# Introduction to MPLS

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# Agenda

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- **Background**
- **Technology Basics**
  - **What is MPLS? Where Is it Used?**
- **Label Distribution in MPLS Networks**
  - **LDP, RSVP, BGP**
- **Building MPLS Based Services**
  - **VPNs**
  - **AToM**
  - **Traffic Engineering**
- **Configurations**
  - **Configuring MPLS, LDP, TE**
- **Summary**

# Background

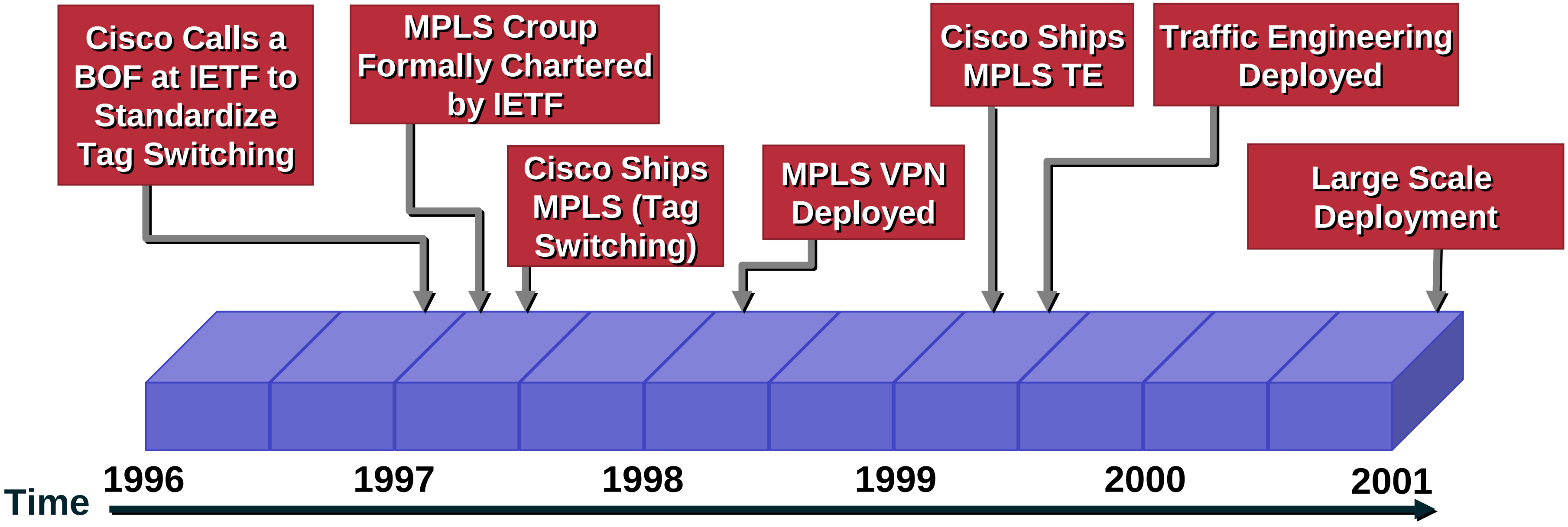
# Terminology

- **Acronyms**
  - **PE—provider edge router**
  - **P—Provider core router**
  - **CE—Customer Edge router (also referred to as CPE)**
  - **ASBR—Autonomous System Boundary Router**
  - **RR—Route Reflector**
- **TE—Traffic Engineering**
  - **TE Head end—Router that initiates a TE tunnel**
  - **TE Midpoint—Router where the TE Tunnel transits**
- **VPN—Collection of sites that share common policies**
- **AToM—Any Transport over MPLS**
  - **Commonly known scheme for building layer 2 circuits over MPLS**
  - **Attachment Circuit—Layer 2 circuit between PE and CE**
  - **Emulated circuit—Pseudowire between PEs**

# Evolution of MPLS



- **From Tag Switching**
- **Proposed in IETF—Later combined with other proposals from IBM (ARIS), Toshiba (CSR)**



# What Is MPLS?

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- **Multi Protocol Label Switching**
- **MPLS is an efficient encapsulation mechanism**
- **Uses "Labels" appended to packets (IP packets, AAL5 frames) for transport of data**
- **MPLS packets can run on other layer 2 technologies such as ATM, FR, PPP, POS, Ethernet**
- **Other layer 2 technologies can be run over an MPLS network**
- **Labels can be used as designators**

    **For example—IP prefixes, ATM VC, or a bandwidth guaranteed path**
- **MPLS is a technology for delivery of IP Services**

# Original Motivation of MPLS



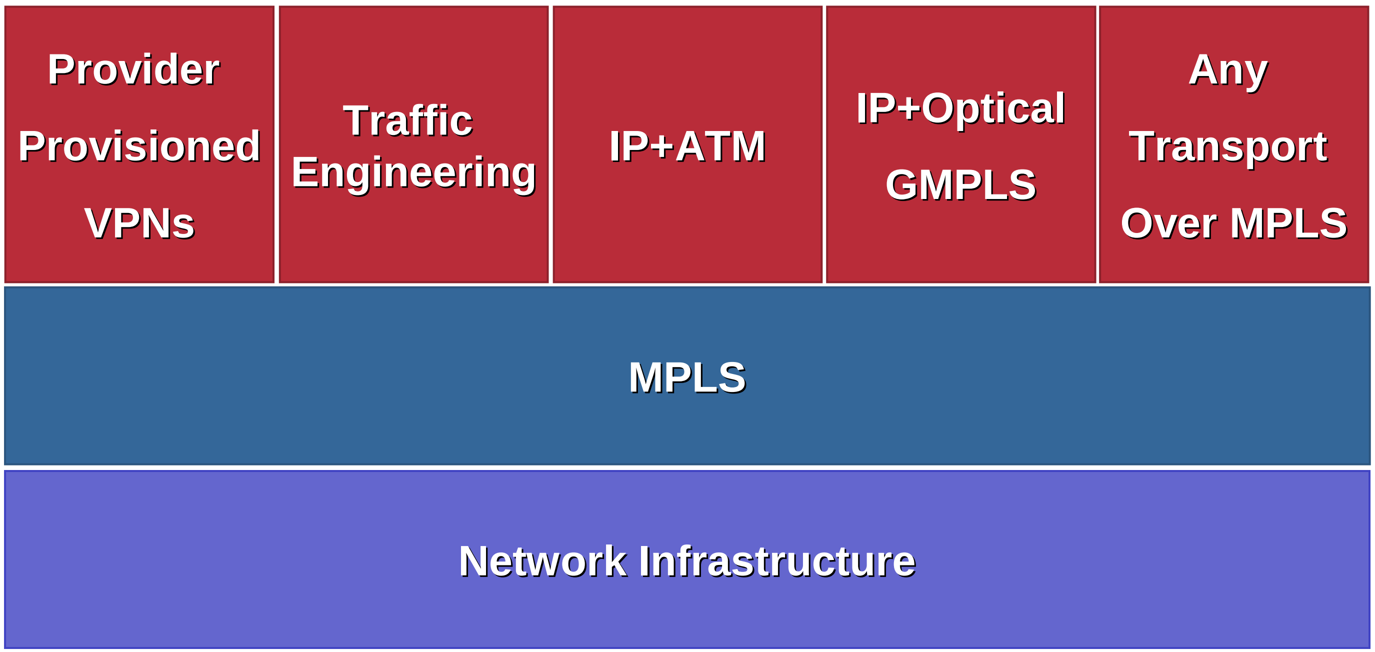
- **Allow Core routers/networking devices to switch packets based some simplified header**
- **Provide a highly scalable mechanism that was topology driven rather than flow driven**
- **Leverage hardware so that simple forwarding paradigm can be used**
- **It has evolved a long way from the original goal**

  **Hardware became better and looking up longest best match was no longer an issue**

  **By associating Labels with prefixes, groups of sites or bandwidth paths or light paths new services such as MPLS VPNs and Traffic engineering, GMPLS were now possible**

# MPLS as a Foundation for Value Added Services





# Technology Basics

# Label Header for Packet Media

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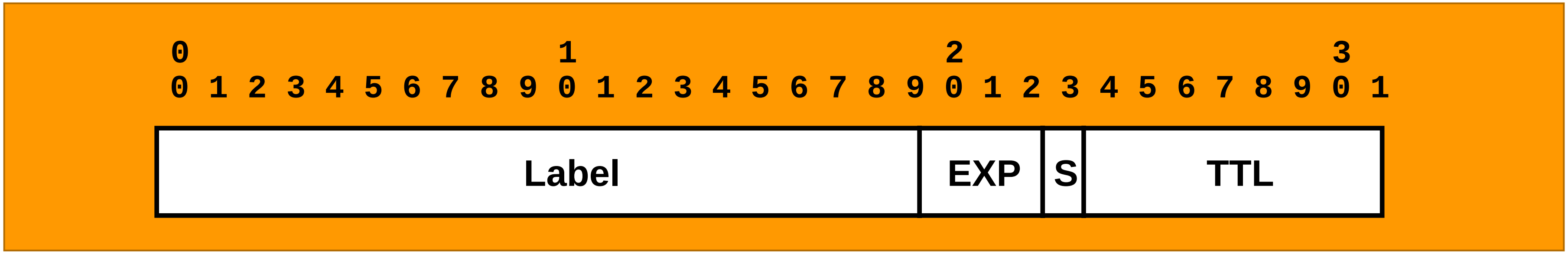


**Label = 20 bits**
**COS/EXP = Class of Service, 3 bits**
**S = Bottom of Stack, 1 bit**
**TTL = Time to Live, 8 bits**

- **Can be used over Ethernet, 802.3, or PPP links**
- **Uses two new Ethertypes/PPP PIDs**
- **Contains everything needed at forwarding time**
- **One word per label**

# Encapsulations

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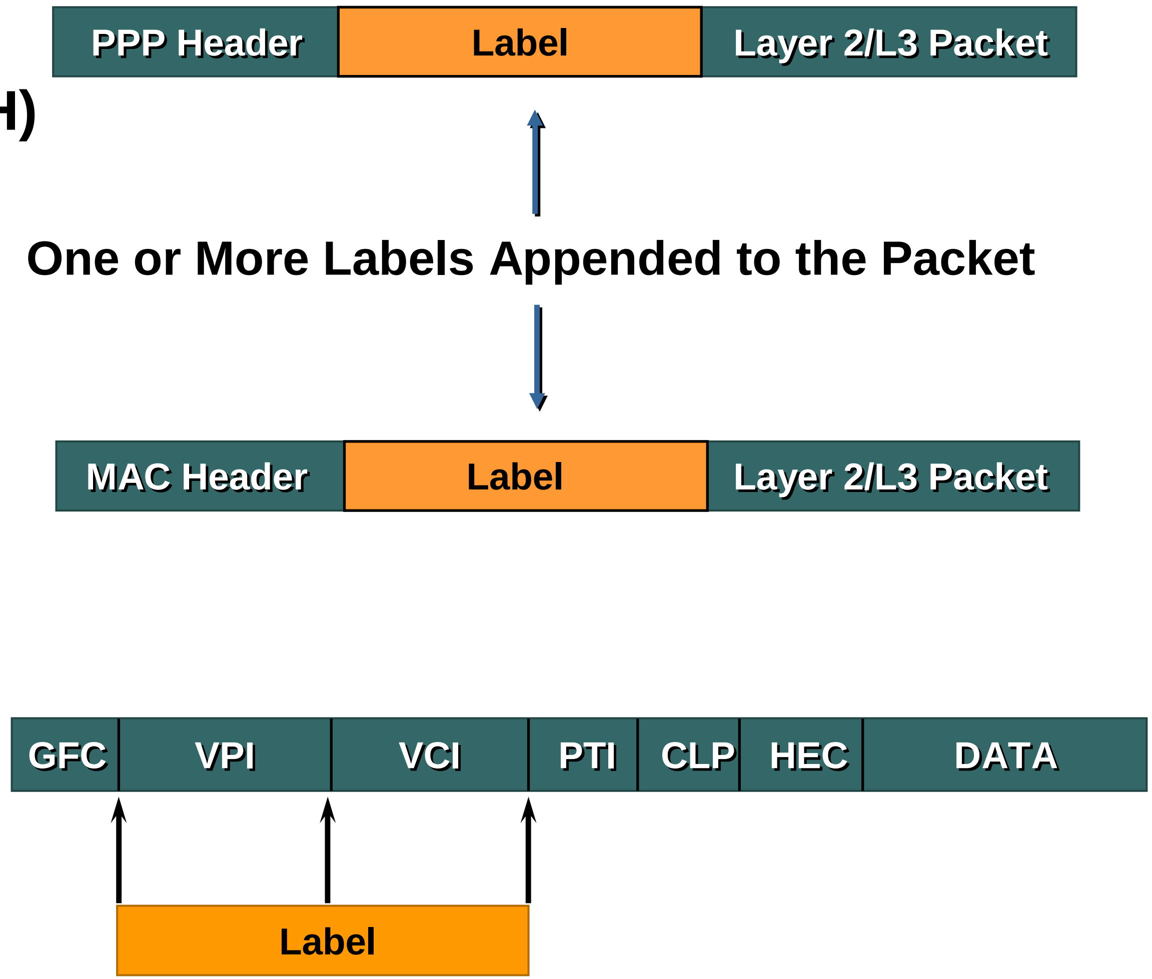
PPP Header
(Packet over SONET/SDH)

