What You Make Possible
The CCIE Candidate’s Introduction to MPLS L3VPN Networks
BRKCCIE-3345
Objectives

- Define network and tasks
- MPLS IP Unicast Forwarding
- What are VRFs
- MPLS L3 VPNs
- Tasks into CCIE Labs
- MPLS L3 VPN Game
Define Network and Tasks
Cisco Learning Lab for this session
MPLS IP Unicast Forwarding
Control Plane and Data Plane

- Dynamic protocols build the control plane.
- Packets are forwarded on the data plane.
Who do we Turn to for Lookups?

Control Plane

- IP Routing protocols
- Routing Information Base (RIB)

Data Plane

- IP only packets forwarding
- Cisco Express Forwarding (CEF) and its Forwarding Information Base (FIB)
MPLS (Layer 2.5) Header Fields:

- Label, 20 bits
- Experimental (CoS), 3 bits
- Stacking bit, 1 bit. This is the bottom-of-stack bit. 1=on=last label.
- Time to live, 8 bits
The Birth of a Label

- For routes in the routing table, each router assigns a locally significant label for each IP route.
Won’t You Be My Neighbor?

- Two step process
  - LDP neighbor discovery
    LDP link hello uses destination UDP port 646 and is sent to 224.0.0.2
    Hello may include the IP address desired for peering, different than the source IP in the header.
  - Setup LDP session with neighbor who says hello.
    Session is TCP based on destination port 646
    Router with highest LDP router ID will initiate this TCP session (called the active LSR). Keepalives are sent every 60 seconds.
MPLS Label Distribution

- Labels are created and advertised in Control plane
  - LDP label mapping
    - Each router assigns local label
    - Each router advertises that label
    - Label 3 is a reserved implicit null label for PHP

```
<table>
<thead>
<tr>
<th>In</th>
<th>Out</th>
<th>In</th>
<th>Out</th>
<th>In</th>
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<td></td>
</tr>
</tbody>
</table>
```

I am downstream router closest to 10.1.11.1

I am upstream router away from 10.1.11.1
How Routers Use Labels

Three Major “Operations” Have Been Defined for Data plane

- **PUSH** – impose label (Ingress Router)
- **POP** – dispose label (Egress Router)
- **SWAP** – which is a pop/push combo (Intermediate Router)

![Packet Flow Diagram](image)

- **P1**
- **P2**
- **PE1**
- **PE3**
- **I am upstream router away from 10.1.11.1**

**10.1.11.1/32**
How Routers are Use Labels

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---

Packet Flow

10.1.11.1/32

PE1  P1  P2  PE3

I am upstream router away from 10.1.11.1
How Routers are Use Labels

Three Major “Operations” Have Been Defined for Data plane

- **PUSH** – impose label (Ingress Router)
- **POP** – dispose label (Egress Router)
- **SWAP** – which is a pop/push combo (Intermediate Router)

Packet Flow

I am upstream router away from 10.1.11.1
Device Roles on the Topology

- **LSR – Label Switch Router**
  Router that supports MPLS

- **Ingress LSR (upstream)**
  Provider Edge (PE) first hop. Takes IP naked transit packet and pushes/imposes a label and forwards.

- **Intermediate LSR**
  Provider (P) takes labelled packet and swaps labels and forwards to next LSR

- **Egress LSR (downstream)**
  Provider Edge (PE) last hop. Pops/disposes label and forwards naked IP packet

---

**Packet Flow**

10.1.11.1/32
Where Do Routers Turn to for Lookups?

