Advanced Computer Networks

MPLS

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Contents

- MPLS (Multi Protocol Label Switching)
  - Label swapping
  - Elements of MPLS
  - Label switching
  - Label distribution
  - Interaction with IGP
  - Traffic engineering

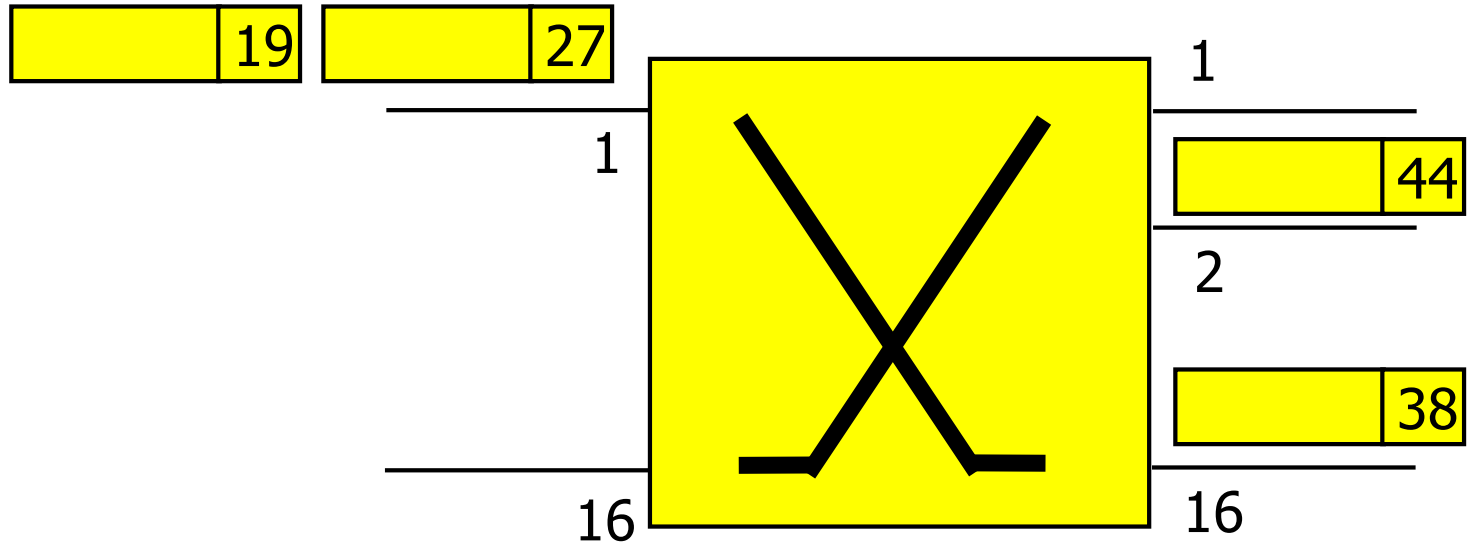
MPLS

- IGP limits
  - IP routing may ignore the real physical topology
  - OSPF algorithms send traffic on a shared path and may ignore unloaded links
    - even if load balancing can be done in some cases (Equal Cost)
- Goals of MPLS
  - increase forwarding performance
  - provide more flexibility than IGP routing
    - explicit routing, QoS routing
    - backup routes, load balancing, VPN
  - multiprotocol - a unifying view at 2.5 layer - a unified way of controlling the underlying Layer 2 network
    - Ethernet, PPP, SDH/DWDM

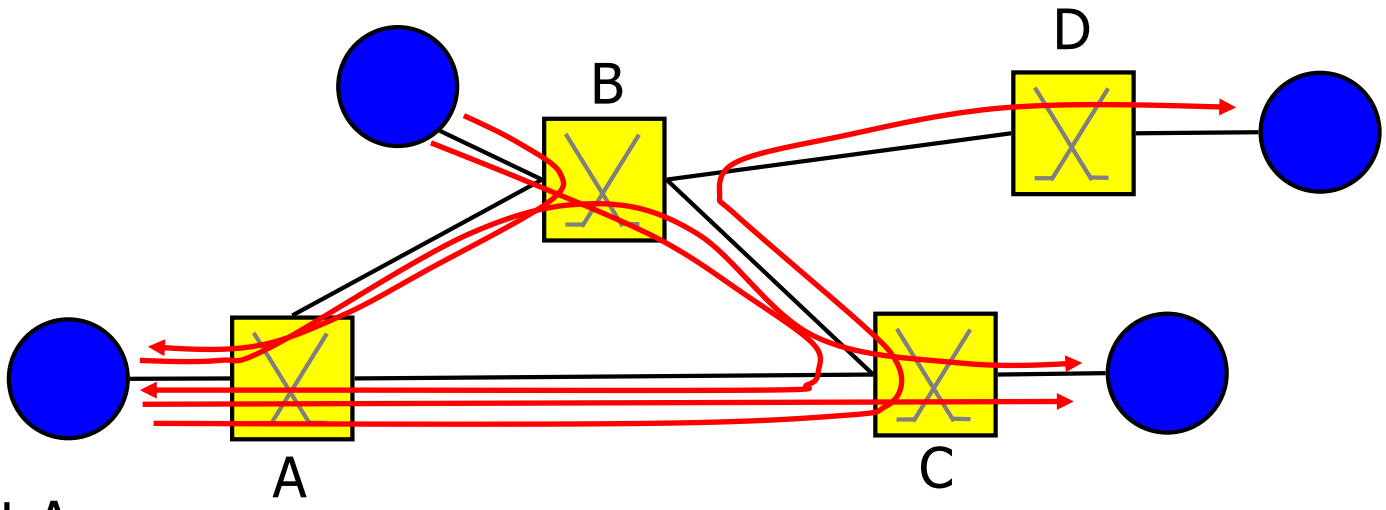
Virtual Circuits
ATM VPI/VCI switching

in	VPI/VCI	out	VPI/VCI
1	27	2	44
1	19	16	38

ATM cells
header contains VPI/VCI
(Virtual Path/Virtual Circuit)



Label swapping



VC table at A:

in	VPI/VCI	out	VPI/VCI
H	0	B	0
H	1	C	0
C	1	H	2
B	1	H	3
H	4	C	2

Virtual circuits opened in the following order:

ABC

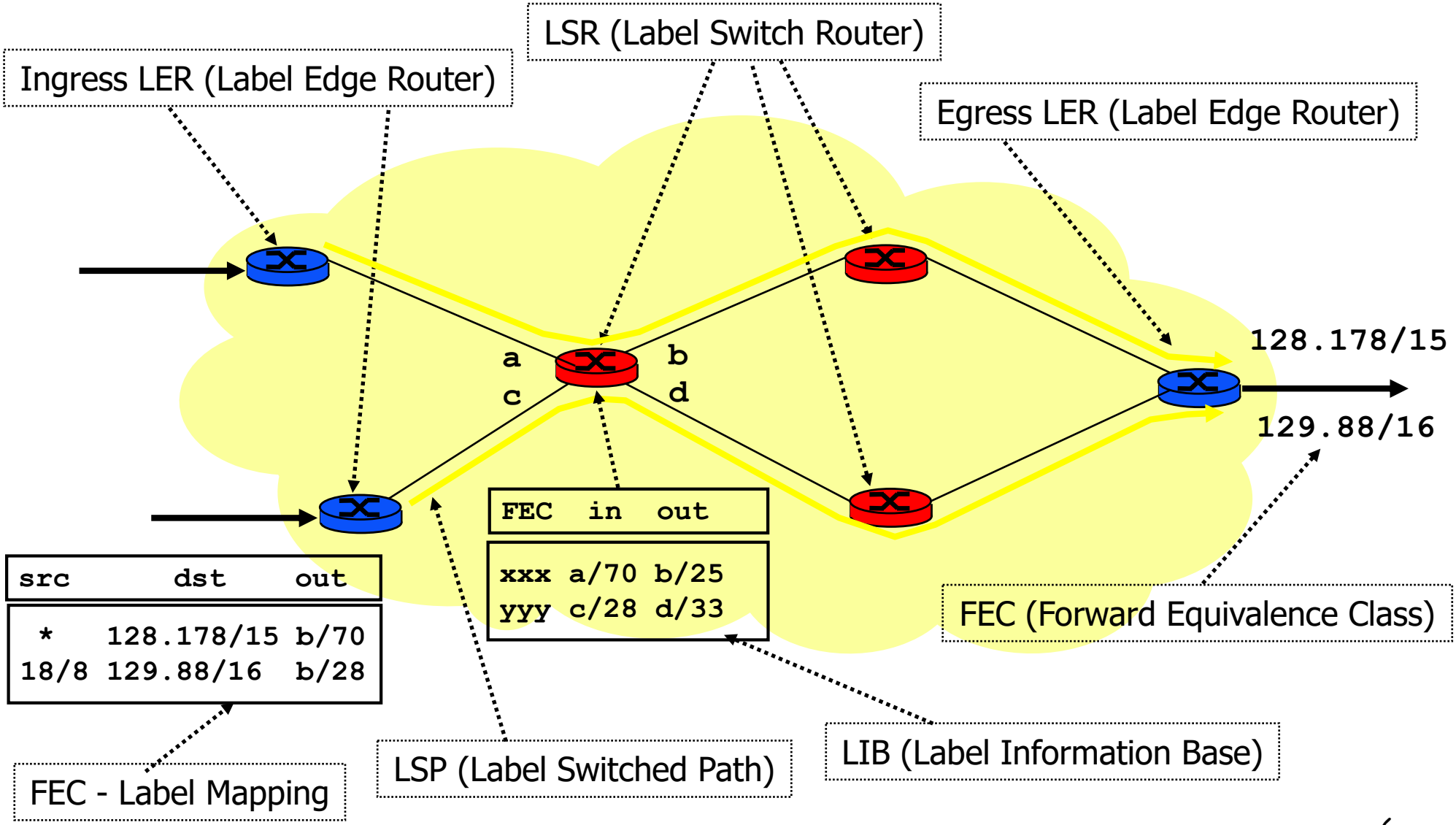
AC

BCA

BA

ACBD

MPLS elements



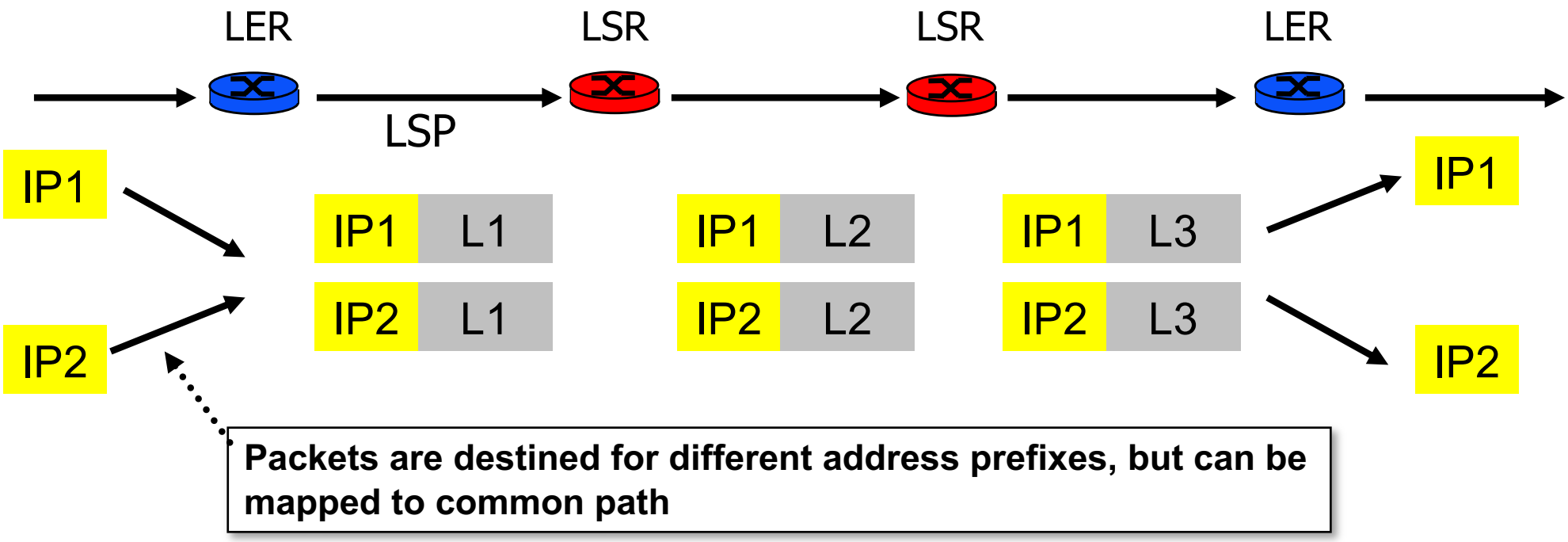
MPLS Principles

- Labels
  - ingress LER classifies packets to identify FEC that determines a label; inserts the label (32 bits)
  - LSR switches based on the label
  - label swapping - label has meaning local to one LSR (requires label distribution protocol)
  - egress LER removes the label
- LSR
  - contains LIB - switching table that determines the path in the network (LSP)
  - LSP - similar to a ATM/FR virtual circuit
- Change of the forwarding paradigm
  - instead of hop by hop
  - LSP determined at entry in function of FEC, source, or other

