Introduction to Multiprotocol Label Switching (MPLS)

An MFA Forum Sponsored Tutorial

About This Tutorial

- Introductory level
  - Expected: basic understanding of IP networking
- Context
  - MPLS fundamentals
  - Technical focus
- Target audience
  - Service providers
  - Network operators and designers
  - End customers

Introduction to MPLS - Agenda

MFA FORUM

1. Introduction to the MFA Forum
2. MPLS Architecture and Protocols
3. Traffic Engineering with MPLS
4. MPLS Applications

Presenters

MFA FORUM

- Sections 1 and 2
  - Victoria Fineberg
    - Department of Defense, DISA Office of the CTO
    - MFA Forum Ambassador
    - Victoria.Fineberg@DISA.mil
- Sections 3 and 4
  - David Christophe
    - Lucent Technologies
    - MFA Forum Education Working Group Chair dchristophe@lucent.com

Section 1:
Introduction to the MFA Forum

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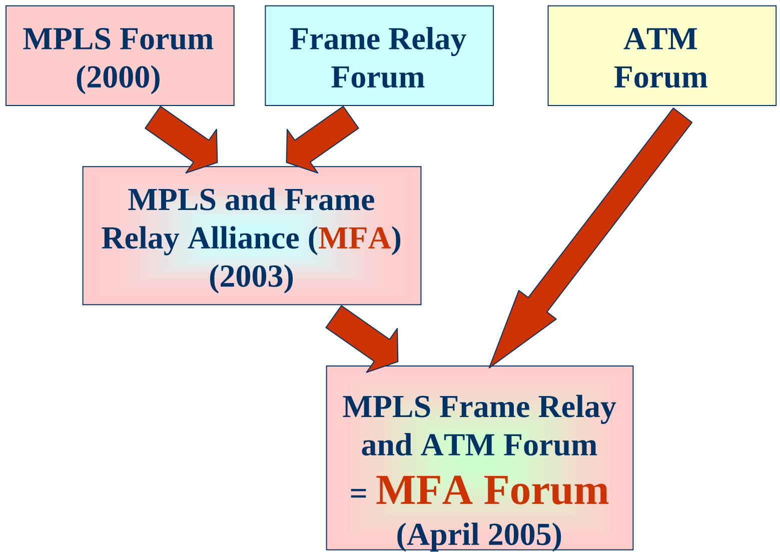
MFA Forum Mission

An international, industry-wide, non-profit association of telecommunications, networking, and other companies focused on advancing the deployment of multi-vendor, multi-service packet-based networks, associated applications, and interworking solutions.

MFA Forum Evolution



MFA Forum Composition

- 39 members
- Committees
  - Marketing Awareness and Education (MAE) committee
  - Technical Committee (TC)
    - Applications and Deployment Working Group
    - ATM Architecture Working Group
    - ATM Signaling Working Group
    - Interoperability Working Group
    - Interworking and Frame Relay Working Group
  - Service Provider Council (SPC)
  - MPLS User Group (MUG)
- Andrew G. Malis, Chairman and President
  - MFA presentation at MPLSCon on 23 May 2006

MFA Forum Education

- Marketing Awareness and Education
  - Tutorials

➢ Introduction to MPLS	½ day and full day
➢ MPLS VPNs and VPLS	½ day and full day
➢ MPLS VPN Security	½ day
➢ Traffic Engineering	½ day
➢ GMPLS	½ day
➢ Migrating Legacy Services to MPLS	½ day
➢ MPLS OAM	½ day
➢ Voice over MPLS	½ day

    - ➢ New tutorials based upon demand
  - Conferences and exhibitions
    - ➢ MFA Forum speaker at almost every MPLS conference globally
  - Website and Newsletter
  - Public message board
- Next meeting: June 27-29 in Vancouver, BC, Canada
- Please join us!
  - Subscribe to information mail list info@mfaforum.org
  - Contact Alexa Morris, Executive Director
    - ➢ E-Mail: amorris@mfaforum.org Phone: 510-608-5914

For More Information. . .

- http://www.mfaforum.org
- http://www.ietf.org
- http://www.itu.int
- http://www.mplsrc.com

For questions, utilize the MFA Forum message board

Website: http://www.mfaforum.org/board/

Section 2:
MPLS Architecture and Protocols

Section-2 Agenda

- MPLS Basics
  - Overview of data delivery and protocols
  - MPLS drivers and features
- Traditional Routing
  - Overview
  - Data Plane and Control Plane
- MPLS Architecture
  - MPLS terminology and operation
  - Label Distribution Protocol (LDP)
  - Penultimate Hop Popping, Aggregation, TTL

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Data Delivery

- Switching methods
  - **Circuit**-switching, e.g.:
    - circuit-switched voice
  - **Packet**-switching, e.g.:
    - packet-switched data
- Types of connectivity
  - Connection-**less**, e.g.:
    - IP, IPX, Ethernet
  - Connection-**oriented**, e.g.:
    - Frame Relay, ATM, MPLS
- MPLS offers unifying multi-service features of a packet-based technology in a connection-oriented environment.

Datagram Delivery: *Connection-less Routing*

- Analogy: a mail system operation:
  - each time a letter is sent it can travel a different path towards the destination.
  - each office reads the address and forwards it to the next post office by the most expeditious path on that leg.
- Mail system characteristics:
  - different arrival times, mis-ordering on arrival, hard to impose differentiated performance, but
  - very resilient to outages of single office as easy reroute in transit to other paths.
- Internet has adopted a connection-less IP approach – analogous to a mail system. Features:
  - immediate and easy connectivity to everyone
  - very resilient to individual node failures
  - rerouting task is shared across the network.

Datagram Delivery: *Connection-Oriented Routing*

- Analogy: a telephone system operation:
  - first: each call is setup
    - dial digits; signaling to reserve a path
  - then: can talk
    - voice conversation travels along the same path: same wires and same offices.
- Phone system characteristics:
  - very precise ordering of arrival; exact, predefined delays; quality can be pre-set on individual connections; suitable for engineering and control contracts and billing, but
  - not as suitable to any-to-any connectivity as must always pre-set a path (time consuming)
  - not as resilient to node and link failures – must re-set all connections on a failed link (time consuming).
- Service Providers (SP) offering service guarantees adapted a connection-oriented approach, e.g.:
  - Frame Relay and ATM for voice and video

Connection-less vs. Connection-Oriented

- Differences in:
  - routing protocols deployed
  - applications served
- Connection-less datagram delivery:
  - Examples: IP, IPX, AppleTalk, DECnet, bridging, etc.
  - Routing Protocols: OSPF, ISIS, BGP4
  - Deployment: IP for Internet / Intranet / Extranet
- Connection-oriented datagram delivery:
  - Examples: Frame Relay, ATM, SNA, CS Voice, MPLS
  - Routing Protocols: proprietary, PNNI, SS7, OSPF, ISIS
  - Deployment: FR, ATM, Voice, MPLS

MPLS employs same routing protocols as IP. MPLS technology can be more easily implemented wherever IP is deployed

IP vs. MPLS Delivery

	Circuit-switching	Packet-switching
Connection-oriented	Voice	MPLS
Connection-less		IP

• MPLS offers unifying multi-service features of a packet-based technology in a connection-oriented environment
• Connection-oriented environment is a foundation for TE, rerouting, QoS

MPLS Definition

- Multiprotocol Label Switching (MPLS) is a network technology that enables network operators to implement a variety of advanced network features, both to serve their customers and to enhance their own network utilization.
- These features are a result of the transformation of the connectionless per-hop behavior of an Internet Protocol (IP) network into a connection-oriented forwarding along MPLS Label Switched Paths (LSP).
- MPLS operates over enhanced IP routers, using enhanced IP protocols and leveraging IP Operations Administration and Management (OAM) systems. Thus, MPLS can be viewed as an extension of IP, rather than its replacement.
- MPLS works with both IPv4 and IPv6, it is complementary to IPv6 and can facilitate the IPv6 transition.

Label-Switching and MPLS

- Concept of "Label Switching" has been with the industry for over 20 years.
- Operation: add an independent "label" to user's packets and use this label to forward the packets through the network.
- Primary advantages of labels in initial schemes:
  - label can be precisely controlled
  - hardware and software can be optimized around the label
- Examples of a label-switching technique in connection-oriented services: ATM, Frame Relay.
- MPLS is also a "labeling scheme" but the principal difference is that MPLS uses the same routing and end-point addressing schemes as IP.

MPLS History

- Early multi-layer switching initiatives:
  - IP Switching (Ipsilon / Nokia)
  - Tag Switching (Cisco)
  - IP Navigator (Cascade/Ascend/Lucent)
  - ARIS (IBM)
- IETF MPLS Working Group (WG) was chartered in spring 1997 with the following goals:
  - enhance performance and scalability of IP routing
  - facilitate explicit routing and traffic engineering
  - separate control (routing) from the forwarding mechanism so each can be modified independently
  - develop a single forwarding algorithm to support a wide range of routing functionality
- Now:
  - several IETF WGs related to MPLS, many RFCs and I-Ds
  - MPLS, Frame Relay and ATM Forum (MFA Forum)
  - MPLS work in the ITU-T

Technical Significance of MPLS

- MPLS enables Traffic Engineering (TE)
  - placing traffic where network resources are, improving network utilization
  - fast reroute, diverse routing, load balancing, and other protection mechanisms
- MPLS allows Service Providers (SP) to offer advanced SLAs and guarantee QoS in otherwise connectionless IP networks
- MPLS is versatile ("multi-protocol")
  - works over all major Layer-2 technologies in the backbone
  - allows to interconnect various Layer-2 networks at the edge
  - supports various Layer-3 protocols (IPv4, IPv6, IPsec)
- MPLS provides mechanisms for Layer-2 and Layer-3 Virtual Private Networks (VPN)
  - logical separation by customer (common commercial application)
  - logical separation by security level
- MPLS can serve as an IPv6 transition mechanism
- GMPLS (Generalized MPLS) extends the MPLS control plane across optical and legacy networks

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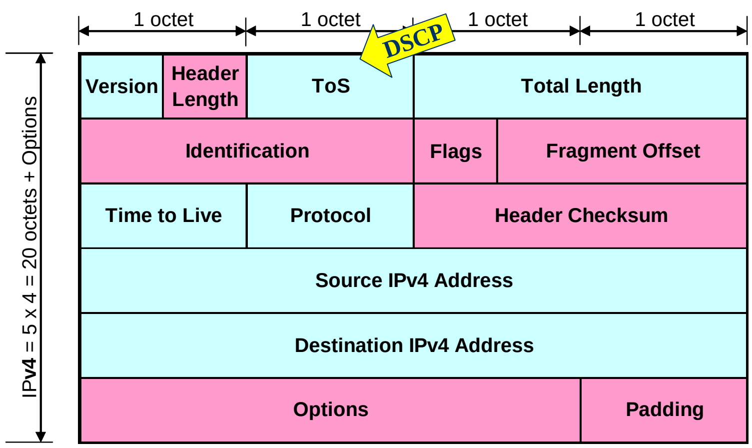
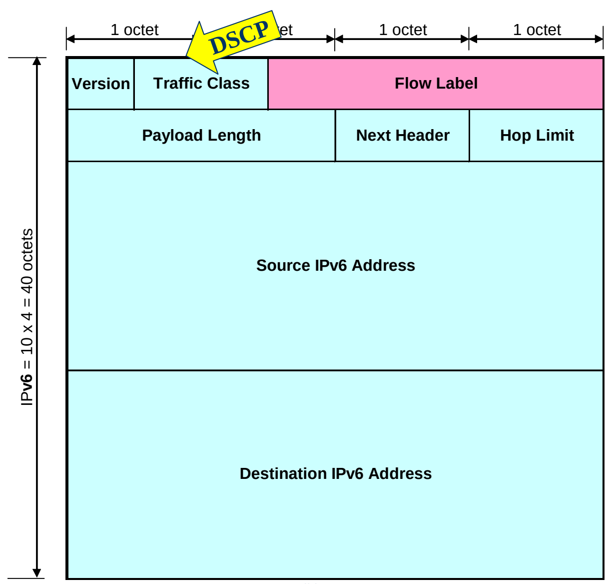
IPv4 Header

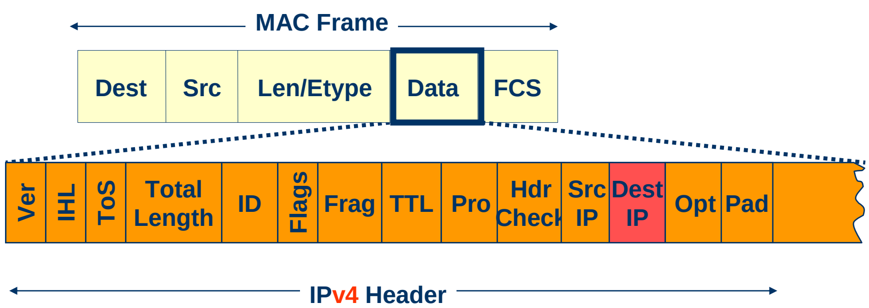


IPv6 Header

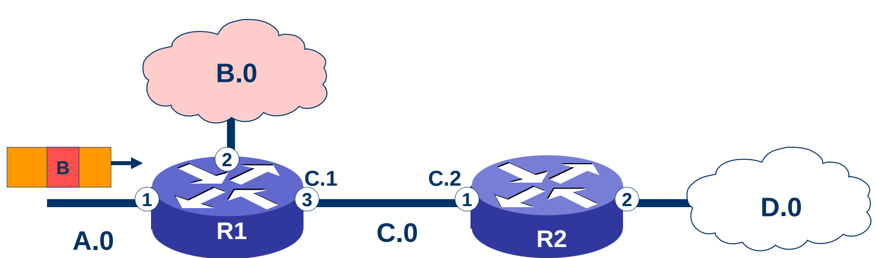


Traditional IP Routing

- Router examines the <u>destination IP address</u> for each packet received (strict interpretation of connectionless routing)

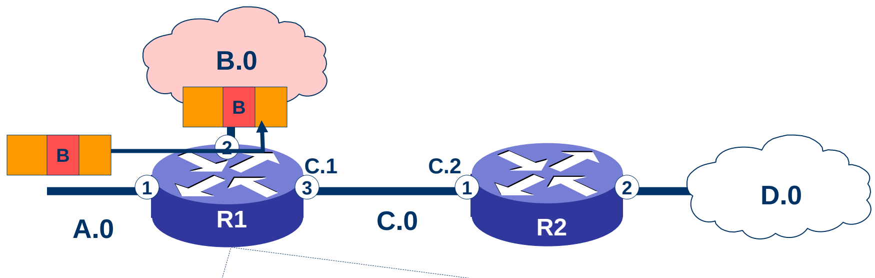


Case 1: Direct Route (1 of 2)



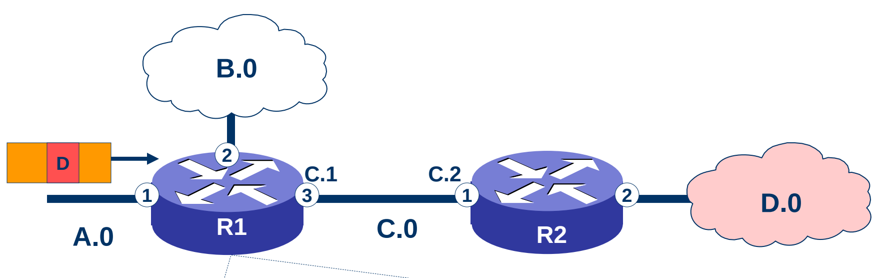
Dest.	Next Hop	Cost	Port
A.0	direct	0	1
B.0	direct	0	2
C.0	direct	0	3
D.0	C.2	1	3

Case 1: Direct Route (2 of 2)



Dest.	Next Hop	Cost	Port
A.0	direct	0	1
B.0	direct	0	2
C.0	direct	0	3
D.0	C.2	1	3

Case 2: Indirect Route (1 of 3)



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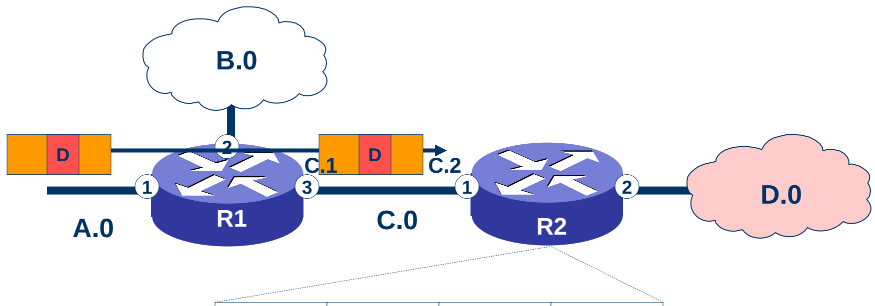
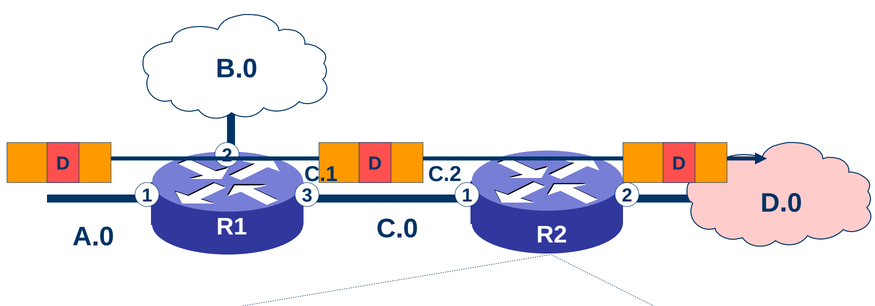


Dest.	Next Hop	Cost	Port
A.0	C.1	1	1
B.0	C.1	1	1
C.0	direct	0	1
D.0	direct	0	2

Case 2: Indirect Route (3 of 3)



Dest.	Next Hop	Cost	Port
A.0	C.1	1	1
B.0	C.1	1	1
C.0	direct	0	1
D.0	direct	0	2

Per-Hop Routing:
Three Important Questions

- **Q: What packet header field do we use to make the forwarding decision?**
- **Q: When we use this field as an index into the Routing Table, what do we look up?**
- **Q: What other vital piece of information does the Routing Table contain?**

Per-Hop Routing:
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Per-Hop Routing:
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  - A: The next hop IP address
- Q: What other vital piece of information does the Routing Table contain?
  - A: An internal reference to the output interface

How are Routing Tables Populated?