LAN MAC Label Header

ATM MPLS Cell Header



# Forwarding Equivalence Class



- **Determines how packets are mapped to LSP**

  **IP Prefix/host address**

  **Layer 2 Circuits (ATM, FR, PPP, HDLC, Ethernet)**

  **Groups of addresses/sites—VPN x**

  **A Bridge/switch instance—VSI**

  **Tunnel interface—Traffic Engineering**

# MPLS Concepts

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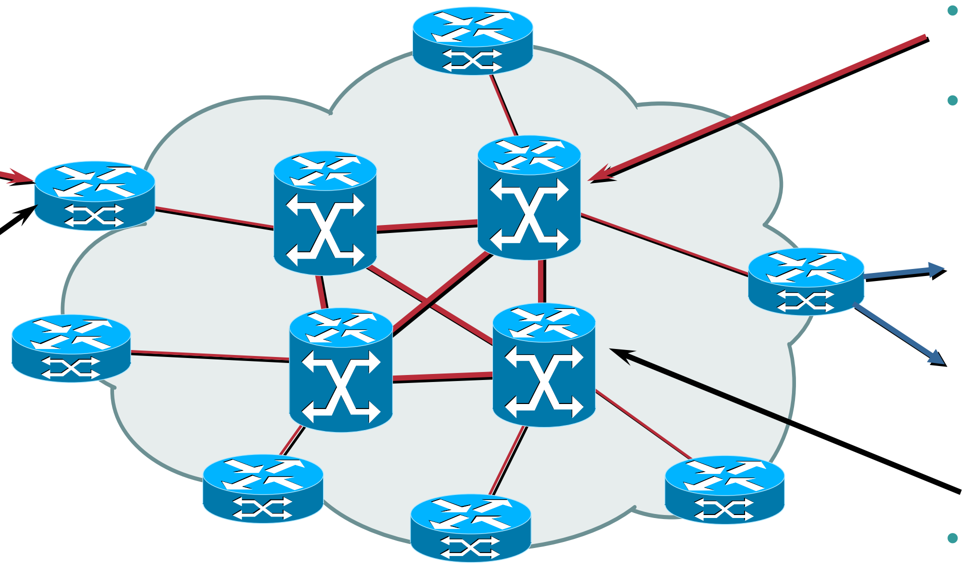
**At Edge:**
- Classify packets
- Label them

**Label Imposition**

**Edge Label Switch Router** (ATM Switch or Router)



**Label Distribution Protocol**

**In Core:**
- Forward using labels (as opposed to IP addr)
- Label indicates service class and destination

**Label Swapping or Switching**

**At Edge:**
Remove Labels and forward packets

**Label Disposition**

**Label Switch Router (LSR)**
- Router
- ATM switch + Label Switch Controller

- **Create new services via flexible classification**
- **Provides the ability to setup bandwidth guaranteed paths**
- **Enable ATM switches to act as routers**

# MPLS Operation

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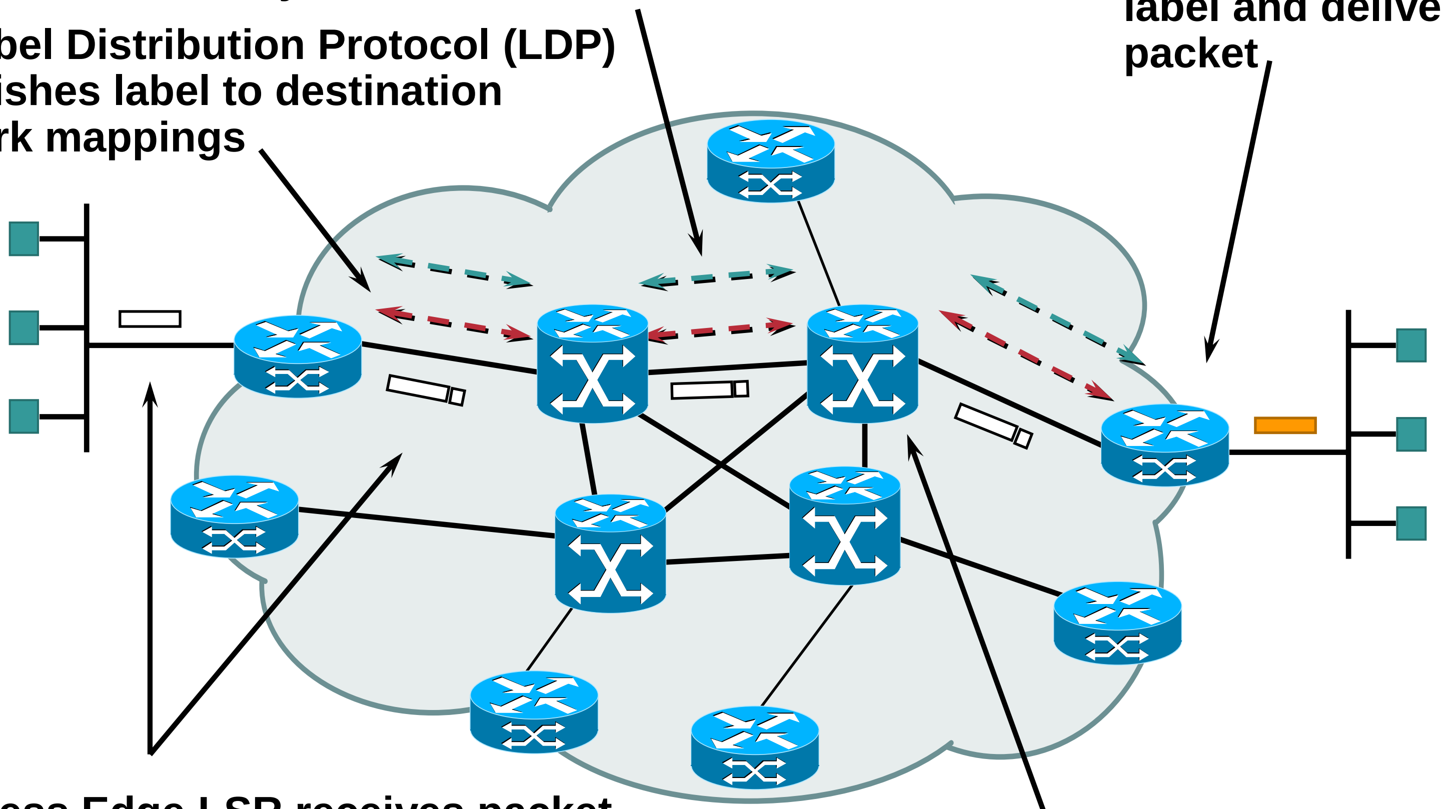
**1a. Existing routing protocols (e.g. OSPF, IS-IS) establish reachability to destination networks**

**1b. Label Distribution Protocol (LDP) establishes label to destination network mappings**

**4. Edge LSR at egress removes label and delivers packet**



**2. Ingress Edge LSR receives packet, performs Layer 3 value-added services, and "labels" packets**

**3. LSR switches packets using label swapping**

# Label Distribution in MPLS Networks

# Unicast Routing Protocols

- **OSPF, IS-IS, BGP are needed in the network**
- **They provide reachability**
- **Label distribution protocols distribute labels for prefixes advertised by unicast routing protocols using**
    - **Either a dedicated Label Distribution Protocol (LDP)**
    - **Extending existing protocols like BGP to distribute Labels**

# Label Distribution Protocol



- **Defined in RFC 3035 and 3036**
- **Used to distribute Labels in a MPLS network**
- **Forwarding Equivalence Class**