Forwarding Equivalence Classes

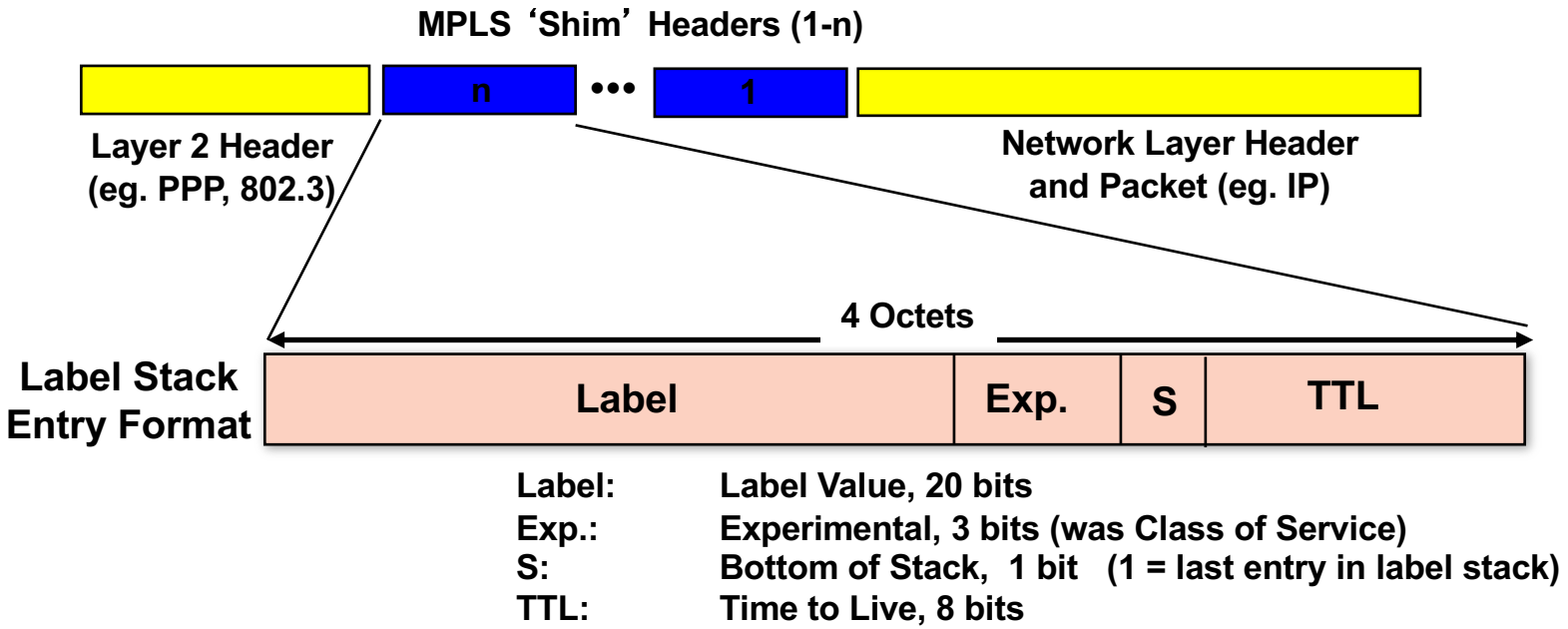
- FEC - group of IP packets
  - forwarded in the same manner, over the same path, and with the same forwarding treatment
- FEC may correspond to
  - destination IP subnet
  - source and destination IP subnet
  - traffic class that LER considers significant
- For example, all traffic with a certain value of IP precedence may constitute a FEC
- FEC in our examples
  - IP prefix

Forwarding Equivalence Classes



- FEC = "A subset of packets that are all treated the same way by a router"
- 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

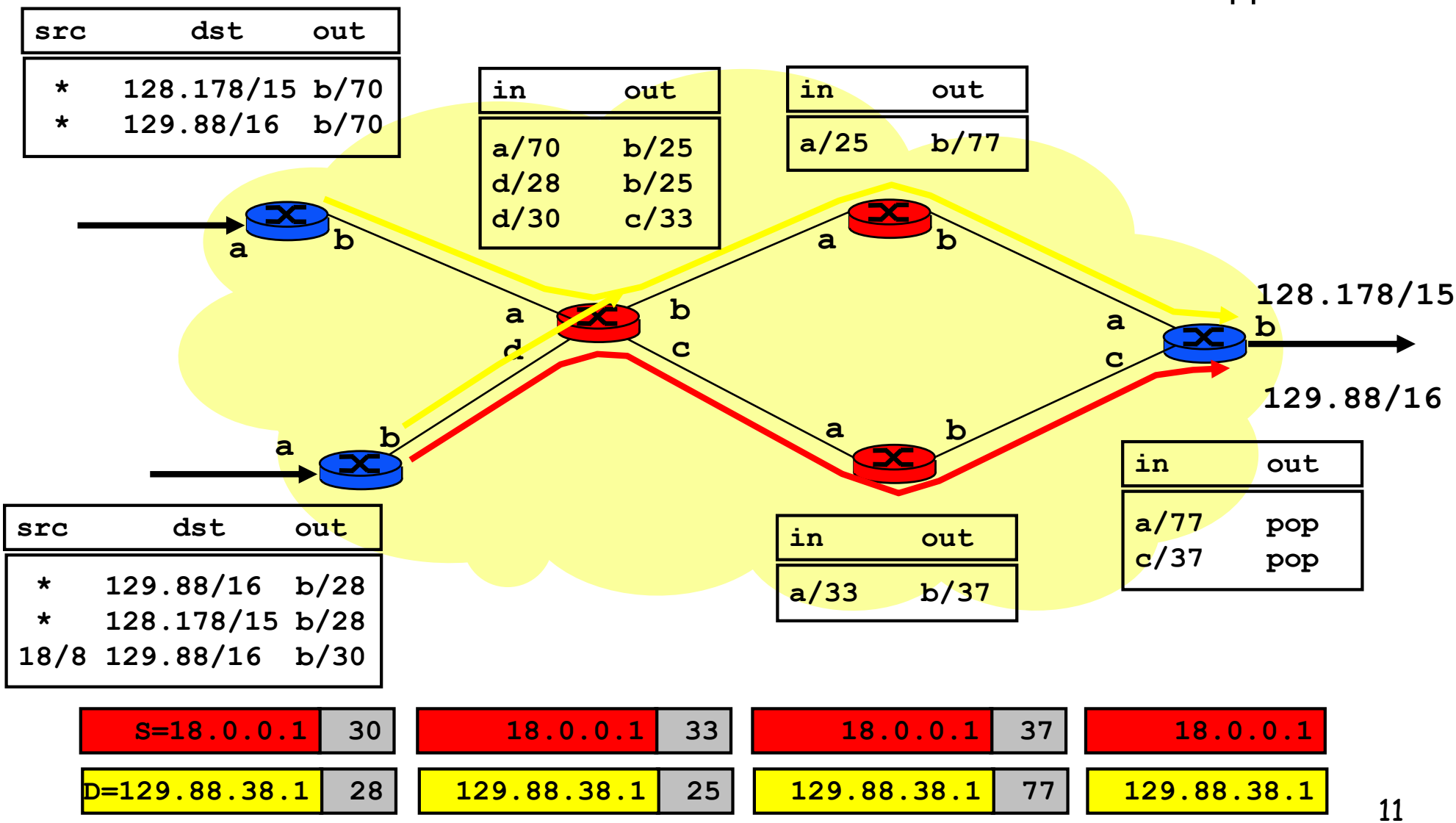
MPLS Encapsulation - PPP & LAN



- MPLS on PPP links and LANs uses shim header
  - inserted between layer 2 and 3 headers

