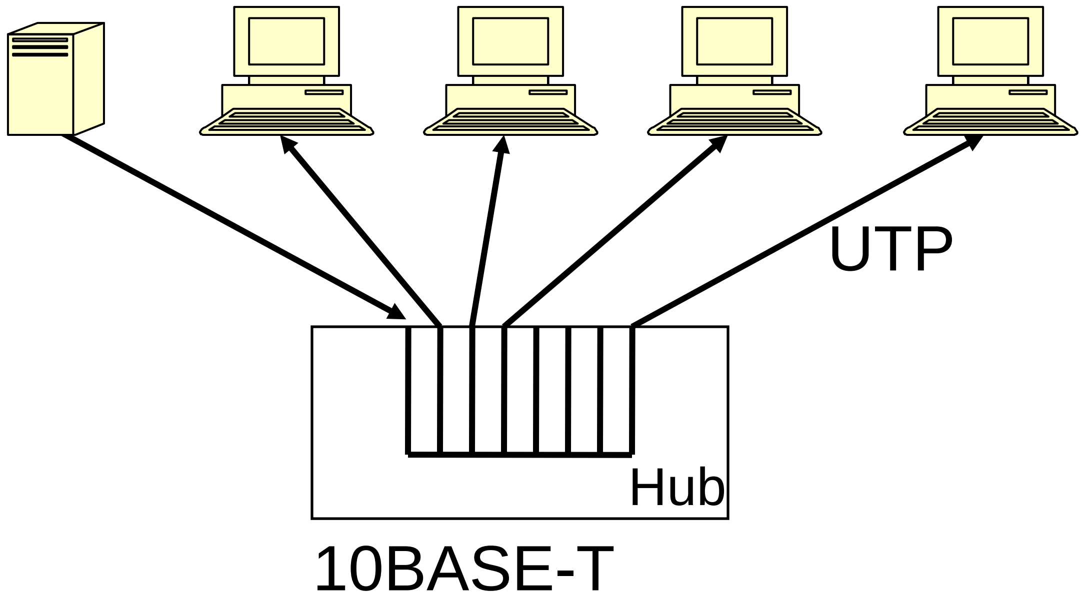
Hubs (1/2)

- Physical layer devices:
  - Essentially repeaters operating at bit levels
  - Repeat received bits on one interface to all other interfaces
- Disconnection/cable break rarely affects other devices
- Easy to install

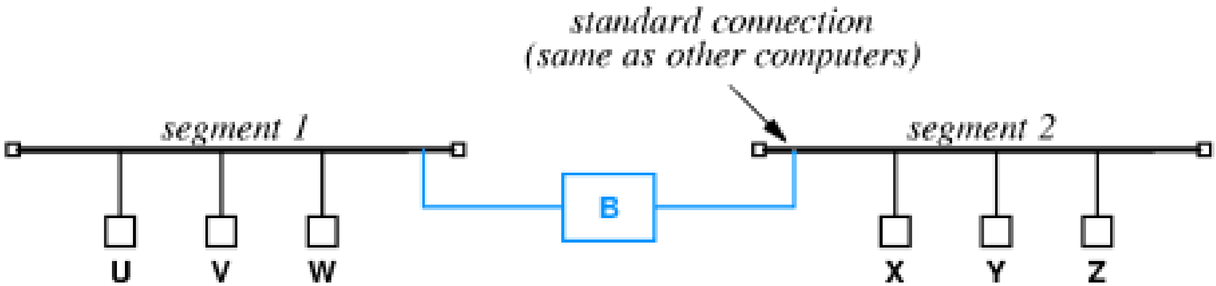


Hubs (2/2)

- Very easy to use - just plug in
- Re-transmit analog signals
- Transient problems - noise propagates throughout network
- Can't extend Ethernet with repeaters indefinitely
- Cannot connect different Ethernet types
- Hubs can be arranged in a hierarchy
- Each connected LAN is referred to as a LAN segment
- Hubs do not isolate collision domains: A node may collide with any node residing at any segment in the LAN

Bridges (1/2)

- Link layer devices: They operate on Ethernet frames, examining the frame header and selectively forwarding a frame base on its destination
- Bridge isolates collision domains since it buffers frames
- Can connect different types of Ethernet since it is a store and forward device



