MPLS - Outline

- Overview
  - Label Distribution Protocols
  - Constraint Based Routing with CR-LDP and Traffic Engineering (TE)
  - Summary
Current Internet Architecture

- Provides only best effort service
  - All packets are treated the same.
  - It is impossible to guarantee QoS.
- Routing is based on shortest path
  - Network resources are used inefficiently.
  - A single link parameter (number of hops) is used to compute the route.
  - It is very difficult to do routing based on other parameters (such as BW, delay, …).

Shortest Path Routing Problem

- RIP/OSPF selects A-B-C as the shortest path from A to C, although B-C is congested.
- A-D-E-C is under-utilized while A-B-C is over-utilized!
Tools to Improve the Internet

- **QoS guarantee**
  - Integrated services (Intserv)
    - Provides per-flow QoS guarantees.
  - Differentiated services (Diffserv)
    - Provides per-aggregate QoS guarantees.

- **Superior routing and forwarding**
  - Multiprotocol label switching (MPLS)
    - Overcomes the IP shortest path routing problem.
    - Permits routing based on any constraints including TE or QoS constraints.

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**MPLS - Multiprotocol Label Switching**

- Overview

- Switching vs routing
- IP Switching (Ipsilon)
- Tag Switching (CISCO)
- Multi-protocol label switching
Routing vs Switching

- Routing: Based on address lookup. Max prefix match.
  - Search Operation
  - Complexity $\approx O(\log_2 n)$
- Switching: Based on circuit numbers
  - Indexing operation
  - Complexity $O(1)$
  - Fast and Scalable for large networks and large address spaces
- These distinctions apply on all datalinks: ATM, Ethernet, SONET

IP Switching

- Developed by Ipsilon
- Routing software in every ATM switch in the network
- Initially, packets are reassembled by the routing software and forwarded to the next hop
- Long term flows are transferred to separate VCs. Mapping of VCIs in the switch $\Rightarrow$ No reassembly
Tag Switching

- Proposed by CISCO
- Similar to VLAN tags
- Tags can be explicit or implicit L2 header

L2 Header | Tag

- Ingress router/host puts a tag. Egress router strips it off.

Tag Switching (Cont)

- Switches switch packets based on labels. Do not need to look inside ⇒ Fast.
- One memory reference compared to 4-16 in router
- Tags have local significance ⇒ Different tag at each hop (similar to VC #)
MPLS

- Multiprotocol Label Switching
- IETF working group to develop switched IP forwarding
- Initially focused on IPv4 and IPv6. Technology extendible to other L3 protocols.
- Not specific to ATM. ATM or LAN.
- Not specific to a routing protocol (OSPF, RIP, ...)

IP Switching (Cont)

- Flow-oriented traffic: FTP, Telnet, HTTP, Multimedia
- Short-lived Traffic: DNS query, SMTP, NTP, SNMP, request-response. Ipsilon claimed that 80% of packets and 90% of bytes are flow-oriented.
- Ipsilon claimed their Generic Switch Management Protocol (GSMP) to be 2000 lines, and Ipsilon Flow Management Protocol (IFMP) to be only 10,000 lines of code
- Runs as added software on an ATM switch
- Implemented by several vendors
SO WHAT IS MPLS?

- Hop-by-hop or source routing to establish labels
- Uses label native to the media
- Multi level label substitution transport
ROUTE AT EDGE, SWITCH IN CORE

IP Forwarding

LABEL SWITCHING

IP Forwarding

MPLS: HOW DOES IT WORK?

UDP-Hello

TCP-open

Initialization(s)

Label request

Label mapping

TIME
WHY MPLS?

- Leverage existing ATM hardware
- Ultra fast forwarding
- IP Traffic Engineering
  - Constraint-based Routing
- Virtual Private Networks
  - Controllable tunneling mechanism
- Voice/Video on IP
  - Delay variation + QoS constraints

BEST OF BOTH WORLDS

MPLS + IP form a middle ground that combines the best of IP and the best of circuit switching technologies.
MPLS Terminology

- **LDP**: Label Distribution Protocol
- **LSP**: Label Switched Path
- **FEC**: Forwarding Equivalence Class
- **LSR**: Label Switching Router
- **LER**: Label Edge Router

Multiprotocol Label Switching (MPLS)