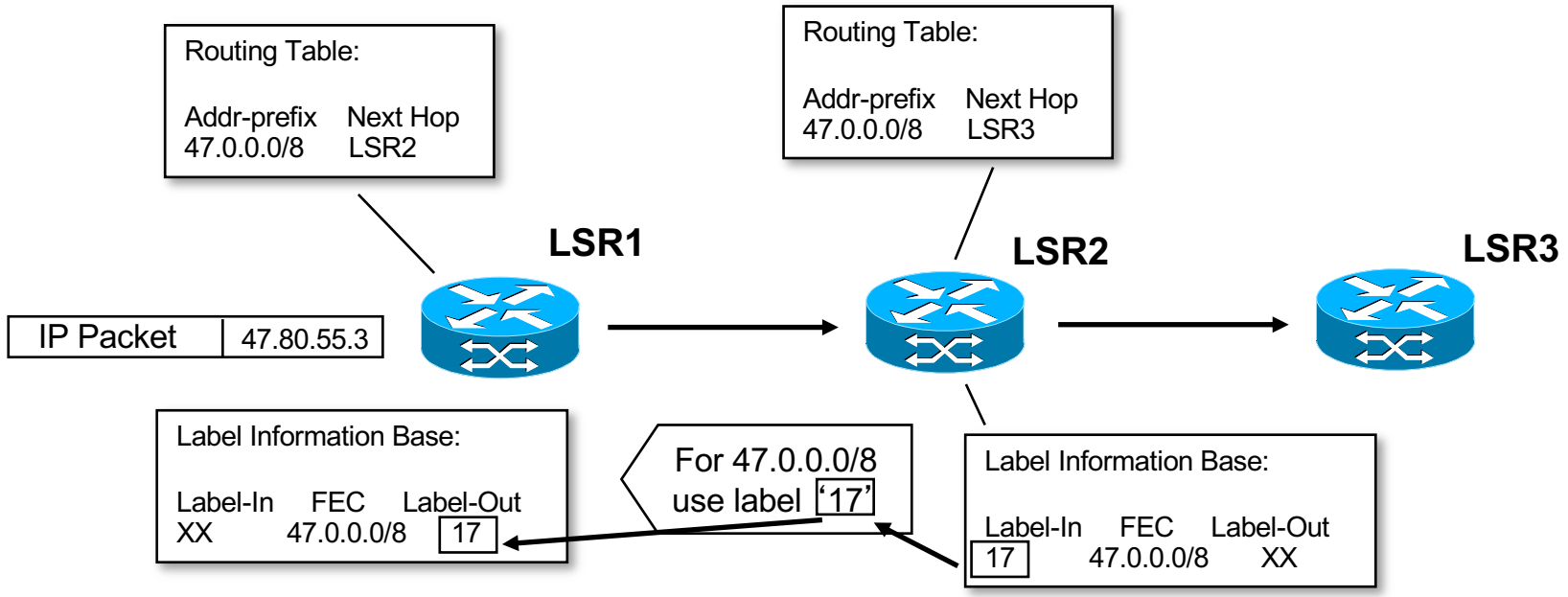
MPLS example

FEC skipped in LIB



Label Distribution Protocol (LDP)

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



Step 3: LSR inserts label value into forwarding base

Step 2: LSR communicates binding to adjacent LSR

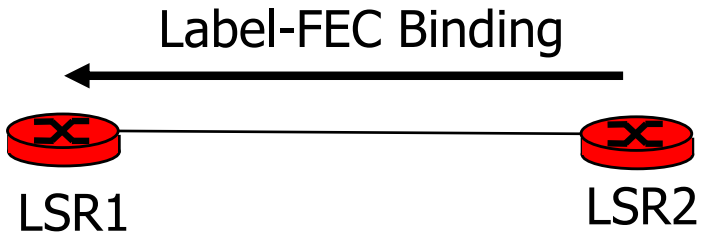
Step 1: LSR creates binding between FEC and label value

Common understanding of which FEC the label is referring to!

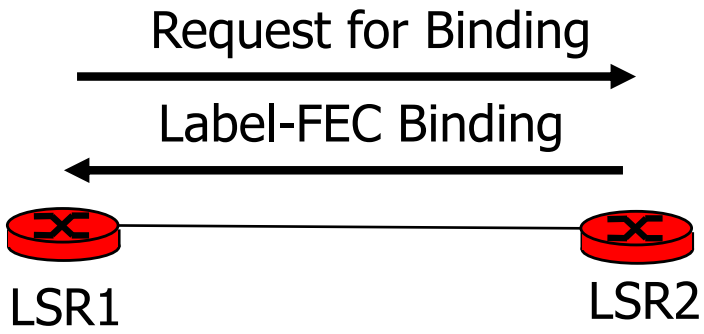
Label distribution can either piggyback on top of an existing routing protocol, or a dedicated label distribution protocol (LDP) can be created.

Label distribution

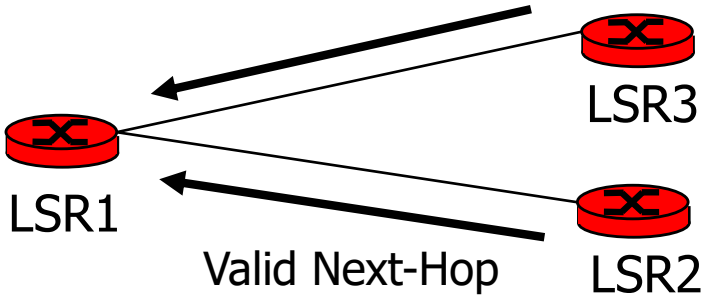
- Label distribution is always done from downstream to upstream
  - **downstream-unsolicited**: new route => send new label



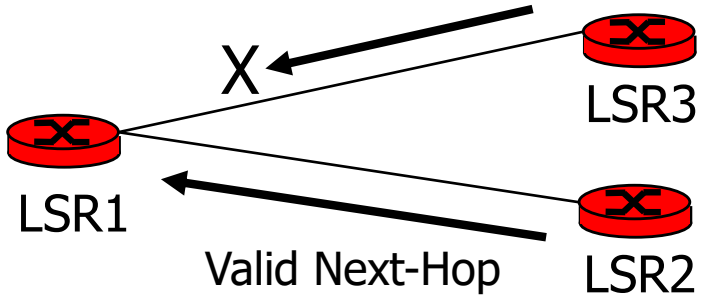
  - **downstream-on-demand**: upstream LSR asks for a label