- Option 1: Direct Routes
  – Router is directly connected to this network
  – Port addresses and directly connected networks are provisioned in a router
- Option 2: Manually
  – Static routes
- Option 3: Automatically
  – Interior and Exterior Gateway (Routing) Protocols
    - IGP: RIP, OSPF, ISIS
    - EGP: BGP
- Option 4: Default Route

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Drawbacks of Conventional Routing

- Performance
  – ***In the past***, routing was perceived as processor-limited
    - each forwarding decision could required ~1000 machine instructions
    - longest prefix match was difficult to transfer to silicon
  – ***Today***, wire-speed routing is regularly performed in the silicon
- Connectionless IP does not support Traffic Engineering (TE)
  – the "hyper aggregation problem“
  – cannot provide Fast Reroute and other protection mechanisms
  – cannot provide load balancing, path redundancy and other advanced routing topologies
- Difficulty of implementing QoS

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The Hyper Aggregation Problem

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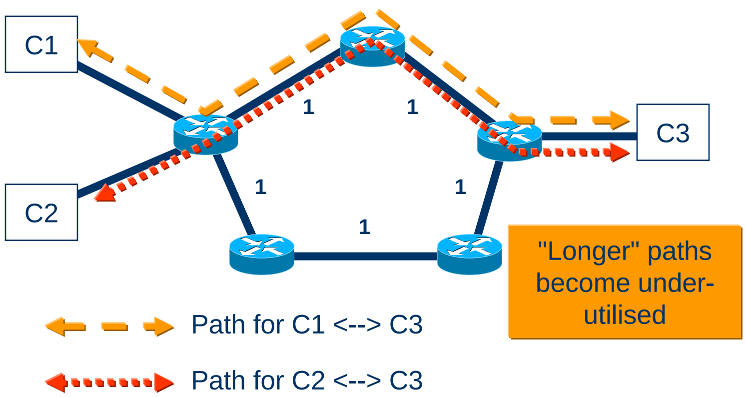
- Routing protocols create a single “shortest path"



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OSPFv2 Metric

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RFC2328/STD54 “OSPF Version 2,” April 1998:

- **Cost of a route:**
  - described by a single dimensionless metric
  - associated with a router egress interface
  - configurable by the system administrator
- **Selection of a route:**
  - the lower the cost, the more likely the interface is to be used to forward data traffic

Cost calculations do not take into account the already existing traffic on a link

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OSPF Cost in Routers

- Default:
  - Cost = Reference BW / Actual BW
  - Default Reference BW = 100 Mbps
  - Examples:
    - ✓ for 10 Mbps, cost = 100 Mbps / 10 Mbps = 10
    - ✓ for 2 Mbps, cost = 100 Mbps / 2 Mbps = 50
  - Lower-cost links are selected, i.e., 10 Mbps link has a lower cost and would be selected over 2 Mbps (i.e., 10 < 50)
- User-specified:
  - Default Reference BW: <u>ospf auto-cost reference-bandwidth</u>
  - Cost: <u>ip ospf cost <cost></u>

Cost calculations do not take into account the already existing traffic on a link

Data Plane vs. Control Plane

- Data Plane carries user information
- Control Plane creates the paths over which the Data Plane operates
- IP:
  - <u>Data Plane:</u> routing table lookup for egress interface
  - <u>Control Plane:</u> routing protocols
- ATM:
  - <u>Data Plane:</u> ATM header lookup
  - <u>Control Plane:</u> PNNI
- MPLS:
  - <u>Data Plane:</u> label pushing, swapping and popping
  - <u>Control Plane:</u>
    - ✓ extended routing protocols (e.g., ISIS-TE)
    - ✓ label distribution protocols (e.g., RSVP-TE)
    - ✓ discovery protocols (e.g., BGP)

Network Engineering vs. Traffic Engineering

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- Network Engineering
  - "Put the ***bandwidth*** where the ***traffic*** is"
    - physical cable deployment
    - virtual connection provisioning
- Traffic Engineering
  - "Put the ***traffic*** where the ***bandwidth*** is"
    - on-line or off-line optimisation of routes
    - ability to diversify routes

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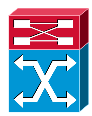
Label Switching Router (LSR)

- Label Switching Router (LSR) is a device that forwards:
  - labeled packets - using label only
  - un-labeled (native IP) packets - regular “un-engineered" IP routing
- Router-based LSR

- ATM-based LSR



Types of LSRs

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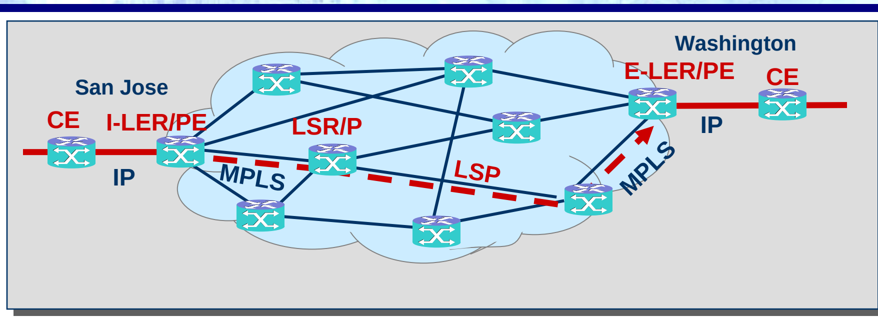
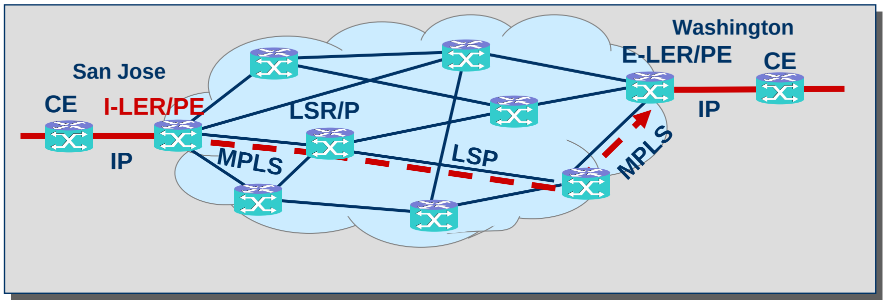


- **LSR** = Label Switching Router - router or switch that handles MPLS and IP traffic; **swaps** labels
  - **P** = Provider router, VPN term for LSR
- **LER** = Label Edge Router - LSR at the edge of MPLS networks
  - **I-LER** = Ingress LER - classifies unlabeled IP packets and **pushes** labels
  - **E-LER** = Egress LER - **pops** labels and routes unlabeled IP packets
  - **PE** = Provider Edge, VPN term for LER
- **LSP** = Label Switched Path – **unidirectional** path between I-LER and E-LER

LSRs participate in IP routing and MPLS control protocols

Ingress LER (I-LER)



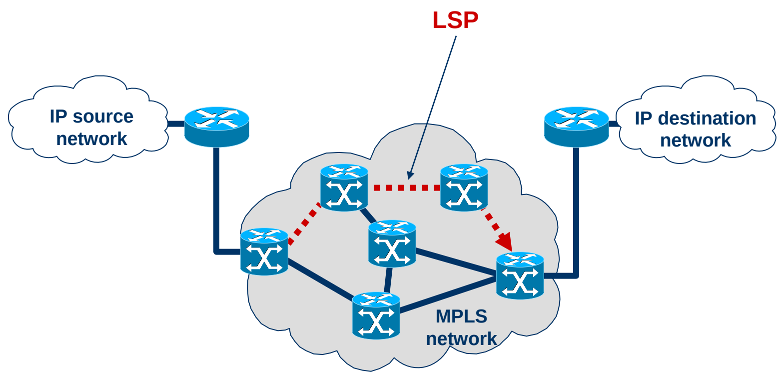
- Is upstream from all other LSRs in the LSP
- Examines inbound IP packets
- Classifies each packet into a Forwarding Equivalence Class (FEC)
- Generates an MPLS header and assigns (binds) the initial label
- In the Control Plane, I-LER may be responsible for initiating a label distribution protocol, constraint-based routing, pruning and other functions (and many additional functions in L2 and L3 VPNs)

Forwarding Equivalence Class (FEC)

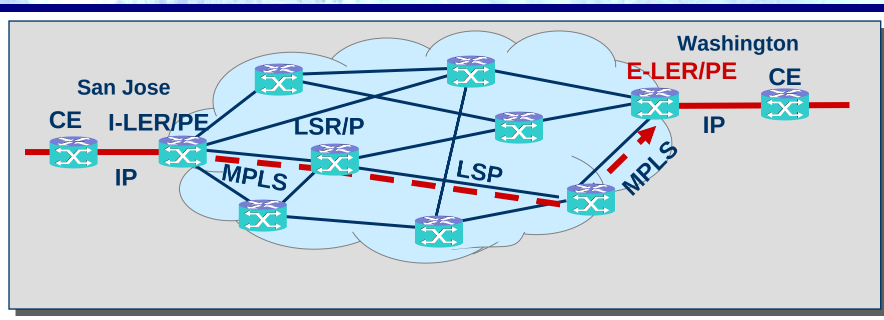
- FEC is
  - a “class” (“C”)
  - this class is formed based on the equivalence in forwarding, i.e., “forwarding equivalence”
- Flow (stream, traffic trunk) of IP packets:
  - forwarded over the same path (LSP)
  - treated in the same manner
  - mapped to the same label
    - multiple flows may be mapped to the same FEC
- FEC-to-label binding mechanism
  - binding is done once, at the ingress
  - usually based on the destination IP address prefix
  - future mappings based on SP-defined policy

Label Switched Path (LSP)

- LSP is the path followed by labeled packets that are assigned to the same FEC



Egress LER (E-LER)



- Is downstream from all other LSRs in the LSP
- Removes the MPLS header - unless the Penultimate Hop (PH) router has already removed it
- Processes traffic as it leaves the MPLS domain - based on the packet's destination IP address
- In the Control Plane, E-LER may be responsible for initiating a label distribution and other functions (and many additional functions in L2 and L3 VPNs)

Shim Header Structure – *Diagram*

OSI Layers →

MPLS "Shim" Header = 32 bits / 4 octets

L2 Header	**Label** (unstructured)	**Exp**	**S**	**TTL**	IP Header	IP Data
	20	3	1	8		

- **Label**
  - ✓ **short, fixed-length packet identifier**
  - ✓ **unstructured**
  - ✓ **link-local significance**
- **"Label stacking" means shim header stacking**

Shim Header Structure – *Description*

- **L2 header (below MPLS)**
  - **"L3 type" (e.g., "Ethertype" in Ethernet, or "Protocol ID" in PPP) indicates MPLS, but not whether it carries IPv4 or IPv6**
  - **different indicators are used for MPLS unicast and MPLS multicast**
- **Label = locally significant key into the switching table for packet forwarding (forwarding semantics and *possibly* resource reservation semantics)**
- **Exp = a field for experimental use**
  - **Exp can be used to map Precedence markings from ToS / DiffServ (resource reservation semantics)**
  - **custom mappings from DSCP to Exp can be defined**
- **S = an indicator of the MPLS label stack (stack of 32-bit words) (S=1 indicates the bottom of the stack)**
- **TTL = Time To Live**
  - **parameter used for loop prevention**

Reserved Label Values

- Reserved label values (RFC3032; updated in RFC4182):
  - 0 - IPv4 Explicit NULL
    - ✓ Old: works only for the bottom of the stack (S = 1)
    - ✓ New: anywhere in the stack
    - ✓ a router pops the label and forwards an IPv4 packet
  - 1 - Router Alert
    - ✓ works only when *not* the last label on the stack (S = 0)
    - ✓ a router pops this label, looks at the label below it and follows the instructions
  - 2 - IPv6 Explicit NULL (similar to 0 above)
  - 3 - Implicit NULL
    - ✓ distributed in the Control Plane but does not appear in the Data Plane

Break 1000-1010

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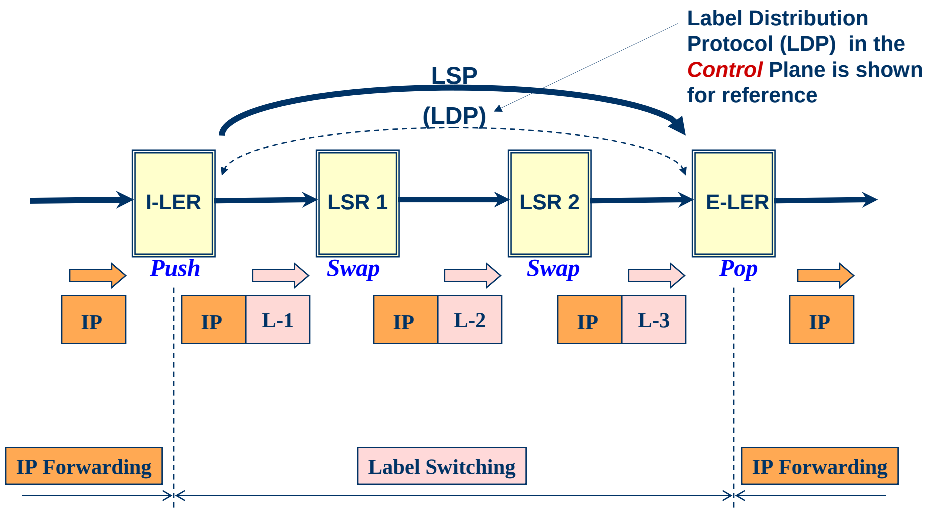
MPLS *Data* Plane Operation



Steps in the MPLS Process

- Topology determination
- Path creation
- Data forwarding

Steps in the MPLS Process

- **Topology determination**
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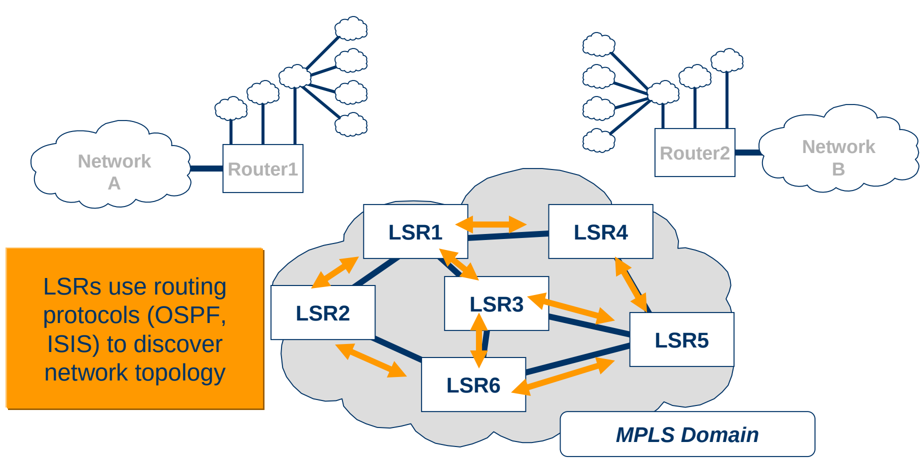
Topology Determination
What Happens When We Switch on?



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Topology Determination

What Happens When We Add IP Networks?

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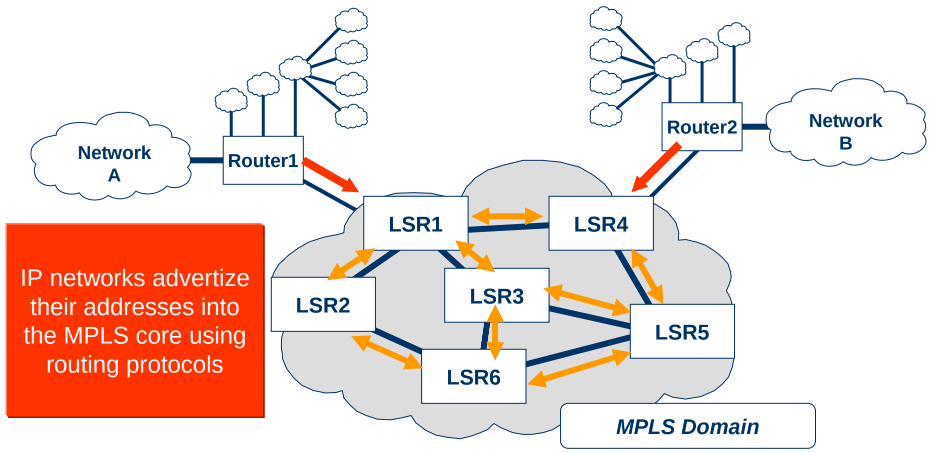

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Steps in the MPLS Process

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- Topology determination
- **Path creation**
- Data forwarding

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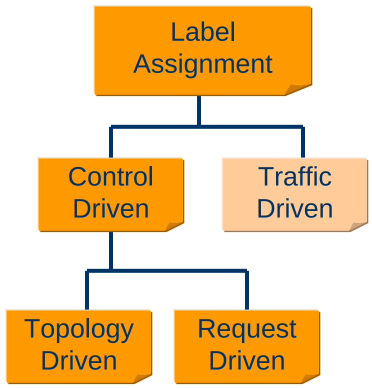
Label Assignment and Distribution



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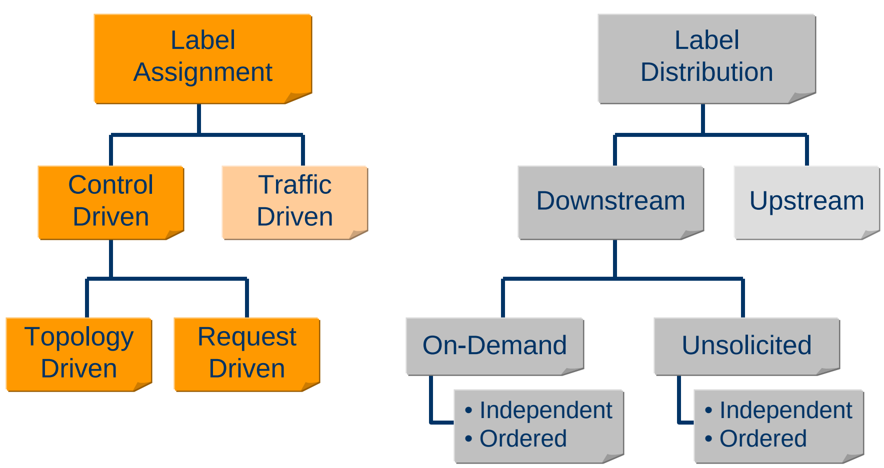
Label Assignment and Distribution



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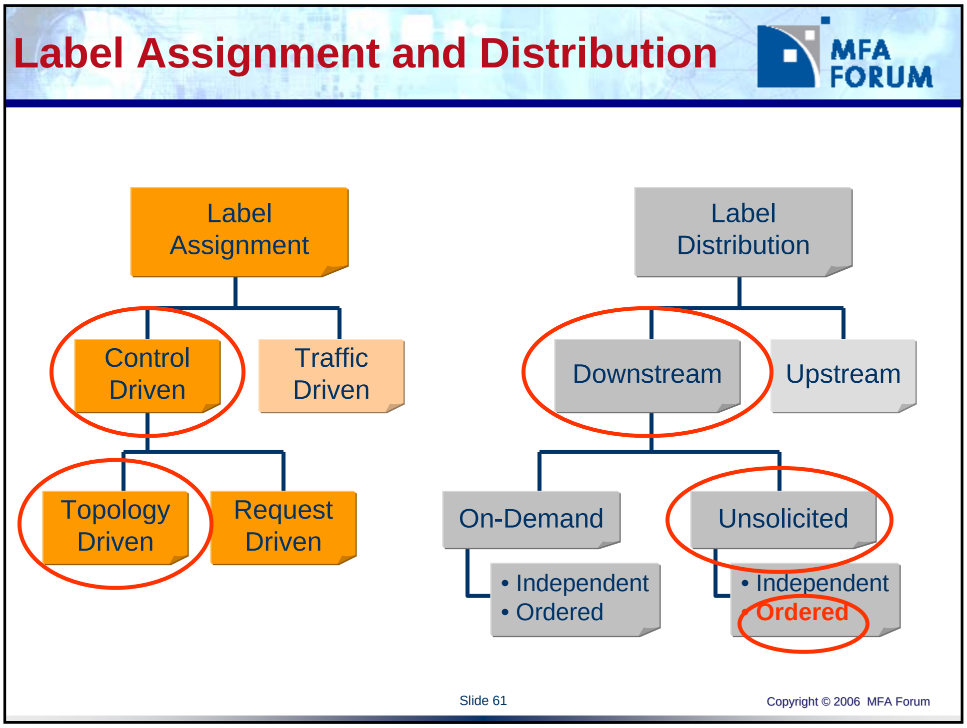
Label Assignment and Distribution
MFA FORUM
Label Assignment
Control Driven
Traffic Driven
Topology Driven
Request Driven
Label Distribution
Downstream
Upstream
On-Demand
• Independent
• Ordered
Unsolicited
• Independent
• Ordered
Slide 61
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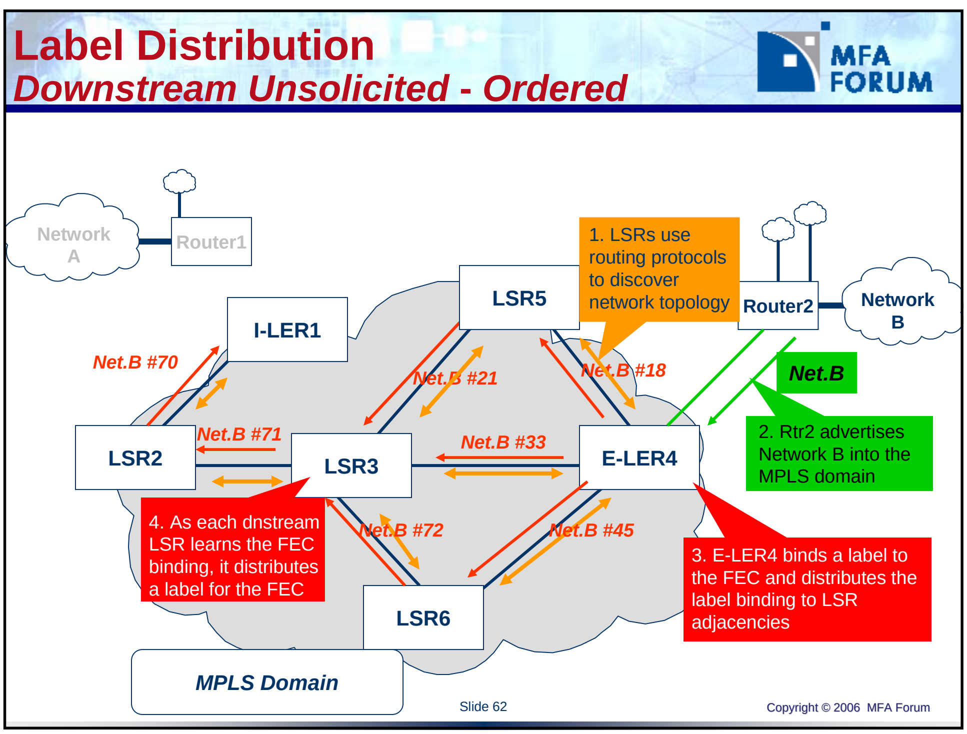
Label Distribution
Downstream Unsolicited - Ordered
MFA FORUM
Network A
Router1
I-LER1
LSR5
1. LSRs use routing protocols to discover network topology
Router2
Network B
Net.B #70
Net.B #21
Net.B #18
Net.B
LSR2
Net.B #71
LSR3
Net.B #33
E-LER4
2. Rtr2 advertises Network B into the MPLS domain
4. As each dnstream LSR learns the FEC binding, it distributes a label for the FEC
Net.B #72
Net.B #45
3. E-LER4 binds a label to the FEC and distributes the label binding to LSR adjacencies
LSR6
MPLS Domain
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Downstream Unsolicited - *Ordered*

