, 1 subnets
B        12.12.12.12 [200/0] via 6.6.6.6, 00:01:18
PE1#
```

Figure 34


```
PE1#sh ip route vrf Bank-B

Routing Table: Bank-B
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      7.0.0.0/32 is subnetted, 1 subnets
B        7.7.7.7 [20/0] via 10.1.0.1 (Bank-A), 00:10:57
      8.0.0.0/32 is subnetted, 1 subnets
S        8.8.8.8 [1/0] via 10.1.0.5
      10.0.0.0/8 is variably subnetted, 5 subnets, 2 masks
B        10.1.0.0/30 is directly connected (Bank-A), 00:10:50, FastEthernet0/0
L        10.1.0.2/32 is directly connected, FastEthernet0/0
C        10.1.0.4/30 is directly connected, FastEthernet1/0
L        10.1.0.6/32 is directly connected, FastEthernet1/0
B        10.3.0.8/30 [200/0] via 6.6.6.6, 00:04:54
PE1#
```

Figure 35

```
PE1#sh ip route vrf Bank-C

Routing Table: Bank-C
Codes: L - local, C - connected, S - static, R - RIP, M - mobile, B - BGP
       D - EIGRP, EX - EIGRP external, O - OSPF, IA - OSPF inter area
       N1 - OSPF NSSA external type 1, N2 - OSPF NSSA external type 2
       E1 - OSPF external type 1, E2 - OSPF external type 2
       i - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
       ia - IS-IS inter area, * - candidate default, U - per-user static route
       o - ODR, P - periodic downloaded static route, H - NHRP, l - LISP
       + - replicated route, % - next hop override

Gateway of last resort is not set

      7.0.0.0/32 is subnetted, 1 subnets
B        7.7.7.7 [20/0] via 10.1.0.1 (Bank-A), 00:11:25
      9.0.0.0/32 is subnetted, 1 subnets
S        9.9.9.9 [1/0] via 10.1.0.9
      10.0.0.0/8 is variably subnetted, 5 subnets, 2 masks
B        10.1.0.0/30 is directly connected (Bank-A), 00:11:18, FastEthernet0/0
L        10.1.0.2/32 is directly connected, FastEthernet0/0
C        10.1.0.8/30 is directly connected, FastEthernet2/0
L        10.1.0.10/32 is directly connected, FastEthernet2/0
B        10.3.0.8/30 [200/0] via 6.6.6.6, 00:05:10
      12.0.0.0/32 is subnetted, 1 subnets
B        12.12.12.12 [200/0] via 6.6.6.6, 00:05:12
PE1#
```
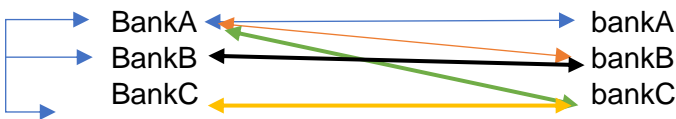
Figure 36

Plan for Implementation

Ping test according to policy
A to All

Figure 37

BankA-bankC