**Control Plane**
- IP Routing protocols
- Routing Information Base (RIB)
- Label Distribution Protocol (LDP)
- Label Information Base (LIB)

**Data Plane**
- IP only packets forwarding
- Cisco Express Forwarding (CEF) and its Forwarding Information Base (FIB)
- MPLS labeled packet forwarding
- Label Forwarding Information Base (LFIB)
PHP

- PHP – Penultimate Hop Pop
  - Next to last LSR, removes top label, so that egress LSR (PE) doesn’t have to
- Penultimate Hop Popping (PHP) saves the egress PE from an extra database lookup.
Follow the Bouncing Ball (Label)

```
PE1#show mpls ldp bindings 10.1.11.1 32
tib entry: 10.1.11.1/32, rev 4
   local binding: tag: imp-null
P1#show mpls ldp bindings 10.1.11.1 32
tib entry: 10.1.11.1/32, rev 2
   local binding: tag: 16
   remote binding: tsr: 10.1.1.2:0, tag: 16
   remote binding: tsr: 10.1.1.1:0, tag: imp-null
P2#show mpls ldp bindings 10.1.11.1 32
tib entry: 10.1.11.1/32, rev 2
   local binding: tag: 16
   remote binding: tsr: 10.1.1.1:0, tag: 16
PE3#show mpls ldp binding 10.1.11.1 32
tib entry: 10.1.11.1/32, rev 2
   local binding: tag: 16
   remote binding: tsr: 10.1.1.2:0, tag: 16
PE3#show mpls forwarding-table 10.1.11.1
Local   Outgoing   Prefix   Bytes tag   Outgoing   Next Hop
tag or VC or Tunnel Id     switched interface
tag  16  10.1.11.1/32   0      Et0/0     10.2.23.1
```
The Order of Things

- IP IGP routing protocols build the IP tables
- LSRs assign a *local* label for each route
- LSRs share their labels with other LSRs using LDP
- LSRs build their own LIB, LFIB and FIBs based on what they have learned from their LDP neighbors
MPLS MTU Problem

- MTU is automatically adjusted
- You can change with `mpls mtu` command
  - `mpls mtu 1512` -- would support 3 labels (4 bytes per MPLS header)

- Large packets dropped
  MTU not supported by switches. Multiple labels may be present pushing the MTU to a size not supported by the infrastructure.
LDP Features

- (config)# no mpls ldp advertise-labels
- (config)# mpls ldp advertise-labels [for (ACL-of-networks)] [to (ACL-peers)]
- (config-if)# mpls label range 200 120000

- Security – Computes MD5 Signatures
  - (config)# mpls ldp neighbor (ip#) password (pw)

- Label filters – inbound from neighbor
  - (config)# mpls ldp neighbor (ip#) labels accept (#)
    (ip#) = IP address of LDP neighbor
    (#) = number of access-list of network prefixes
Hide the MPLS Core from the Client

- Traceroute uses TTL manipulation to trigger feedback.
- Disabling the TTL propagation will not copy the initial IP TTL to the MPLS TTL, and MPLS will start at 255.
- Results: MPLS LSRs become the invisible network to the eyes of traceroute.
No mpls ip propagate-ttl (on All LSRs)

```
PE3(config)#do trace 10.1.11.1

Type escape sequence to abort.
Tracing the route to 10.1.11.1

  1 10.2.23.1 [MPLS: Label 16 Exp 0] 12 msec 0 msec 0 msec
  2 10.2.12.1 [MPLS: Label 16 Exp 0] 0 msec 4 msec 0 msec
  3 10.2.11.1 0 msec * 0 msec

PE3(config)#no mpls ip propagate-ttl
PE3(config)#do trace 10.1.11.1

Type escape sequence to abort.
Tracing the route to 10.1.11.1

  1 10.2.11.1 4 msec * 0 msec

PE3(config)#
```
Troubleshooting MPLS

- LDP neighborship failed
  - MPLS not enabled, LDP TCP/646 or TDP TCP/711 ports filtered, no L3 route to LDP neighbor LSR router-id, highest loopback address.

- Labels not assigned
  - CEF not enabled

- Labels not shared
  - LDP/TDP between neighbors

- Slow convergence
  - Get rid of RIP ☺ IGP is biggest factor in convergence delay

- Large packets dropped
  - MTU not supported by switches. Multiple labels may be present pushing the MTU to a size not supported by the infrastructure.
Minimal Configuration to Enable MPLS

- (config)# ip cef
- (config)# mpls ip
- (config)# interface ethernet 0/0
- (config-if)# mpls ip
- (config)# interface ethernet 0/1
- (config-if)# mpls ip
What are VRFs
VRF: The Virtual Routing Table

- VRF: Virtual Routing and Forwarding instance

IP routing table
CEF
FIB

Eth0/0
Eth0/1
Eth0/2
Eth0/3
Eth1/0
Eth1/1

IP routing table
CEF
FIB
Uniquely Identifying Similar Routes

- What if customer A and customer B both have a 10.0.0.0/8 network, how do we differentiate these?

