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INTRODUCTION TO MPLS

SESSION RST-1601

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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**

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BACKGROUND

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Terminology

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- **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**
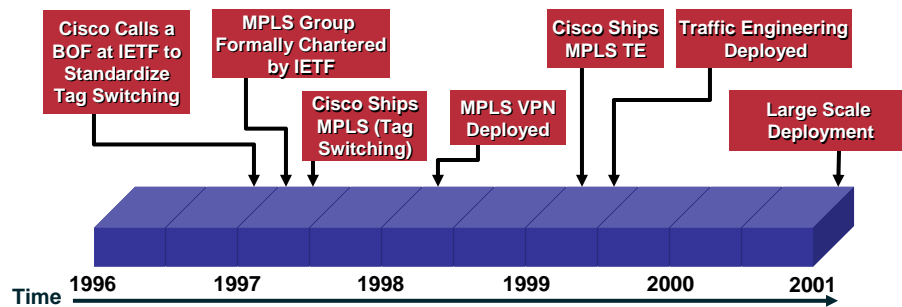
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Evolution of MPLS

- **From tag switching**

- **Proposed in IETF—later combined with other proposals from IBM (ARIS), Toshiba (CSR)**

Cisco Calls a BOF at IETF to Standardize Tag Switching

MPLS Group Formally Chartered by IETF

Cisco Ships MPLS (Tag Switching)

MPLS VPN Deployed

Cisco Ships MPLS TE

Traffic Engineering Deployed

Large Scale Deployment

Time   1996   1997   1998   1999   2000   2001

What Is MPLS?

- **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 on 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
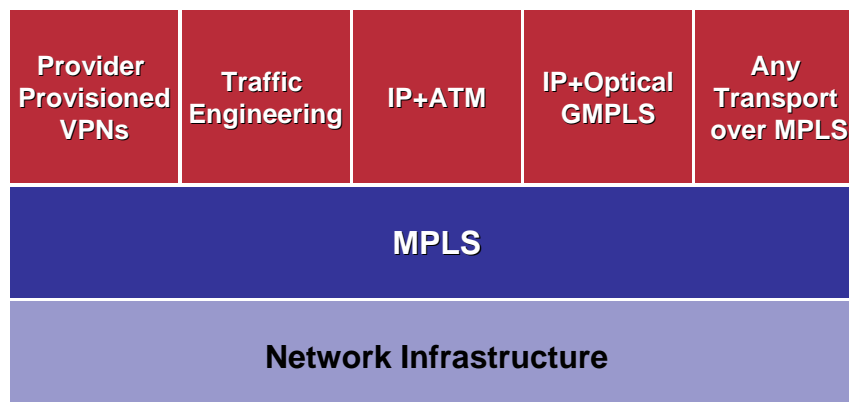
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MPLS as a Foundation for Value-Added Services

Provider Provisioned VPNs	Traffic Engineering	IP+ATM	IP+Optical GMPLS	Any Transport over MPLS

MPLS

Network Infrastructure

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TECHNOLOGY BASICS

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Label Header for Packet Media

```
0                   1                   2                   3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
```

| Label | EXP | S | TTL |
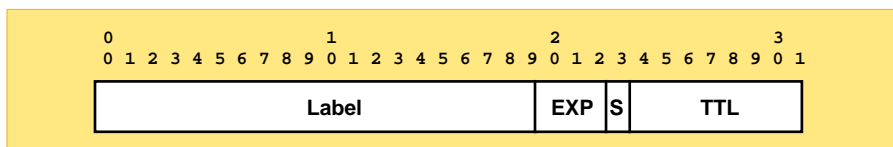
Label = 20 Bits
COS/EXP = Class of Service, 3 Bits
S = Bottom of Stack, 1 Bit
TTL = Time to Live, 8 Bits

- **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**

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Encapsulations

PPP Header
(Packet over SONET/SDH)

PPP Header	Label	Layer 2/L3 Packet

One or More Labels Appended to the Packet

LAN MAC Label Header

MAC Header	Label	Layer 2/L3 Packet

ATM MPLS Cell Header
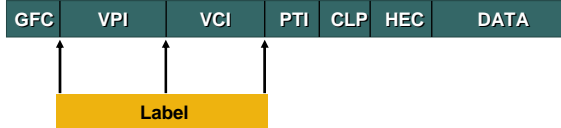
GFC	VPI	VCI	PTI	CLP	HEC	DATA

Label

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**

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MPLS Concepts

At Edge:
- Classify packets
- Label them
  Label Imposition

Edge Label
Switch Router
(ATM Switch or
Router)
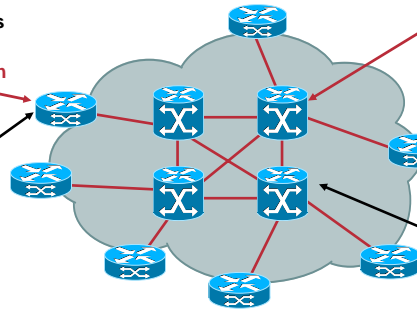
In Core:
- Forward using labels
  (as opposed to IP addr)
- Label indicates service class
  <u>and</u> destination
  Label Swapping or Switching

At Edge:
Remove Labels and
Forward Packets
Label Disposition

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

Label Distribution Protocol

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

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MPLS Operation

**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**
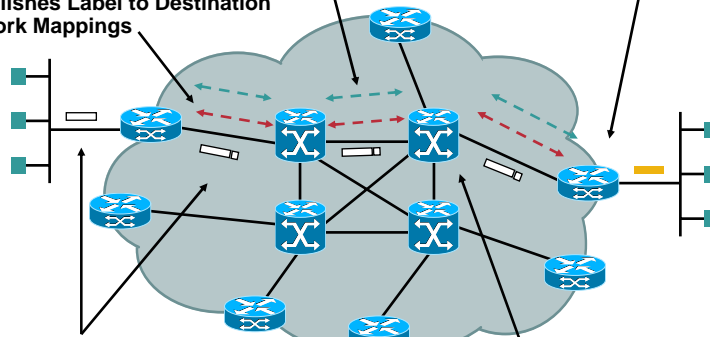
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**LABEL DISTRIBUTION
IN MPLS NETWORKS**

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Unicast Routing Protocols

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- **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

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Label Distribution Protocol

- **Defined in RFC 3035 and 3036**
- **Used to distribute labels in a MPLS network**
    - Uses a TCP session—multiple sessions require multiple TCP sessions
- **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**

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Router Example: Forwarding Packets

