Introduction to MPLS VPN

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Agenda

- Introduction to MPLS VPN
  - MPLS VPN Architecture
  - Control Plane Functionality
  - Data Plane Functionality
  - Basic Configuration
- MPLS VPN Troubleshooting Overview
- Summary

MPLS VPNs

Layer 3

What Is a Virtual Private Network?

- VPN is a set of sites or groups which are allowed to communicate with each other
- VPN is defined by a set of administrative policies
  - Policies established by VPN customers
  - Policies could be implemented completely by VPN service providers
- Flexible inter-site connectivity
  - Ranging from complete to partial mesh
- Sites may be either within the same or in different organizations
  - VPN can be either intranet or extranet
- Site may be in more than one VPN
  - VPNs may overlap
- Not all sites have to be connected to the same service provider
  - VPN can span multiple providers

L2 vs. L3 VPNs

Layer 2 VPNs

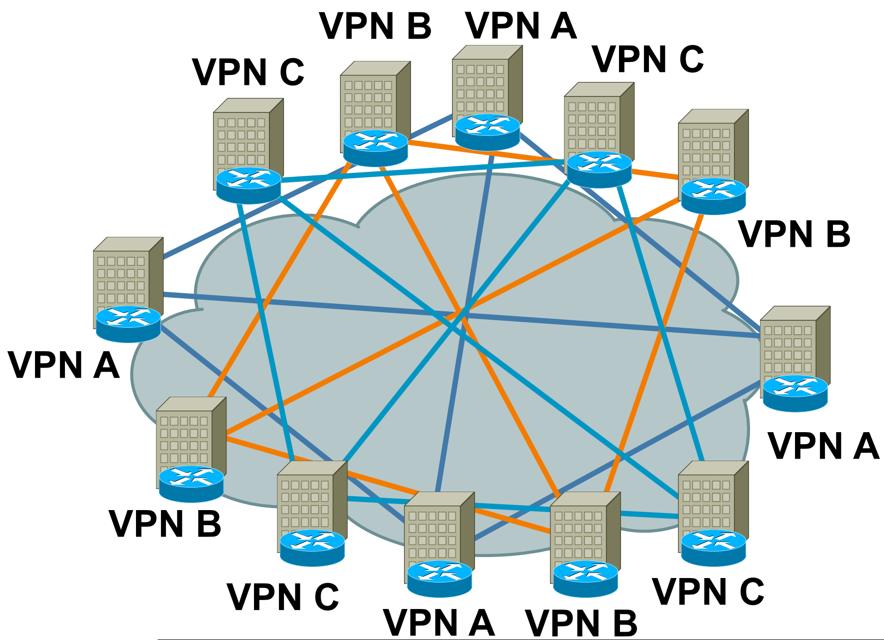
- Customer endpoints (CPE) connected via Layer 2 such as Frame Relay DLCI, ATM VC or point-to-point connection
- Provider network is not responsible for distributing site routers as routing relationship is between the customer endpoints
- Provider will need to manually fully mesh end points if any-to-any connectivity is required

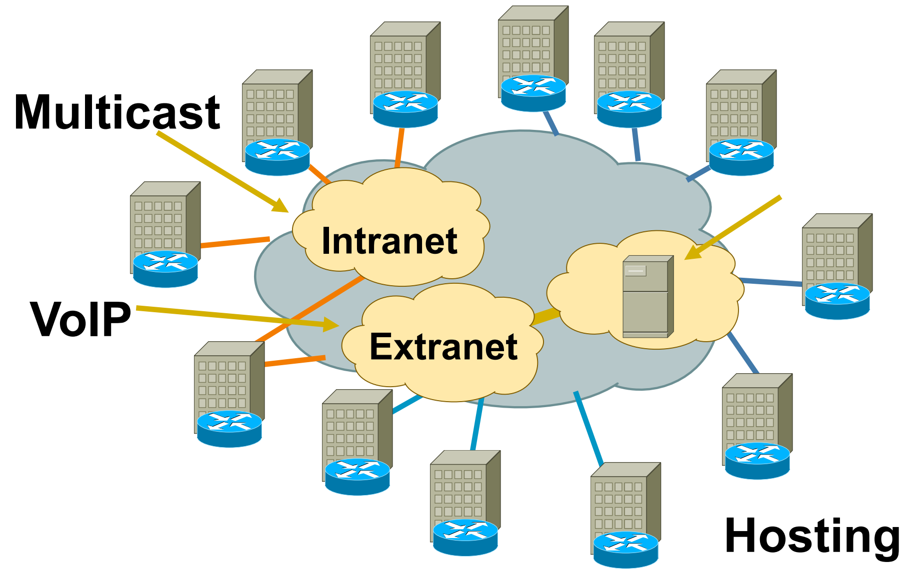
Layer 3 VPN

- Customer end points peer with providers' routers @ L3
- Provider network responsible for distributing routing information to VPN sites
- Don't have to manually fully mesh customer endpoints to support any-to-any connectivity

Layer 3 VPNs

IP L3 vs. MPLS L3 VPNs





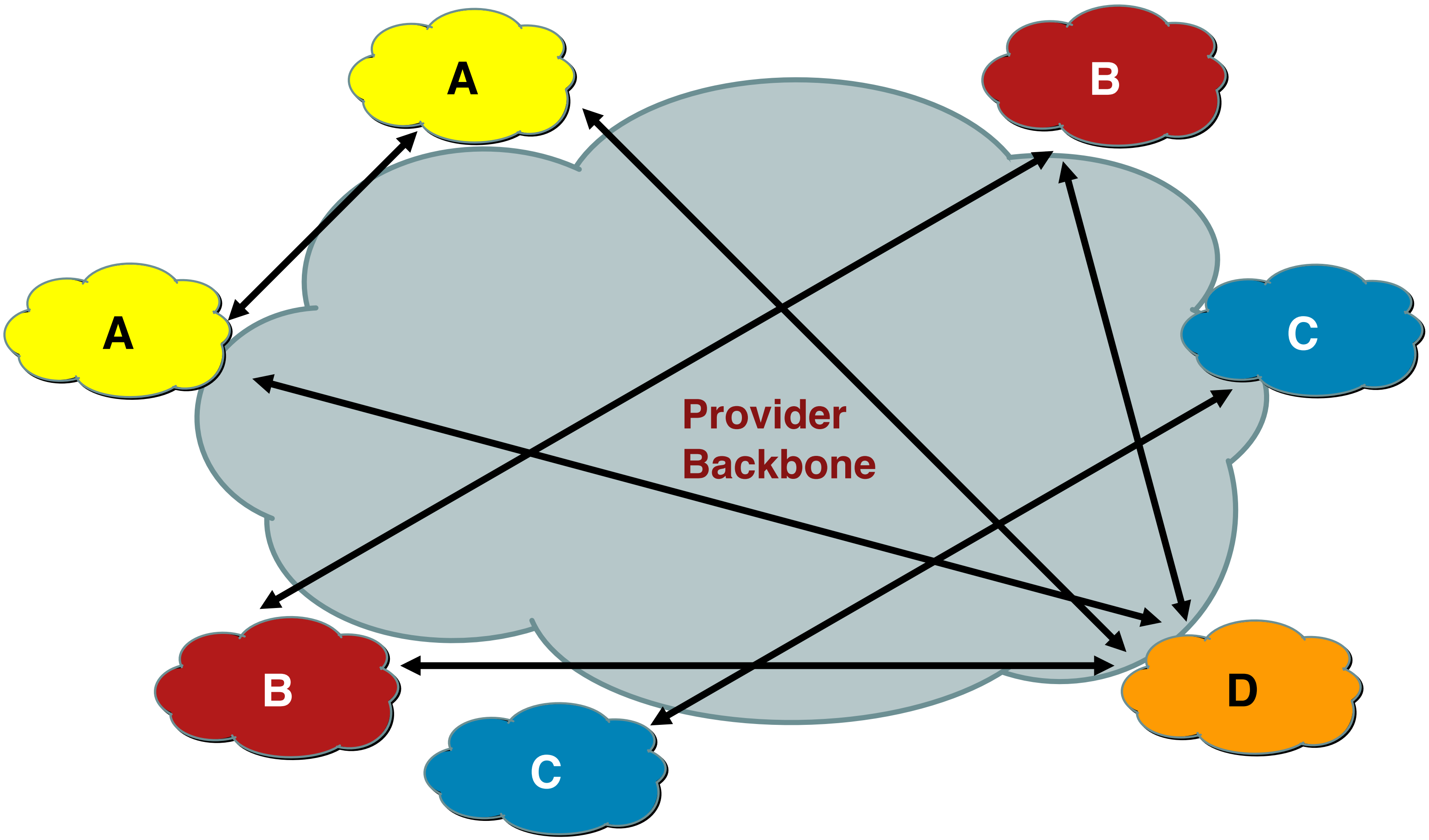
Overlay VPN

- ACLs, ATM/FR, IP tunnels, IPSec, …etc. requiring n*(n-1) peering points
- Transport dependent
- Groups endpoints, not groups
- Pushes content outside the network
- Costs scale exponentially
- NAT necessary for overlapping address space
- Limited scaling
- QoS complexity