    **How packets are mapped to LSPs (Label Switched Paths)**

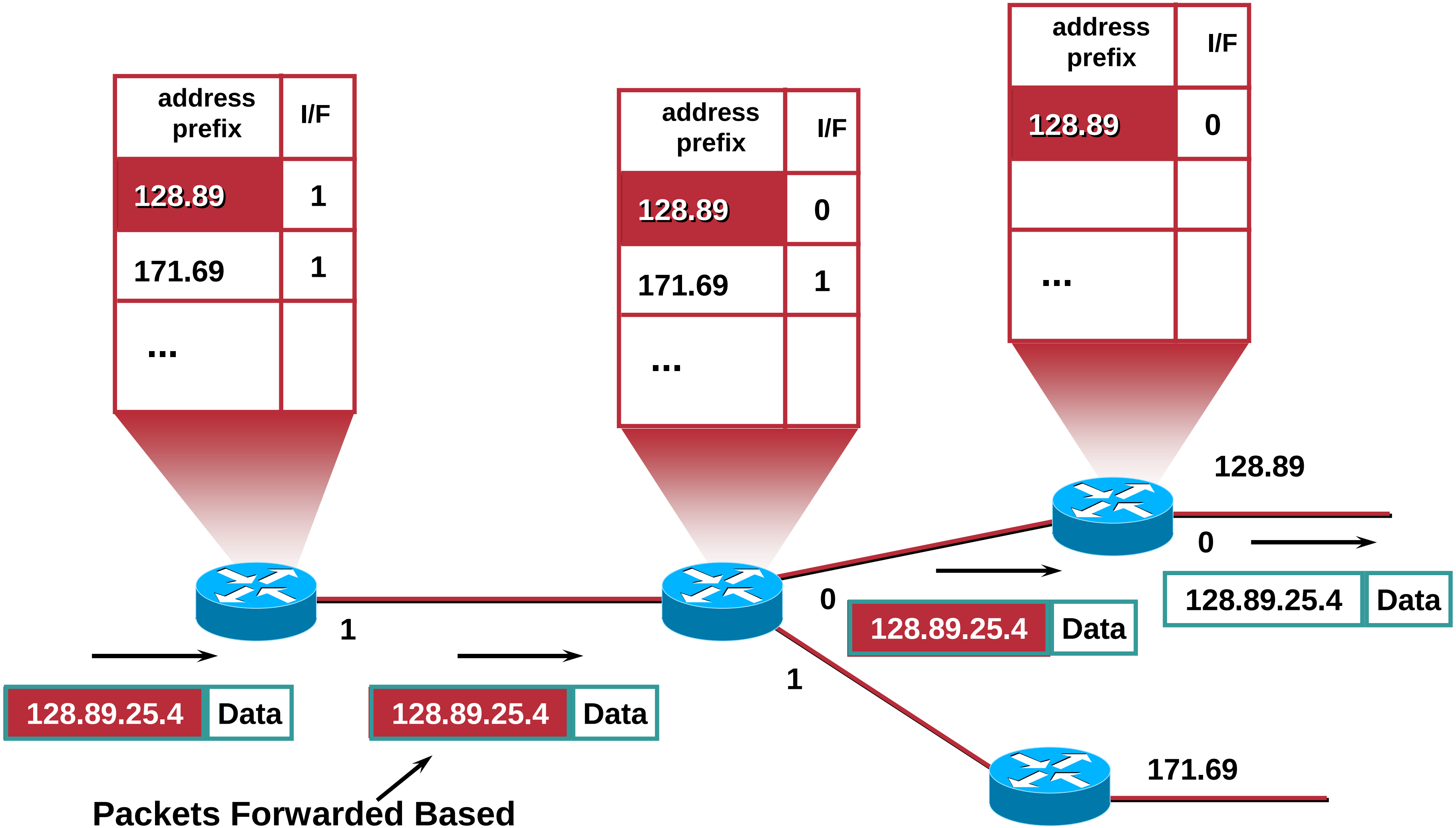
- **Advertise Labels per FEC**

    **Reach destination a.b.c.d with label x**

- **Discovery**

# Router Example: Forwarding Packets






Packets Forwarded Based on IP Address

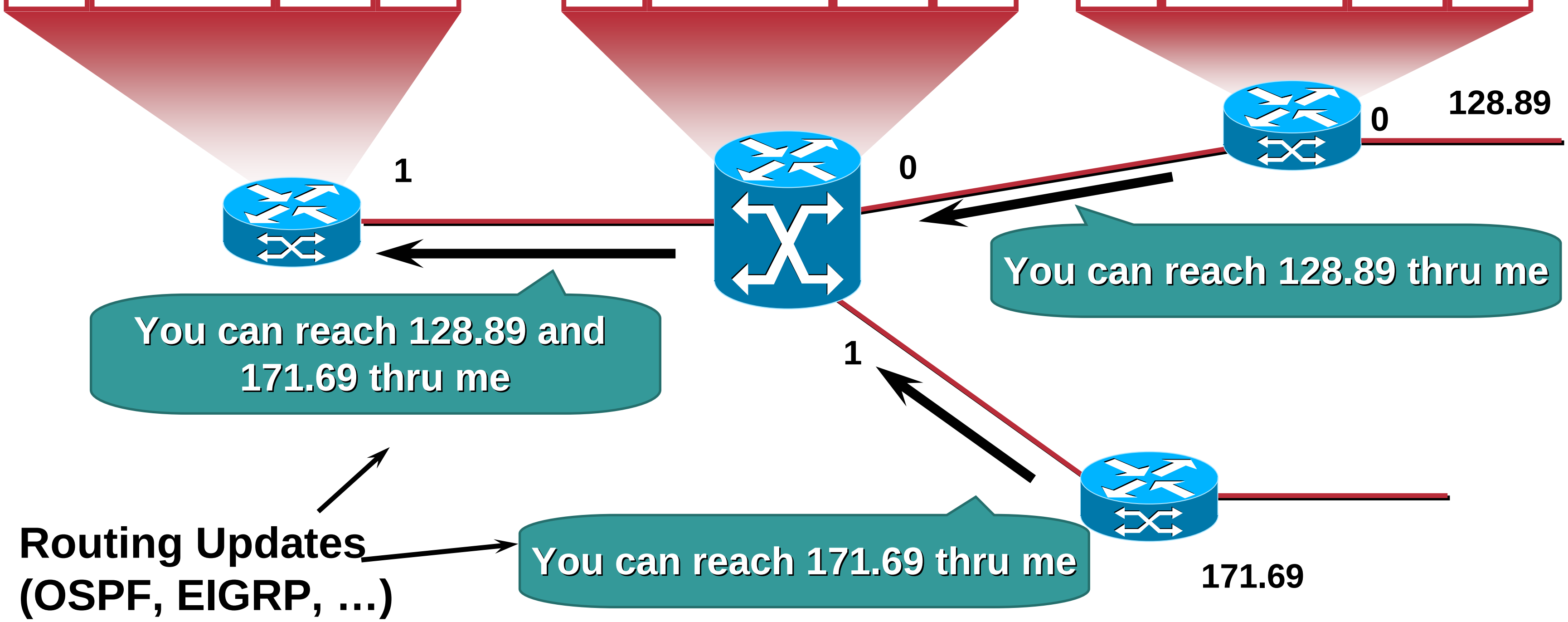
# MPLS Example: Routing Information



| In label | Address Prefix | Out I'face | Out label |
|---|---|---|---|
| | 128.89 | 1 | |
| | 171.69 | 1 | |
| | ... | ... | |

| In label | Address Prefix | Out I'face | Out label |
|---|---|---|---|
| | 128.89 | 0 | |
| | 171.69 | 1 | |
| | ... | ... | |

| In label | Address Prefix | Out I'face | Out label |
|---|---|---|---|
| | 128.89 | 0 | |
| | | | |
| | ... | ... | |



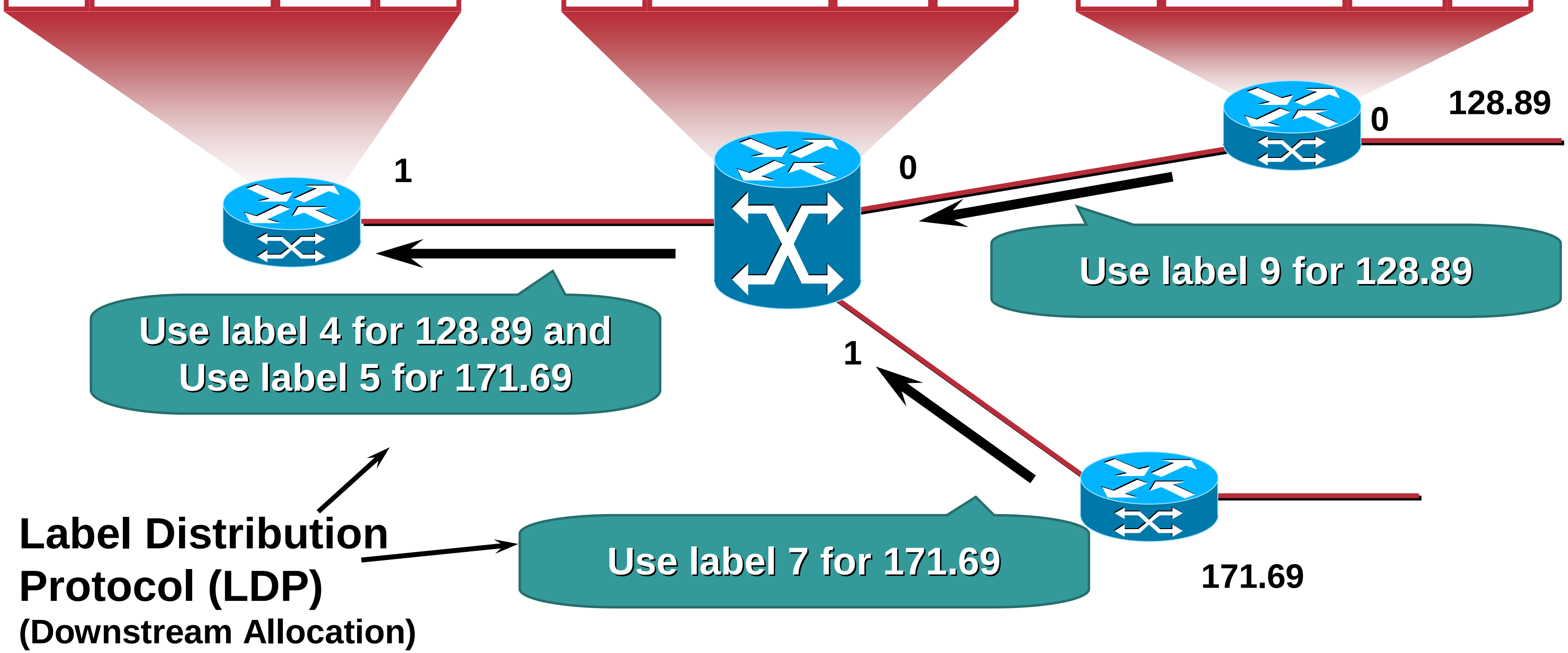
# MPLS Example: Assigning Labels



| In label | Address Prefix | Out I'face | Out label |
|---|---|---|---|
| - | 128.89 | 1 | 4 |
| - | 171.69 | 1 | 5 |
| ... | ... | ... | ... |

| In label | Address Prefix | Out I'face | Out label |
|---|---|---|---|
| 4 | 128.89 | 0 | 9 |
| 5 | 171.69 | 1 | 7 |
| ... | ... | ... | ... |

| In label | Address Prefix | Out I'face | Out label |
|---|---|---|---|
| 9 | 128.89 | 0 | - |
| | | | |
| ... | ... | ... | ... |



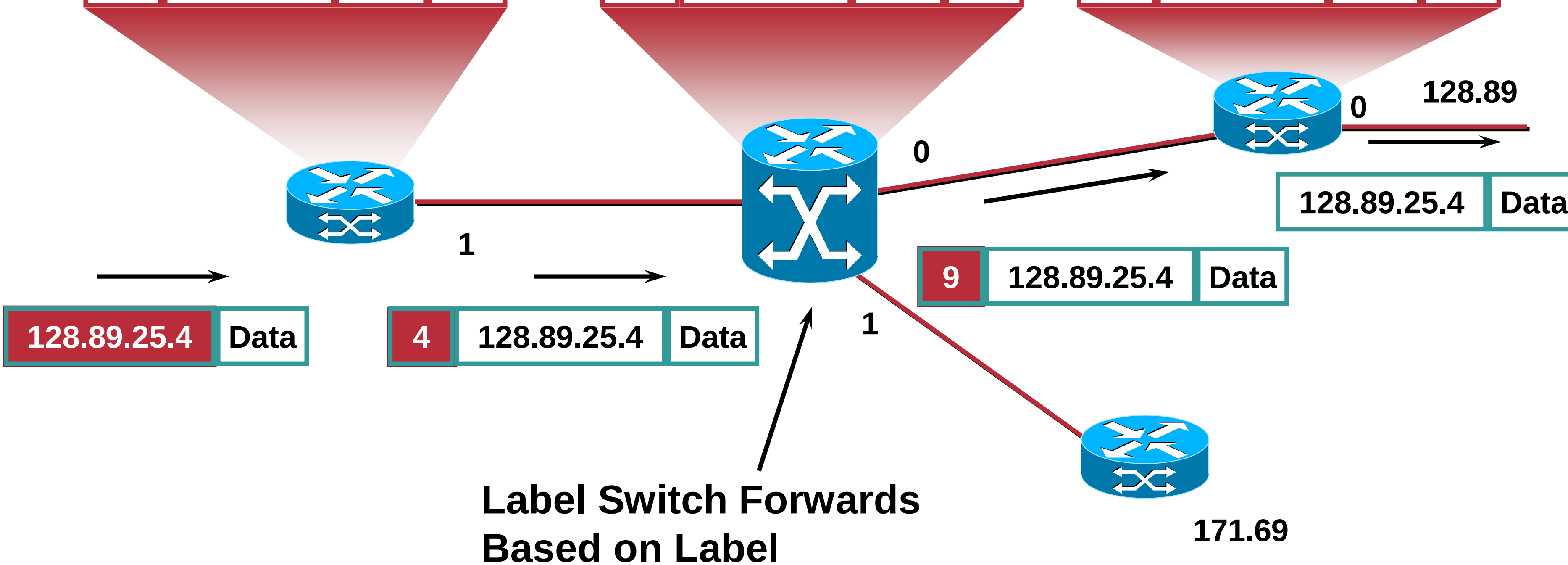
# MPLS Example: Forwarding Packets



| In label | Address Prefix | Out I'face | Out label |
|---|---|---|---|
| - | 128.89 | 1 | 4 |
| - | 171.69 | 1 | 5 |
| ... | ... | ... | ... |

| In label | Address Prefix | Out I'face | Out label |
|---|---|---|---|
| 4 | 128.89 | 0 | 9 |
| 5 | 171.69 | 1 | 7 |
| ... | ... | ... | ... |

| In label | Address Prefix | Out I'face | Out label |
|---|---|---|---|
| 9 | 128.89 | 0 | - |
| | | | |
| ... | ... | ... | ... |



# LDP



- **Neighbor discovery**
  - Discover directly attached Neighbors—pt-to-pt links (including Ethernet)
  - Establish a session
  - Exchange prefix/FEC and label information
- **Extended Neighbor Discovery**
  - Establish peer relationship with another router that is not a neighbor
  - Exchange FEC and label information
  - May be needed to exchange service labels

# TDP and LDP



- **Tag Distribution Protocol—Cisco proprietary**
  - **Pre-cursor to LDP**
  - **Used for Cisco Tag Switching**
- **TDP and LDP supported on the same device**
  - **Per neighbor/link basis**
  - **Per target basis**
- **LDP is a superset of TDP**
- **Uses the same label/TAG**
- **Has different message formats**

# Other Label Distribution Protocols—RSVP



- **Used in MPLS Traffic Engineering**
- **Additions to RSVP signaling protocol**
- **Leverage the admission control mechanism of RSVP to create an LSP with bandwidth**
- **Label requests are sent in PATH messages and binding is done with RESV messages**
- **EXPLICT-ROUTE object  defines the path over which setup messages should be routed**
- **Using RSVP has several advantages**

# Other Label Distribution Protocols—BGP

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- **Used in the context of MPLS VPNs**
- **Need multiprotocol extensions to BGP**
- **Routers need to be BGP peers**
- **Label mapping info carried as part of NLRI (Network Layer Reacheability Information)**

# MPLS Control and Forwarding Planes

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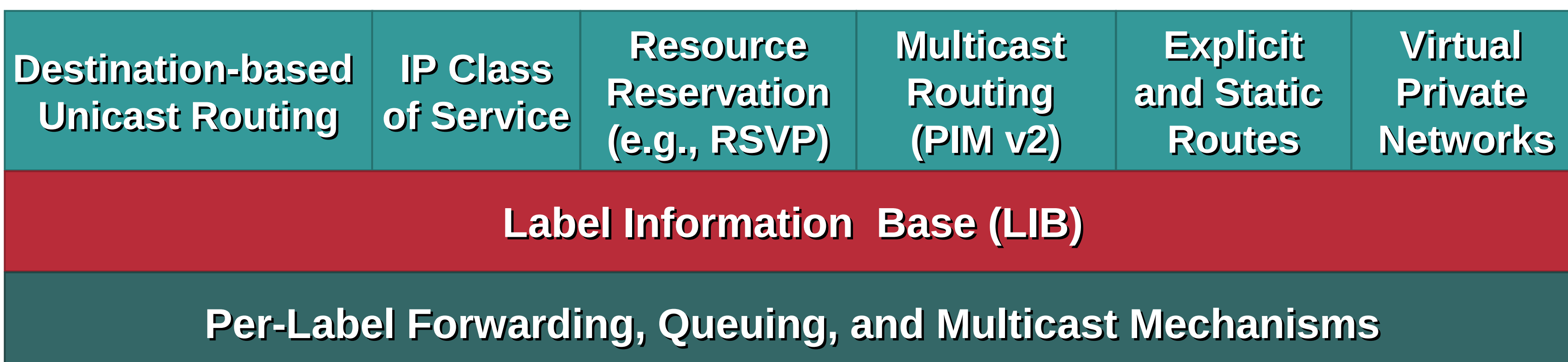
- Control plane used to distribute labels—BGP, LDP, RSVP
- Forwarding plane consists of label imposition, swapping and disposition—no matter what the control plane
- Key: There is a separation of Control Plane and Forwarding Plane
  - Basic MPLS: destination-based unicast
  - Labels divorce forwarding from IP address
  - Many additional options for assigning labels
  - Labels define destination and service



