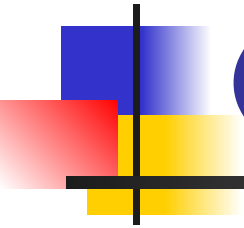


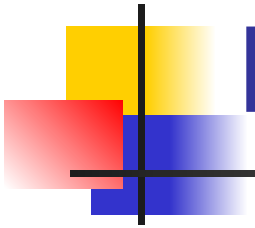
Multi-Protocol Label Switch (MPLS)

What is MPLS?

- From MPLS Resource center:
  - "MPLS stands for "Multiprotocol Label Switching". In an MPLS network, incoming packets are assigned a "label" by a "label edge routers (LER)". Packets are forwarded along a "label switch path (LSP)" where each "label switch router (LSR)" makes forwarding decisions based solely on the contents of the label. At each hop, the LSR strips off the existing label and applies a new label which tells the next hop how to forward the packet.
  - Label Switch Paths (LSPs) are established by network operators for a variety of purposes, such as to guarantee a certain level of performance, to route around network congestion, or to create IP tunnels for network-based virtual private networks. In many ways, LSPs are no different than circuit-switched paths in ATM or Frame Relay networks, except that they are not dependent on a particular Layer 2 technology.
  - An LSP can be established that crosses multiple Layer 2 transports such as ATM, Frame Relay or Ethernet. Thus, one of the true promises of MPLS is the ability to create end-to-end circuits, with specific performance characteristics, across any type of transport medium, eliminating the need for overlay networks or Layer 2 only control mechanisms."

What is MPLS?

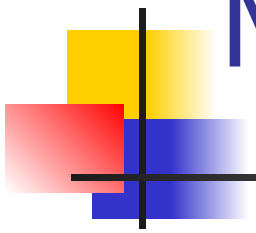
- OK now in plain English now please?
  - Packets enter MPLS Network at a "Label Edge Router" (LER)
  - LER Affix a label to packet and forwards it to the MPLS network
  - Label switches in the network at each hop makes forwarding decision solely based on label. That decision is made based on a pre-established "Label Switch Path" (LSP).
  - Labels can be integrated with existing L2 info such as DLCI or ATM VCs.
- Diagram in class.



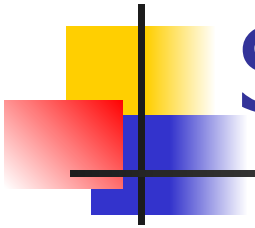
MPLS Motivation

- **Original drivers towards label switching:**
  - Designed to make routers faster
    - ATM switches were faster than routers
    - Fixed length label lookup faster than longest match used by IP routing
    - Allow a device to do the same job as a router with performance of ATM switch
  - Enabled IP + ATM integration
    - Mapping of IP to ATM had become very complex, hence simplify by replacing ATM signalling protocols with IP control protocols

MPLS Motivation

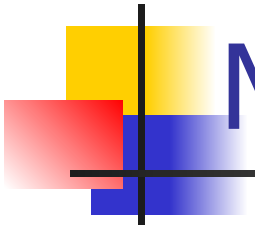


- Growth and evolution of the Internet
  - The need to evolve routing algorithm
  - The need for advanced forwarding algorithm
  - routing vs. forwarding (switching)
    - routing: flexibility
    - forwarding: price/performance
    - Can we forward/switch IP packets?
  - Allow speed of L2 switching at L3
  - Router makes L3 forwarding decision based on a single field: similar to L2 forwarding ☐ Spppppppeeeeed



Some MPLS Benefits

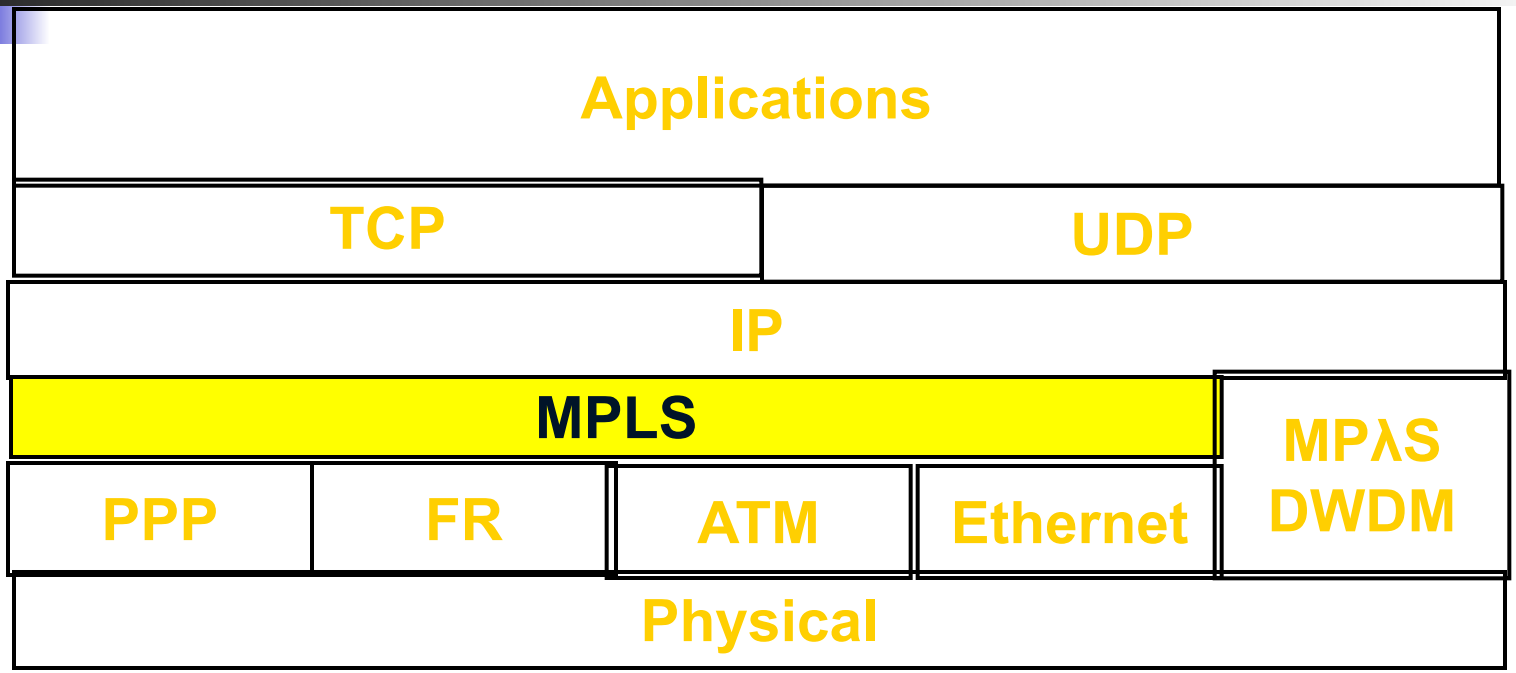
- Traffic Engineering - the ability to set the path traffic will take through the network, and the ability to set performance characteristics for a class of traffic
- VPNs - using MPLS, service providers can create IP tunnels throughout their network, without the need for encryption or end-user applications
- Layer 2 Transport - New standards being defined by the IETF's PWE3 and PPVPN working groups allow service providers to carry Layer 2 services including Ethernet, Frame Relay and ATM over an IP/MPLS core
- Elimination of Multiple Layers - Typically most carrier networks employ an overlay model where SONET/SDH is deployed at Layer 1, ATM is used at Layer 2 and IP is used at Layer 3. Using MPLS, carriers can migrate many of the functions of the SONET/SDH and ATM control plane to Layer 3, thereby simplifying network management and network complexity. Eventually, carrier networks may be able to migrate away from SONET/SDH and ATM all-together, which means elimination of ATM's inherent "cell-tax" in carrying IP traffic.



