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Your Time Is Now
Introduction to MPLS

BRKMPL-1100

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Session Goals

Objectives

• Understand history and business drivers for MPLS
• Learn about MPLS customer and market segments
• Understand the problems MPLS is addressing
• Understand the major MPLS technology components
• Understand typical MPLS applications
• Understand benefits of deploying MPLS
• Learn about MPLS futures; where MPLS is going
Agenda

• Introduction
• MPLS Technology Basics
• MPLS Layer-3 VPNs
• MPLS Layer-2 VPNs
• Advanced Topics
• Summary
Introduction
## What Is MPLS?

<table>
<thead>
<tr>
<th>Multi</th>
<th>Multi-Protocol: The ability to carry any payload</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Have: IPv4, IPv6, Ethernet, ATM, FR</td>
</tr>
<tr>
<td>Protocol</td>
<td></td>
</tr>
<tr>
<td>Label</td>
<td>Uses Labels to tell a node what to do with a packet; separates forwarding (hop by hop behavior) from routing (control plane)</td>
</tr>
<tr>
<td>Switching</td>
<td>Routing == IPv4 or IPv6 lookup. Everything else is Switching.</td>
</tr>
</tbody>
</table>
What is MPLS?

Brief Summary

• 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

Technology Evolution and Main Growth Areas

- 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
MPLS Technology Basics
Topics

Basics of MPLS Signaling and Forwarding

- MPLS reference architecture
- MPLS Labels
- MPLS signaling and forwarding operations
- MPLS Traffic Engineering
- MPLS OAM
MPLS Reference Architecture

Different Type of Nodes in a MPLS Network

- P (Provider) router
  - Label switching router (LSR)
  - Switches MPLS-labeled packets

- PE (Provider Edge) router
  - Label edge router (LER)
  - Imposes and removes MPLS labels

- CE (Customer Edge) router
  - Connects customer network to MPLS network
MPLS Labels

Label Definition and Encapsulation

- Labels used for making forwarding decision

- Multiple labels can be used for MPLS packet encapsulation
  - No limit on the number of labels in a stack

- Outer label always used for switching MPLS packets in network

- Inner labels usually used for services (e.g. L2/L3 VPN)

MPLS Label Stack Entry

- Label = 20 bits
- TC = Traffic Class: 3 Bits; S = Bottom of Stack; TTL = Time to Live

MPLS Label Stack (1 label)

MPLS Label Stack (2 labels)
MPLS QoS

QoS Marking in MPLS Labels

• MPLS label has 3 Traffic Class (TC) bits

• Used for packet classification and prioritization
  • Similar to Type of Service (ToS) field in IP packet (DSCP values)

• DSCP values of IP packet mapped into TC bits of MPLS label
  • At ingress PE router

• Most providers have defined 3–5 service classes (TC values)

• Different DSCP <-> TC mapping schemes possible
  • Uniform mode, pipe mode, and short pipe mode
Basic MPLS Forwarding Operations

How Labels Are Being Used to Establish End-to-end Connectivity

• Label imposition (Push)
  • By ingress PE router; classify and label packets
  • Based on Forwarding Equivalence Class (FEC)

• Label swapping
  • 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
MPLS Path (LSP) Setup and Traffic Forwarding

MPLS Traffic Forwarding and MPLS Path (LSP) Setup

- **LSP signaling protocols**
  - Either LDP* or RSVP
  - Leverages IP routing
  - Routing table (Routing Information Base – RIB)

- **Exchange of labels**
  - Label bindings
  - Downstream MPLS node advertises what label to use to send traffic to node

- **MPLS forwarding**
  - MPLS Forwarding table (Forwarding Information Base – FIB)

<table>
<thead>
<tr>
<th></th>
<th>IP</th>
<th>MPLS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forwarding</strong></td>
<td>Destination address based</td>
<td>Label based Forwarding table learned</td>
</tr>
<tr>
<td></td>
<td>Forwarding table learned from control</td>
<td>from control plane</td>
</tr>
<tr>
<td></td>
<td>plane</td>
<td>TTL support</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Control Plane</strong></td>
<td>OSPF, IS-IS, BGP</td>
<td>LDP, RSVP, BGP, OSPF, IS-IS</td>
</tr>
<tr>
<td><strong>Packet Encapsulation</strong></td>
<td>IP Header</td>
<td>One or more labels</td>
</tr>
<tr>
<td><strong>QoS</strong></td>
<td>8 bit TOS field in IP header</td>
<td>3 bit TC field in label</td>
</tr>
<tr>
<td><strong>OAM</strong></td>
<td>IP ping, traceroute</td>
<td>MPLS OAM</td>
</tr>
</tbody>
</table>