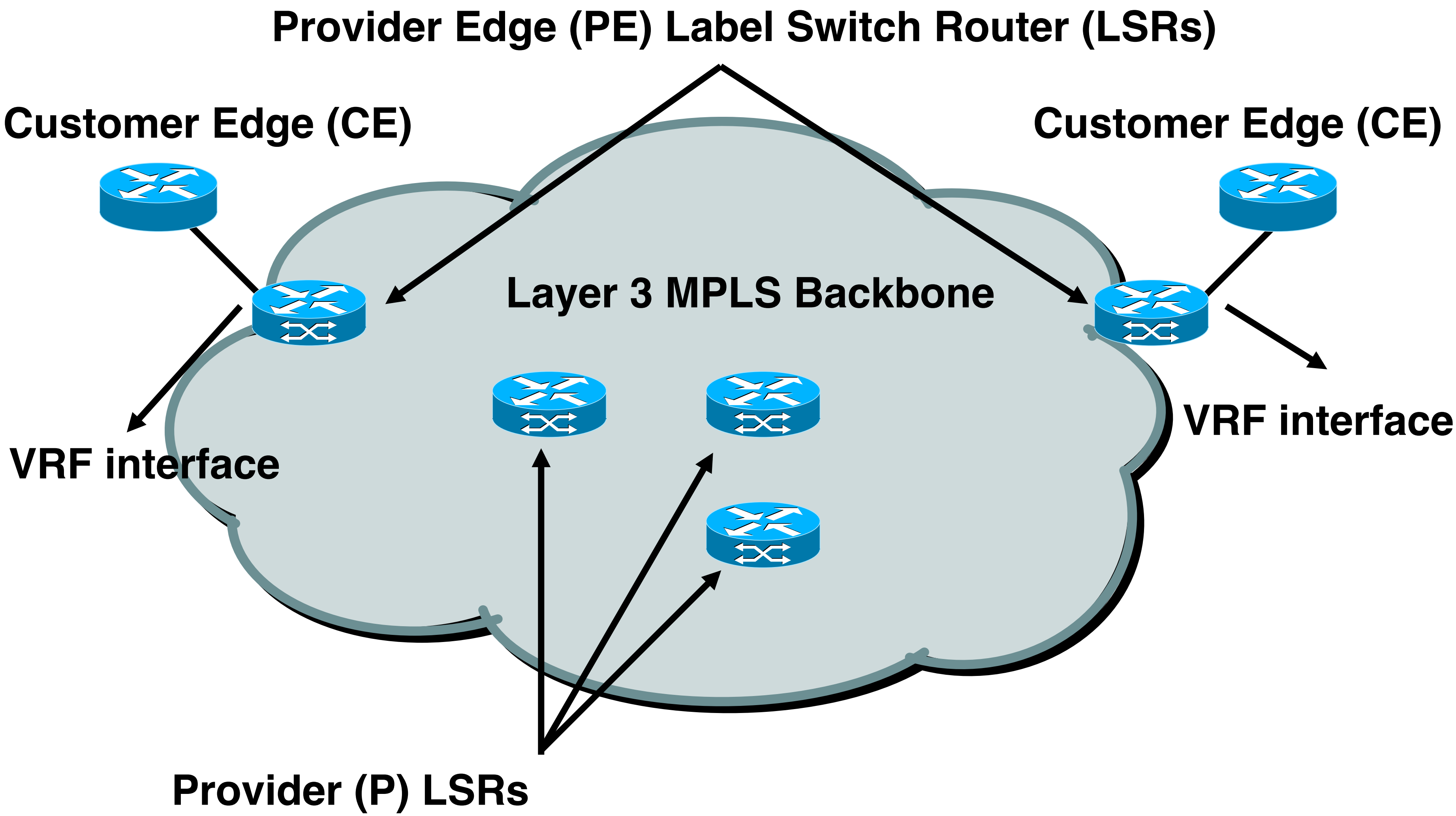
MPLS-Based VPNs

- Point to Cloud single point of connectivity
- Transport independent
- Easy grouping of users and services
- Enables content hosting inside the network
- “Flat” cost curve
- Supports private overlapping IP addresses
- Scalable to over millions of VPNs
- Per VPN QoS

VPN Model



MPLS VPN Architecture



MPLS VPN Building Blocks

- MPLS framework (labels) in the core
  - IGP (any)
  - LDP or MPLS Traffic Engineering
- VRF (Virtual Routing/Forwarding) context to keep VPNs seperate
  - VRF on PE interface towards CE
  - VRF routing table
  - VRF CEF table

VRF knowledge only needed on edge routers

- RD attached to prefixes to make VPN prefixes unique
  - RD is 64 bits
  - RD allows for overlapping VPN prefixes
- Route targets (ext BGP community) attached to VPN prefixes to allow prefixes to be imported/exported to VPNs
- BGP in the core to advertise <u>VPN prefix</u> and <u>VPN label</u> to all Provider Edge (PE) routers

VRF

- Virtual Routing/Forwarding
- Seperate context for each VPN
    - Seperate RIB per VPN
    - Seperate FIB per VPN
- Each protocol needs to be “VRF-aware” when running across VRF interface
    - e.g. any routing protocol
    - DHCP
    - NAT
    - MIB
    - etc.

VRF Routing Tables

- VRF routing table contains routes that should be available to a particular set of VPN sites
- VRF routing tables support the same set of mechanisms as the standard (default/global) routing table
- There is still the "global" routing table used in the core MPLS network

```
PE1#show ip vrf interfaces
Interface              IP-Address      VRF          Protocol
Se2/0                  11.1.1.2        one          up
Lo999                  200.1.1.1       two          up

PE1#show ip vrf
  Name                 Default RD         Interfaces
  one                  1:1                Se2/0
  three                3.3.3.3:3
  two                  1:2                Lo999
```

VRF RIB

```
PE1# show ip route vrf one

Routing Table: one
Codes:    C   - connected,  S - static,  R - RIP,  M - mobile,  B - BGP
          D   - EIGRP,  EX - EIGRP external,  O - OSPF, IA - OSPF inter area
          N1  - OSPF NSSA external type 1,  N2 - OSPF NSSA external type 2
          E1  - OSPF external type 1,  E2 - OSPF external type 2
           I  - IS-IS, su - IS-IS summary, L1 - IS-IS level-1, L2 - IS-IS level-2
           ia - IS-IS inter area, * - candidate default, U - per-user static route
           o - ODR, P - periodic downloaded static route

Gateway of last resort is not set

     11.0.0.0/8  is  variably  subnetted,  6  subnets,  2  masks
B    11.1.2.0/24     [200/0]  via  10.100.1.4,  2d18h
B    11.1.3.0/24     [200/0]  via  10.100.1.6,  2d18h
C    11.1.1.0/24  is  directly  connected,  Serial2/0
B    11.100.1.7/32   [200/1]  via  10.100.1.6,  2d18h
B    11.100.1.5/32   [200/1]  via  10.100.1.4,  2d18h
R    11.100.1.1/32   [120/1]  via  11.1.1.1,  00:00:05,  Serial2/0
```

VRF routing tables are normal routing tables, but the next hop IP address can be in global routing table

VRF FIB

```
PE1#show ip cef vrf one
    Prefix          Next Hop       Interface
    0.0.0.0/0       drop           Null0 (default route handler entry)
    0.0.0.0/32      receive
    11.1.1.0/24     attached       Serial2/0
    11.1.1.0/32     receive
    11.1.1.2/32     receive
    11.1.1.255/32   receive
    11.1.2.0/24     10.1.1.3       Serial3/0
    11.1.3.0/24     10.1.5.6       Ethernet0/0
    11.100.1.1/32   11.1.1.1       Serial2/0
    11.100.1.5/32   10.1.1.3       Serial3/0
    11.100.1.7/32   10.1.5.6       Ethernet0/0

PE1#show ip cef vrf one 11.1.2.0
    11.1.2.0/24, version 9, epoch 0, cached adjacency to Serial3/0
    0 packets, 0 bytes
    tag information set
    local tag: VPN-route-head
    fast tag rewrite with Se3/0, point2point, tags imposed: {19 22}
    via 10.100.1.4, 0 dependencies, recursive
    next hop 10.1.1.3, Serial3/0 via 10.100.1.4/32
    valid cached adjacency
    tag rewrite with Se3/0, point2point, tags imposed: {19 22}
```

RD

- Makes customer IPv4 prefix unique
- RD is present in the NLRI (MP_REACH_NLRI or MP_UNREACH_NLRI), together with the IPv4 prefix and MPLS label
- RD = 64 bits is added to make VPNv4 prefix unique
- RD comprises Administrator subfield:Assigned number subfield
- Two formats

```
PE1(config)#ip vrf three
PE1(config-vrf)#rd ?
  ASN:nn or IP-address:nn  VPN Route Distinguisher
```

```
!
ip vrf three
 rd 3.3.3.3:3
 route-target export 1:3
 route-target import 1:3
!
ip vrf two
 rd 1:2
 route-target export 1:2
 route-target import 1:2
```