MPLS History

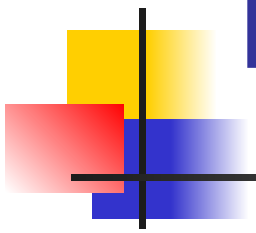
- IP over ATM
- IP Switching by Ipsilon
- Cell Switching Router (CSR) by Toshiba
- **Tag switching** by Cisco
- Aggregate Route-based IP Switching (IBM)
- IETF – **MPLS**
  - http://www.ietf.org/html.charters/mpls-charter.html
  - RFC3031 – MPLS Architecture
  - RFC2702 – Requirements for TE over MPLS
  - RFC3036 – LDP Specification

MPLS and ISO model (MPLS is a layer 2.5 protocol)



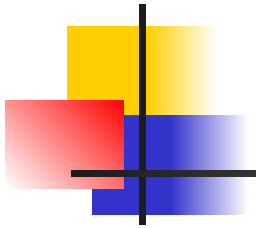
When a layer is added, no modification is needed on the existing layers.

Label Switching



- What is it?
- Goal: sending a packet from A to B
  - We can do it in a *broadcast* way.
  - We can use *source routing* where the source determines the path.
  - How do we do it on the Internet today?
    - **Hop-by-hop routing**: continue asking who is closer to B at every stop (hop).

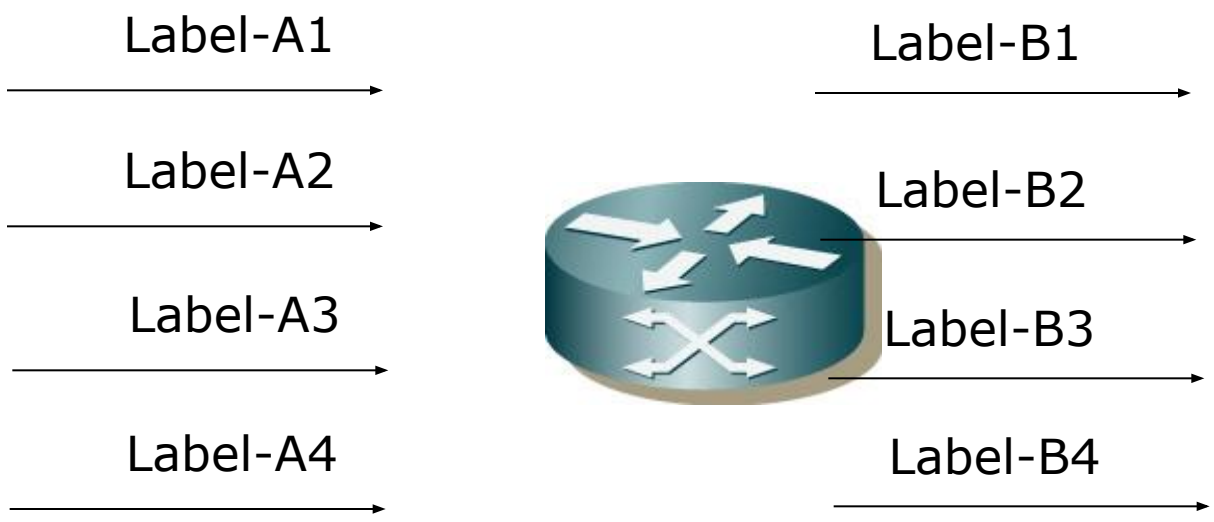
Using *Label* on the network (This is not new!)

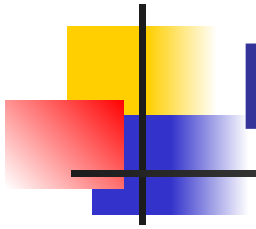


- ATM: VPI/VCI
- Frame Relay: DLCI
- X.25: LCI (logical Channel Identifier)
- TDM: the time slot (Circuit Identification Code)
- Ethernet switching: ???

Q: do you see any commonality of these *labels*?

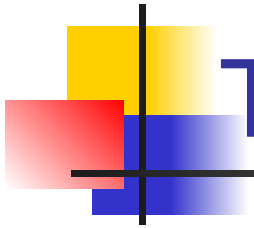
Label Substitution (swapping)





MPLS

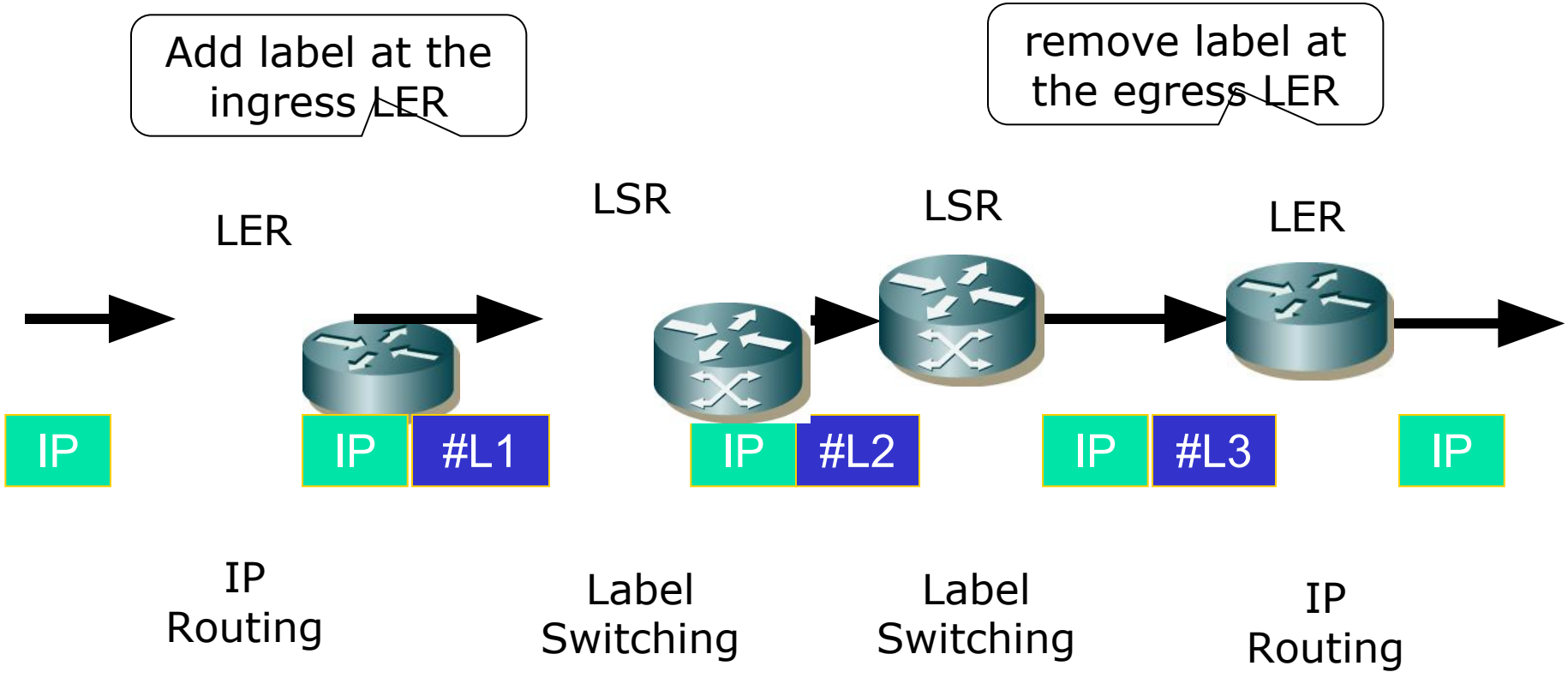
- A protocol to establish an end-to-end path from source to the destination
- A *hop-by-hop* forwarding mechanism
- Use labels to set up the path
  - Require a *protocol* to set up the labels along the path
- It builds a *connection-oriented* service on the IP network