Address Prefix	I/F
128.89	1
171.69	1
…	

Address Prefix	I/F
128.89	0
171.69	1
…	

Address Prefix	I/F
128.89	0
171.69	1
…	

128.89

0

1

128.89.25.4 Data

128.89.25.4 Data

128.89.25.4 Data

128.89.25.4 Data

128.89.25.4 Data

171.69

Packets Forwarded Based on IP Address
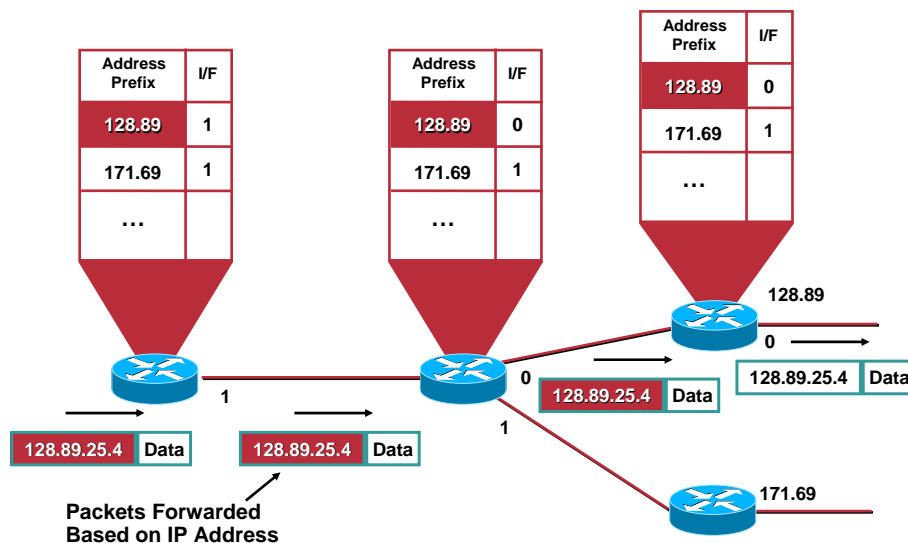
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MPLS Example: Routing Information

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	
	...	...	

You Can Reach 128.89 and 171.69 Thru Me

You Can Reach 128.89 Thru Me

Routing Updates (OSPF, EIGRP, …)

You Can Reach 171.69 Thru Me

171.69

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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	-
...	...	...	...

Use Label 4 for 128.89 and Use Label 5 for 171.69

Use Label 9 for 128.89

Label Distribution Protocol (LDP)
(Downstream Allocation)

Use Label 7 for 171.69

171.69

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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	-
...	...	...	...

0   128.89

128.89.25.4 | Data

1

9 | 128.89.25.4 | Data

128.89.25.4 | Data

4 | 128.89.25.4 | Data

1

Label Switch Forwards Based on Label

171.69

Label Distribution Modes

- **Downstream unsolicited**

   Downstream node just advertises labels for prefixes/FEC reachable via that device

   Previous example

- **Downstream on-demand**

   Upstream node requests a label for a learnt prefix via the downstream node
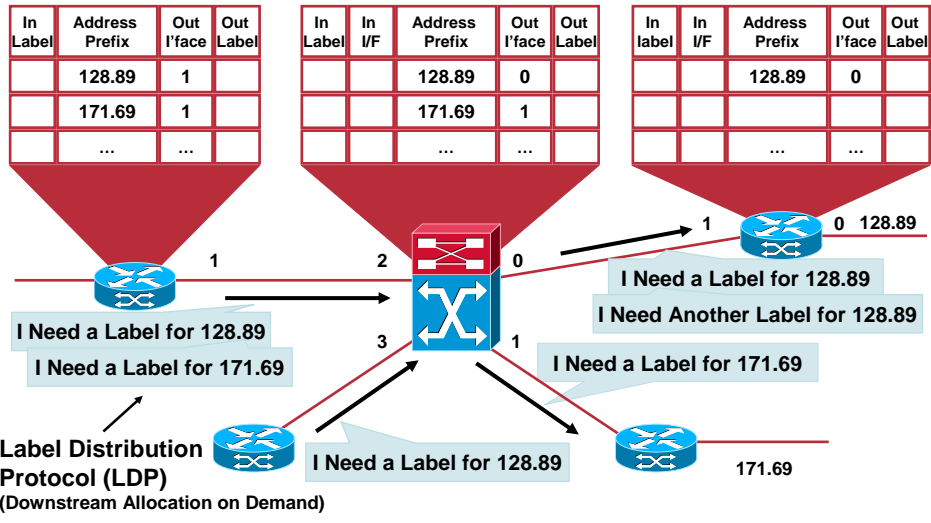
   Next example—ATM MPLS

ATM MPLS Example: Requesting Labels

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

In Label	In I/F	Address Prefix	Out I'face	Out Label
		128.89	0	
		171.69	1	
		...	...	

In label	In I/F	Address Prefix	Out I'face	Out Label
		128.89	0	
		...	...	

0 128.89

I Need a Label for 128.89
I Need Another Label for 128.89

I Need a Label for 128.89
I Need a Label for 171.69

I Need a Label for 171.69

Label Distribution Protocol (LDP)
(Downstream Allocation on Demand)

I Need a Label for 128.89

171.69

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ATM MPLS Example: Assigning Labels

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

In Label	In I/F	Address Prefix	Out I'face	Out Label
4	2	128.89	0	9
8	3	128.89	0	10
5	2	171.69	1	7

In label	In I/F	Address Prefix	Out I'face	Out Label
9	1	128.89	0	-
10	1	128.89	0	-
		...	...	

0 128.89

Use Label 9 for 128.89
Use Label 10 for 128.89

Use Label 4 for 128.89
Use Label 5 for 171.69

Use Label 7 for 171.69

Use Label 8 for 128.89

171.69
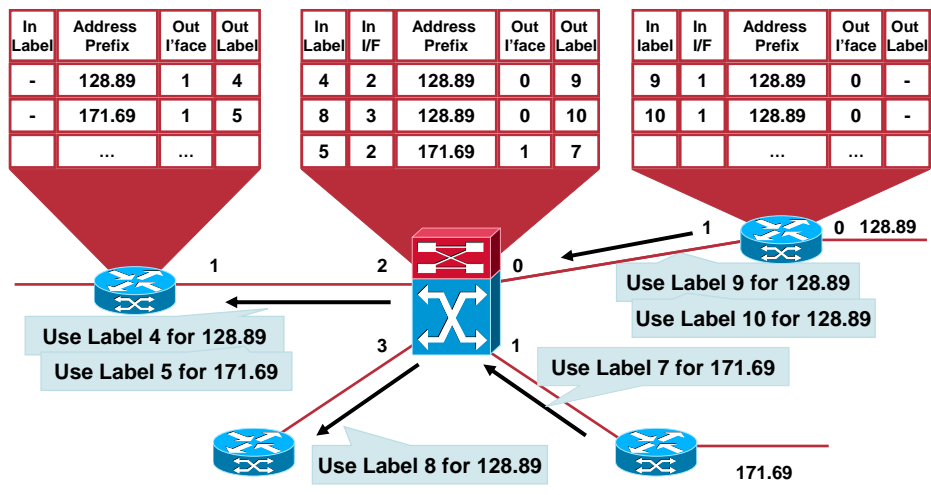
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ATM MPLS Example: Packet Forwarding

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

In Label	In I/F	Address Prefix	Out I'face	Out Label
4	**2**	**128.89**	0	9
8	3	128.89	0	10
5	2	171.69	1	7

In label	In I/F	Address Prefix	Out I'face	Out Label
9	1	**128.89**	0	-
10	1	128.89	0	-
		...	...	