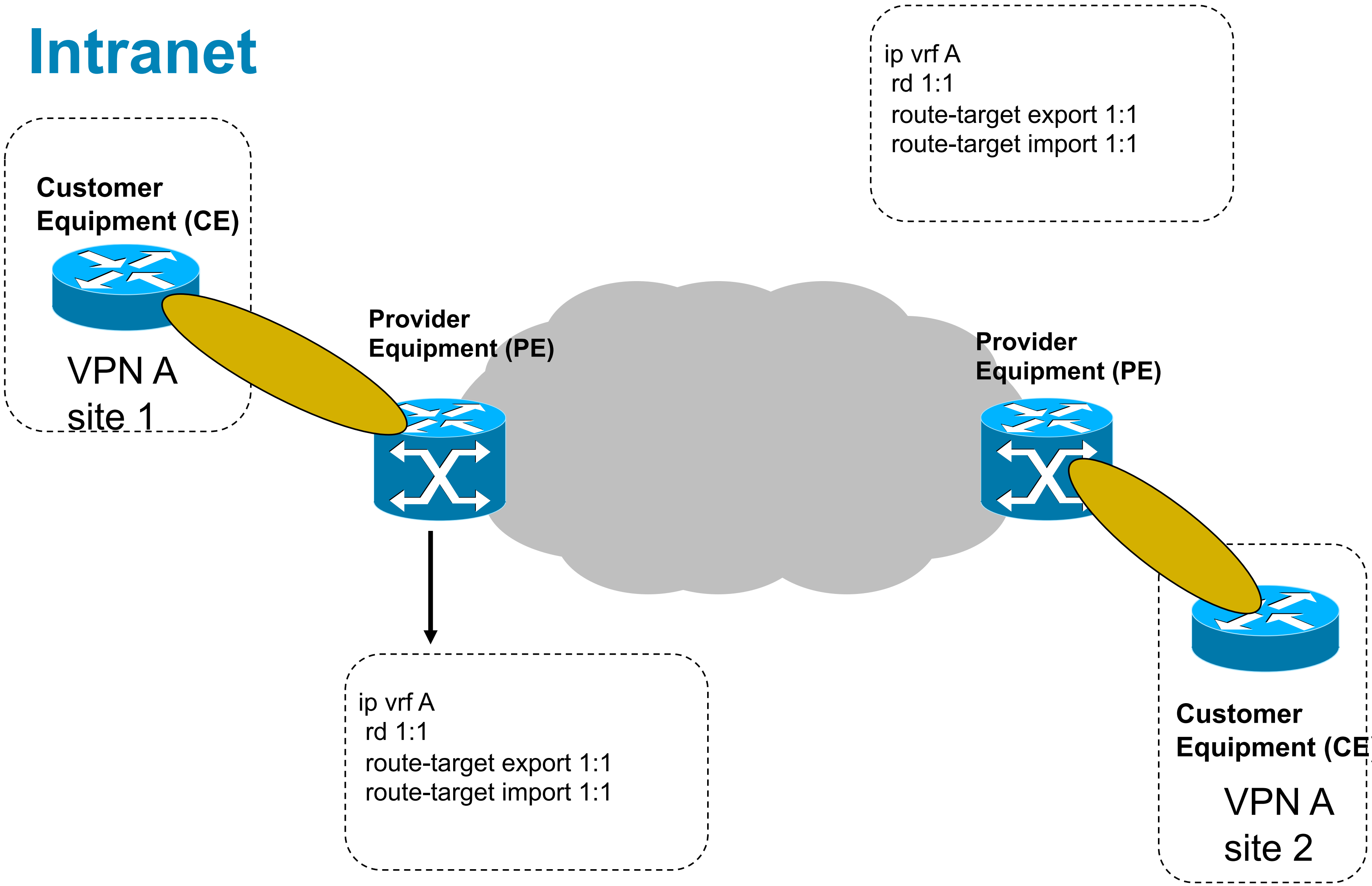
RD-type 1

RD-type 0

Route-Targets

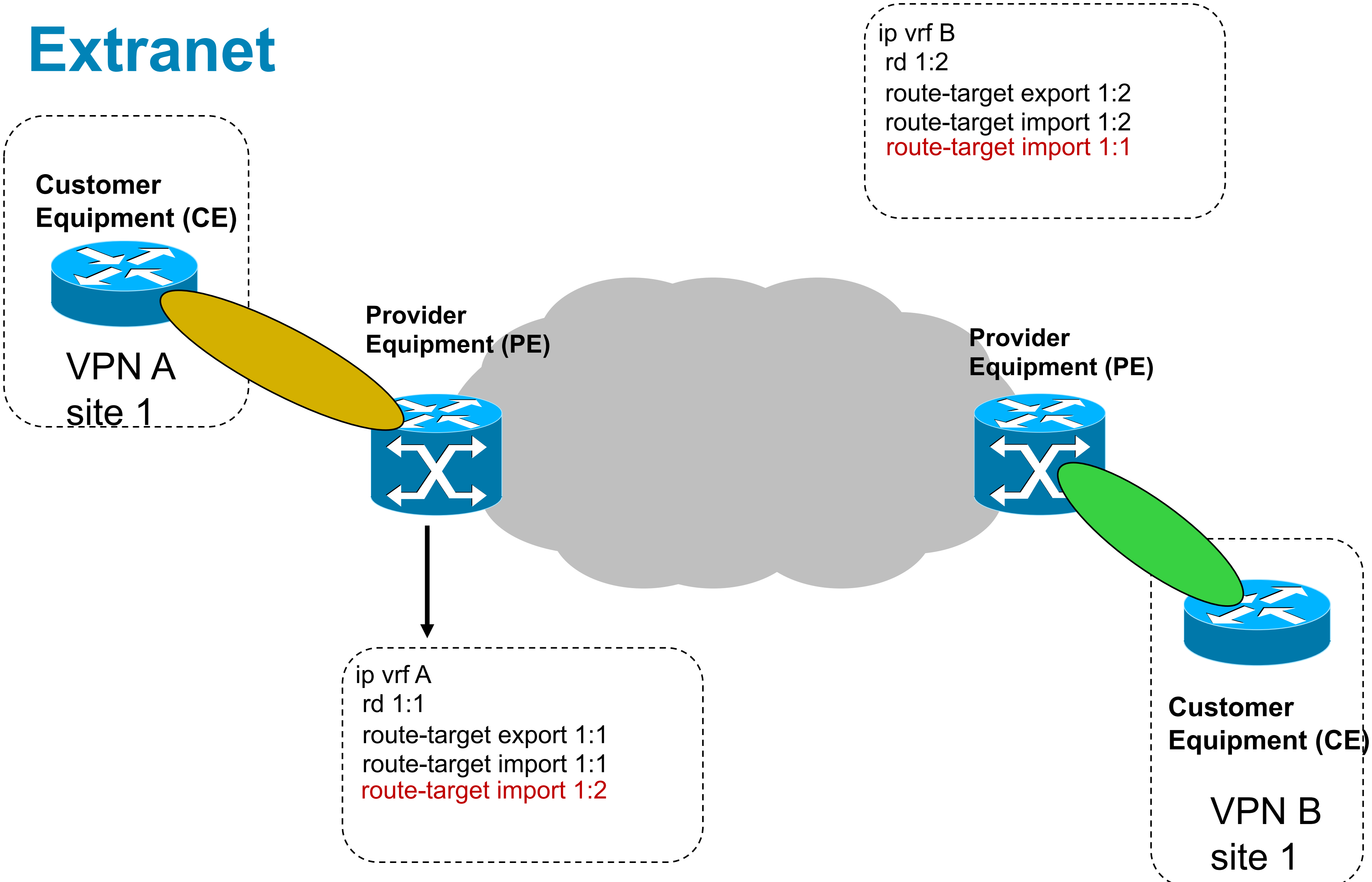
- **Operation**
  - Used to control which routes are imported into which VRFs from the remote PE routers and with which Route Targets the vpnv4 routes are exported towards the remote PE routers
  - There could be more than one Route Target attached to the vpnv4 route
  - For the import into the VRF to be permitted, only one Route Target from the vpnv4 route needs to be matched with the configuration of the imported Route Targets under the *ip vrf* section on the PE router
- **Exporting a Route Target (RT)** means that the exported vpnv4 route will receive an additional BGP extended community (this is the Route Target) as configured under *ip vrf* on the PE router, when the route is redistributed from the VRF routing table into MP-BGP.
- **Importing a Route Target (RT)** means that the received vpnv4 route from MP-BGP is checked for a matching extended community (this is the route target) with the one in the configuration.