Terminology

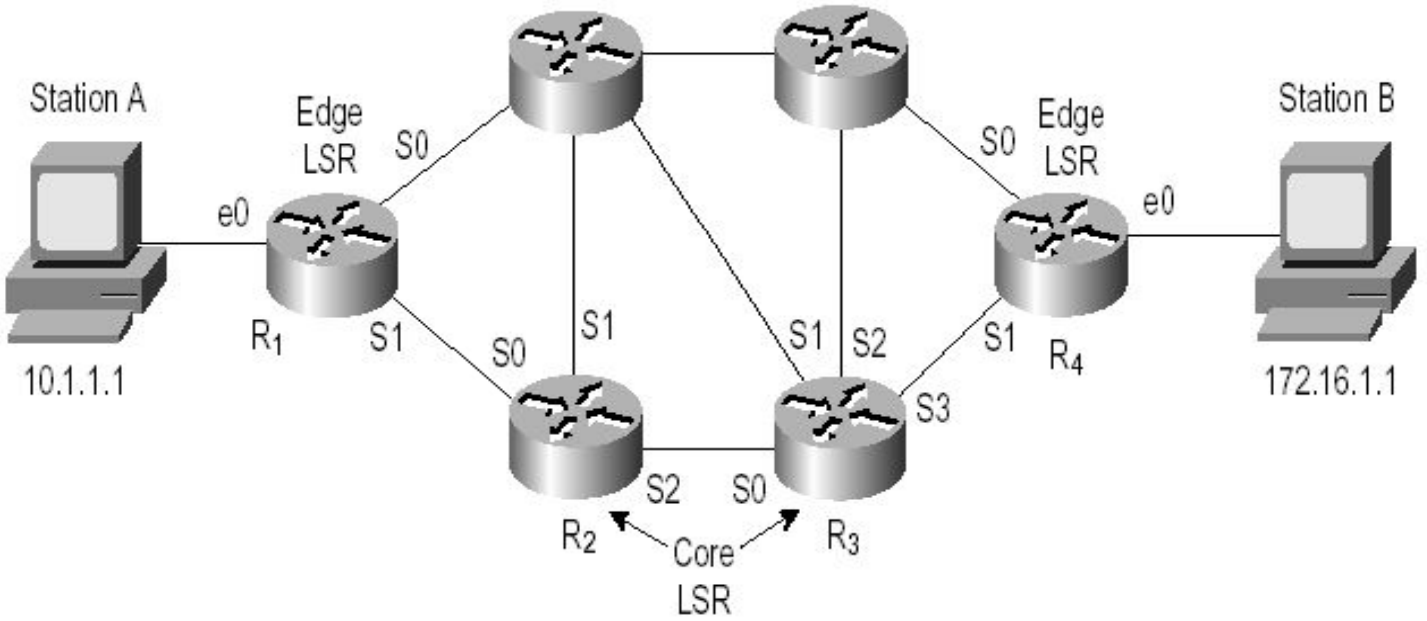
- LSR - Routers that support MPLS are called Label Switch Router
- LER - LSR at the edge of the network is called Label Edge Router (a.k.a Edge LSR)
  - Ingress LER is responsible for adding labels to unlabeled IP packets.
  - Egress LER is responsible for removing the labels.
- Label Switch Path (LSP) – the path defined by the labels through LSRs between two LERs.
- Label Forwarding Information Base (LFIB) – a forwarding table (mapping) between labels to outgoing interfaces.
- Forward Equivalent Class (FEC) – All IP packets follow the same path on the MPLS network and receive the same treatment at each node.

How does it work?



MPLS Operation

Figure 28-1 Series of LSRs Interconnect.