# Label Stacking

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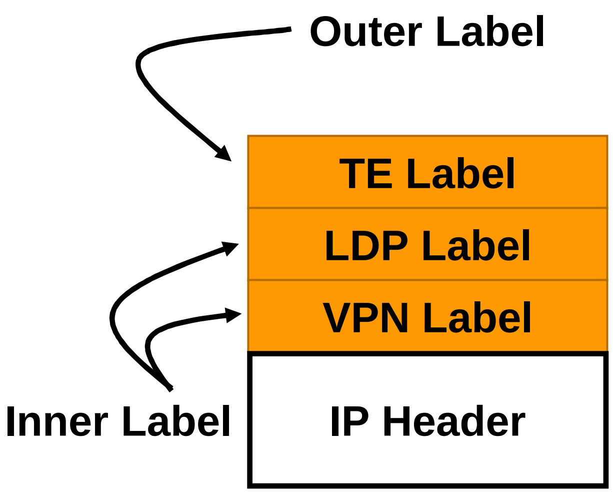
- There may be more than one label in an MPLS packet
- As we know Labels correspond to forwarding equivalence classes
    - Example—There can be one label for routing the packet to an egress point and another that separates a customer A packet from Customer B
    - Inner labels can be used to designate services/FECs etc
        - E.g VPNs, Fast Re-route
- Outer label used to route/switch the MPLS packets in the network
- Last label in the stack is marked with EOS bit
- Allows building services such as
    - MPLS VPNs
    - Traffic Engineering and Fast Re-route
    - VPNs over Traffic Engineered core
    - Any Transport over MPLS



# MPLS-Based Services

# MPLS VPNs

## Layer 2 and Layer 3

# What Is a VPN ?

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- VPN is a set of sites which are allowed to communicate with each other
- VPN is defined by a set of administrative policies
  - Policies determine both connectivity and QoS among sites
  - Policies established by VPN customers
  - Policies could be implemented completely by VPN Service Providers
    - Using BGP/MPLS VPN mechanisms

# What Is a VPN (Cont.)?



- **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

# VPNs

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- **Layer 2 VPNs**

  **Customer End points (CPE) connected via layer 2 such as Frame Relay DLCI, ATM VC or point to point connection**

  **If it connects IP routers then peering or routing relationship is between the end points**

  **Multiple logical connections (one with each end point)**

- **Layer 3 VPNs**

  **Customer end points peer with provider routers**

  **Single peering relationship**

  **No mesh of connections**

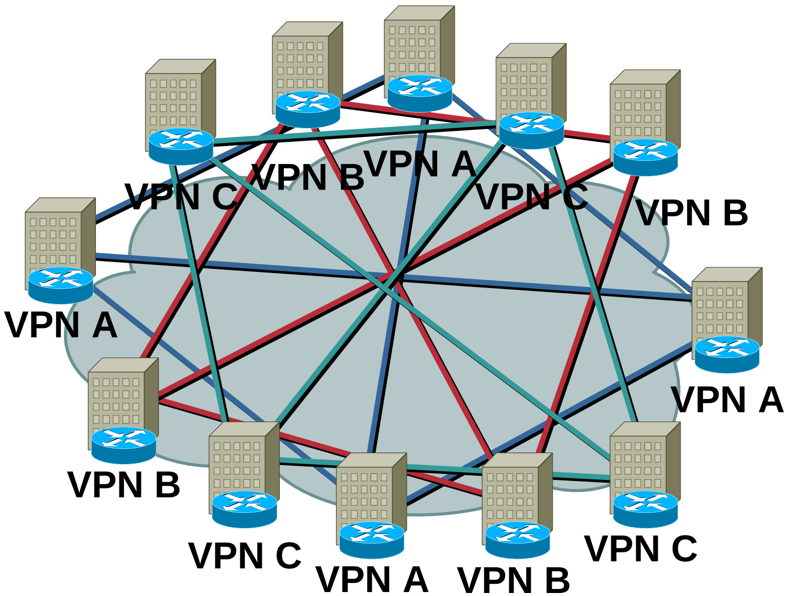
  **Provider network responsible for**

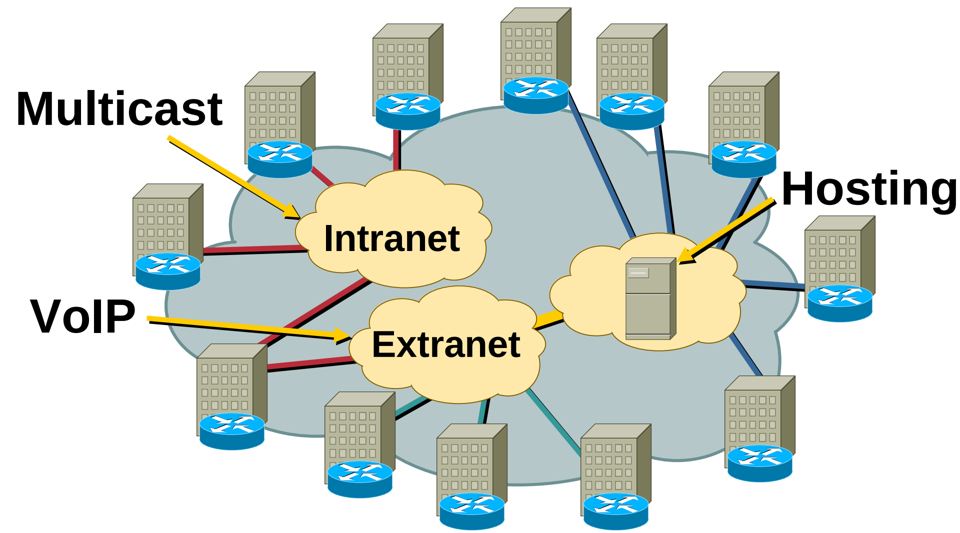
  - **Distributing routing information to VPN sites**
  - **Separation of routing tables from one VPN to another**

# Layer 3 VPNs

# Service Provider Benefits of MPLS-Based VPNs






## Overlay VPN

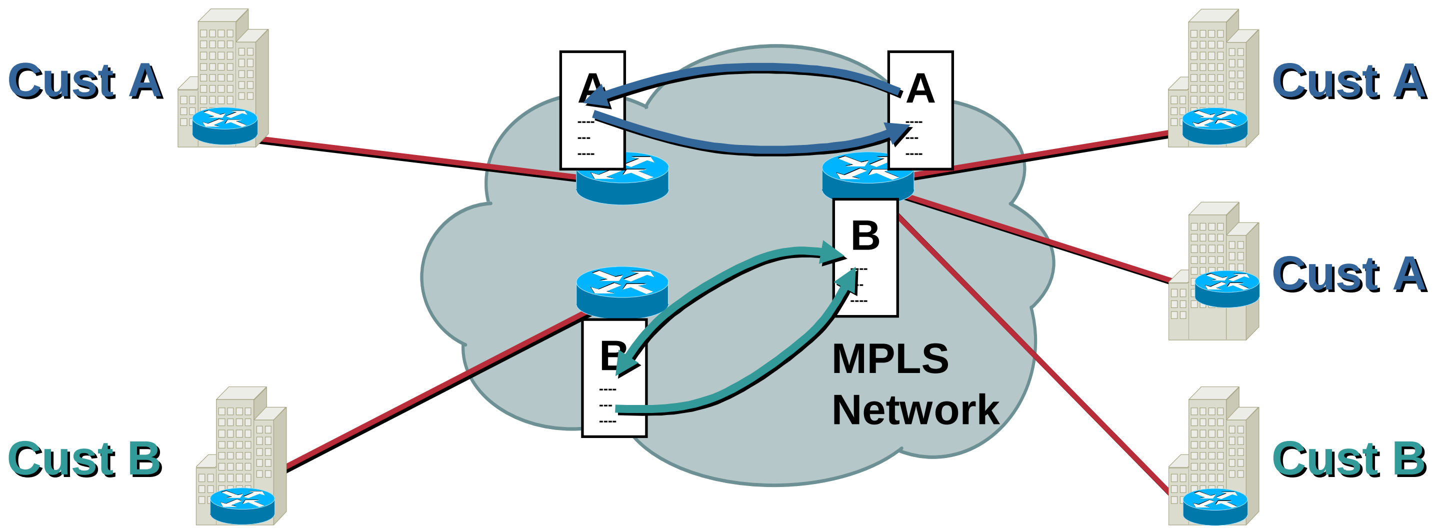
- Pushes content *outside* the network
- Costs scale exponentially
- Transport dependent
- Groups endpoints, not groups
- Complex overlay with QoS, tunnels, IP

## MPLS-based VPNs

- Enables content hosting inside the network
- "Flat" cost curve
- Transport independent
- Easy grouping of users and services
- Enables QoS inside the VPNs

# Using Labels to Build an IP VPN






- **The network distributes labels to each VPN**
  - **Only labels for other VPN members are distributed**
  - **Each VPN is provisioned automatically by IP routing**
- **Privacy and QoS of ATM without tunnels or encryption**
  - **Each network is as secure as a Frame Relay connection**
- **One mechanism (labels) for QoS and VPNs—no tradeoffs**

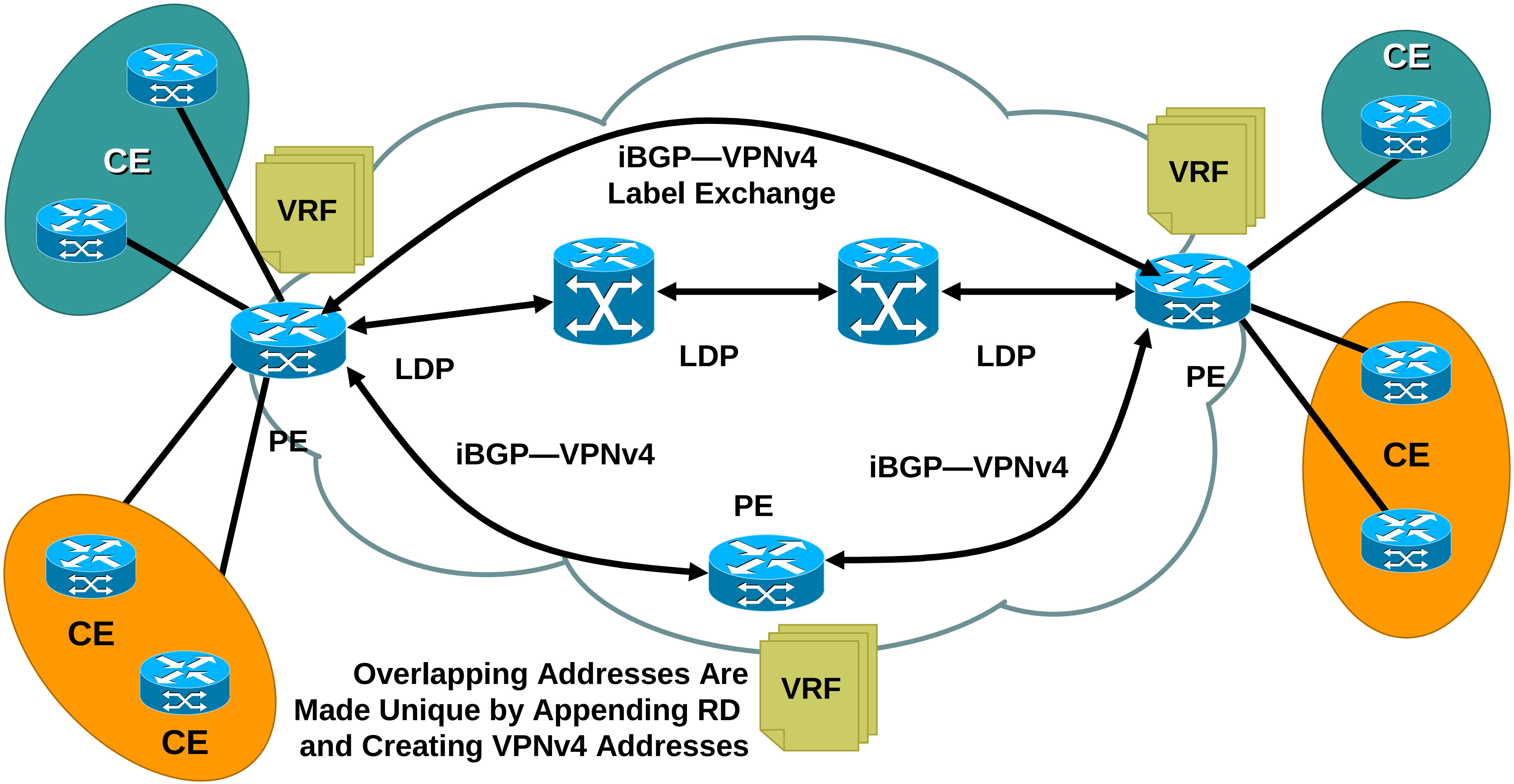
# How Does It Work?