Intranet



Prefixes from VPN A site 1 will be imported into site 2 of VPN A and vice versa

Extranet

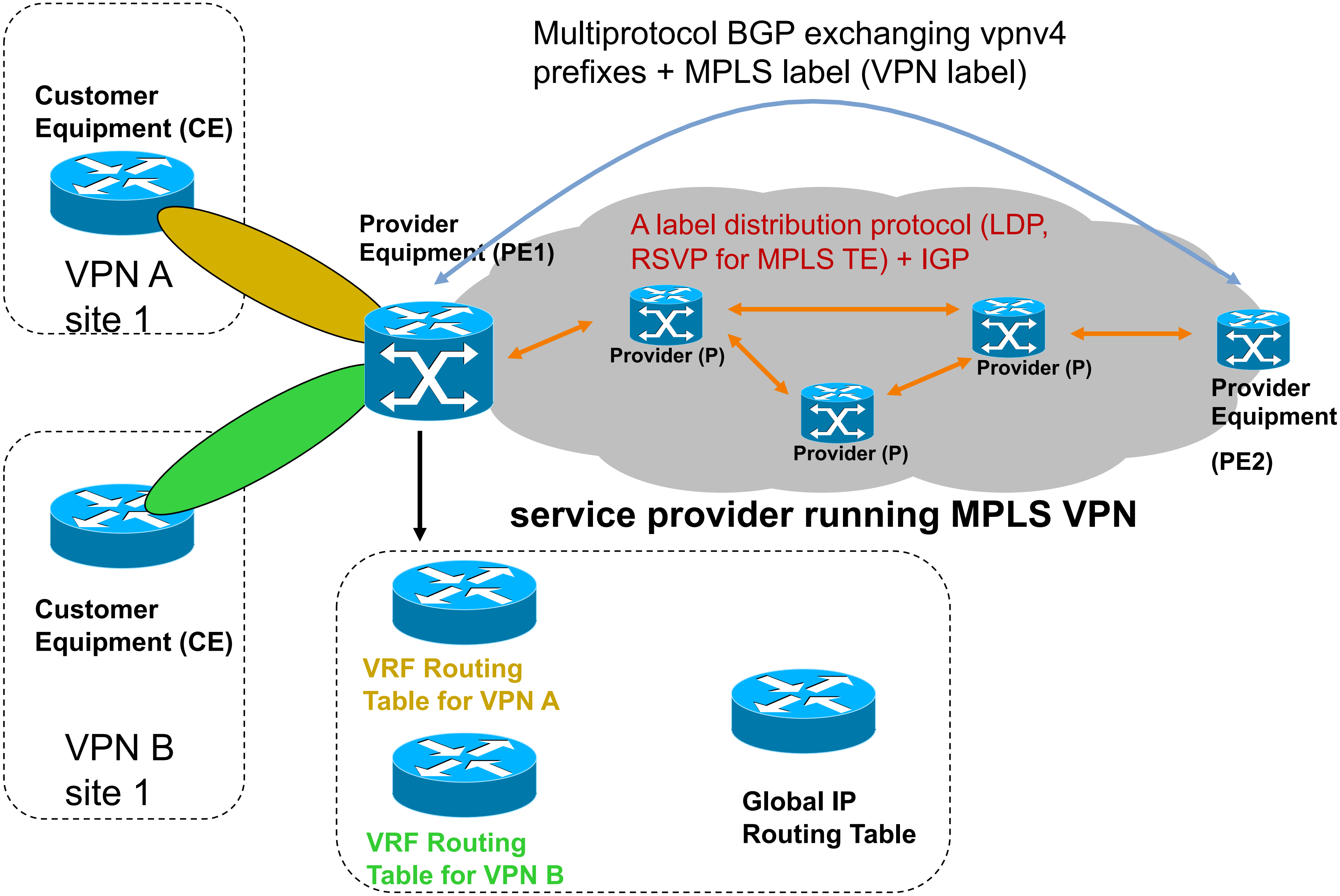


Prefixes from VPN A site 1 will be imported into site 1 of VPN B and vice versa

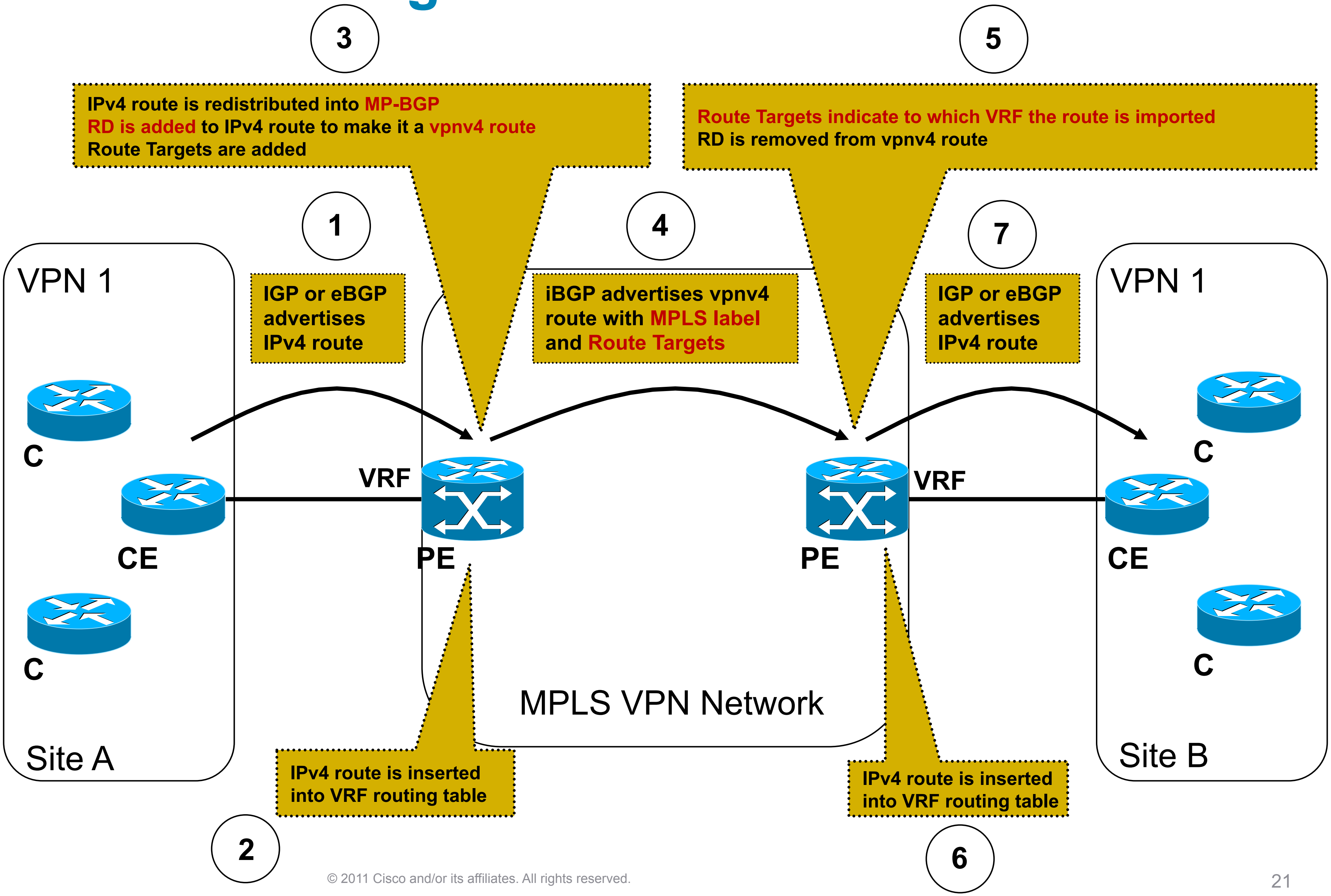
Role of BGP

- iBGP carries:
  - the vpnv4 prefix
    - vpnv4 prefix = RD + IPv4 prefix
  - Route Target (RT)
  - Any other community and BGP attribute
  - The MPLS label
- Address-family (AF) vpnv4 is used
- Label is automatically advertised in AF vpnv4

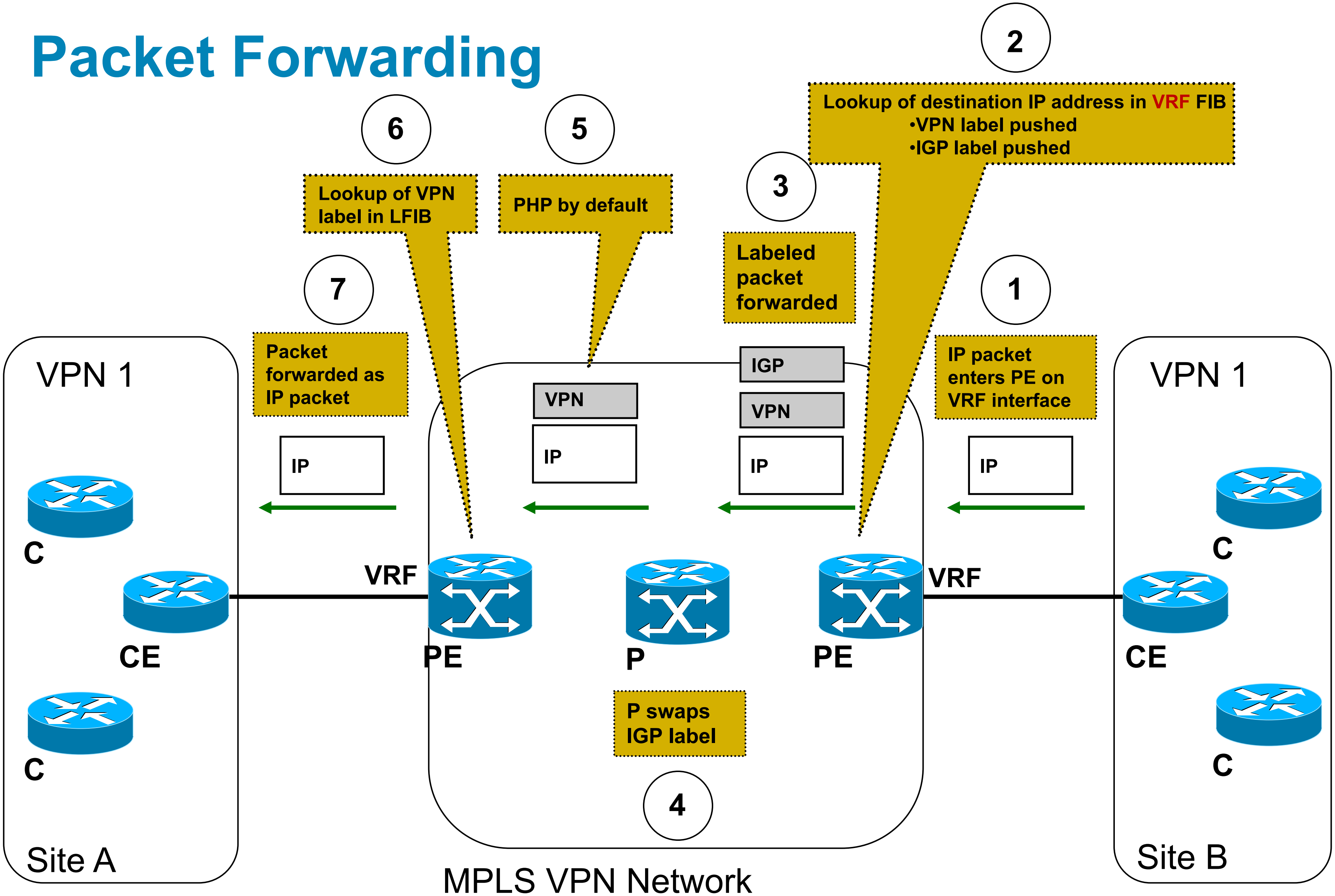
Context


Customer
Equipment (CE)
VPN A
site 1
Provider
Equipment (PE1)
Multiprotocol BGP exchanging vpnv4
prefixes + MPLS label (VPN label)
A label distribution protocol (LDP,
RSVP for MPLS TE) + IGP
Provider (P)
Provider (P)
Provider (P)
Provider
Equipment
(PE2)
service provider running MPLS VPN
Customer
Equipment (CE)
VPN B
site 1
VRF Routing
Table for VPN A
VRF Routing
Table for VPN B
Global IP
Routing Table