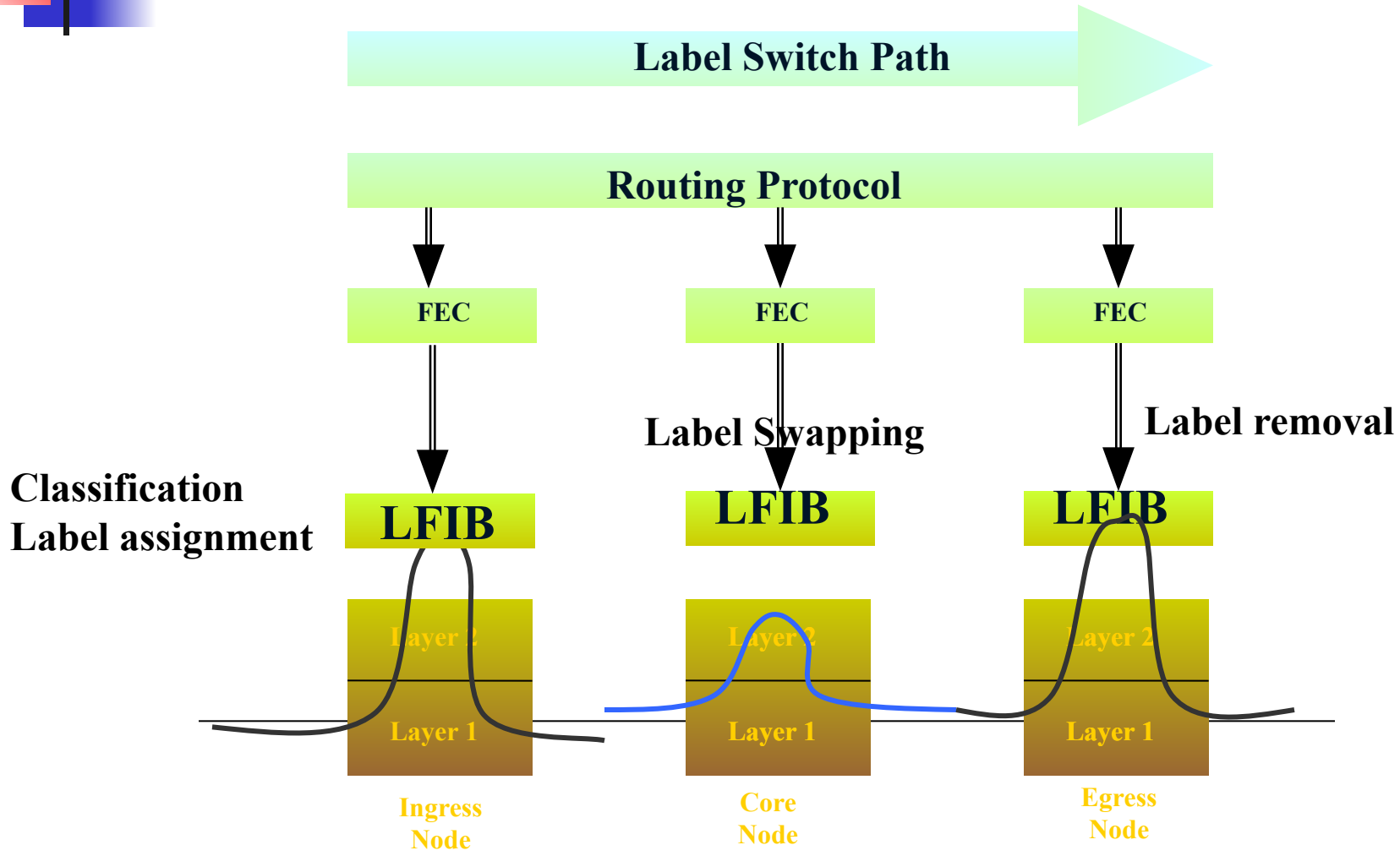
Label Path: R1 => R2 => R3 => R4

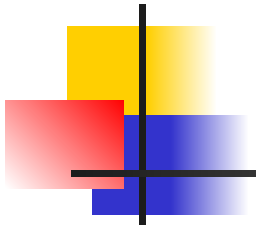
Label Forwarding Information Base (LFIB)

Router	Incoming Label	Incoming Interface	Destination Network (FEC)	Outgoing Interface	Outgoing Label
R1	---	E0	172.16.1.0	S1	6
R2	6	S0	172.16.1.0	S2	11
R3	11	S0	172.16.1.0	S3	7
R4	7	S1	172.26.1.0	E0	--

Q: create LFIB for R4 => R3 => R2 => R1

MPLS process





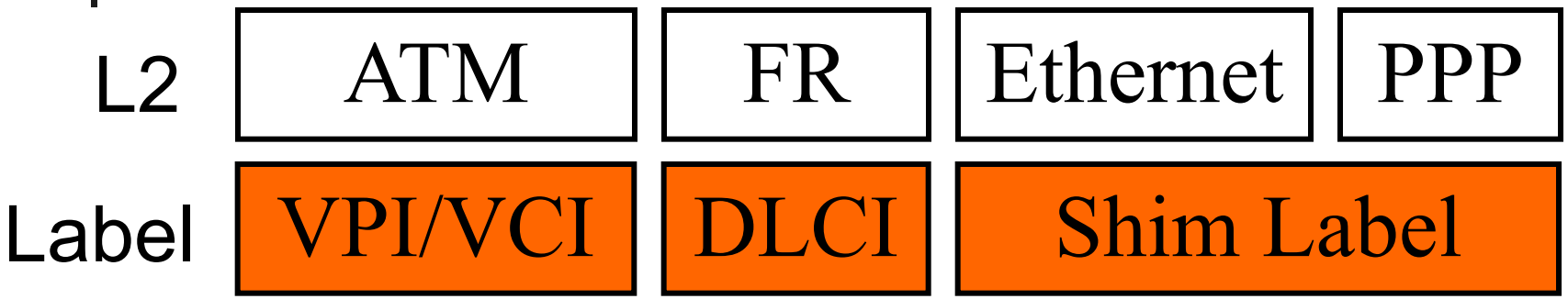
Label Encapsulation

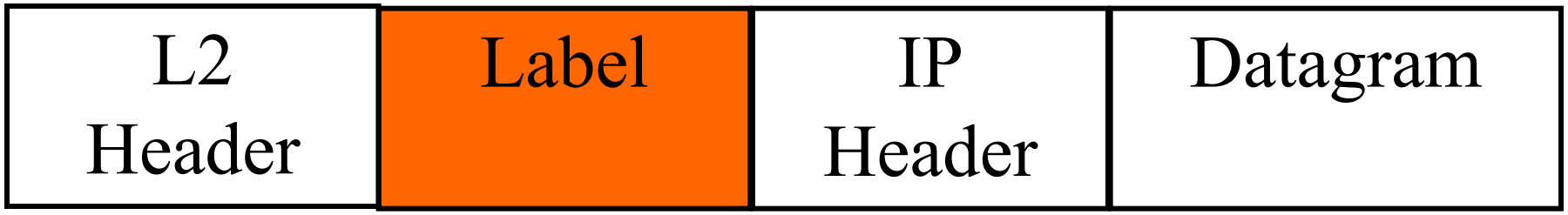
Label information can be carried in a packet in a variety of ways:

- A small, *shim* label header inserted between the Layer 2 and network layer headers.
- As part of the Layer 2 header, if the Layer 2 header provides adequate semantics (such as ATM).
- As part of the network layer header (future, such as IPv6).

- In general, MPLS can be implemented over any media type, including point-to-point, Ethernet, Frame Relay, and ATM links. The label-forwarding component is independent of the network layer protocol.

Label Encapsulation

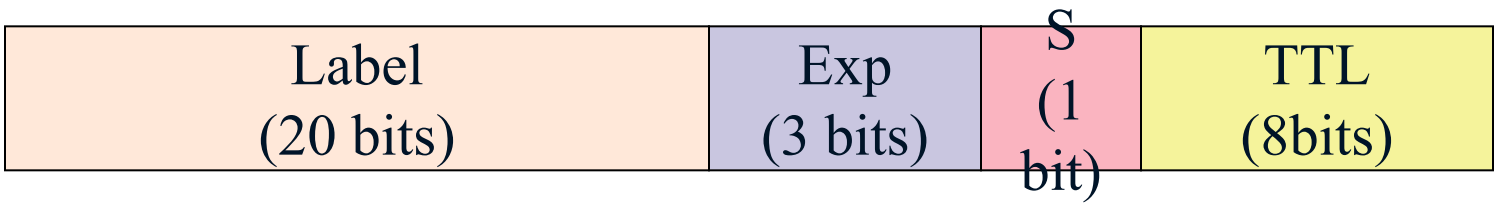




MPLS Encapsulation is specified over various media types. Labels may use existing format (e.g., VPI/VCI) or use a new *shim* label format.