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Downstream Unsolicited

- LSR1 and LSR2 have an "LDP adjacency"
- In the *Data* Plane: LSR1 is upstream; LSR2 is downstream
- LSR2 discovers the 'next hop' for a particular FEC
- LSR2 (a downstream router) generates a label for the FEC and communicates the binding to LSR1 (without solicitation from LSR1)
- LSR1 inserts the binding into its forwarding table
- If LSR2 is the next hop for the FEC, LSR1 can use that label knowing that its meaning is understood

Ordered Control

- Label-FEC binding is communicated to upstream peers if:
  - ✓ an LSR is the egress LSR for a particular FEC
  - ✓ label binding for this FEC has been received from a downstream LSR
- LSP formation 'flows' from egress to ingress, in order

Label Assignment and Distribution

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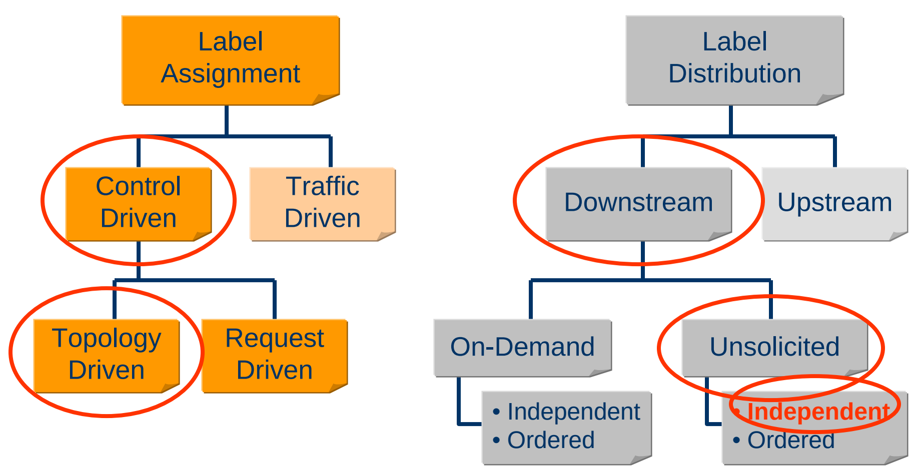
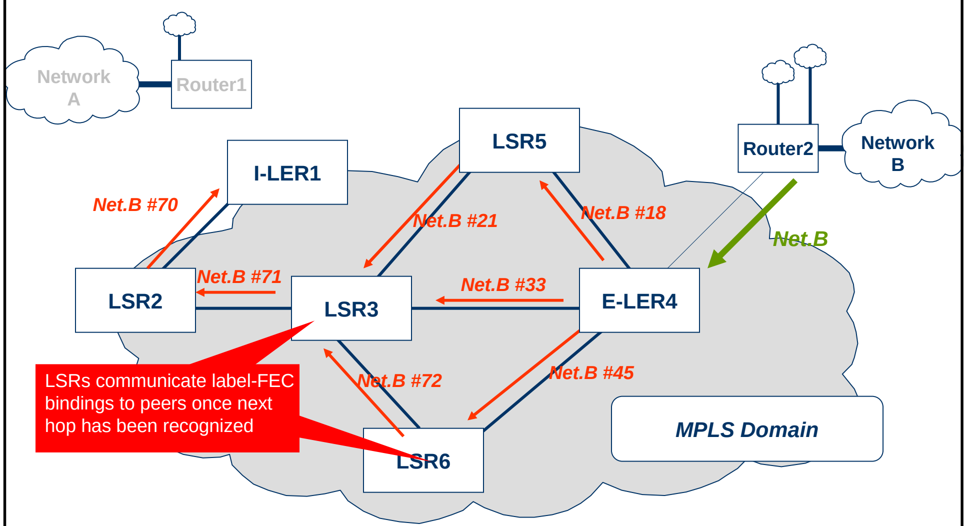


Label Distribution
Downstream Unsolicited - Independent



Downstream Unsolicited - *Independent*

Downstream Unsolicited

- LSR1 and LSR2 have an "LDP adjacency"
- In the *Data* Plane: LSR1 is upstream; LSR2 is downstream
- LSR2 discovers the 'next hop' for a particular FEC
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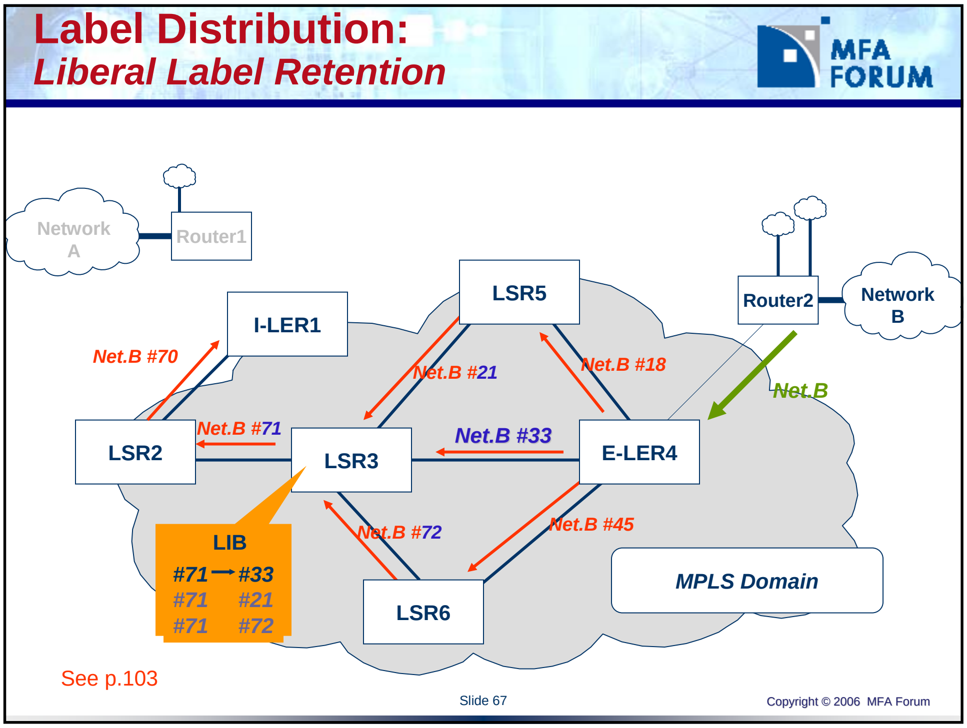
- LSR1 inserts the binding into its forwarding table
- If LSR2 is the next hop for the FEC, LSR1 can use that label knowing that its meaning is understood

Independent Control

- Each LSR makes independent decisions on when to generate labels and communicate them to upstream peers
- Communication of label-FEC binding to peers is done once next-hop has been recognized, without an order
- LSP is formed as incoming and outgoing labels are spliced together



Label Distribution:
Liberal Label Retention
MFA FORUM
Network A
Router1
Router2
Network B
I-LER1
LSR5
LSR2
LSR3
E-LER4
LSR6
Net.B #70
Net.B #21
Net.B #18
Net.B
Net.B #71
Net.B #33
Net.B #72
Net.B #45
LIB
#71 → #33
#71 #21
#71 #72
MPLS Domain
See p.103
Slide 67
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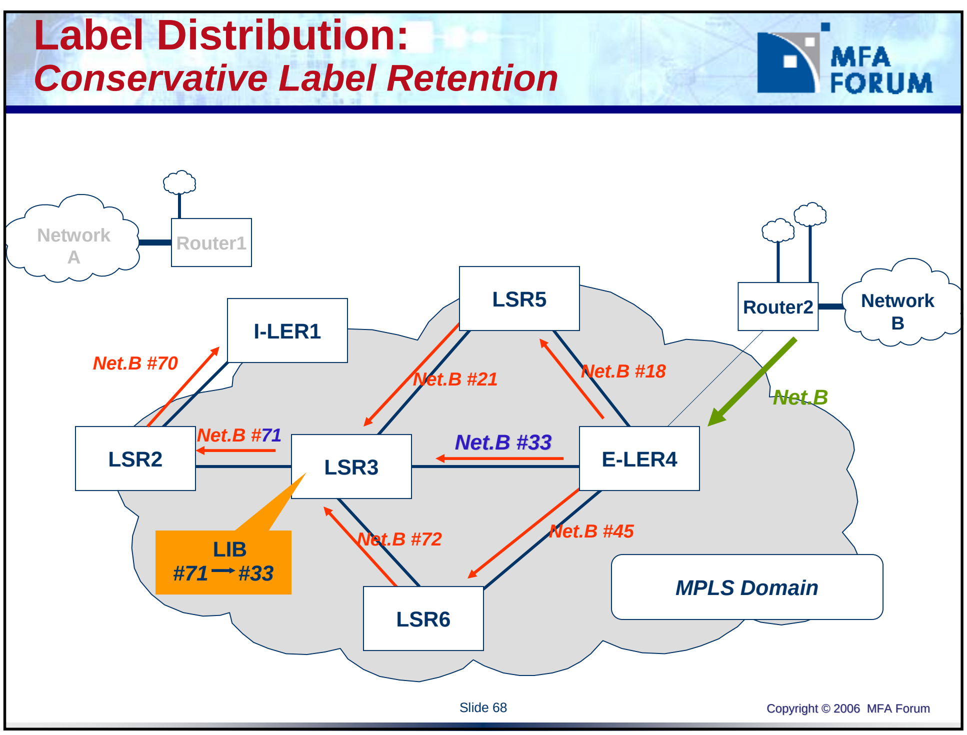

Label Distribution:
Conservative Label Retention
MFA FORUM
Network A
Router1
Router2
Network B
I-LER1
LSR5
LSR2
LSR3
E-LER4
LSR6
Net.B #70
Net.B #21
Net.B #18
Net.B
Net.B #71
Net.B #33
Net.B #72
Net.B #45
LIB
#71 → #33
MPLS Domain
Slide 68
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Liberal vs. Conservative Label Retention

Liberal

- LSR maintains bindings received from LSRs <u>other than the valid</u> next hop (for a given FEC)
- If the next-hop changes, LSR may begin using existing bindings immediately
- Rapid adaptation to routing changes
- LSR must maintain many labels

Conservative

- LSR only maintains only the binding received from the <u>valid</u> next hop (for a given FEC)
- If the next-hop changes, LSR must request a binding from the new valid next hop
- Restricted adaptation to routing changes
- LSR can maintain fewer labels

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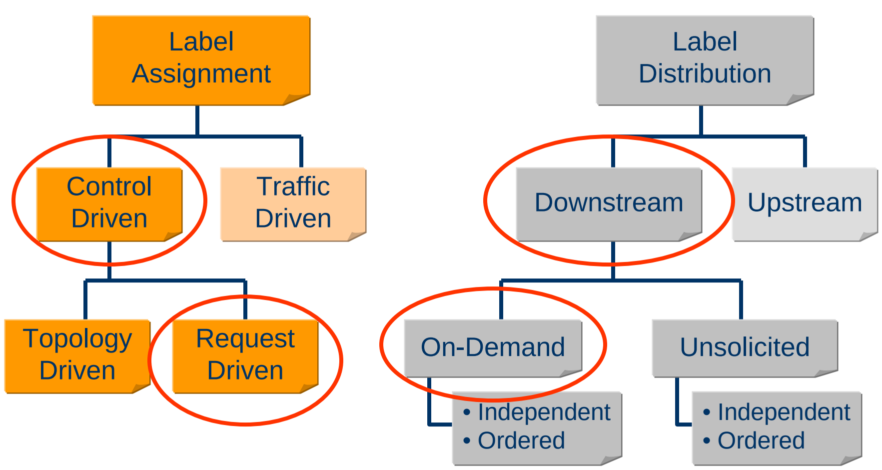
Label Assignment and Distribution



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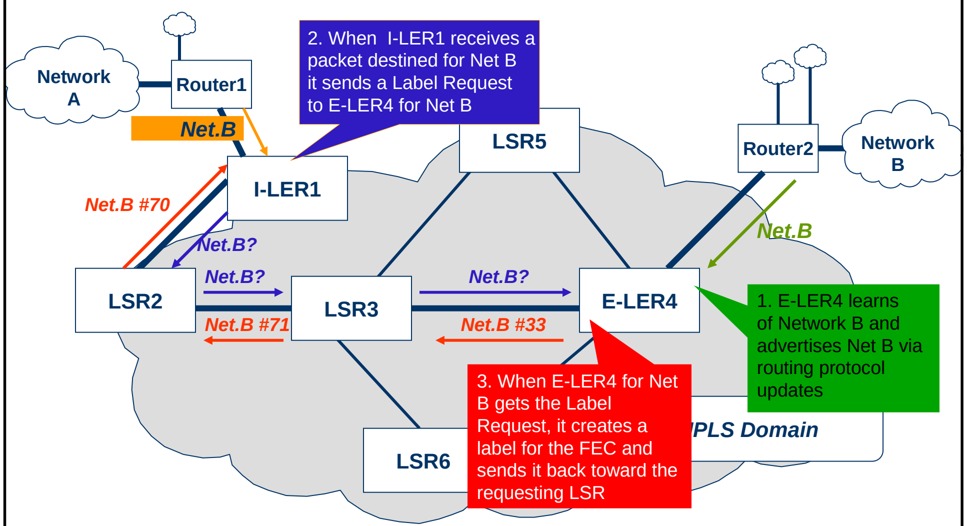
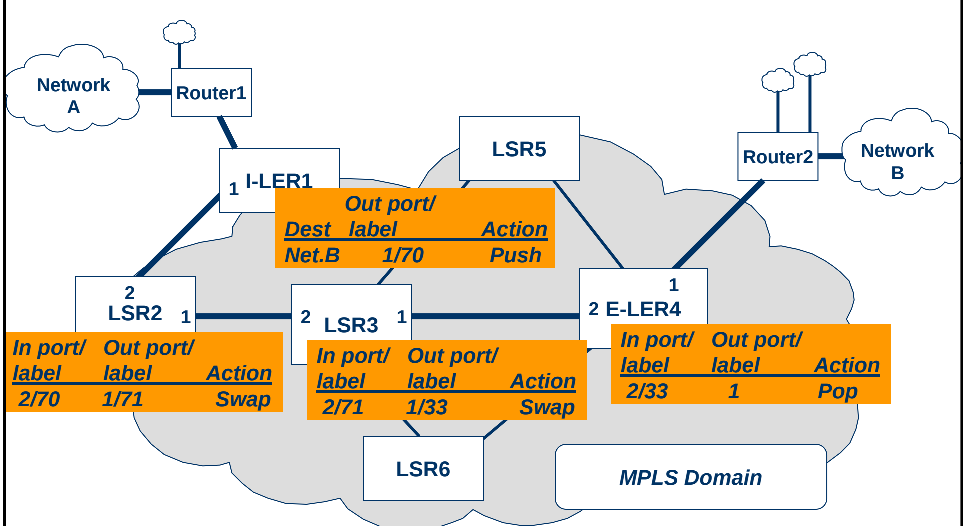
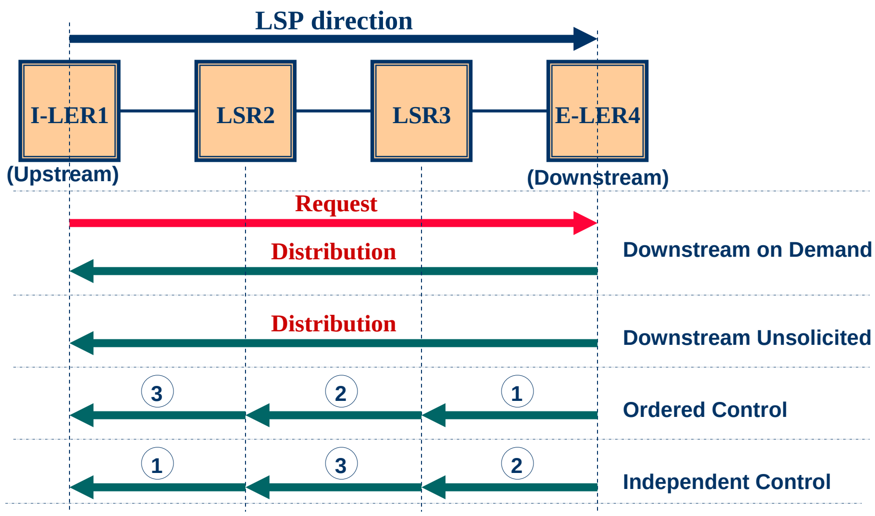
Label Distribution: *Downstream-on-Demand*



Label Switched Path – *Created*



Label Distribution Scenarios
Summary



Label Management Options Supported by LDP

- Label distribution
  - Downstream Unsolicited = downstream LSR advertises FEC-to-Label bindings without being asked ("push")
  - Downstream On Demand = downstream LSR distributes labels on demand ("pull")
- Control mode of label advertisements
  - Ordered control = a label binding is sent only after one is received from the next hop (or if it is an E-LER)
  - Independent control = LSR decides when to send label bindings
- Label retention
  - Liberal = old labels are stored even if they are not used
  - Conservative = store only the labels for the immediate use
- Selection of the label management options depends on the size of the label space (e.g., MPLS over ATM may have a small label space) and other considerations

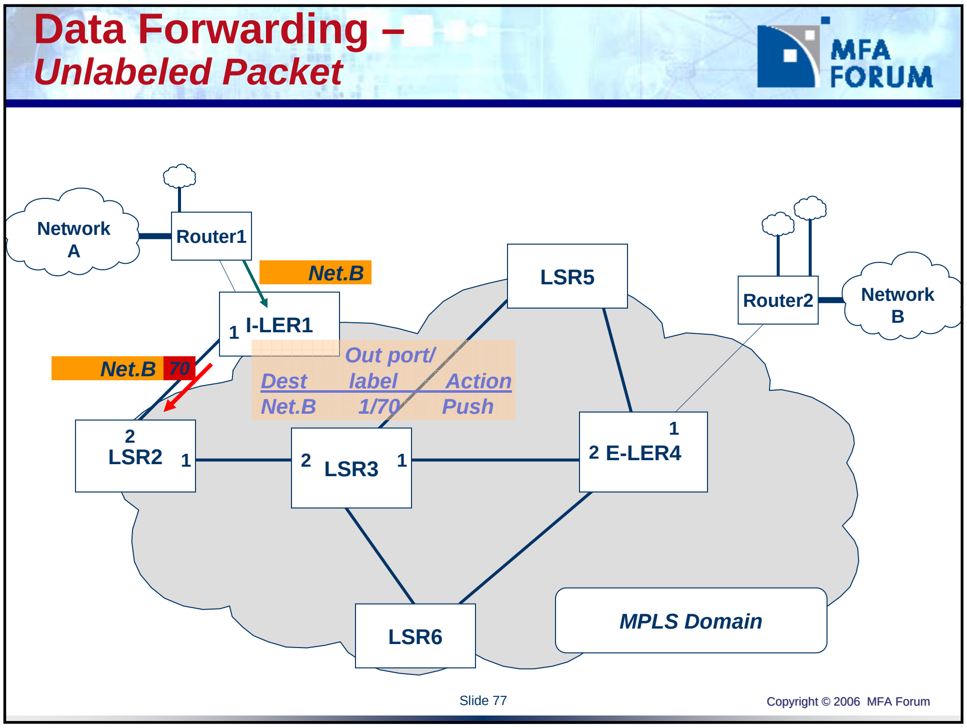
Label Distribution Scenarios

- Downstream *Unsolicited* with *Ordered* Control
  - E-LER initiates label distribution
  - label distribution proceeds from E-LER to I-LER
  - trigger by a change in the routing table or a timer
- Downstream *Unsolicited* with *Independent* Control
  - various LSRs independently send labels to their upstream peers
  - fast convergence
- Downstream *on Demand* with *Ordered* Control
  - I-LER starts label requests
  - E-LER starts label distribution
- Note that *RSVP-TE* supports only Downstream *on Demand* with *Ordered* Control
- LDP was designed specifically to accommodate a variety of label distribution scenarios

Steps in the MPLS Process

- Topology determination
- Path creation
- **Data forwarding**

Let's look at a "day in the life" of a packet...