1   **2**   **0**   **1**   **0 128.89**

128.89.25.4 Data

4 128.89.25.4 Data   **1**

9 128.89.25.4 Data

128.89.25.4 Data

171.69

Label Switch Forwards Based on Label
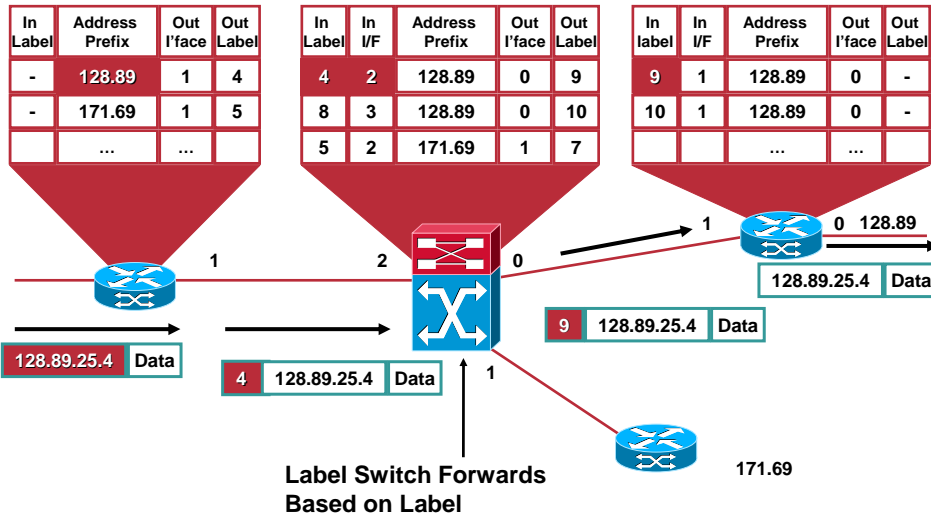
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Why Multiple Labels with ATM?

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If Didn't Allocate Multiple Labels:

- **Cells of different packets would have same label (VPI/VCI)**
- **Egress router can't reassemble packets**

In I/F	In Label	Address Prefix	Out I/F	Out Label
1	5	128.89	0	3
2	8	128.89	0	3
...	...	...	...	...

Cells

5 5 5 5

Packet   **1 0**   **Help!**

Packet   **8 8 8 8   2**   **3 3 3 3 3 3**   **128.89**

8 8 8
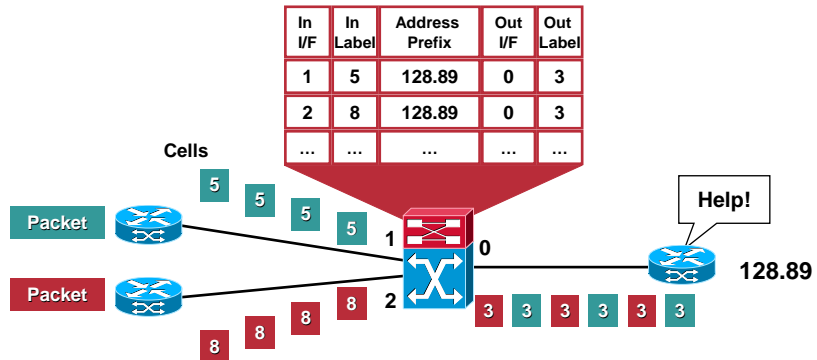
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Multiple Labels

**Multiple Labels Enables Edge Router
to Reassemble Packets Correctly**

In I/F	In Label	Address Prefix	Out I/F	Out Label
1	5	128.89	0	3
2	8	128.89	0	7
...	...	...	...	...

Cells

Packet

Packet

Much Better!

128.89
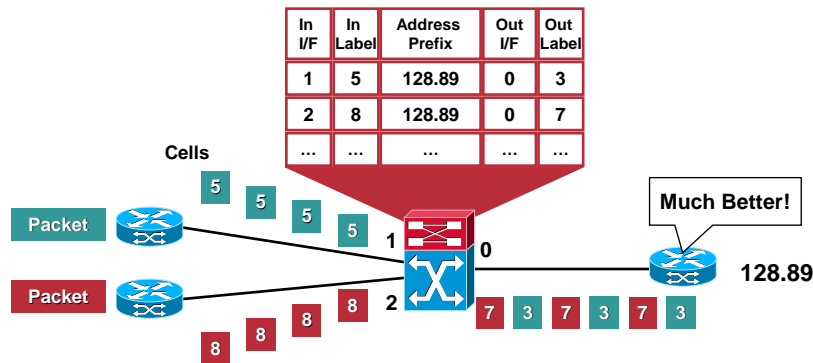
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Label Distribution Protocol

Label Merge

- **Done by default for packet networks—unique label advertised per FEC**

- **Requires VC merge for ATM networks**

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LDP: Label Merge

IGP—Equal Cost Multipath

Prefix 129.161/16
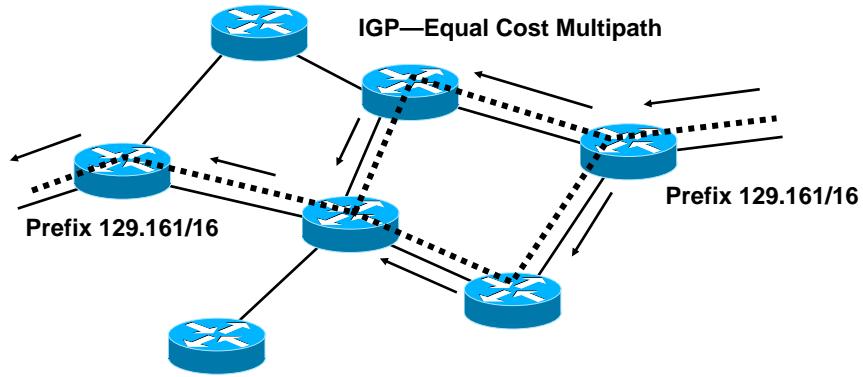
Prefix 129.161/16

Labels for Prefix 129.161 Are Advertised Along Both Paths

VC Merge

With ATM Switch that Can Merge VC's:

- **Can reuse outgoing label**
- **Hardware prevents cell interleave**
- **Fewer labels required**
- **For very large networks**

In I/F	In Label	Address Prefix	Out I/F	Out Label
1	5	128.89	0	3
2	8	128.89	0	3
...	...	...	...	...

