Introduction to MPLS

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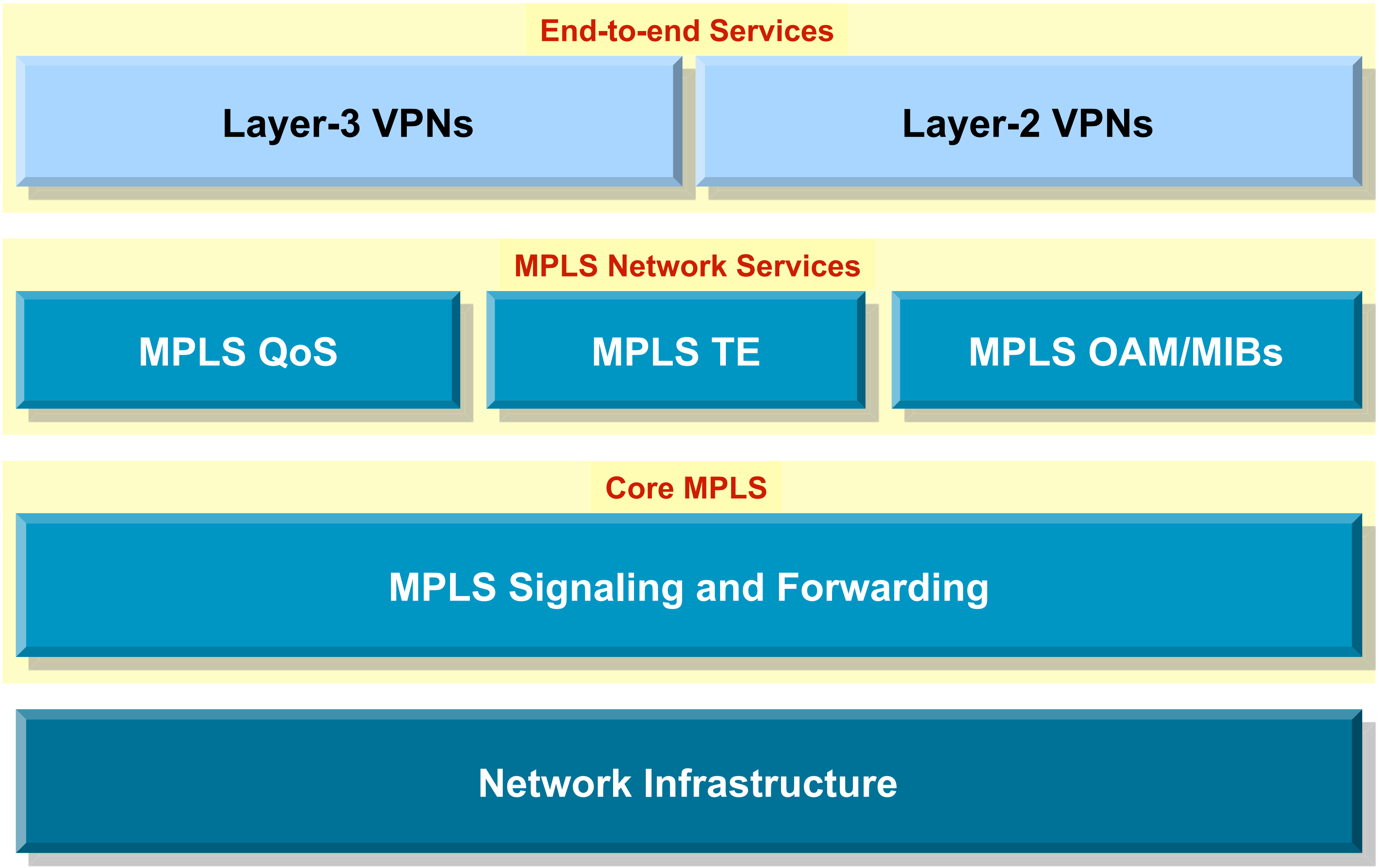
Goals of this Session

- Understand history and business drivers for MPLS
- Learn about MPLS customer and market segments
- Understand the problems MPLS is addressing
- Understand benefits of deploying MPLS
- Understand the major MPLS technology components
- Learn the basics of MPLS technology
- Understand typical applications of MPLS

The Big Picture



Agenda

- Introduction
- MPLS Network Components → **Core MPLS**
- MPLS VPNs
  - MPLS Layer-3 VPNs
  - MPLS Layer-2 VPNs

  } → **End-to-end MPLS Services**
- MPLS QoS
- MPLS Traffic Engineering
- MPLS Management

  } → **MPLS Network Services**
- Summary

Introduction

The business drivers for MPLS

Why Multi Protocol Label Switching?

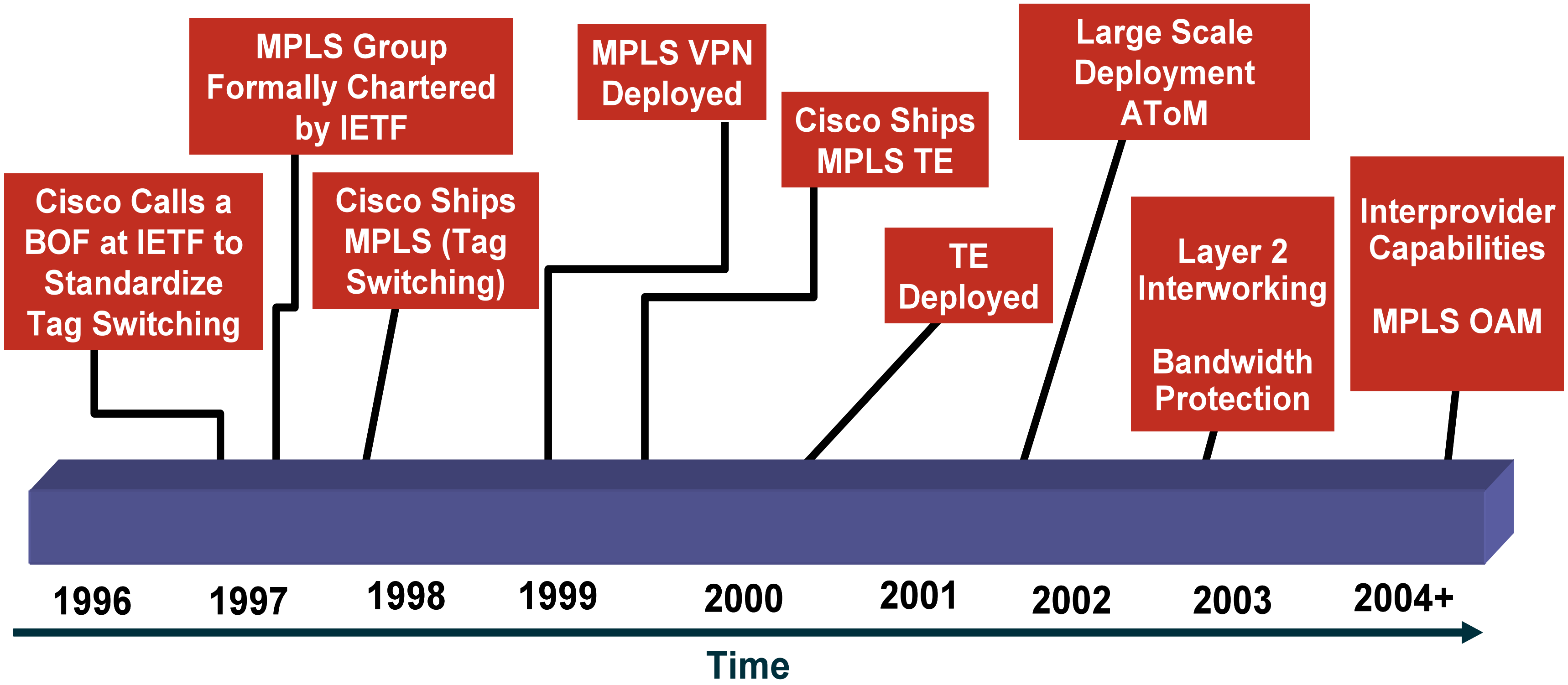
- SP/Carrier perspective
  - Reduce costs (CAPEX); consolidate networks
  - Consolidated network for multiple Layer-2/3 services
  - Support increasingly stringent SLAs
  - Handle increasing scale/complexity of IP-based services
- Enterprise/end-user perspective
  - Campus/LAN
    - Need for network segmentation (users, applications, etc.)
  - WAN connectivity (connecting enterprise networks)
    - Need for easier configuration of site-to-site WAN connectivity

What Is MPLS Technology?

- It's all about labels …
- Use the best of both worlds
  - Layer-2 (ATM/FR): efficient forwarding and traffic engineering
  - Layer-3 (IP): flexible and scalable
- MPLS forwarding plane
  - Use of labels for forwarding Layer-2/3 data traffic
  - Labeled packets are being switched instead of routed
    - Leverage layer-2 forwarding efficiency
- MPLS control/signaling plane
  - Use of existing IP control protocols extensions + new protocols to exchange label information
    - Leverage layer-3 control protocol flexibility and scalability

Evolution of MPLS

- Evolved from tag switching in 1996 to full IETF standard, covering over 130 RFCs
- Key application initially were Layer-3 VPNs, followed by Traffic Engineering (TE), and Layer-2 VPNs



For your reference only

MPLS Applications

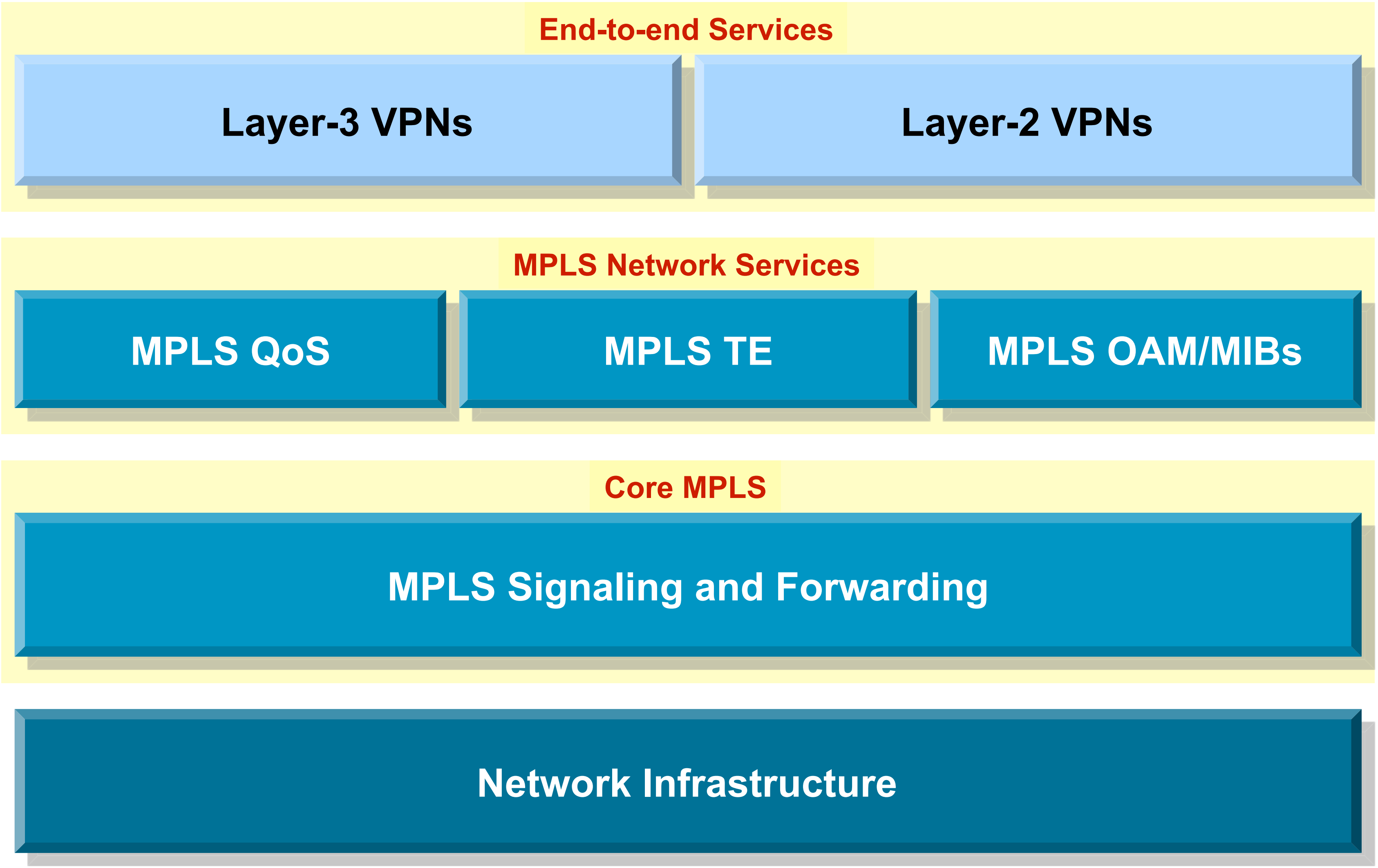
	Service Providers	Enterprise Data Center	Data center interconnects	EWAN Edge
Key Features	L2/L3VPN's TE/FRR QoS High Availability	VPN's TE/FRR High Availability	VPN's / VRF's VRF-Aware Security High Availability	VPN's / VRF's VRF Aware Security High Availability
Applications	Hosted Data centers Data center interconnect Segmentation for IT Mergers, Acquisitions, spinoffs	Departmental segmentation Service multiplexing Security Mergers, Acquisitions, spinoffs	Disaster Recovery Vmotion support Branch Interconnects	Internet Access Branch Connectivity

- **Network Consolidation** – Merging Multiple parallel network into a shared infrastructure
- **Network segmentation** – By user groups or business function
- **Service and policy centralization** – Security policies and appliances at a central location
- **New applications readiness** – Converged multi-service network
- **Increased network security** – User groups segmentation with VPNs

Enterprise MPLS Customers

- Two types of enterprise customers for MPLS technology
- MPLS indirectly used as subscribed WAN service
  - Enterprise subscribes to WAN connectivity data service offered by external Service Provider
  - Data connectivity service implemented by Service Provider via MPLS VPN technology (e.g., layer-2 and layer-3 VPNs)
  - VPN Service can be managed or unmanaged
- MPLS used as part of self managed network
  - Enterprise deploys MPLS in it’s own network
  - Enterprise manages it’s own MPLS-based network

MPLS Technology Framework

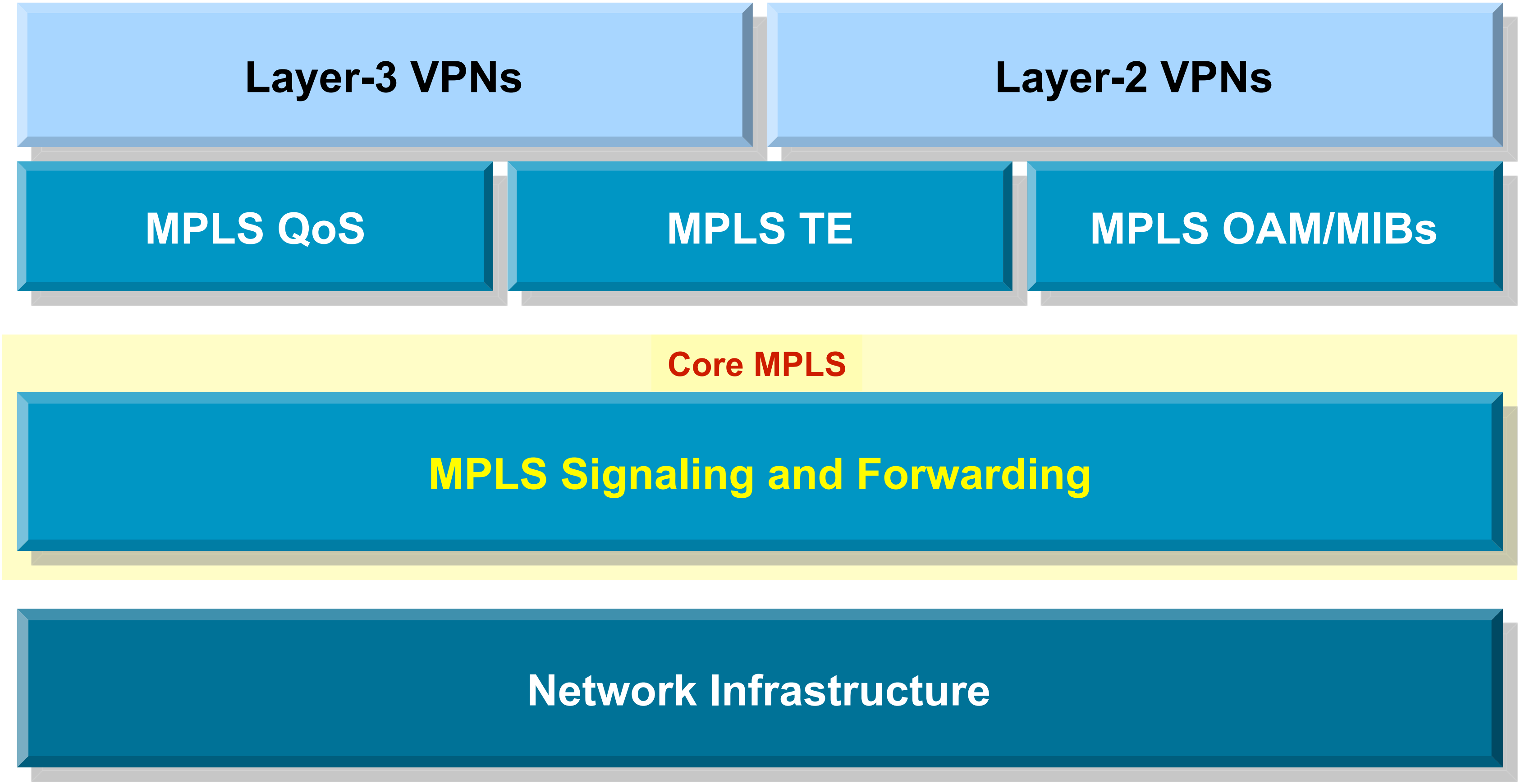


MPLS Technology Components

Basic building blocks of MPLS

MPLS Forwarding and Signaling

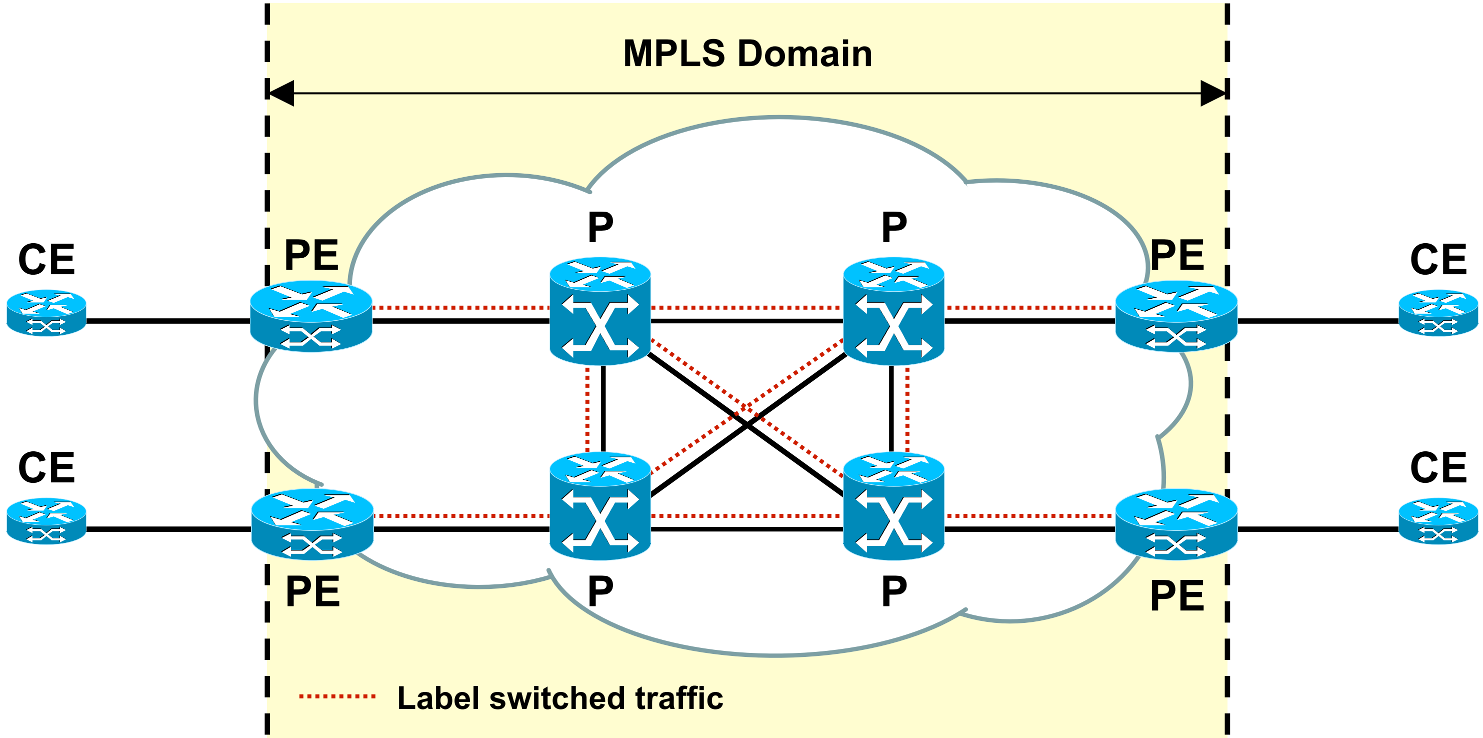
- MPLS label forwarding and signaling mechanisms



Basic Building Blocks

- The big picture
  - MPLS-enabled network devices
  - Label Switched Paths (LSPs)
- The internals
  - MPLS labels
  - Processing of MPLS labels
  - Exchange of label mapping information
  - Forwarding of labeled packets
- Other related protocols and protocols to exchange label information
  - Between MPLS-enabled devices

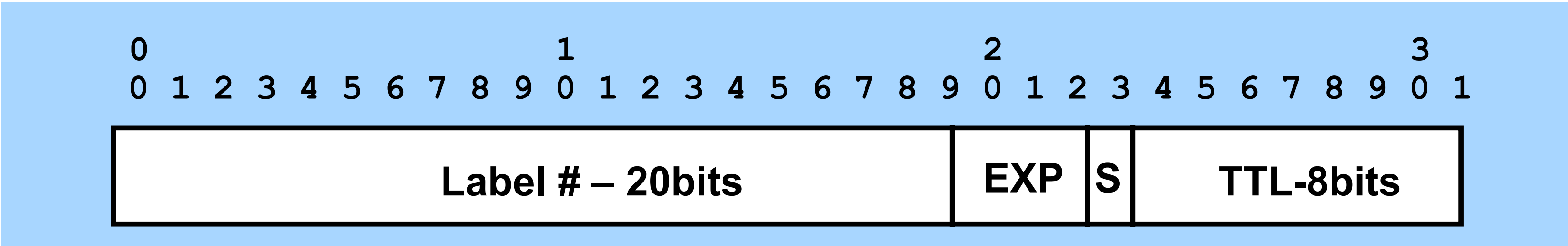
MPLS Network Overview



- P (Provider) router = label switching router = core router (LSR)
  - Switches MPLS-labeled packets
- PE (Provider Edge) router = edge router (LSR)
  - Imposes and removes MPLS labels
- CE (Customer Edge) router
  - Connects customer network to MPLS network