Label retention



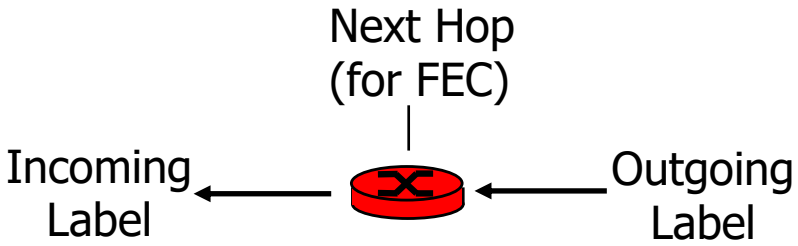
Liberal



Conservative

- Label retention can be
  - **liberal**: memorize all labels from downstream LSR (faster)
  - **conservative**: memorize only selected labels (less memory)

Label control



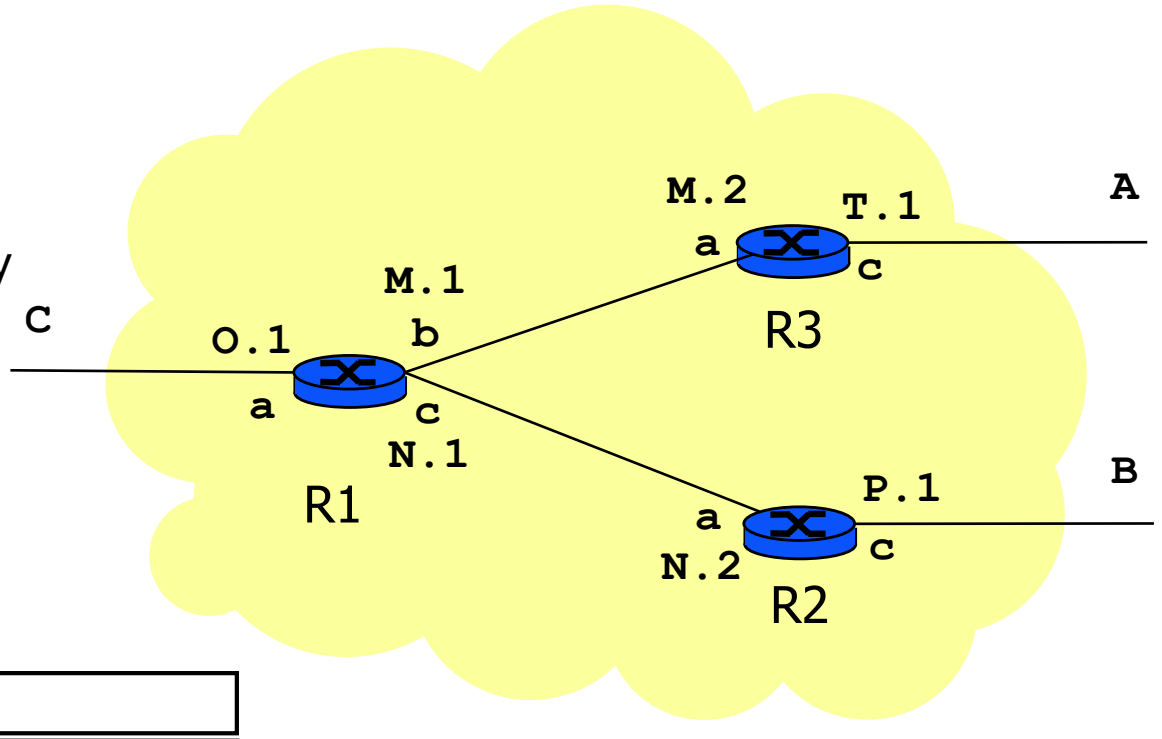
- Label control can be
  - **ordered**: LSR only binds and advertise a label for a particular FEC if
    - it is the egress LSR for that FEC or
    - it has already received a label binding from its next-hop
    - LSP formation 'flows' from egress to ingress
  - **independent**: LSR binds a Label to a FEC independently, whether or not the LSR has received a label from the next-hop for the FEC
    - LSR then advertises the label to its neighbor
    - LSP is formed as incoming and outgoing labels are spliced together

Label distribution

- Different label distribution protocols
- LDP (Label Distribution Protocol)
  - defined for MPLS
- Extension of BGP
- Extension of RSVP
  - RSVP-TE: traditional RSVP + Explicit Route
- CR-LDP (Constraint-Based LDP)
  - LDP + Explicit Route