- Route Distinguisher (RD) is a 64-bit identifier prepended to each IP address to make it globally unique into our network.

- The resulting 96-bit address is called VPNv4 address.

- VPNv4 addresses can only be exchanged via BGP between PE routers.
  - BGP supporting other address families than IPv4 addresses is called multi-protocol BGP or MP-BGP.
Vrf RED and vrf GREEN, with Interfaces

RD 111:111
Customer A

RD 111:111
Customer A

RD 222:222
Customer B

RD 222:222
Customer B

CE1A

CE2A

CE1B

CE2B

PE1

PE2

PE3

P1

P2

Lo11=11.11.11.11/32
192.168.11.0/24

Lo0=192.168.1.1/32

Lo0=10.1.1.1/32

Lo0=192.168.2.1/32

Lo11=11.11.11.11/32

RD 111:111

RD 222:222

RD 111:111

RD 222:222

Lo0=192.168.2.2/32

Lo0=192.168.1.2/32

Lo0=192.168.2.3/24

Lo0=192.168.2.2/32

Lo0=192.168.2.3/24

192.168.12.0/24

192.168.12.0/24
To exchange routes between Customer and Provider’s VRF we can use OSPF, RIP, EIGRP, BGP or static routing.

Provider side router runs this protocols inside VRFs or uses VRF-aware implementations.
Minimal Configuration for VRF

ip vrf CompanyC
  rd 300:300

interface e0/0
  ip vrf forwarding CompanyC
  ip address 10.2.22.2 255.255.255.0
MPLS L3 VPNs
Ingredient List for MPLS L3 VPNs…

- MPLS
- VRFs
- BGP
- Routers
Stacks

IP Packet

Label (20 bits)  CoS  S  TTL

L2 Header  MPLS Header  MPLS Header

32 bits  32 bits

Stacking bit = 0  Stacking bit = 1

Switching through MPLS core  VPN identifier

MPLS Header

VPN identifier
MP-BGP for Exchange Addresses

Only MP-BGP can exchange VPNv4 addresses (if you remember, this is address constructed from RD and IP address). So we need to configure MP-BGP between PE routers and enable VPNv4 address-family routing exchange.

PE1(config)#router bgp 65530
PE1(config-router)#address-family vpnv4 unicast
PE1(config-router-af)#neigh 10.1.11.3 activate

BGP routing instances for VRFs will be created automatically - to be able transfer routes from IGP via VPNv4 (uses routes redistribution).
MP-BGP for Exchange Labels

Labels are delivered into extended communities together with VPNv4 addresses.

PE3#show ip bgp vpnv4 vrf RED 192.168.1.1
BGP routing table entry for 111:111:192.168.1.1/32, version 37
Paths: (1 available, best #1, table RED)
  Advertised to update-groups:
    2
  Local, (Received from a RR-client)
    10.1.11.1 (metric 40) from 10.1.11.1 (10.1.11.1)
      Origin incomplete, metric 11, localpref 100, valid, internal, best
    Extended Community: RT:100:100 OSPF DOMAIN ID:0x0005:0x000000020200
    OSPF RT:0.0.0.0:2:0 OSPF ROUTER ID:192.168.11.2:512
    mpls labels in/out nolabel/24
MPLS Labels for VPN (Control plane)

Lo0=192.168.1.1/32

10.1.11.1/32

Egress LSR

PE1

Label: 3

P1

Label: 19

Ingress LSR

PE3

Label: 16

CE1A

CE2A

Traffic flow

In
Out
No label
No label

In
Out
E0/1
19
No label

In
Out
E0/0
16
E0/1
19

Label: 24

MP-BGP

In
Out
24
No label

In
Out
No label
24

LDP
MPLS Labels for VPN (Data plane)