MPLS Label and Label Encapsulation

MPLS Label

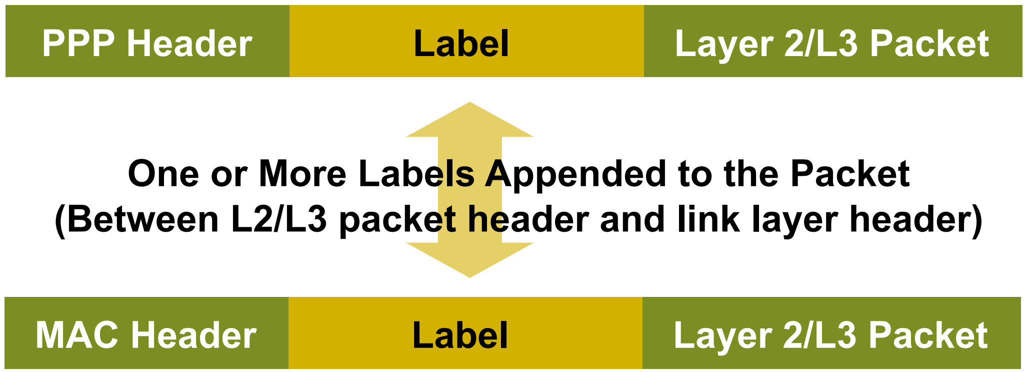


COS/EXP = Class of Service: 3 Bits; S = Bottom of Stack; TTL = Time to Live

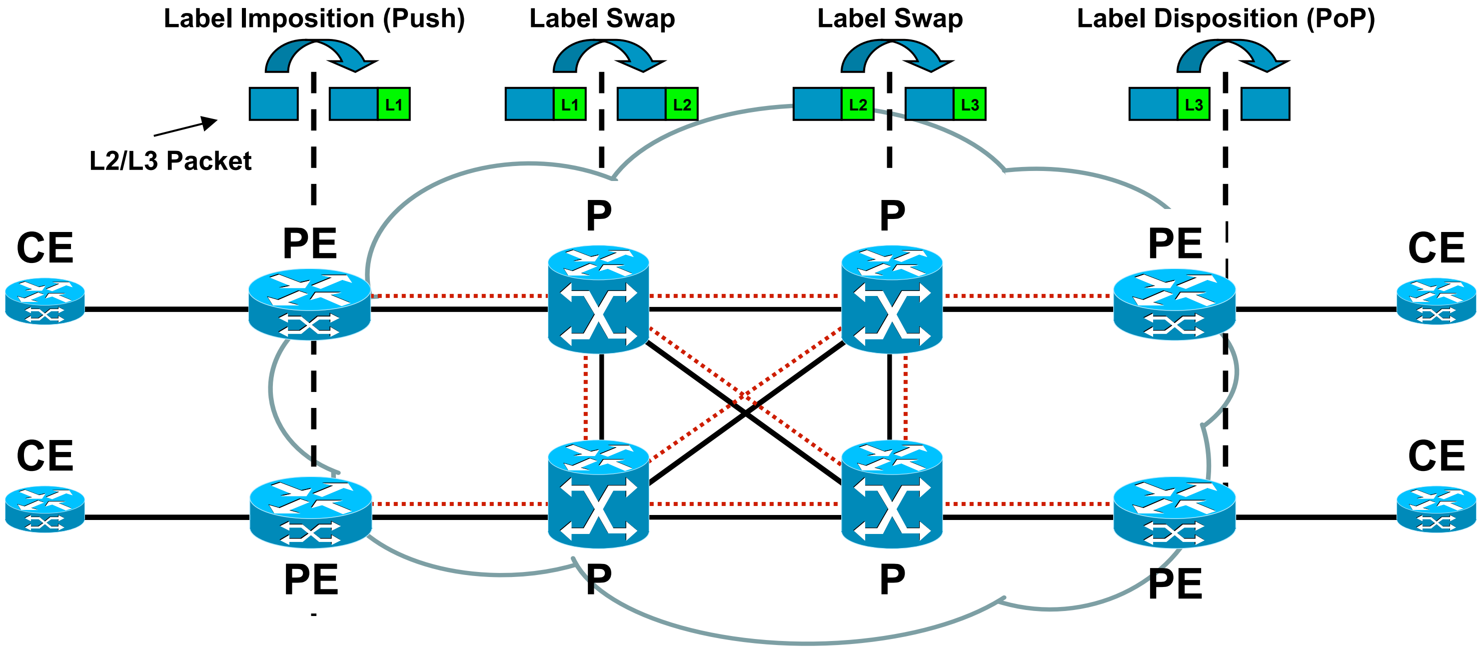
MPLS Label Encapsulation

PPP Header
(Packet over SONET/SDH)

LAN MAC Label Header



MPLS Label Operations



- Label imposition (Push)

  By ingress PE router; classify and label packets

- Label swapping or switching

  By P router; forward packets using labels; indicates service class & destination

- Label disposition (PoP)

  By egress PE router; remove label and forward original packet to destination CE

Forwarding Equivalence Class

- Mechanism to map ingress layer-2/3 packets onto a Label Switched Path (LSP) by ingress PE router
  - Part of label imposition (Push) operation
- Variety of FEC mappings possible
  - IP prefix/host address
  - Groups of addresses/sites (VPN x)
    - Used for L3VPNs
  - Layer 2 circuit ID (ATM, FR, PPP, HDLC, Ethernet)
    - Used for Pseudowires (L2VPNs)
  - A bridge/switch instance (VSI)
    - Used for VPLS (L2VPNs)
  - Tunnel interface
    - Used for MPLS traffic engineering (TE)

Label Distribution Protocol

- MPLS nodes need to exchange label information with each other
  - Ingress PE node (Push operation)
    - Needs to know what label to use for a given FEC to send packet to neighbor
  - Core P node (Swap operation)
    - Needs to know what label to use for swap operation for incoming labeled packets
  - Egress PE node (Pop operation)
    - Needs to tell upstream neighbor what label to use for specific FEC type LDP used for exchange of label (mapping) information
- Label Distribution Protocol (LDP)
  - Defined in RFC 3035 and RFC3036; updated by RFC5036
  - LDP is a superset of the Cisco-specific Tag Distribution Protocol
- Note that, in addition LDP, also other protocols are being used for label information exchange
  - Will be discussed later

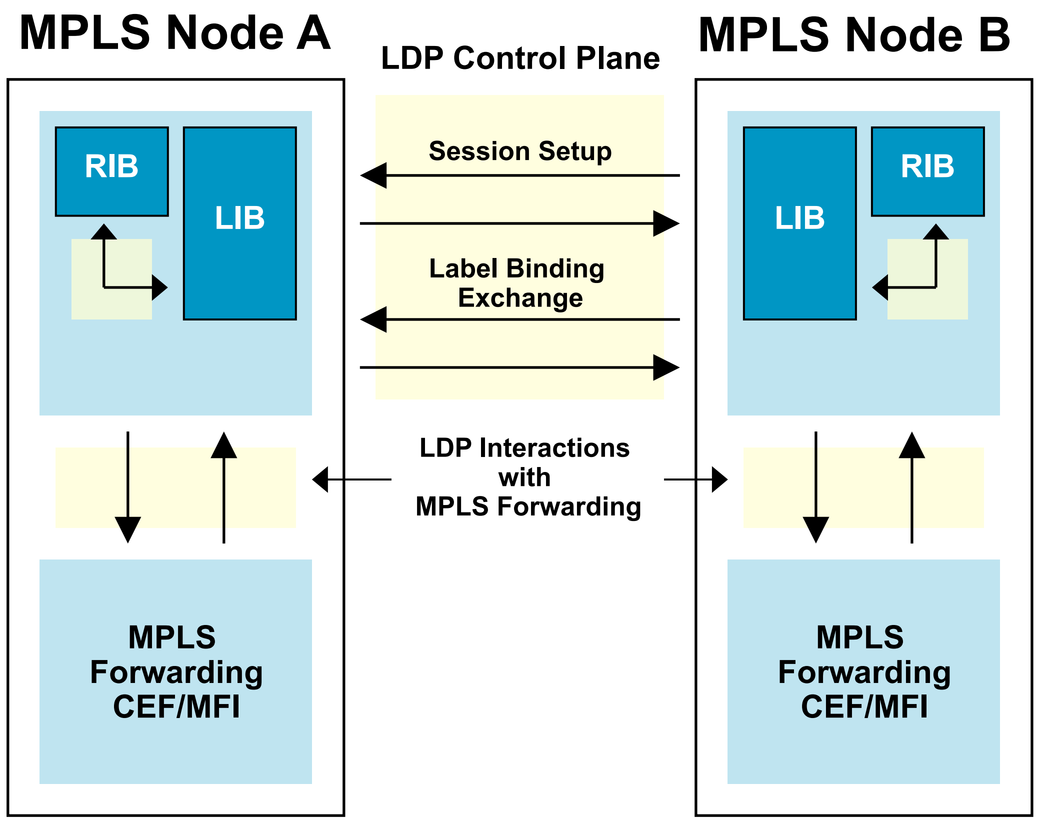
Some More LDP Details

For your reference only

- Assigns, distributes, and installs (in forwarding) labels for prefixes advertised by unicast routing protocols
  - OSPF, IS-IS, EIGRP, etc.
- Also used for Pseudowire/PW (VC) signaling
  - Used for L2VPN control plane signaling
- Uses UDP (port 646) for session discovery and TCP (port 646) for exchange of LDP messages
- LDP operations
  - LDP Peer Discovery
  - LDP Session Establishment
  - MPLS Label Allocation, Distribution, and Updating MPLS forwarding
- Information repositories used by LDP
  - LIB: Label Information Database (read/write)
  - RIB: Routing Information Database/routing table (read-only)

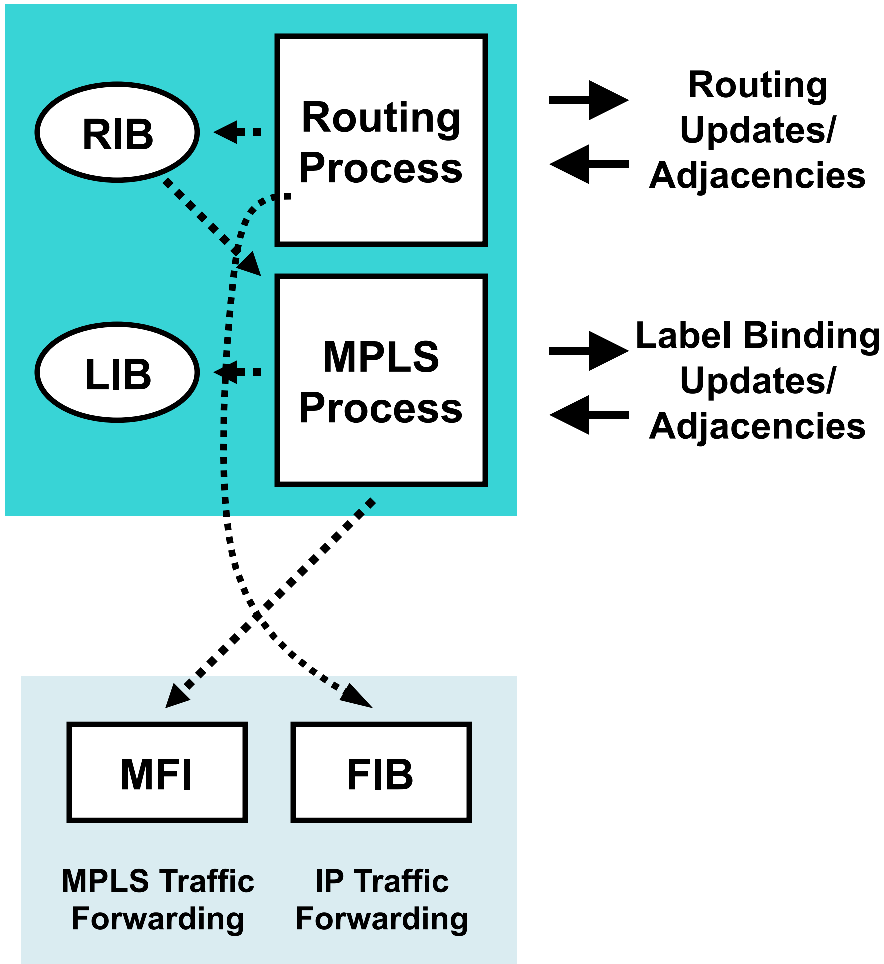
LDP Operations

- LDP startup
  - Local labels assigned to RIB prefixes and stored in LIB
  - Peer discovery and session setup
  - Exchange of MPLS label bindings
- Programming of MPLS forwarding
  - Based on LIB info
  - CEF/MFI updates

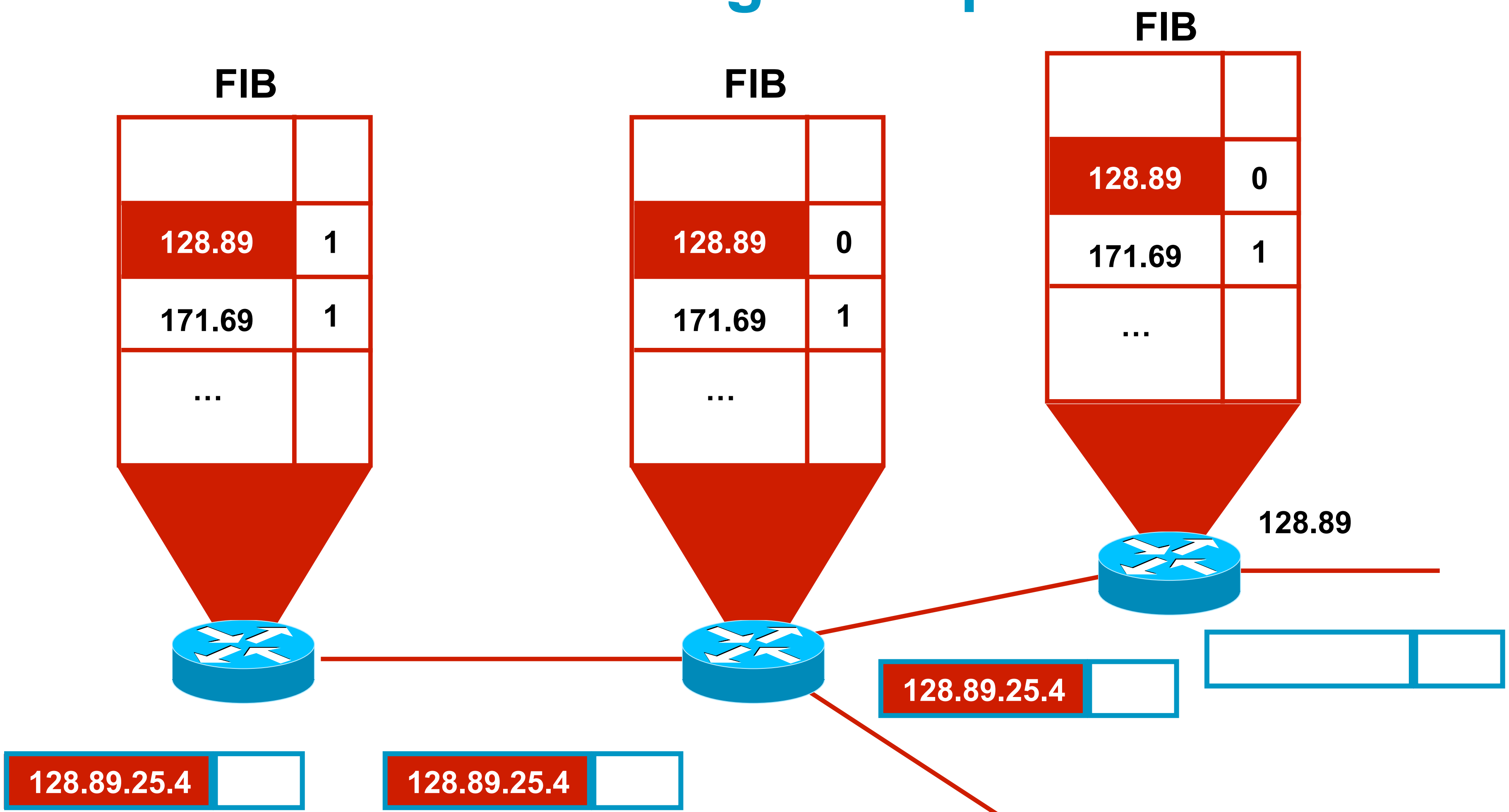


MPLS Control and Forwarding Plane

- MPLS control plane
  - Used for distributing labels and building label-switched paths (LSPs)
  - Typically supported by LDP; also supported via RSVP and BGP
  - Labels define destination and service
- MPLS forwarding plane
  - Used for label imposition, swapping, and disposition
  - Independent of type of control plane
  - Labels separate forwarding from IP address-based routing

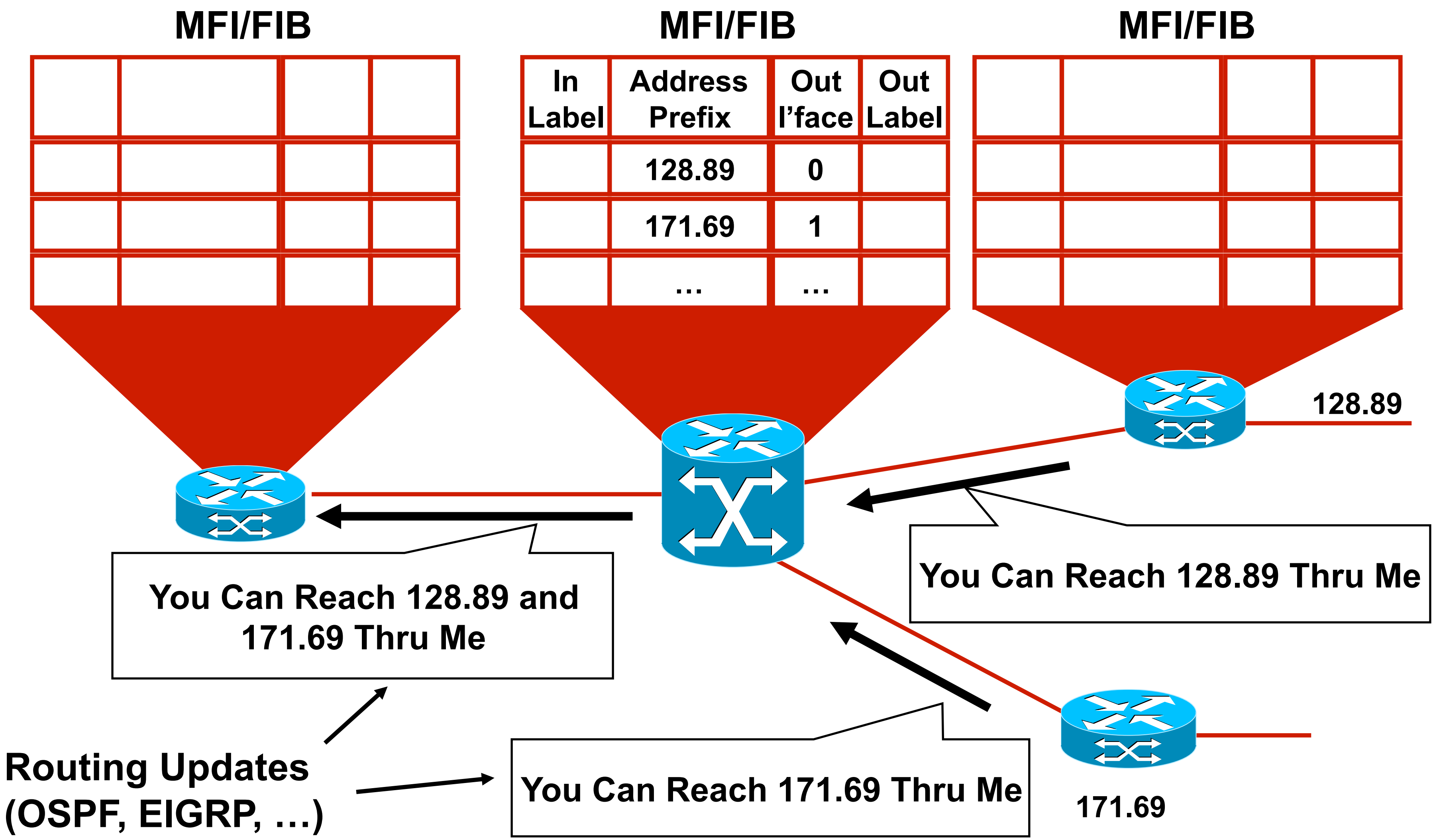


IP Packet Forwarding Example

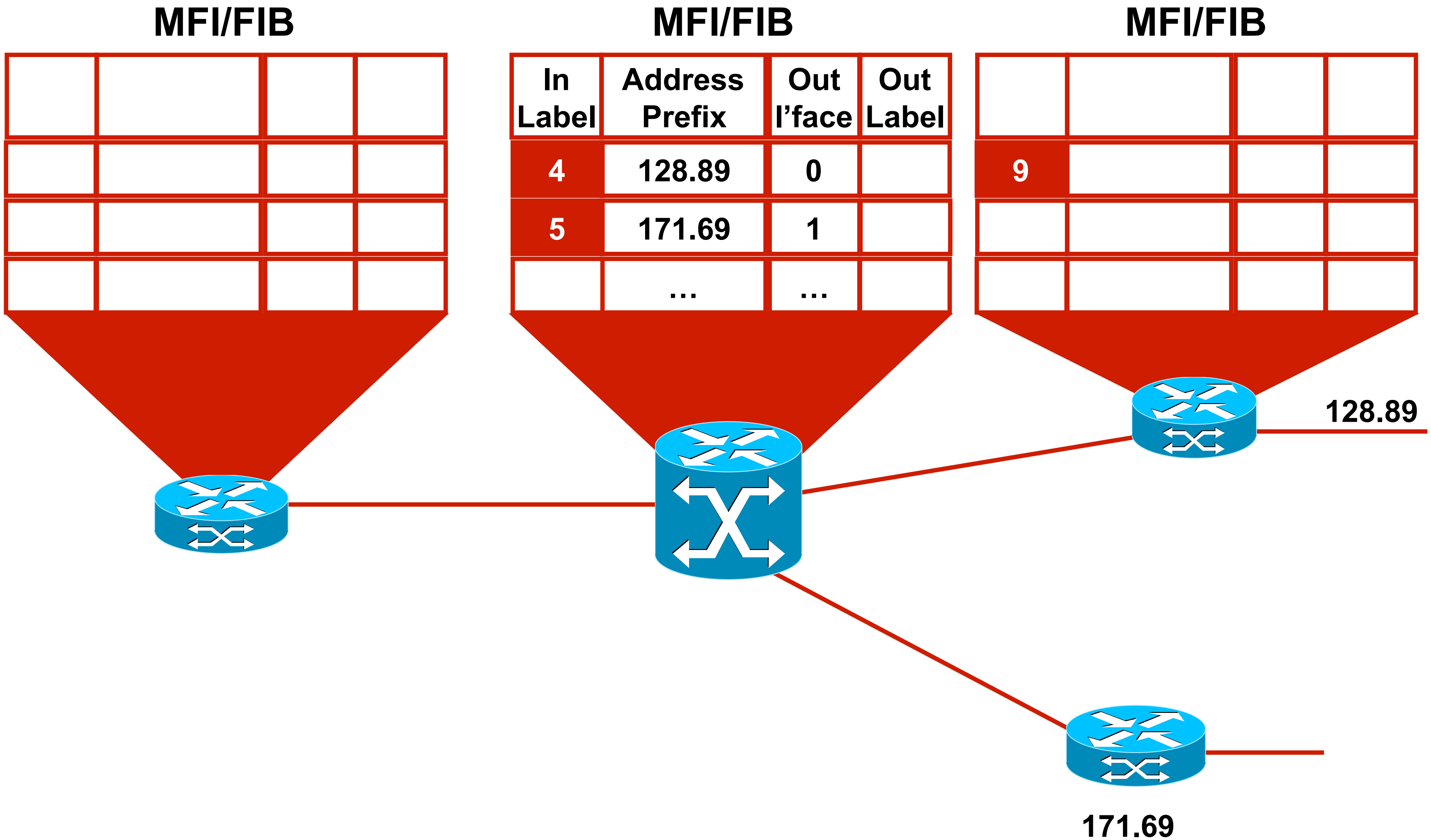


Packets Forwarded Based on IP Address (via RIB lookup)

