Introduction to MPLS and Traffic Engineering

Session 2201
Motivations for MPLS

MPLS Overview

Applications

Roadmap

Why MPLS?

Integrate best of Layer 2 and Layer 3

- Keep up with growth
- Reduce operations costs
- Increase reliability
- Create new revenue from advanced IP services
- Standards based
Key Cisco MPLS Solutions

- IP/ATM Integration
- Traffic Engineering
- Internet Scale VPN/CoS

MPLS: Routing Scalability for IP over ATM

- Internal routing scalability
  Limited adjacencies
- External routing scalability
  Full BGP4 support, with all the extras
- VC merge for very large networks
MPLS: End-to-End IP Services over ATM

- IP services directly on ATM switches
  - ATM switches support IP protocols directly
  - Avoids complex translation
- Full support for IP CoS, RSVP, IP multicast, future IP services

Benefits of MPLS Class of Service with ATM

- Allocate resources:
  - Per individual, edge-to-edge VCs
  - By kbps bandwidth
  - Mesh of VCs to configure
- Allocate resources:
  - Per class, per link
  - By % bandwidth
  - No VCs to configure
  - Simpler to provision and engineer
  - Even simpler with ABR
MPLS: Traffic Engineering

- Characteristics
  - High performance
  - Low overhead
  - End-to-end connectivity

- Applications
  - Constraint-based routing
  - Fast reroute
  - Guaranteed bandwidth
  - Frame/ATM transport
  - Control plane for ATM and OXCs

Motivations for Traffic Engineering

- Links not available
- Economics
- Failure scenarios
- Unanticipated traffic

New Release of Netscape Software

Link Failure
No Physical Link
300 Mbps Traffic Flow
155 Mbps Fiber Link
**MPLS: Bringing Layer 2 Benefits to Layer 3**

- **Traffic engineering**
  - Aligning traffic flows to resources
  - Optimize link utilization

- **Fast re-route**
  - Fast, local, link and node protection

- **Guaranteed bandwidth**
  - Hard end-to-end bandwidth and delay guarantees

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**IP VPN Taxonomy**

- **IP VPNs**
  - **DIAL**
    - Client-Initiated
  - **NAS-Initiated**
  - **DEDICATED**
    - IP Tunnel
    - Virtual Circuit
    - Security Appliance
    - Router
    - FR
    - ATM
    - MPLS/BGP VPNs

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**Route Chosen By**

**Route Specified By**

Traffic Engineering
Cisco MPLS/BGP VPNs

Benefits of MPLS/BGP VPNs

- Private, connectionless IP VPNs
- Outstanding scalability
- Customer IP addressing freedom
- Multiple QoS classes
- Secure support for intranets and extranets
- Simplified VPN Provisioning
- Support over any access or backbone technology
MPLS Benefits

Benefits of MPLS

<table>
<thead>
<tr>
<th>IP/ATM Integration</th>
<th>Shared Backbone for Economies of Scale</th>
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<tbody>
<tr>
<td></td>
<td>Reduced Complexity for Lower Operational Cost</td>
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<tr>
<td></td>
<td>Faster Time to Market for IP Services =&gt; More Revenue</td>
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<tr>
<td></td>
<td>Use Best Technology =&gt; Lower Costs</td>
</tr>
<tr>
<td>Traffic Engineering</td>
<td>Traffic Eng. for Lower Trunk Costs and Higher Reliability</td>
</tr>
<tr>
<td></td>
<td>Fast Reroute for Protection and Resiliency</td>
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<tr>
<td></td>
<td>Guaranteed Bandwidth for Hard QoS Guarantees</td>
</tr>
<tr>
<td>MPLS BGP VPNs</td>
<td>New Revenue Opportunity for SPs</td>
</tr>
<tr>
<td></td>
<td>Scalability for Lower Operational Costs and Faster Rollout</td>
</tr>
<tr>
<td></td>
<td>L2 Privacy and Performance for IP</td>
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</tbody>
</table>

Topics

- Motivations for MPLS
- MPLS Overview
- Applications
- Roadmap
MPLS Concept

At Edge (Edge LSR):
Classify Packets
Label Them

In Core (LSR):
Forward Using Labels
As Opposed to IP Addr

• Enable ATM switches to act as routers
• Create new IP capabilities via flexible classification

Router Example:
Distributing Routing Information

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
Router Example: Forwarding Packets

Packets Forwarded Based on IP Address

MPLS Example: Routing Information

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
MPLS Example: Assigning Labels

Routing Updates (OSPF, EIGRP...)