- Not really a protocol layer
  - Part of L2 or L3.
- Connection-oriented technology.
- Based on label swapping (similar to ATM/FR).
- Decouples forwarding from routing.
- Enables efficient explicit routing.
**Multiprotocol Nature of MPLS**

- **L1**: Physical layer
  - SONET

- **L2**: Data Link layer
  - HDLC/PPP
  - ATM

- **L3**: Network layer
  - MPLS
  - IPv4
  - IPv6
  - MPLS

MPLS supports all L2/L3 layers

**MPLS Label Encapsulation and Format**

- **Part of L2 header**
  - VPI: 24 bits
  - VCI: 24 bits
  - PT: 3 bits
  - CLP: 1 bit
  - HEC: 8 bits

- **Between L2&L3**
  - PPP
  - MPLS Shim
  - IP Header

- **Shim Header**
  - Label: 20 bits
  - CoS: 3 bits
  - S: 1 bit
  - TTL: 8 bits

*S* = Indicates end of stack

**CoS** = Class of Service

**TTL** = Time to live (same as IP)
Separation of Routing and Forwarding

Routing

Routing updates

Routing protocol

Routing table

Forwarding

Forwarding updates

Forwarding table

Packet Switching

Switch fabric

Line card

Packet In

Packet Out

MPLS Forwarding Model

- Ingress LSR determines a packet’s FEC.
  - Based on destination address prefix and/or other parameters.
- It then assigns a label to the packet.
- Traffic is label swapped at each transit LSR.
- Egress LSR removes the label.
- It then forwards the packet based on destination address
  - Normal IP hop-by-hop routing.
Hop-by-Hop vs. Explicit Routing

### Hop-by-Hop Routing
- Distributes routing of control traffic
- Builds a set of trees either fragment by fragment like a random fill, or backwards, or forwards in organized manner.
- Reroute on failure impacted by convergence time of routing protocol
- Existing routing protocols are destination prefix based
- Difficult to perform traffic engineering, QoS-based routing

### Explicit Routing
- Source routing of control traffic
- Builds a path from source to destination
- Requires manual provisioning, or automated creation mechanisms.
- LSPs can be ranked so some reroute very quickly and/or backup paths may be pre-provisioned for rapid restoration
- Operator has routing flexibility (policy-based, QoS-based)
- Adapts well to traffic engineering

Explicit routing shows great promise for traffic engineering

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**Forwarding Equivalence Classes**

- FEC = “A subset of packets treated the same way by a router”
- FECs provides for a great deal of flexibility and scalability
- In conventional routing, a packet is assigned to a FEC at each hop (i.e. L3 look-up), in MPLS it is only done once at the network ingress.
A Vanilla LSP is actually part of a tree from every source to that destination (unidirectional).

Vanilla LDP builds that tree using existing IP forwarding tables to route the control messages.

- Destination based forwarding tables as built by OSPF, IS-IS, RIP, etc.
IP FORWARDING USED BY HOP-BY-HOP CONTROL

MPLS Label Distribution
Label Switched Path (LSP)

ERBLSP follows route that source chooses. In other words, the control message to establish the LSP (label request) is source routed.
**Example of a MPLS Domain**

- Ingress LSR
- Edge LSR
- LSR
- LIB
- MPLS Network
- Label Switch Path (LSP)

**Explicitly Routed LSP ER-LSP**

<table>
<thead>
<tr>
<th>Inf In</th>
<th>Label</th>
<th>Dest</th>
<th>Inf Out</th>
<th>Label</th>
<th>Out</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0.50</td>
<td>47.1</td>
<td>1</td>
<td>0.40</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>47.1</td>
<td>1</td>
<td>0.50</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- IP 47.1.1.1
- 47.2

**Example of a MPLS Domain**
Peer Instruction Questions:

1. LDP Label Mapping

- A new FEC: subnetwork 192.1.5.0/24 is added
- Assume the routing for this FEC is: ABCEDF
- Add an appropriate entry to LIB (Label Information Base) at each node after the LDP label mapping
- Pick the next available label at each node in the label mapping at each hop, starting from egress LSR F (Figure on Slide 34)

Labels selected for LSRs <F,D,E,C,B> are:

(a) <6,18,32,124,124>  (b) <6,18,32,124,18>
(c) <2,18,32,124,95>  (d) <6,18,0,0,124>  (e) None
Example of a MPLS Domain

New FEC: subnetwork 192.1.5.0/24

ER LSP - advantages

- Operator has routing flexibility (policy-based, QoS-based)
- Can use routes other than shortest path
- Can compute routes based on constraints in exactly the same manner as ATM based on distributed topology database. (traffic engineering)
ER LSP - discord!