Data Forwarding –
Unlabeled Packet
MFA FORUM
Network A
Router1
Net.B
I-LER1
1
LSR5
Router2
Network B
Net.B 70
Out port/
Dest label Action
Net.B 1/70 Push
2
LSR2 1
2 LSR3 1
1
2 E-LER4
LSR6
MPLS Domain
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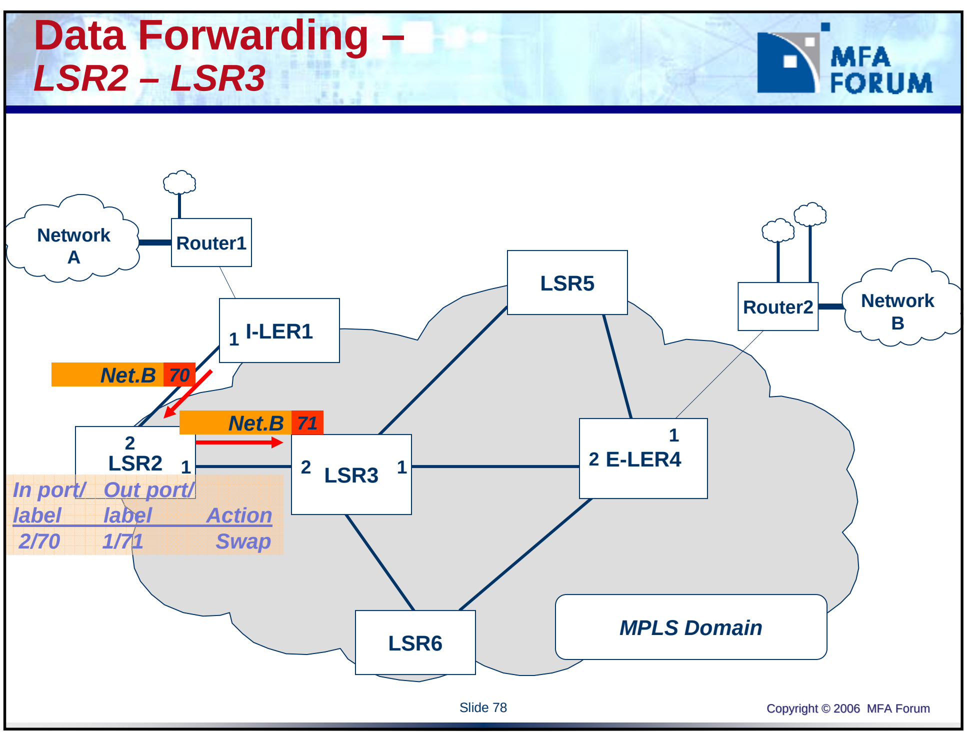
Data Forwarding –
LSR2 – LSR3
MFA FORUM
Network A
Router1
I-LER1
1
LSR5
Router2
Network B
Net.B 70
Net.B 71
2
LSR2 1
2 LSR3 1
1
2 E-LER4
In port/ Out port/
label label Action
2/70 1/71 Swap
LSR6
MPLS Domain
Slide 78
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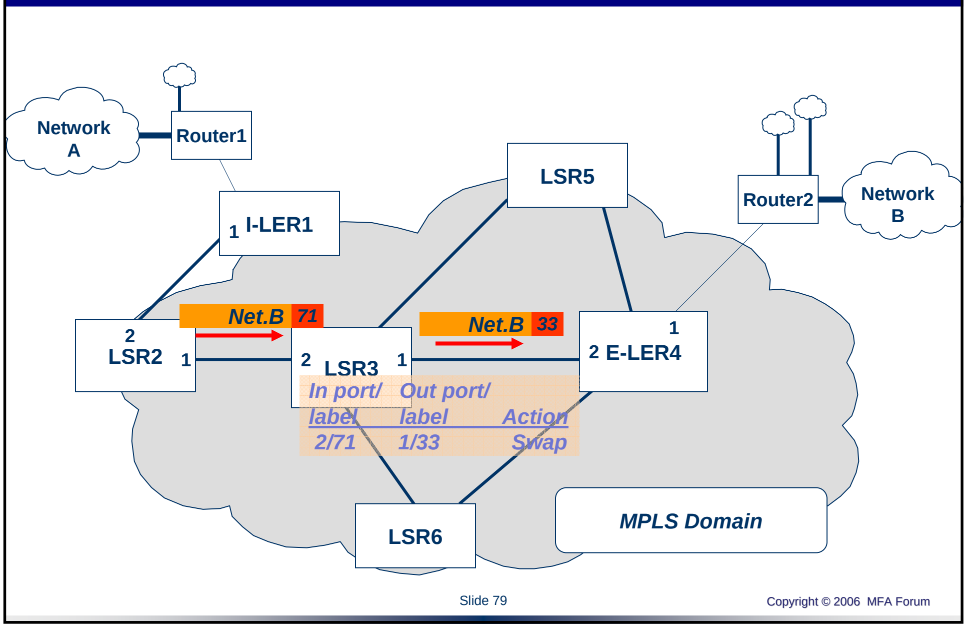
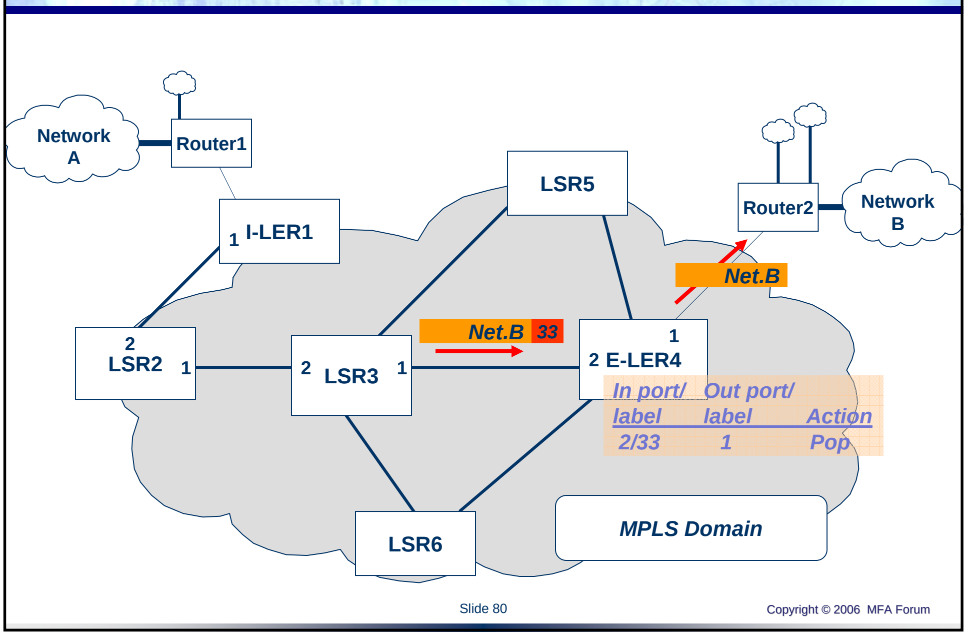
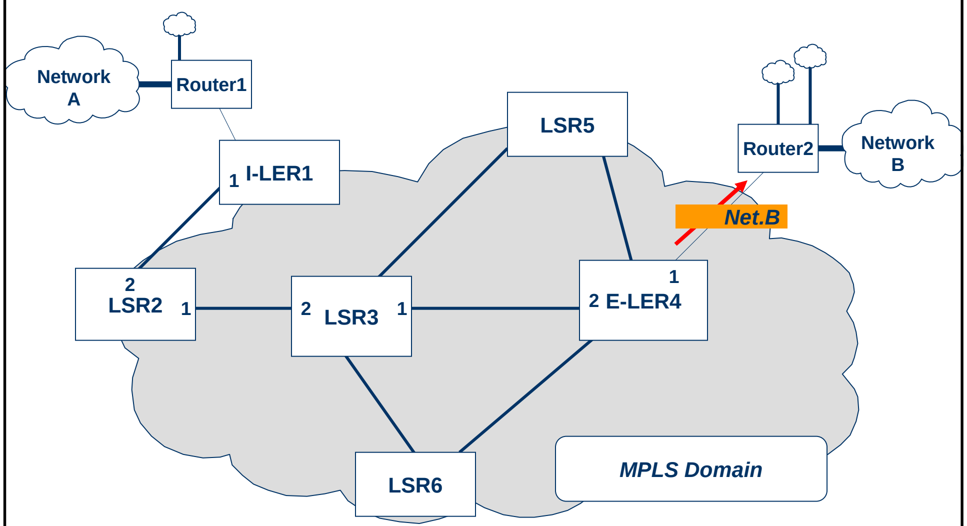
Data Forwarding – *LSR3 – E-LER4*



Data Forwarding – E-*LER4 – Router2*



Data Forwarding –
Unlabelled Packet Delivered



Label Switching:
Three Important Questions

- Q: What ***labeled*** packet field do we use to make the forwarding decision?
  - –
- Q: When we use this field as an index into the Label Information Base (LIB) table, what do we look up?
  - –
- Q: What other vital piece of information does the LIB contain?
  - –

Label Switching:
Three Important Questions

- **Q: What *labeled* packet field do we use to make the forwarding decision?**
  - **A: The outermost label**
- **Q: When we use this field as an index into the Label Information Base (LIB) table, what do we look up?**
  -
- **Q: What other vital piece of information does the LIB contain?**
  -

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Label Switching:
Three Important Questions

- **Q: What *labeled* packet field do we use to make the forwarding decision?**
  - **A: The outermost label**
- **Q: When we use this field as an index into the Label Information Base (LIB) table, what do we look up?**
  - **A: The output interface (or queue) reference**
- **Q: What other vital piece of information does the LIB contain?**
  -

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Label Switching:
Three Important Questions

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- Q: What ***labeled*** packet field do we use to make the forwarding decision?
  - A: The outermost label
- Q: When we use this field as an index into the Label Information Base (LIB) table, what do we look up?
  - A: The output interface (or queue) reference
- Q: What other vital piece of information does the LIB contain?
  - A: The outbound label value

Section-2 Agenda

MFA FORUM

- MPLS Basics
  - Overview of data delivery and protocols
  - MPLS drivers and features
- Traditional Routing
  - Overview
  - Data Plane and Control Plane
- MPLS Architecture
  - MPLS terminology and operation
  - ➡ Label Distribution Protocol (LDP)
  - Penultimate Hop Popping, Aggregation, TTL

1100-1130

Reasons for an MPLS Signaling Protocol

- MPLS requires a signaling protocol to:
  - coordinate label distribution
  - prevent loops
  - explicitly route an LSP
  - make bandwidth reservation
  - specify Class of Service (DiffServ-style CoS)
  - enable pre-emption of existing LSPs

Label Distribution Protocols (ldp's)

- Choices for LSP establishment:
  - LDP = Label Distribution Protocol
    - ✓LDP = Original
  - RSVP = Resource reservation Protocol
    - ✓RSVP-TE = Tunneling Extensions
- LDP was specifically designed for MPLS
  - supports LSPs based on IP next-hop routing
  - good for single-link LSPs such as PWs and MPLS UNI
  - does not support TE
  - runs over TCP
- RSVP-TE is RSVP adaptation
  - presently, the dominant protocol for MPLS-TE
  - runs directly over IP

Label Distribution-Related Terminology

- "ldp" vs. "LDP"
  - Low-case "label distribution protocol (ldp)" is used to designate a *generic network function* of distributing MPLS labels
  - Capital-case "Label Distribution Protocol (LDP)" is used to designate a *specific protocol* defined in RFC3036 / RFC3037
    - *"LDP" is one of the "ldp's"*
- Soft State – a path that needs to be refreshed to stay alive
- Hard State – a path that will stay alive until it is specifically terminated
- Implicit Route – a path formed from hop-by-hop links determined by regular routing protocols
- Explicit Route – a path across an IP network where all routers are specified, and packets must follow this path
- Destination-based Routing (DR) – normal operation of routing protocols
- Constraint-based Routing (CR) – finding a route after applying some constraints to the routes found by routing protocols

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Types of ldp's

- MPLS architecture does *not* specify a particular ldp and does *not* assume a single ldp
  - the standards do *not* specify whether the same LSR can support more than one ldp
  - router vendors specify which ldp's their products support
- ldp types:
  - MPLS forwarding along *implicitly-routed (hop-by-hop) paths* determined by *destination-based routing* protocols ← LDP
  - MPLS forwarding along *explicitly-routed paths* determined by *Traffic Engineering-based routing* protocols ← RSVP-TE
  - label distribution function *piggybacked* on *existing* signaling protocols ← RSVP-TE

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LDP Features

- LDP **features**:
  - defined *specifically* as an ldp for MPLS networks
  - specification consists of a set of *procedures and messages*
  - LSRs establish LSPs by *mapping* network-layer routing information *directly* into data-link layer switched paths
- **LDP peers**:
  - two LSRs that exchange label mapping information
- **LDP session**:
  - exchange of information between LDP peers
- LDP protocol is *bi-directional*
  - LDP peers can learn each other's label mappings in a single LDP session
- LDP messages are encoded as Type-Length-Value (*TLV*) data structure
  - "Value" may itself be a TLV-encoded object (*nested TLVs*)

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LDP Message Categories

- **Discovery messages** (over *UDP*)
  - announce and maintain the presence of an LSR in a network
  - HELLO messages in a *UPD* packet to the *LDP port* at the "all routers on this subnet" group multicast address
  - eliminates the need for operators to explicitly provision all LDP peers
- **Session messages** (over *TCP*)
  - establish, maintain, and terminate sessions between LDP Peers
- **Advertisement messages** (over *TCP*)
  - create, change, and delete label mappings for FECs
- **Notification messages** (over *TCP*)
  - provide advisory information and signal error information
- *TCP* assures *reliable* message delivery and eliminates the need for refreshes

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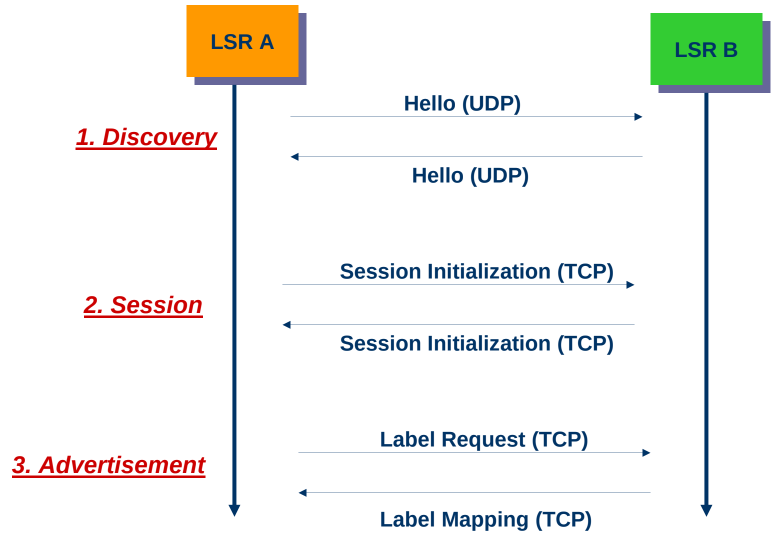
LDP Message Exchange



Slide 93

LDP Notification (4) Categories

- **Error notifications (over *TCP*)**
  - signal fatal errors
  - when received, a router closes the TCP session and discards all label mappings learned from that session
- **Advisory notifications (over *TCP*)**
  - pass to an LSR information about the LDP session
  - status of some previous message received from the peer.