Shim Header

- The Label (Shim Header) is represented as a sequence of Label Stack Entry
- Each Label Stack Entry is 4 bytes (32 bits)
- 20 Bits is reserved for the Label Identifier (also named Label)



Label : Label value (0 to 15 are reserved for special use)
Exp : Experimental Use
S : Bottom of Stack (set to 1 for the last entry in the label)
TTL : Time To Live

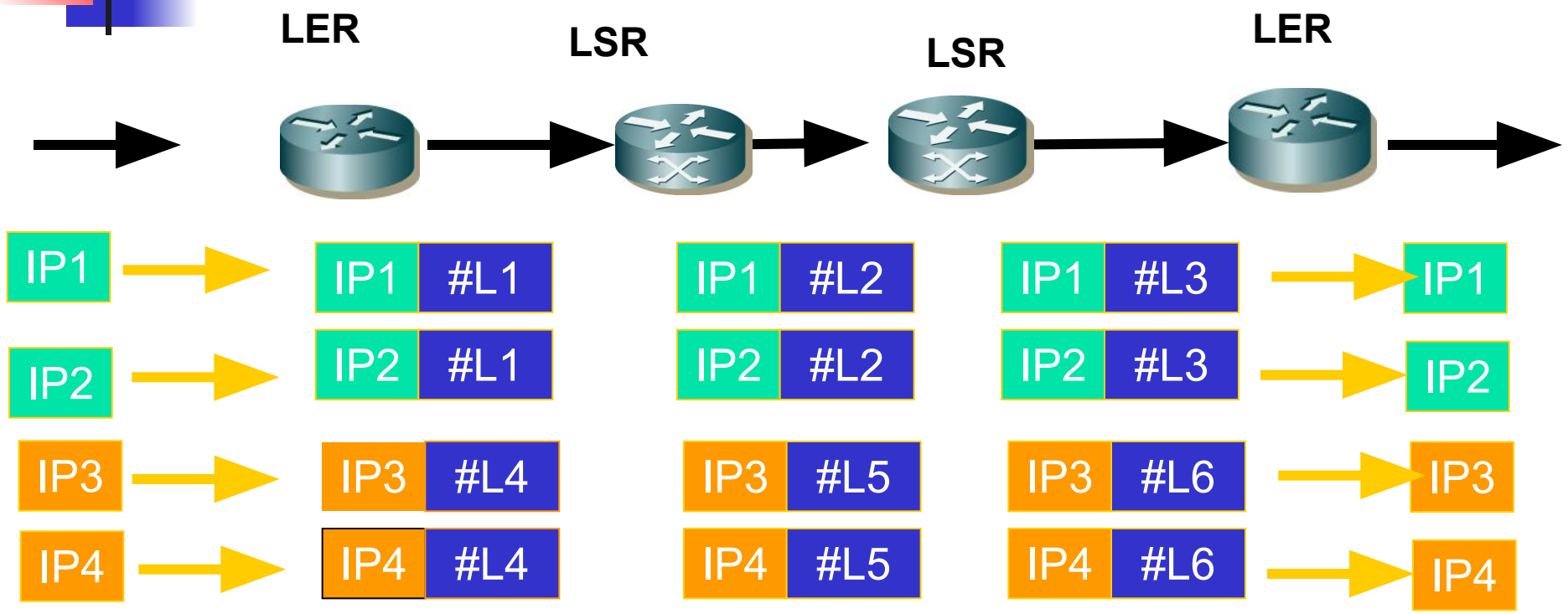
Forward Equivalent Class (FEC) Classification

A packet can be mapped to a particular FEC based on the following criteria:

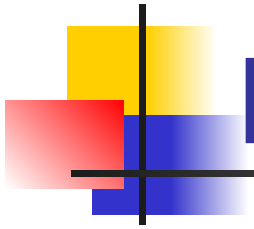
- **destination IP address,**
- **source IP address,**
- **TCP/UDP port,**
- **class of service (CoS) or type of service (ToS),**
- **application used,**
- **…**
- **any combination of the previous criteria.**

Ingress Label	FEC	Egress Label
6	138.120.6.0/24	9

Forwarding Equivalence Classes (FEC)

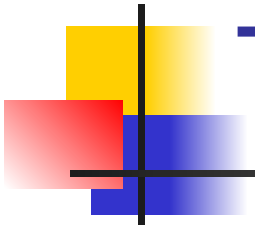


- FEC = A group of packets that are treated the same way by a router.
- The concept of FECs provides for flexibility, scalability, and traffic engineering.
- In legacy routing, the ToS field is used to determine FEC at each hop. In MPLS it is only done once at the network ingress.



MPLS Applications

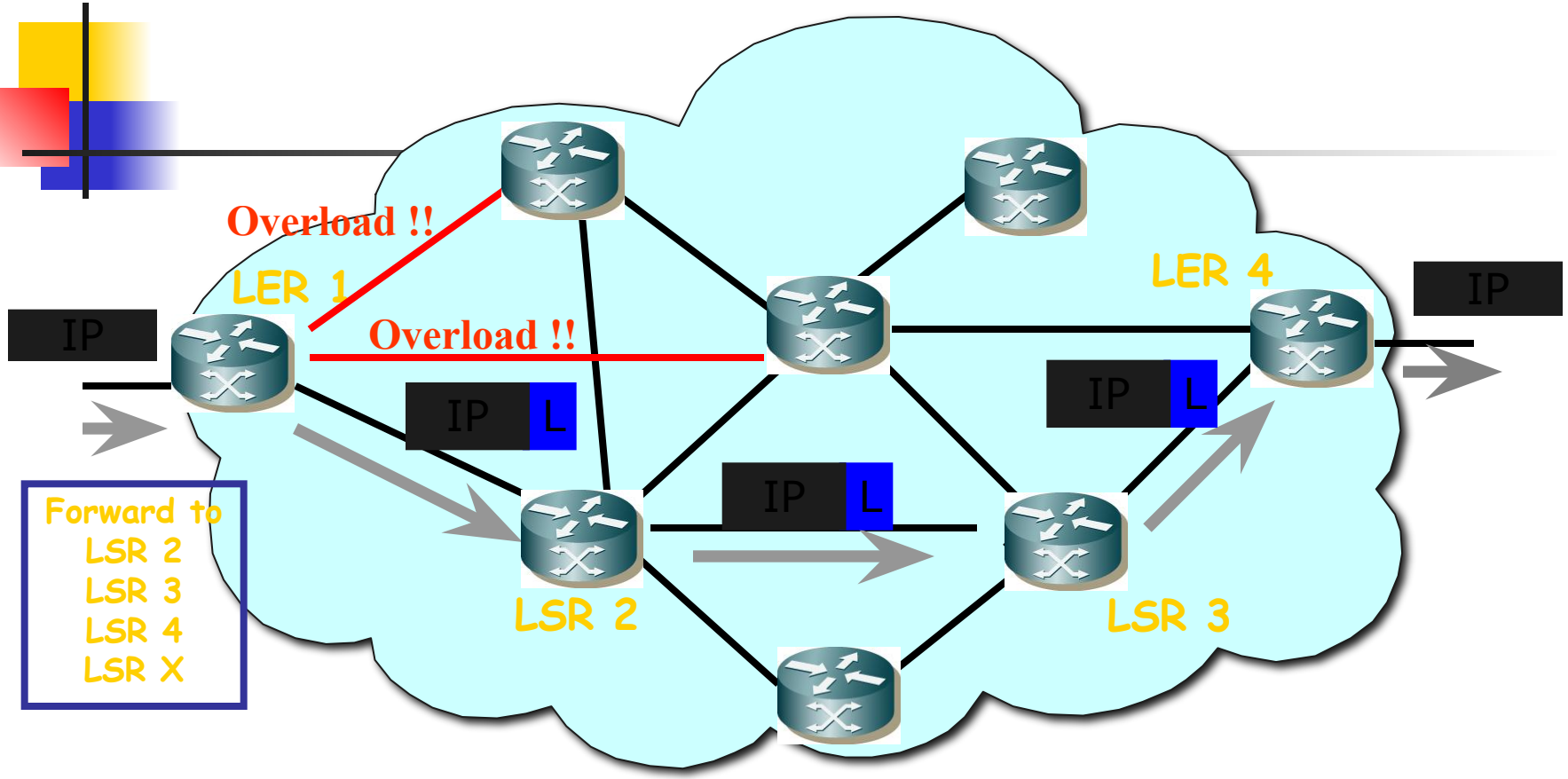
- Traffic Engineering
- Virtual Private Network
- Quality of Service (QoS)