Cells

Packet 5 5 5 5 **1** **0**

Packet 8 8 8 8 **2** 3 3 3 3 3 3

8 8 8

128.89
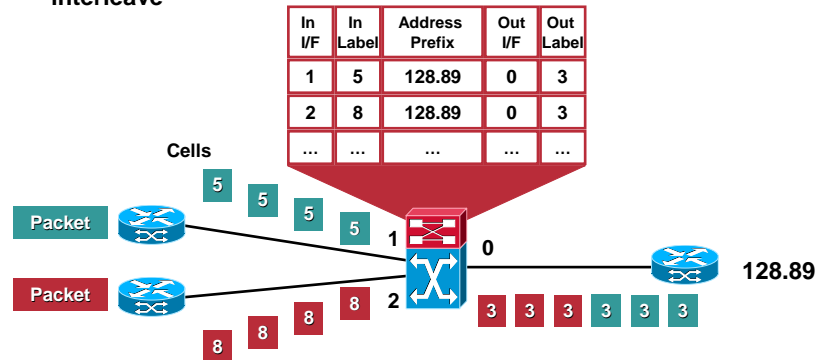
Label Retention Modes

- **In downstream unsolicited mode—label mapping advertisements are received for all routes from all peers**

- **Liberal label retention**

  These mappings are retained regardless of whether the LSR is the next hop for the advertised mapping

  Once Labels are allocated to a prefix these labels are retained

  Reaction to routing changes is fast

- **Conservative label retention**

  Used with DOD mode

  Label mappings are retained only if they are used to forward packets

  Can save some label space—however, reacts slower to changes

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Label Allocation Modes

- **Independent mode**

  Labels are allocated independently of neighbors' bindings

  As long as the router has routes—it allocates a label irrespective of the neighbor

- **Ordered mode**

  Labels are allocated only after the bindings from neighbors are received

  Takes care of propagation delays in routing changes

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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

- **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

- **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**

Destination-Based Unicast Routing	IP Class of Service	Resource Reservation (e.g., RSVP)	Multicast Routing (PIM v2)	Explicit and Static Routes	Virtual Private Networks
Label Information Base (LIB)					
Per-Label Forwarding, Queuing, and Multicast Mechanisms					

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Control and Forward Plane Separation
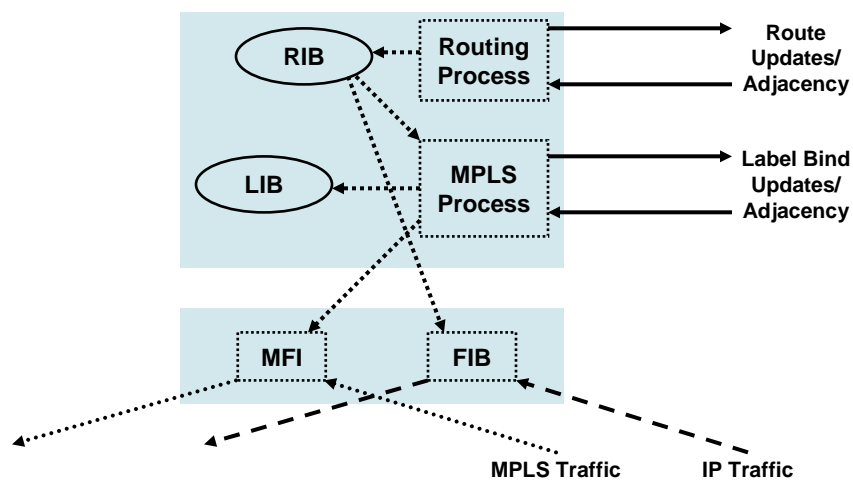
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Label Stacking

- **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 reroute**
- **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**

Outer Label

| TE Label |
| LDP Label |
| VPN Label |
| IP Header |

Inner Label
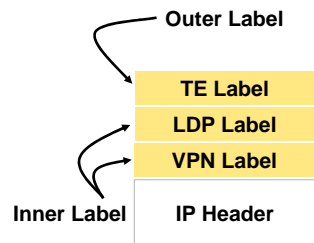
MPLS VPNS
LAYER 2 AND LAYER 3

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What Is a VPN?

- **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

- **Layer 2 VPNs**
  - **Customer endpoints (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 endpoints**
  - **Multiple logical connections (one with each endpoint)**
- **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**

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LAYER 3 VPNS

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Service Provider Benefits of MPLS-Based VPNs

VPN B VPN A

VPN C VPN C

VPN B

VPN A

VPN A

VPN B

VPN C VPN C

VPN A VPN B

Multicast

Intranet

Hosting

VoIP

Extranet
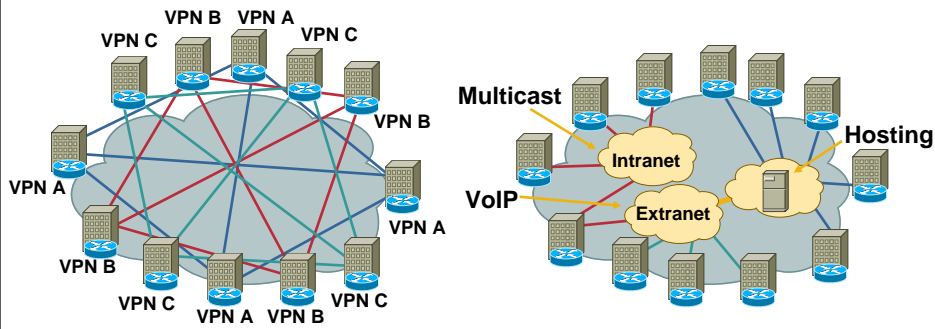
Overlay VPN

- 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

Cust A

A   A   Cust A

B   Cust A

B

Cust B   MPLS
                Network   Cust B
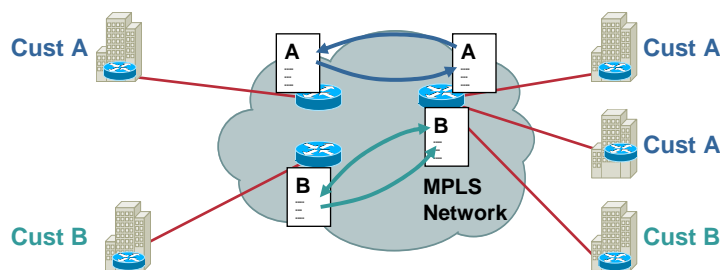
- **The network distributes labels to each VPN**
  - Only labels for other VPN members are distributed
  - Each VPN is provisioned automatically by IP routing
- **Privacy and QoS of ATM without tunnels or encryption**
  - Each **network** is as secure as a Frame Relay **connection**
- **One mechanism (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

CE

CE

VRF

iBGP—VPNv4 Label Exchange

VRF

CE

PE

LDP

LDP

LDP

PE

iBGP—VPNv4

iBGP—VPNv4

CE

CE

PE

VRF

CE

Overlapping Addresses Are Made Unique by Appending RD and Creating VPNv4 Addresses