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FEC Specification

- Each **LSP** is created for the packets that adhere to the *FEC specification* associated with that LSP
- **FEC specification** consists of a set of *FEC elements* that define which IP packets are mapped into this LSP
- Types of **FEC elements**:
  – *Address Prefix* - from 0 bits to full address
  – *Host Address* – full host address
- Matching rules:
  – IP address matches Address Prefix *if* it begins with that prefix
  – IP packet matches an LSP *if* the packet's Destination IP address matches the Address Prefix FEC element of the FEC specification for that LSP
- Multiple FEC elements could be mapped into the same LSP

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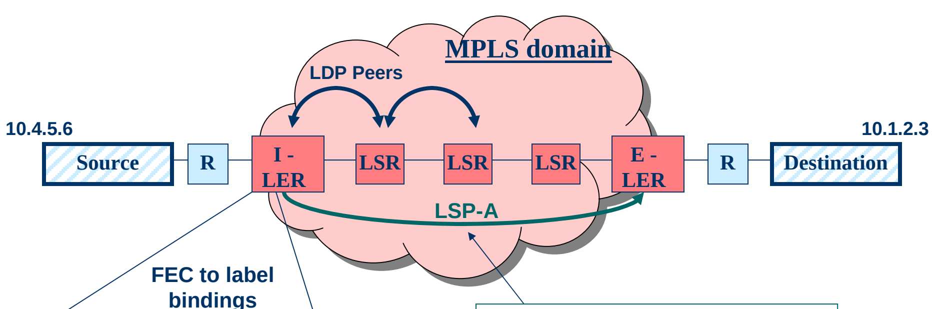
Elements of the LDP Definition



Dest IP Addr	LSP
10.1	A
10.2	A
10.3.4.5	A
10.3.4.6	A
10.4	B
10.5	B

FEC Specification elements for LSP-A:

- Address Prefix 10.1
- Address Prefix 10.2
- Host Address 10.3.4.5
- Host Address 10.3.4.6

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LDP vs. RSVP-TE

- Support of TE
  - LDP – *no* (if un-extended)
  - RSVP-TE – *yes*
- Protocol state
  - LDP – *hard* (no refreshes, less chat, slower recovery)
  - RSVP-TE – *soft* (periodic refreshes, chatty, faster recovery)
- Networking
  - LDP – over *TCP*
  - RSVP-TE – over *IP*
- Label distribution
  - LDP – *variety of combinations* of Downstream on Demand, Downstream Unsolicited, Ordered Control and Independent Control
  - RSVP-TE – only Downstream *on Demand* with *Ordered* Control
- Other
  - LDP is a better choice for single-link LSPs, e.g., between Autonomous Systems (AS)
  - LDP implementation does not require that LSRs support RSVP

Section-2 Agenda

- MPLS Basics
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  - MPLS terminology and operation
  - Label Distribution Protocol (LDP)
  - ➡ Penultimate Hop Popping, Aggregation, TTL

1130-1200

Penultimate Hop Popping (PHP)

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- Requested by Egress LER (ultimate hop) to the previous (penultimate) neighboring LSR by using a special label value, e.g.:
  - in the Control Plane, the E-LER sends “Implicit Null” label = 3 to the PH
  - in the Data Plane, the PH does not use label = 3; instead it pops the stack and forwards the unlabeled packet to the E-LER
- Penultimate LSR forwards packet without an MPLS label
- PHP is used to prevent an Egress LER from having to perform two lookups on a packet
  - the packet has no Label so only the routing Forwarding Information Base (FIB) needs to be looked at to determine where to forward the packet

1130-1145

PHP Signaled by Egress LSR

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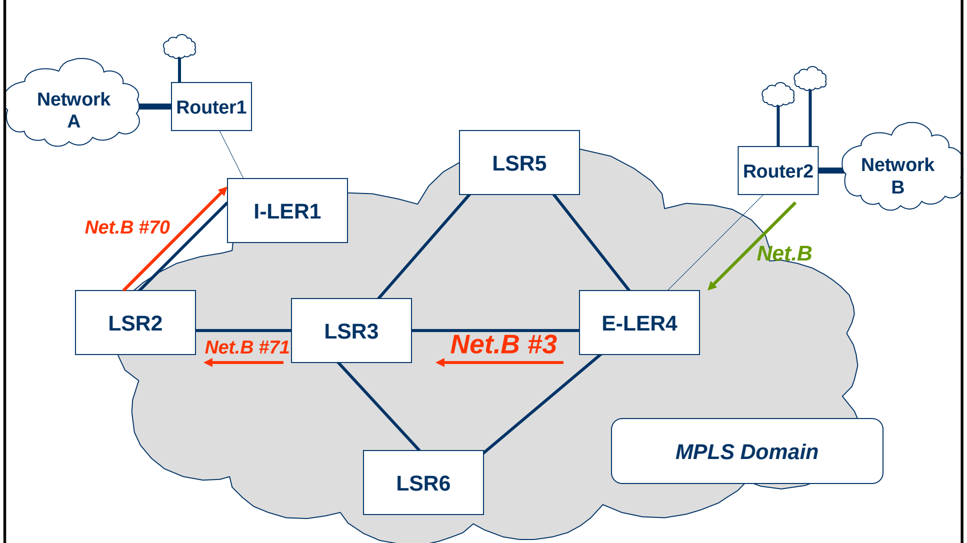

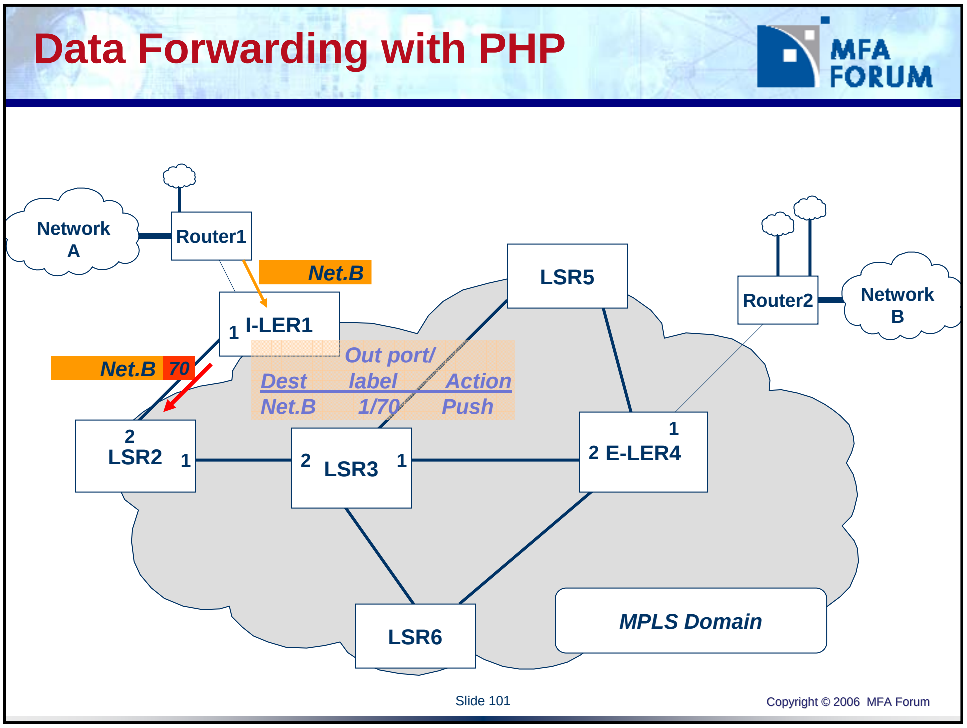
Data Forwarding with PHP
MFA FORUM
Network A
Router1
Net.B
LSR5
Router2
Network B
1 I-LER1
Net.B 70
Out port/
Dest label Action
Net.B 1/70 Push
2 LSR2 1
2 LSR3 1
1
2 E-LER4
LSR6
MPLS Domain
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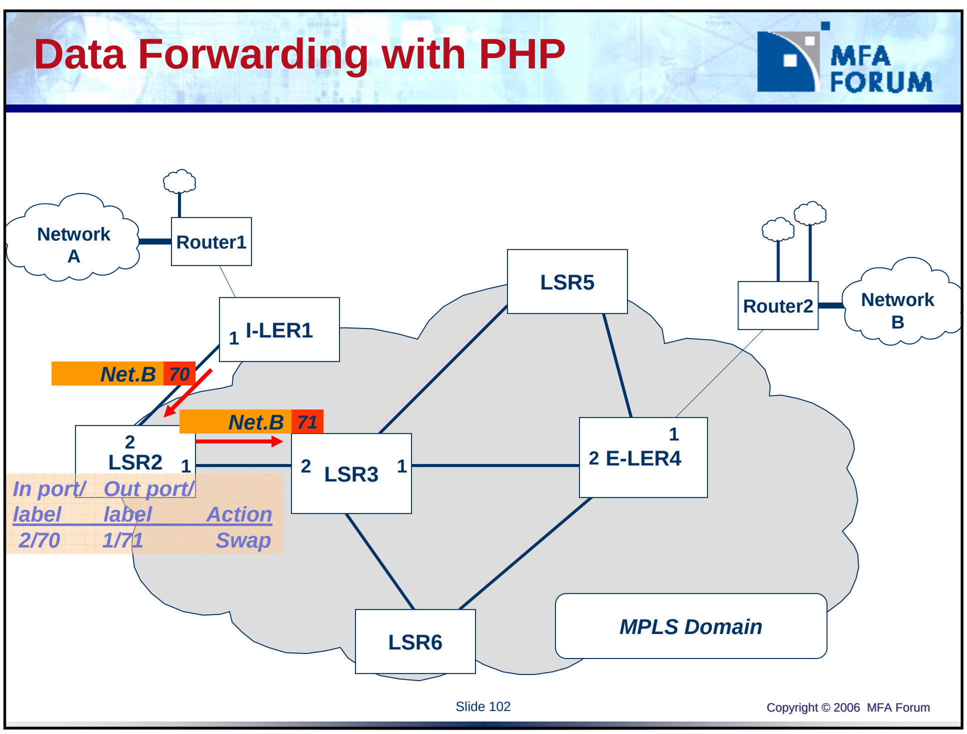
Data Forwarding with PHP
MFA FORUM
Network A
Router1
LSR5
Router2
Network B
1 I-LER1
Net.B 70
Net.B 71
2 LSR2 1
2 LSR3 1
1
2 E-LER4
In port/ Out port/
label label Action
2/70 1/71 Swap
LSR6
MPLS Domain
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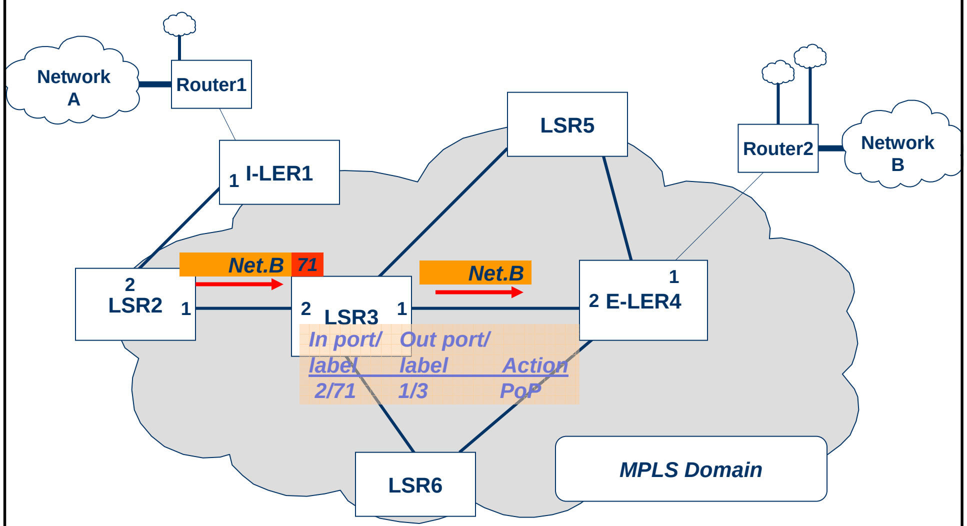
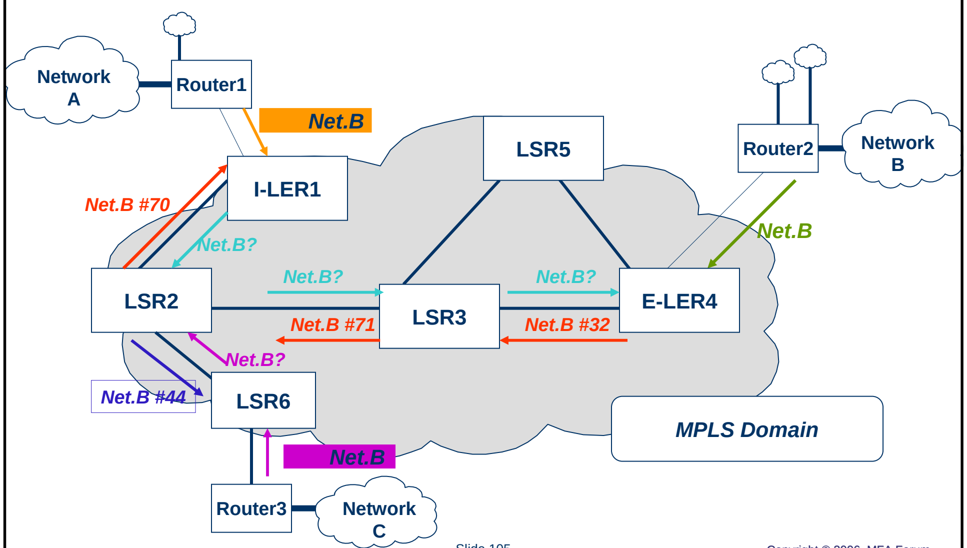
Data Forwarding with PHP



Route Aggregation

- Procedure for binding a single label to a union of all traffic with a common FEC
- Reduces the number of labels needed to handle a particular set of packets
- Reduces the amount of label distribution control traffic
- One of the MPLS scalability mechanisms

Route Aggregation



Time To Live (TTL) Approaches

- 1. TTL applied consistently across IP and MPLS domains:
  - I-LER copies IP TTL into the MPLS header
  - MPLS TTL is decremented at each LSR
  - At E-LER, MPLS TTL is copied into IP TTL
    - prevents loops
- 2. MPLS is treated as a single TTL hop
  - At I-LER, IP TTL copied into MPLS Header
  - At E-LER, MPLS TTL is decremented and copied into IP TTL
    - hides structure of MPLS domain

1145-1200

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End of Section 2

Thank You

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Introduction to MPLS

Section 3: Traffic Engineering with MPLS

Section 3 Agenda

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- Why MPLS for Traffic Engineering
  - Evaluating MPLS as a solution for TE in IP networks
  - Traditional Traffic Engineering procedures
  - Routing and re-routing in an MPLS network
- Constraint Based Routing
  - Signaling mechanisms
  - RSVP-TE
  - Recovering LSP-TE tunnels

Review Terminology...

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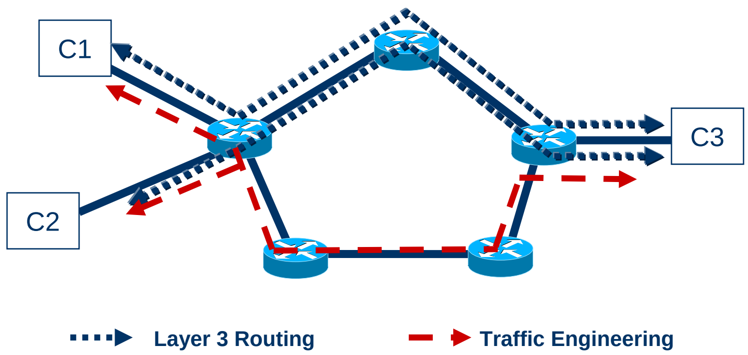
- Network Engineering
  - "Put the ***bandwidth*** where the ***traffic*** is"
    - Physical cable deployment
    - Virtual connection provisioning
- Traffic Engineering
  - "Put the ***traffic*** where the ***bandwidth*** is"
    - On-line or off-line optimization of routes
    - Implies the ability to "explicitly" route traffic

Traditional Traffic Engineering



- **Move traffic from IGP path to less congested path**

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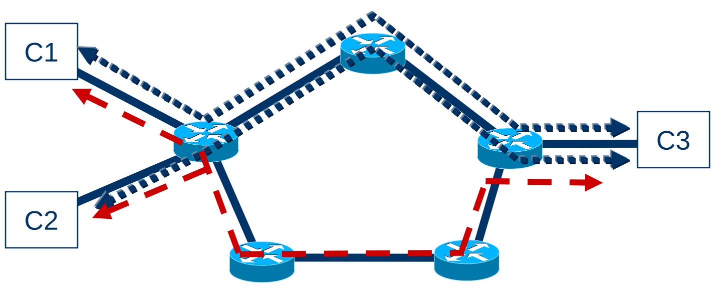
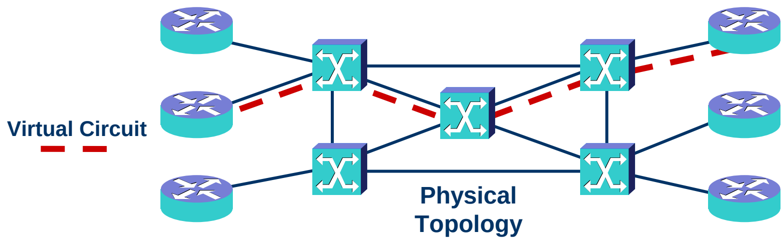
Traditional Traffic Engineering
Limitations



- TE Mechanisms
  - ✓ Over-provisioning
  - ✓ Metric manipulation
- Limitations
  - ✓ Some links become under-utilized or over-utilized
  - ✓ Trial-and-error approach

Slide 112

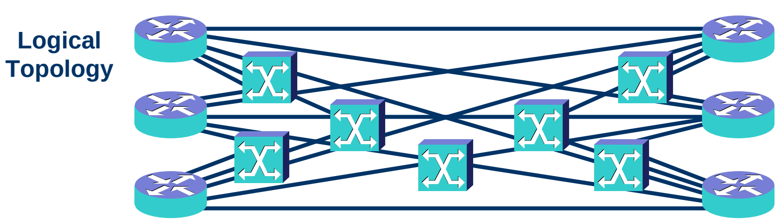
Traffic Engineering with ATM Core



- **Infrastructure**
  - **Routed edge over ATM switched core**
  - **Introduced full Traffic Engineering (TE) ability**

Slide 113

Traffic Engineering with ATM Core - *Limitations*



- **TE Mechanisms**
  - **VC routing**
  - **Overlay network**
- **Benefits**
  - **Full traffic control**
  - **Per-circuit statistics**

- Limitations
  - ✓ Overlay of IP and ATM
  - ✓ "N-squared" VCs
  - ✓ IGP Stress
  - ✓ Cell tax

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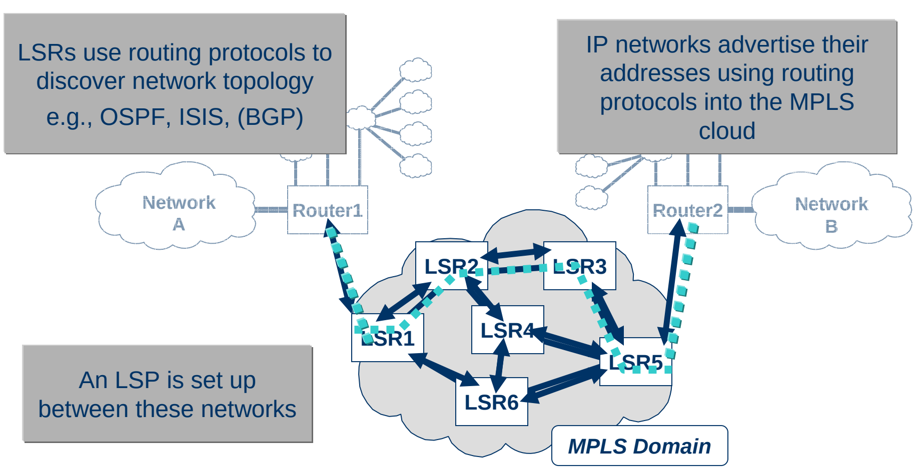
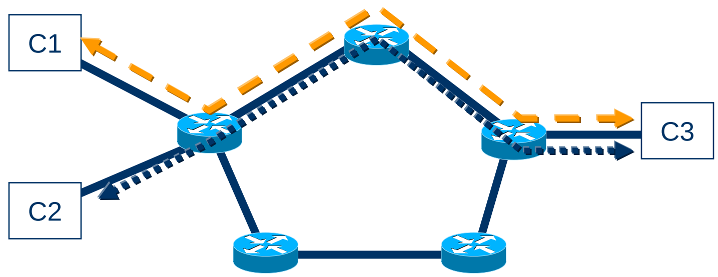
MPLS Traffic Engineering

- Traditional TE controls traffic flows in a network
  - "The ability to move traffic away from the shortest path calculated by the IGP to a less congested path"
- MPLS Traffic Engineering
  - Allows Explicit Routing and set-up of LSPs
  - Provides control over how LSPs are recovered in the event of a failure
  - Enables Value Added Services
    - Virtual Private Networks – VPNs
    - Service Level Agreements - SLAs
    - Multi-media over IP solutions – MMoIP, VoIP

Review Topology and LSP Set-up



But, this is a simple example . . .