(*) LDP signaling assumed for next the examples
MPLS Path (LSP) Setup

Signaling Options

- LDP signaling
  - Leverages existing routing
- RSVP signaling
  - Aka MPLS RSVP / TE
  - Enables enhanced capabilities, such as Fast ReRoute (FRR)
- Can use both protocols simultaneously
  - They work differently, they solve different problems
  - Dual-protocol deployments are very common

<table>
<thead>
<tr>
<th></th>
<th>LDP</th>
<th>RSVP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forwarding path</strong></td>
<td>LSP</td>
<td>LSP or TE Tunnel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Primary and, optionally, backup</td>
</tr>
<tr>
<td><strong>Forwarding Calculation</strong></td>
<td>Based on IP routing database</td>
<td>Based on TE topology database</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shortest-Path based</td>
</tr>
<tr>
<td><strong>Packet Encapsulation</strong></td>
<td>Single label</td>
<td>One or two labels</td>
</tr>
<tr>
<td><strong>Signaling</strong></td>
<td>By each node independently</td>
<td>Initiated by head-end node towards tail-end node</td>
</tr>
<tr>
<td></td>
<td>Uses existing routing protocols/information</td>
<td>Uses routing protocol extensions/information</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supports bandwidth reservation</td>
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<tr>
<td></td>
<td></td>
<td>Supports link/node protection</td>
</tr>
</tbody>
</table>
MPLS Path (LSP) Setup with LDP

Step 1: IP Routing (IGP) Convergence

- Exchange of IP routes
  - OSPF, IS-IS, EIGRP, etc.
- Establish IP reachability

<table>
<thead>
<tr>
<th>In Label</th>
<th>Address Prefix</th>
<th>Out Label</th>
<th>Out I'face</th>
</tr>
</thead>
<tbody>
<tr>
<td>128.89</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>171.69</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Routing Updates (OSPF, EIGRP, ...)

You Can Reach 128.89 and 171.69 Thru Me

You Can Reach 128.89 Thru Me

You Can Reach 171.69 Thru Me
IP Packet Forwarding Example

Basic IP Packet Forwarding

- IP routing information exchanged between nodes
  - Via IGP (e.g., OSFP, IS-IS)
- Packets being forwarded based on destination IP address
  - Lookup in routing table (RIB)
MPLS Path (LSP) Setup with LDP

Step 2: Assignment of Remote Labels

- Local label mapping are sent to connected nodes
- Receiving nodes update forwarding table
  - Out label
- LDP label advertisement happens in parallel (downstream unsolicited)
MPLS Traffic Forwarding with LDP

Hop-by-hop Traffic Forwarding Using Labels

- Ingress PE node adds label to packet (push)
  - Via forwarding table
- Downstream node use label for forwarding decision (swap)
  - Outgoing interface
  - Out label
- Egress PE removes label and forwards original packet (pop)
MPLS Traffic Forwarding with LDP

Quick recap

- Routing protocol distributes routes
- LDP distributes labels that map to routes
- Packets are forwarded using labels
- ...

- So what?
- ...

- MPLS’s benefit shows up later, in two places:
  - Divergence from IP routed shortest path
  - Payload-independent tunneling
MPLS Path (RSVP) Setup

- MPLS-TE lets you deviate from the IGP shortest-cost path
- This gives you lots of flexibility around how you send traffic across your network
- Three steps:
  - Information distribution
  - Path calculation
  - LSP signaling
MPLS Path (RSVP) Setup

• Flood link characteristics in the IGP
  • Reservable bandwidth, link colors, other properties
MPLS Path (RSVP) Setup

• IGP: Find shortest (lowest cost) path to all nodes

• TE: Per node, find the shortest (lowest cost) path which meets constraints
MPLS Path (RSVP) Setup

- Set up the calculated path using RSVP (Resource ReSerVation Protocol)

- Once labels are learned, they’re programmed just like LDP labels
  - At the forwarding level, you can’t tell whether your label came from RSVP or LDP
  - All the hard work is in the control plane
  - No per-packet forwarding hit for any of this
MPLS TE Fast ReRoute (FRR)