Step 1: IP Routing (IGP) Convergence

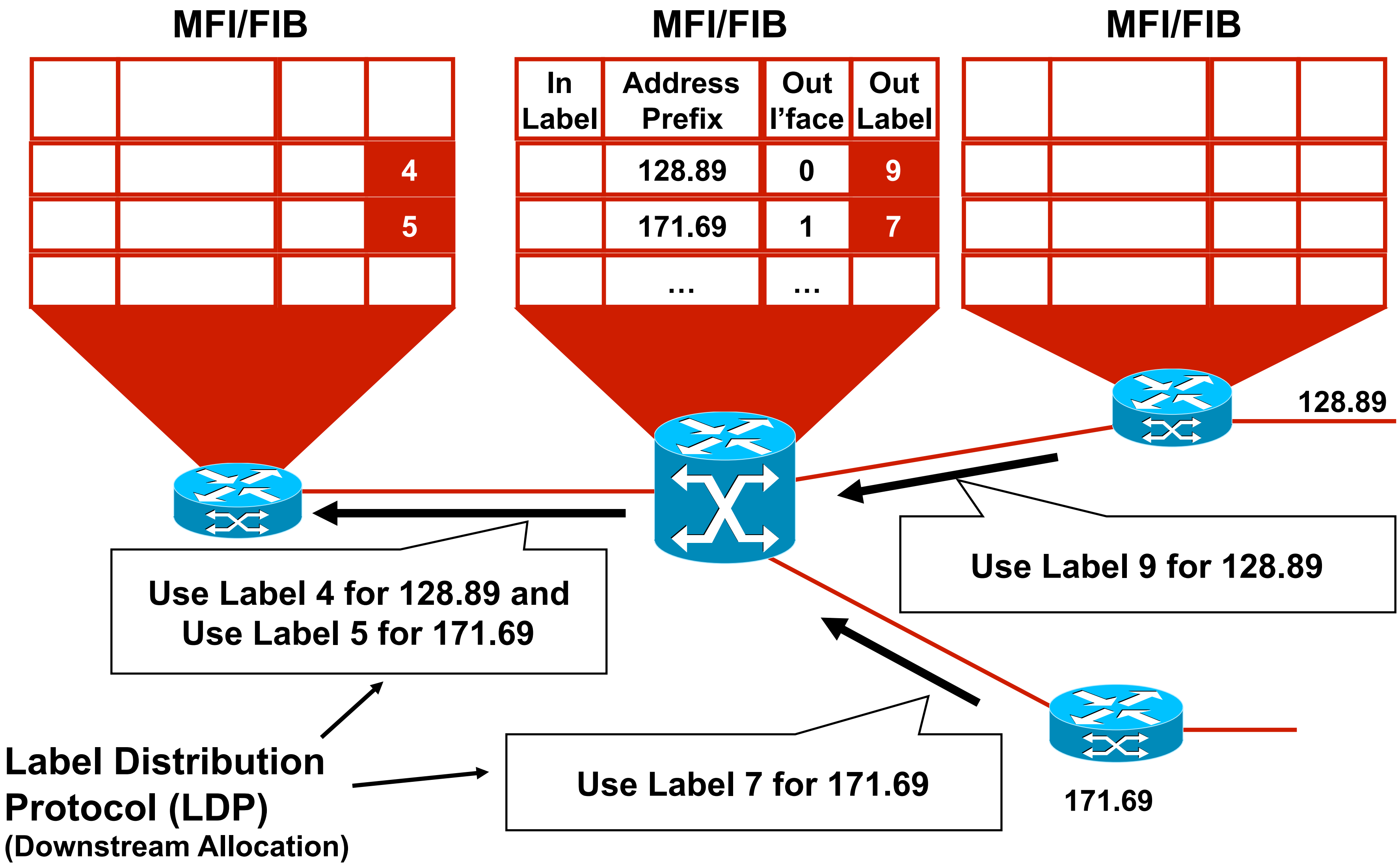


Step 2a: LDP Assigns Local Labels

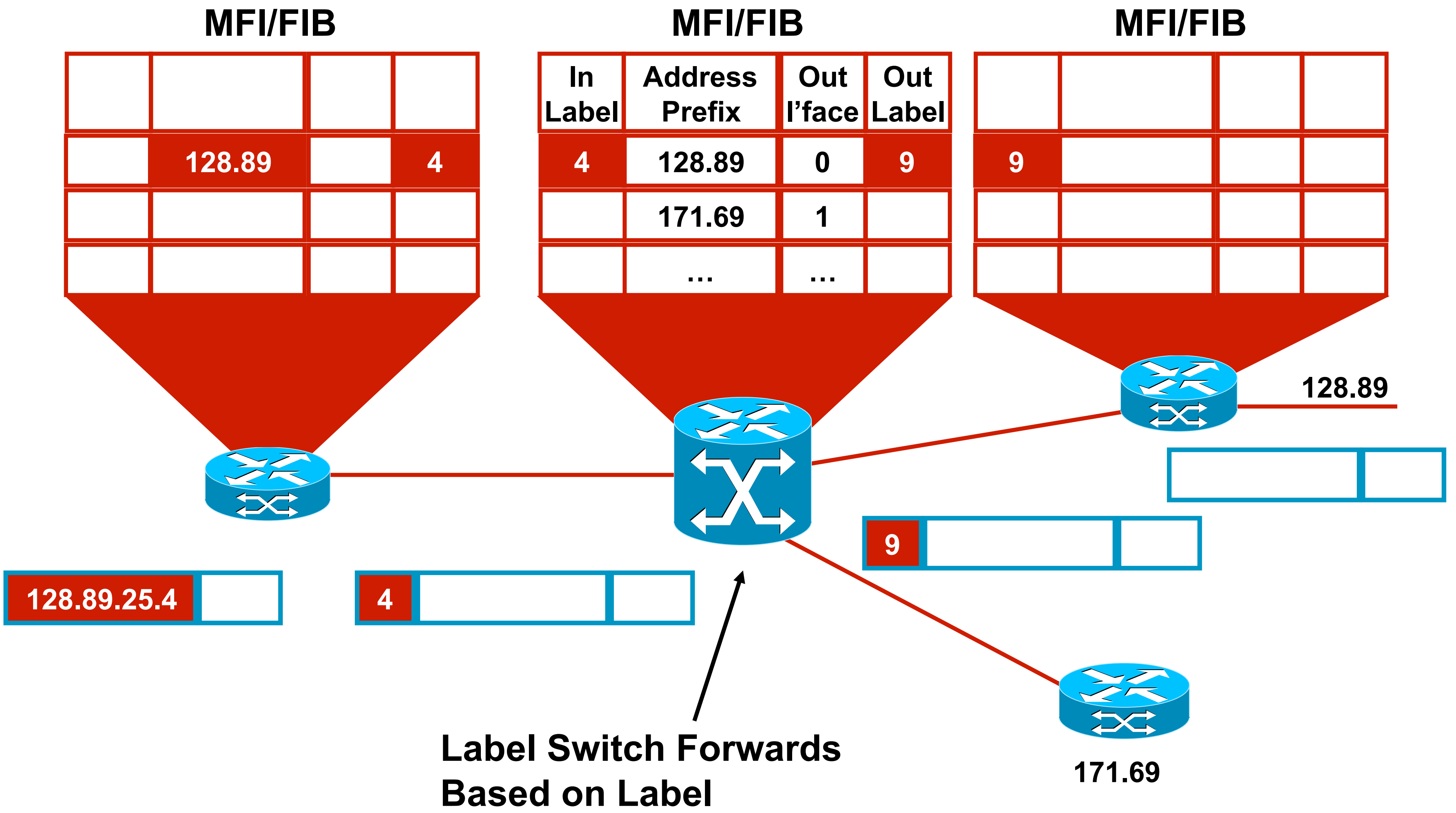


In Label	Address Prefix	Out I'face	Out Label
4	128.89	0	
5	171.69	1	
	...	...	

Step 2b: LDP Assigns Remote Labels



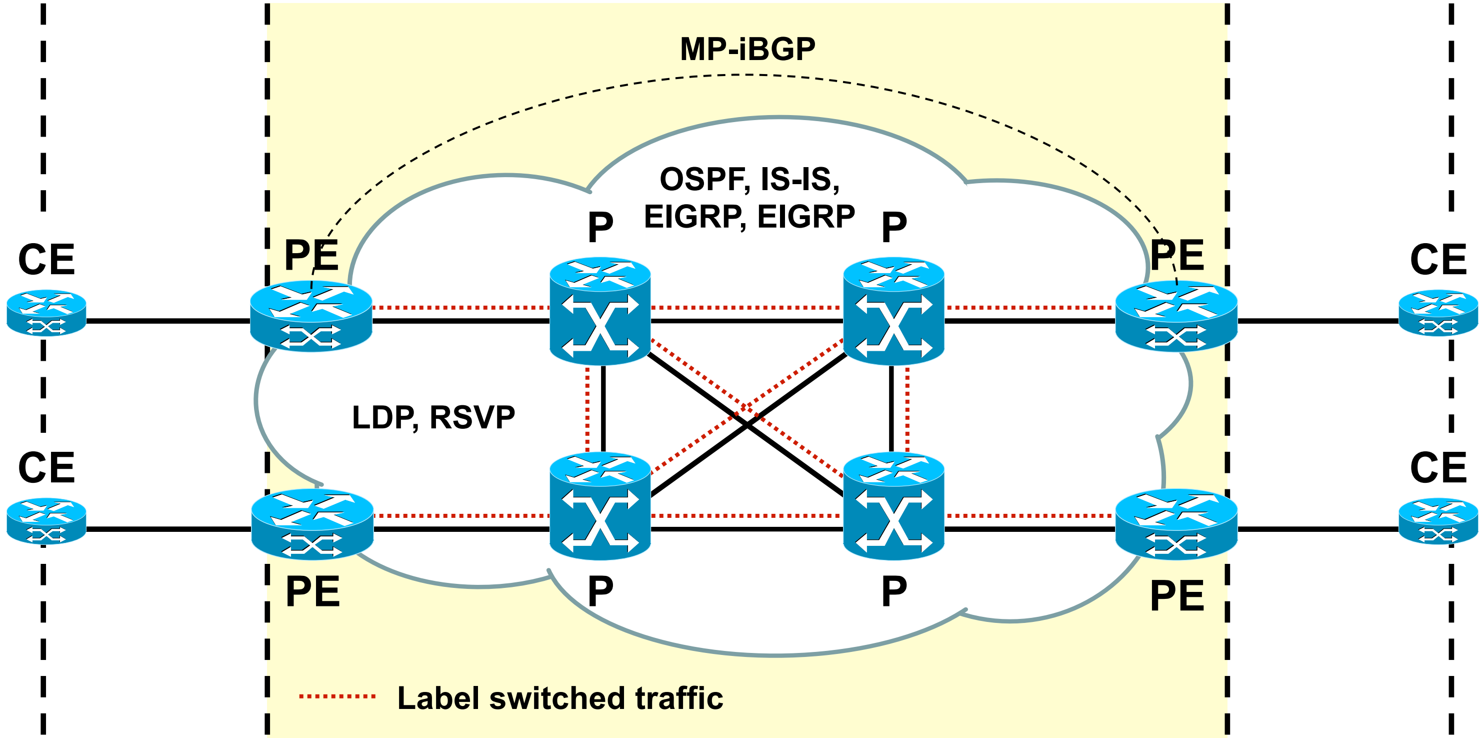
Step 3: Forwarding MPLS Packets



Summary Steps For MPLS Forwarding

- Each node maintains IP routing information via IGP
  - IP routing table (RIB) and IP forwarding table (FIB)
- LDP leverages IGP routing information
- LDP label mapping exchange (between MPLS nodes) takes place after IGP has converged
  - LDP depends on IGP convergence
  - Label binding information stored in LIB
- Once LDP has received remote label binding information MPLS forwarding is updated
  - Label bindings are received from remote LDP peers
  - MPLS forwarding via MFI

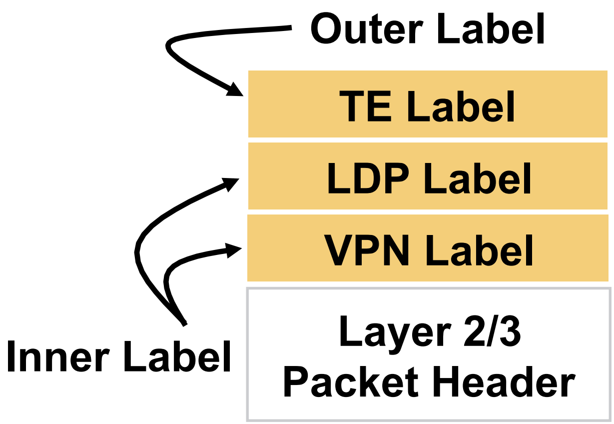
MPLS Network Protocols



- IGP: OSPF, EIGRP, IS-IS on core facing and core links
- RSVP and/or LDP on core and/or core facing links
- MP-iBGP on PE devices (for MPLS services)

Label Stacking

- More than one label can be used for MPLS packet encapsulation
  - Creation of a label stack
- Recap: labels correspond to Forwarding Equivalence Class (FEC)
  - Each label in stack used for different purposes
- Outer label always used for switching MPLS packets in network
- Remaining inner labels used to specific services/FECs, etc.
- Last label in stack marked with EOS bit
- Allows building services such as
  - MPLS VPNs; LDP + VPN label
  - Traffic engineering (FRR): LDP + TE label
  - VPNs over TE core: LDP + TE + VPN label
  - Any transport over MPLS: LDP + PW label



Summary

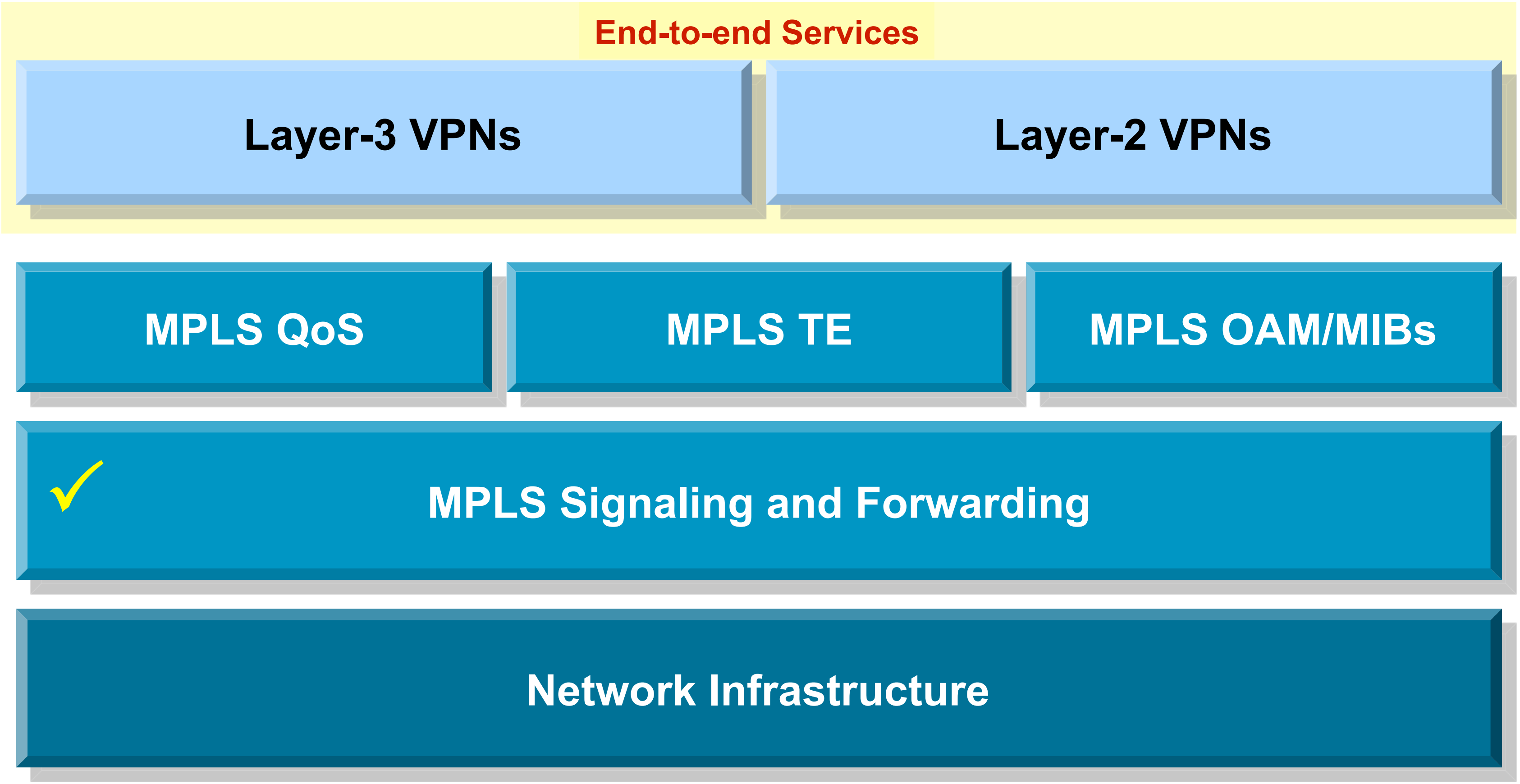
- MPLS uses labels to forward traffic
- More than one label can be used for traffic encapsulation; multiple labels make up a label stack
- Traffic is encapsulated with label(s) at ingress and at egress labels are removed in MPLS network
- MPLS network consists of PE router at ingress/egress and P routers in the core
- MPLS control plane used for signaling label mapping information to set up end-to-end Label Switched Paths
- MPLS forwarding plane used for label imposition (PUSH), swapping, and disposition (POP) operation

MPLS VPNs

Overviews

MPLS Technology Framework

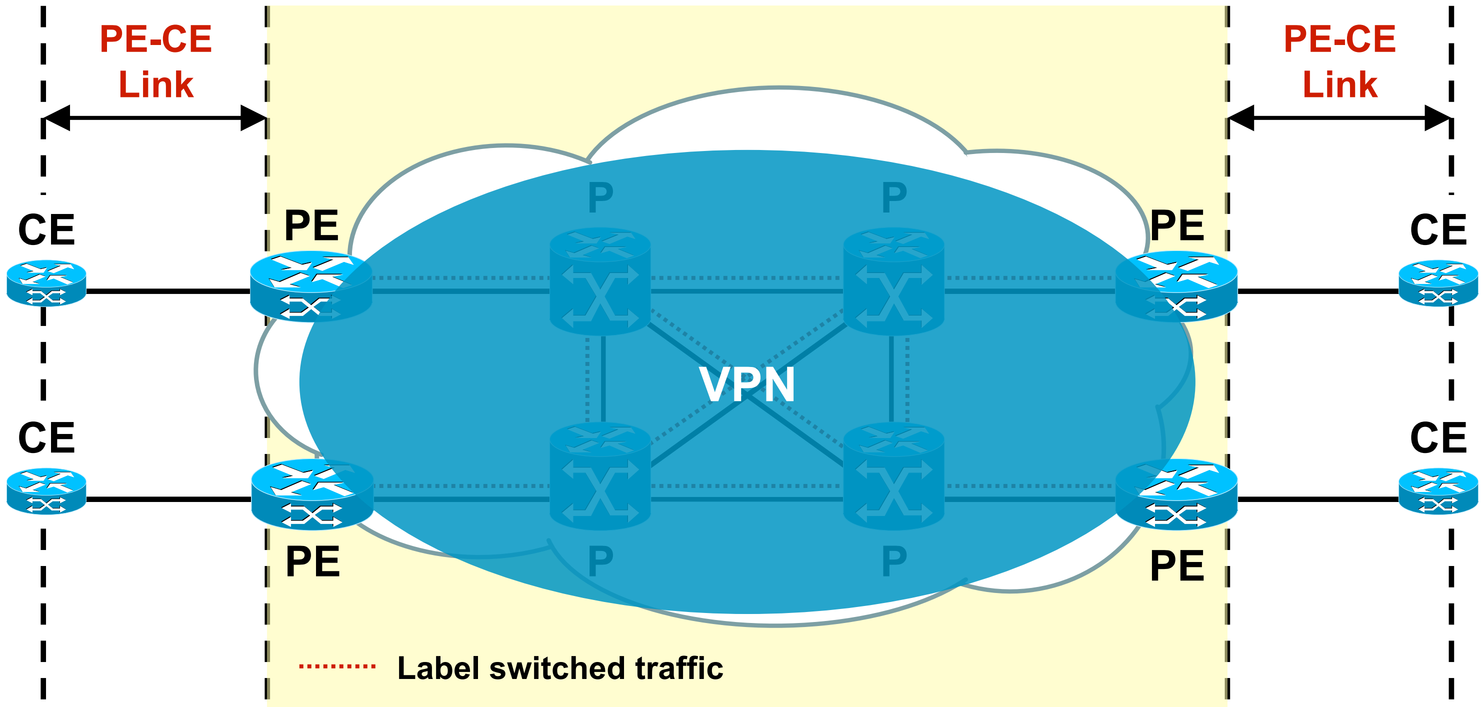
- End-to-end data connectivity services across MPLS networks (from PE to PE)



What Is a Virtual Private Network?

- VPN is a set of sites or groups which are allowed to communicate with each other in a secure way
  - Typically over a shared public or private network infrastructure
- VPN is defined by a set of administrative policies
  - Policies established by VPN customers themselves (DIY)
  - Policies implemented by VPN service provider (managed/ unmanaged)
- Different inter-site connectivity schemes possible
  - Ranging from complete to partial mesh, hub-and-spoke
- 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

MPLS VPN Example



- PE-CE link

  Connect customer network to SP network; layer-2 or layer-3

- VPN

  Dedicated secure connectivity over shared infrastructure

MPLS VPN Benefits

- SP/Carrier perspective
  - Reduce costs (CAPEX)
    - Leverage same network for multiple services and customers
    - Migrate legacy networks onto single converged network
  - Reduce costs (OPEX)
    - Easier service enablement; only edge node configuration
- Enterprise/end-user perspective
  - Enables site/campus network segmentation
    - Allows for dedicated connectivity for users, applications, etc.
  - Enables easier setup of WAN connectivity
    - Easier configuration of site-to-site WAN connectivity (for L3VPN and VPLS); only one WAN connection needed

MPLS VPN Options

MPLS VPN Models

Layer-2 VPNs

Point-to-Point Layer-2 VPNs

- CPE connected to PE via p2p Layer-2 connection (FR, ATM)
- CEs peer with each other (IP routing) via p2p layer-2 VPN connection
- CE-CE routing; no SP involvement

Multi-Point Layer-2 VPNs

- CPE connected to PE via Ethernet connection (VLAN)
- CEs peer with each other via fully/ partial mesh Layer-2 VPN connection
- CE-CE routing; no SP involvement

Layer-3 VPNs

- CPE connected to PE via IP-based connection (over any layer-2 type)
  - Static routing
  - PE-CE routing protocol; eBGP, OSPF, IS-IS
- CEs peer with PE router
- PE routers maintain customer-specific routing tables and exchange customer=specific routing information
- Layer-3 VPN provider’s PE routers are part of customer routing

MPLS Layer-3 VPNs

Technology Overview and Applications

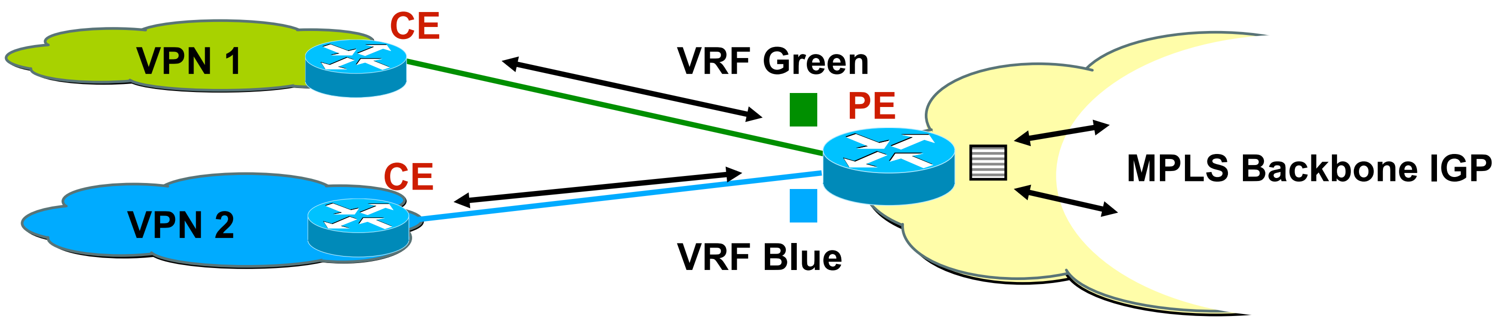
MPLS L3 VPN Overview

- Customer router (CE) has a IP peering connection with PE/edge router in MPLS network
  - IP routing/forwarding across PE-CE link
- MPLS VPN network responsible for distributing routing information to remote VPN sites
  - MPLS VPN part of customer IP routing domain
- MPLS VPNs enable full-mesh, hub-and-spoke, and hybrid connectivity among connected CE sites
- MPLS VPN service enablement in MPLS networks only requires VPN configuration at edge/PE nodes
  - Connectivity in core automatically established via BGP signaling

MPLS L3 VPN Technology Components

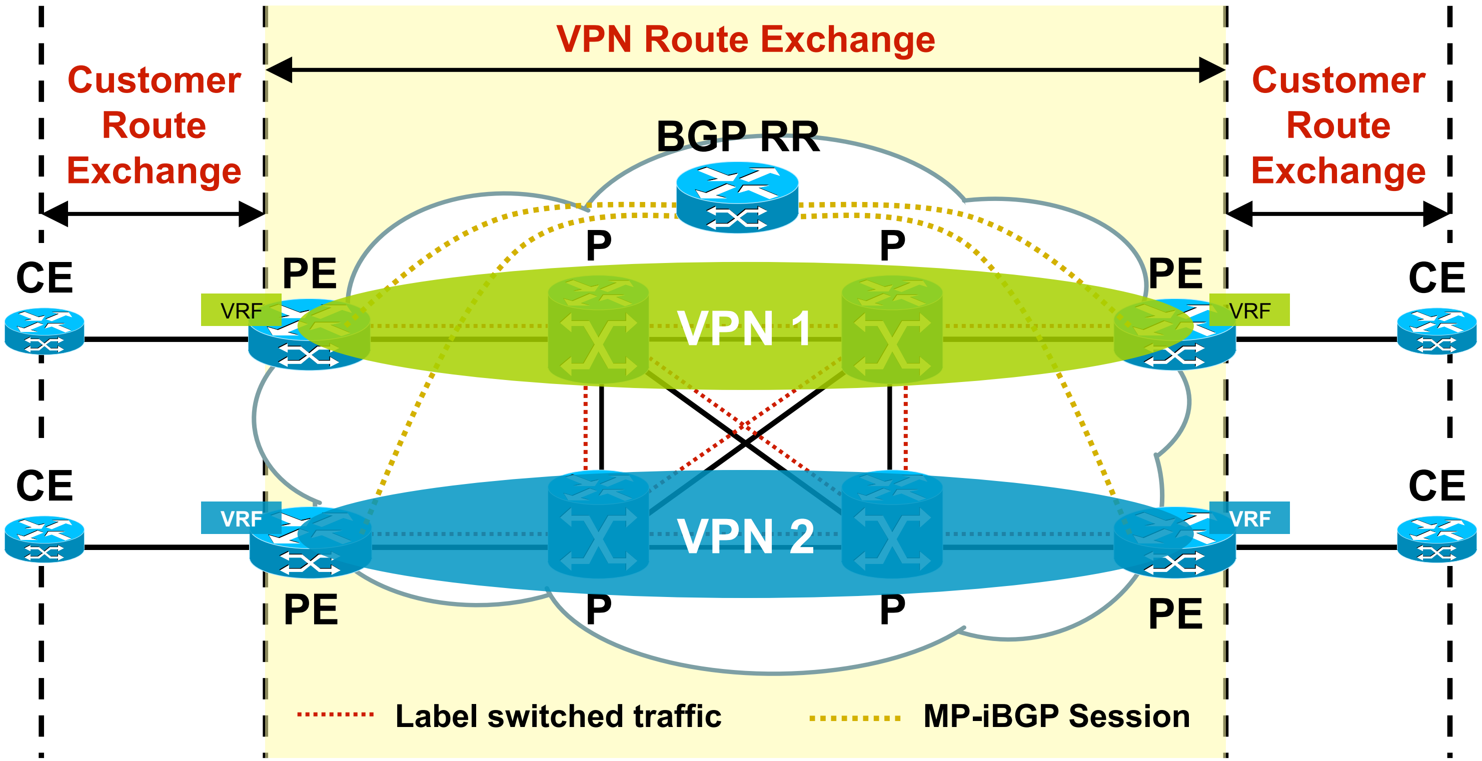
- PE-CE link
  - Can be any type of layer-2 connection (e.g., FR, Ethernet)
  - CE configured to route IP traffic to/from adjacent PE router
  - Variety of routing options; static routes, eBGP, OSPF, IS-IS
- MPLS L3VPN Control Plane
  - Separation of customer routing via virtual VPN routing table
  - In PE router: customer I/Fs connected to virtual routing table
  - Between PE routers: customer routes exchanged via BGP
- MPLS L3VPN Forwarding Plane
  - Separation of customer VPN traffic via additional VPN label
  - VPN label used by receiving PE to identify VPN routing table