Lo0=192.168.1.1/32

CE1A

PE1

P1

LSP

Egress LSR

P2

PE3

CE2A

Inress LSR

10.1.11.1/32

Packet Flow

= Control Plane

= Data Plane

MP-BGP

LDP

Label: 24
MP-BGP for Exchange Routes

Check BGP instance for VRF (it should be enabled automatically when you configure VRF and MP-BGP)

```
address-family ipv4 vrf RED
no synchronization
exit-address-family
```

Configure redistribution

```
PE3(config)#router bgp 65530
PE3(config-router)#address-family ipv4 vrf RED
PE3(config-router-af)#redistribute ospf 2 vrf RED

PE3(config)#router ospf 2 vrf RED
PE3(config-router)#redistribute bgp 65530 subnets
```
**Viewing Routes in MP-BGP by RD**

```plaintext
PE3#sh ip bgp vpnv4 rd 222:222
BGP table version is 17, local router ID is 10.1.11.3
Status codes: s suppressed, d damped, h history, * valid, > best, i - internal,
r RIB-failure, S Stale
Origin codes: i - IGP, e - EGP, ? - incomplete

<table>
<thead>
<tr>
<th>Network</th>
<th>Next Hop</th>
<th>Metric</th>
<th>LocPrf</th>
<th>Weight</th>
<th>Path</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route Distinguished: <strong>222:222</strong> (default for vrf GREEN)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*&gt;i11.11.11.11/32</td>
<td>10.1.11.2</td>
<td>11</td>
<td>100</td>
<td>0</td>
<td>?</td>
</tr>
<tr>
<td>*&gt;i192.168.2.1/32</td>
<td>10.1.11.2</td>
<td>11</td>
<td>100</td>
<td>0</td>
<td>?</td>
</tr>
<tr>
<td>*&gt; 192.168.2.2/32</td>
<td>192.168.23.1</td>
<td>11</td>
<td>32768</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>*&gt;i192.168.12.0</td>
<td>10.1.11.2</td>
<td>0</td>
<td>100</td>
<td>0</td>
<td>?</td>
</tr>
<tr>
<td>*&gt; 192.168.23.0</td>
<td>0.0.0.0</td>
<td>0</td>
<td>32768</td>
<td>?</td>
<td></td>
</tr>
<tr>
<td>*&gt; 192.168.112.0</td>
<td>192.168.23.1</td>
<td>20</td>
<td>32768</td>
<td>?</td>
<td></td>
</tr>
</tbody>
</table>
```
How do we Deliver the Correct Routes?

RD 111:111
Customer A

CE1A
Lo0=192.168.1/32
Lo0=10.1.1.1/32
CE1B
Lo1=11.11.11.1/32

P1
CE1B
CE2A
CE2B

RD 111:111
Customer A

RD 222:222
Customer B

PE1
E0/0
CE1A
CE1B
Lo0=192.168.2.1/32

PE2
E0/0
192.168.12.0/24
CE1B

PE3
E0/0
192.168.23.0/24
CE2B

Lo0=192.168.12.0/24
Lo0=10.1.1.2/32
Lo0=10.1.1.3/32
Lo0=192.168.2.2/32
Lo0=192.168.1.1/32
Lo0=192.168.1.2/32
Lo0=192.168.1.3/32

How do we Deliver the Correct Routes?
Route Target

- Route Targets are additional attributes attached to VPNv4 BGP routes to indicate VPN membership.
- Extended BGP communities are used to encode these attributes:
  - Extended communities carry the meaning of the attribute together with its value.
- Any number of route targets can be attached to a single route.
How do we Deliver the Correct Routes?