Use Label 4 for 128.89 and Use Label 5 for 171.69

Use Label 7 for 171.69

MPLS Example: Forwarding Packets

LSR Forwards Based on Label

128.89.25.4 Data

4 128.89.25.4 Data

1 128.89.25.4 Data

128.89.25.4 Data
**MPLS Example: More Details**

<table>
<thead>
<tr>
<th>In Label</th>
<th>Address Prefix</th>
<th>Out l'face</th>
<th>Out Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>128.89</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>171.69</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>117.59</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>In Label</th>
<th>Address Prefix</th>
<th>Out l'face</th>
<th>Out Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>128.89</td>
<td>0</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>171.69</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>117.59</td>
<td>0</td>
<td>X</td>
</tr>
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Prefixes That Share a Path Can Share Label

Remove Tag One Hop Prior to De-Aggregation Point

De-Aggregation Point Does L3 lookup

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**Encapsulations**

**ATM Cell Header**

- GFC
- VPI
- VCI
- PTI
- CLP
- HEC
- DATA

**PPP Header**

(Packet over SONET/SDH)

**LAN MAC Label Header**
Label Header for Packet Media

- Label = 20 bits
- COS = 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 ether types/PPP PIDs
- Contains everything needed at forwarding time
- One word per label

ATM MPLS Example:
Routing Information

You Can Reach 128.89 and 171.69 thru Me
Routing Updates (OSPF, EIGRP...)
You Can Reach 171.69 thru Me
ATM MPLS Example: Requesting Labels

<table>
<thead>
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<th>In Label</th>
<th>Address Prefix</th>
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</tr>
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<td>1</td>
<td></td>
<td></td>
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Need a Label for 128.89
Need a Label for 171.69

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

ATM MPLS Example: Assigning Labels

<table>
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<th>In Label</th>
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<tbody>
<tr>
<td>128.89</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>171.69</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

Use Label 4 for 128.89
Use Label 5 for 171.69

Use Label 8 for 128.89
ATM MPLS Example: Packet Forwarding

LSR Forwards Based on Label

Why Multiple Labels with ATM?

- If didn’t allocate multiple labels
  Cells of different packets would have same label (VPI/VCI)
  Egress router can’t reassemble packets
Multiple Labels

- Multiple labels enable edge router to reassemble packets correctly

VC Merge

- With ATM switch that can merge VCs
  - Can reuse outgoing label
  - Hardware prevents cell interleave
  - Fewer labels required
  - For very large networks
Advanced MPLS

- Basic MPLS: destination-based unicast
- Many additional options for assigning labels
- The key: separation of routing and forwarding

<table>
<thead>
<tr>
<th>Destination-Based Unicast Routing</th>
<th>IP Class of Service</th>
<th>Resource Reservation (eg RSVP)</th>
<th>Multicast Routing (PIM v2)</th>
<th>Explicit and Static Routes</th>
<th>Virtual Private Networks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Label Information Base (LIB)</td>
<td>Per-Label Forwarding, Queuing, and Multicast Mechanisms</td>
<td></td>
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</tr>
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Building VPNs with MPLS

- Constrained distribution of routing information
  Routes are only communicated to routers that are members of a VPN
- VPN-IP addresses
  Supports overlapping address spaces
- Multiprotocol Label Switching (MPLS)
  Labels used to define VPNs
  Labels used to represent VPN-IP addresses
- Peer model
  Simplifies routing for end customers
Routing Information Distribution

**Step 1:** From site (CE) to service provider (PE)
E.g. via RIP, OSPF, static routing, or BGP

**Step 2:** Export to provider’s BGP at ingress PE

**Step 3:** Within/across service provider(s) (among PEs):
E.g. via BGP

**Step 4:** Import from provider’s BGP at egress PE

**Step 5:** From service provider (PE) to site (CE)
E.g. via RIP, or static routing, or BGP
Packet Forwarding

- IP packet received on sub-interface
- Sub-interfaced configured with VPN ID
- BGP binds labels to VPN-IP routes
- LDP binds labels to IGP routes and defines CoS
- Logically separate forwarding information base (FIB) for each VPN

MPLS VPN Example

VPN B/Site 1

VPN B/Site 2

VPN C/Site 2

VPN A/Site 1

VPN C/Site 1
Explicit Routing

- Traffic engineering requires the capability to specify a path
- Voice networks, Frame Relay, ATM are explicitly routed at connection setup
- But IP uses hop-by-hop destination-based routing

The "Fish" Problem

IP Uses Shortest Path Destination-Based Routing
Shortest Path May Not Be the only path
Alternate Paths May Be under-Utilized while the Shortest Path Is over-Utilized
An LSP Tunnel

Labels, Like VCIs Can Be Used to Establish Virtual Circuits
- Normal Route: R1->R2->R3->R4->R5
- Tunnel: R1->R2->R6->R7->R4

Traffic Engineering

- Provides
  - Constraint-based routing
  - Similar to PNNI routing
  - Control of traffic engineering
  - Path selection
  - Tunnel setup
Basic Traffic Engineering

- LSP tunnels used to steer traffic
  (Termed traffic engineering or TE tunnels)
- Represent inter-POP traffic as flows in bits/sec
- Determine bandwidth requirements for tunnels between POP pairs
- Automated procedures route and setup the inter-POP TE tunnels

TE Components

1. Information distribution
   Distributes constraints pertaining to links
   Available bandwidth is just one type of constraint
2. Path selection algorithm
   Selects paths that obey the constraints
(3) Route setup
Uses RSVP for signaling LSPs

(4) Link admission control
Decides which tunnels may have resources

(5) Traffic engineering control
Establishes and maintains tunnels

(6) Forwarding data
LSP Tunnel Setup

Setup: Path (R1 -> R2 -> R6 -> R7 -> R4 -> R9) Tunnel ID 5, Path ID 1
Reply: Communicates Labels and Label Operations
Reserves Bandwidth on Each Link

Rerouting to an Alternate Path

Setup: Path (R1 -> R2 -> R3 -> R4 -> R9) Tunnel ID 5, Path ID 2
Until R9 Gets New Path Message, Current Resv Is Refreshed
Assigning Traffic to Tunnels

- Automatic assignment based on IGP
- Modified SPF calculation

When the endpoint of a tunnel is reached, the next hop to that node is set to the tunnel interface.