- **Simple idea**
  - Use a label to designate VPN prefix
  - Route that VPN packet to egress PE advertising that prefix
    - Use the IGP label to the VPN packet to the egress node
- **How is it done?**
  - Routers need to maintain separate VPN routing tables called VRFs (Virtual Routing and Forwarding Tables)
  - Routers then export and import routes using BGP extensions to identify and separate one VPNs routes from another
  - Routers then exchange labels for VPN routes in addition to IGP routes

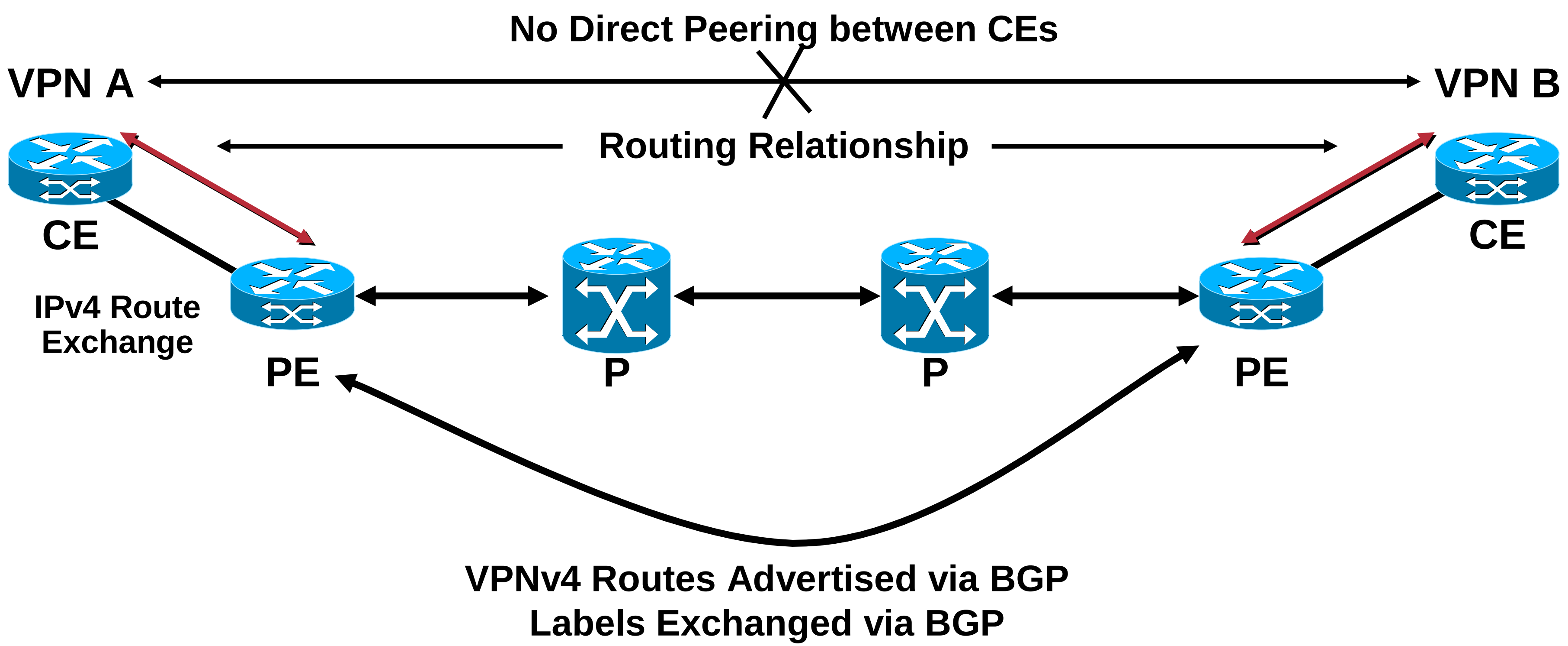
# RFC 2547—MPLS VPNs





# Control Plane Path






- **RD—8 Byte field—assigned by provider—significant to the provider network only**
- **VPNv4 Address: RD+VPN Prefix**
- **Unique RD per VPN makes the VPNv4 address unique**

# Data Plane Path

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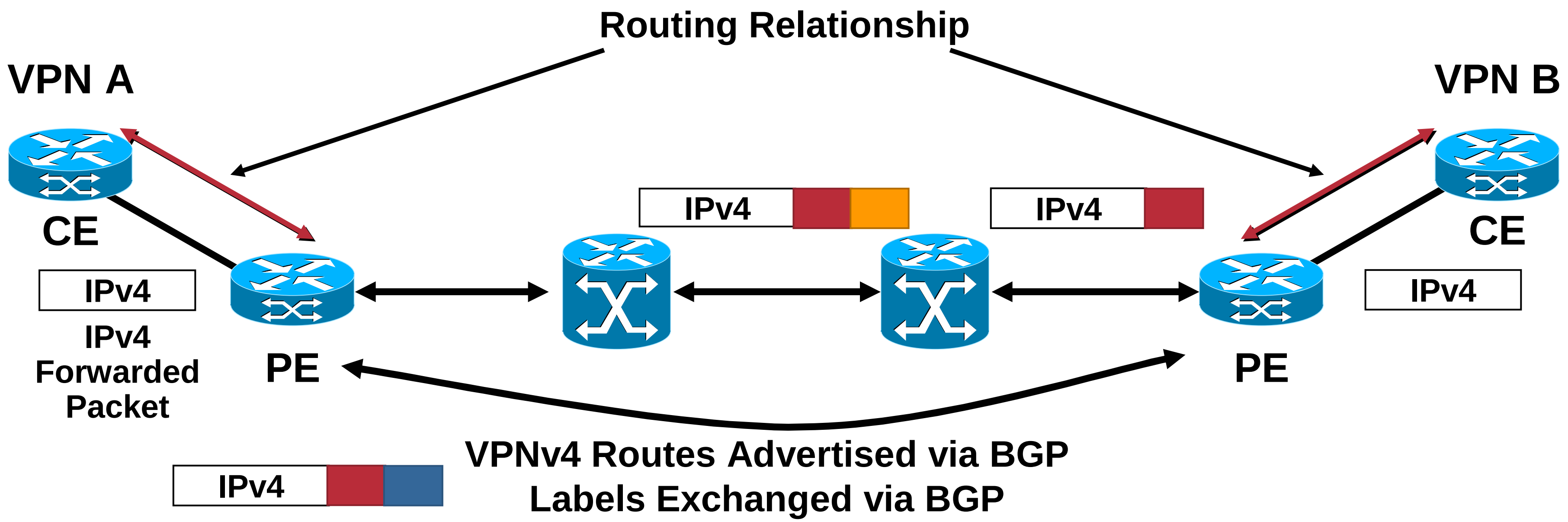
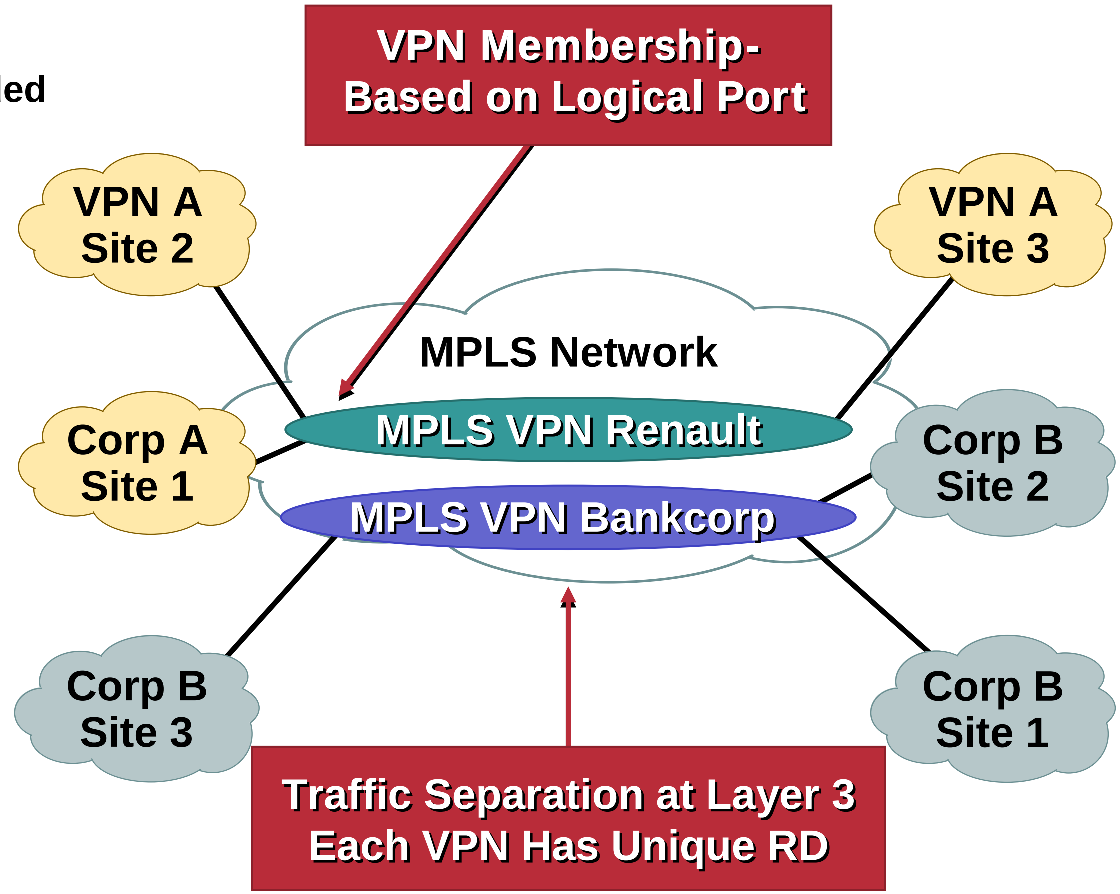



- **Ingress PE is imposing 2 labels**

# MPLS-Based IP-VPN Architecture



- Scalable VPNs
  - Add more PEs if more VPNs are needed
  - No N^2 mesh
  - VPNs are built in to the cloud
- IP QoS and traffic engineering
- Easy to manage and no VC mesh provisioning required
- Provides a level of security/ separation equivalent to Frame Relay and ATM
- Supports the deployment of new value-added applications
- Customer IP address freedom



# Key Features

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- **No constraints on addressing plans used by VPNs—a VPN customer may:**
  - **Use globally unique and routable/non-routable addresses,**
  - **Use private addresses (RFC1918)**
- **Security:**
  - **Basic security is comparable to that provided by FR/ATM-based VPNs without providing data encryption**
  - **VPN customer may still use IPSec-based mechanisms**
    - **e.g., CE- CE IPSec-based encryption**

# Key Features (Cont.)



- **Quality of Service:**

  **Flexible and scaleable support for a CoS-based networks**

- **Scalability:**

  **Total capacity of the system isn't bounded by the capacity of an individual component**

  **Scale to virtually unlimited number of VPNs per VPN Service Provider and scale to thousands of sites per VPN**

# Key Features (Cont.)

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- **Connectivity to the Internet:**

  **VPN Service Provider may also provide connectivity to the Internet to its VPN customers**

  **Common infrastructure is used for both VPN and the Internet connectivity services**

- **Simplifies operations and management for VPN Service Providers:**

  **No need for VPN Service Providers to set up and manage a separate backbone or "virtual backbone" for each VPN**

# BGP/MPLS VPN—Summary



- Supports large scale VPN service
- Increases value add by the VPN Service Provider
- Decreases Service Provider cost of providing VPN services
- Mechanisms are general enough to enable VPN Service Provider to support a wide range of VPN customers