- Routing protocols create a "Shortest Path“ route
- LSPs follow the "shortest path"

This mechanism does NOT give us
Traffic Engineering

MPLS Traffic Engineering
Requires

- Enhancements to the ***Routing Protocols***
  - OSPF ➔ OSPF-TE
  - ISIS ➔ ISIS-TE
- Enhancements to the ***Signalling Protocols*** to allow explicit constraint-based routing
  - RSVP ➔ RSVP-TE
  - LDP ➔ CR-LDP
- Constraint-Based Routing
  - Explicit route selection
  - Bandwidth parameters and recovery mechanisms defined
  - Connection Admission Control (CAC) enforced
    - (policing, marking, metering, scheduling, etc.)

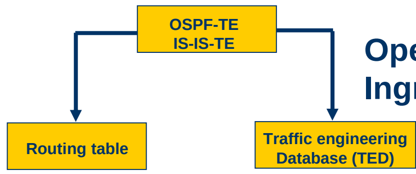
Section 3 Agenda

- Why MPLS for Traffic Engineering
  - Evaluating MPLS as a solution for TE in IP networks
  - Traditional Traffic Engineering procedures
  - Routing and re-routing in an MPLS network
- Constraint Based Routing
  - Signaling mechanisms
  - RSVP-TE
  - Recovering LSP-TE tunnels

Constraint-Based Routing

- Parameters over and above "best effort" are constraints
- Constraint examples:
  - order in which LSRs are reached
  - description of traffic flow, bandwidth, delay, class, priority
  - edge traffic conditioning functions such as marking, metering, policing, and shaping
  - Recovery mechanism for "protection" of a working LSP
- Supports and enables QoS/CoS functions for
  - IP DiffServ
  - IP IntServ

Constraint Route Signaling
Operational Model



Operations performed by the Ingress LER

1) Store information from IGP flooding

2) Store traffic engineering information

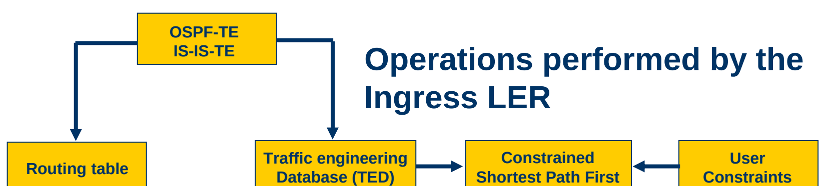
<u>OSPF and IS-IS - **TE** Extensions</u>

Distributed (piggybacked) on Opaque Link State Advertisements (LSA)

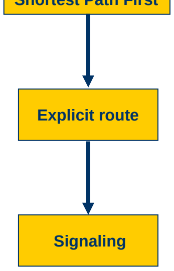
Encoded as new Type Length Values (TLVs)

Metrics: Bandwidth, *Unreserved Bandwidth, Available Bandwidth, Delay, Delay-Jitter, Loss Probability, Administrative Weight, Economic Cost*

Constraint Route Signaling
Operational Model



Operations performed by the Ingress LER



1) Store information from IGP flooding

2) Store traffic engineering information

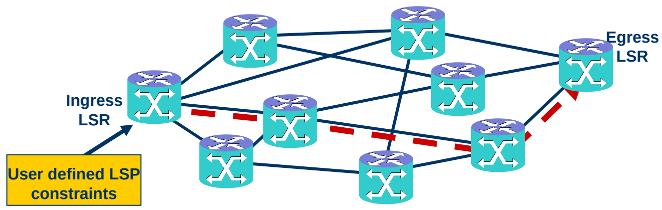
3) Examine user defined constraints

4) Calculate the physical path for the LSP

5) Represent path as an explicit route

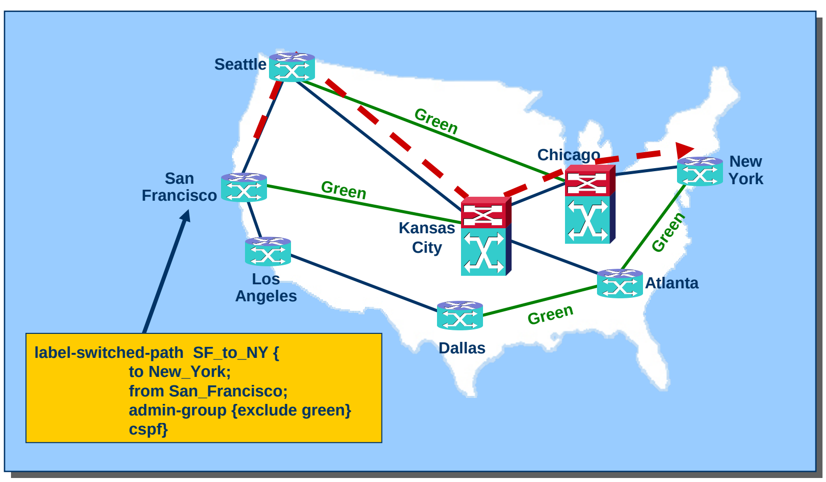
6) Pass ER to RSVP for signaling

Constraint Route Signaling



- Operator configures LSP constraints at ingress LSR
  - Bandwidth reservation
  - Include or exclude a specific link(s)
  - Include specific node traversal(s)
- Network actively participates in selecting an LSP path that meets the constraints

Constraint Route Signaling
Example



Constraint Route Signaling
Example

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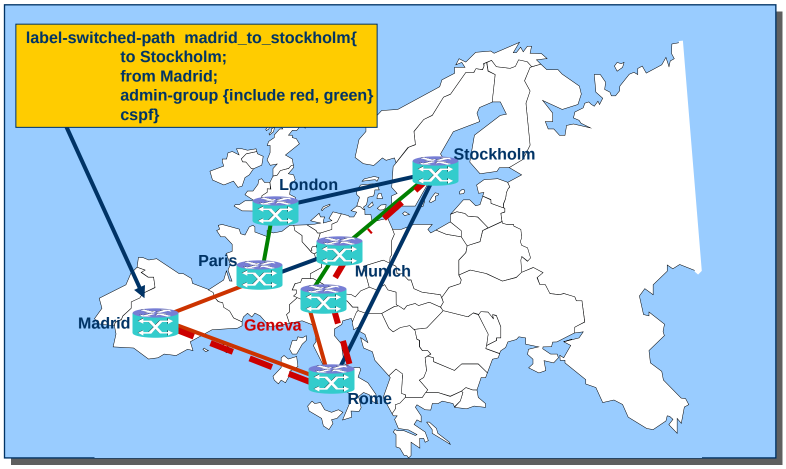

Signaling Mechanisms

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- LDP Label Distribution Protocol
- RSVP-TE Extensions to RSVP for Traffic Engineering
- BGP-4 Carrying Label Information in BGP- 4

Section 3 Agenda

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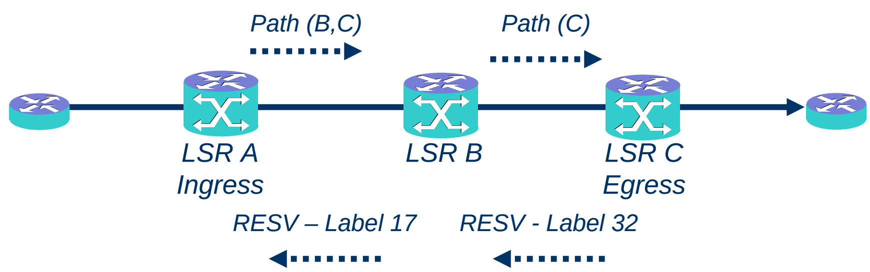
RSVP –TE
RSVP with Traffic Engineering Extensions

- Generic RSVP - Internet standard for reserving resources
- Generic RSVP uses a message exchange to "reserve" resources across a network for IP flows
- RSVP-TE uses IP Datagrams (UDP at the edge) between LSR peers to send LDP messages
  - No TCP session maintenance
- RSVP-TE- a mechanism for establishing explicitly routed LSPs
  - An Explicit Route is a Constrained Route

RSVP –TE

RSVP with Traffic Engineering Extensions



- **Basic flow of LSP set-up using RSVP**

RSVP –TE

RSVP with Traffic Engineering Extensions

- **PATH is sent in the downstream direction**
- **RESV is sent in the upstream direction towards the ingress LSR**
- **RSVP –TE supports downstream-on-demand label allocation *only***
- **LSR does Connection Admission Control (CAC)**
- **Each LSR processes the RESV using received label for outgoing traffic associated with this LSP**
- **When ingress LSR receives the RESV, the LSP is established**

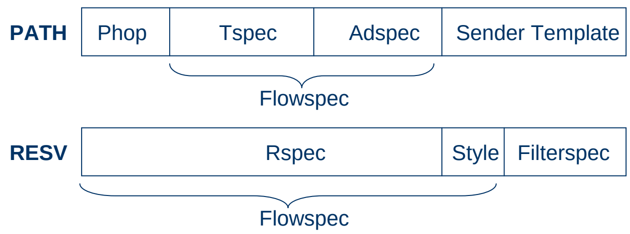
RSVP –TE *Path* Message

Common Headers
Label Request Object
Explicit Route Object (ERO) (optional)
Record Route Object (RRO) (optional)
Session Attribute Object (optional)
FlowSpec Object (optional)

RSVP – TE *RESV* Message

Common Headers
Label Object
Record Route Object (RRO) (optional)
Session Object (optional)
Style Object (FF or SE) (optional)
<Filter Descriptor Lists> (optional)

RSVP – TE Flow Descriptors



- **Flowspec included in both PATH and RESV message**
- **The routers / LSRs use PATH message (Tspec) and RESV message (Rspec) to reserve the appropriate resources**

RSVP – TE Styles

- **Part of RESV that defines the merging capabilities of the flow**
- ***Wildcard-Filter (WF) style* creates a single reservation for all flows from upstream senders**
- ***Fixed-Filter (FF) style* – creates a distinct reservation for selected senders**
- ***Shared Explicit (SE) style* – creates a shared reservation for selected senders**

Fixed Filter Style

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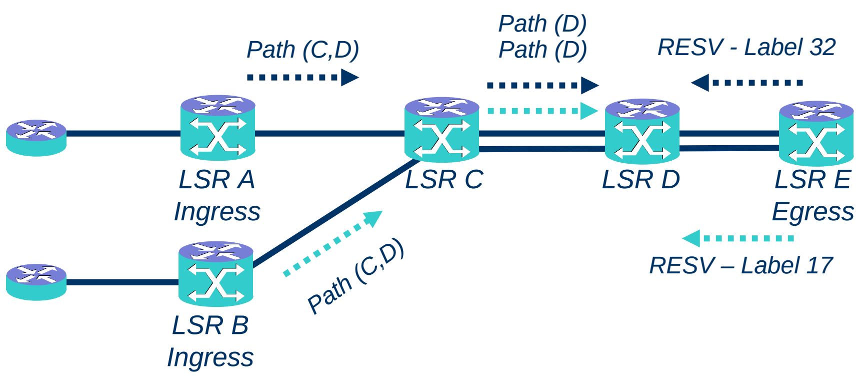

Shared Explicit Style

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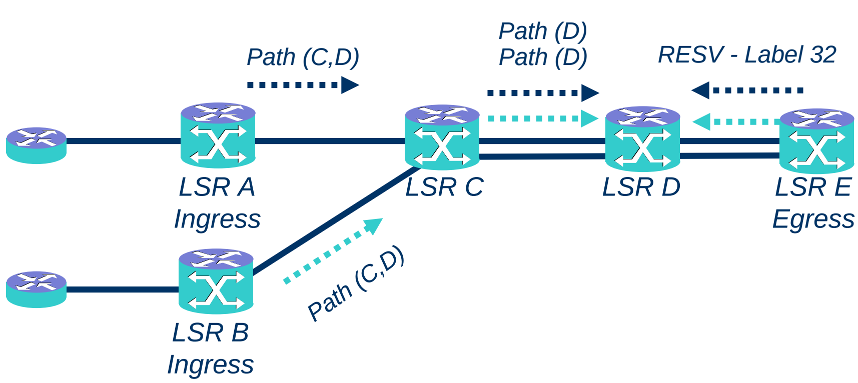
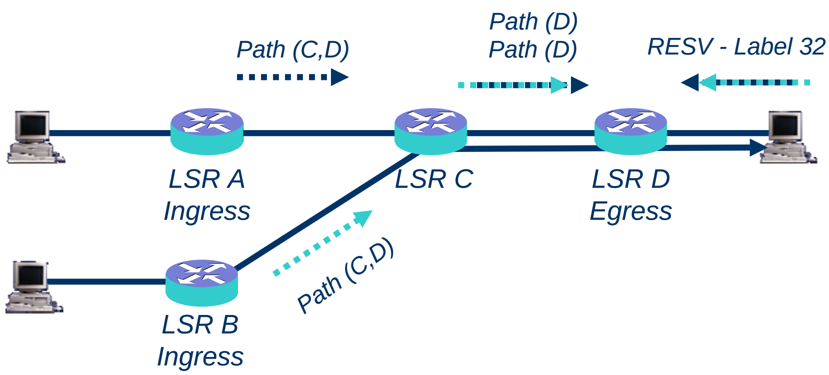
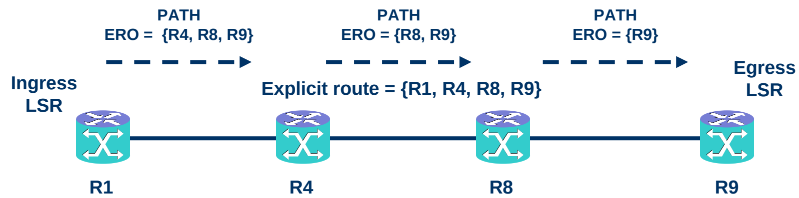


Shared Explicit Style

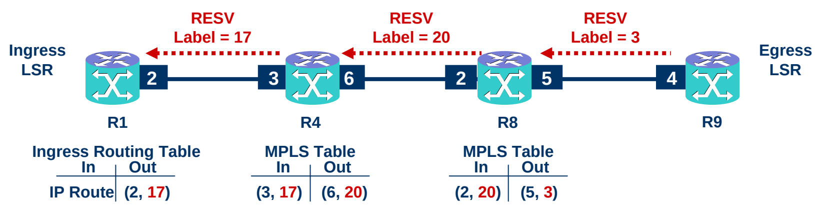


RSVP – TE *PATH* Message



- **Establish state and request label assignment**
- **R1 transmits a PATH message addressed to R9**
  - **Label Request Object**
  - **ERO = {strict R4, strict R8, strict R9}**
  - **RRO = {ingress LSR IP add, store and add IP hop addr}**
  - **Session object identifies LSP name**
  - **Session Attributes: Priority, preemption, and fast reroute**
  - **Flow_Spec: Request bandwidth reservation**

RSVP – TE *RESV* Message



- Distribute labels & reserve resource
- R9 transmits a RESV message to R8
  - Label = 3
  - Session object to uniquely identify the LSP
- R8 and R4
  - Stores “outbound” label, allocate an “inbound” label
  - Transmits RESV with inbound label to upstream LSR
  - R1 binds label to FEC

Section 3 Agenda

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Recovering LSP Tunnels

- When a more “optimal” route/path becomes available
- When a failure of a resource occurs along a TE LSP
- “Make Before Break”
  - Adaptive, smooth rerouting and traffic transfer *before* tearing down the old LSP
  - Not disruptive to traffic
  - Handling overlapping resource requests on common segments
  - Can be used to increase bandwidth for an LSP

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Recovering LSP Tunnels

- Re-Routing
  - A recovery mechanism in which the LSPs are created dynamically
- Protection Switching
  - A recovery mechanism in which the LSPs are created prior to detection of a fault
- Recovery Path
  - The path (LSP) by which traffic is restored after the occurrence of a fault

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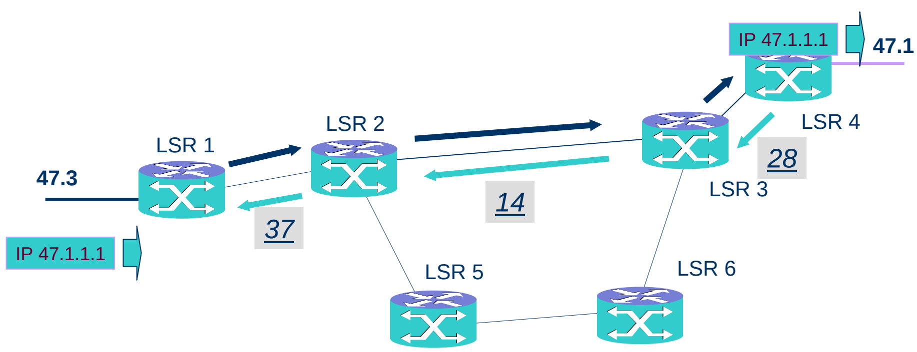
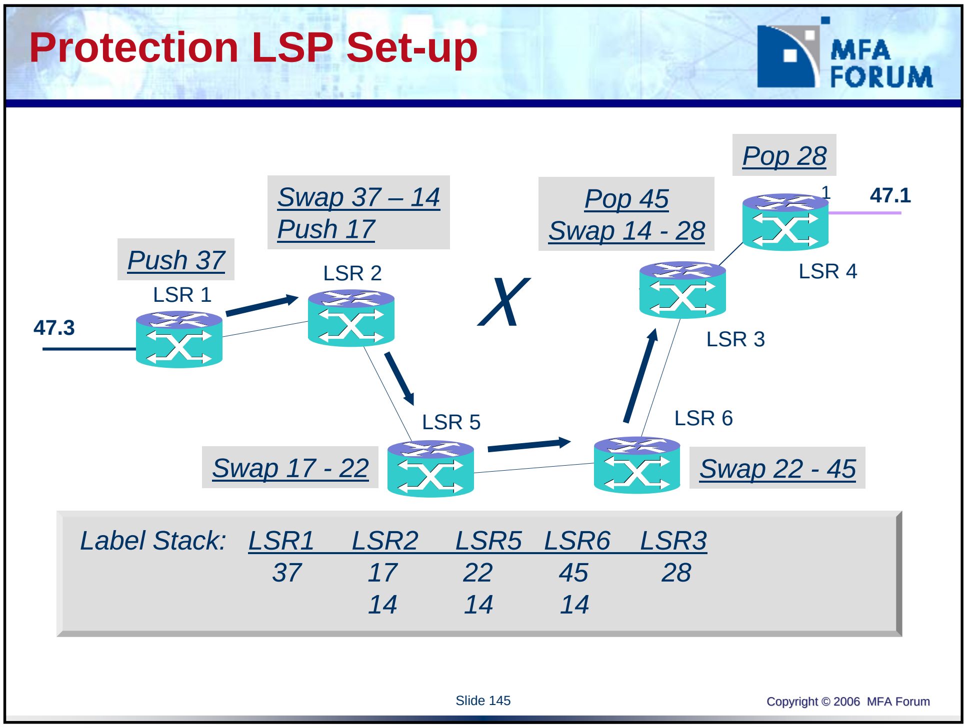
Recovering LSP Tunnels

- Path Set-up
  - Pre-established path before fault
  - Pre-qualified path before fault, but without a path created
- Topology
  - Local Repair
    - To protect a single link or neighbor node fault
  - Global
    - To protect against any link or node along an LSP