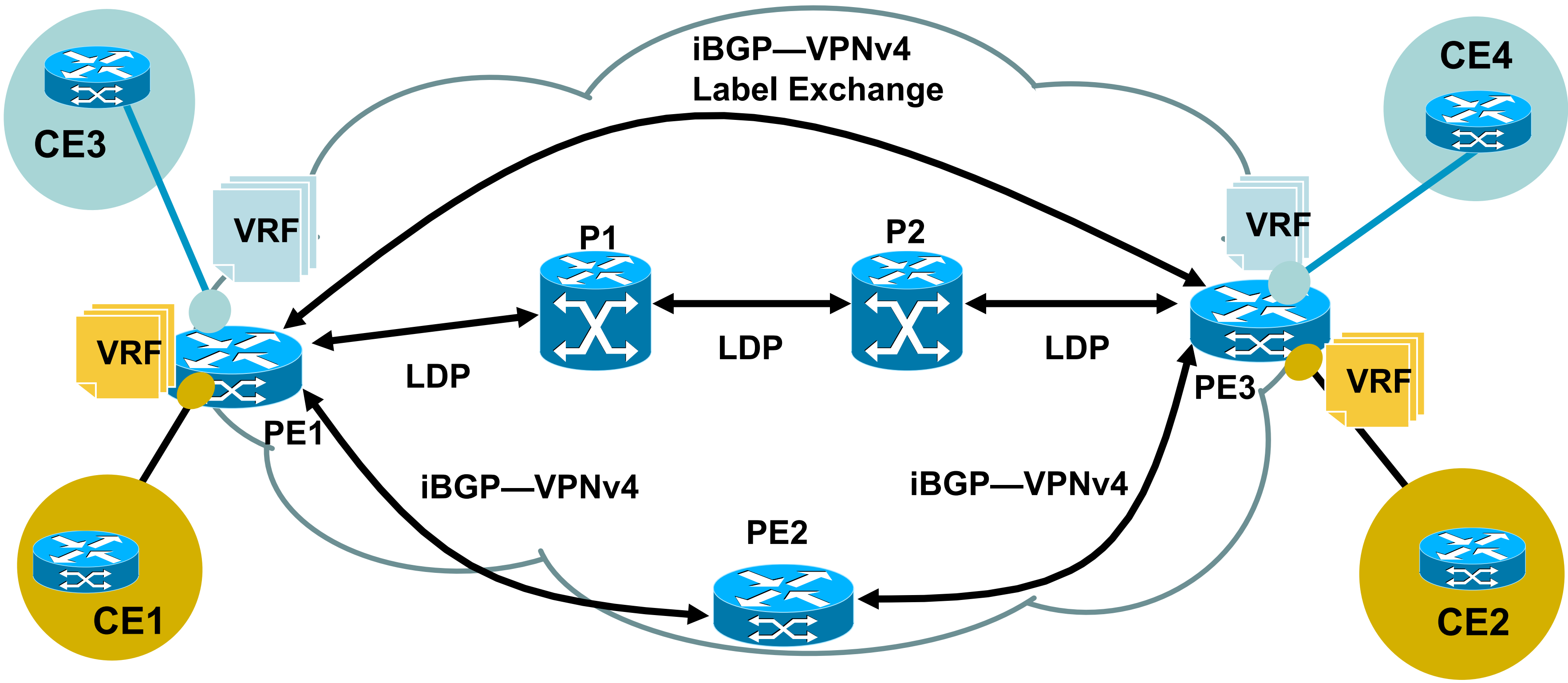
Route Exchange



Packet Forwarding



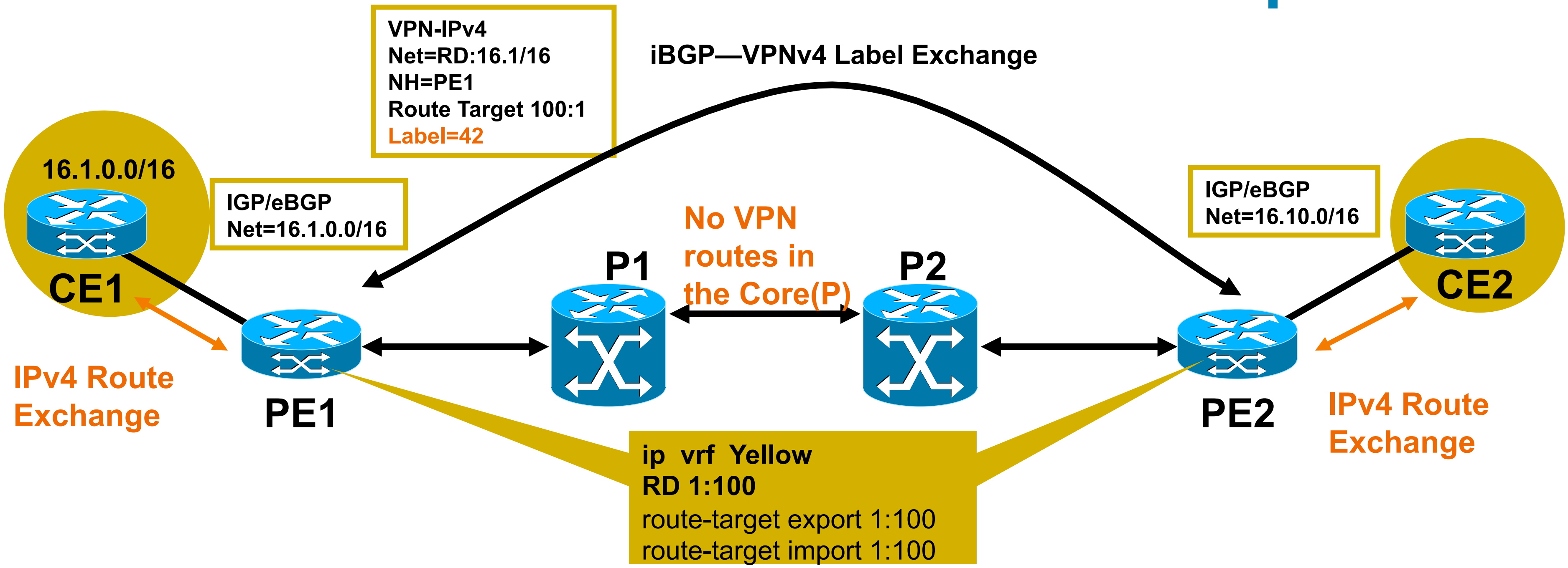
MPLS L3 VPN Control Plane Basics



1. VPN service is enabled on PEs (VRFs are created and applied to VPN site interface)
2. VPN site's CE1 connects to a VRF enabled interface on a PE1
3. VPN site routing by CE1 is distributed to MP-iBGP on PE1
4. PE1 allocates VPN label for each prefix, sets itself as a next hop and relays VPN site routes to PE3
5. PE3 distributes CE1's routes to CE2

   (Similar happens from CE2 side…)

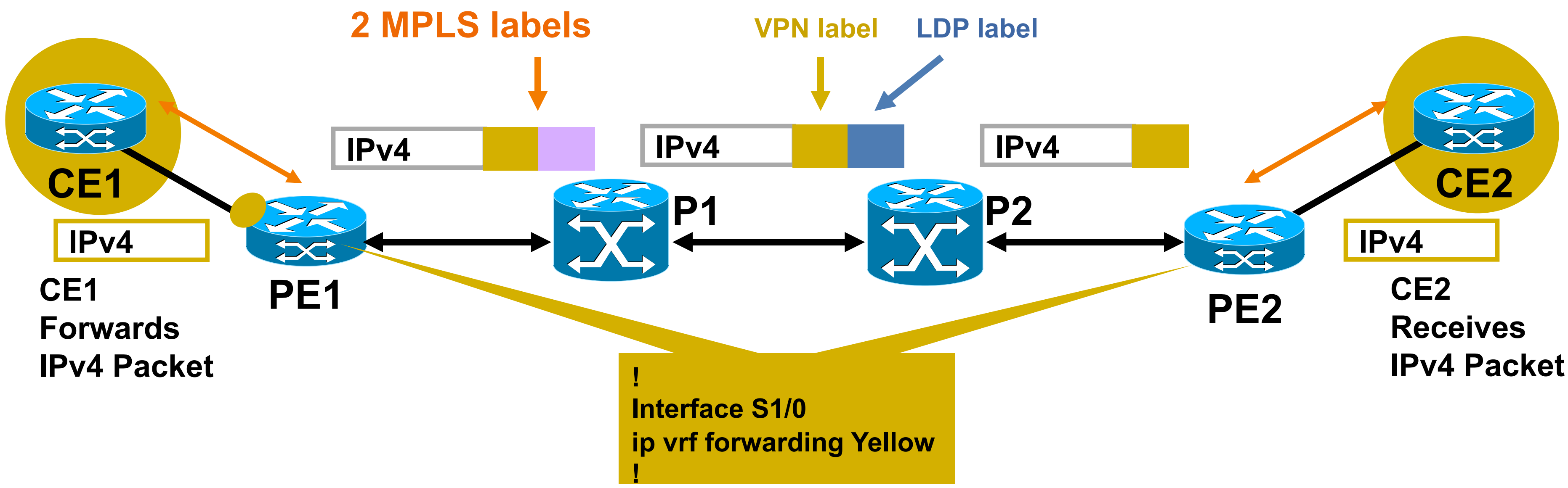
How Control Plane Information Is Separated