Customer A

CE1A

Customer B

CE1B

Customer A

CE2A

Customer B

CE2B

192.168.11.0/24

192.168.23.0/24

192.168.32.0/24

192.168.11.0/24

192.168.11.1/32

192.168.12.0/24

192.168.2.1/32

192.168.2.2/32

192.168.2.3/32

192.168.11.1/32

192.168.2.1/32

192.168.2.2/32

192.168.11.11.1/32

Lo0=10.1.11.2/32

Lo0=10.1.11.3/32

Lo0=10.1.11.1/32

Lo0=192.168.1.2/32

Lo0=192.168.1.1/32

Lo0=192.168.1.2/32

Lo0=192.168.2.1/32

Lo0=192.168.2.2/32

Lo0=192.168.2.3/32

RT 100:200

RT 100:100

RT 200:221

RT 200:212
Viewing the Route Target in MP-BGP

PE3#show ip bgp vpnv4 vrf GREEN 192.168.2.1
BGP routing table entry for 222:222:192.168.2.1/32, version 53
 Paths: (1 available, best #1, table GREEN)
   Advertised to update-groups:
     2
   Local, (Received from a RR-client)
     10.1.11.2 (metric 40) from 10.1.11.2 (10.1.11.2)
       Origin incomplete, metric 11, localpref 100, valid, internal, best
       Extended Community: RT:200:212 OSPF DOMAIN ID:0x0005:0x000000010200
       OSPF RT:0.0.0.0:2:0 OSPF ROUTER ID:192.168.12.2:512
       mpls labels in/out nolabel/25
How do we Deliver the Correct Routes?

- **Customer A**
  - CE1A
  - CE2A
  - PE1

- **Customer B**
  - CE1B
  - CE2B

**Routing Targets (RT):**
- RT 100:100
- RT 100:200
- RT 200:212
- RT 200:221
- RT 303:333

** prefixes:
- 192.168.11.0/24
- 192.168.12.0/24
- 192.168.23.0/24

**Loopback Addresses:**
- Lo0=192.168.1.1/32
- Lo0=192.168.2.1/32
- Lo0=192.168.1.2/32
- Lo0=192.168.2.2/32
How to Control RT?

We can mark route with the other extcommunity and receive on the other VRF.
Do not forget about REVERSE PATH!!!
MPLS VPN LSP Troubleshooting

- Look for route to BGP next-hop
  - `show ip route`

- Check VRF for route “inside”
  - `show ip route vrf RED`

- Check LFIB for route
  - `show mpls forwarding vrf [name] [address] detail`

- Check MP-BGP VPNv4
  - `show ip bgp vpnv4 vrf [name] [address]`

- Check LFIB for next-hop
  - `show mpls forwarding [address] detail`
Sham-Link to Correct OSPF Backdoor

Intra Area Routes

PE2

P1

P2

PE3

CE1B

CE2B

Customer B

Customer B

Lo11=11.11.11.11/32

Lo0=192.168.2.2/32

EO/0

EO/1

E0/0

E0/1

192.168.112.0/24

192.168.12.0/24

192.168.23.0/24

192.168.2.1/32

Lo0=192.168.2.1/32

192.168.12.0/24

192.168.23.0/24

Lo0=192.168.2.2/32

Intra Area Routes
Configure Sham-Link

Configure a separate /32 address on the remote PE for sham-link. This /32 address must meet the following criteria:

- **Belong to a VRF.**
- **Not be advertised by OSPF.**
- **Be advertised by BGP.**
- Associate the sham-link with an existing OSPF area.

```
interface Loopback1
  ip vrf forwarding GREEN
  ip address 22.1.1.2 255.255.255.255
  address-family ipv4 vrf GREEN
    redistribute ospf 1 vrf GREEN
    no synchronization
    network 22.1.1.2 mask 255.255.255.255
  router ospf 1 vrf GREEN
    log-adjacency-changes
    area 0 sham-link 22.1.1.2 22.1.1.3
```

```
interface Loopback1
  ip vrf forwarding GREEN
  ip address 22.1.1.3 255.255.255.255
  address-familyipv4 vrf GREEN
    redistribute ospf 1 vrf GREEN
    no synchronization
    network 22.1.1.3 mask 255.255.255.255
  router ospf 1 vrf GREEN
    log-adjacency-changes
    area 0 sham-link 22.1.1.3 22.1.1.2
```
Minimal MPLS L3 VPN configuration

- `ip vrf CompanyA`
- `route-target both 300:300`

- `interface Ethernet 0/0`
- `ip vrf forwarding CompanyA`
- `ip address 192.168.10.1 255.255.255.0`