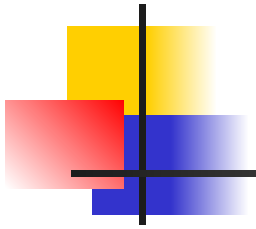
Traffic Engineering

- *Traffic engineering* allows a network administrator to make the path deterministic and bypass the normal routed hop-by-hop paths. An administrator may elect to explicitly define the path between stations to ensure QoS or have the traffic follow a specified path to reduce traffic loading across certain hops.
- The network administrator can reduce congestion by forcing the frame to travel around the overloaded segments. Traffic engineering, then, enables an administrator to define a policy for forwarding frames rather than depending upon dynamic routing protocols.
- Traffic engineering is similar to **source-routing** in that an explicit path is defined for the frame to travel. However, unlike source-routing, the hop-by-hop definition is not carried with every frame. Rather, the hops are configured in the LSRs ahead of time along with the appropriate label values.

MPLS – Traffic Engineering



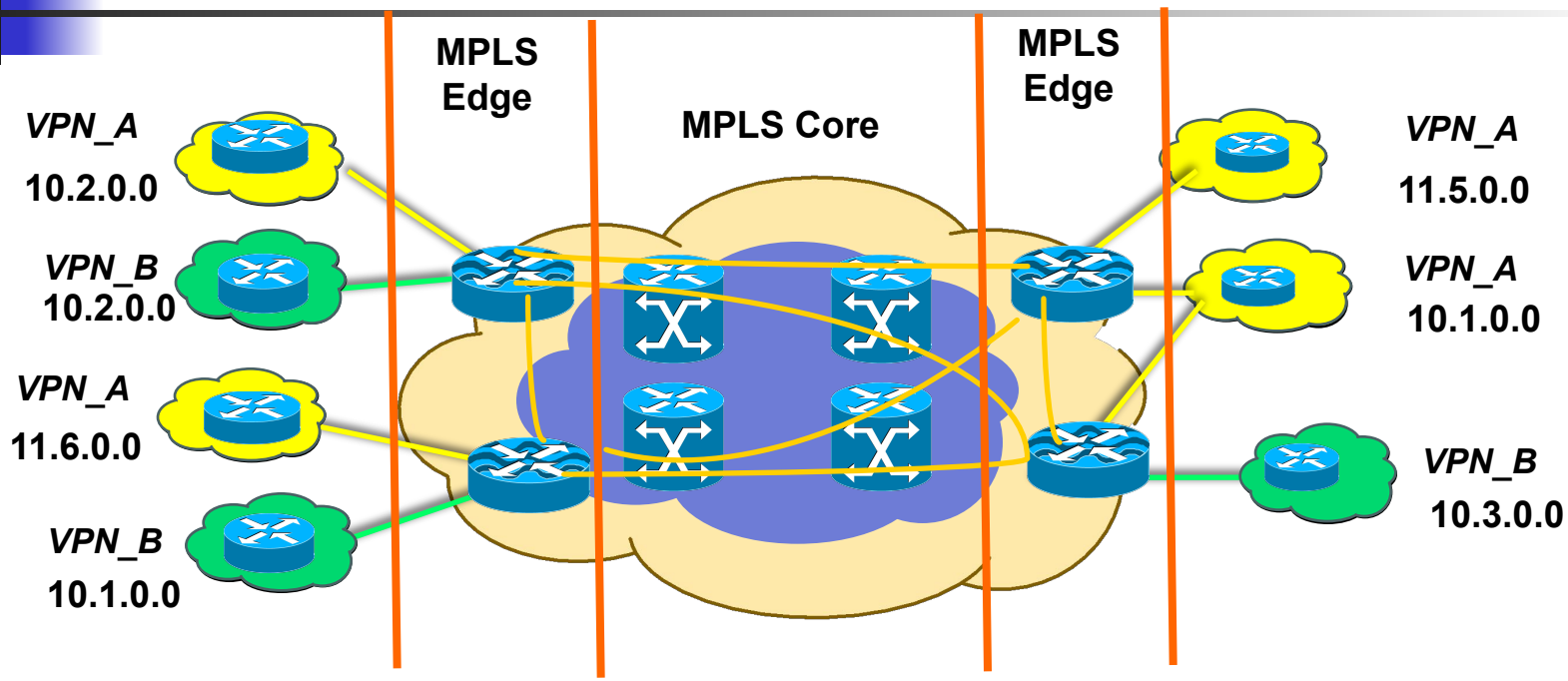
- **End-to-End forwarding decision determined by ingress node.**
- **Enables Traffic Engineering**