LSP Set-up



PATH SETUP: {ERO = LSR1 – LSR2 – LSR3 – LSR4}
LABEL RESV


Protection LSP Set-up
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Pop 28
Swap 37 – 14
Push 17
Pop 45
Swap 14 - 28
47.1
1
Push 37
LSR 2
LSR 4
LSR 1
X
47.3
LSR 3
LSR 5
LSR 6
Swap 17 - 22
Swap 22 - 45
Label Stack: LSR1 LSR2 LSR5 LSR6 LSR3
37 17 22 45 28
14 14 14
Slide 145
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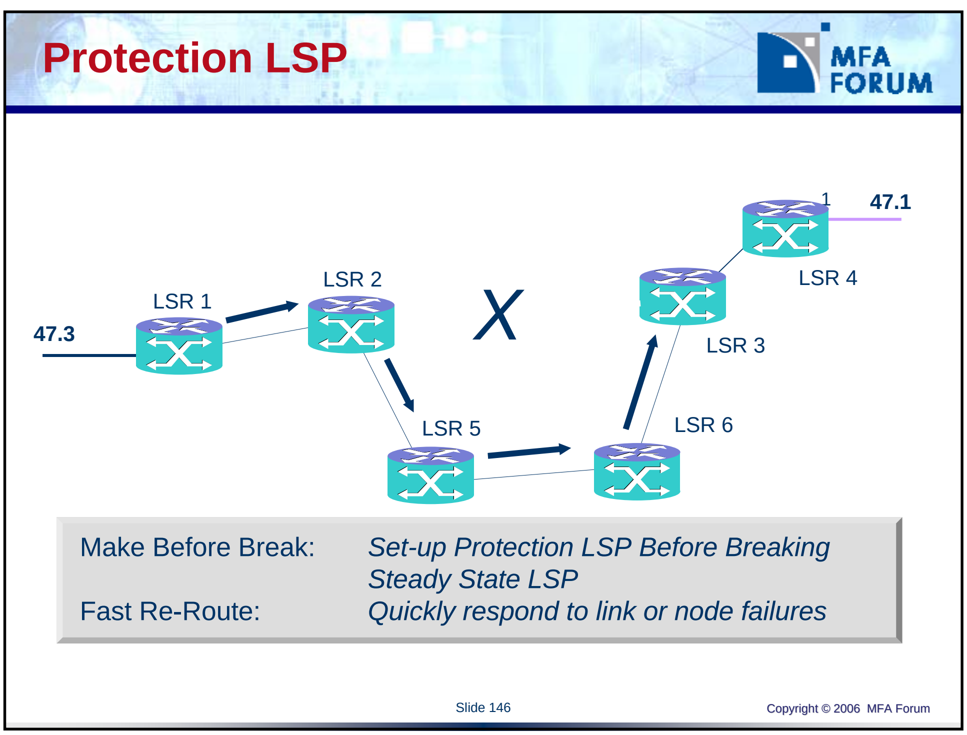
Protection LSP
MFA FORUM
1
47.1
LSR 4
LSR 2
LSR 1
X
47.3
LSR 3
LSR 5
LSR 6
Make Before Break: Set-up Protection LSP Before Breaking Steady State LSP
Fast Re-Route: Quickly respond to link or node failures
Slide 146
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End of Section 3

Thank You

Section 4: MPLS Applications

Agenda – MPLS Applications

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- Role in the IP core - Traffic Engineering in IP networks
- Virtual Private Networks (VPNs)
- Voice over MPLS
- Legacy support via PWE3
- Using MPLS to simplify current network architectures
- ASON/GMPLS – using MPLS as the universal control plane – optical / core / edge / end-to-end

Role of MPLS in the IP Core

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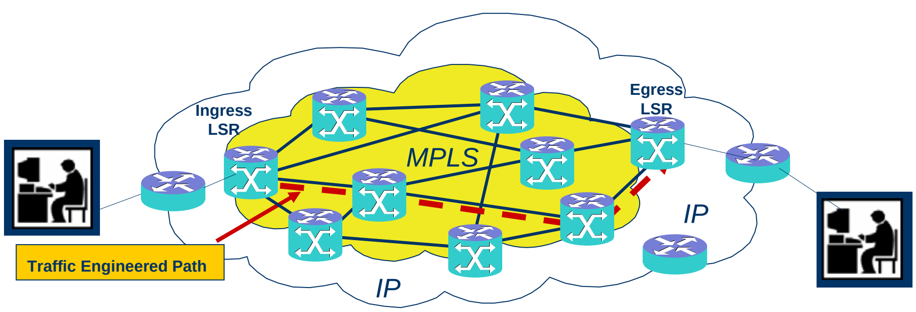


Deployed to manage IP 'traffic paths' in the core
Used to 'steer' traffic to preferential paths
Enable 'load-spreading' of traffic across multiple paths

MPLS for IP Core
- Industry Status

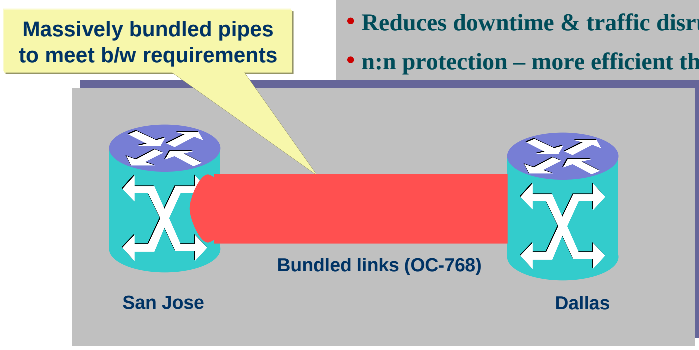
- Widely deployed – most large IP Carriers/ ISPs employ MPLS today to traffic engineer their IP cores (some exceptions)
- Has largely replaced ATM in this role – ATM links speeds too slow (OC-48c IP/ATM)
- MPLS enabled cores can operate at 10Gbps and above
- Fast reroute protection mechanism deployed to protect paths and minimize number of network hops

IP/MPLS over Bundled Links - *Inverse Multiplexing*

- Allows multiple lower speed links to be viewed as a single fat pipe
- Allows easy upgrade to higher speed links (add new link to bundle, delete old low speed link)
- Increases network survivability (flows on a failed link failover to other bundled members)
- Allows intelligent path decisions on shared links

Link Bundling - Advantages

- Deploy very high speed links (OC-768 or higher)
- Traffic engineering and management simplicity
- Add or delete link and take it in/out of service
- Reduces downtime & traffic disruption
- n:n protection – more efficient than SONET



Still in early stages of evaluation/deployment

Agenda – MPLS Applications

- Role in the IP core - Traffic Engineering in IP networks
- Virtual Private Networks (VPNs)
- Voice over MPLS
- Legacy support via PWE3
- Using MPLS to simplify current network architectures
- ASON/GMPLS – using MPLS as the universal control plane – optical / core / edge / end-to-end

What is a VPN?

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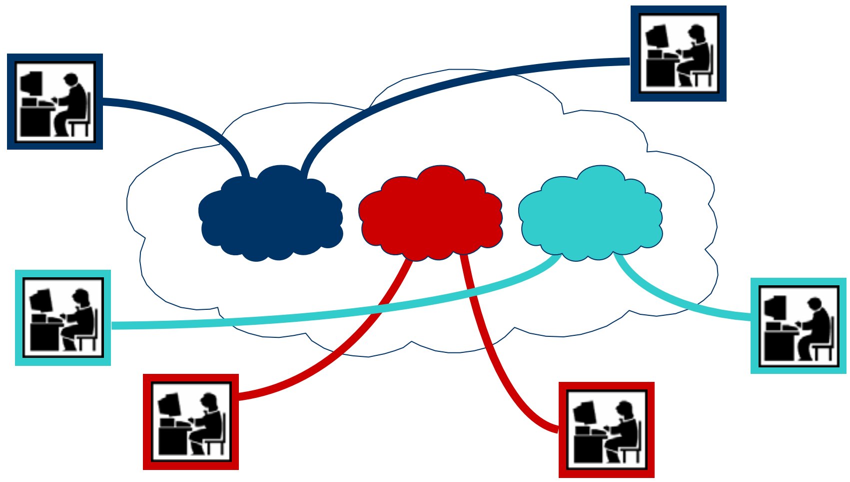

- A Network within a Network

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Current VPN Technologies

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- GRE
- PPTP
- L2TP
- IPSec

Customer Premises Equipment based

MPLS VPN architectures
- RFC 2574bis
- Virtual Router

Provider Edge equipment based

- VPNs based on tunneling at Layer 3 (Network Layer) are Layer 3 VPNs, (BGP/MPLS, VR, IPSec)
- VPNs based on a Layer 2 (Data Link Layer) technology and managed at that layer are defined as Layer 2 VPNs (MPLS, ATM, Frame Relay)

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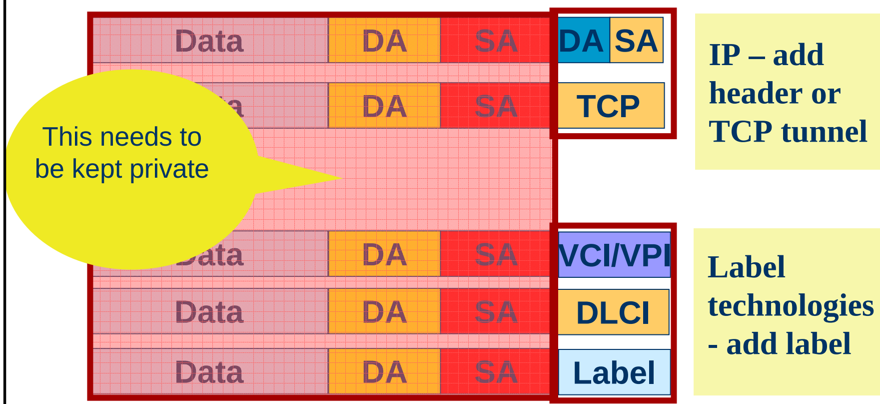
Keeping Things Private
- Encapsulation



What Does MPLS Help With ?

- **Tunnels (encapsulation)**
  - Necessary to hide private addresses.
  - Other alternatives - IP/IP, ATM
- **Provide appropriate security**
  - Makes IP as secure as Frame Relay
  - No need for encryption!
- **Quality of service**
  - Allows connectionless IP to look like connection orientated
  - Provides signaling of bandwidth and QoS requirements

Some MPLS VPN Benefits

- Offers the similar advantages as VC based VPNs such as Frame Relay or ATM
- But operates over both legacy (DS0, DS1, SONET) and new infrastructure (Ethernet 10/100/GbE/10GbE)
- Allows for the customer to use private IP addresses
- Provides a single Virtual Router (IP) interface to the corporate customer – preserves legacy IP routers at customer's locations
- Allows Any-to-Any connectivity between corporate locations
- One MPLS VPN router serves several customers (with VRs) - scales much better than CPE based VPNs: Minimizes the N-Squared connectivity issue

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State of the Nation on MPLS VPNs

- MPLS VPNs may be categorized into two broad classes of VPN – those that operate at either Layer 3 or Layer 2 in the network.
- The Layer 3 category was first to be investigated and two classes of L3 VPNs have been further described in the 'informational' IETF documents
  - RFC2547bis – based on BGP4 and MPLS and
  - RFC2917 – Layer 3 Virtual Router Architecture
- Currently RFC2547bis has received the most widespread deployment – although strictly speaking there are no agreed upon IP/MPLS based VPN standards – all are informational.
- Today many large successful deployments of RFC2547bis in the core of carrier networks both in US and internationally.

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Layer 3 MPLS VPNs

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Advantages:

- Primary advantage of L3 VPNs is the ability to manage enterprise networks address space, all core routing is addressed by the carrier.
- In addition it removes the 'N-Squared Mesh' problem from the enterprise network.
- All this significantly simplifies the enterprise IT role, as connectivity to new sites is elegantly addressed by just connecting to the VPN and managed by carrier.
- Seamlessly interoperates over all legacy services such as Frame Relay or any new access mechanism like Ethernet.

Dis-Advantages:

- Complex for carrier to operate, now must get involved in the the IP address space in every customer.
- Supports only IP or "IP Encapsulated" enterprise traffic
- Scaling is proving to be an issue as every VPN router must peer large BGP tables with peers – may prove to be a limit to upper scalability.

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Visually - Layer 3 VPN

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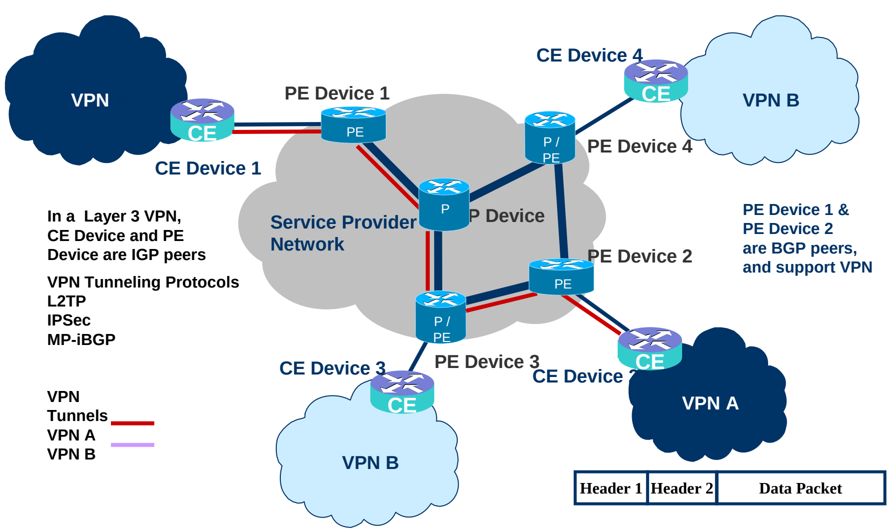

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Layer 2 MPLS VPNs

- Layer 2 VPNs attempt to circumvent some of these issues.
- VPN characteristics are more akin to Frame Relay.
- Can transport <u>any</u> Layer 3 enterprise protocol.
- Standards are still in early state
  - VPLS (Virtual Private LAN Service) is emerging as a primary contender.
  - Mapping of service to MPLS is being addressed by PWE3
  - Still considerable discussion around the edge addressing scheme (MAC based) and how it will be learned. Also the end customer interface – will it be 802.1Q VLAN tags?
- It is clear however that MPLS will be retained as the core routing scheme – why?

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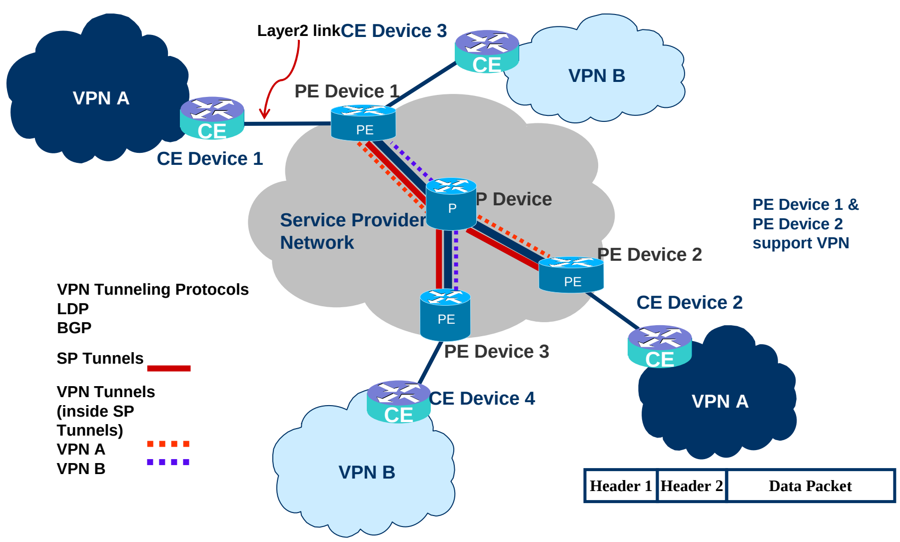
Visually - Layer 2 VPN



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Value of MPLS VPNs

- MPLS will be retained as the core encapsulation scheme because
  - Provides a recognized encapsulation that already is supported by many IP & ISP core networks
  - The connection-oriented nature of MPLS ensures QoS, Traffic Engineering and guarantees can be assigned against the core if required.
  - The routing schemes and addressing schemes are interoperable with existing routers.
- It operates over diverse media, Ethernet and legacy interfaces DS1, DS3 and SONET
  - also interoperates over/with Legacy Services.

Agenda – MPLS Applications

- Role in the IP core - Traffic Engineering in IP networks
- Virtual Private Networks (VPNs)
- ➡ Voice over MPLS
- Legacy support via PWE3
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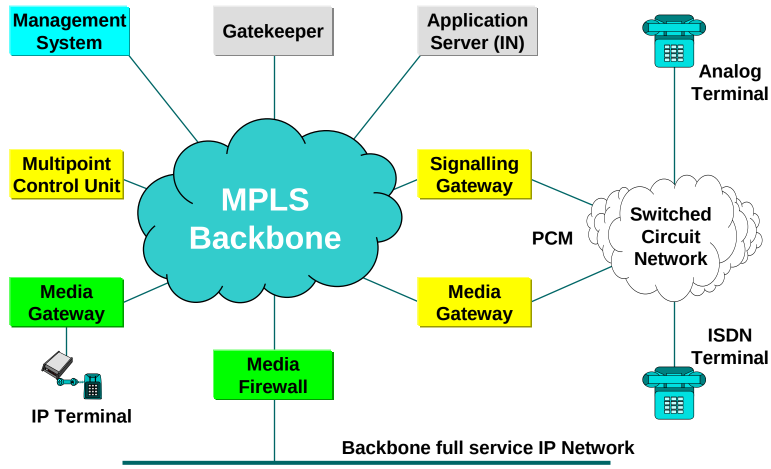
- ASON/GMPLS – using MPLS as the universal control plane – optical / core / edge / end-to-end

A Packet Voice Architecture - *SoftSwitch*



Implementation Considerations

- Infrastructure Cost
  - Expected to be the same as/less than today's voice access infrastructure - After 100 years of engineering the cost is LOW
  - Replacing an existing solution with a new one with equal/lower cost is driven by new revenue generation opportunities created by data services support
- Quality
  - Capable of delivering the same or better quality than the current voice network
- Features
  - Should provide at least the same key features that are available in today's voice networks and preferably also some new ones
  - Provide a compatible infrastructure for new converged services – IP Multimedia Subsystem

Why Voice over MPLS?

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<u>Applications</u>

- Trunking between gateways
- Multiple voice streams per LSP
- Circuit emulation
- Interconnect of legacy equipment

<u>Advantages</u>

- Carriers can migrate voice traffic to IP with QoS
- MPLS path protection meets strict voice requirements
- Increased efficiency and QoS over basic VoIP

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Two Approaches for Voice over MPLS

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- Voice over IP over MPLS (VoIPoMPLS)
  - IP Encapsulation of Voice Packet
    - Header Overhead = Transport Inefficiencies
    - [Voice/RTP/UDP/IP/MPLS] on top of an MPLS transport arrangement such as Frame Relay, ATM, PPP, or Ethernet.
- Voice over MPLS (VoMPLS)
  - Voice directly over MPLS
    - i.e. Without the traditional IP encapsulation of the voice packet
    - Voice/MPLS* on top of an MPLS transport arrangement such as Frame, ATM, PPP, or Ethernet.