Implementing Network Failure Protection Using MPLS RSVP/TE

- Steady state
  - Primary tunnel:
    - A → B → D → E
  - Backup tunnel:
    - B → C → D (pre-provisioned)

- Failure of link between router B and D

- Traffic rerouted over backup tunnel

- Recovery time 50 ms
  - Actual Time Varies—Well Below 50 ms in Lab Tests
MPLS OAM

Tools for Reactive and Proactive Trouble Shooting of MPLS Connectivity

• MPLS LSP Ping
  • Used for testing end-to-end MPLS connectivity similar to IP ping
  • Can we used to validate reachability of LDP-signaled LSPs, TE tunnels, and PWs

• MPLS LSP Trace
  • Used for testing hop-by-hop tracing of MPLS path similar to traceroute
  • Can we used for path tracing LDP-signaled LSPs and TE tunnels

• MPLS LSP Multipath (ECMP) Tree Trace
  • Used to discover of all available equal cost LSP paths between PEs
  • Unique capability for MPLS OAM; no IP equivalent!

• Auto IP SLA
  • Automated discovery of all available equal cost LSP paths between PEs
  • LSP pings are being sent over each discovered LSP path
Summary

Key Takeaways

- MPLS networks consist of PE routers at in/egress and P routers in core
- Traffic is encapsulated with label(s) at ingress (PE router)
- Labels are removed at egress (PE router)
- MPLS forwarding operations include label imposition (PUSH), swapping, and disposition (POP)
- LDP and RSVP can be used for signaling label mapping information to set up an end-to-end Label Switched Path (LSP)
- RSVP label signaling enables setup of TE tunnels, supporting enhanced traffic engineering capabilities; traffic protection and path management
MPLS Virtual Private Networks

Topics

- Definition of MPLS VPN service
- Basic MPLS VPN deployment scenario
- Technology options
What Is a Virtual Private Network?

Definition

• Set of sites which communicate with each other in a secure way
  • Typically over a shared public or private network infrastructure

• 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
  • Full mesh, partial mesh, hub-and-spoke, etc.

• VPN sites may be either within the same or in different organizations
  • VPN can be either intranet (same org) or extranet (multiple orgs)

• VPNs may overlap; site may be in more than one VPN
MPLS VPN Example

Basic Building Blocks

- **VPN policies**
  - Configured on PE routers (manual operation)

- **VPN signaling**
  - Between PEs
  - Exchange of VPN policies

- **VPN traffic forwarding**
  - Additional VPN-related MPLS label encapsulation

- **PE-CE link**
  - Connects customer network to MPLS network; either layer-2 or layer-3
MPLS VPN Models

Technology Options

- MPLS Layer-3 VPNs
  - Peering relationship between CE and PE

- MPLS Layer-2 VPNs
  - Interconnect of layer-2 Attachment Circuits (ACs)

MPLS Layer-2 VPNs

- CE connected to PE via L2 (Eth, FR, ATM, etc) connection
- CE-CE L2 p2p connectivity
- CE-CE routing; no SP involvement

MPLS Layer-3 VPNs

- CE connected to PE via IP-based connection (over any layer-2 type)
  - Static routing
  - PE-CE routing protocol; eBGP, OSPF, IS-IS
- CE routing has peering relationship with PE router; PE routers are part of customer routing
- PE routers maintain customer-specific routing tables and exchange customer-specific routing information
MPLS Layer-3 Virtual Private Networks
MPLS Layer-3 Virtual Private Networks

Topics

• Technology components
• VPN control plane mechanisms
• VPN forwarding plane
• Deployment use cases
  • Business VPN services
  • Network segmentation
  • Data Center access
MPLS Layer-3 VPN Overview

Technology Components

• VPN policies
  • Separation of customer routing via virtual VPN routing table (VRF)
  • In PE router, customer interfaces are connected to VRFs

• VPN signaling
  • Between PE routers: customer routes exchanged via BGP (MP-BGP)

• VPN traffic forwarding
  • Separation of customer VPN traffic via additional VPN label
  • VPN label used by receiving PE to identify VPN routing table

• 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
Virtual Routing and Forwarding Instance