- Two signaling options proposed in the standards: CR-LDP, RSVP extensions:
  - CR-LDP = LDP + Explicit Route
  - RSVP ext = Traditional RSVP + Explicit Route + Scalability Extension
- ITU has decided on LDP/CR-LDP for public networks.
- Survival of the fittest not such a bad thing although RSVP has lots of work in scalability to do.

MPLS Label Swapping

- Forwarding table maintains mappings
- Exact match lookup
- Input (port, label) determines:
  - Label operation
  - Output (port, label)
- Same forwarding algorithm used in FR and ATM
MPLS - Outline

- Overview
- Label Distribution Protocols
- Constraint Based Routing with CR-LDP and Traffic Engineering
- MPLS & ATM
- Summary

Label Distribution Protocols

- Overview of Hop-by-hop & Explicit
- Label Distribution Protocol (LDP)
- Constraint-based Routing LDP (CR-LDP)
- Extensions to RSVP
MPLS Control Plane (Label Distribution Protocol - LDP)

- Down-stream label distribution
  - Downstream LSR assigns a label to each entry in its routing table.
  - It then distributes the label bindings to upstream LSRs.
- Downstream-on-demand label distribution
  - Upstream LSR requests a label for an FEC from a downstream LSR.
  - Downstream LSR assigns a label to that FEC.
  - It then distributes the label binding to the upstream LSR.

LDP Messages

- Initialization (modes: unsolicited, on-demand; ordered, independent; liberal, conservative; Timer values, range of labels,...)
- Keepalive (after timeout, assume LSR or connection down)
- Label Mapping: to advertise label binding to FEC
- Label Withdrawal (e.g. due to routing change)
- Label Release (label not needed for FEC as next hop is not advertising LSR)
- Label Request: used in on-demand mode
- Label Request Abort: to revoke Label Request, e.g. due to change in next hop for FEC
Label Distribution Protocol (LDP) - Purpose

Label distribution ensures that adjacent routers have a common view of FEC <-> label bindings.

Routing Table:
- Addr-prefix: 47.0.0.0/8
- Next Hop: LSR2

Label Information Base:
- Label-In: XX
- FEC: 47.0.0.0/8
- Label-Out: 17

IP Packet: 47.80.55.3

Step 1: LSR creates binding between FEC and label value.
Step 2: LSR communicates binding to adjacent LSR.
Step 3: LSR inserts label value into forwarding base.

Common understanding of which FEC the label is referring to!

Label distribution can either piggyback on top of an existing routing protocol, or a dedicated label distribution protocol (LDP) can be created.
Label Distribution - Methods

Label Distribution can take place using one of two possible methods:

**Downstream Unsolicited Label Distribution**
- LSR2 and LSR1 are said to have an “LDP adjacency” (LSR2 being the downstream LSR)
- LSR2 discovers a ‘next hop’ for a particular FEC
- LSR2 generates a label for the FEC and communicates the binding to LSR1
- LSR1 inserts the binding into its forwarding tables
- If LSR2 is the next hop for the FEC, LSR1 can use that label knowing that its meaning is understood

**Downstream-on-Demand Label Distribution**
- LSR1 recognizes LSR2 as its next hop for an FEC
- A request is made to LSR2 for a binding between the FEC and a label
- If LSR2 recognizes the FEC and has a next hop for it, it creates a binding and replies to LSR1
- Both LSRs then have a common understanding

Both methods are supported, even in the same network at the same time.
For any single adjacency, LDP negotiation must agree on a common method.

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**Downstream Label Distribution**

- LSRs A, B, C, D, E, and F are connected in a network.
- Each LSR is associated with a label-FEC binding.
- LSRs communicate using LDP (Label Distribution Protocol).
- FEC1, L1 through FEC1, L7 are shown, representing different labels.
- LDP Label mapping message is used for label distribution.