Label distribution example - OSPF

A, B… - IP prefix
M.1… - IP address
a, b… - interface
a/L1-c/L3 - LIB entry

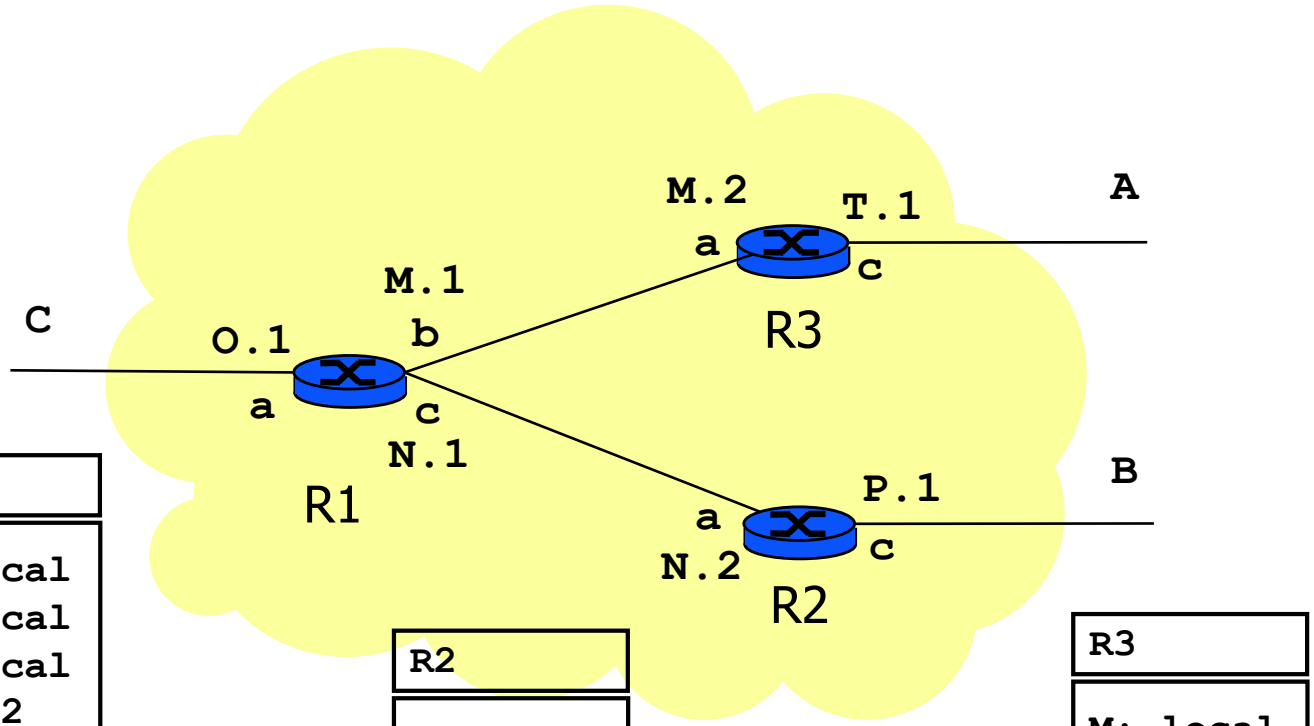


R1
C, M, N, O

R3
A, M, T

R2
B, N, P

OSPF - routing tables

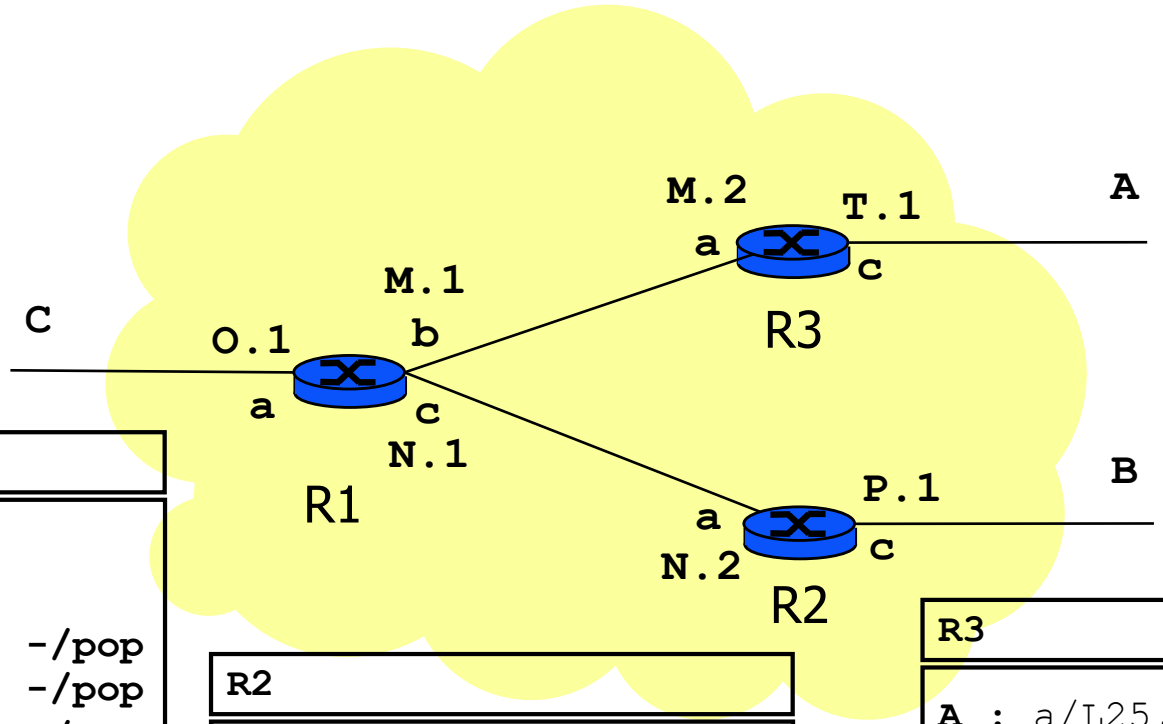


R1
O: local
M: local
N: local
C: O.2
A: M.2
B: N.2
T: M.2
P: N.2

R2
N: local
P: local
B: P.2
C: N.1
A: N.1
T: N.1
M: N.1
O: N.1

R3
M: local
T: local
A: T.2
C: M.1
B: M.1
N: M.1
P: M.1
O: M.1

Label bindings



R1

A :	**b/L01**, c/L02
B :	b/L03, **c/L04**
C :	b/L05, c/L06, **-/pop**
M :	b/L07, c/L08, **-/pop**
N :	b/L09, c/L10, **-/pop**
O :	b/L11, c/L12, **-/pop**
P :	b/L13, **c/L14**
T :	**b/L15**, c/L16

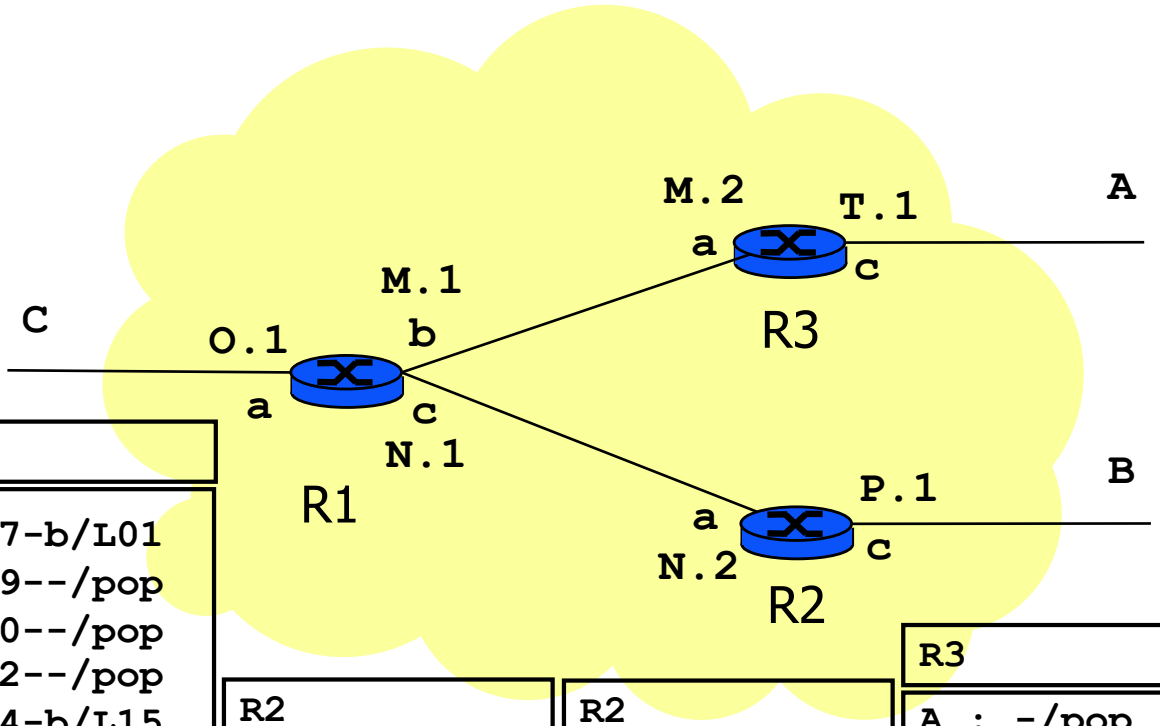
R2

A :	**a/L17**
B :	a/L18, **-/pop**
C :	**a/L19**
M :	**a/L20**
N :	a/L21, **-/pop**
O :	**a/L22**
P :	a/L23, **-/pop**
T :	**a/L24**