Virtual Routing Table and Forwarding to Separate Customer Traffic

- Virtual routing and forwarding table
  - On PE router
  - Separate instance of routing (RIB) and forwarding table

- Typically, VRF created for each customer VPN
  - Separates customer traffic

- VRF associated with one or more customer interfaces

- VRF has its own routing instance for PE-CE configured routing protocols
  - E.g., eBGP
VPN Route Distribution

Exchange of VPN Policies Among PE Routers

- Full mesh of BGP sessions among all PE routers
  - Or BGP Route Reflector (common)
- Multi-Protocol BGP extensions (MP-iBGP) to carry VPN policies
- PE-CE routing options
  - Static routes
  - eBGP
  - OSPF
  - IS-IS
  - EIGRP
VPN Control Plane Processing

• Make customer routes unique:
  • Route Distinguisher (RD):
    • 8-byte field, VRF parameters; unique value to make VPN IP routes unique
    • VPNv4 address: RD + VPN IP prefix

• Selective distribute VPN 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
VPN Control Plane Processing

Interactions Between VRF and BGP VPN Signaling

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

![Diagram of VPN Control Plane Processing]

BGP advertisement:
VPN-IPv4 Addr = RD:16.1/16
BGP Next-Hop = PE1
Route Target = 100:1
Label=42

VRF parameters:
Name = blue-vpn
RD = 1:100
Import Route-Target = 100:1
Export Route-Target = 100:1
VPN Forwarding Plane Processing
Forwarding of Layer-3 MPLS VPN Packets

- CE2 forwards IPv4 packet to PE2
- PE2 imposes pre-allocated VPN label to IPv4 packet received from CE2
  - Learned via MP-IBGP
- PE2 imposes outer IGP label A (learned via LDP) and forwards labeled packet to next-hop P-router P2
- P-routers P1 and P2 swap outer IGP label and forward label packet to PE1
  - A->B (P2) and B->C (P1)
- Router PE1 strips VPN label and IGP labels and forwards IPv4 packet to CE1
Service Provider Deployment Scenario

**MPLS Layer-3 VPNs for Offering Layer-3 Business VPN Services**

- **Deployment Use Case**
  - Delivery of IP VPN services to business customers

- **Benefits**
  - Leverage same network for multiple services and customers (CAPEX)
    - Highly scalable
  - Service enablement only requires edge node configuration (OPEX)
  - Different IP connectivity can be easily configured; e.g., full/partial mesh
Enterprise Deployment Scenario

MPLS Layer-3 VPNs for Implementing Network Segmentation

• Deployment Use Case
  • Segmentation of enterprise network to provide selective connectivity for specific user groups and organizations

• Benefits
  • Network segmentation only requires edge node configuration
  • Flexible routing; different IP connectivity can be easily configured; e.g., full/partial mesh
Data Center Deployment Scenario

MPLS Layer-3 VPNs for Segmented L3 Data Center Access and Interconnect

• Deployment Use Case
  • Segmented WAN Layer-3 at Data Center edge
  • Layer-3 segmentation in Data Center

• Benefits
  • Only single Data Center edge node needed for segmented layer-3 access
  • Enables VLAN/Layer-2 scale (> 4K)
MPLS L3 VPN: Build vs buy?

• Key consideration: bringing SP into the customer’s routing domain
• Easy to solve with BGP, the world’s only political routing protocol!
• Also works with static routes: no dynamic handoff, no potential for dynamic mess
• BGP and static are very popular
• EIGRP, OSPF, RIP are also options
Summary

Key Takeaways

- MPLS Layer-3 VPNs provide IP connectivity among CE sites
  - MPLS VPNs enable full-mesh, hub-and-spoke, and hybrid IP connectivity
- CE sites connect to the MPLS network via IP peering across PE-CE links
- MPLS Layer-3 VPNs are implemented via VRFs on PE edge nodes
  - VRFs providing customer routing and forwarding segmentation
- BGP used for signaling customer VPN (VPNv4) routes between PE nodes
- To ensure traffic separation, customer traffic is encapsulated in an additional VPN label when forwarded in MPLS network
- Key applications are layer-3 business VPN services, enterprise network segmentation, and segmented layer-3 Data Center access
MPLS Layer-2 Virtual Private Networks
MPLS Layer-2 Virtual Private Networks