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Spring 2010– Dr. Son Vuong
Cpsc 527
**Downstream-on-demand Label Distribution**

- **A** (Source) sends a label request message to **B**.
- **B** forwards the request to **C**.
- **C** further forwards the request to **D** and **E**.
- **D** and **E** forward the request to **F**.

**Label Request Message**

- **FEC1, L?** from **F** to **D**.
- **FEC1, L?** from **F** to **E**.

**CR-LDP/RSVP-TE**

- **Label request message**

---

**Downstream-on-demand Label Distribution**

- **A** (Source) sends a label mapping message to **B**.
- **B** further forwards the message to **C**.
- **C** forwards the message to **D** and **E**.
- **D** and **E** forward the message to **F**.

**Label Mapping Message**

- **FEC1, L1** from **A** to **B**.
- **FEC1, L2** from **A** to **B**.
- **FEC1, L3** from **A** to **F**.

**CR-LDP/RSVP-TE**

- **Label mapping message**
MPLS in Action

Mapping: 47.1/16, [4]

(Downstream label distribution is assumed)

Downstream Mode - Making SPF Tree

- A Vanilla LSP is actually part of a tree from every source to that destination (unidirectional).
- Vanilla LDP builds that tree using existing IP forwarding tables to route the control messages.
Downstream On Demand
Making SPF Tree Copy In H/W

Distribution Control: Ordered v. Independent

MPLS path forms as associations are made between FEC next-hops and incoming and outgoing labels

### Independent LSP Control
- Each LSR makes independent decision on when to generate labels and communicate them to upstream peers
- Communicate label-FEC binding to peers once next-hop has been recognized
- LSP is formed as incoming and outgoing labels are spliced together

### Ordered LSP Control
- Label-FEC binding is communicated to peers if:
  - LSR is the 'egress' LSR to particular FEC
  - label binding has been received from upstream LSR
- LSP formation 'flows' from egress to ingress

### Definition
- Labels can be exchanged with less delay
- Does not depend on availability of egress node
- Granularity may not be consistent across the nodes at the start
- May require separate loop detection/mitigation method

### Comparison
- Requires more delay before packets can be forwarded along the LSP
- Depends on availability of egress node
- Mechanism for consistent granularity and freedom from loops
- Used for explicit routing and multicast

Both methods are supported in the standard and can be fully interoperable
Label Retention Methods

An LSR may receive label bindings from multiple LSRs. Some bindings may come from LSRs that are not the valid next-hop for that FEC.

Liberal Label Retention
- LSR maintains bindings received from LSRs other than the valid next hop
- If the next-hop changes, it may begin using these bindings immediately
- May allow more rapid adaptation to routing changes
- Requires an LSR to maintain many more labels

Conservative Label Retention
- LSR only maintains bindings received from valid next hop
- If the next-hop changes, binding must be requested from new next hop
- Restricts adaptation to changes in routing
- Fewer labels must be maintained by LSR

Label Retention method trades off between label capacity and speed of adaptation to routing changes.
LIBERAL RETENTION MODE

These labels are kept in case they are needed after a failure.

CONSERVATIVE RETENTION MODE

These labels are released the moment they are received.
Example of a MPLS Domain

Peer Instruction Questions:
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- Add an appropriate entry to LIB (Label Infor Base) at each node after the LDP label mapping
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Labels selected for LSRs <F,D,E,C,B> are:

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(c) <2,18,32,124,95>  (d) <6,18,0,0,124>  (e) None
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- Label Distribution Protocols
- **Constraint Based Routing with CR-LDP and Traffic Engineering**
- Summary

**Label Switched Path (Two Types)**

Two types of Label Switched Paths:
- Hop by hop ("Vanilla" LDP)
- Explicit Routing (LDP+"ER")
Explicit Routing Using MPLS

**Diagram 1:**
- A-D-E-C
- FEC2, L?
- CR-LDP/RSVP-TE
  - Label request message
  - Label mapping message

**Diagram 2:**
- Explicit Routed LSP (non-shortest path)
- ER MPLS tunnel (LSP)
- ER traffic
CR-LDP

- CR = “Constraint” based “Routing”
- eg: USE: (links with sufficient resources AND
  (links of type “someColor”) AND
  (links that have delay less than 200 ms)

Constraint-based LSP - Setup using LDP

- Uses LDP Messages (request, map, notify)
- Shares TCP/IP connection with LDP
- Can coexist with vanilla LDP and inter-work with it, or can exist as an entity on its own
- Introduces additional data to the vanilla LDP messages to signal ER, and other “Constraints”
ER-LSP Setup using CR-LDP

1. Label Request message. It contains ER path <B,C,D>.
2. Request message processed and next node determined. Path list modified to <C,D>.
3. Request message terminates.
5. LSR C receives label to use for sending data to LER D. Label table updated.
6. When LER A receives label mapping, the ER established.