Virtual Routing and Forwarding Instance



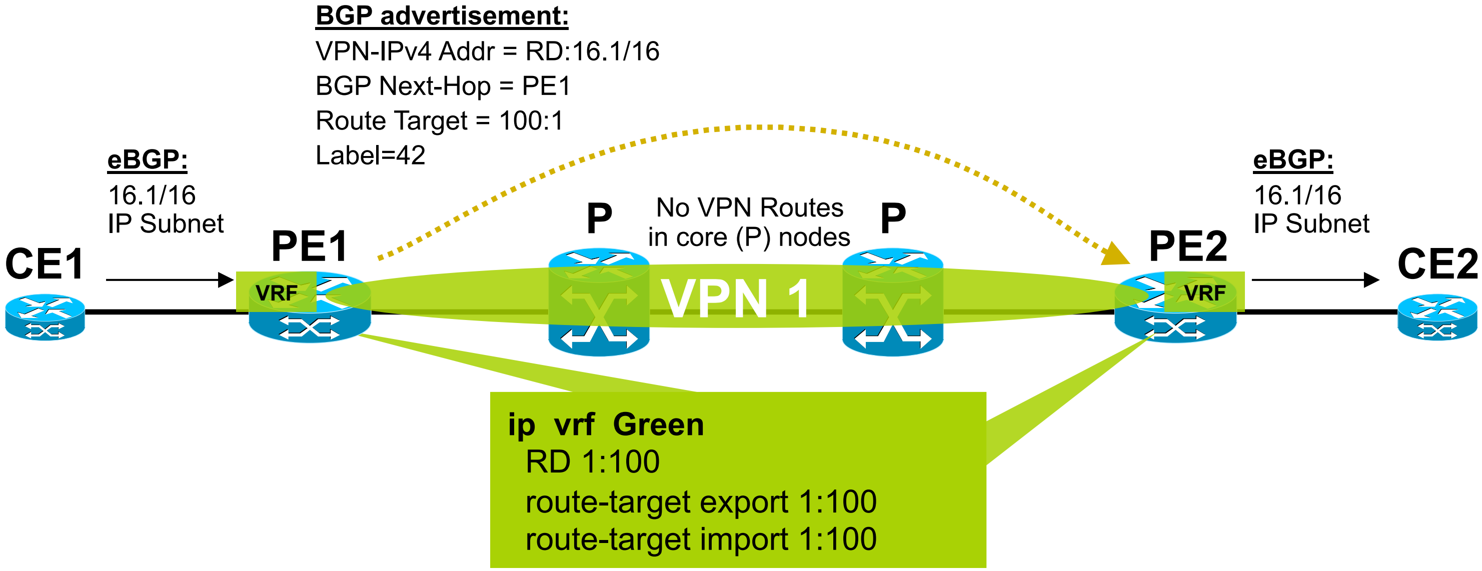
- Virtual Routing and Forwarding Instance (VRF)
- Typically one VRF created for each customer VPN on PE router
- VRF associated with one or more customer interfaces
- VRF has its own instance of routing table (RIB) and forwarding table (CEF)
- VRF has its own instance for PE-CE configured routing protocols

VPN Route Distribution



- Full mesh of BGP sessions among all PE routers
  - Multi-Protocol BGP extensions (MP-iBGP)
  - Typically BGP Route Reflector (RR) used for improved scalability

VPN Control Plane Processing



Make customer routes unique:

- Route Distinguisher (RD): 8-byte field, VRF parameters; unique value assigned by a provider to each VPN to make different VPN routes unique
- VPNv4 address: RD+VPN IP prefix

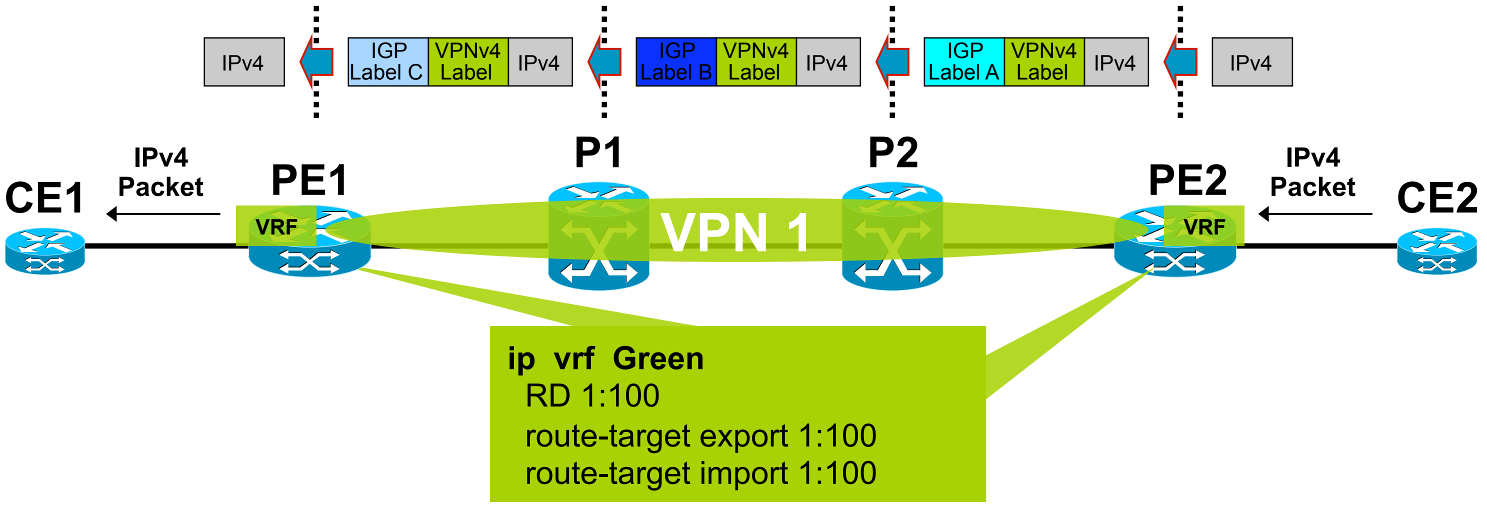
Selective distribute customer routes:

- Route Target (RT): 8-byte field, VRF parameter, unique value to define the import/export rules for VPNv4 routes
- MP-iBGP: advertises VPNv4* prefixes + labels

Processing Steps:

1. CE1 redistribute IPv4 route to PE1 via eBGP.
2. PE1 allocates VPN label for prefix learnt from CE1 to create unique VPNv4 route
3. PE1 redistributes VPNv4 route into MP-iBGP, it sets itself as a next hop and relays VPN site routes to PE2
4. PE2 receives VPNv4 route and, via processing in local VRF (green), it redistributes original IPv4 route to CE2.

VPN Forwarding Plane Processing



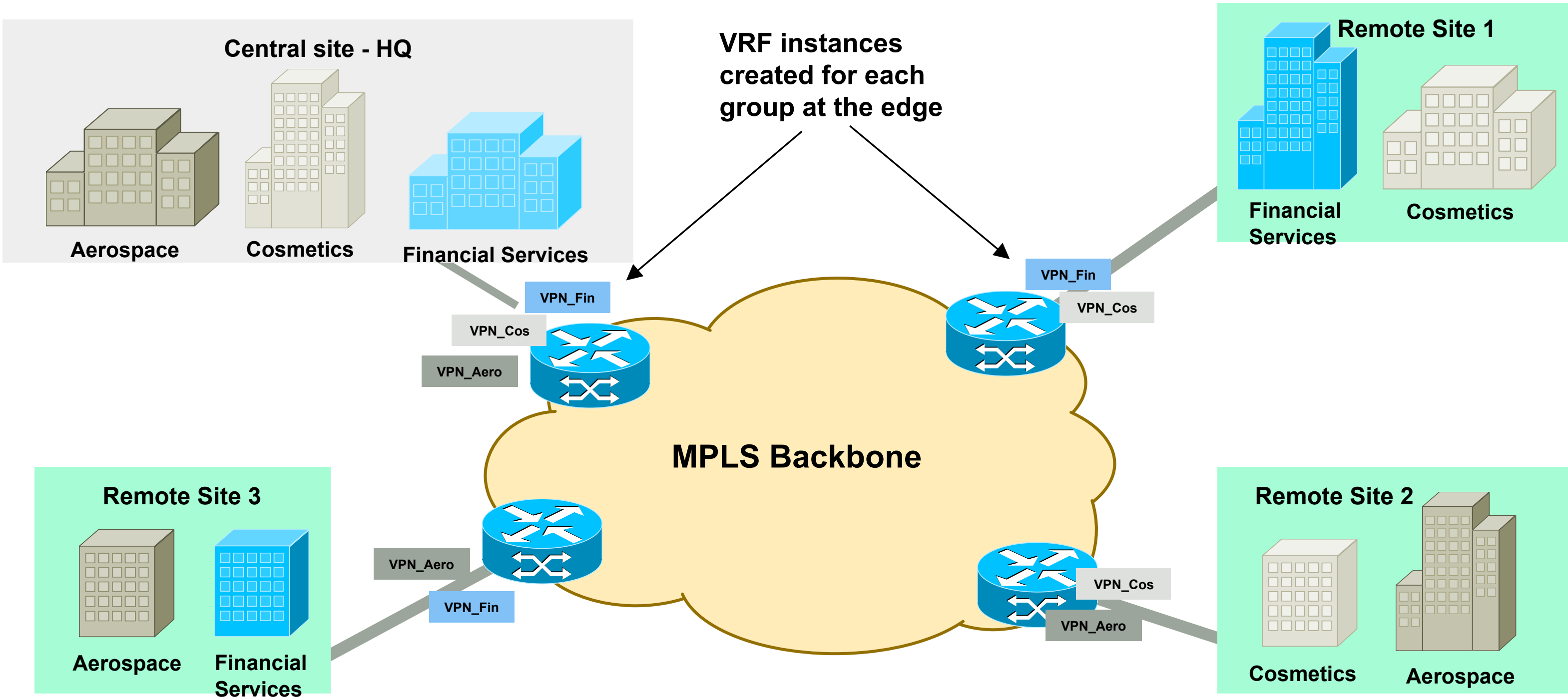
Processing Steps:

1. CE2 forwards IPv4 packet to PE2.
2. PE2 imposes pre-allocated VPN label (learned via MP-IBGP) to IPv4 packet received from CE2.
3. PE2 imposes outer IGP label (learned via LDP) and forwards labeled packet to next-hop P-router P2.
4. P-routers P1 and P2 swap outer IGP label and forward label packet to PE1.
5. Router PE1 strips VPN label and forwards IPv4 packet to CE1.

Use Case 1: Traffic Separation

Requirement: Need to ensure data separation between Aerospace, Cosmetics and Financial Services, while leveraging a shared infrastructure

Solution: Create MPLS VPN for each group

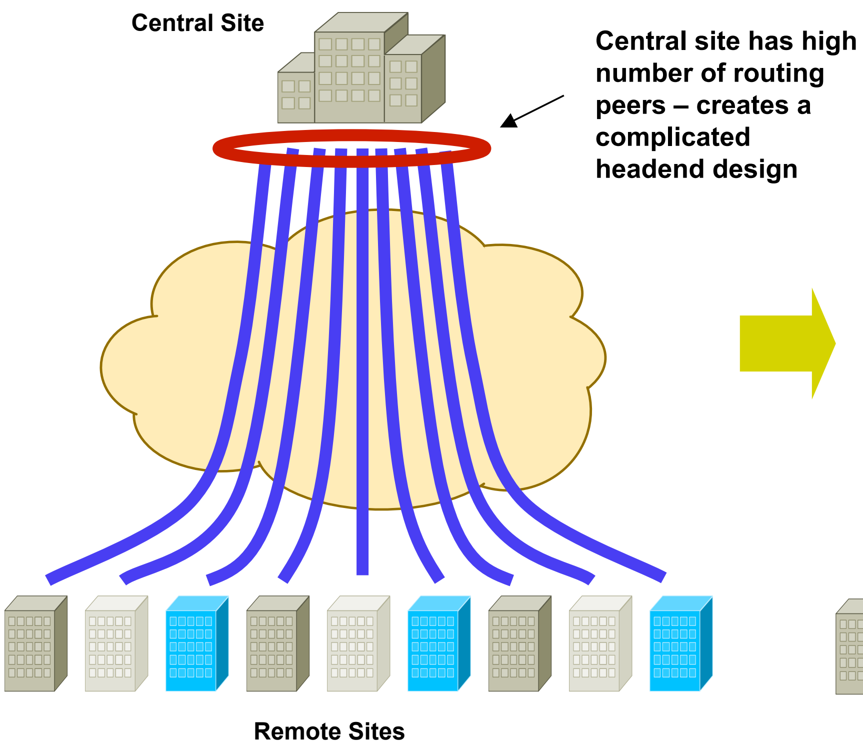


Use Case 2: Simplify Hub Site Design

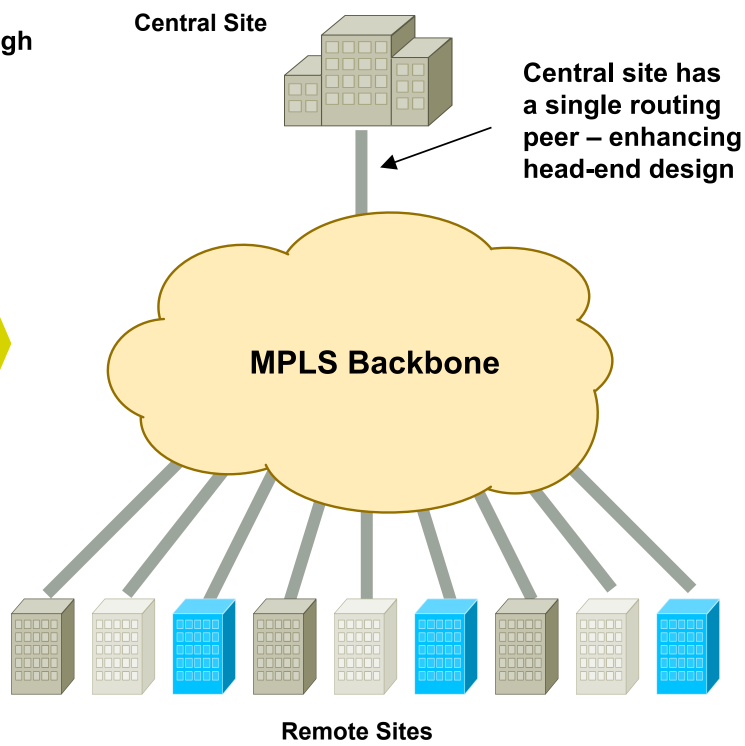
Requirement: To ease the scale and design of head-end site

Solution: Implement MPLS Layer 3 VPNs, which reduces the number of routing peers of the central site

Without MPLS

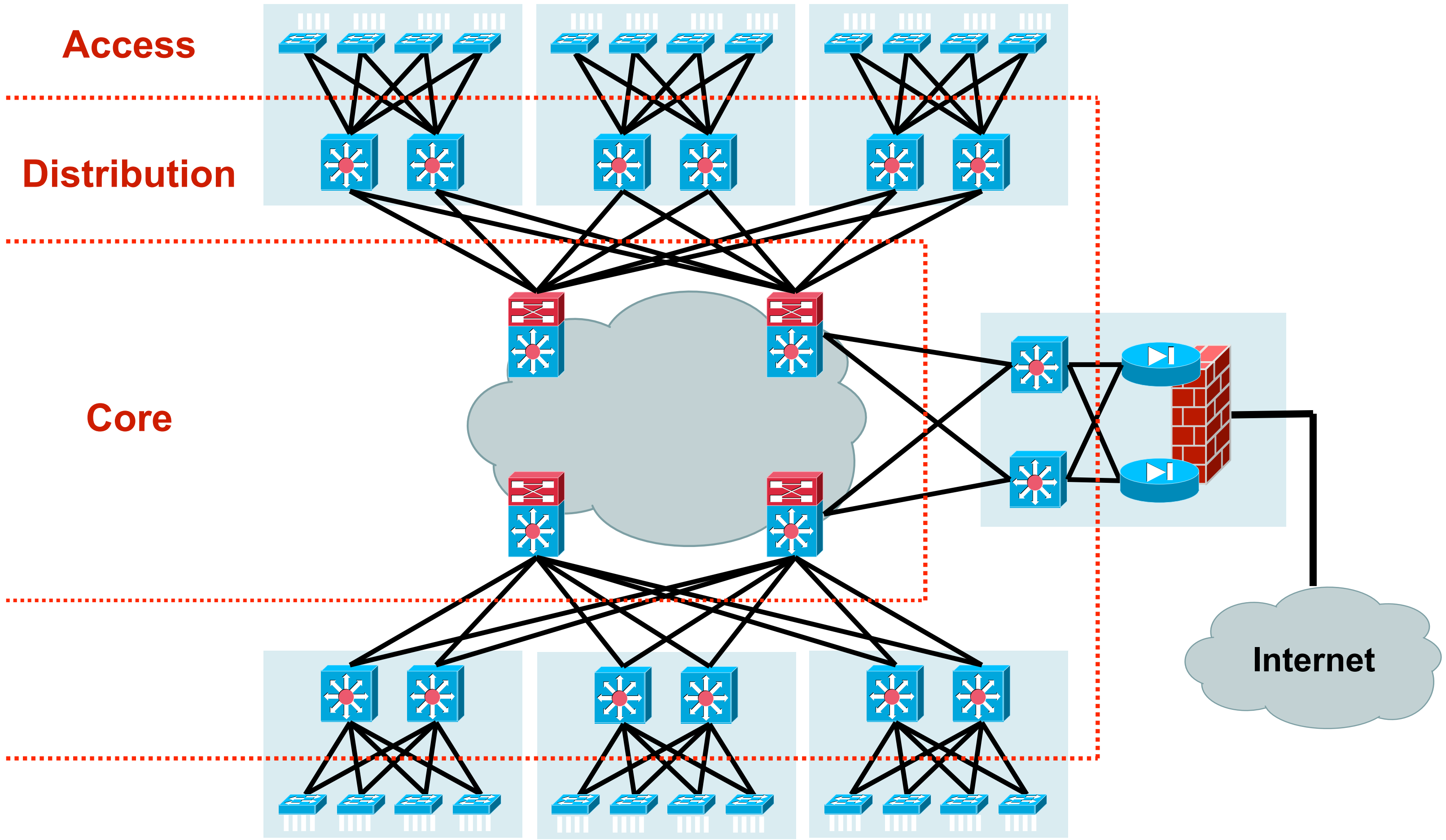


With MPLS



Enterprise Network Architecture

For your reference only



Enterprise Network Segmentation

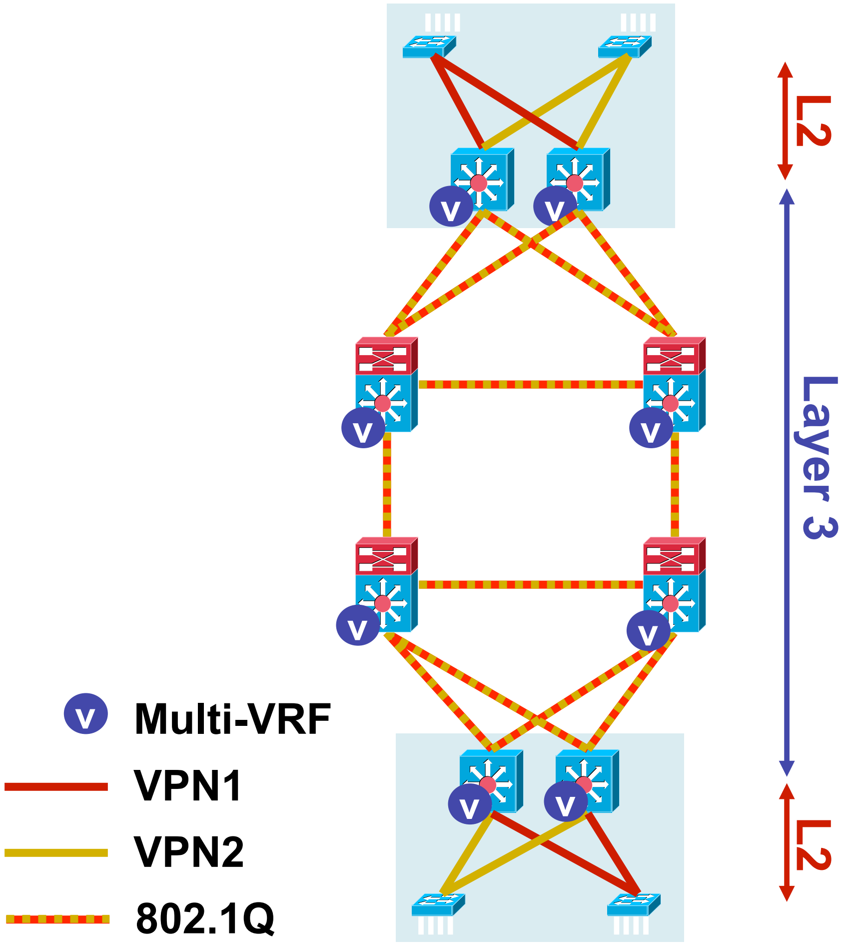
For your reference only

	Distribution	Core	End-to-end Connectivity
VRF-lite + 802.1Q VLANs	VRF lite configured on distribution nodes VLAN mapping onto VRFs	VRF lite configured on core nodes 802.1Q VLAN ID mapping onto VRFs	Device Separation: VRF Data Path Separation: 802.1Q VLAN ID
VRF-lite + GRE tunnels	VRF lite configured on distribution nodes VRFs associated with GRE tunnels	Core nodes forward IP packets (GRE IP Packets)	End-to-end GRE tunnels between distribution nodes
Layer-3 MPLS VPNs	Distribution nodes configured as PE routers with VRF(s)	Core nodes forward MPLS packets (via LFIB)	End-to-end label switched paths (LSPs) between distribution nodes (PE routers)

Option 1: VRF-lite + 802.1Q

For your reference only

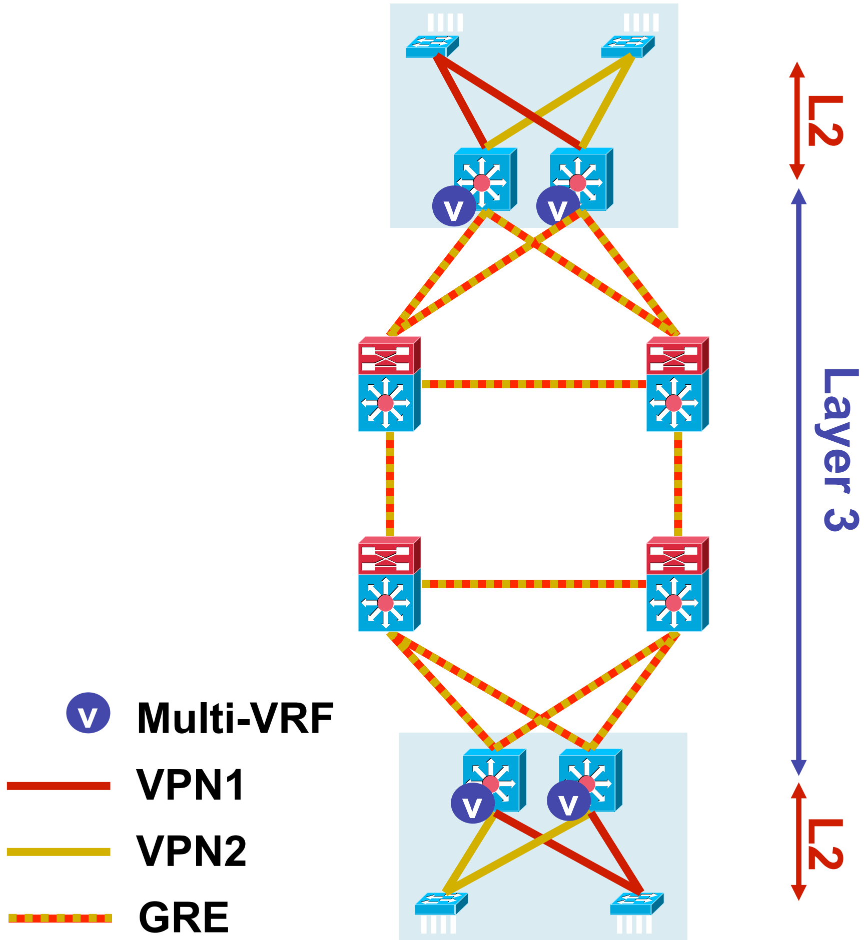
- Layer-2 access
- No BGP or MPLS
- VRF-lite configured on core and distribution nodes
- MPLS labels substituted by 802.1q tags end-to-end
- Every link is a 802.1Q trunk
- Many-to-Many model
- Restricted scalability
- Typical for department inter-connectivity