MPLS-based VPN

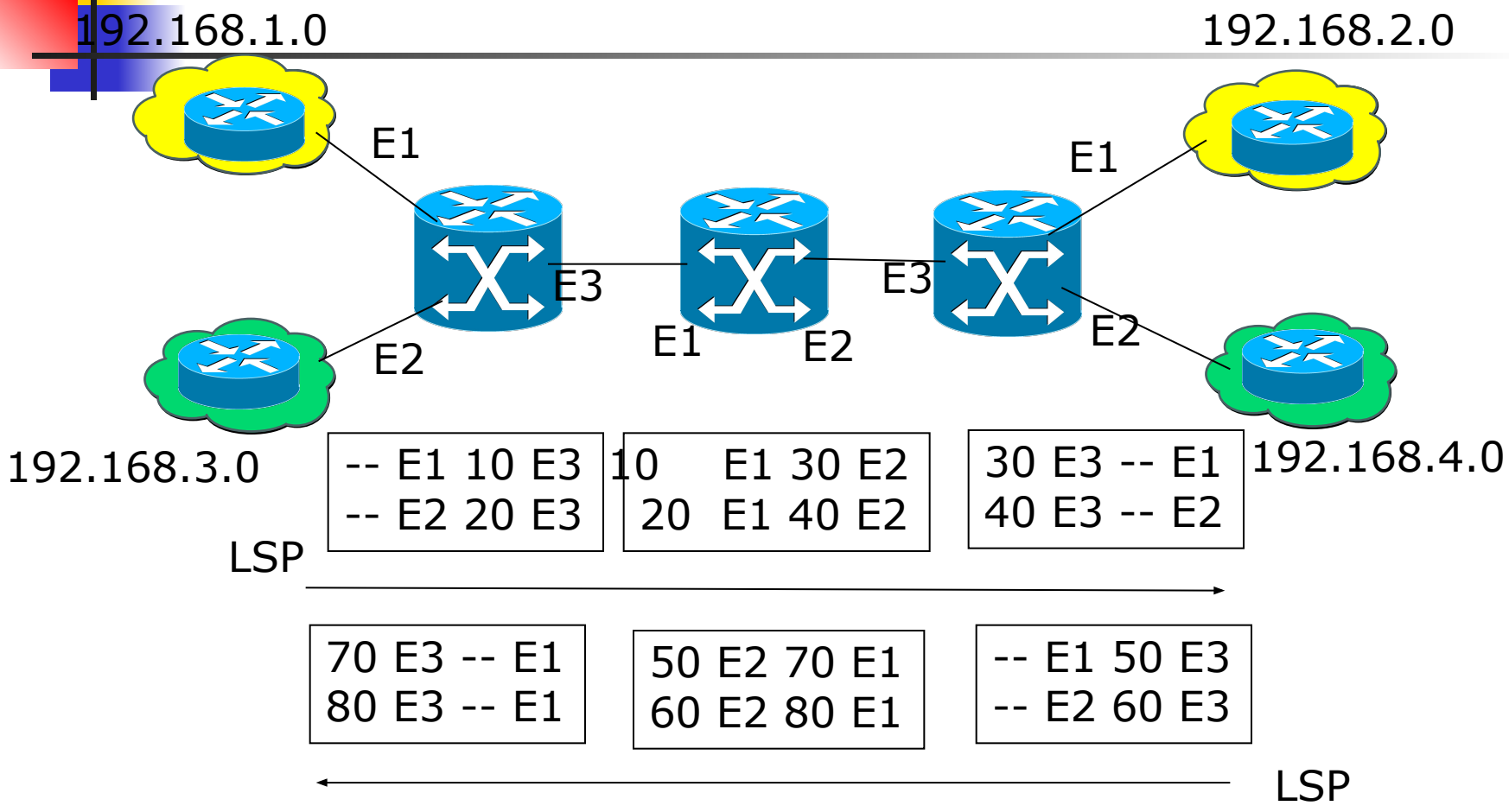
- One of most popular MPLS applications is the implementation of VPN.
- The basic concept is the same as ATM transparent LAN.
- Using label (instead of IP address) to interconnect multiple sites over a carrier's network. Each site has its own private IP address space.
- Different VPNs may use the same IP address space.
- Same as Frame Relay separation of different user traffic… but more" fashionable" to use word "VPN" today.

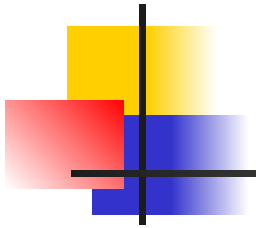
MPLS VPN Connection Model



VPN_A: **10.2.0.0**/24, 11.6.0.0/24, 11.5.0.0/24
VPN_B: **10.2.0.0**/24, 10.1.0.0/24, 10.3.0.0/24

MPLS VPN - Example

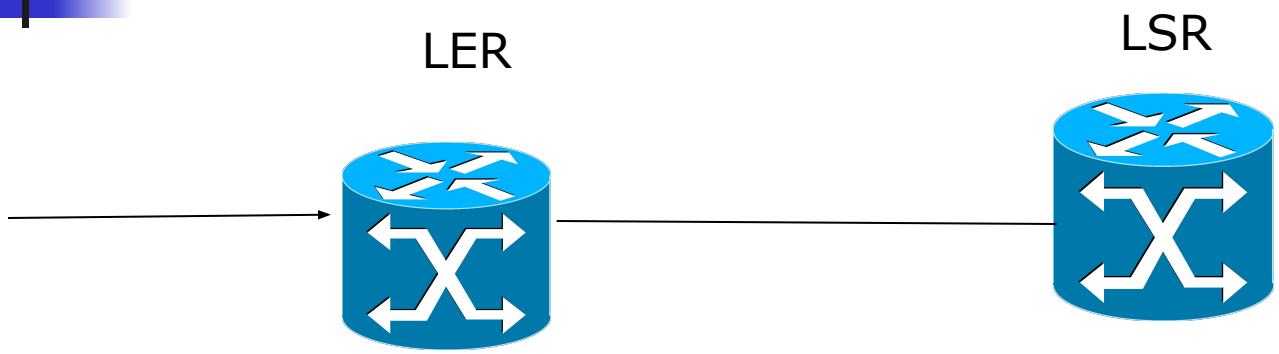




MPLS and QoS

- An important proposed MPLS capability is quality of service (QoS) support.
- QoS mechanisms:
  - Pre-configuration based on physical interface
  - Classification of incoming packets into different classes
  - Classification based on network characteristics (such as congestion, throughput, delay, and loss)
- A label corresponding to the resultant class is applied to the packet.
- Labeled packets are handled by LSRs in their path without needing to be reclassified.
- MPLS enables simple logic to find the state that identifies how the packet should be scheduled.
- The exact use of MPLS for QoS purposes depends a great deal on how QoS is deployed.
- Support various QoS protocols, such as IntServ, DiffServ, and RSVP.