# Layer 2 VPNs

# Layer 2 VPNs



## Similar to L3VPN

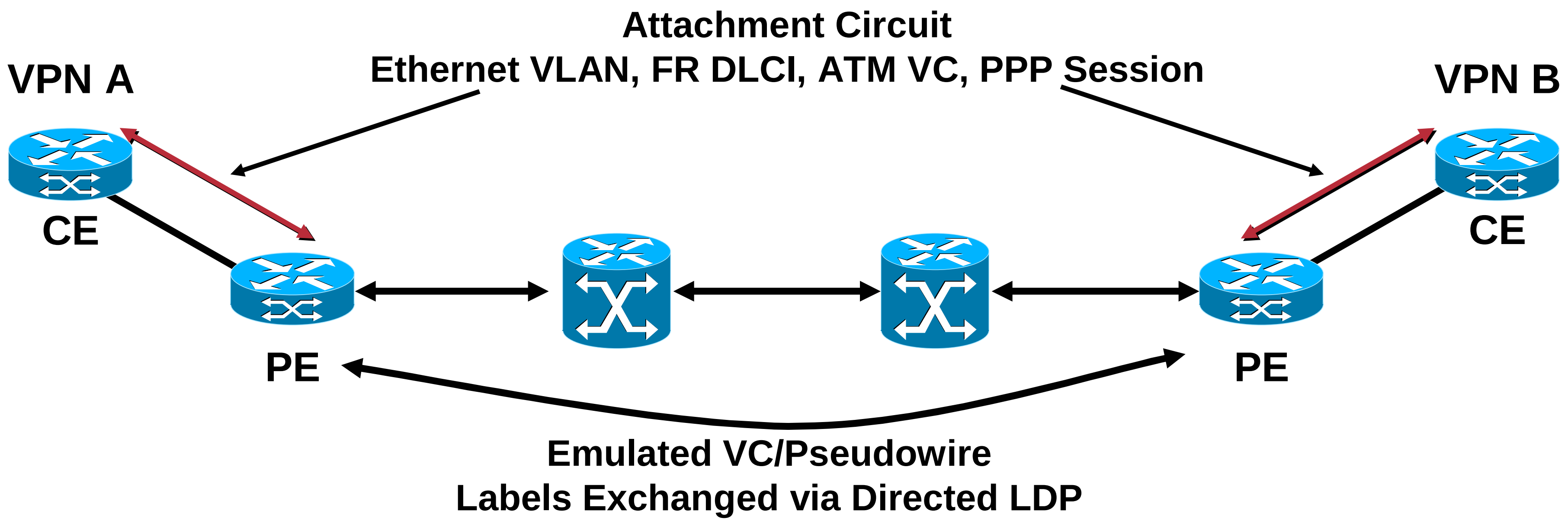
- Designate a label for the circuit
- Exchange that label information with the egress PE
- Encapsulate the incoming traffic (layer 2 frames)
- Apply label (learnt through the exchange)
- Forward the MPLS packet (l2 encapsulated to destination on an LSP)
- At the egress

  Lookup the L2 label

  Forward the packet onto the L2 attachment circuit

# Architecture

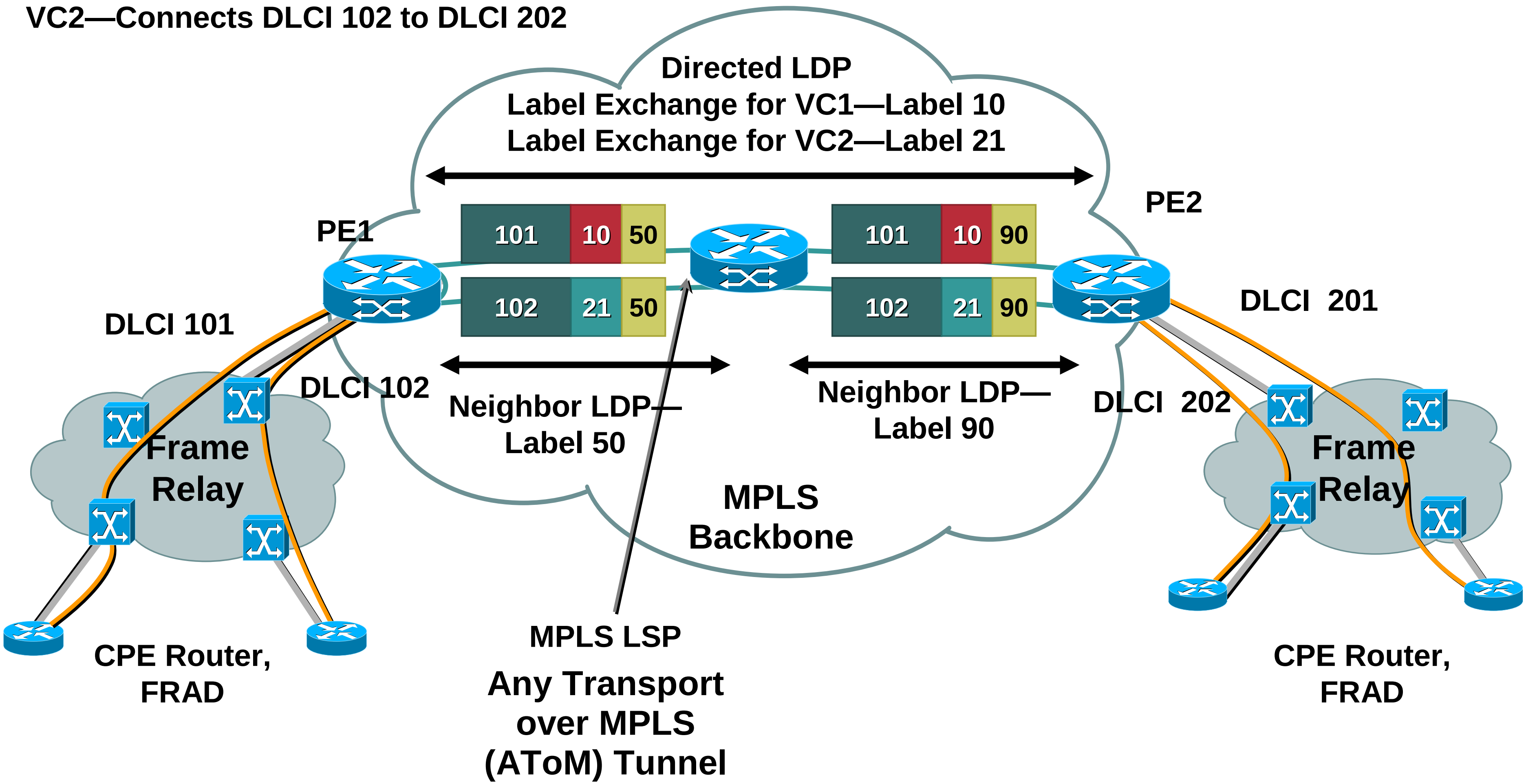




# Frame Relay over MPLS—Example



VC1—Connects DLCI 101 to DLCI 201
VC2—Connects DLCI 102 to DLCI 202



# Summary



- **Easy way of transporting layer 2 frames**
- **Can be used to transport ATM AAL5 frames, Cells, FR DLCI, PPP sessions, Ethernet VLANs**
- **Point-to-point transport with QoS guarantees**
- **Combine with TE and QoS to emulate layer 2 service over a packet infrastructure**
- **Easy migration towards network convergence**

# MPLS Traffic Engineering

# What Is MPLS Traffic Engineering?

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- Process of routing data traffic in order to balance the traffic load on the various links, routers, and switches in the network
- Key in most networks where multiple parallel or alternate paths are available

# Why Traffic Engineering?

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- **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

# IP Routing and The Fish

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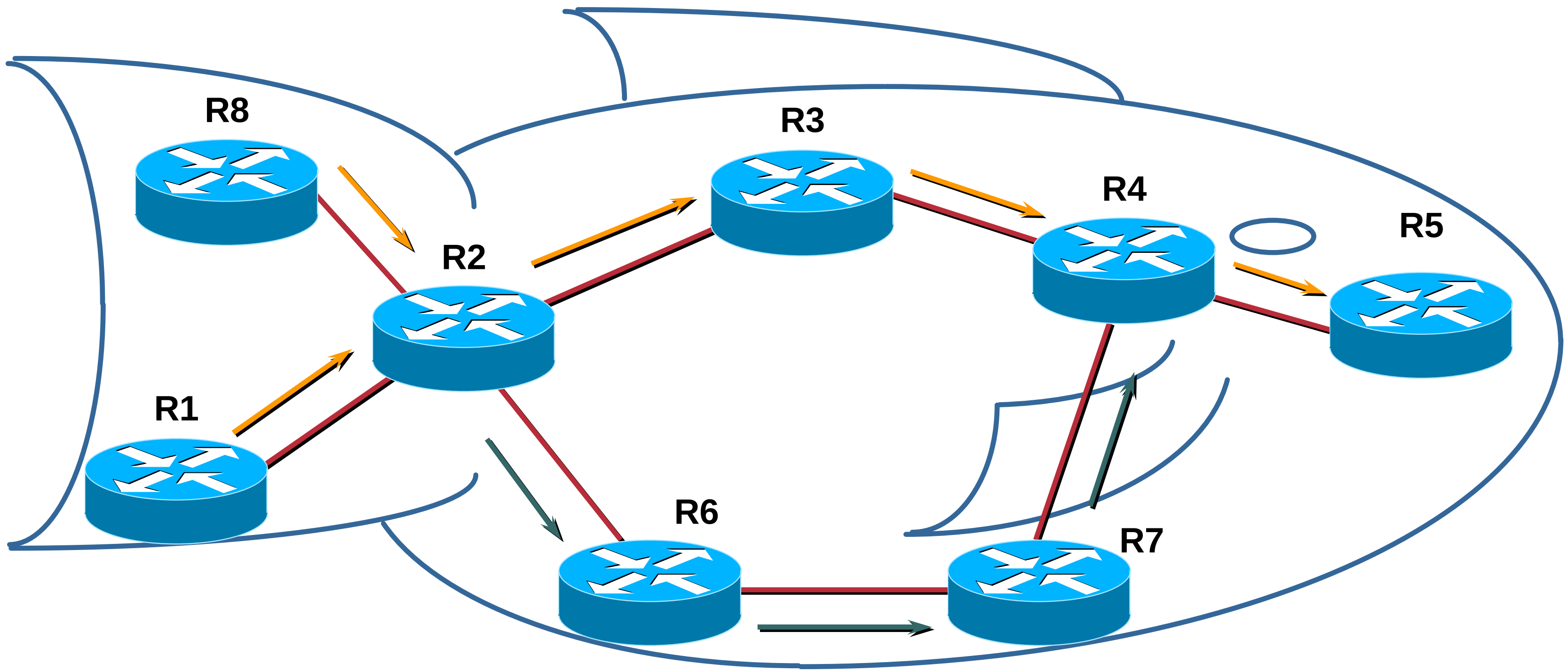



IP (Mostly) Uses Destination-Based Least-Cost Routing
Flows from R8 and R1 Merge at R2 and Become Indistinguishable
From R2, Traffic to R3, R4, R5 Use Upper Route

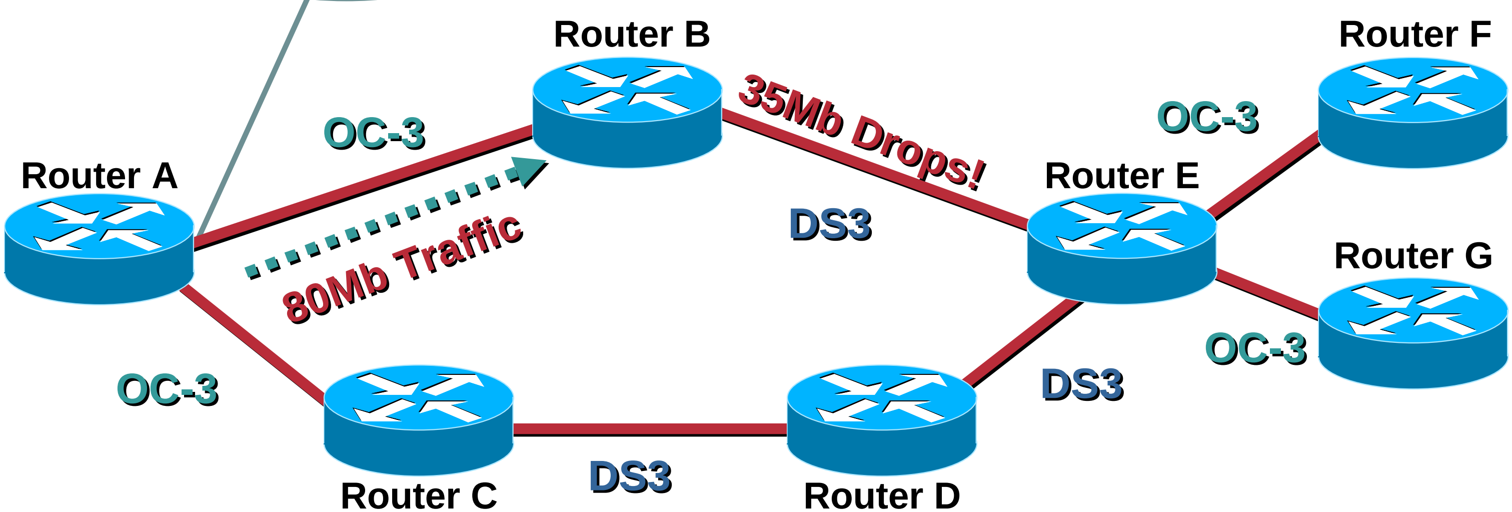
Alternate Path Under-Utilized

# The Problem with Shortest-Path

| 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 40Mb of traffic for Route F, 40Mb of traffic for Router G
- Massive (44%) packet loss at Router B->Router E!