Option 2: VRF-lite + GRE

For your reference only

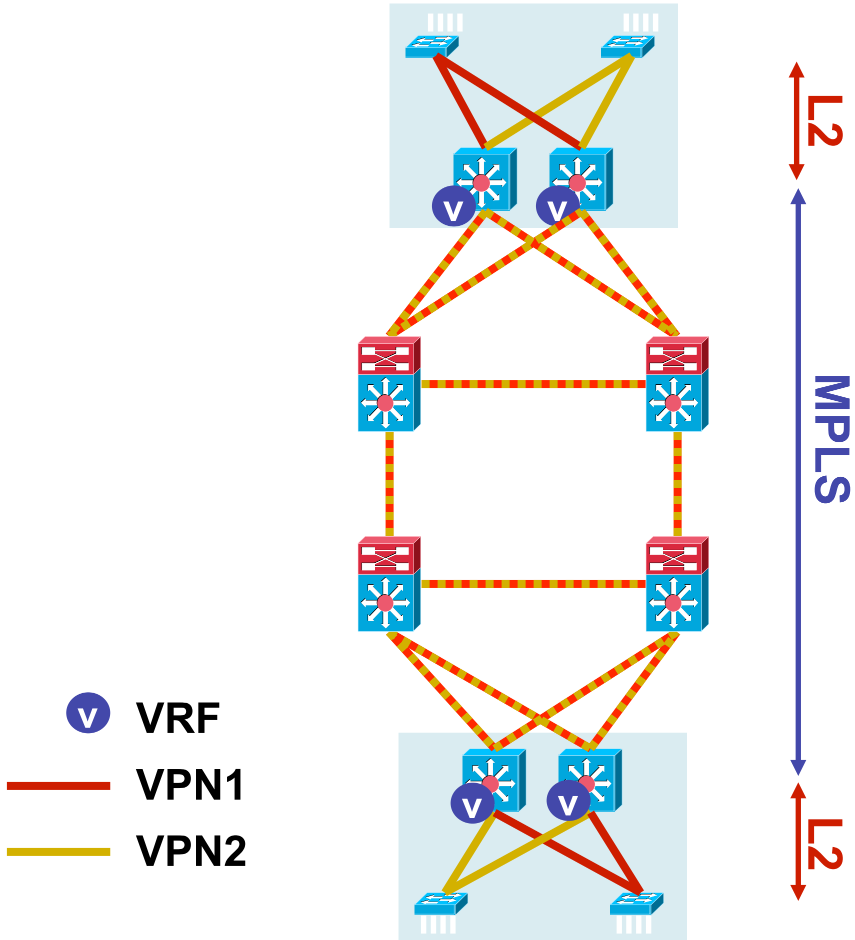
- L2 access
- No BGP or MPLS
- VRF-lite only configured on distribution nodes
- VLANs associated with end-to-end GRE Tunnels
- Many-to-One model
- Restricted scalability
- Typical for user-specific VPN connectivity



Option 3: Layer-3 MPLS VPNs

For your reference only

- L2 access
- Distribution nodes configured as PE routers with VRFs
- MP-iBGP between distribution nodes
- MPLS packet forwarding by core nodes
- Many-to-Many model
- High scalability



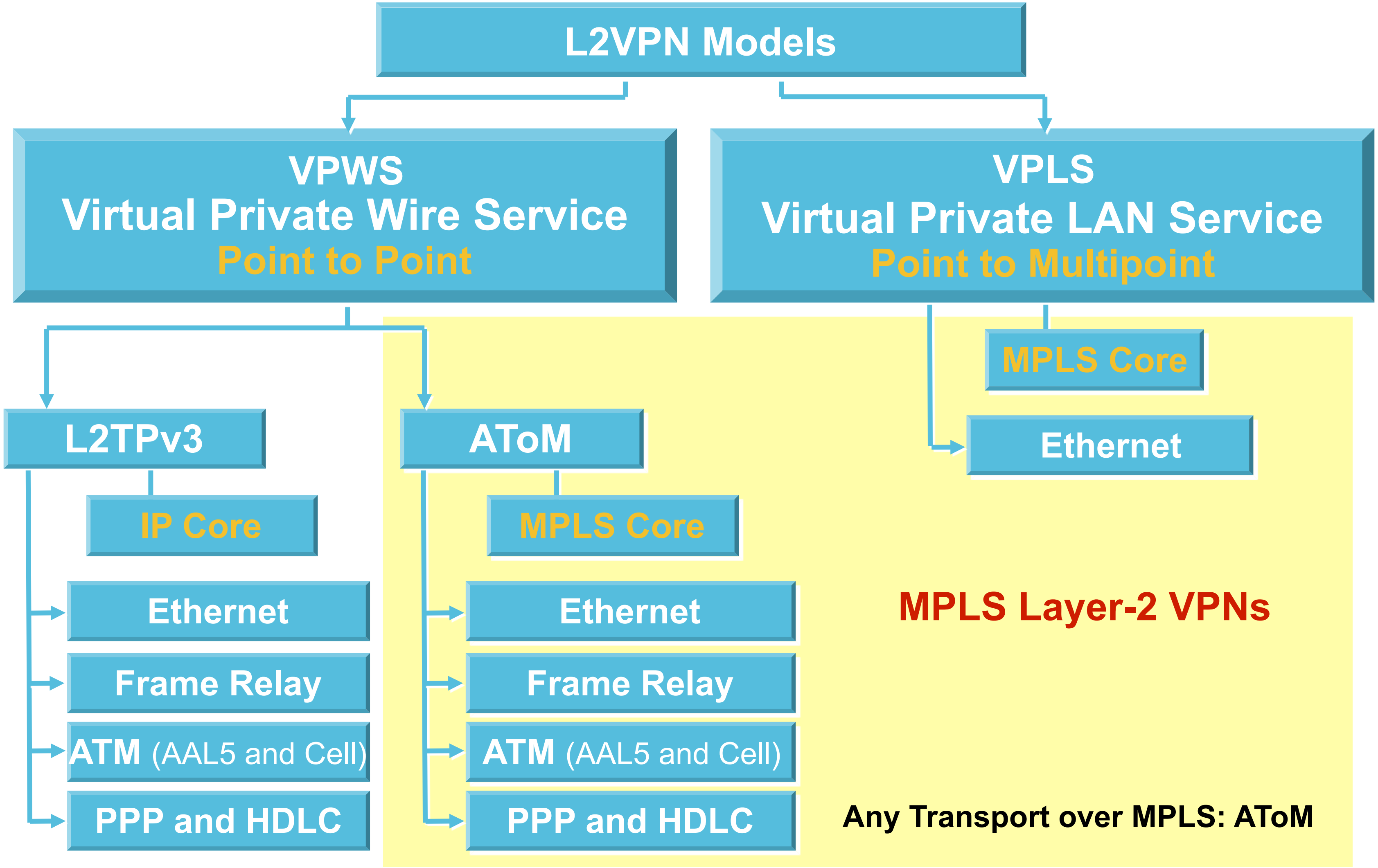
MPLS Layer-3 VPN Summary

- Provide layer-3 connectivity among CE sites via IP peering (across PE-CE link)
- Implemented via VRFs on edge/PE nodes providing customer route and forwarding segmentation
- BGP used for control plane to exchange customer VPN (VPNv4) routes between PE routers
- MPLS VPNs enable full-mesh, hub-and-spoke, and hybrid IP connectivity among connected CE sites
- L3 VPNs for enterprise network segmentation can also be implemented via VRFs + GRE tunnels or VLANs

MPLS Layer-2 VPNs

Technology Overview and Applications

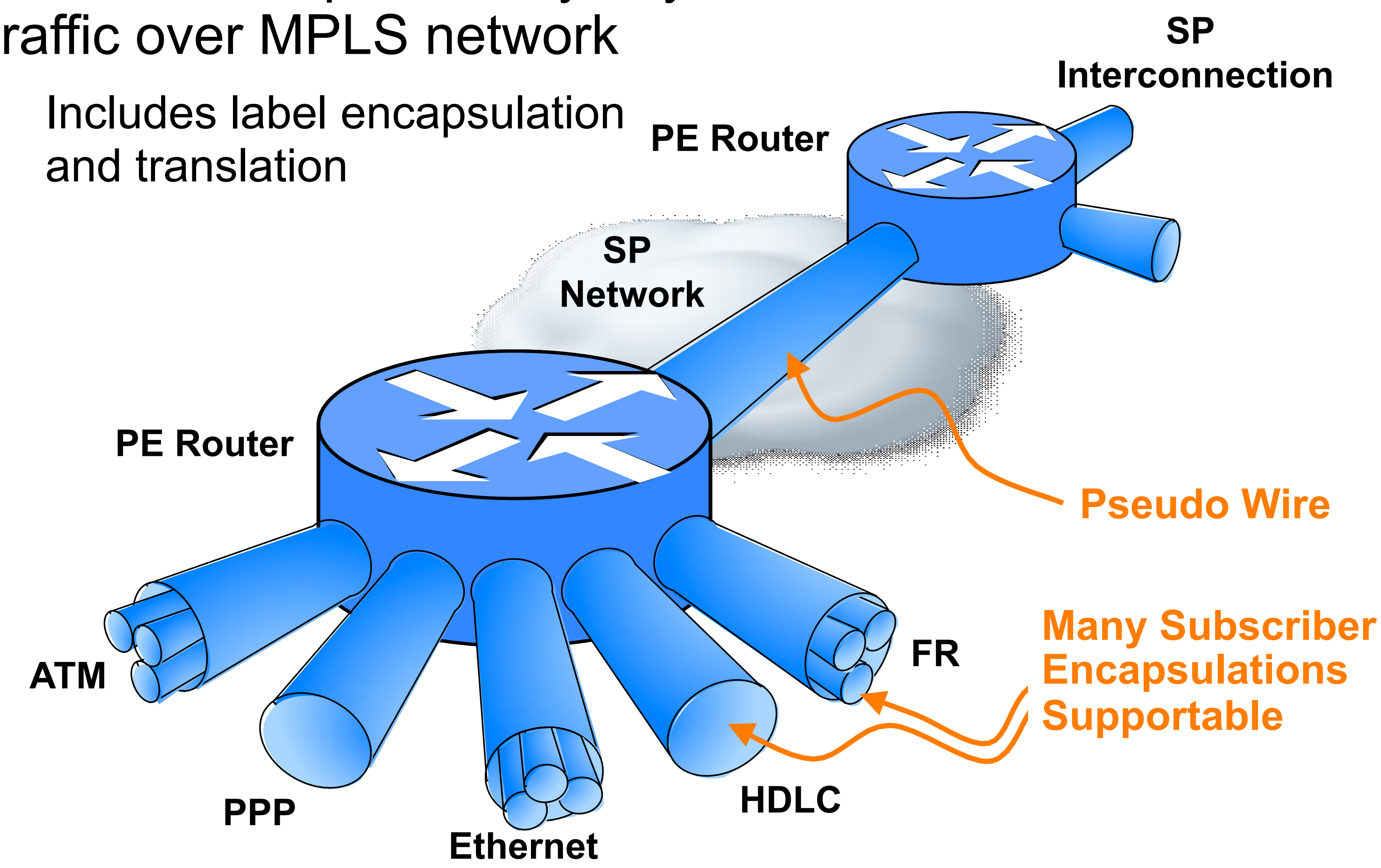
L2VPN Options



Layer-2 VPN Overview

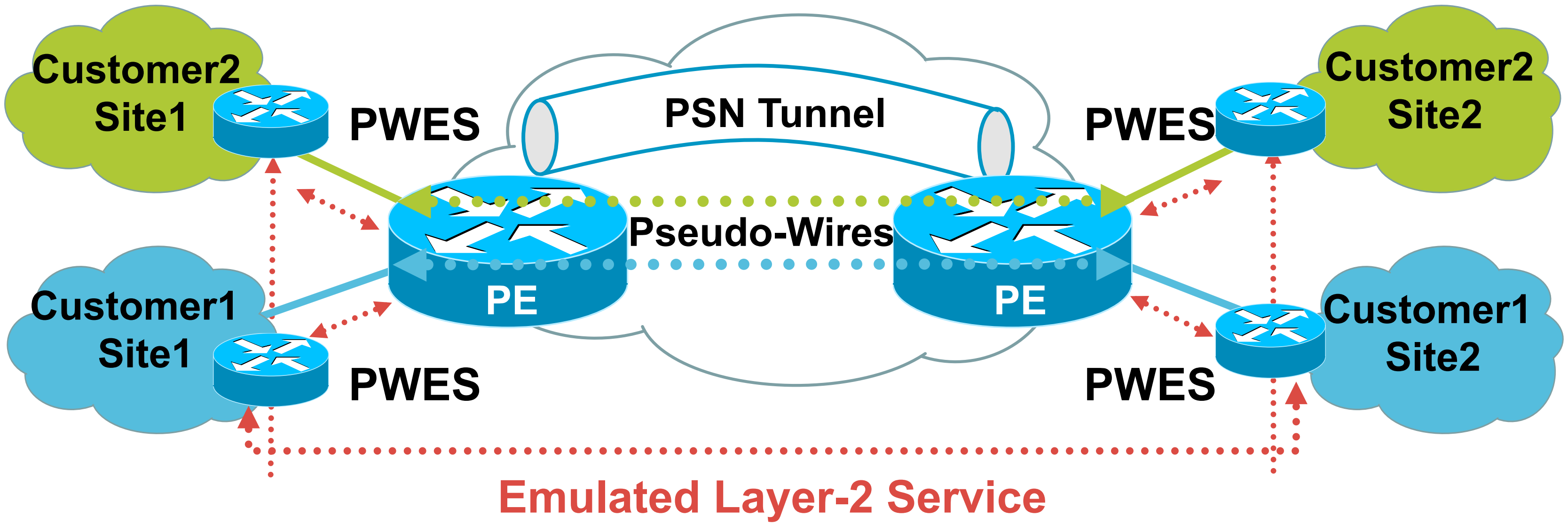
- Enables transport of any Layer-2 traffic over MPLS network

  Includes label encapsulation and translation



Any Transport over MPLS Architecture

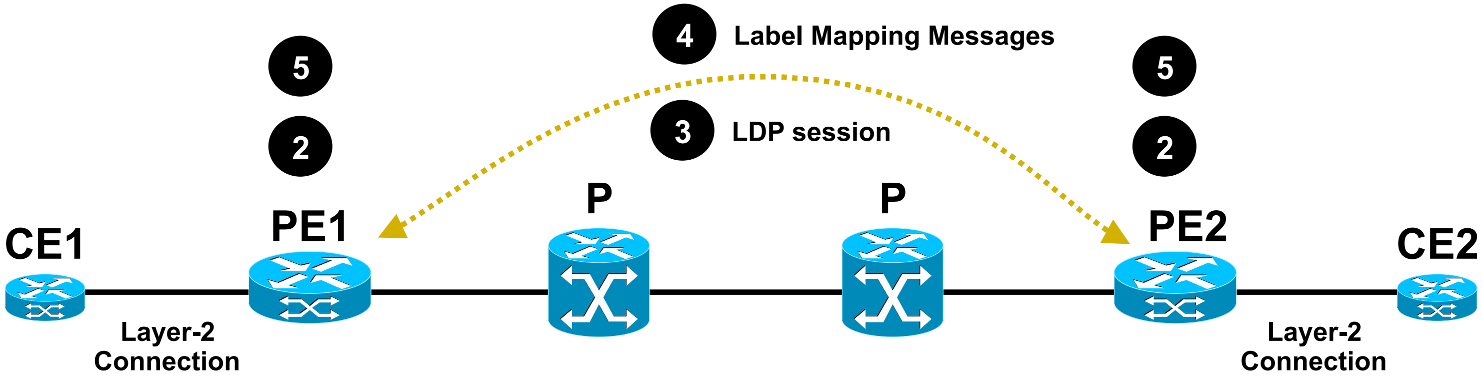
- Based on IETF's Pseudo-Wire (PW) Reference Model
- PW is a connection (tunnel) between 2 PE Devices, which connects 2 PW End-Services
  - PW connects 2 Attachment Circuits (ACs)
  - Bi-directional (for p2p connections)
  - Use of PW/VC label for encapsulation



AToM Technology Components

- PE-CE link
    - Referred to as Attachment Circuit (AC)
    - Can be any type of layer-2 connection (e.g., FR, Ethernet)
- AToM Control Plane
    - Targeted LDP (Label Distribution Protocol) Session
        - Virtual Connection (VC)-label negotiation, withdrawal, error notification
- AToM Forwarding Plane
    - 2 labels used for encapsulation + control word
    - Outer tunnel (LDP) label
        - To get from ingress to egress PE using MPLS LSP
    - Inner de-multiplexer (VC) label
        - To identify L2 circuit (packet) encapsulated within tunnel label
    - Control word
        - Replaces layer-2 header at ingress; used to rebuild layer-2 header at egress

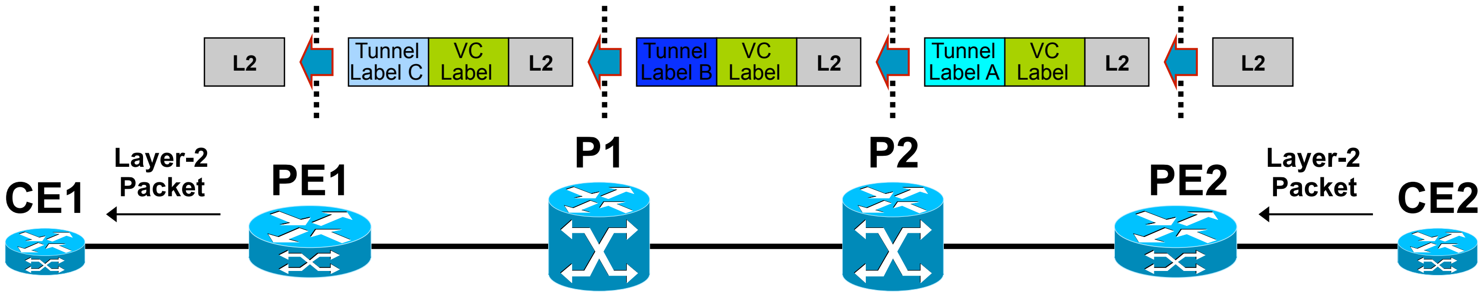
AToM Control Plane Processing



Processing Steps (for both P1 and P2):

1. CE1 and CE2 are connected to PE routers via layer-2 connections
2. Via CLI, a new virtual circuit cross-connect is configured, connecting customer interface to manually provided VC ID with target remote PE
3. New targeted LDP session between PE routers established, in case one does not already exist
4. PE binds VC label with customer layer-2 interface and sends label-mapping message to remote PE over LDP session
5. Remote PE receives LDP label binding message and matches VC ID with local configured cross-connect

AToM Forwarding Plane Processing



Processing Steps:

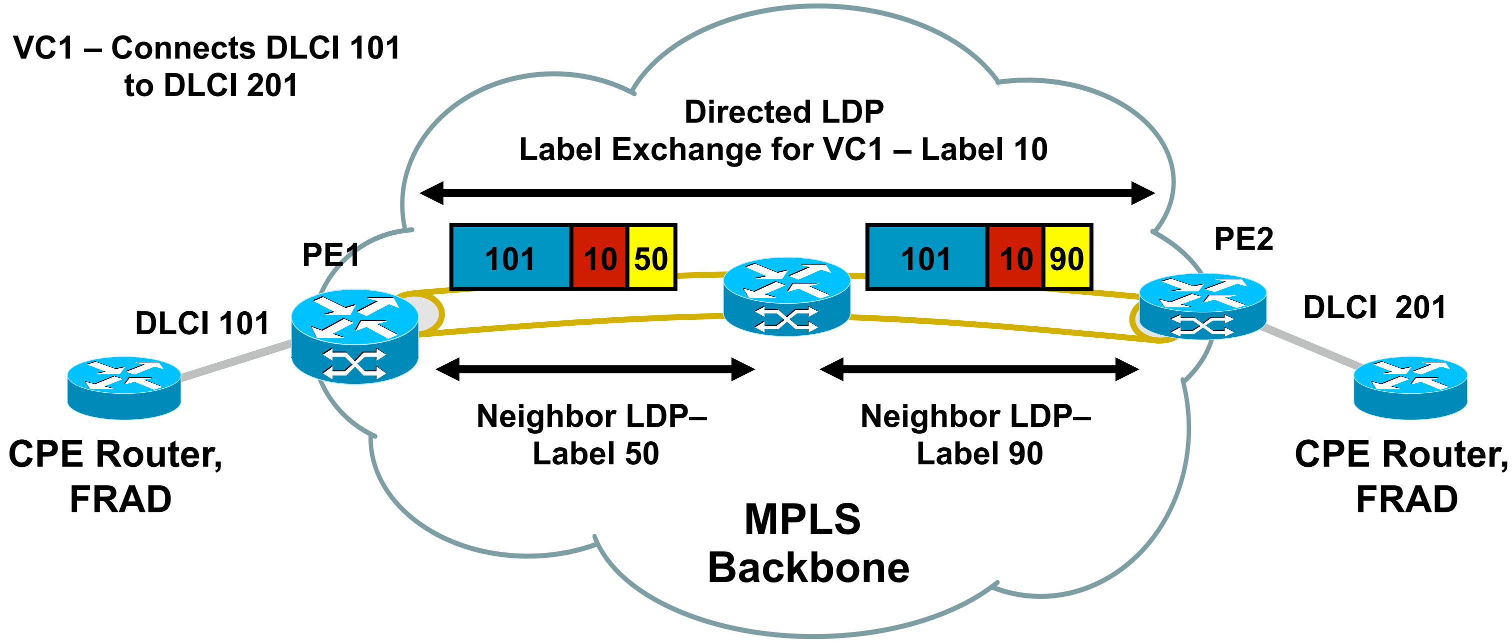
1. CE2 forwards layer-2 packet to PE2.
2. PE2 imposes VC (inner) label to layer-2 packet received from CE2 and optionally a control word as well (not shown).
3. PE2 imposes Tunnel outer label and forwards packet to P2.
4. P2 and P1 router forwards packet using outer (tunnel) label.
5. Router PE2 strips Tunnel label and, based on VC label, layer-2 packet is forwarded to customer interface to CE1, after VC label is removed

   In case control word is used, new layer-2 header is generated first.

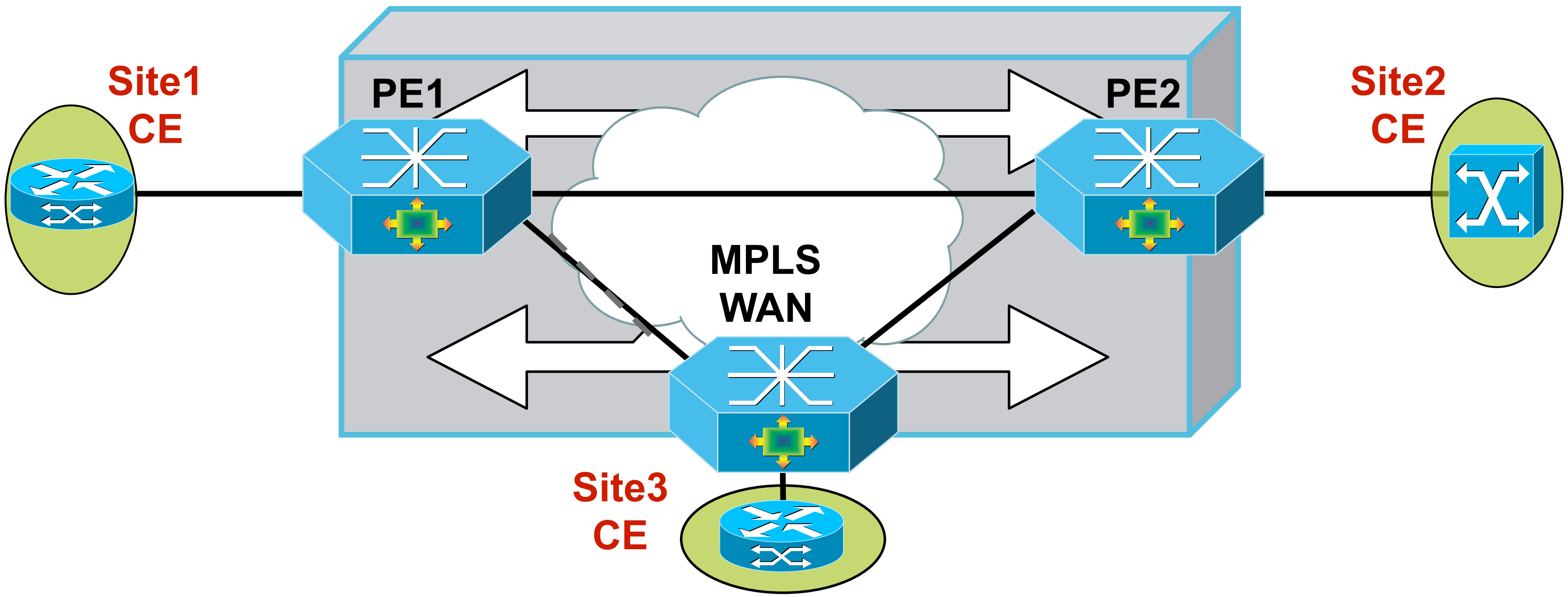
Use Case: L2 Network Interconnect

Requirement: Need to create connectivity between remote customer sites, currently interconnected via Frame Relay WAN connectivity. Only point-to-point connectivity required.