- `router bgp 65530`
- `address-family vpnv4 unicast`
- `neighbor 10.10.10.1 activate`
- `address-family ipv4 vrf CompanyA`
- `redistribute connected`

- `ip vrf CompanyA`
- `route-target both 300:300`

- `interface Ethernet 0/0`
- `ip vrf forwarding CompanyA`
- `ip address 192.168.20.1 255.255.255.0`

- `router bgp 65530`
- `address-family vpnv4 unicast`
- `neighbor 10.10.20.1 activate`
- `address-family ipv4 vrf CompanyA`
- `redistribute connected`
Tasks into CCIE Labs
Into CCIE Labs and into Real Life

- CCIE R&S TS (Troubleshooting) part – problems with MPLS, LDP, BGP
- CCIE R&S CFG (Configuration) part – MPLS L3VPN configuration with features
- CCIE SP – 😊
- CCIE Security
- CCIE Wireless
- CCIE Voice
- CCIE DataCentre – VRF, MPLS
MPLS L3 VPN Game
Routing for Core

Customer A 192.168.1.1

CE1A 10.1.11.1 PE1 10.1.11.1 P1 10.1.11.1 P2 10.1.11.2 PE3 10.1.11.3 CE2A 192.168.1.2

IGP

Routing Table

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<tr>
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Routing Table

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<td>PE1</td>
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Routing Table

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<td>P1</td>
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Routing Table

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<th>Out</th>
</tr>
</thead>
<tbody>
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<td>Outside</td>
<td>P2</td>
</tr>
</tbody>
</table>

Routing Table

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<th>In</th>
<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside</td>
<td>PE1</td>
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Routing Table

<table>
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<tr>
<th>In</th>
<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>PE3</td>
</tr>
</tbody>
</table>

Routing Table

<table>
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Traffic flow

Customer A 192.168.1.1

CE1A

PE1

P1

P2

PE3

CE2A

10.1.11.1

10.1.11.3

10.1.11.1

10.1.11.1

10.1.11.1

10.1.11.3

Routing Table

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Routing Table

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Routing Table

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Routing Table

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Traffic flow

Customer A 192.168.1.1

CE1A

PE1

P1

P2

PE3

CE2A

10.1.11.1

10.1.11.3

10.1.11.1

10.1.11.1

10.1.11.1

10.1.11.3

Routing Table

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Routing Table

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Routing Table

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Traffic flow

Customer A 192.168.1.1

CE1A

PE1

P1

P2

PE3

CE2A

10.1.11.1

10.1.11.3

10.1.11.1

10.1.11.1

10.1.11.1

10.1.11.3

Routing Table

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Routing Table

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Routing Table

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Label Assignment for MPLS Core

Customer A 192.168.1.1

CE1A

10.1.11.1

PE1

P1

P2

PE3

CE2A

Customer A 192.168.1.2

LDP

Traffic flow

MPLS Table

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MPLS Table

<table>
<thead>
<tr>
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<tbody>
<tr>
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MPLS Table

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MPLS Table

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MPLS Table

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MPLS Table

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Traffic flow

10.1.11.1

10.1.11.1 -&gt; 3
10.1.11.3 -&gt; 16
10.1.11.3 -&gt; 18
10.1.11.3 -&gt; 3
10.1.11.1 -&gt; 20
10.1.11.1 -&gt; 35
10.1.11.1 -&gt; 3
10.1.11.3 -&gt; 18
10.1.11.3 -&gt; 3
10.1.11.3 -&gt; 35
10.1.11.3 -&gt; 18
10.1.11.3 -&gt; 3
10.1.11.3 -&gt; 18
10.1.11.3 -&gt; 3
10.1.11.3 -&gt; 18
10.1.11.3 -&gt; 3
Label Assignment for VPN

Customer A (192.168.1.1)

CE1A → PE1 → P1 → P2 → PE3 → CE2A

MBGP

192.168.1.1 -> RT 100:100 -> label 26
192.168.1.2 -> RT 100:200 -> label 25

Traffic flow

MPLS Table

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MPLS Table

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MPLS Table

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<tbody>
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192.168.1.2

Traffic flow
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