MPLS VPN Control Plane Components:

- Route Distinguisher: 8 byte field—unique value assigned by a provider to each VPN to make a route unique so customers don't see each other's routes
- VPNv4 address: RD+VPN IP prefix;
- Route Target: RT-8bytes field, unique value assigned by a provider to define the import/export rules for the routes from/to each VPN
- MP-BGP: facilitates the advertisement of VPNv4* prefixes + labels between MP-BGP peers
- Virtual Routing Forwarding Instance (VRF): contains VPN site routes
- Global Table: Contains core routes, Internet or routes to other services

How Does It Work?
How Data Plane Is Separated



1. PE1 imposes pre allocated label for the prefix
2. Core facing interface allocates IGP label
3. Core swap IGP labels
4. PE2 strips off VPN label and forwards the packet to CE2 as an IP packet

Config on PE Router

Definition of VRF

Assigning CE-facing interface to VRF

PE-CE routing protocol

Confiuring BGP vpnv4 peering

(to all other PEs or RRs)

Configuring VRF BGP (redistribution)

```
ip vrf one
 rd 1:1
 route-target export 1:1
 route-target import 1:1
!
interface FastEthernet2/1
 ip vrf forwarding one
 ip address 99.1.1.2 255.255.255.0
!
router ospf 100 vrf one
 log-adjacency-changes
 redistribute bgp 1 metric 10 subnets
 network 99.1.1.0 0.0.0.255 area 0
!
router bgp 1
 bgp log-neighbor-changes
 neighbor 11.100.100.4 remote-as 1
 neighbor 11.100.100.4 update-source Loopback0
!
 address-family ipv4
 no synchronization
 neighbor 11.100.100.4 activate
 neighbor 11.100.100.4 send-community both
 exit-address-family
 !
 address-family vpnv4
 neighbor 11.100.100.4 activate
 neighbor 11.100.100.4 send-community both
 exit-address-family
 !
 address-family ipv4 vrf one
 redistribute connected
 redistribute ospf 100 vrf one
 exit-address-family
```

Verifying VPNv4 Prefixes in BGP

```
PE1#show ip bgp vpnv4 all
BGP table version is 15, local router ID is 10.100.1.2
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
Route Distinguisher: 1:1 (default for vrf one)
*> 11.1.1.0/24      0.0.0.0               0         32768 ?
*>i11.1.2.0/24      10.100.1.4            0        100      0 ?
*>i11.1.3.0/24      10.100.1.6            0        100      0 ?
*> 11.100.1.1/32    11.1.1.1              1         32768 ?
*>i11.100.1.5/32    10.100.1.4            1         100      0 ?
*>i11.100.1.7/32    10.100.1.6            1         100      0 ?
Route Distinguisher: 1:2 (default for vrf two)
*>i14.1.1.1/32      10.100.1.4            0    100      0 ?

PE1#debug ip bgp vpnv4 unicast updates
BGP updates debugging is on for address family: VPNv4 Unicast

BGP(2): 10.100.1.4 rcvd UPDATE w/ attr: nexthop 10.100.1.4, origin ?, localpref 100, metric 0, extended community RT:
    1:2
BGP(2): 10.100.1.4 rcvd 1:2:14.1.1.1/32
```

MPLS Aware ICMP

```
PE1#trace vrf one 11.100.1.5


Type escape sequence to abort.

Tracing the route to 11.100.1.5


  1 10.1.1.3 [MPLS: Labels 19/23 Exp 0] 32 msec 60 msec 40 msec

  2 11.1.2.4 [MPLS: Label 23 Exp 0] 40 msec 20 msec 20 msec

  3 11.1.2.5 60 msec *  64 msec
```

ICMP in IOS can carry the label stack when generating ICMP reply messages

PE-CE Routing Protocols

- Connected
- Static
- RIPv2
- OSPF
- EIGRP
- eBGP

VRF Access

- Cisco IOS commands were made VRF aware in order to be able to communicate with the CE devices or IP addresses on the PE router in the VRF context

london# **ping vrf** **cust-one 10.10.100.1**

london# **traceroute vrf** **cust-one 10.10.100.1**

london# **telnet** **10.10.100.1** **/vrf** **cust-one**

MPLS VPN Troubleshooting

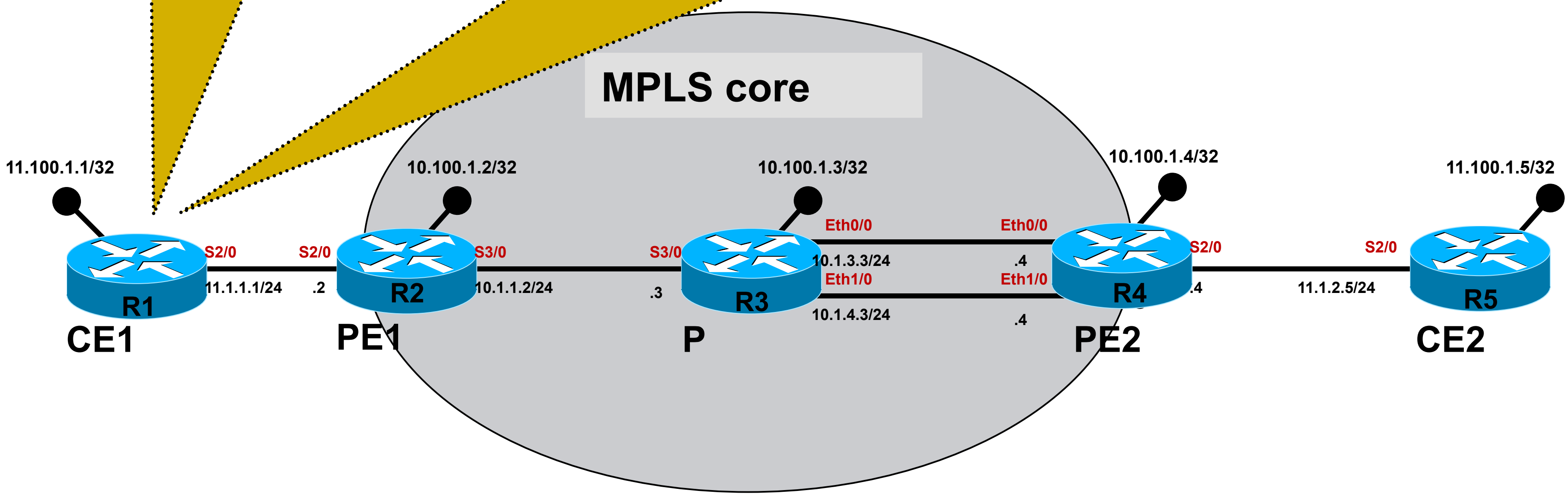
- Basic Checks:
  - ping and traceroute CE-to-CE
  - Ping local PE-CE
  - Ping from PE to remote PE-CE
  - Ping and traceroute PE-to-PE in global RIB (between PE loopback)
- Ping check connectivity
- Traceroute can tell us if LSP is broken (look for missing label)
- If there is a failure:
  - check routing tables (global and VRF)
    - Check forwarding vector
  - Check CEF tables (global and VRF)
    - Check forwarding vector and labels
  - Check BGP vpnv4 table
    - Check next-hop and labels

MPLS VPN Troubleshooting: Example

```
CE1#ping 11.100.1.5

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 11.100.1.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 60/60/64 ms
```

```
CE1#trace 11.100.1.5
Type escape sequence to abort.
Tracing the route to 11.100.1.5
  1 11.1.1.2 20 msec 20 msec 20 msec
  2 10.1.1.3 [MPLS: Labels 19/23 Exp 0] 60 msec 60 msec 60 msec
  3 11.1.2.4 [MPLS: Label 23 Exp 0] 40 msec 40 msec 40 msec
  4 11.1.2.5 48 msec *  64 msec
```



MPLS VPN Troubleshooting: Example

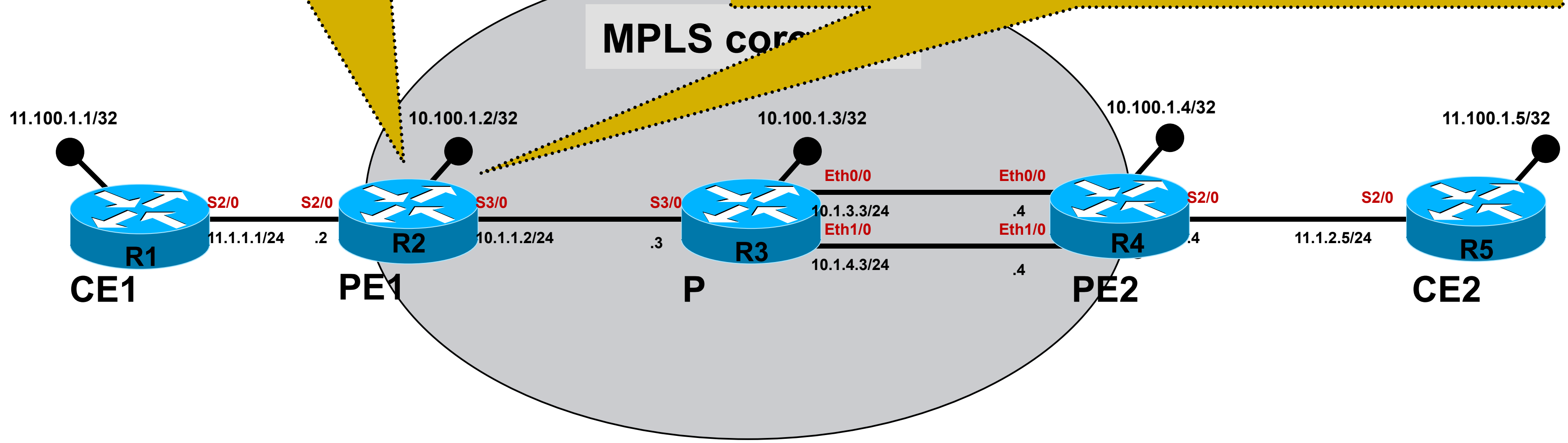
```
PE1#ping vrf one 11.100.1.5

Type escape sequence to abort.
Sending 5, 100-byte ICMP Echos to 11.100.1.5, timeout is 2 seconds:
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 40/52/72 ms
```

```
PE1#trace vrf one 11.100.1.5

Type escape sequence to abort.
Tracing the route to 11.100.1.5

  1 10.1.1.3 [MPLS: Labels 19/23 Exp 0] 32 msec 60 msec 40 msec
  2 11.1.2.4 [MPLS: Label 23 Exp 0] 40 msec 20 msec 20 msec
  3 11.1.2.5 60 msec *  64 msec
```