Solution: Interconnect AToM PW between sites, enabling transparent Frame Relay WAN connectivity.



Virtual Private LAN Service Overview

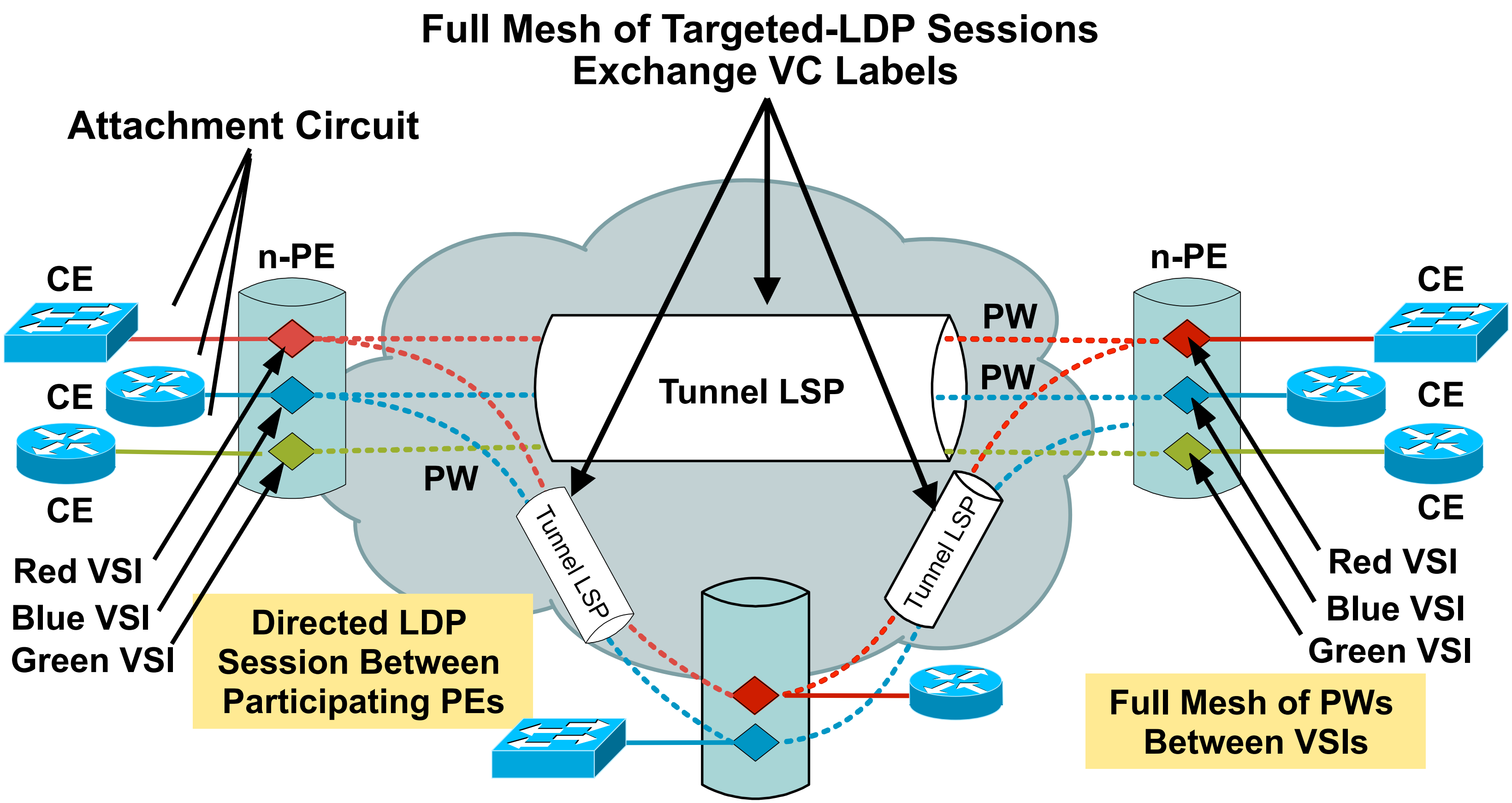


- Architecture for Ethernet Multipoint Services (EMS) over MPLS
- Emulates IEEE Ethernet bridge; VPLS network acts like a virtual switch that emulates conventional L2 bridge
- Fully meshed or Hub-Spoke topologies supported

VPLS Technology Components

- PE-CE link
  - Referred to as Attachment Circuit (AC)
  - Ethernet VCs are either port mode or VLAN ID
- VPLS Control Plane
  - Full mesh of targeted LDP sessions
    - Virtual Connection (VC)-label negotiation, withdrawal, error notification
- VPLS Forwarding Plane
  - Virtual Switching Instance: VSI or VFI (Virtual Forwarding Instance)
  - VPN ID: Unique value for each VPLS instance
  - PWs for interconnection of related VSI instances

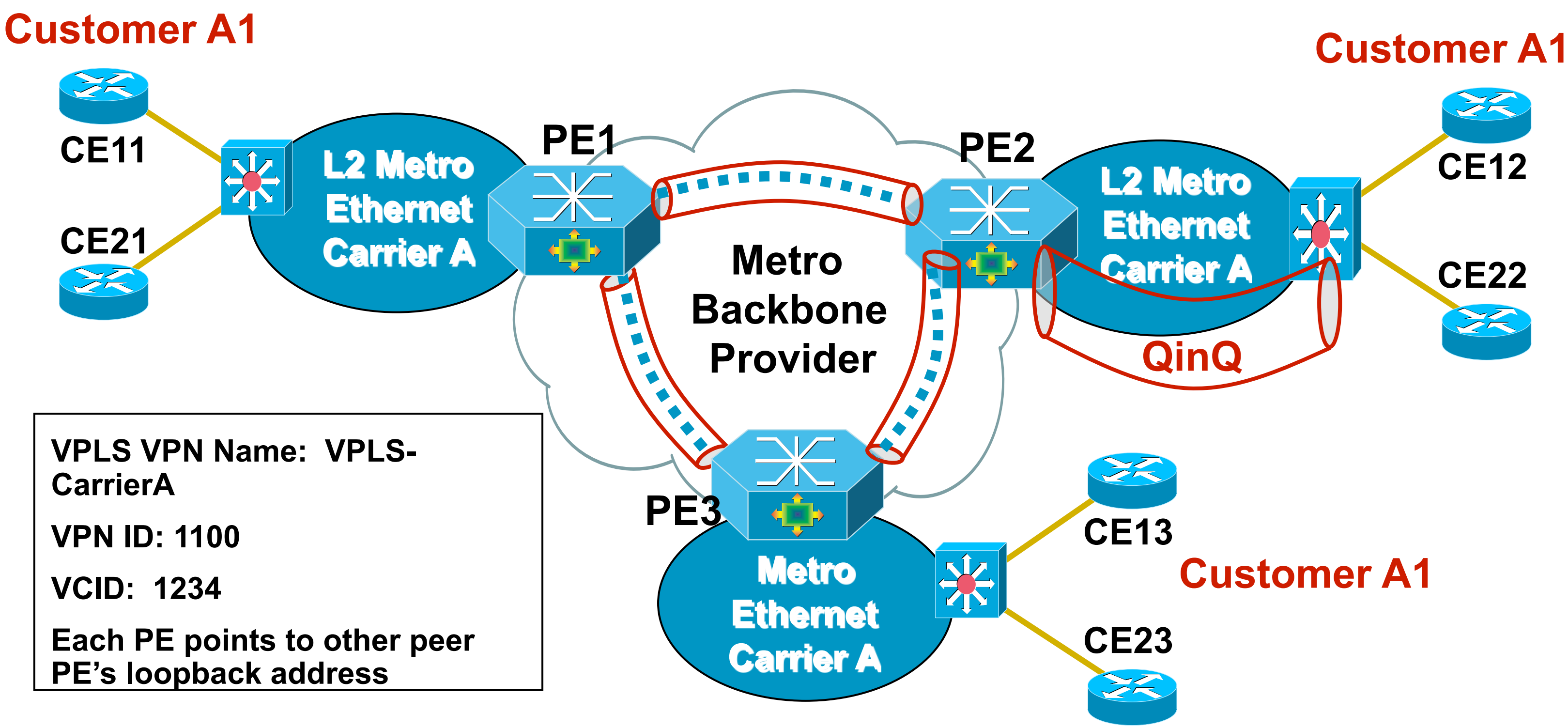
VPLS Overview



Use Case: VPLS Network Interconnect

Requirement: Need to create full-mesh connectivity between separate metro networks.

Solution: Use VPLS to create transparent bridge layer-2 Ethernet connectivity between ethernet networks.



VPLS VPN Name: VPLS-CarrierA

VPN ID: 1100

VCID: 1234

Each PE points to other peer PE's loopback address

Layer-2 VPN Summary

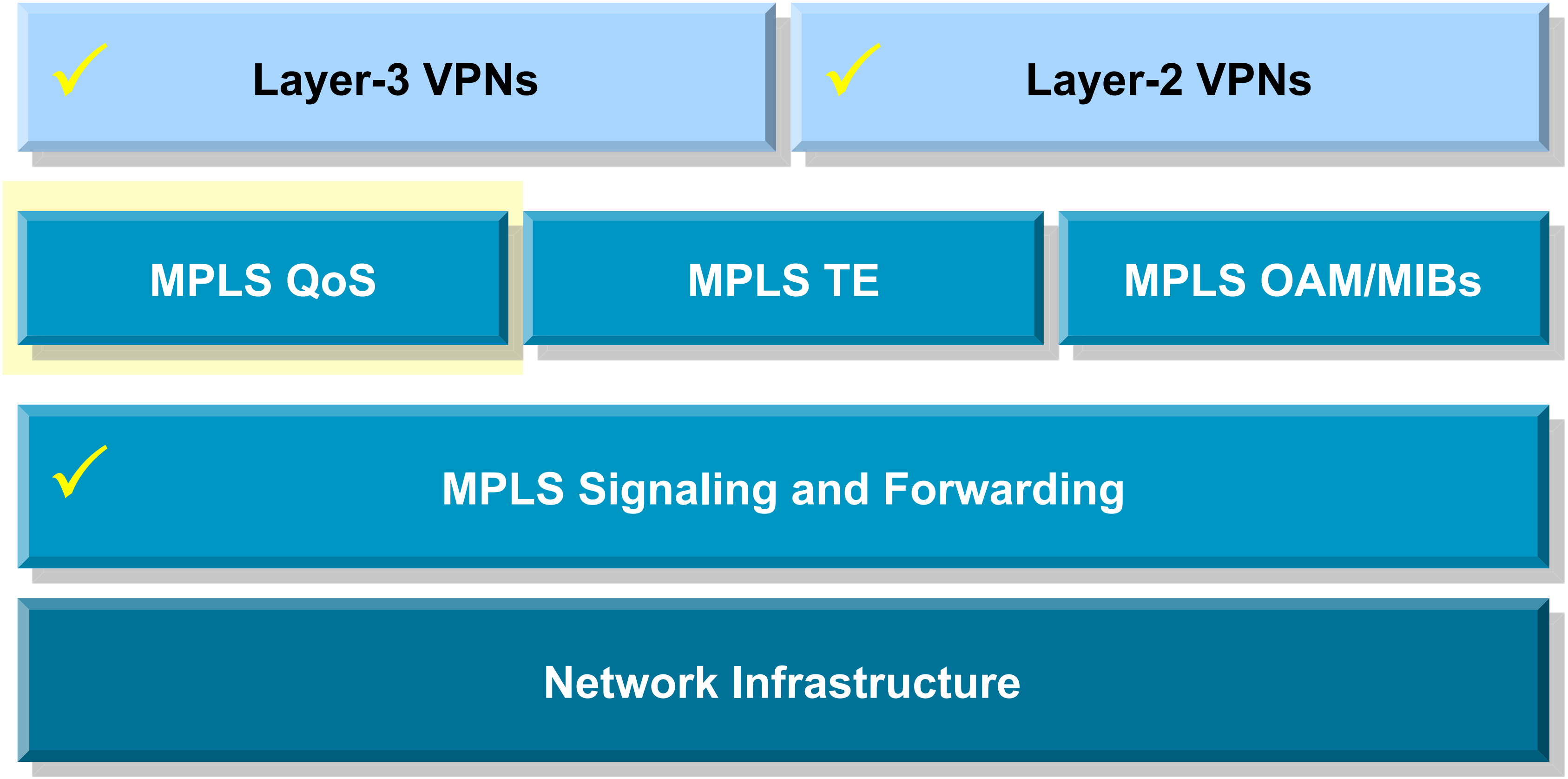
- Enables transport of any Layer-2 traffic over MPLS network
- Two types of L2 VPNs; AToM for point-to-point and VPLS point-to-multipoint layer-2 connectivity
- Layer-2 VPN forwarding based on Pseudo Wires (PW), which use VC label for L2 packet encapsulation
  - LDP used for PW signaling
- AToM PWs suited for implementing transparent point-to-point connectivity between Layer-2 circuits
- VPLS suited for implementing transparent point-to-multipoint connectivity between Ethernet links/sites

MPLS QoS

Technology Overview and Applications

MPLS Technology Framework

- MPLS QoS support for traffic marking and classification to enable differentiated services

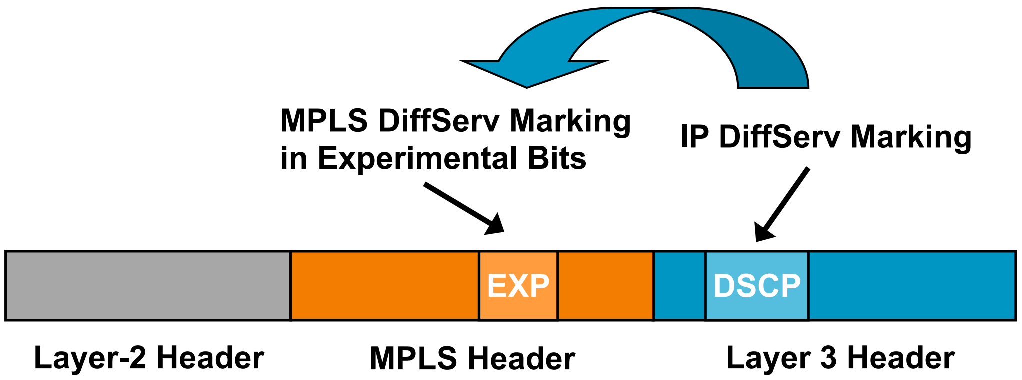


Why MPLS QoS?

- Typically different traffic types (packets) sent over MPLS networks
  - E.g., Web HTTP, VoIP, FTP, etc.
- Not all application traffic types/flows are the same …
  - Some require low latency to work correctly; e.g., VoIP
- MPLS QoS used for traffic prioritization to guarantee minimal traffic loss and delay for high priority traffic
  - Involves packet classification and queuing
- MPLS leverages mostly existing IP QoS architecture
  - Based on Differentiated Services (DiffServ) model; defines per-hop behavior based on IP Type of Service (ToS) field

MPLS QoS Operations

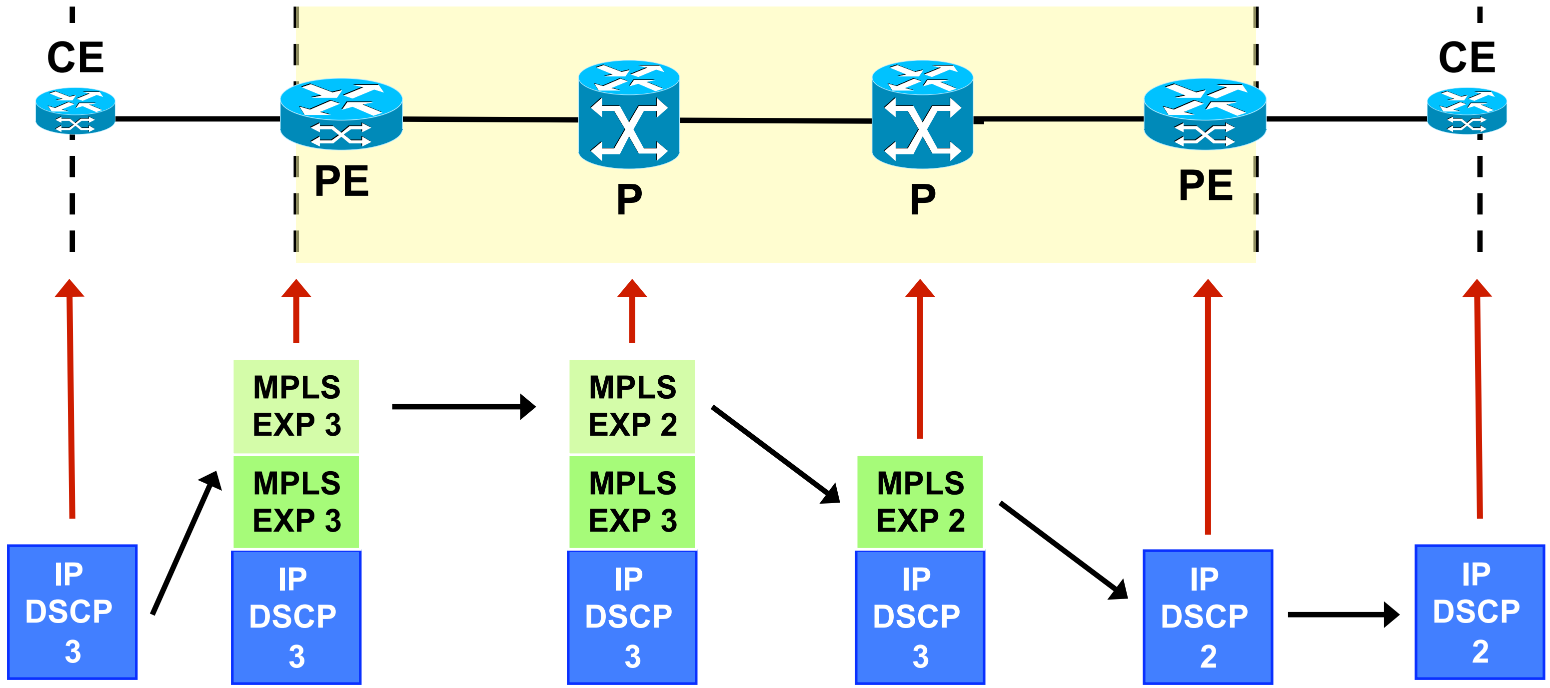
- MPLS EXP bits used for packet classification and prioritization instead of IP Type of Service (ToS) field
  - DSCP values mapped into EXP bits at ingress PE router
- Most providers provide 3–5 service classes
- Different DSCP <-> EXP mapping schemes
  - Uniform mode, pipe mode, and short pipe mode



MPLS Uniform Mode

For your reference only

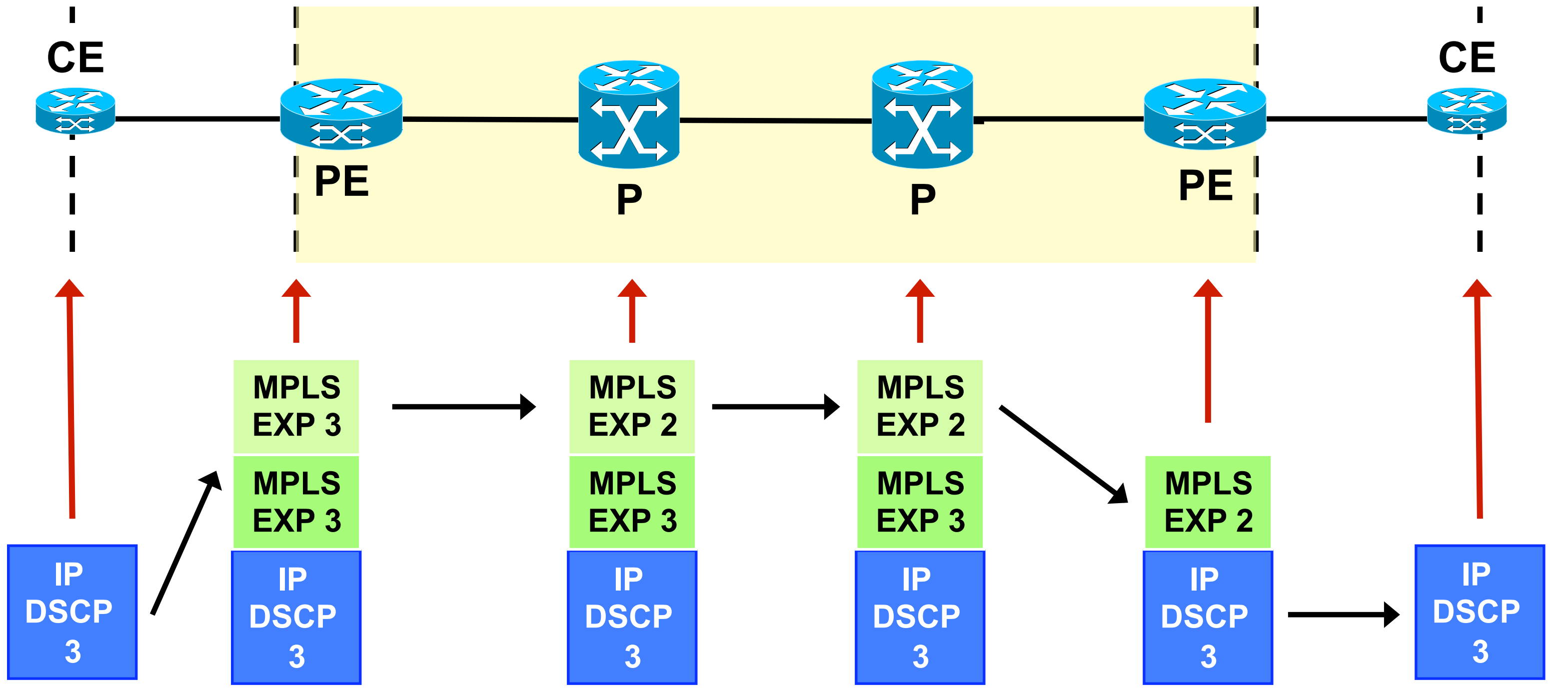
- End-to-end behavior: original IP DSCP value not preserved
  - At ingress PE, IP DSCP value copied in EXP value
  - EXP value changed in the MPLS core
  - At egress PE, EXP value copied back into IP DSCP value



MPLS Pipe Mode

For your reference only

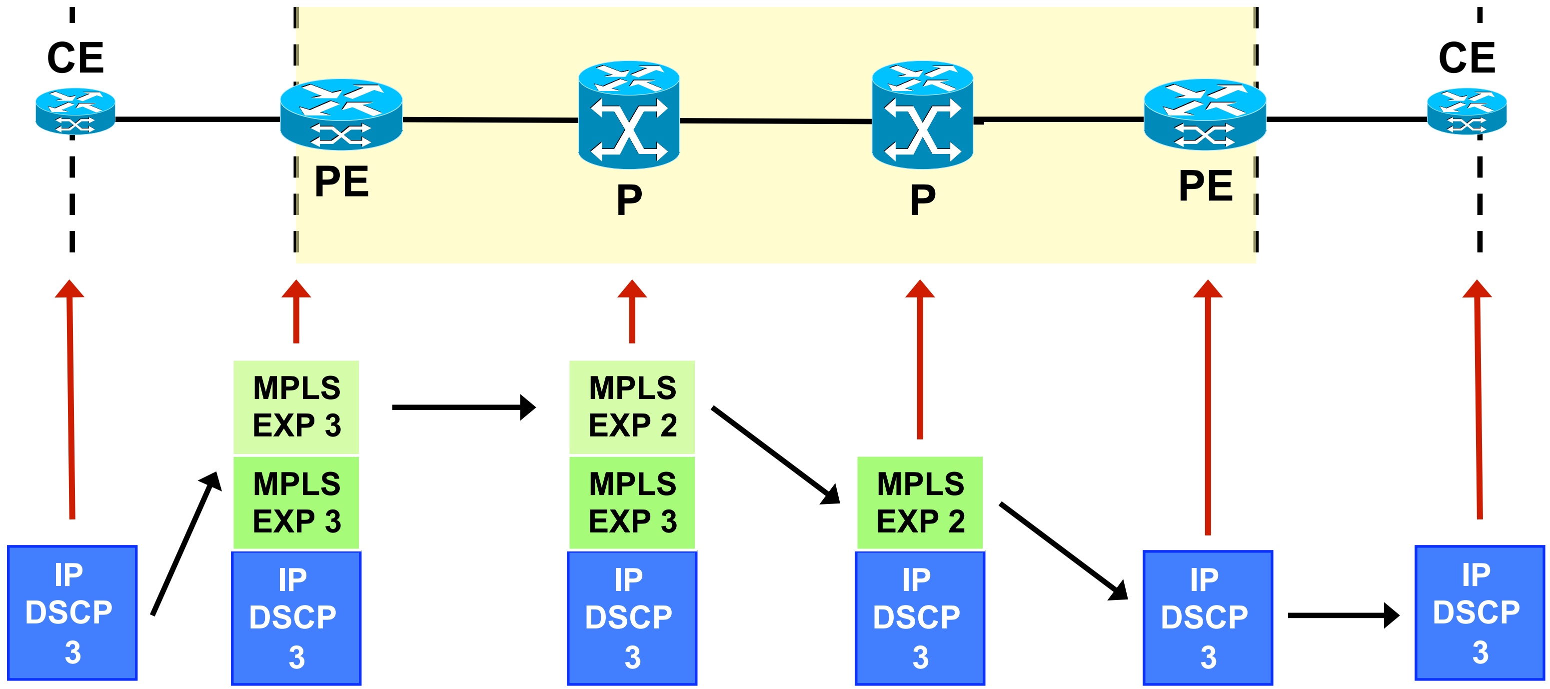
- End-to-end behavior: original IP DSCP is preserved
  - At ingress PE, EXP value set based on ingress classification
  - EXP changed in the MPLS core
  - At egress PE, EXP value not copied back into IP DSCP value