Bridges (2/2)

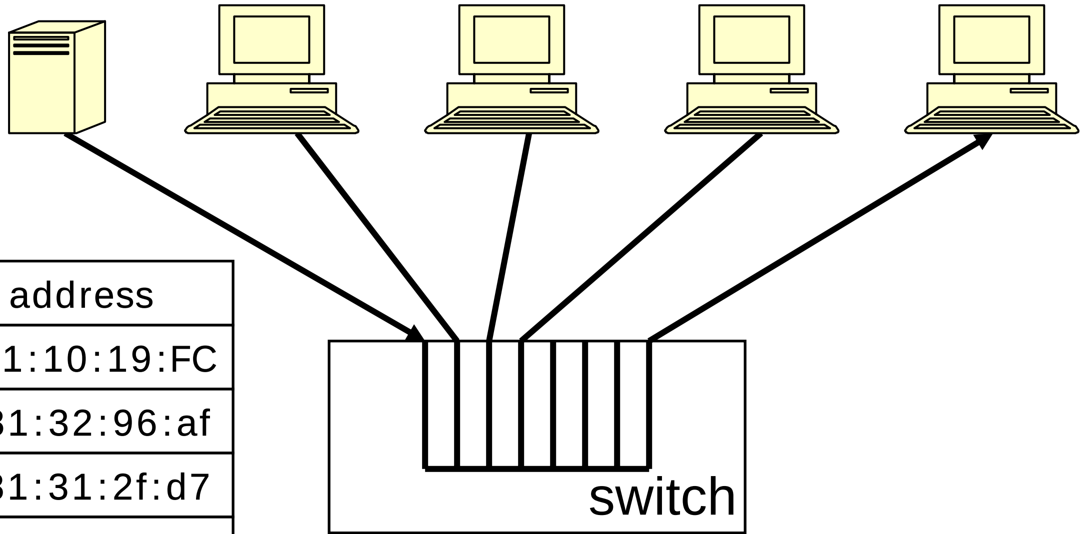
- Bridges learn which hosts can be reached through which interfaces and maintain filtering tables
- A filtering table entry:

  (Node LAN Address, Bridge Interface, Timestamp)
- Filtering procedure:

```
if destination is on LAN on which frame was received
    then drop the frame
    else { lookup filtering table
        if entry found for destination
          then forward the frame on interface indicated;
          else flood;    /* forward on all but the interface on
                            which the frame arrived */
      }
```

Switches

- Effectively a separate LAN segment for each port
- Hub simulates a single shared medium
- Switch simulates a bridged LAN with one computer per segment
- Switches only send data to the intended receiver (an improvement on hubs)
- Builds an index of which device has which MAC address