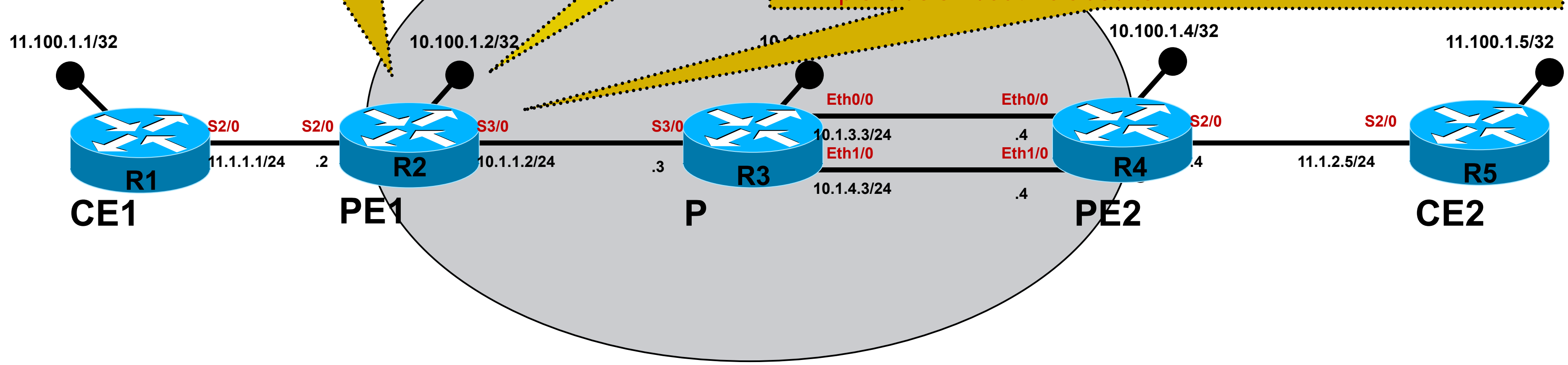
MPLS VPN Troubleshooting: Example

PE1#**show ip cef vrf one 11.100.1.5**
11.100.1.5/32, version 10, epoch 0, cached adjacency to Serial3/0 0 packets, 0 bytes
  tag information set
    local tag: VPN-route-head
    fast tag rewrite with Se3/0, point2point, tags imposed: {19 23}
  via **10.100.1.4,** 0 dependencies, recursive
    next hop 10.1.1.3, Serial3/0 via 10.100.1.4/32
    valid cached adjacency
    tag rewrite with Se3/0, point2point, tags imposed: {19 23}

PE1#**show ip cef 10.100.1.4**
10.100.1.4/32, version 20, epoch 0, cached adjacency to Serial3/0 0 packets, 0 bytes
  tag information set, shared
    local tag: 23
    fast tag rewrite with Se3/0, point2point, tags imposed: {19}
  via 10.1.1.3, Serial3/0, 2 dependencies
    next hop 10.1.1.3, Serial3/0
    valid cached adjacency
    tag rewrite with Se3/0, point2point, tags imposed: {19}

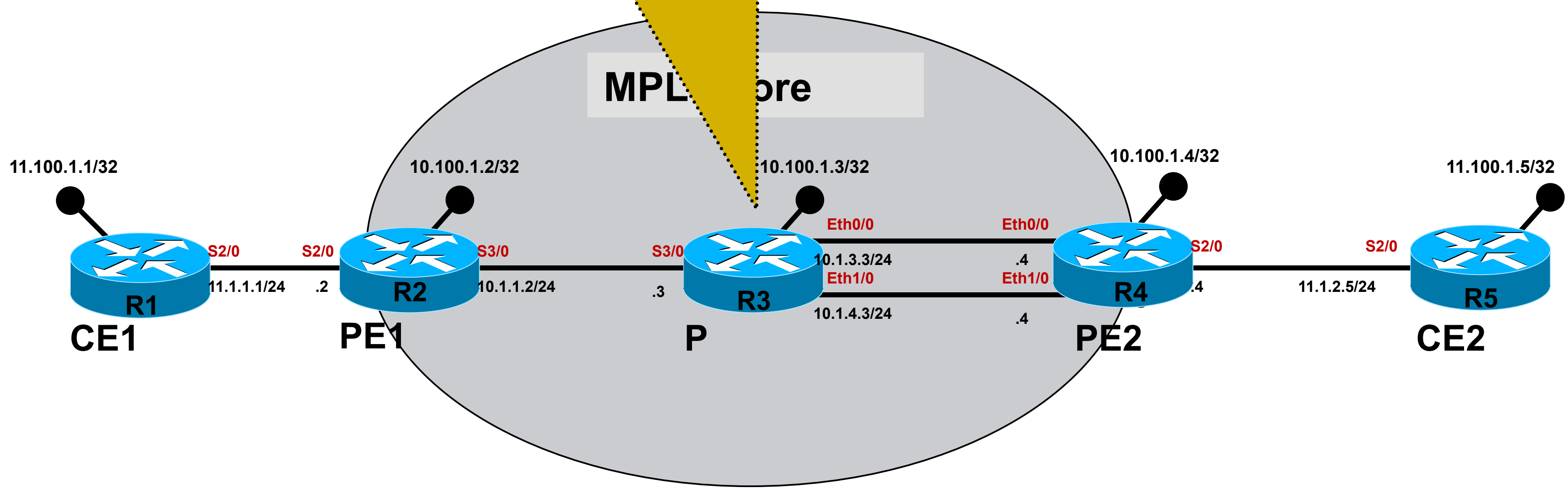
BGP next-hop

PE1#**show ip bgp vpnv4 vrf one 11.100.1.5**
BGP routing table entry for 1:1:11.100.1.5/32, version 12
Paths: (1 available, best #1, table one)
  Not advertised to any peer
  Local
    10.100.1.4 (metric 75) from 10.100.1.4 (10.100.1.4)
    Origin incomplete, metric 0, localpref 100, valid, internal, best
    Extended Community: RT:1:1
    mpls labels in/out nolabel/23



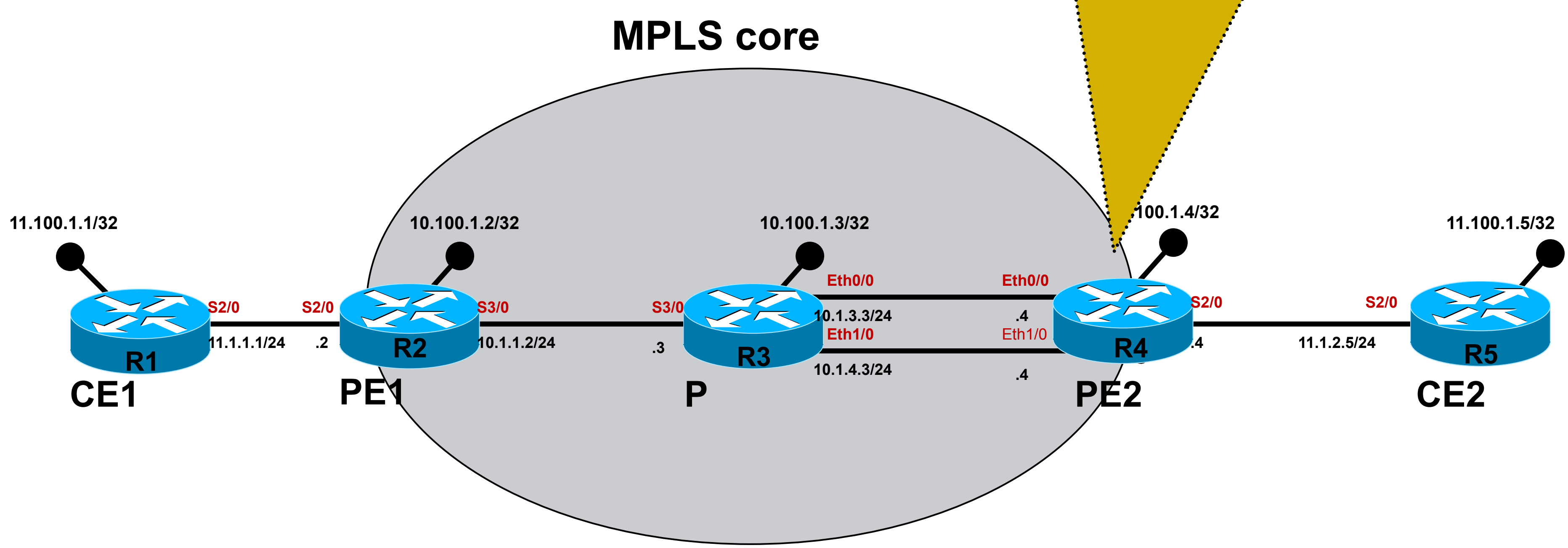
MPLS VPN Troubleshooting: Example

```
P#show mpls forwarding-table 10.100.1.4
Local  Outgoing    Prefix           Bytes tag  Outgoing   Next Hop
tag    tag or VC   or Tunnel Id     switched   interface
19     Pop tag     10.100.1.4/32    1220       Et1/0      10.1.4.4
       Pop tag     10.100.1.4/32    1051348    Et0/0      10.1.3.4
```