R3

A :	a/L25, **-/pop**
B :	**a/L26**
C :	**a/L27**
M :	a/L28, **-/pop**
N :	**a/L29**
O :	**a/L30**
P :	**a/L31**
T :	a/L32, **-/pop**

Switching tables



R1	
A	b/L01
B	c/L04
C	-/pop
M	-/pop
N	-/pop
O	-/pop
P	c/L14
T	b/L15

R1
c/L17-b/L01
c/L19--/pop
c/L20--/pop
c/L22--/pop
c/L24-b/L15
b/L26-c/L04
b/L27--/pop
b/L29--/pop
b/L30--/pop
b/L31-c/L14

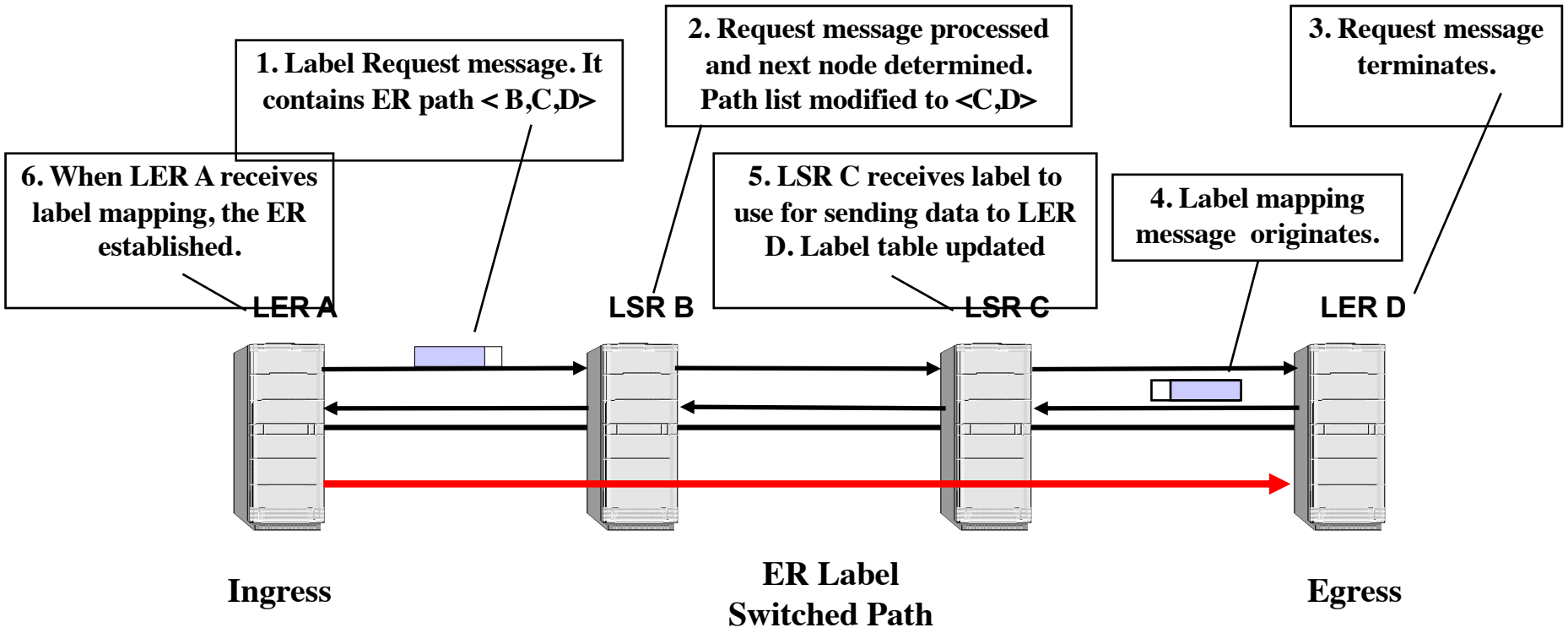
R2	
A	a/L17
B	-/pop
C	a/L19
M	a/L20
N	-/pop
O	a/L22
P	-/pop
T	a/L24