```
BankA#ping 12.12.12.12
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 12.12.12.12, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 128/176/224 ms
BankA#
```

Figure 38

BankC-bankC

Figure 38

bankB-BankA

Figure 39

bankb – BankB

Figure 40

And As per the policy bankB cannot communicate with Bank C

Figure 41

bankC- BankA
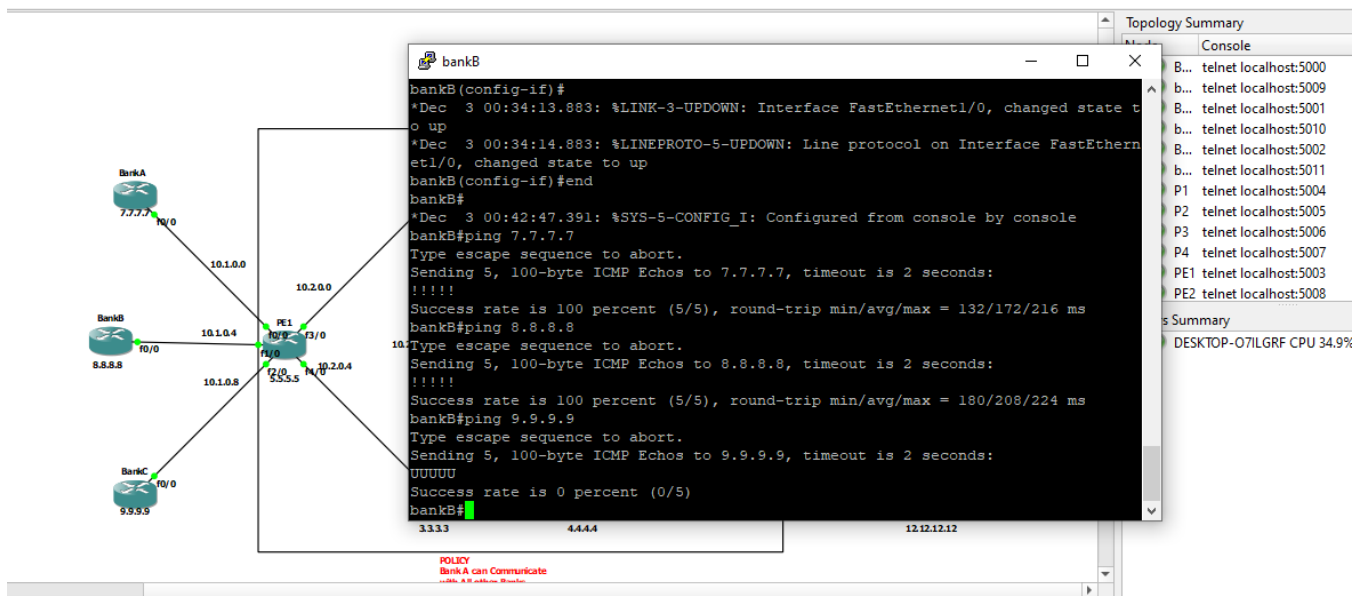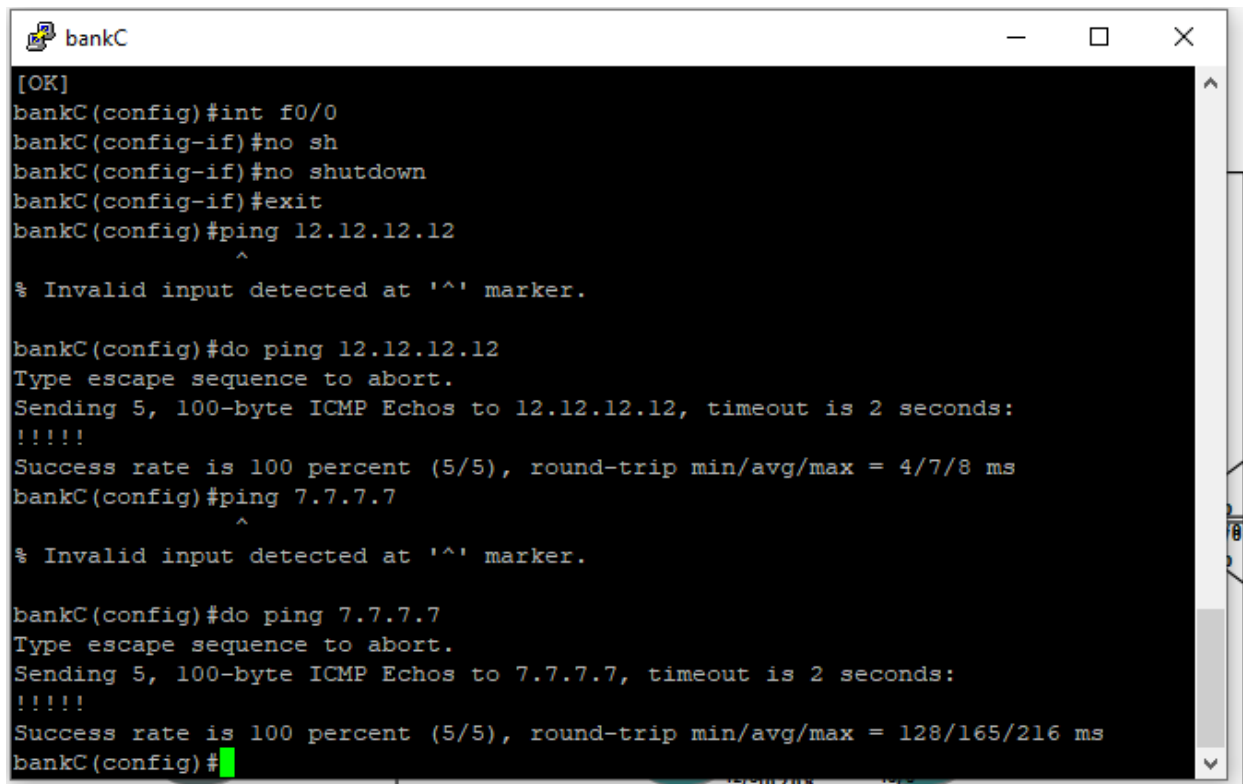


```
bankC                                                     —    □    ✕

[OK]
bankC(config)#int f0/0
bankC(config-if)#no sh
bankC(config-if)#no shutdown
bankC(config-if)#exit
bankC(config)#ping 12.12.12.12
                   ^
% Invalid input detected at '^' marker.

bankC(config)#do ping 12.12.12.12
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 12.12.12.12, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 4/7/8 ms
bankC(config)#ping 7.7.7.7
                     ^
% Invalid input detected at '^' marker.

bankC(config)#do ping 7.7.7.7
Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 7.7.7.7, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 128/165/216 ms
bankC(config)#
```

Figure 42