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

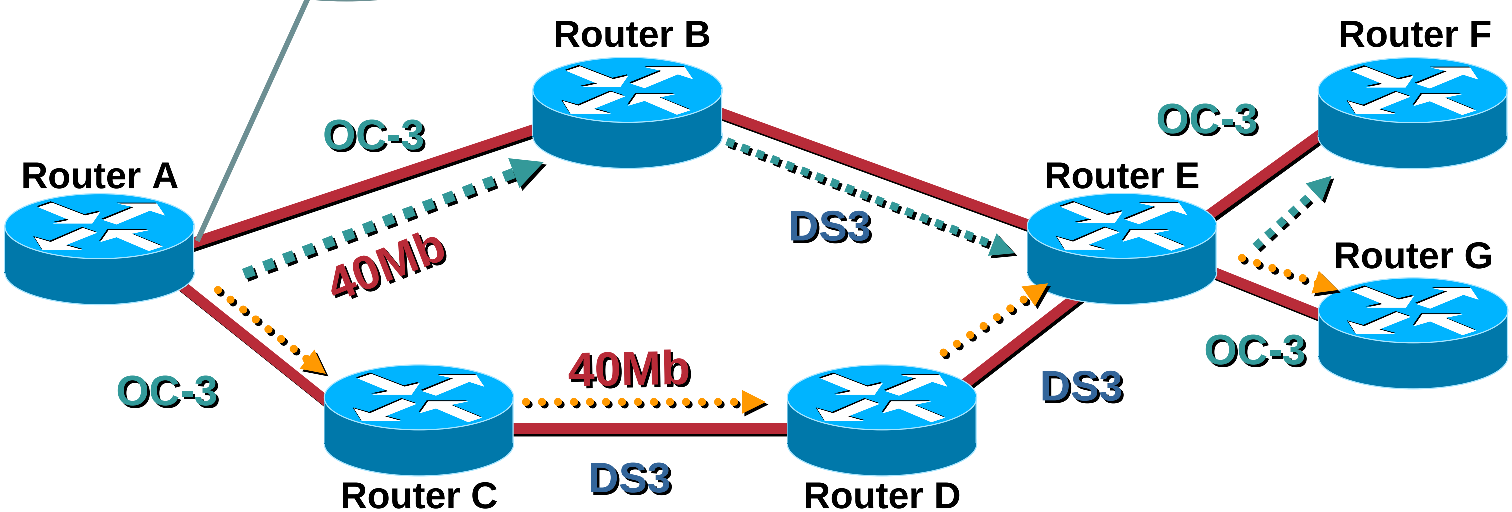


# How MPLS TE Solves the Problem



| 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
- No link oversubscribed!



# Information Distribution



- You need a link-state protocol as your IGP
  - IS-IS or OSPF
- Link-state requirement is only for MPLS-TE!
  - Not a requirement for VPNs, etc!
- Why do I need a link-state protocol?
  - To make sure info gets flooded
  - To build a picture of the entire network
- Information flooded includes Link, Bandwidth, Attributes, etc.

# Benefits of TE over Policy Routing

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- **Policy Routing**

  Hop-by-hop decision making

  No accounting of bandwidth

- **Traffic Engineering**

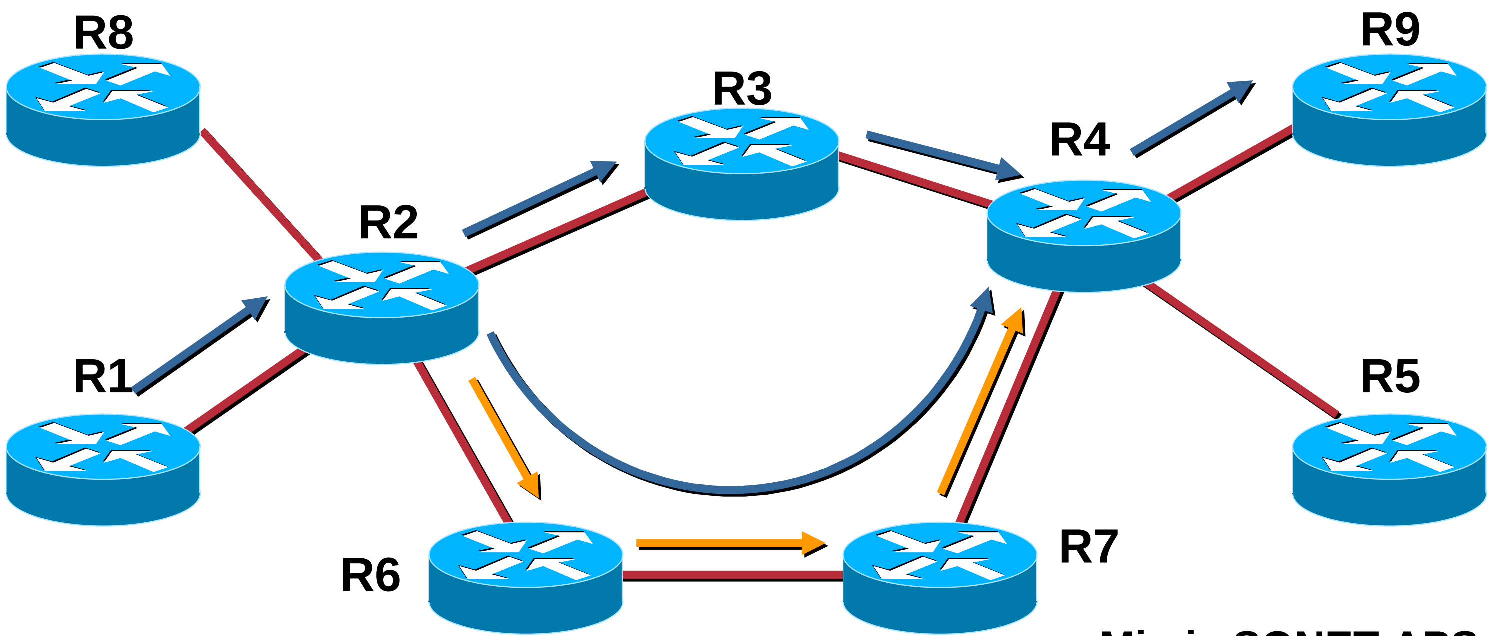
  Head end based

  Accounts for available link bandwidth

  Admission control

# Applications of MPLS TE






**Mimic SONET APS**
**Re-route in 50ms or Less**

- Multiple hops can be by-passed; R2 swaps the label which R4 expects before pushing the label for R6
- R2 locally patches traffic onto the link with R6

# TE Deployment Scenarios

# Tactical TE Deployment

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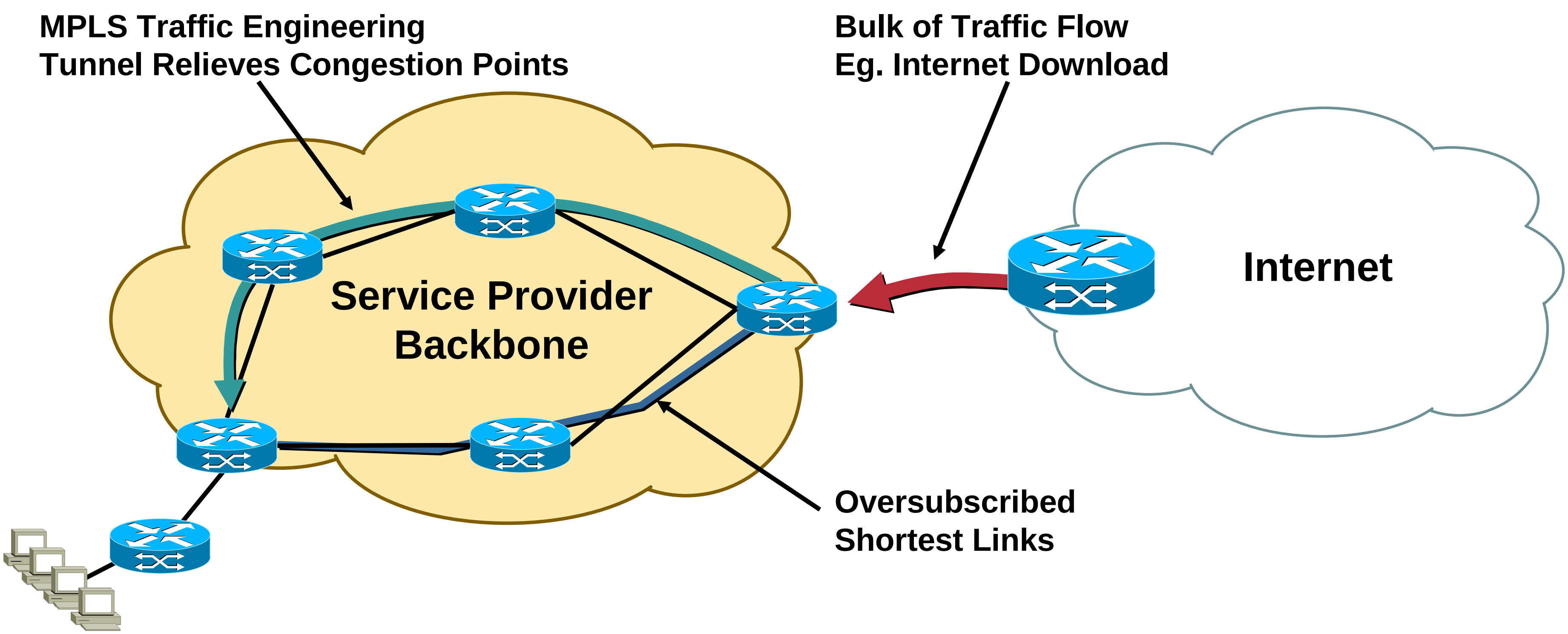
**Requirement: Need to handle scattered congestion points in the Network**
**Solution: Deploy MPLS TE on only those nodes that face congestion**

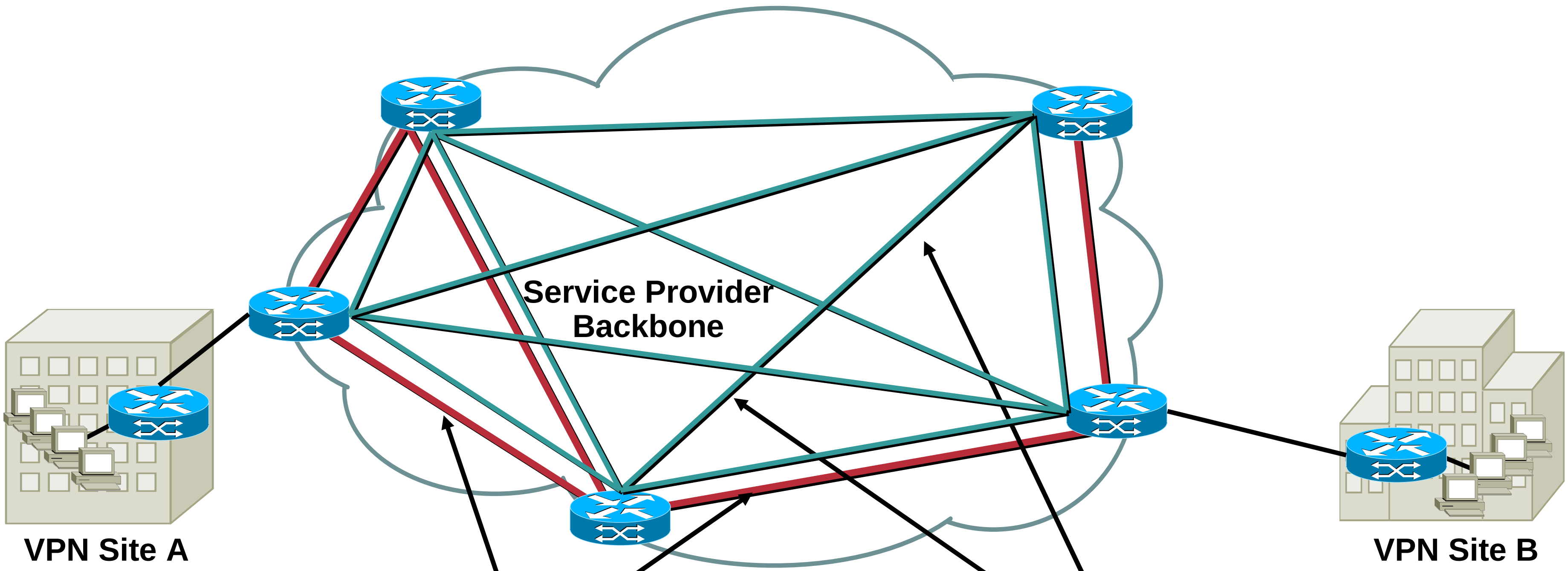


# Full Mesh TE Deployment



**Requirement:** Need to increase "bandwidth inventory" across the network

**Solution:** Deploy MPLS TE with a full logical mesh over a partial physical mesh and use Offline Capacity Planning Tool