LDP/CR-LDP INTERWORKING

- It is possible to take a vanilla LDP label request let it flow vanilla to the edge of the core, insert an ER hop list at the core boundary at which point it is CR-LDP to the far side of the core.
Basic LDP Message additions

- **LSPID**: A unique tunnel identifier within an MPLS network.
- **ER**: An explicit route, normally a list of IPv4 addresses to follow (source route) the label request message.
- **Resource Class (Color)**: to constrain the route to only links of this Color. Basically a 32 bit mask used for constraint based computations.
- **Traffic Parameters**: similar to ATM call setup, which specify treatment and reserve resources.

### CR-LDP Traffic Parameters

<table>
<thead>
<tr>
<th>U</th>
<th>F</th>
<th>Traf. Param. TLV</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flags</td>
<td>Frequency</td>
<td>Reserved</td>
<td>Weight</td>
</tr>
<tr>
<td>Peak Data Rate (PDR)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak Burst Size (PBS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Committed Data Rate (CDR)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Committed Burst Size (CBS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excess Burst Size (EBS)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Flags** control "negotiability" of parameters
- **Frequency** constrains the variable delay that may be introduced
- **Weight** of the CRLSP in the "relative share"
- **Peak rate** (PDR+PBS) maximum rate at which traffic should be sent to the CRLSP
- **Committed rate** (CDR+CBS) the rate that the MPLS domain commits to be available to the CRLSP
- **Excess Burst Size (EBS)** to measure the extent by which the traffic sent on a CRLSP exceeds the committed rate

32 bit fields are short IEEE floating point numbers

Any parameter may be used or not used by selecting appropriate values
### Negotiation flags

If a parameter is flagged as negotiable then LSRs may replace the parameter value with a smaller value in the label request message. LSRs discover the negotiated values in the label mapping message.

**Label request** - possible downward negotiation

**Label mapping** - no negotiation

<table>
<thead>
<tr>
<th>Res</th>
<th>F6</th>
<th>F5</th>
<th>F4</th>
<th>F3</th>
<th>F2</th>
<th>F1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight Negotiation Flag</td>
<td>EBS Negotiation Flag</td>
<td>CBS Negotiation Flag</td>
<td>CDR Negotiation Flag</td>
<td>PBS Negotiation Flag</td>
<td>PDR Negotiation Flag</td>
<td></td>
</tr>
</tbody>
</table>

### Frequency

- Specifies how frequently the committed rate should be given to CRLSP
- Defined in terms of “granularity” of allocation of rate
- Constrains the variable delay that the network may introduce
- Constrains the amount of buffering that a LSR may use
- Values:
  - Very frequently: no more than one packet may be buffered
  - Frequently: only a few packets may be buffered
  - Unspecified: any amount of buffering is acceptable
Weight

- Specifies the CRLSP’s weight in the “relative share algorithm”

- Implied but not stated:
  - CRLSPs with a larger weight get a bigger relative share of the “excess bandwidth”

- Values:
  - 0 — the weight is not specified
  - 1-255 — weights; larger numbers are larger weights

- The definition of “relative share” is network specific

Peak rate

- The maximum rate at which traffic should be sent to the CRLSP

- Defined by a token bucket with parameters
  - Peak data rate (PDR)
  - Peak burst size (PBS)

- Useful for resource allocation

- If a network uses the peak rate for resource allocation then its edge function should regulate the peak rate

- May be unused by setting PDR or PBS or both to positive infinity
Committed rate

- The rate that the MPLS domain commits to be available to the CRLSP
- Defined by a token bucket with parameters
  - Committed data rate (CDR)
  - Committed burst size (CBS)
- Committed rate is the bandwidth that should be reserved for the CRLSP
- CDR = 0 makes sense; CDR = \(+\infty\) less so
- CBS describes the burstiness with which traffic may be sent to the CRLSP

Excess burst size

- Measure the extent by which the traffic sent on a CRLSP exceeds the committed rate
- Defined as an additional limit on the committed rate’s token bucket
- Can be useful for resource reservation
- If a network uses the excess burst size for resource allocation then its edge function should regulate the parameter and perhaps mark or drop packets
- EBS = 0 and EBS = \(+\infty\) both make sense
Policing Mechanisms

- Token Bucket mechanism, provides a means for limiting input to specified Burst Size and Average Rate.