Topics

• L2VPN technology options
• P2P services (VPWS)
  • Overview & Technology Basics
  • VPN control plane
  • VPN forwarding plane
• MP2MP services (VPLS / xEVPN)
  • Overview & Technology Basics
  • VPN control / forwarding plane
• Deployment use cases
  • L2 Business VPN services
  • Data Center Interconnect
MPLS Layer-2 Virtual Private Networks

Technology Options

- VPWS services
  - Point-to-point
  - Referred to as Pseudowires (PWs)
- VPLS services
  - Multipoint
- EVPN
  - Multipoint with BGP-based MAC learning
- PBB-EVPN
  - Combines scale tools from PBB (aka MAC-in-MAC) with BGP-based MAC learning from EVPN
Virtual Private Wire Services (VPWS)

Overview of Pseudowire (PW) Architecture

- Based on IETF’s Pseudo-Wire (PW) Reference Model
- Enables transport of any Layer-2 traffic over MPLS
- PE-CE link is referred to as Attachment Circuit (AC)
- Provides a p2p service
- Discovery: manual (config)
- Signaling: LDP
- Learning: none
VPWS Control Plane Processing

Signaling of a New Pseudo-Wire

- (1) New Virtual Circuit (VC) cross-connect connects customer L2 interface (AC) to new PW via VC ID and remote PE ID
- (2) New targeted LDP session between PE1 and PE2 is established, in case one does not already exist
- (3) PE binds VC label with customer layer-2 interface and sends label-mapping to remote PE
- (4) Remote PE receives LDP label binding message and matches VC ID with local configured VC cross-connect
VPWS Forwarding Plane Processing

Forwarding of Layer-2 Traffic Over PWs

- CE2 forwards L2 packet to PE2.
- PE2 pushes VC (inner) label to L2 packet received from CE2
  - Optionally, a control word is added as well (not shown)
- PE2 pushed outer (Tunnel) label and forwards packet to P2
- P2 and P1 forward packet using outer (tunnel) label (swap)
- Router PE1 pops Tunnel label and, based on VC label, L2 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
Virtual Private LAN Services

Overview of VPLS Architecture

- VPLS network acts like a virtual switch that emulates conventional L2 bridge
- Fully meshed or Hub-Spoke topologies supported
- Provides a multipoint ethernet service
- Discovery: manual or auto (BGP)
- Signaling: LDP or BGP (PW label)
- Learning: data plane
EVPN

• Ethernet VPN
• Provides a multipoint ethernet service
• Discovery: BGP, using MPLS VPN mechanisms (RT)
• Signaling: BGP (MAC prefixes)
• Learning: Control plane (BGP)
• Allows for multihomed CEs

BGP advertisement:
L2VPN/EVPN Addr = CE1.MAC
BGP Next-Hop = PE1
Route Target = 100:1
Label=42
PBB-EVPN

- Combines Provider Backbone Bridging (MAC-in-MAC) with EVPN
  - Scales better than EVPN
  - Removes the need to advertise Customer MAC addresses in BGP
- Provides multipoint ethernet service
- Discovery: BGP, using MPLS VPN mechanisms (RT)
- Signaling: BGP (B-MAC prefixes)
- Learning: Control plane (BGP) and forwarding plane
- Allows for multihomed CEs

CE-CE MAC addresses learned in the data plane

BGP advertisement:
L2VPN/EVPN Addr = PE1.B-MAC
BGP Next-Hop = PE1
Route Target = 100:1
Label=42

C-MAC = Customer MAC address
B-MAC = Backbone MAC address
Service Provider Deployment Scenario

PWs for Offering Layer-2 Business VPN Services

• Deployment Use Case
  • Delivery of E-LINE services to business customers

• Benefits
  • Leverage same network for multiple services and customers (CAPEX)
    • Highly scalable
  • Service enablement only requires edge node configuration (OPEX)
Data Center Deployment Scenario

VPLS for Layer-2 Data Center Interconnect (DCI) Services

• Deployment Use Case
  • E-LAN services for Data Center interconnect

• Benefits
  • Single WAN uplink to connect to multiple Data Centers
  • Easy implementation of segmented layer-2 traffic between Data Centers
Summary