R2
a/L04--/pop
a/L14--/pop

R3	
A	-/pop
B	a/L26
C	a/L27
M	-/pop
N	a/L29
O	a/L30
P	a/L31
T	-/pop

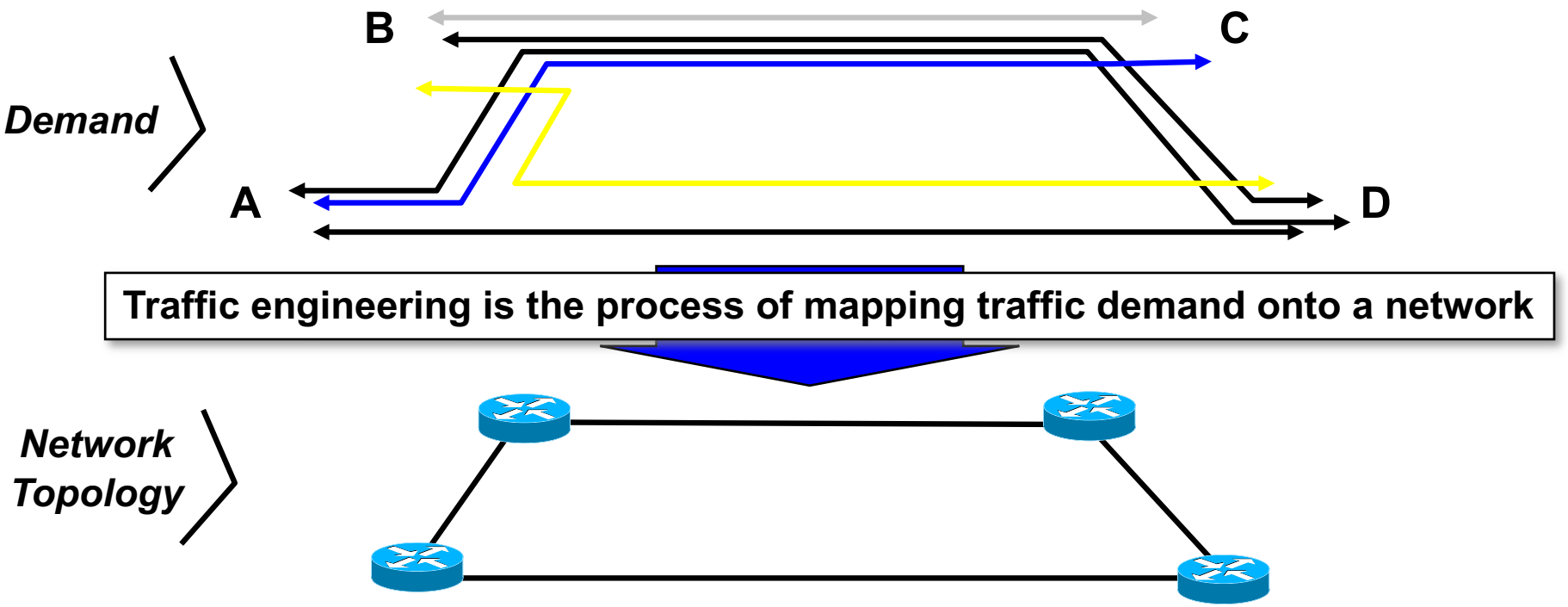
R3
a/L01--/pop
a/L15--/pop

ER-LSP setup using CR-LDP



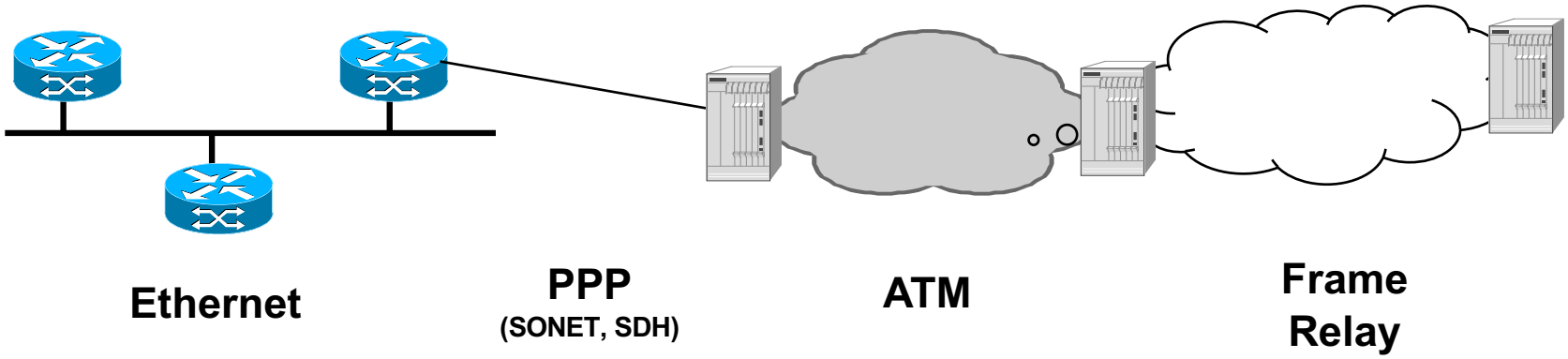
- Explicit Route setup
- CR-LDP can also be used to reserve resources
  - peak rate, committed rate, burst size

Traffic Engineering with MPLS



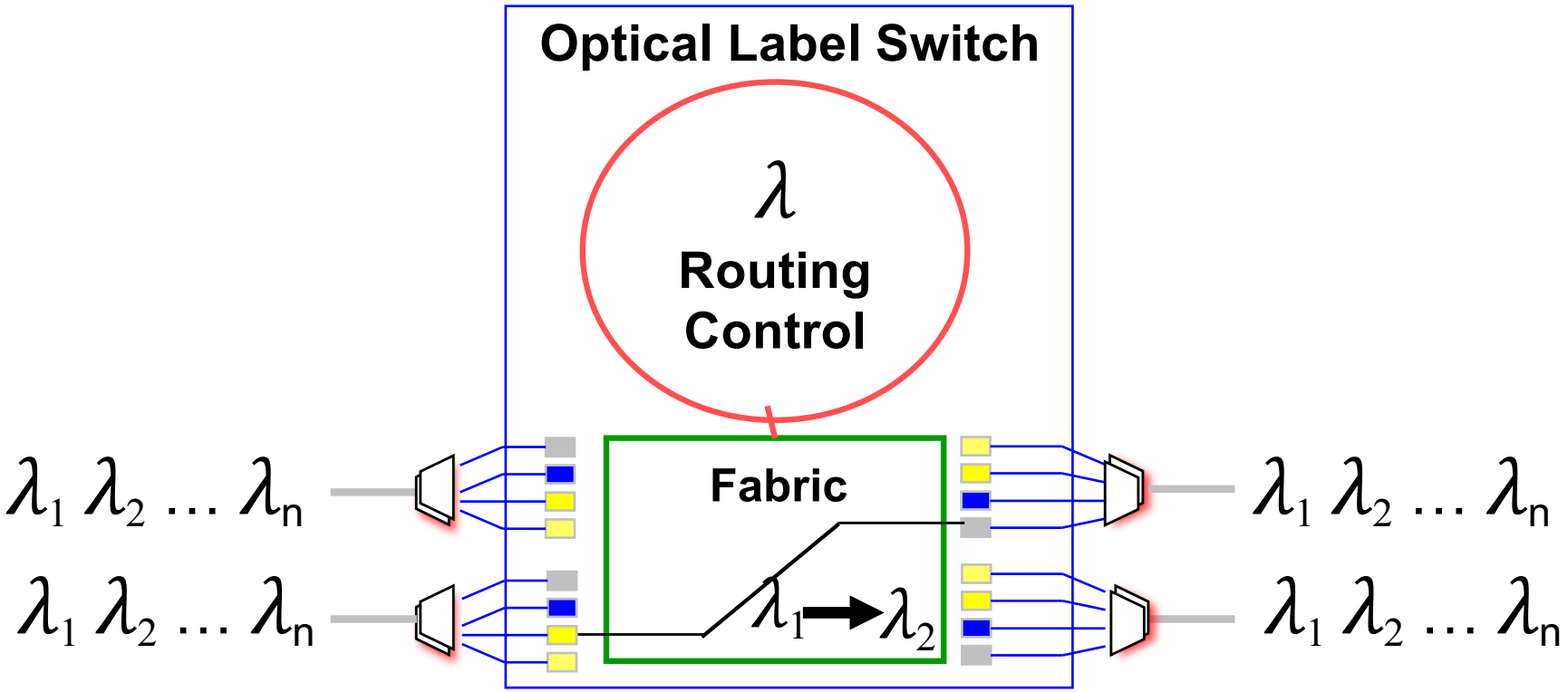
- Maximize utilization of links and nodes
- Engineer links to achieve required delay
- Spread the network traffic across network links, minimize impact of single failure
- Ensure available spare link capacity for re-routing traffic

Unifying forwarding paradigm



- MPLS offers an end-to-end unifying forwarding paradigm
  - MPLS is “multiprotocol” below (link layer) as well as above (network layer)
  - provides for consistent operations, engineering across multiple technologies
  - allows operators to control different technologies in a unified manner

GMPLS/MPλS



- Optical networks such as DWDM
  - λ is just another label to distribute - no new protocols required

Facts to remember

- MPLS allows flexible packet classification and network resources optimization
- Labels are distributed by different protocols
  - LDP, RSVP, BGP
- Labels have local (LSR) significance
  - no need for global (domain) wide label allocation/numbering
- Different link layer protocols may co-exist in the same LSR