Control Plane Path

No Direct Peering Between CEs

VPN A ←—————————— ✕ ——————————→ VPN A

←————————— **Routing Relationship** —————————→

CE

IPv4 Route Exchange

PE   **P**   **P**   **PE**   **CE**

VPNv4 Routes Advertised via BGP
Labels Exchanged via BGP
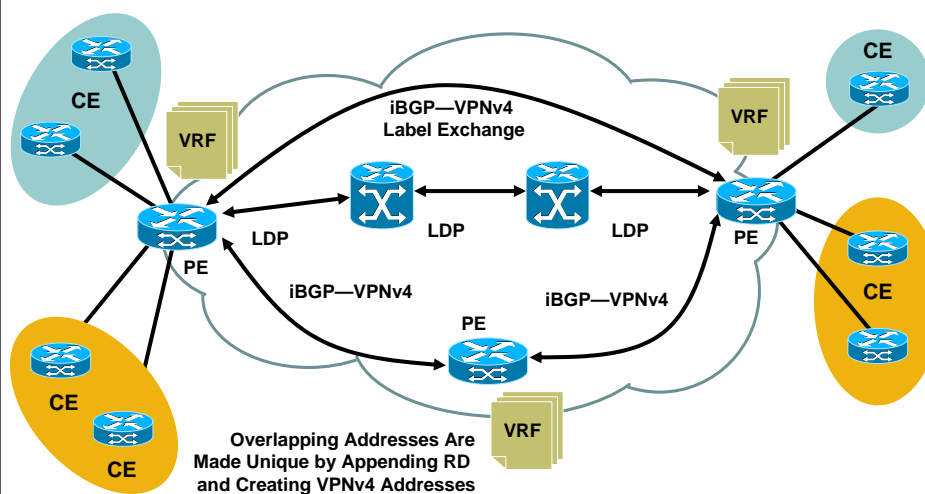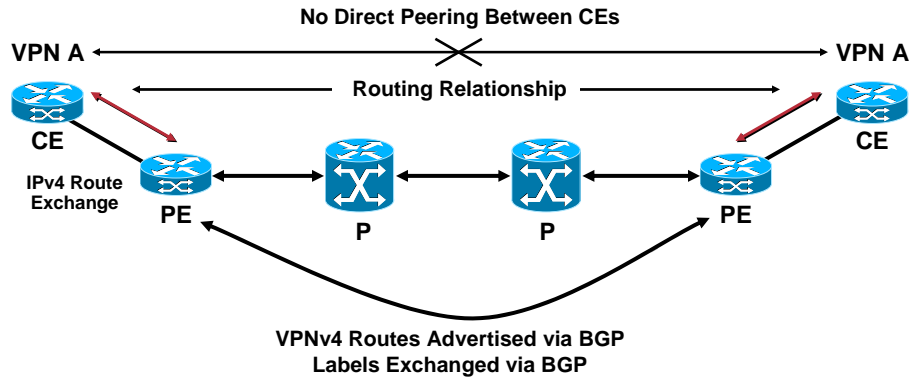
- RD—8 Byte field—assigned by provider—significant to the provider network only
- VPNv4 Address: RD+VPN Prefix
- Unique RD per VPN makes the VPNv4 address unique

Data Plane Path

Routing Relationship

VPN A   VPN A

CE

| IPv4 |

IPv4 Forwarded Packet

PE   **PE**   **CE**

| IPv4 |

| IPv4 |

Vpnv4 Routes Advertised via BGP
Labels Exchanged via BGP

| IPv4 |
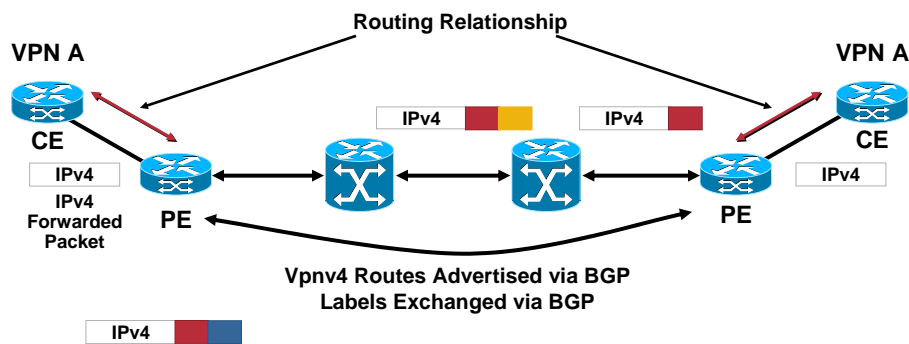
- **Ingress PE is imposing 2 labels**

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**
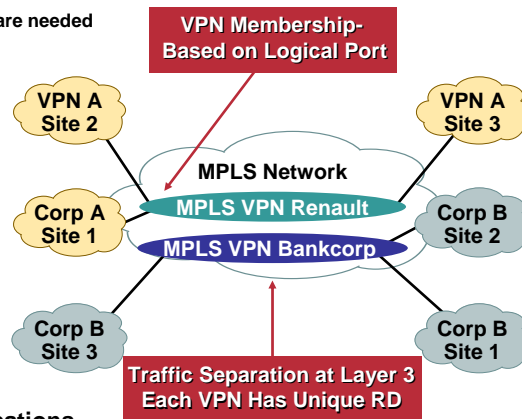
VPN Membership-Based on Logical Port

VPN A Site 2   **VPN A Site 3**

MPLS Network

Corp A Site 1   **MPLS VPN Renault**   **Corp B Site 2**

MPLS VPN Bankcorp

Corp B Site 3   **Corp B Site 1**

Traffic Separation at Layer 3 Each VPN Has Unique RD

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Key Features

- **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

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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.)

- **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

Attachment Circuit
Ethernet VLAN, FR DLCI, ATM VC, PPP Session

VPN A

CE

VPN A

CE

PE

PE

Emulated VC/Pseudowire
Labels Exchanged via Directed LDP
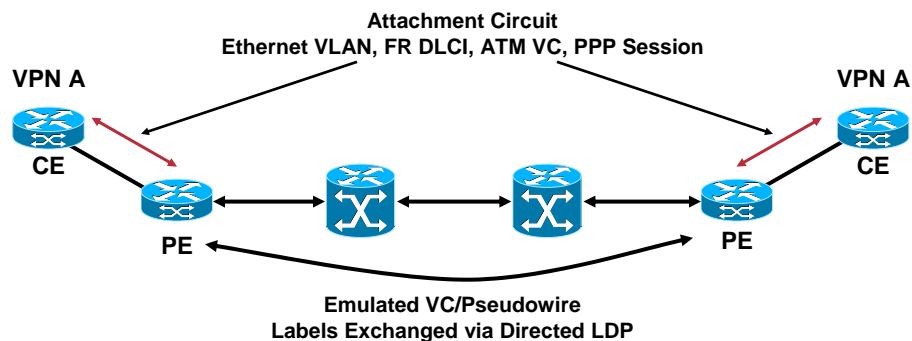
Frame Relay over MPLS: Example