Key Takeaways

• L2VPNs enable transport of any Layer-2 traffic over MPLS network
• L2 packets encapsulated into additional VC label
• Both LDP and BGP can be used Pseudowire (PW) signaling
• PWs suited for implementing transparent point-to-point connectivity between Layer-2 circuits (E-LINE services)
• VPLS suited for implementing transparent point-to-multipoint connectivity between Ethernet links/sites (E-LAN services)
• EVPN / PBB-EVPN are next-generation L2VPN solutions based on BGP control-plane for MAC distribution/learning over the core
• Typical applications of L2VPNs are layer-2 business VPN services and Data Center interconnect
Advanced Topics
MPLS And IPv6
IPv6 Support for Native MPLS Deployments and MPLS Layer-3 Services

- MPLS allows IPv6 to be deployed as an edge-only service, no need to run v6 in the core
  - Easier to deploy
  - Security mechanism

- 6PE: All IPv6 can see each other (single VPN)
  - IPv6+label (no RD, no RT)

- 6VPE: Separate IPv6 VPNs
  - VPNv6, includes RD and RT
Label Switched Multicast (LSM)

Point-to-Multi-Point MPLS Signaling and Connectivity

- What is Label Switched Multicast?
  - MPLS extensions to provide P2MP connectivity
  - RSVP extensions and multicast LDP

- Why Label-Switched Multicast?
  - Enables MPLS capabilities, which can not be applied to IP multicast traffic (e.g., FRR)

- Benefits of Label-Switched Multicast
  - Efficient IP multicast traffic forwarding
  - Enables MPLS traffic protection and BW control of IP multicast traffic
Segment Routing

Control Plane

- Segment routing provides
  - Rich forwarding behaviors
  - Minimal forwarding state (encapsulated in packet)

- Simple IS-IS / OSPF extensions program MPLS forwarding plane

- IGP advertises
  - Node segment id (label) per node (globally significant)
  - Adjacency segment id (label) per link (locally significant)

- Packet with node segment id forwarded along shortest path to destination

- Packet with adjacency segment id forwarded over adjacency
Segment Routing
Forwarding Plane

Node Path
A → B → E

Adjacency Path
A → B → C → D → E

Combined Path
A → B → E (via C and D)

Payload:
- 103
- 201
- 202

Cisco live!
**Enhanced Path Computation for MPLS TE LSPs with Path Computation Element (PCE)**

**Inter-Area MPLS TE**

- ABRs act as stateless PCEs
- ABRs implement backward recursive PCE-Based Computation
- Introduced in IOS XR 3.5.2
- Out-of-network, stateless PCE server
- PCC initiates LSPs
- Introduced in IOS XR 3.5.2

**SDN WAN Orchestration**

- Out-of-network, stateful PCE server
- PCE always initiates LSPs
- Introduced in IOS XR 5.1.1

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**Application**
**Path Request**
**Stateful PCE**
**LSP DB**
**Stateless PCE**
**TED**
**PCEP**
**PCC**
**PCEP**
**PCC**
**PCEP**
**PCC**
---
Futures
New MPLS Developments on the Horizon

- MPLS Multilayer Optimization
  - PCE/GMPLS
- WAN Orchestration
  - PCE/SDN
- Control Plane Simplification
  - Segment Routing
Summary
Summary

Key Takeaways

- It’s all about labels …
  - Label-based forwarding and protocol for label exchange
  - Best of both worlds … L2 deterministic forwarding and scale/flexible L3 signaling

- Key MPLS applications are end-to-end 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
  - De facto for most SPs, large enterprises, and increasingly in Data Centers

- Ongoing technology evolution
  - Control-plane simplification (Segment Routing) and WAN orchestration (PCE/SDN)
Consider MPLS When …

**Decision Criteria**

- Is there a need for network segmentation?
  - Segmented connectivity for specific locations, users, applications, etc.

- Is there a need for flexible connectivity?
  - E.g., Flexible configuration of full-mesh or hub-and-spoke connectivity

- Is there a need for implementing/supporting multiple (integrated) services?
  - Leverage same network for multiple services

- Are there specific scale requirements?
  - Large number of users, customer routes, etc.