Nodes downstream of the tunnel inherit the tunnel interface as their next hop.

(Encountering a node with its own tunnel replaces the next hop.)
**Topology with Tunnel**

Tunnel1: Path (R1->R2->R6->R7->R4)
Tunnel2: Path (R1->R2->R3->R4->R5)

Normal Dijkstra, Except Tunnel Interfaces Used when Tunnel Tail Is Encountered

**Forwarding Tree**

R4 and R8 Have Tunnel1 Interface as Next Hop; R5 Has Tunnel2
Fast Reroute

- Goal—match Sonet restoral times—50 ms
- Locally patch around lost facilities
- Strategies
  - Alternate tunnel (1->1 mapping)
  - Tunnel within tunnel (n->1 mapping)

Fast Reroute

- Labels are carried in a stack, making it possible to nest tunnels
- RSVP has a notion of PHOP, allowing the protocol to be independent of the back channel
- A tunnel can use another tunnel as a tunnel hop to enable fast reroute
**Nested Tunnels—Outer**

Setup: Path (R2->R3->R4) Session 5, ID 2
Labels Established on Resv Message

**Nested Tunnels—Inner**

Setup: Path (R1->R2->R4->R9) Path Message Travels on Tunnel from R2 to R4
R4 Send Resv Message Directly to R2
On Failure of Link from R2 -> R3, R2 Simply Changes the Outgoing Interface and Pushes on the Label for the Tunnel to R3
**Conclusions: MPLS Fundamentals**

- Based on the label-swapping forwarding paradigm
- As a packet enters an MPLS network, it is assigned a label based on its Forwarding Equivalence Class (FEC) as determined at the edge of the MPLS network
- FECs are groups of packets forwarded over the same Label Switched Path (LSP)

**Conclusions: MPLS Main Ideas**

- Separate forwarding information (label) from the content of IP header
- Single forwarding paradigm (label swapping)—multiple routing paradigms
- Multiple link-specific realizations of the label swapping forwarding paradigm
- Flexibility of forming Forwarding Equivalence Classes (FECs)
- Forwarding hierarchy via label stacking
Topics

- Motivations for MPLS
- MPLS Overview
- Applications
- Roadmap

Application: Multiservice ATM Backbone with IP

- MPLS provides
  - Scalable IP routing
  - Advanced IP services
  - Internet scale VPNs

- Benefits
  - Lower operations costs
  - Keep up with Internet growth
  - New revenue services
  - Multiservice backbone
  - Faster time to market
Application: Packet over SONET/SDH IP Backbone

- **MPLS provides**
  - Isolation of backbone from BGP
  - Traffic engineering
  - Guaranteed bandwidth
  - Internet scale VPNs
  - FR/ATM over MPLS

- **Benefits**
  - Improved line utilization
  - Increased reliability
  - Convergence
  - New revenue services

Application: Mixed POS/ATM Backbone

- **MPLS provides**
  - Tight integration of routers and ATM switches
  - End-to-end IP services
  - Internet scale VPNs

- **Benefits**
  - Network design flexibility
  - Transition to IP router backbone
  - Faster time to market
Applications: Enterprise Backbone

- MPLS provides
  - Scalability
  - IP services
  - Traffic engineering

- Benefits
  - Flexibility
  - Reduced complexity for lower cost

Topics

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- MPLS Overview
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- Roadmap
Leadership MPLS Solutions

- IP and ATM integration
- MPLS traffic engineering
- MPLS VPNs with integrated QoS

Available Today!

Leadership MPLS Solutions

- MPLS VPN management
- MPLS connection services

Available Today!
In Field Trial!
MPLS Platform Support

- BPX 8650
- BPX 8680
- LS1010
- Catalyst 8540
- MGX 8850
- GSR 12000
- Cisco 3600, 2600
- Cisco 4500, 4700
- Cisco 7200
- Cisco 7500

All Available Today!

Building on Open Standards

MPLS is based on Cisco’s tag switching
Cisco is using MPLS as the basis for developing support for new value-added IP services
Expect IETF ratification of the 12 MPLS RFCs in summer 2000
MPLS: The Cisco Advantage

- Industry IP leadership
- Most advanced MPLS solutions
- Broadest range of platforms supported in the industry today
- MPLS solutions deployed in real world production networks
- Standards-based solutions
Please Complete Your Evaluation Form

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