MPLS Short Pipe Mode

For your reference only

- End-to-end behavior: original IP DSCP is preserved
  - At ingress PE, EXP value set based on ingress classification
  - EXP changed in the MPLS core
  - At egress PE, original IP DSCP value used for QoS processing



MPLS QoS Summary

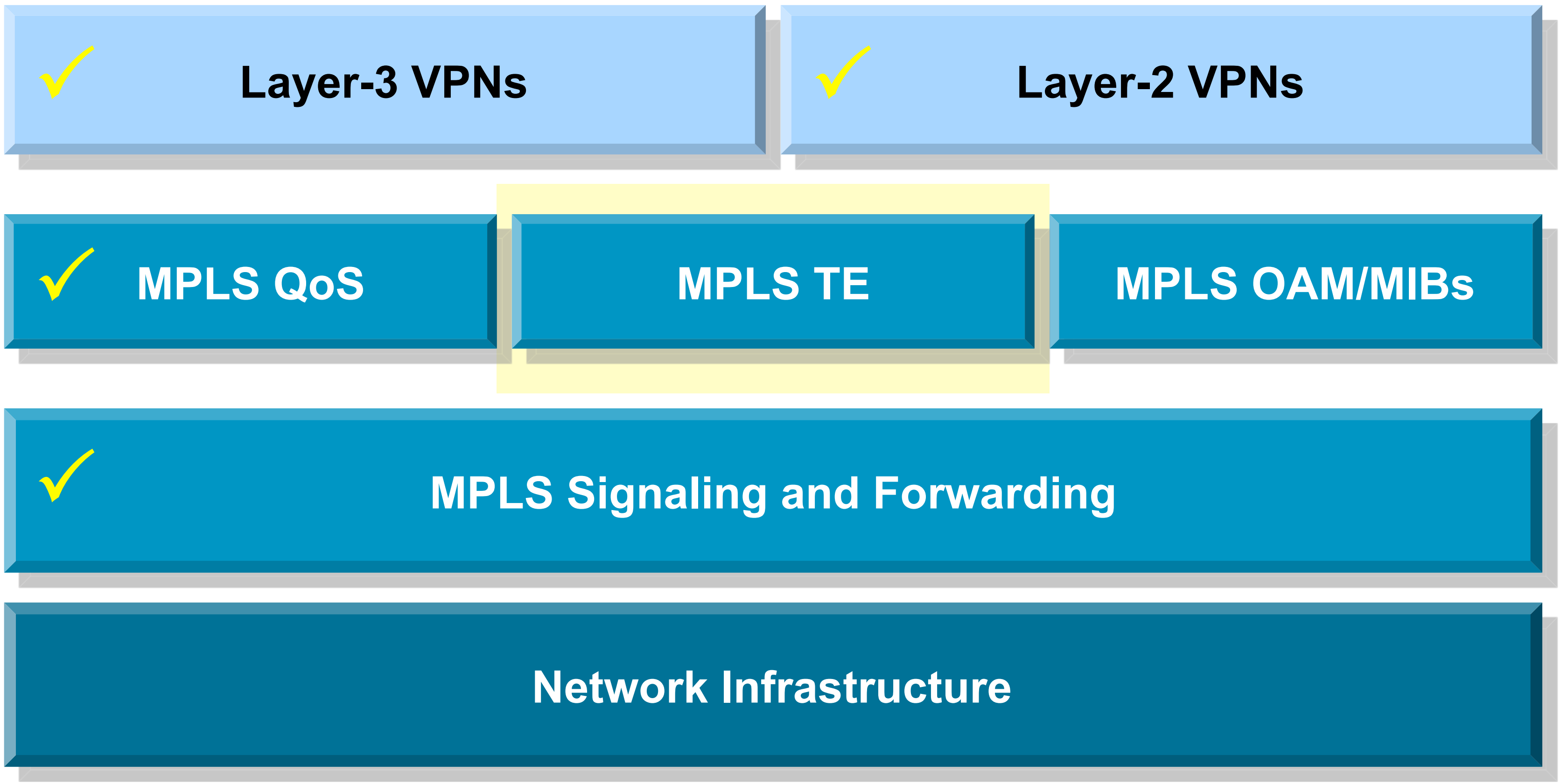
- MPLS QoS used for MPLS packet-specific marking and classification
  - Based on EXP bits
- Different schemes for mapping between IP (ToS/ DSCP) and MPLS packet (EXP) classification
  - At ingress and egress PE router
  - MPLS pipe mode mostly used; preserves end-to-end IP QoS
- Enables traffic prioritization to guarantee minimal traffic loss and delay for high priority traffic
  - Useful when packet loss and delay guarantees must be provided for high priority traffic across MPLS network

MPLS Traffic Engineering

Technology Overview and Applications

MPLS Technology Framework

- Traffic engineering capabilities for bandwidth management and network failure protection



Why Traffic Engineering?

- Congestion in the network due to changing traffic patterns
  - Election news, online trading, major sports events
- Better utilization of available bandwidth
  - Route on the non-shortest path
- Route around failed links/nodes
  - Fast rerouting around failures, transparently to users
  - Like SONET APS (Automatic Protection Switching)
- Build new services—virtual leased line services
  - VoIP toll-bypass applications, point-to-point bandwidth guarantees
- Capacity planning
  - TE improves aggregate availability of the network

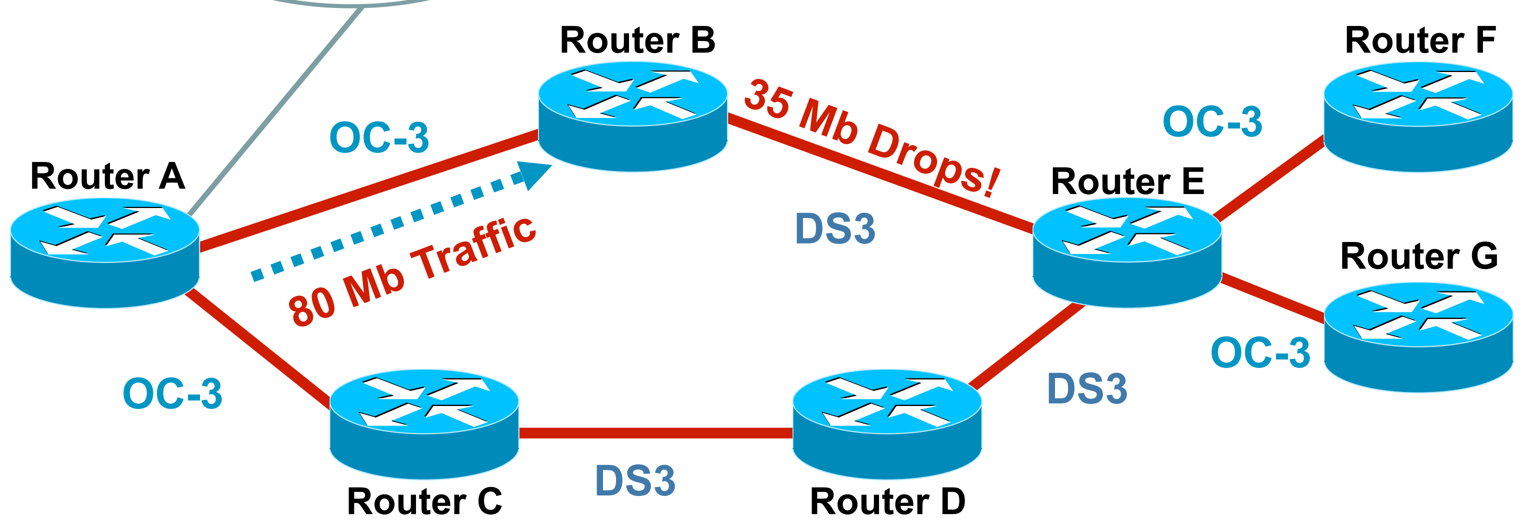
The Problem with Shortest-Path

IP (Mostly) Uses Destination-Based Least-Cost Routing
Alternate Path Under Utilized

Node	Next-Hop	Cost
B	B	10
C	C	10
D	C	20
E	B	20
F	B	30
G	B	30

- Some links are DS3, some are OC-3
- Router A has 40M of traffic for router F, 40M of traffic for router G
- Massive (44%) packet loss at router B→router E!

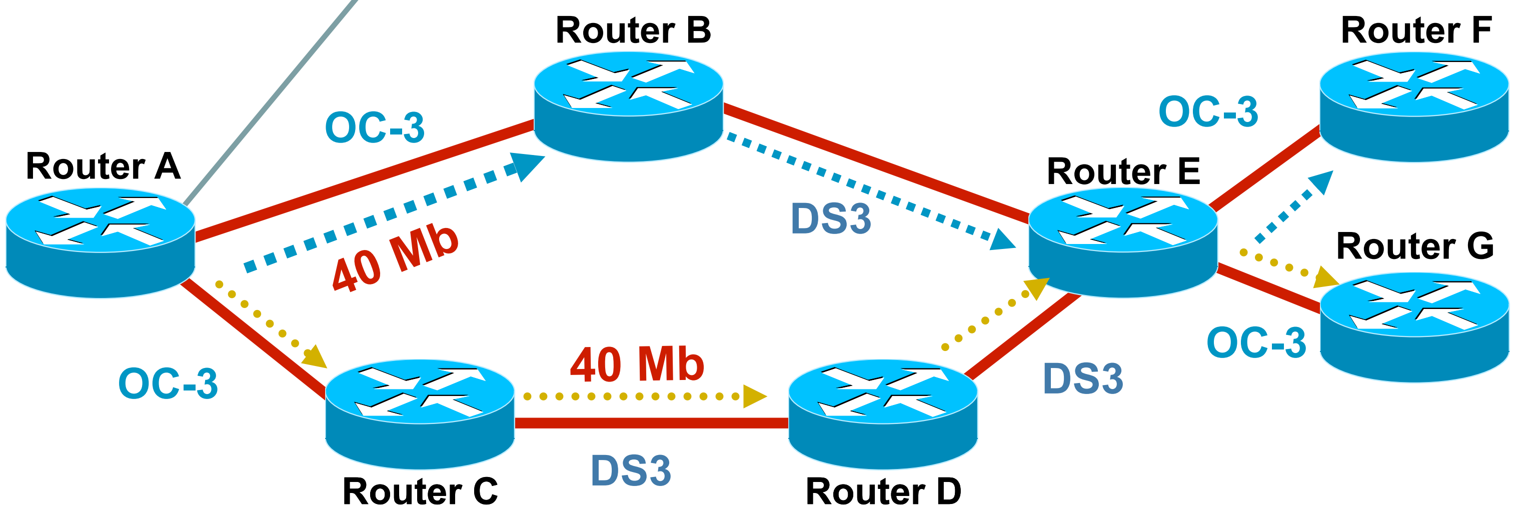
Changing to A->C->D->E won't help



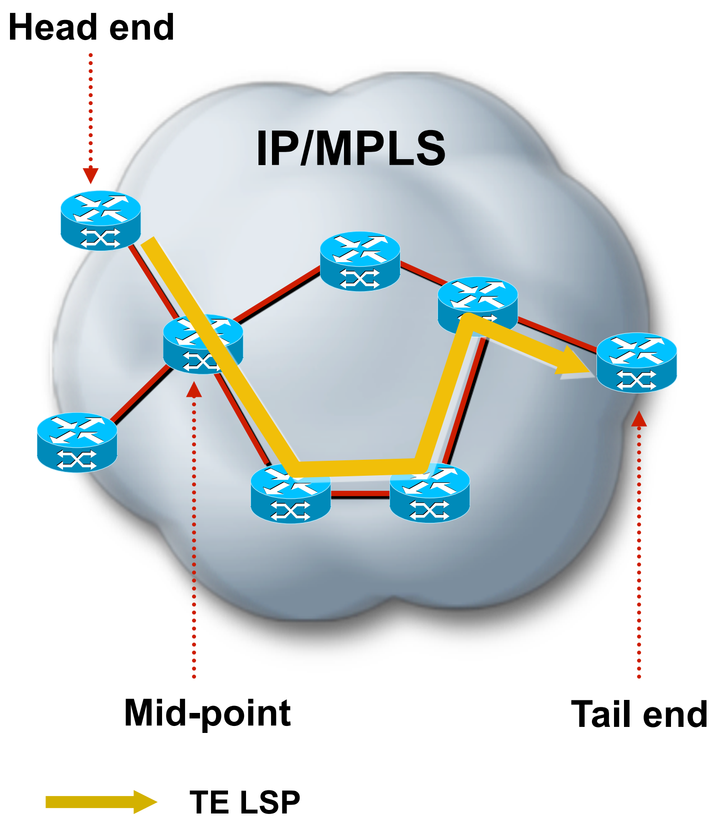
How MPLS TE Solves the Problem

Node	Next-Hop	Cost
B	B	10
C	C	10
D	C	20
E	B	20
F	Tunnel 0	30
G	Tunnel 1	30

- Router A sees all links
- Router A computes paths on properties other than just shortest cost; creation of 2 tunnels
- No link oversubscribed!



How MPLS TE Works



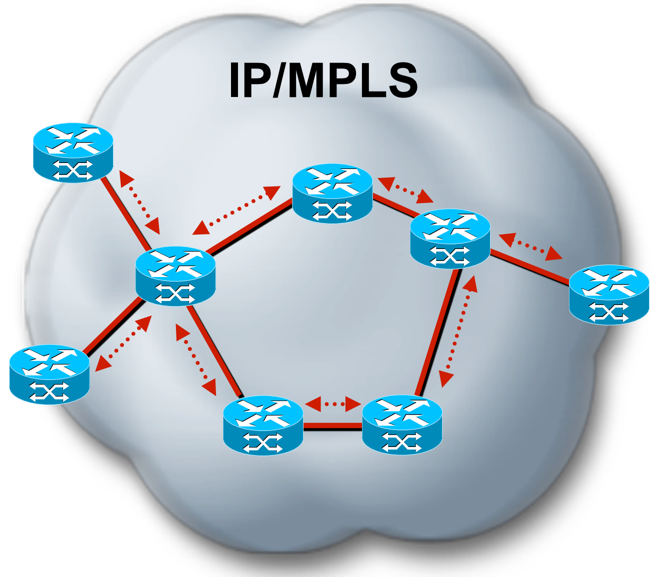
- Link information Distribution*
  - ISIS-TE
  - OSPF-TE
- Path Calculation (CSPF)*
- Path Setup (RSVP-TE)
- Forwarding Traffic down Tunnel
  - Auto-route
  - Static
  - PBR
  - CBTS / PBTS
  - Forwarding Adjacency
  - Tunnel select

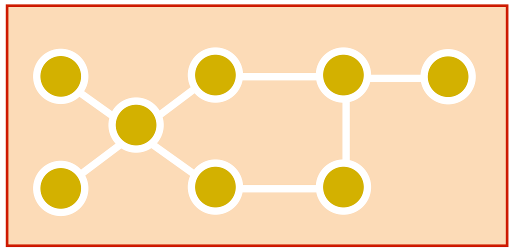
*** Optional**

Link Information Distribution

For your reference only

- Additional link characteristics
  - Interface address
  - Neighbor address
  - Physical bandwidth
  - Maximum reservable bandwidth
  - Unreserved bandwidth (at eight priorities)
  - TE metric
  - Administrative group (attribute flags)
- IS-IS or OSPF flood link information
- TE nodes build a topology database
- Not required if using off-line path computation

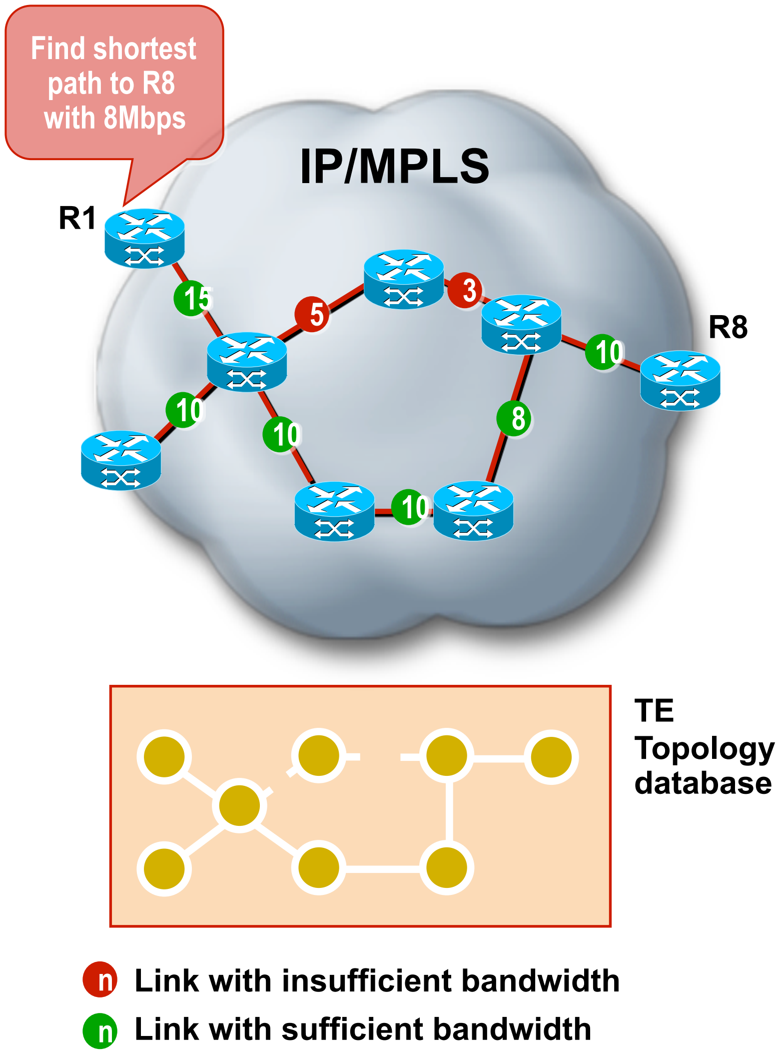




TE Topology database

http://www.cisco.com/go/mpls

Path Calculation

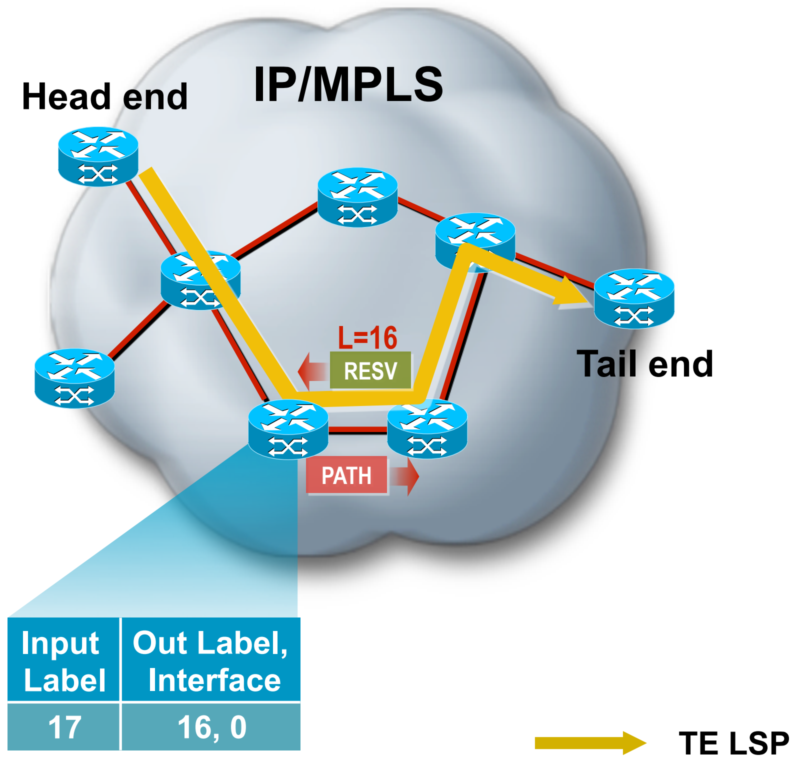


- TE nodes can perform constraint-based routing
- Constraints and topology database as input to path computation
- Shortest-path-first algorithm ignores links not meeting constraints
- Tunnel can be signaled once a path is found
- Not required if using offline path computation

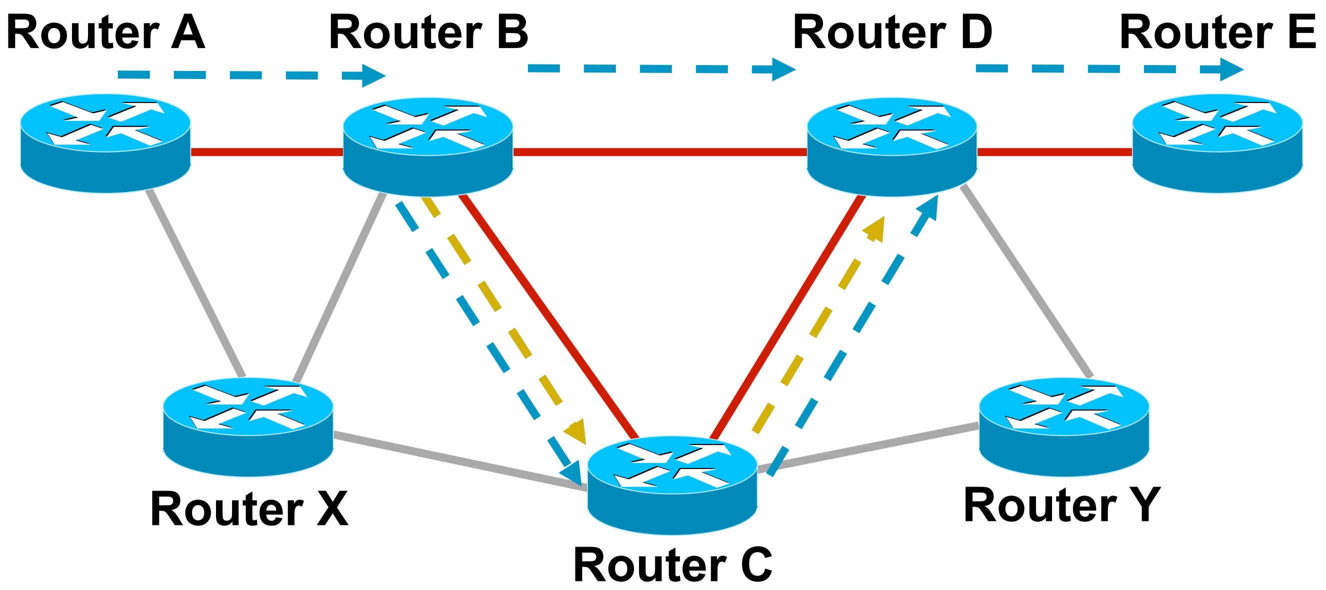
For your reference only

TE LSP Signaling

- Tunnel signaled with TE extensions to RSVP
- Soft state maintained with downstream PATH messages
- Soft state maintained with upstream RESV messages
- New RSVP objects
  - LABEL_REQUEST (PATH)
  - LABEL (RESV)
  - EXPLICIT_ROUTE
  - RECORD_ROUTE (PATH/RESV)
  - SESSION_ATTRIBUTE (PATH)
- LFIB populated using RSVP labels allocated by RESV messages