- Is there a need for optimized network availability and performance?
  - Node/link protection, pro-active connectivity validation
  - Bandwidth traffic engineering and QoS traffic prioritization
MPLS Sessions at Cisco Live

- BRKMPL-1100  Introduction to MPLS
- BRKMPL-1102  MPLS Enterprise Switching Product Update and Designs
- BRKMPL-2100  Deploying MPLS Traffic Engineering
- BRKMPL-2102  Designing MPLS-based IP VPNs
- BRKMPL-2108  Designing MPLS in Next Generation Data Center: A Case Study
- BRKMPL-2110  Enterprise MPLS - Customer Case Studies
- BRKMPL-2115  MPLS Architectural approaches for Data Center and Cloud
- BRKMPL-2333  E-VPN & PBB-EVPN: the Next Generation of MPLS-based L2VPN
- BRKMPL-3124  Troubleshooting End-to-End MPLS
- LTRMPL-2104  Cisco WAN Automation Engine (WAE) Network Programmability with Segment Routing
- LTRMPL-3102  Enterprise Network Virtualization using IP and MPLS Technologies: Advanced
- TECMPL-3200  SDN WAN Orchestration in MPLS and Segment Routing Networks
# Terminology Reference

**Acronyms Used in MPLS Reference Architecture**

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>Attachment Circuit. An AC is a Point-to-Point, Layer 2 Circuit Between a CE and a PE.</td>
</tr>
<tr>
<td>AS</td>
<td>Autonomous System (a Domain)</td>
</tr>
<tr>
<td>CoS</td>
<td>Class of Service</td>
</tr>
<tr>
<td>ECMP</td>
<td>Equal Cost Multipath</td>
</tr>
<tr>
<td>IGP</td>
<td>Interior Gateway Protocol</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LDP</td>
<td>Label Distribution Protocol, RFC 3036.</td>
</tr>
<tr>
<td>LER</td>
<td>Label Edge Router. An Edge LSR Interconnects MPLS and non-MPLS Domains.</td>
</tr>
<tr>
<td>LFIB</td>
<td>Labeled Forwarding Information Base</td>
</tr>
<tr>
<td>LSP</td>
<td>Label Switched Path</td>
</tr>
<tr>
<td>LSR</td>
<td>Label Switching Router</td>
</tr>
<tr>
<td>NLRI</td>
<td>Network Layer Reachability Information</td>
</tr>
<tr>
<td>P Router</td>
<td>An Interior LSR in the Service Provider's Autonomous System</td>
</tr>
<tr>
<td>PE Router</td>
<td>An LER in the Service Provider Administrative Domain that Interconnects the Customer Network and the Backbone Network.</td>
</tr>
<tr>
<td>PSN Tunnel</td>
<td>Packet Switching Tunnel</td>
</tr>
</tbody>
</table>
# Terminology Reference

## Acronyms Used in MPLS Reference Architecture (cont.)

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudo-Wire</td>
<td>A Pseudo-Wire Is a Bidirectional &quot;Tunnel&quot; Between Two Features on a Switching Path.</td>
</tr>
<tr>
<td>PWE3</td>
<td>Pseudo-Wire End-to-End Emulation</td>
</tr>
<tr>
<td>QoS</td>
<td>Quality of Service</td>
</tr>
<tr>
<td>RD</td>
<td>Route Distinguisher</td>
</tr>
<tr>
<td>RIB</td>
<td>Routing Information Base</td>
</tr>
<tr>
<td>RR</td>
<td>Route Reflector</td>
</tr>
<tr>
<td>RT</td>
<td>Route Target</td>
</tr>
<tr>
<td>RSVP-TE</td>
<td>Resource Reservation Protocol based Traffic Engineering</td>
</tr>
<tr>
<td>VPN</td>
<td>Virtual Private Network</td>
</tr>
<tr>
<td>VFI</td>
<td>Virtual Forwarding Instance</td>
</tr>
<tr>
<td>VLAN</td>
<td>Virtual Local Area Network</td>
</tr>
<tr>
<td>VPLS</td>
<td>Virtual Private LAN Service</td>
</tr>
<tr>
<td>VPWS</td>
<td>Virtual Private WAN Service</td>
</tr>
<tr>
<td>VRF</td>
<td>Virtual Route Forwarding Instance</td>
</tr>
<tr>
<td>VSI</td>
<td>Virtual Switching Instance</td>
</tr>
</tbody>
</table>
Further Reading

MPLS References at Cisco Press and cisco.com

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

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

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

- Layer 2 VPN Architectures — Cisco Press®
  - Wei Luo, Carlos Pignataro, Dmitry Bokotey, and Anthony Chan

- MPLS QoS — Cisco Press®
  - Santiago Alvarez
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