FEC QoS Classification

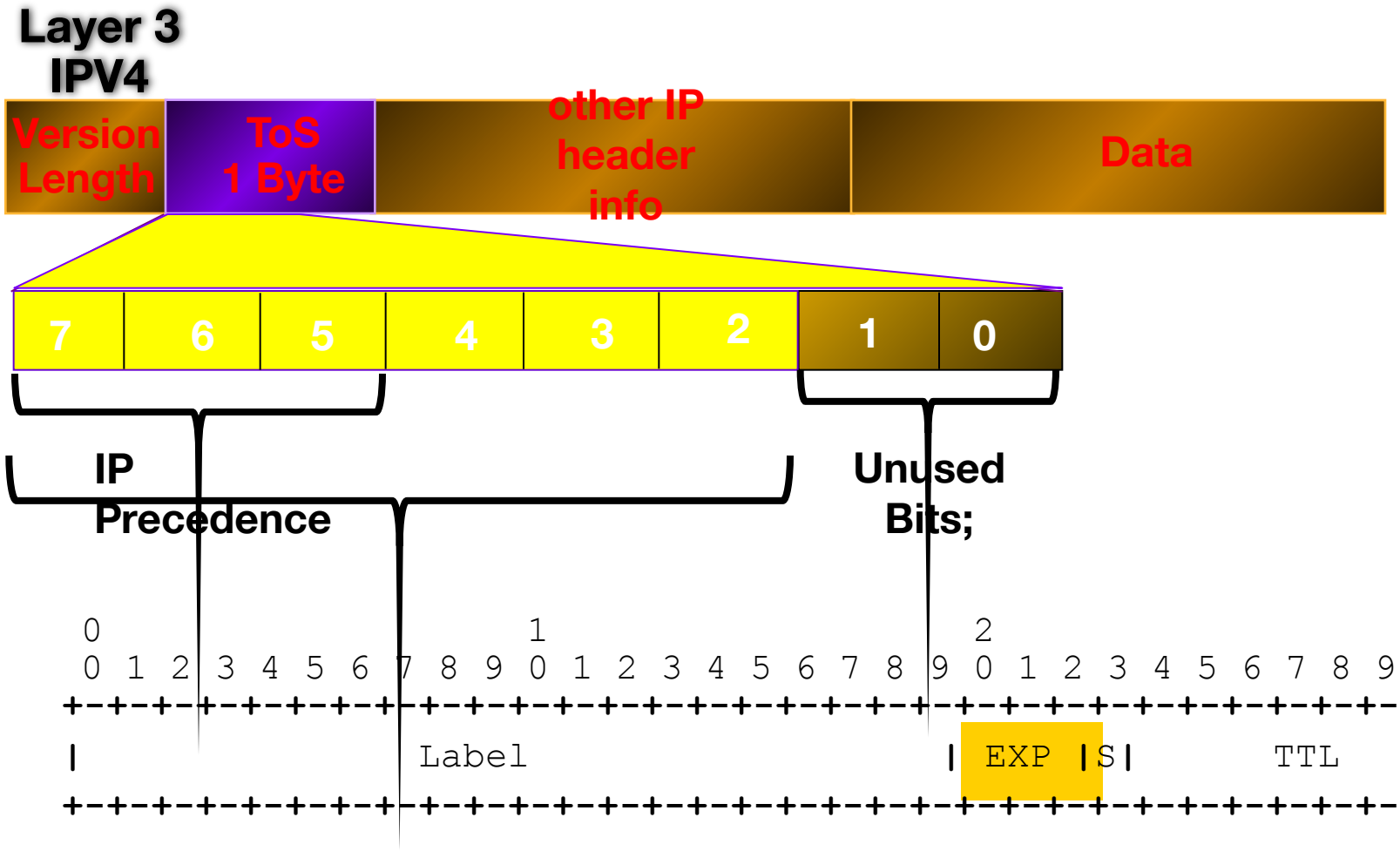


MPLS label based on

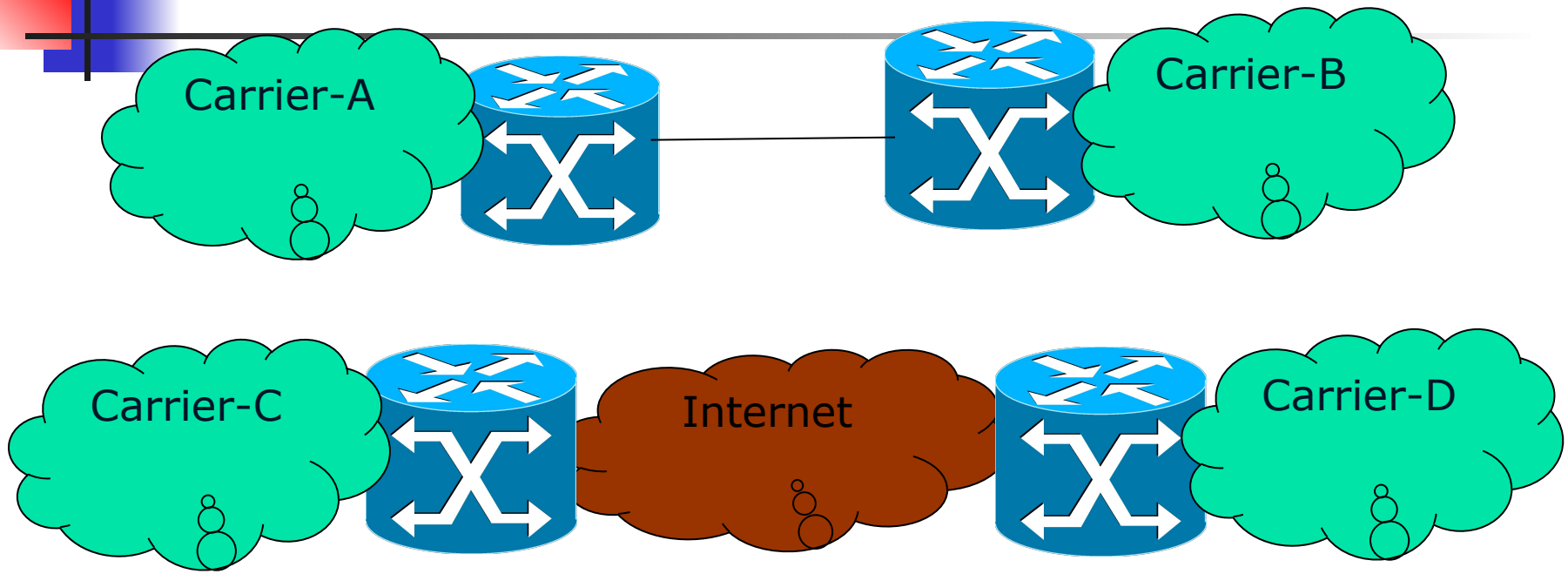
1. physical interface
2. Source IP address
3. Destination IP address
4. Type of Service (ToS)
5. Protocol information
6. etc.

A priority scheme for different label switch path (LSP)

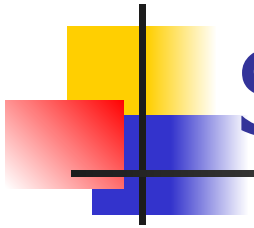
IP Differentiated Model



MPLS between Carriers?



Q: Does LDP work on different carriers' network?
A (short): not yet
A (long): no network-to-network interface (NNI) signaling
.. And I really don't expect it in the near future…



Summary

- MPLS is accepted by the industry to migrate ATM-based core to IP/MPLS-based core.
- It is applied to carrier networks and large enterprise networks.
- How do we set the label path: LDP
- What is the need: traffic classification
- What are the applications: traffic engineering, VPN, QoS, etc.
- Challenges:
  - NNI for MPLS
  - MPLS for the Internet