VC1—Connects DLCI 101 to DLCI 201
VC2—Connects DLCI 102 to DLCI 202
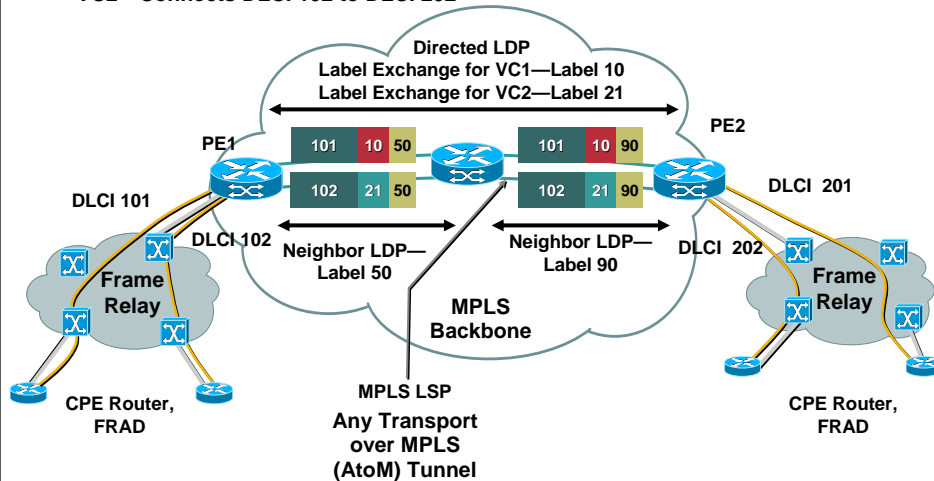
Directed LDP
Label Exchange for VC1—Label 10
Label Exchange for VC2—Label 21

PE1

| 101 | 10 | 50 |
| 102 | 21 | 50 |

| 101 | 10 | 90 |
| 102 | 21 | 90 |

PE2

DLCI 101

DLCI 201

DLCI 102

Neighbor LDP— Label 50

Neighbor LDP— Label 90

DLCI 202

MPLS Backbone

Frame Relay

Frame Relay

CPE Router, FRAD

MPLS LSP

Any Transport over MPLS (AtoM) Tunnel

CPE Router, FRAD

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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**

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MPLS TRAFFIC ENGINEERING

What Is MPLS Traffic Engineering?

Cisco.com

- **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?

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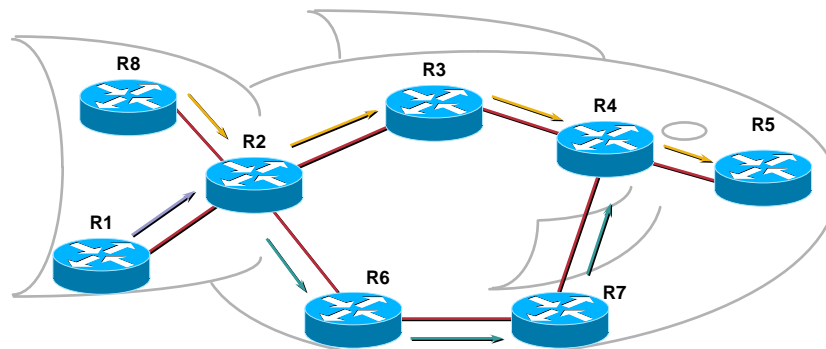
IP (Mostly) Uses Destination-Based Least-Cost Routing
Flows from R8 and R1 Merge at R2 and Become Indistinguishable
From R2, Traffic to R3, R4, R5 Use Upper Route

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**

Router B
Router F
OC-3
OC-3
35Mb Drops!
Router E
Router A
DS3
80Mb Traffic
Router G
OC-3
OC-3
Router C
DS3
Router D
DS3
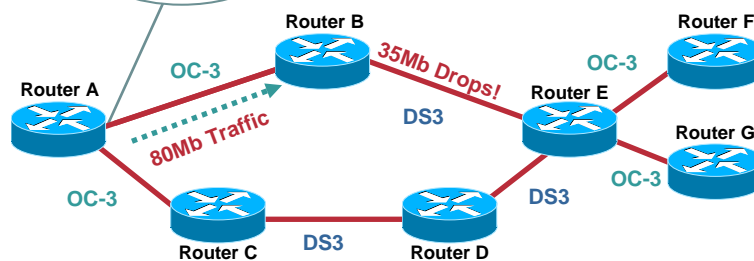
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How MPLS TE Solves the Problem

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!**

Router B
Router F
OC-3
OC-3
Router E
Router A
DS3
40Mb
Router G
OC-3
OC-3
40Mb
Router C
DS3
Router D
DS3
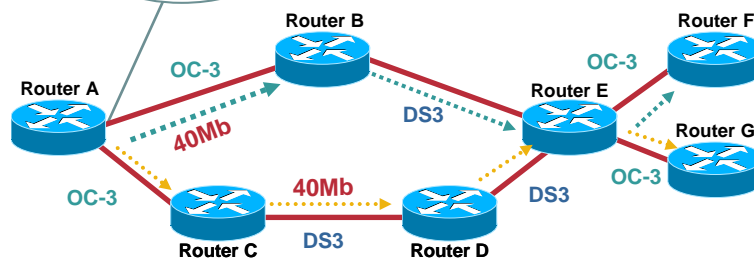
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TE Fundamentals: "Building Blocks"

Path Calculation—Uses IGP Advertisements to Compute "Constrained" Paths

IGP (OSPF or ISIS) Used to Flood Bandwidth Information Between Routers

RSVP/TE Used to Distribute Labels, Provide CAC, Failure Notification, etc.
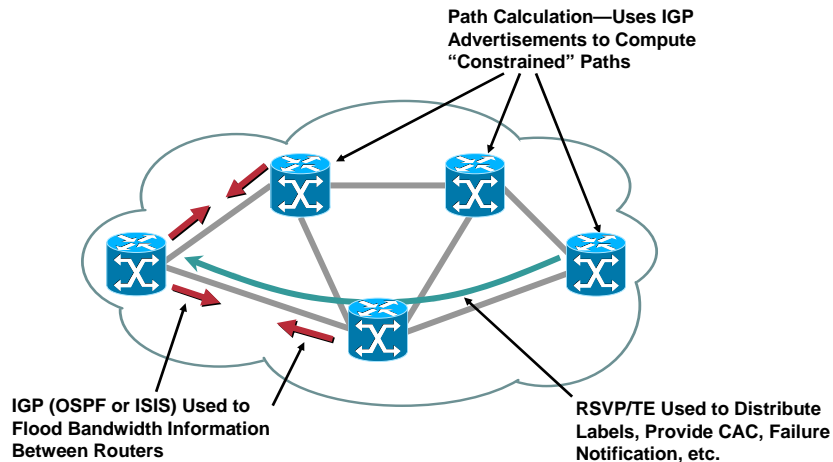
Information Distribution