MPLS VPN Troubleshooting: Example

```
PE2#show mpls forwarding-table labels 23
Local  Outgoing      Prefix            Bytes Label   Outgoing   Next Hop
Label  Label or VC   or Tunnel Id      Switched      interface
23     No Label      11.100.1.5/32[V]  0             Se2/0      point2point
```



MPLS VPN Troubleshooting: Example Debugging Control plane

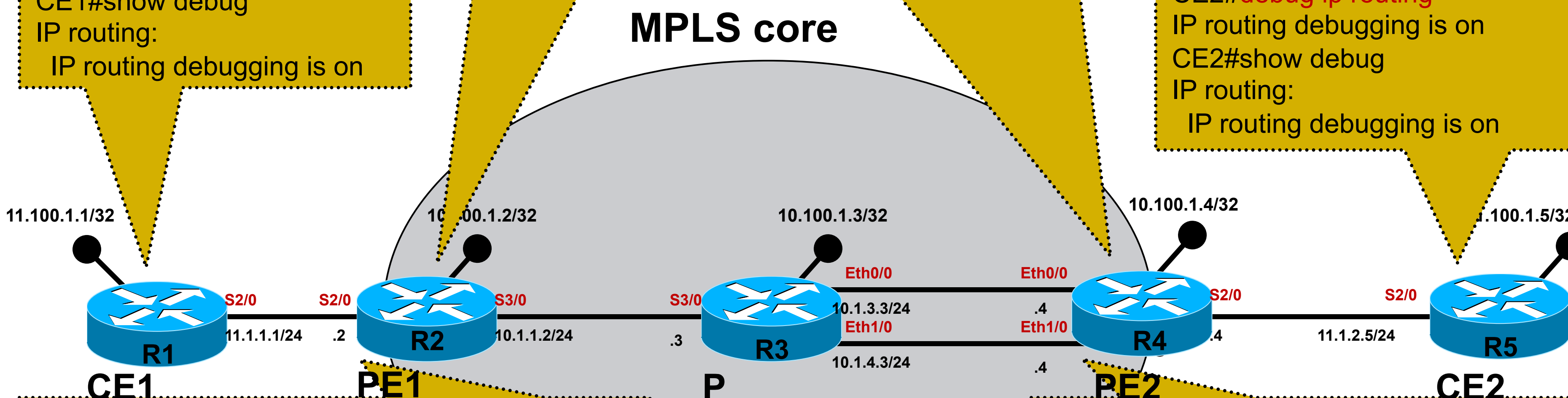
PE1#debug ip bgp vpnv4 unicast updates
BGP updates debugging is on for address family: VPNv4 Unicast
PE1#show debug
IP routing:
BGP updates debugging is on for address family: VPNv4 Unicast

PE2#debug ip bgp vpnv4 unicast updates
BGP updates debugging is on for address family: VPNv4 Unicast

PE2#show debug
IP routing:
BGP updates debugging is on for address family: VPNv4 Unicast

CE1#debug ip routing
IP routing debugging is on
CE1#show debug
IP routing:
IP routing debugging is on

CE2#debug ip routing
IP routing debugging is on
CE2#show debug
IP routing:
IP routing debugging is on

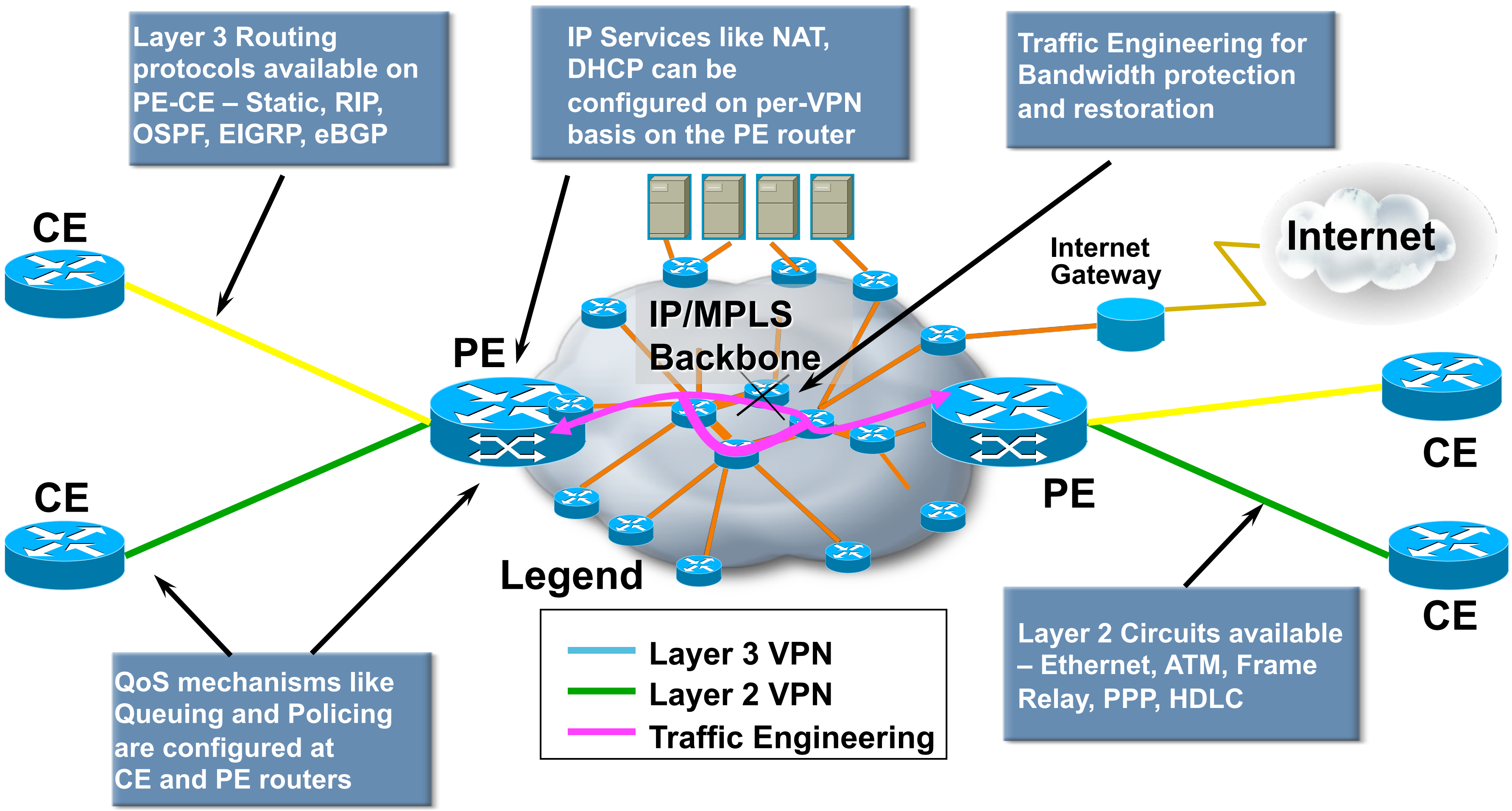


PE1#debug ip routing vrf one
IP routing debugging is on for VRF one
PE1#show debug
IP routing: IP routing debugging is on for VRF one

PE2#debug ip routing vrf one
IP routing debugging is on for VRF one
PE2#show debug
IP routing:
IP routing debugging is on for VRF one

Summary

The Full Service Network: Integrated MPLS Technologies



Layer 3 VPNs & Layer 2 VPNs, Traffic Engineering + QoS + IP Services

Ask The Experts Event (with Nagendra Kumar)

If you have additional questions, you can ask them to Nagendra here:

https://supportforums.cisco.com/community/netpro/ask-the-expert

He will be answering from August 17th to August 26th.

First CSC Expert Series Webcast in Spanish

Topic: Firewall Service Module: Architecture and Operation

Tuesday, August 30th, at

7:00 a.m. Pacific (UTC -7)

9:00 a.m Mexico city (UTC -7)

4:00 p.m Madrid (UTC +2)

Join Security CCIE and Certified Ethical Hacker from EC-Council

Ivan Martiñón from **HTTS group in Latin America**

He will talk about the architecture, operation and configuration of the Firewall Service Modules, as well as Firewall technologies in general.

During this interactive session you will be able ask all your questions related to this topic.

Register for this live Webcast at

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Next CSC Expert Series Webcast

Topic: Things I Can Do to Protect My Network from Getting Hacked

Tuesday, September 13th, at

8:00 a.m. Pacific Time
6:00 p.m. CEST Brussels (UTC +2),
11:00 a.m. EDT New York (UTC -4).

Join double CCIE, Technical Leader

Jazib Frahim from **RTP**.

He will provide reasons why enterprise network segments get compromised despite their state-of-the-art network security technologies and products that are deployed.

During this interactive session you will be able ask all your questions related to this topic.

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