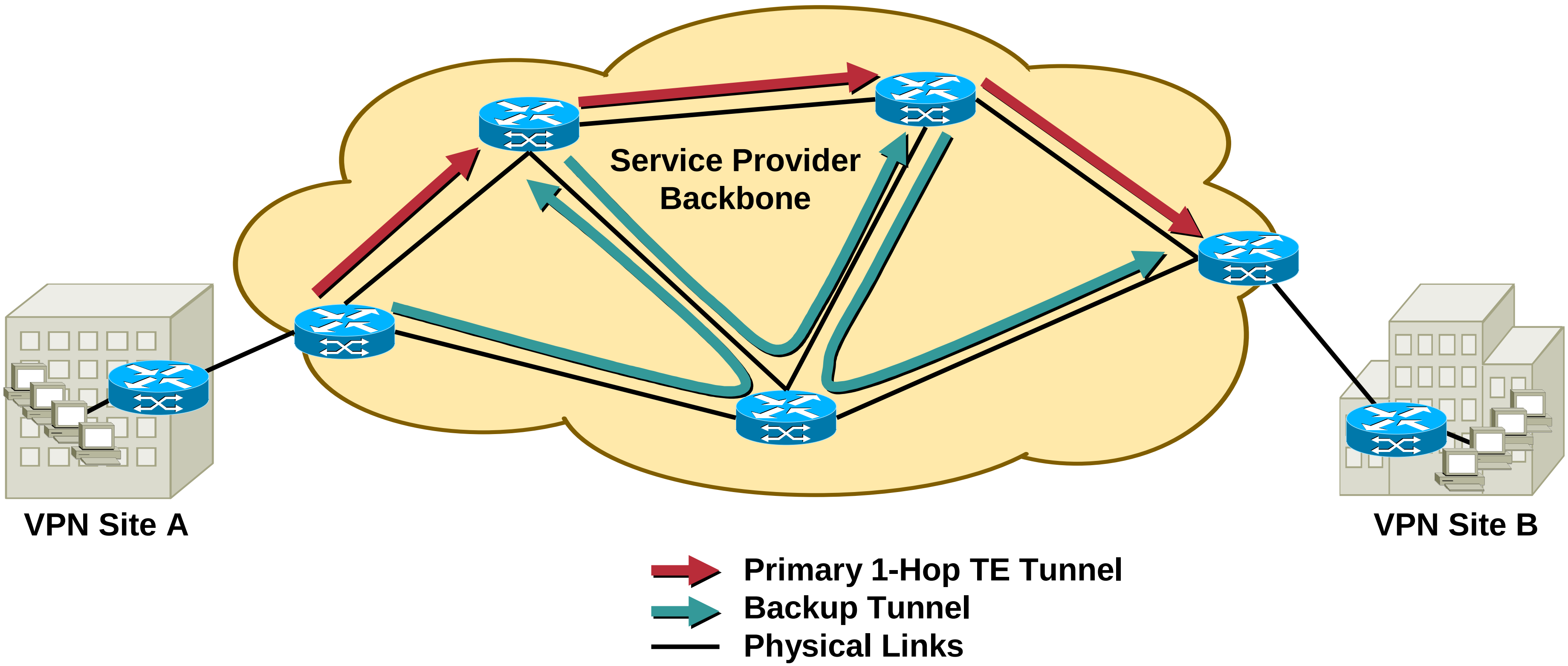


# 1-Hop TE Deployment



**Requirement:** Need protection only—minimize packet loss
Lots 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

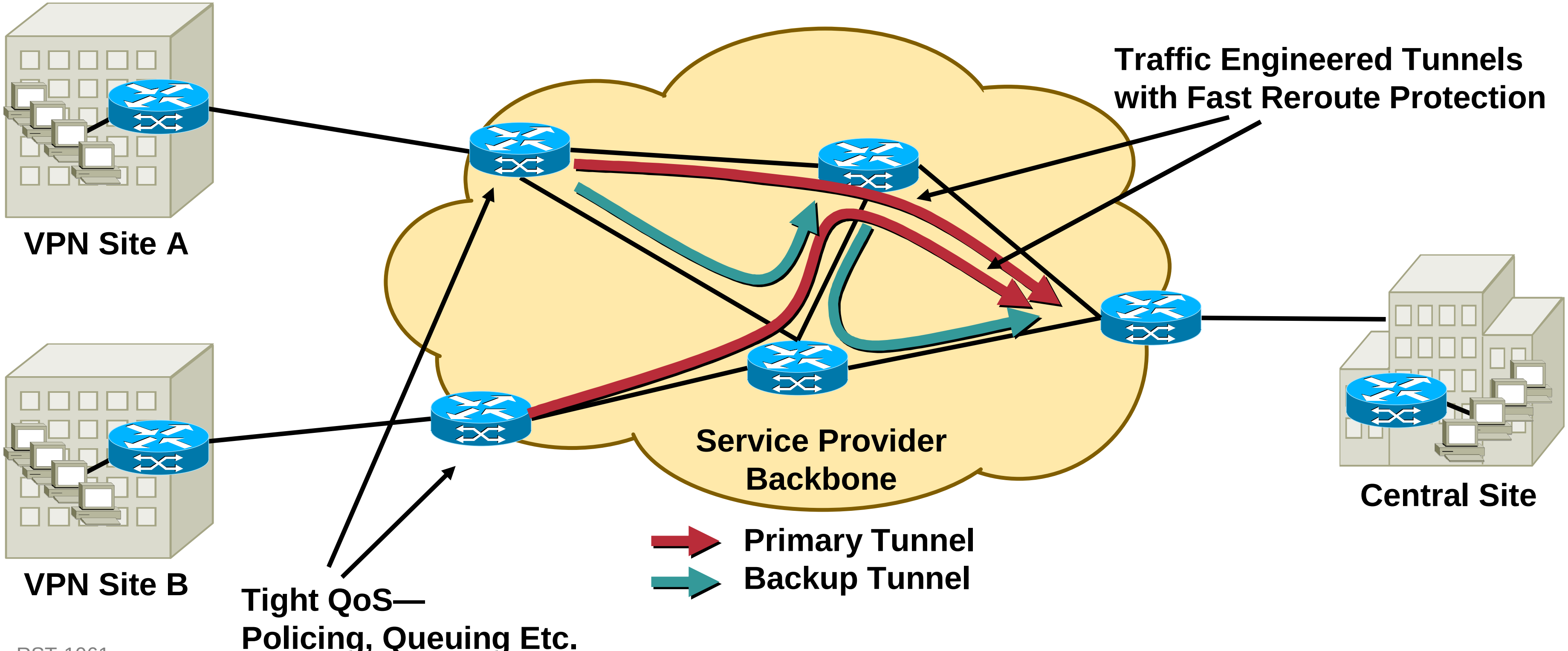


# Virtual Leased Line Deployment



**Requirement:** Need to create dedicated point-to-point circuits with bandwidth guarantees—Virtual Leased Line (VLL)

**Solution:** Deploy MPLS TE (or DS-TE) with QoS; Forward traffic from L3 VPN or L2 VPN into a TE Tunnel; Unlike ATM PVCs, use 1 TE Tunnel for multiple VPNs creating a scalable architecture



# MPLS TE Summary

Cisco.com

- **Useful for re-routing traffic in congested environments**
- **Build innovative services like Virtual Leased line**
- **Build protection solutions using MPLS FRR**

# MPLS and QoS



- IP QoS mechanisms are leveraged for MPLS
- IP Precedence bits copied into MPLS EXP field
- IP DSCP can be mapped to MPLS EXP
- WRED, queuing can be done on MPLS EXP
- DiffServ mechanisms provide similar per hop behavior with MPLS

# Configuring MPLS

Cisco.com

| | | |
|---|---|---|
| **Step 1** | Router# **configure terminal** | **Enables configuration mode** |
| **Step 2** | Router(config)# **ip cef** [**distributed**] | **Configures Cisco Express Forwarding** |
| **Step 3** | Router(config)# **interface** *interface* | **Specifies the interface to configure** |
| **Step 4** | Router(config-if)# **mpls ip** | **Configures MPLS hop-by-hop forwarding for a specified interface** |
| **Step 5** | Router(config-if)# **mpls label protocol ldp** | **Configures the use of LDP for a specific interface;**<br>**Sets the default label distribution protocol for the specified interface to be LDP, overriding any default set by the global mpls label protocol command** |
| **Step 6** | Router# **configure terminal**<br>Router(config)# **mpls label protocol ldp** | **Configures the use of LDP on all interfaces;**<br>**Sets the default label distribution protocol for all interfaces to be LDP** |

# Show Commands

Cisco.com

Router# **show mpls interfaces**
Interface IP Tunnel Operational
Ethernet1/1/1 Yes (tdp) No No
Ethernet1/1/2 Yes (tdp) Yes No
Ethernet1/1/3 Yes (tdp) Yes Yes
POS2/0/0 Yes (tdp) No No
ATM0/0.1 Yes (tdp) No No (ATM labels)
ATM3/0.1 Yes (ldp) No Yes (ATM labels)
ATM0/0.2 Yes (tdp) No Yes

Router# **show mpls ldp discovery**
Local LDP Identifier:
118.1.1.1:0
Discovery Sources:
Interfaces:
POS2/0 (ldp): xmit/recv
LDP Id: 155.0.0.55:0
Tunnel1 (ldp): Targeted -> 133.0.0.33
Targeted Hellos:
118.1.1.1 -> 133.0.0.33 (ldp): active, xmit/recv
LDP Id: 133.0.0.33:0
118.1.1.1 -> 168.7.0.16 (tdp): passive, xmit/recv
TDP Id: 168.7.0.16:0

**show mpls ip binding** [**vrf** ***vpn-name***] [***network*** {***mask*** **|**
***length***} [**longer-prefixes**]]
[**local-label** {**atm** vpi vci **|** label [**-** ***label***]}]
[**remote-label** {**atm** vpi *vci* **|** label [**-** ***label***]}]
[**neighbor** address] [**local**]
[**interface** interface] [**generic | atm**]
**show mpls ip binding summary**

Router# **show mpls ip binding 194.44.44.0 24**
194.44.44.0/24
in label: 24
in vc label: 1/37 lsr: 203.0.7.7:2 ATM1/0.8
Active egress (vcd 56)
out label: imp-null lsr: 155.0.0.55:0 inuse
Router#

# TE—Configuration



| | | |
|---|---|---|
| **Step 1** | Router(config-if)# **mpls traffic-eng tunnels** | **Enables MPLS traffic engineering tunnels on an interface** |
| **Step 2** | Router(config-if)# **ip rsvp bandwidth** bandwidth | **Enables RSVP for IP on an interface and specifies the amount of bandwidth that will be reserved;**<br>**For a description of the ip rsvp command syntax, see the *Quality of Service Solutions Command Reference*** |

| | | |
|---|---|---|
| **Step 1** | Router(config)# **router ospf** process-id | **Configures an OSPF routing process for IP; You are placed in router configuration mode;**<br>**The *process-id* is an internally used identification parameter for an OSPF routing process; It is locally assigned and can be any positive integer; Assign a unique value for each OSPF routing process** |
| **Step 2** | Router(config-router)# **mpls traffic-eng area 0** | **Turns on MPLS traffic engineering for OSPF area 0** |
| **Step 3** | Router(config-router)# **mpls traffic-eng router-id loopback0** | **Specifies that the traffic engineering router identifier for the node is the IP address associated with interface loopback0** |

**Show mpls traffic-eng ←>**

# Further Reading

Cisco.com

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

**MPLS and VPN Architectures—Jim Guichard, Ivan Papelnjak—Cisco Press**

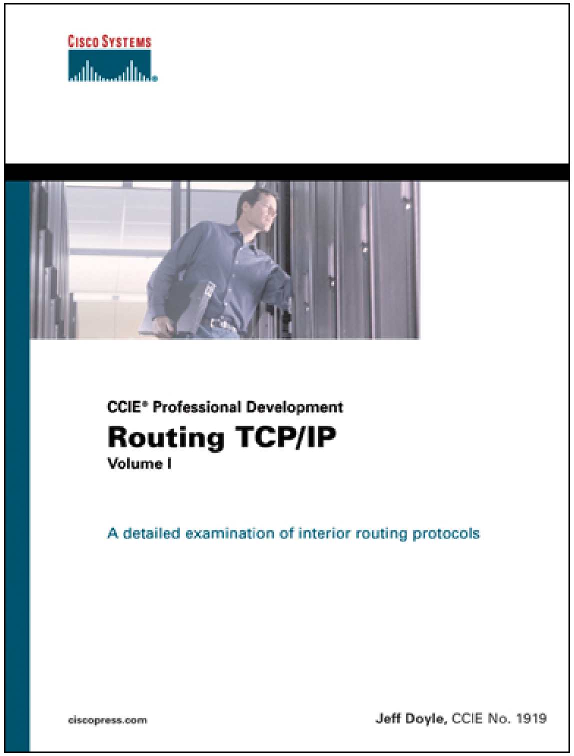
**Traffic Engineering with MPLS—Eric Osborne, Ajay Simha—Cisco Press**

# Recommended Reading

Cisco.com

**MPLS and VPN Architectures Vol I**
ISBN: 1587050021

**MPLS and VPN Architectures Vol II**
ISBN: 1587051125



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