- **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.**

Example

RESV

RESV

RESV

PATH

PATH

PATH

TE Headend

TE Tail End
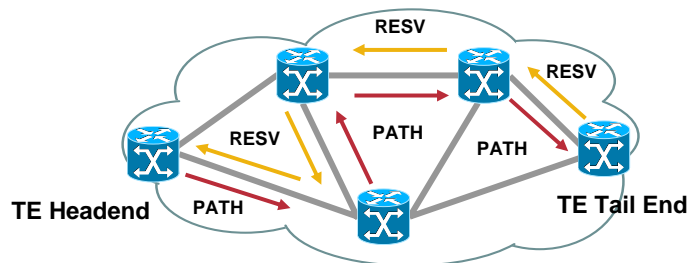
- **PATH messages are sent with requested bandwidth**
- **RESV messages are sent with label bindings for the TE tunnel**
- **Tunnels can be explicitly routes**
- **Admission control at each hop to see if the bandwidth requirement can be met**

- **Packets are mapped to the tunnel via**
  - **Static routed**
  - **Autoroute**
  - **Policy route**
- **Packets follow the tunnel—LSP**

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Benefits of TE over Policy Routing

- **Policy Routing**

  Hop-by-hop decision making

  No accounting of bandwidth

- **Traffic Engineering**

  Headend-based

  Accounts for available link bandwidth

  Admission control

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Applications of MPLS TE:
MPLS Fast Reroute

R8

R3

R9

R2

R4

R1

R5

R6

R7
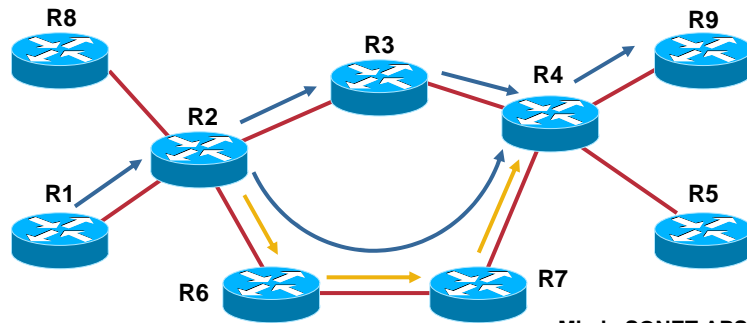
Mimic SONET APS
Reroute in 50ms or Less

- **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**

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Link Protection

Router A   Router B   Router D   Router E

Router X   Router Y

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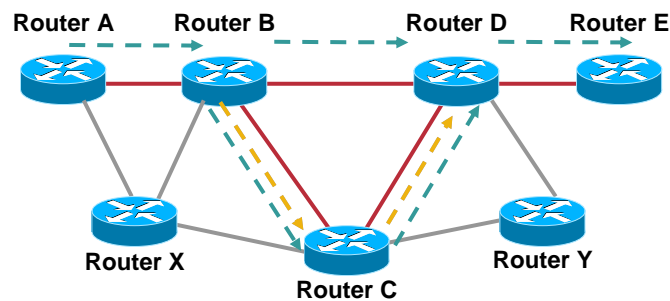
- **Primary tunnel: A -> B -> D -> E**
- **Backup tunnel: B -> C -> D (preprovisioned)**
- **Recovery = ~50ms**

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

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Node Protection

Router A   Router B   Router D   Router E   Router F

Router X

Router C

Router Y
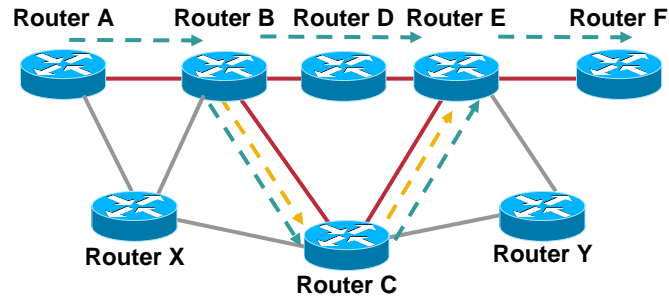
- Primary tunnel: A -> B -> D -> E -> F
- Backup tunnel: B -> C -> E (pre-provisioned)
- Recovery = ~100ms

TE DEPLOYMENT SCENARIOS

Tactical TE Deployment

Requirement: Need to Handle Scattered Congestion Points in the Network

Solution: **Deploy MPLS TE on Only Those Nodes That Face Congestion**

MPLS Traffic Engineering
Tunnel Relieves Congestion Points

Bulk of Traffic Flow
Eg. Internet Download

Service Provider
Backbone

Internet

Oversubscribed
Shortest Links
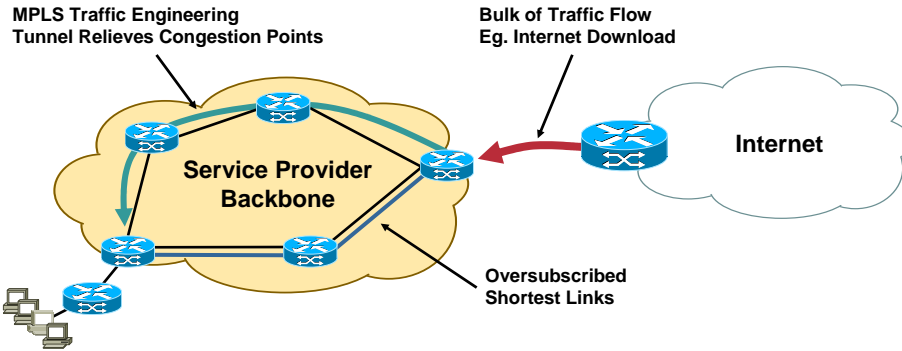
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Full Mesh TE Deployment

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**

Service Provider
Backbone

VPN Site A

VPN Site B

Partial Mesh of
Physical Connections

Full Mesh of MPLS
Traffic Engineering Tunnels

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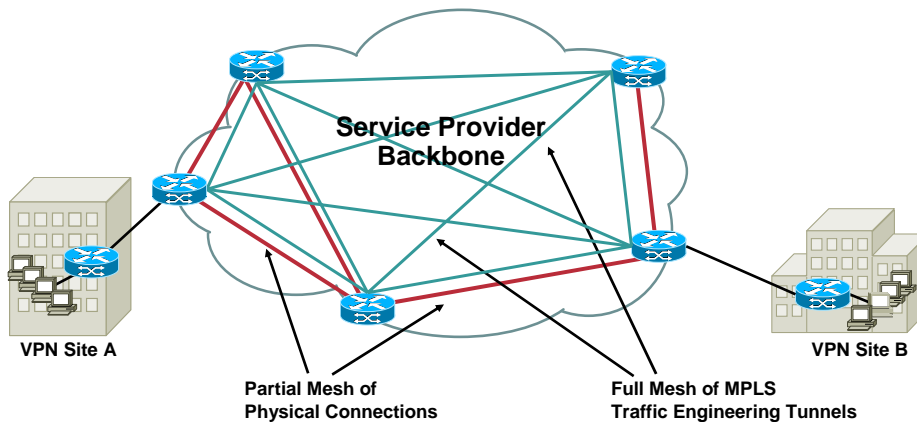
1-Hop TE Deployment