    *Note: MPLS & Frame Relay Alliance Voice over MPLS – Bearer Transport Implementation Agreement 1.0, July 2001

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Packet Voice = Bandwidth Efficiency

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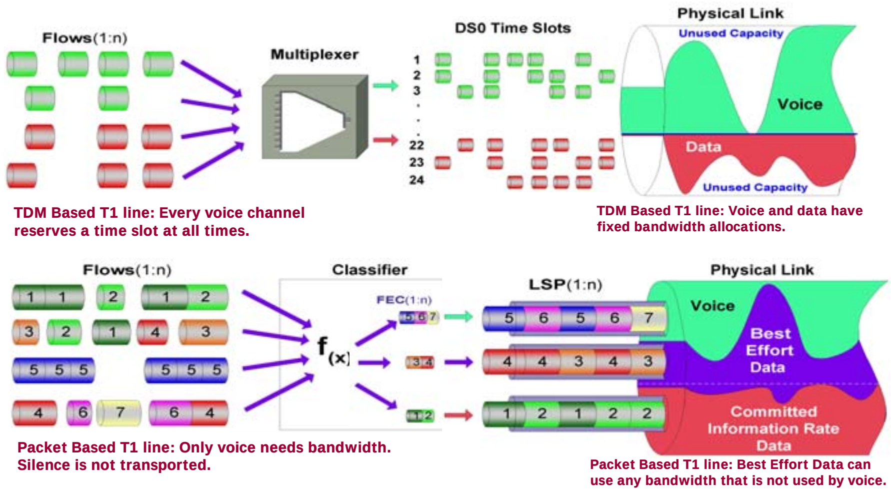

LSP- Level Traffic Management

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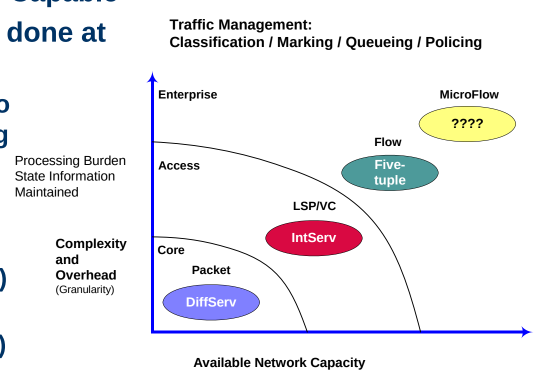
- IP Becomes Multi-Service Capable
  - Traffic Management is done at LSP level.
    - All traffic is subject to metering and policing at the edge.
  - Four traffic classes:
    - Real-time (voice)
    - Committed Rate (CIR)
    - Committed Rate + Best Effort (CIR + BE)
    - Best Effort (BE)
  - Each traffic class is transported over a separate LSP.



Agenda – MPLS Applications

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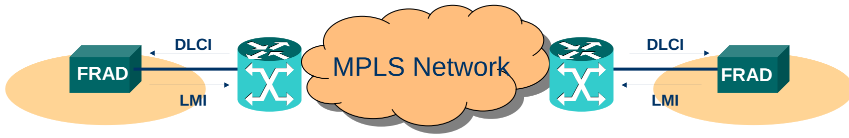
What is PWE3?

- PWE3 – "Pseudo Wire Emulation Edge-to-Edge" – Working Group assigned to study carriage of "Legacy and New Services" over MPLS
- Also known in the IETF as the "Foo-Bar" problem
  - "Foo" is the upper layer
  - "Bar" is the lower layer
- So "Foo" Over MPLS implies that a range of services or protocol encapsulations can be carried over MPLS
  - Legacy Services under consideration are:
    - FR, ATM, SONET & SDH, DS0, DS1, DS3, …
  - and new services such as
    - Ethernet, VLANs, etc.

MPLS – Integrated Access *Frame Relay over MPLS*

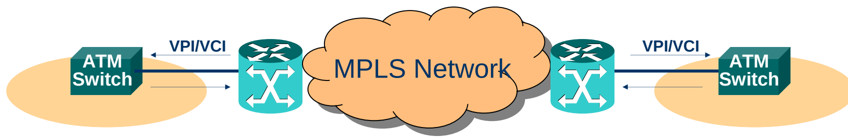


- MPLS defined label distribution and encapsulation
- Supports existing FRADs at the customer premises
- DLCIs are translated at the edge LSR
- LSR maintains the VC label to in/out port & DLCI

MPLS – Integrated Access *Frame Relay over MPLS*

- Frame Relay PDU including header is transported in its entirety
- FECN and BECN bits are also carried, unseen by MPLS
- Detection of a Q.933 a.5 service affecting condition leads to label withdrawal
- Ingress LSR maps the DE bit to corresponding EXP values in the MPLS label
- Egress also optionally considers the EXP field in queuing the packet
- Egress generate Q.933 and Q.922 errors and alarms

MPLS – Integrated Access
ATM over MPLS



- MPLS defined label distribution and encapsulation
- Supports existing ATM switches at the customer premises
- VPI/VCI are translated at the edge LSRs
- LSR maintains the VC label to in/out port & VPI/VCI

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MPLS – Integrated Access
ATM over MPLS

- AAL5 and ATM cell are supported
- ATM AAL5 mode requires the reassembly of PDUs from an incoming VC into a packet
- ATM cell mode transports ATM cell payload as a packet
- F5 OAM cells are not transported over LSPs but are looped back to the VC. OAM cells are generated by LSR
- If a user-defined number of F5 OAM cells are not received, label is withdrawn
- Ingress and egress LSR may consider the CLP bit for mapping into EXP field and vice versa

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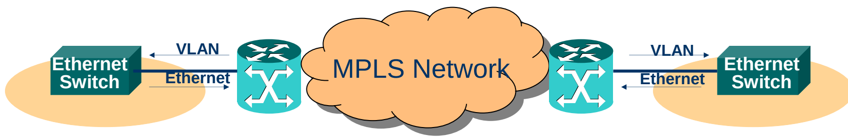
MPLS – Integrated Access
Ethernet over MPLS



- MPLS defined label distribution and encapsulation
- GigE/FastE ports at business or consumers
- MAC Addresses are translated at the edge LSRs
- LSR maintains the MAC label to in/out port & optionally VLAN

MPLS – Integrated Access
Ethernet over MPLS

- Entire Ethernet frame without the preamble and FCS is transported
- In case of VLAN, the VLAN tag is transported
- Ingress and egress may consider the priority field in the tag for mapping into the EXP field of the label
- Out of sequence, hardware, framing, CRC errored frames are discarded
- Sequencing control is optional

MPLS – Integrated Access *Leased Line & SONET/SDH over MPLS*

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- Many drafts under consideration
  - TDM Circuit emulation over MPLS
    - draft-ietf-pwe3-tdm-requirements-xx.txt
    - draft-ietf-pwe3-satop-xx-txt
    - Draft-ietf-pwe3-cesopsn-xx.txt
  - SONET/SDH over MPLS
    - draft-ietf-pwe3-sonet-xx.txt
    - draft-ietf-pwe3-cep-mib-xx.txt

Agenda – MPLS Applications

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- Role in the IP core - Traffic Engineering in IP networks
- Virtual Private Networks (VPNs)
- Voice over MPLS
- Legacy support via PWE3
- ➡ Using MPLS to simplify current network architectures
- ASON/GMPLS – using MPLS as the universal control plane – optical / core / edge / end-to-end

The Past – a Brief Analysis
Anatomy of the Layers

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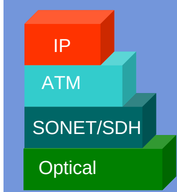

IP: Service and addressing
ATM: Quality of service, TE
SONET: Protection, Multiplexing
Optical: Bandwidth

Traffic Engineering with ATM

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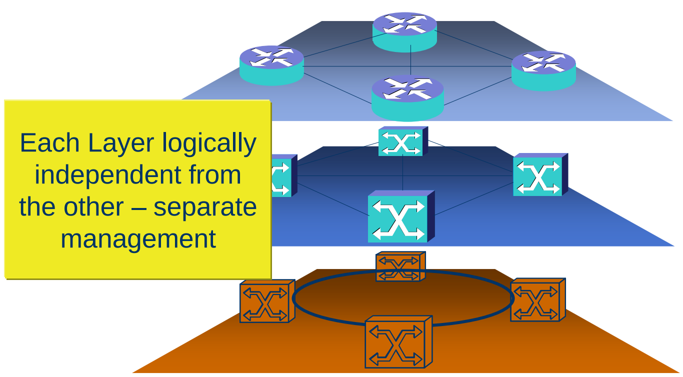

IP

ATM

SONET/
SDH

- **IP/ATM Overlay Model**

IP/ATM Overlay Model: *Advantages*

- Provides TE engineering not possible with IP only
- Protection in the SONET/SDH layer
- ATM provides logical VC connection
- Routers can be logically fully meshed
- Individual flows are aggregated into coarse flows
- Device hops can be masked in VCs
- No failover coordination between layers

IP/ATM Overlay Model: *Disadvantages*

- Scalability (VC full mesh causes IGPs to break)
- Management complexity- (NMS per layer)
- One transport layer failure leads to many upper layer VC failures
- ATM SAR chips are not available beyond OC-48
- No failover coordination between layers
- Cell tax for 40-Byte packets

Separate Control Plane

Control Plane	IP	MPLS	ATM
Admission Control	None	TBD	UNI
Routing	OSPF, IS-IS, BGP	OSPF-TE, IS-IS-TE, BGP-TE	PNNI
Path Computation	Per hop	End-to-End CR and CA	End-to-End CR and CA
Signaling	Per hop	RSVP-TE, CR-LDP	Q.2931, UNI
Connection Name	None	Label Switched Path	VPI, VCI
Connection ID	None	Label –ID	VCID
Explicit Routing	None unless source routed	Explicit Route Objects	Designated Transit Lists
Restoration/Convergence	Yes with routing protocols	Yes with signaling Fast reroute –sub 50 ms	Only with PNNI

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Separate Data Plane

Network Data Plane	IP	MPLS	ATM
Transmission Unit	Packets	Packets / Cells	Packets / Cells
Policing (for fairness)	Yes, if diffserv	Ingress port policing	Yes, Multiple traffic contracts
Marking	Yes, if diffserv	Possible based on EXP field/label	Marked conform or non-conform
Buffer Allocation	Per Flow, if classified	Per Flow	Per Flow / VC
Scheduling (for flow prioritization and fairness)	Limited	Per Port, Per Flow, Per Class	Per port, per flow, per class
Protection/fast reroute	No/Slow Convergence	Yes	Yes

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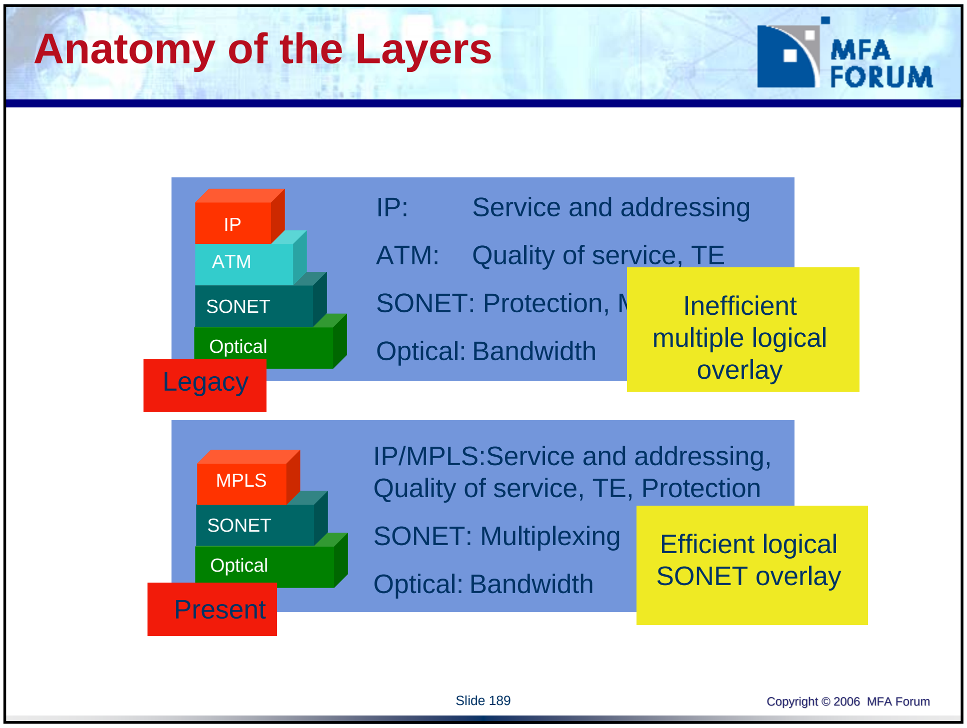
Anatomy of the Layers
MFA FORUM
IP
ATM
SONET
Optical
Legacy
IP: Service and addressing
ATM: Quality of service, TE
SONET: Protection, M
Optical: Bandwidth
Inefficient multiple logical overlay
MPLS
SONET
Optical
Present
IP/MPLS:Service and addressing, Quality of service, TE, Protection
SONET: Multiplexing
Optical: Bandwidth
Efficient logical SONET overlay
Slide 189
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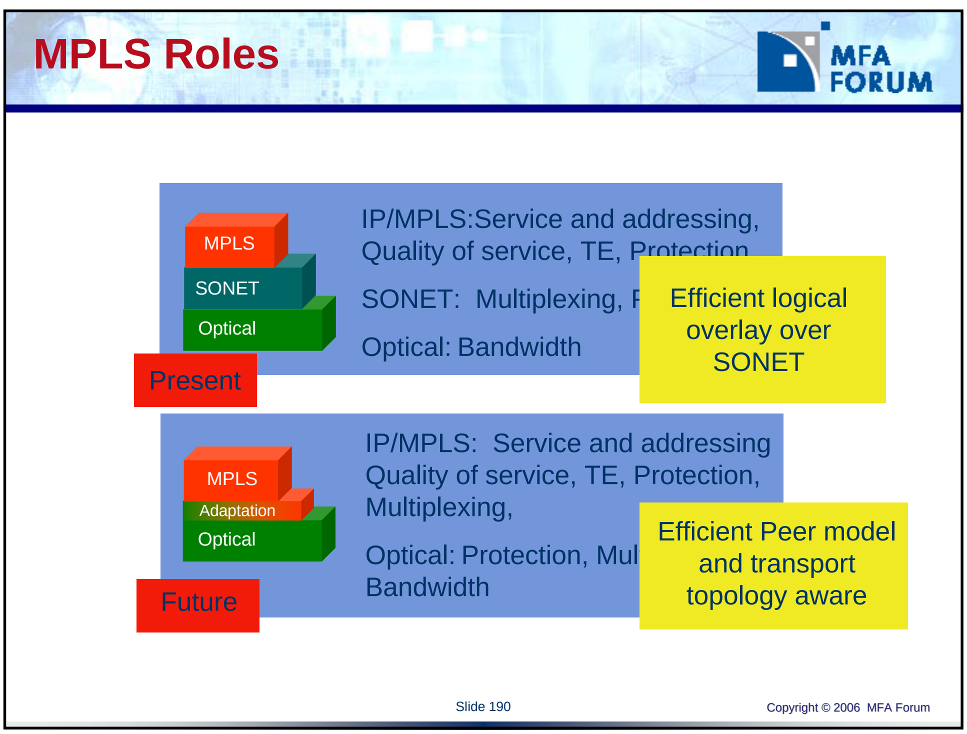
MPLS Roles
MFA FORUM
MPLS
SONET
Optical
Present
IP/MPLS:Service and addressing, Quality of service, TE, Protection
SONET: Multiplexing, P
Optical: Bandwidth
Efficient logical overlay over SONET
MPLS
Adaptation
Optical
Future
IP/MPLS: Service and addressing Quality of service, TE, Protection, Multiplexing,
Optical: Protection, Mul
Bandwidth
Efficient Peer model and transport topology aware
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Agenda – MPLS Applications

- Role in the IP core - Traffic Engineering in IP networks
- Virtual Private Networks (VPNs)
- Voice over MPLS
- Legacy support via PWE3
- Using MPLS to simplify current network architectures
- ASON/GMPLS – using MPLS as the universal control plane – optical / core / edge / end-to-end

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Converging Technology Layers

	Method	Standard Body	Routing	Signaling	Available
L1	Optical	ITU-T, OIF (ASON/ GMPLS)	(I-NNI/E-NNI) OSPF-TE, IS-IS-TE	RSVP-TE, CR-LDP	UNI 1.0 Now E-NNI 1.0 (1Yr+)
L2	MPLS	MPLS Forum	OSPF-TE, IS-IS-TE	RSVP-TE	Now
L3	IP	IETF	OSPF, IS-IS	N/A	Now

Single Control Plane Across the Entire Network

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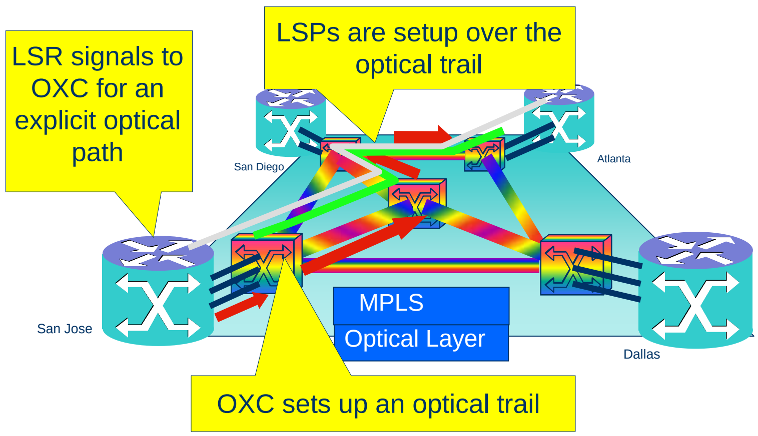
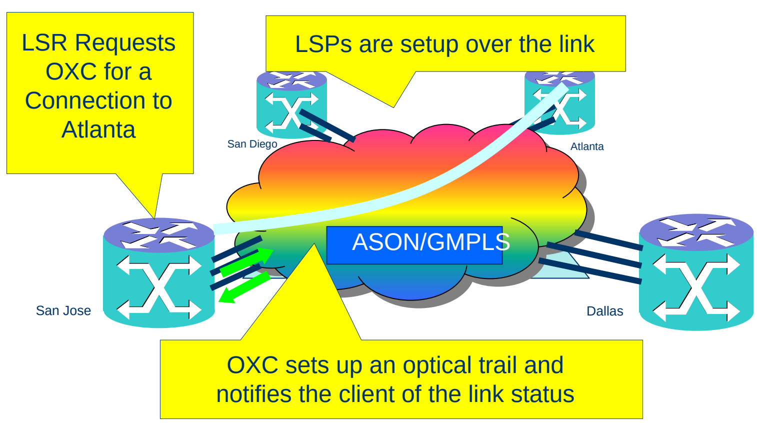
The Control Plane
IETF – GMPLS Model



- **Direct LSP/Optical trail establishment through a desired topology meeting defined constraints via common signaling protocols**

The Optical UNI Model – ASON/GMPLS



- **User-Network Model. Clients request connectivity via an UNI or E-NNI signal. Clients are unaware of the OTN blueprint.**
- **Independent OTN and Client control planes**

ASON/GMPLS

- A control plane of OXCs to facilitate channel layer bandwidth management
- Based on MPLS control protocols
- Mechanism to provide dynamic circuit assignment
- Facilitates protection and restoration in optical links in conjunction to (or without) SONET restoration
- Facilitates 'end-to-end' soft provisioning of TDM circuits
- Integrates true topology discovery into the SONET/SDH network

ASON/GMPLS - *Extending The IGPs*

- Requirement to represent optical parameters in routing protocols
  - OSPF-TE & ISIS-TE: use Opaque LSA to tunnel parameters through "optical unaware" network
  - OSPF-TE & ISIS-TE: Type Length Values (TLV) extended to support Optical parameters, eg.
    - Link Type TLV: Advertise link characteristics
    - Link Media TLV: Advertise format and bit rates
    - Shared Risk Link: Whether the links share common failure points
    - Proprietary TLVs maybe proposed for standardization

Looking Forward
Not so Distant…..

- MPLS networks support increasing revenues
  - VPNs for Ethernet services
  - Adoption of Legacy Services over MPLS
- Adoption of MPLS by voice and data network for QoS engineering
- ASON/GMPLS as the control plane in Optical and SONET/SDH Transport systems (O-UNI & E-NNI)

End of Section 4

Thank You

More Information

MFA FORUM

- http://www.mfaforum.org
- http://www.ietf.org
- http://www.itu.int
- http://www.mplsrc.com

For questions utilize the MFA Forum Message Board

Website: http://www.mfaforum.org/board/

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Thank you **for attending the**

Introduction to MPLS Tutorial