Three criteria:

- (Long term) **Average Rate** (100 packets per sec or 6000 packets per min?), crucial aspect is the interval length
- **Peak Rate**: e.g., 6000 p p minute Avg and 1500 p p sec Peak
- (Max.) **Burst Size**: Max. number of packets sent consecutively, i.e., over a short period of time
A CR-LSP carries an LSP priority. This priority can be used to allow new LSPs to bump existing LSPs of lower priority in order to steal their resources.

This is especially useful during times of failure and allows you to rank the LSPs such that the most important obtain resources before less important LSPs.

These are called the setupPriority and a holdingPriority and 8 levels are provided.

When an LSP is established its setupPriority is compared with the holdingPriority of existing LSPs, any with lower holdingPriority may be bumped to obtain their resources.

This process may continue in a domino fashion until the lowest holdingPriority LSPs either clear or are on the worst routes.
PREEMPTION A.K.A. BUMPING

Route = \{A,B,C\}

TOPOLOGY DB FOR BUMPING

Topology Database sees 8 levels of bandwidth, depending on the setup priority of the LSP, a subset of that bandwidth is seen as available.

The highest priority sees all bandwidth used and free at levels lower, etc. to the lowest priority which only sees unused bandwidth.
ER-LSP setup using RSVP

1. Path message. It contains ER path = B,C,D.

2. New path state. Path message sent to next node.

3. Resv message originates. Contain the label to use and the required traffic/QoS para.


5. When LER A receives Resv, the ER established.

BASIC DIFFERENCE:
RSVP REFRESHES CONTINUALLY!!

NODE A
PATH
REQUEST
FOREVER!!

NODE B
RESV
MAPPING
THAT’S ALL!!

NODE A
PATH
RESV
REQUEST

NODE B
PATH
RESV
MAPPING

LDP/CR-LDP
PATH
RESV
MAPPING
THAT’S ALL!!
Traffic Engineering

Traffic engineering is the process of mapping traffic demand onto a network

Purpose of traffic engineering:
- Maximize utilization of links and nodes throughout the network
- Engineer links to achieve required delay, grade-of-service
- Spread the network traffic across network links, minimize impact of single failure
- Ensure available spare link capacity for re-routing traffic on failure
- Meet policy requirements imposed by the network operator

Traffic engineering key to optimizing cost/performance

MPLS Traffic Engineering Methods

- MPLS can use the source routing (ER) capability to steer traffic on desired path
- Ingress LSR may be config with the path, RSVP used to set up LSP (extend RSVP for MPLS path set-up)
- Ingress may use CR-LDP to set up LSP (many vendors believe RSVP not suited)
- Ingress LSR may be config with one or more LSRs along the desired path, hop-by-hop routing used to set up rest of the path (a.k.a loose source routing, less configuration required)

- In the future, constraint-based routing will offload traffic engineering tasks from the operator to the network itself
Hybrid Switches

MPLS Summary

- MPLS is a connection-oriented technology
- MPLS decouples routing and forwarding
- MPLS overcomes the shortest path routing problems.
- MPLS enables QoS routing.
- MPLS enables efficient explicit routing.
MPLS Applications

- Constraint-based routing (CR)
  - Routing based on QoS, policy, …
- Traffic Engineering (TE)
  - Routing based on optimizing usage of network resources.
- Fast protection switching (P/SW)
- Network-based VPN
- IP over ATM
- Controlling optical network

Conclusion

- Current IP networks don’t support QoS and TE
- Intserv and Diffserv adds QoS capability
- MPLS adds the TE capability
- MPLS enables fast protection switching
- MPLS enables scalable VPN
- MPLS is the glue between IP and ATM
- MPLS is the glue between IP and optical networks.