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

**Service Provider
Backbone**

VPN Site A

VPN Site B

→ Primary 1-Hop TE Tunnel
→ Backup Tunnel
— Physical Links
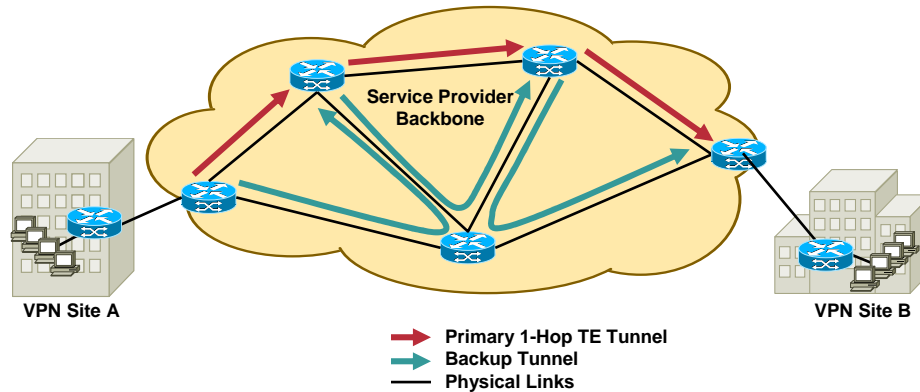
Virtual Leased Line Deployment

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
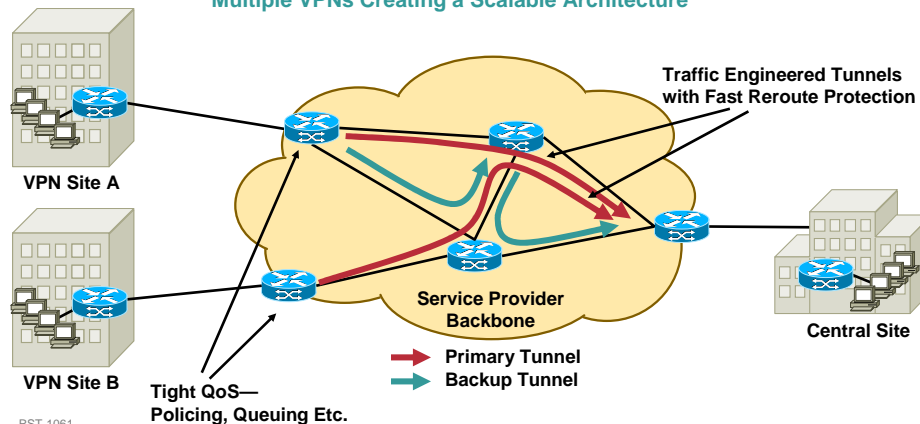
VPN Site A

**Traffic Engineered Tunnels
with Fast Reroute Protection**

VPN Site B

**Service Provider
Backbone**

Central Site

**Tight QoS—
Policing, Queuing Etc.**

→ Primary Tunnel
→ Backup Tunnel

MPLS TE Summary

- **Useful for rerouting traffic in congested environments**
- **Build innovative services like virtual leased line**
- **Build protection solutions using MPLS FRR**

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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**

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Configuring MPLS

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; 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` `Router(config)# mpls label protocol ldp`	**Configures the Use of LDP on All Interfaces; Sets the Default Label Distribution Protocol for All Interfaces To Be LDP**

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Show Commands

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#

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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; 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; 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 ←>

SUMMARY

MPLS: The Key Technology for L2 and L3 Service Delivery

ATM Services **IP Services**

IP

PNNI **MPLS**

IP+ATM Switch
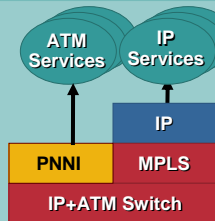
IP+ATM: MPLS Brings IP and ATM Together
- Eliminates IP "over" ATM overhead and complexity
- One network for Internet, Business IP VPNs, and transport
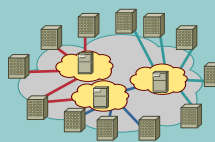
Network-Based VPNs with MPLS: a Foundation for Value-Added Service Delivery
- Flexible user and service grouping (biz-to-biz)
- Flexibility of IP and the QoS and privacy of ATM
- Enables application and content hosting inside each VPN
- Transport independent
- Low provisioning costs enable affordable managed services

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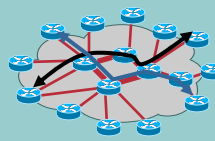# MPLS: The Key Technology for L2 and L3 Service Delivery
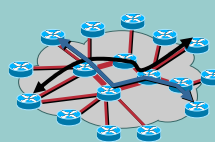
MPLS Traffic Engineering
- Provides Routing on diverse paths to avoid congestion
- Better utilization of the network
- Better availability using Protection Solution (FRR)

Guaranteed Bandwidth Services
- Combine MPLS Traffic Engineering and QoS
- Deliver Point-to-point bandwidth guaranteed pipes
- Leverage the capability of Traffic Engineering
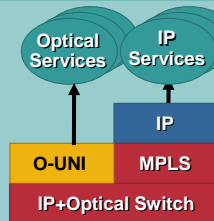- Build Solution like Virtual leased line and Toll Trunking

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MPLS: The Key Technology for IP Service Delivery

Optical Services | **IP Services**

IP

O-UNI | **MPLS**

IP+Optical Switch

IP+Optical Integration
- Eliminates IP "over" Optical Complexity
- Uses MPLS as a control Plane for setting up lightpaths (wavelengths)
- One control plane for Internet, Business IP VPNs, and optical transport

Frame Relay | **Frame Relay**

ATM
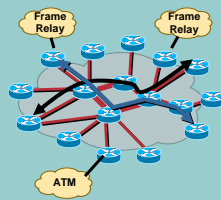
Any Transport over MPLS
- Transport ATM, FR, Ethernet, PPP over MPLS
- Provide Services to existing installed base
- Protect Investment in the installed gear
- Leverage capabilities of the packet core
- Combine with other packet based services such as MPLS VPNs

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Further Reading

- **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**

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WHAT: Complete an online session evaluation and your name will be entered into a daily drawing

WHY: Win fabulous prizes! Give us your feedback!

WHERE: Go to the Internet stations located throughout the Convention Center

HOW: Winners will be posted on the onsite Networkers Website; four winners per day

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