MPLS TE FRR - Link Protection



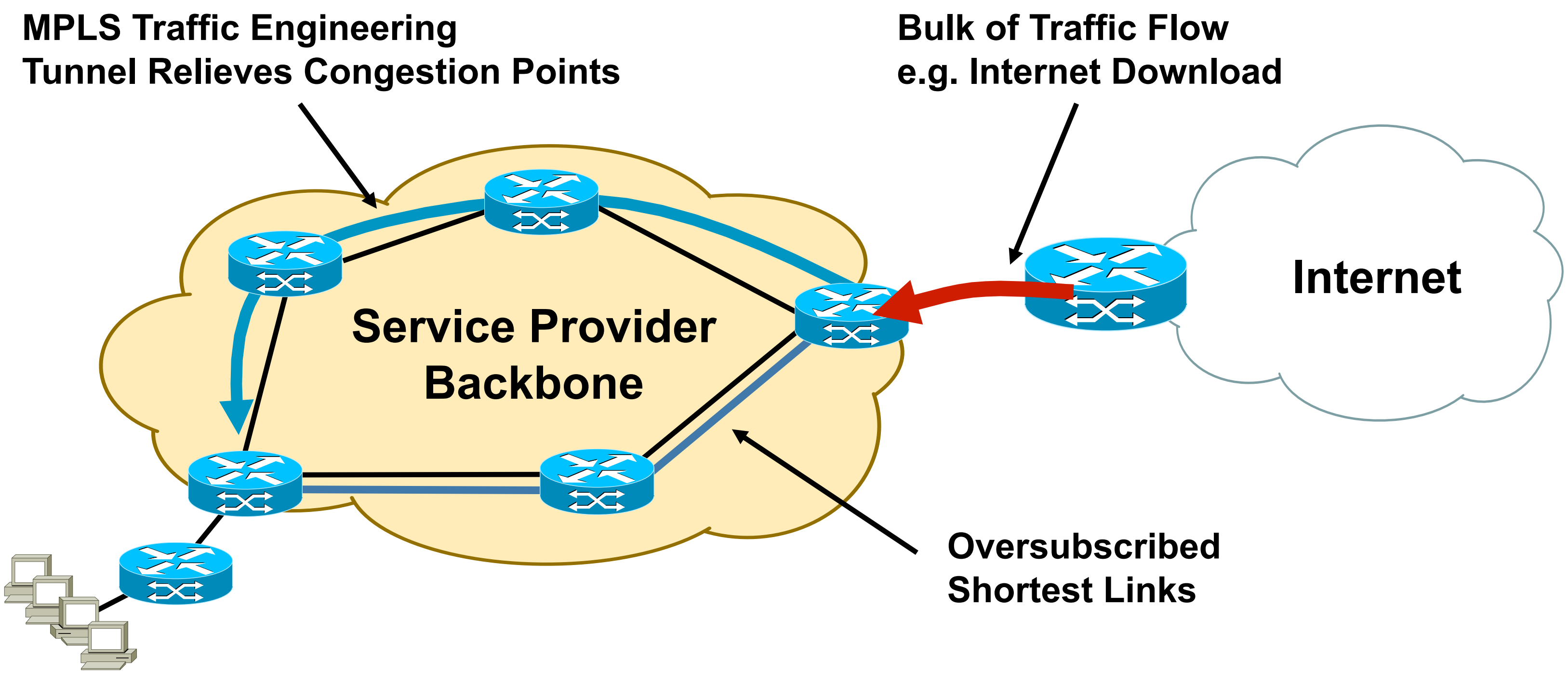
- Primary tunnel: A → B → D → E
- Backup tunnel: B → C → D (preprovisioned)
- Recovery = ~ 50 ms

*Actual Time Varies—Well Below 50 ms in Lab Tests, Can Also Be Higher

Use Case 1: Tactical TE Deployment

Requirement: Need to Handle Scattered Congestion Points in the Network

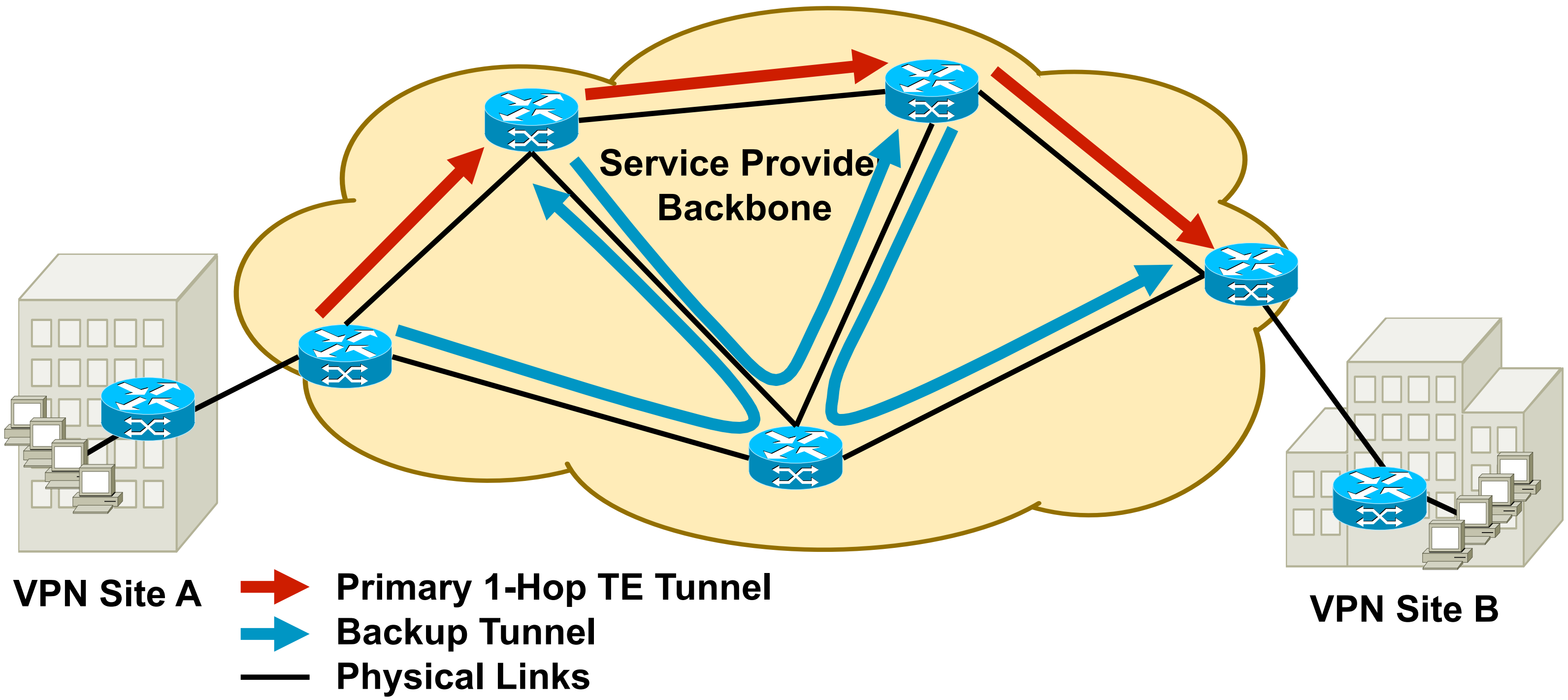
Solution: Deploy MPLS TE on Only Those Nodes that Face Congestion



Use Case 2: 1-Hop Tunnel Deployment

Requirement: Need Protection Only — Minimize Packet Loss of Bandwidth in the Core

Solution: Deploy MPLS Fast Reroute for Less than 50ms Failover Time with 1-Hop Primary TE Tunnels and Backup Tunnel for Each



MPLS TE Summary

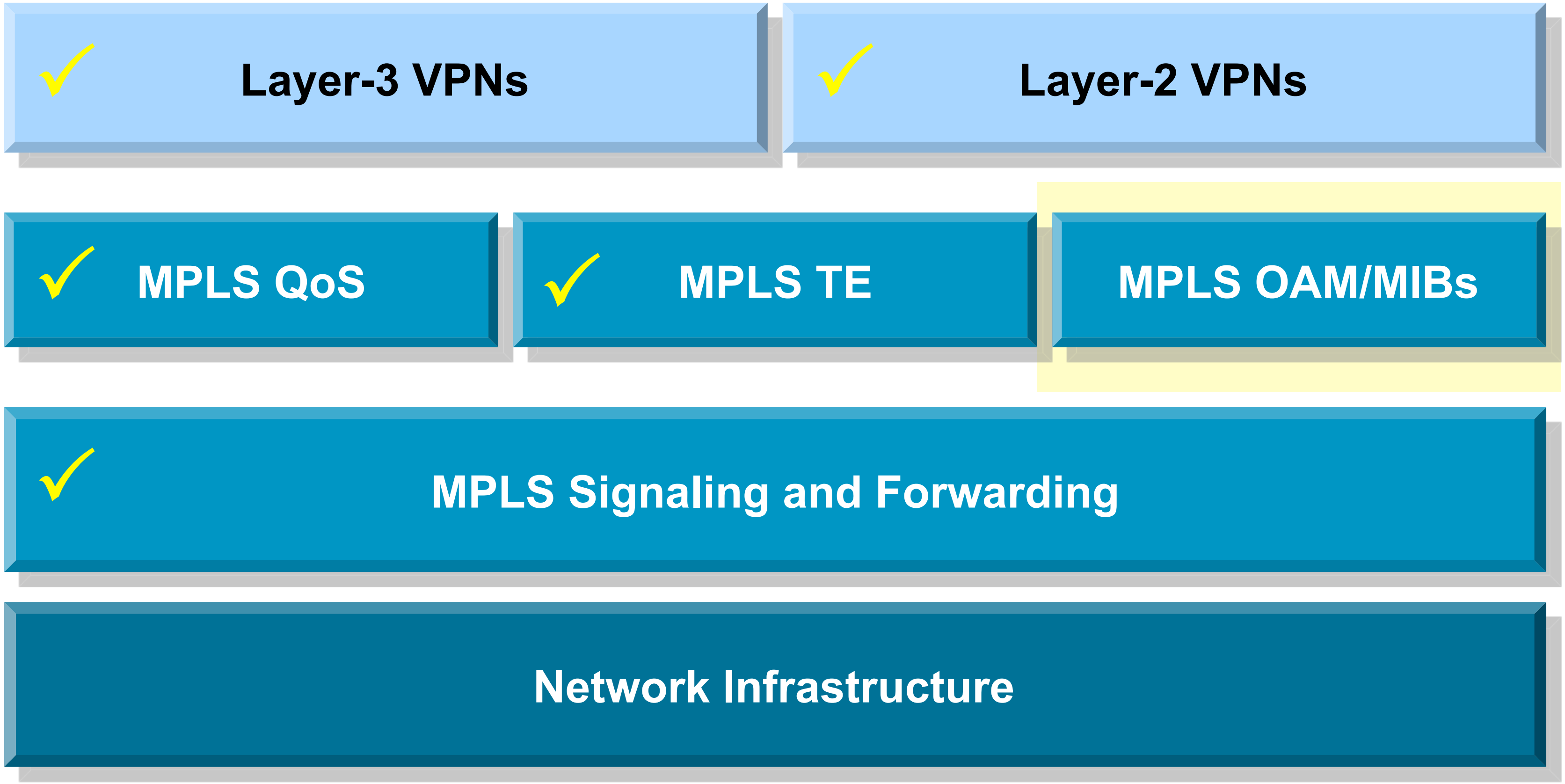
- MPLS TE can be used to implement traffic engineering to enable enhanced network availability, utilization, and performance
- Enhanced network availability can be implemented via MPLS TE Fast Re-Route (FRR)
  - Link, node, and path protection
  - Automatically route around failed links/nodes; like SONET APS
- Better network bandwidth utilization can be implemented via creation of MPLS TE tunnels using explicit routes
  - Route on the non-shortest path
- MPLS TE can be used for capacity planning by creation of bandwidth-specific tunnels with explicit paths through the network
  - Bandwidth management across links and end-to-end paths

MPLS Management

Technology Overview and Applications

MPLS Technology Framework

- MPLS management using SNMP MPLS MIB and MPLS OAM capabilities



What's Needed for MPLS management?

- What's needed beyond the basic MPLS CLI?
  - CLI used for basic configuration and trouble shooting (show commands)

<u>Traditional management tools:</u>

- MIBs to provide management information for SNMP management applications (e.g., HPOV)
  - MIB counters, Trap notifications, etc.

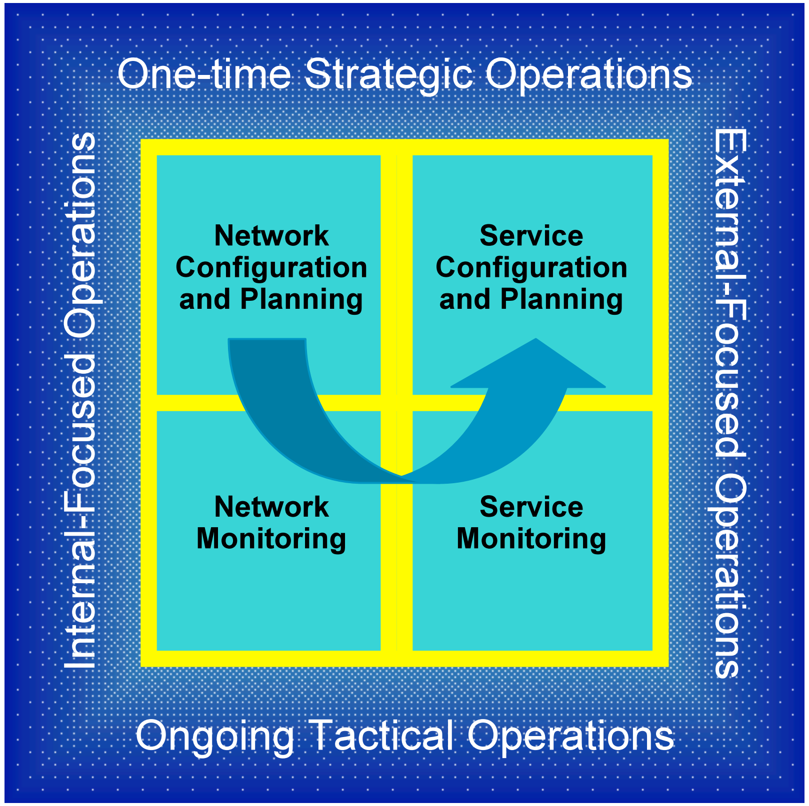
<u>New management tools:</u>

- MPLS OAM -> for reactive trouble shooting
  - Ping and trace capabilities of MPLS label switched paths
- Automated MPLS OAM -> for proactive trouble shooting
  - Automated LSP ping/trace via Auto IP SLA

MPLS Operations Lifecycle

For your reference only

- Build and plan the network
  - Capacity planning and resource monitoring
- Monitor the network
  - Node/link failure detection
  - May impact multiple services
- Provision new services and maintain existing services
  - Edge/service node configuration
- Monitor service
  - End-to-end monitoring
  - Linked to customer SLAs



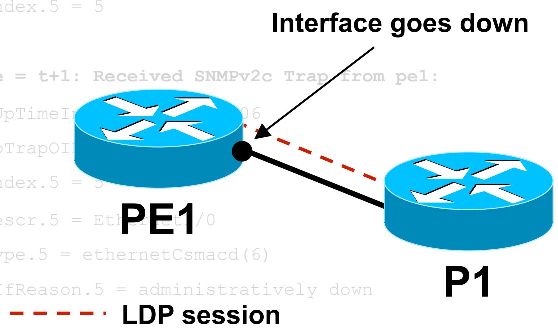
MPLS MIBs and OAM

	Management Feature	Key Functionality
MPLS MIBs	MPLS-LDP-STD-MIB	LDP session status Trap notifications
	MPLS-L3VPN-STD-MIB	VRF max-route Trap notifications
	MPLS-TE-STD-MIB	TE Tunnel status Trap notifications
MPLS OAM	MPLS LSP Ping/Trace for LDP-based LSPs	Validate end-to-end connectivity of LDP-signaled LSPs
	MPLS LSP Ping/Trace for TE tunnels	Validate end-to-end connectivity of TE tunnels
	LSP Multipath (ECMP) Tree Trace	Discovery of all available equal cost LSP paths between PEs

LDP Event Monitoring Using LDP Traps

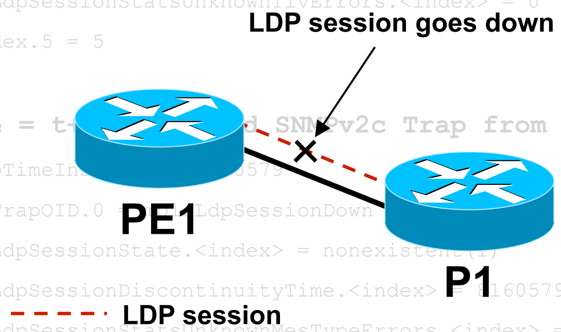
Interface Shutdown (E1/0 on PE1)

```
Time = t: Received SNMPv2c Trap from pe1:
sysUpTimeInstance = 8159606
snmpTrapOID.0 = mplsLdpSessionDown
mplsLdpSessionState.<index> = nonexistent(1)
mplsLdpSessionDiscontinuityTime.<index> = 8159605
mplsLdpSessionStatsUnknownMesTypeErrors.<index> = 0
mplsLdpSessionStatsUnknownTlvErrors.<index> = 0
ifIndex.5 = 5

Time = t+1: Received SNMPv2c Trap from pe1:
sysUpTimeI… 06
snmpTrapOI…
ifIndex.5 = 5
ifDescr.5 = Et… /0
ifType.5 = ethernetCsmacd(6)
locIfReason.5 = administratively down

Time = t+2: Received SNMPv2c Trap from p01:
sysUpTimeInstance = 8160579
snmpTrapOID.0 = mplsLdpSessionDown
mplsLdpSessionState.<index> = nonexistent(1)
mplsLdpSessionDiscontinuityTime.<index> = 8160579
mplsLdpSessionStatsUnknownMesTypeErrors.<index> = 0
mplsLdpSessionStatsUnknownTlvErrors.<index> = 0
ifIndex.5 = 5
```



LDP Session Down (PE1 – P01)

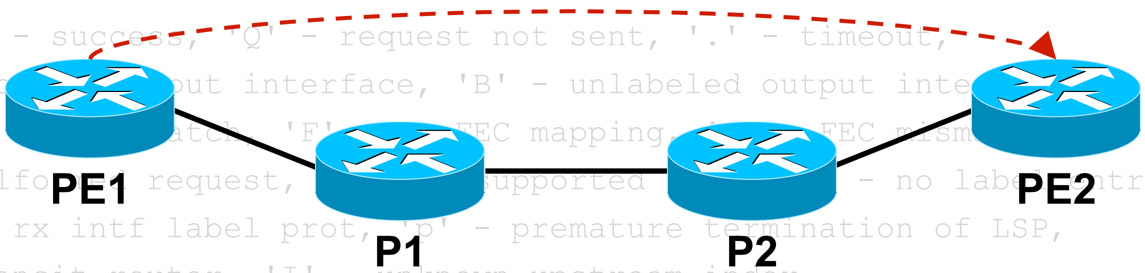
```
Time = t: Received SNMPv2c Trap from pe1:
sysUpTimeInstance = 8159606
snmpTrapOID.0 = mplsLdpSessionDown
mplsLdpSessionState.<index> = nonexistent(1)
mplsLdpSessionDiscontinuityTime.<index> = 8159605
mplsLdpSessionStatsUnknownMesTypeErrors.<index> = 0
mplsLdpSessionStatsUnknownTlvErrors.<index> = 0
ifIndex.5 = 5

Time = t… SNMPv2c Trap from p01:
sysUpTimeIn… 0579
snmpTrapOID.0 … LdpSessionDown
mplsLdpSessionState.<index> = nonexistent(1)
mplsLdpSessionDiscontinuityTime.<index> … 160579
mplsLdpSessionStatsUnknownMesTypeErrors.<index> = 0
mplsLdpSessionStatsUnknownTlvErrors.<index> = 0
ifIndex.5 = 5
```



Validation of PE-PE MPLS Connectivity

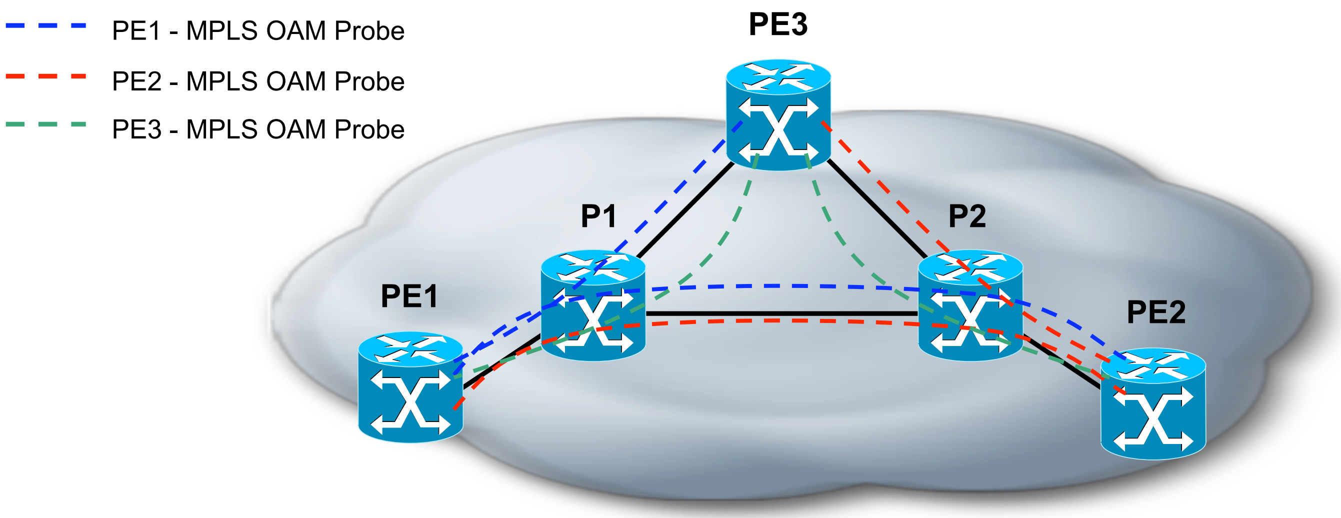
- Connectivity of LSP path(s) between PE routers can be validated using LSP ping (ping mpls command via CLI)

```
pe1>ping mpls ipv4 10.1.2.249/32
Sending 5, 100-byte MPLS Echos to 10.1.2.249/32,
     timeout is 2 seconds, send interval is 0 msec:

Codes: '!' - success, 'Q' - request not sent, '.' - timeout,
  'L' - labeled output interface, 'B' - unlabeled output interface,
  'D' - DS Map mismatch, 'F' - no FEC mapping, 'f' - FEC mismatch,
  'M' - malformed request, 'm' - unsupported tlvs, 'N' - no label entry,
  'P' - no rx intf label prot, 'p' - premature termination of LSP,
  'R' - transit router, 'I' - unknown upstream index,
  'X' - unknown return code, 'x' - return code 0

Type escape sequence to abort.
!!!!!
Success rate is 100 percent (5/5), round-trip min/avg/max = 284/294/300 ms
```



Automated MPLS OAM

- Automatic MPLS OAM probes between PE routers
    - Automatic discovery of PE targets via BGP next-hop discovery
    - Automatic discovery of all available LSP paths for PE targets via LSP multi-path trace
    - Scheduled LSP pings to verify LSP path connectivity
    - 3 consecutive LSP ping failures result in SNMP Trap notification



MPLS Management Summary

- MPLS management operations include MPLS node and service configuration, and monitoring
- In addition to CLI, SNMP MIBs and OAM capabilities are available for MPLS management
- MPLS MIBs provide LDP, VPN, and TE management information, which can be collected by SNMP tools
  - MIB counters, Trap notifications
- Advanced MPLS management capabilities can be implemented via MPLS OAM
  - LSP path discovery and connectivity validation
  - Proactive monitoring via automated MPLS OAM

Summary

Final Notes and Wrap Up

Summary and Key Takeaways

- It's all about labels …
  - Label-based forwarding and IP protocol extensions for label exchange
  - Best of both worlds … L2-type forwarding and L3 control plane
- Key application of MPLS is to implement VPN services
  - Secure and scalable layer 2 and 3 VPN connectivity
- MPLS supports advanced traffic engineering capabilities
  - QoS, bandwidth control, and failure protection
- MPLS is a mature technology with widespread deployments
  - Both SP and enterprise networks
- Two types of MPLS users
  - Indirect (Subscriber): MPLS used as transport for subscribed service
  - Direct (DIY): MPLS implemented in (own) SP or enterprise network

For your reference only

MPLS Applications

	Service Providers	Enterprise Data Center	Data center interconnects	EWAN Edge
Key Features	L2/L3VPN's TE/FRR QoS High Availability	VPN's TE/FRR High Availability	VPN's / VRF's VRF-Aware Security High Availability	VPN's / VRF's VRF Aware Security High Availability
Applications	Hosted Data centers Data center interconnect Segmentation for IT Mergers, Acquisitions, spinoffs	Departmental segmentation Service multiplexing Security Mergers, Acquisitions, spinoffs	Disaster Recovery Vmotion support Branch Interconnects	Internet Access Branch Connectivity

- **Network Consolidation** – Merging Multiple parallel network into a shared infrastructure
- **Network segmentation** – By user groups or business function
- **Service and policy centralization** – Security policies and appliances at a central location
- **New applications readiness** – Converged multi-service network
- **Increased network security** – User groups segmentation with VPNs

Consider MPLS When …

- There's a need for network segmentation
  - Segmented connectivity for specific locations, users, applications, etc.
  - Full-mesh and hub-and-spoke connectivity
- There's a need for network realignment/migration
  - Consolidation of (multiple) legacy networks
  - Staged network consolidation after company merger/acquisition
- There's a need for optimized network availability and performance
  - Node/link protection, pro-active connectivity validation
  - Bandwidth traffic engineering and QoS traffic prioritization

Q and A