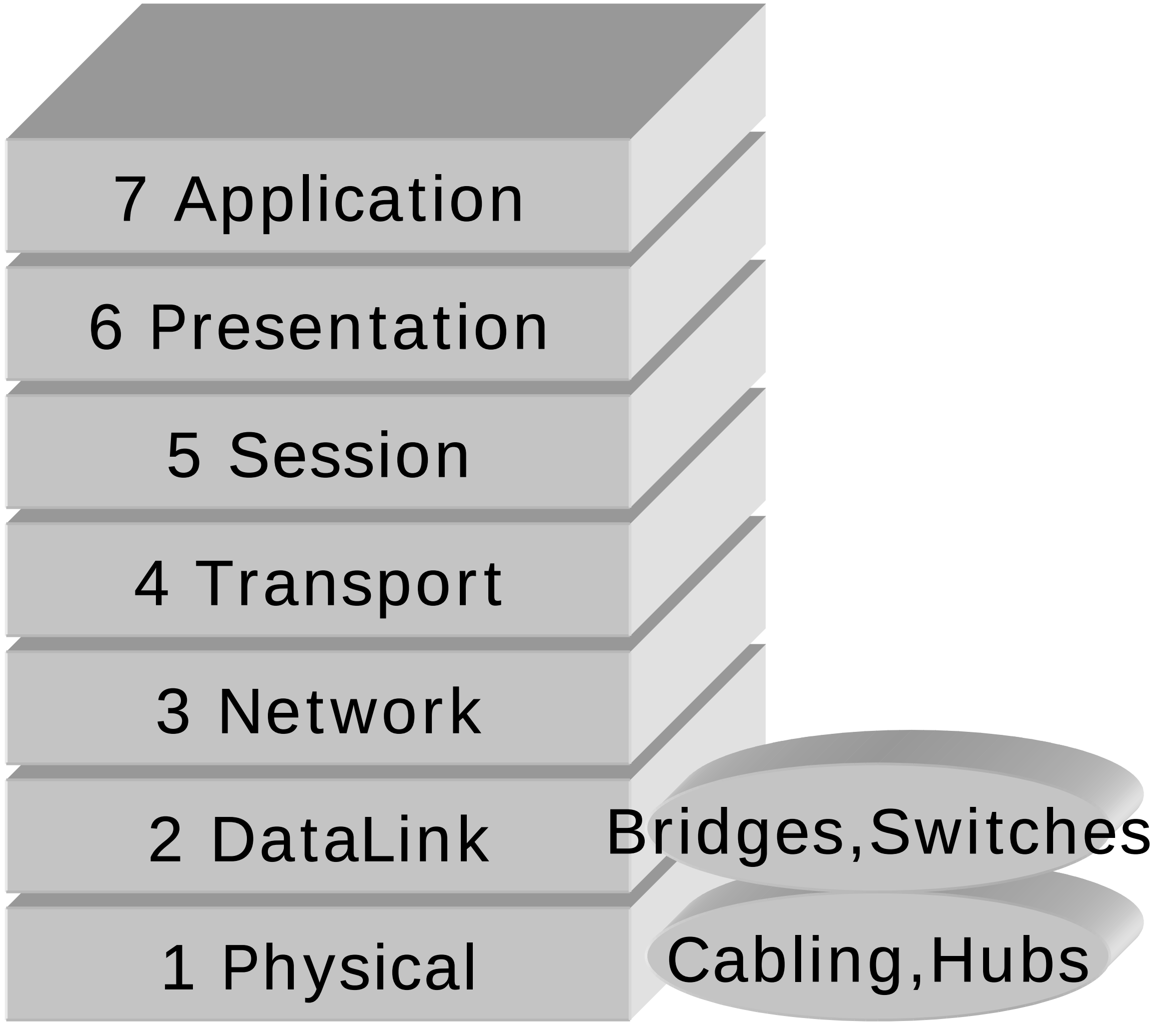


Device	MAC address
1	00:0e:81:10:19:FC
2	00:0e:81:32:96:af
3	00:0e:81:31:2f:d7
4	00:0e:81:97:03:05
8	00:0e:81:10:17:d1

Switch Operation

- When a frame arrives at switch:
  - Switch looks up destination MAC address in index
  - Sends the frame to the device in the index that owns that MAC address
- Switches are often intelligent:
  - Traffic monitoring, remotely configurable
- Switches operate at layer 2
- Switches reduce effectiveness of basic sniffing tools
  - Now a promiscuous NIC only sees traffic intended for it

Where Are We?


7 Application
6 Presentation
5 Session
4 Transport
3 Network
2 DataLink
1 Physical
Bridges,Switches
Cabling,Hubs

IP Routing Disadvantages

- Connectionless
  - Quality of service guarantees are difficult
- Each router has to make independent forwarding decisions based on the IP address
- Large IP header
  - At least 20 bytes
- Routing in network layer
  - Slower than switching, since it is software-based
- Usually designed to obtain shortest path
  - Do not take into account additional metrics

ATM Revisited

- At one point, ATM was viewed as a replacement for IP
  - Could carry both traditional telephone traffic and other traffic
  - Better than IP, since it supports quality of service
- Complex technology
  - Switching core is fairly simple, but
  - Support for different traffic classes
  - Signaling software is very complex
  - Technology did not match people's experience with IP
    * Deploying ATM in LAN is complex (e.g. broadcast)
    * Supporting connectionless service model on connection-based technology
  - With IP over ATM, a lot of functionality is replicated
- Used as a data link layer supporting IP

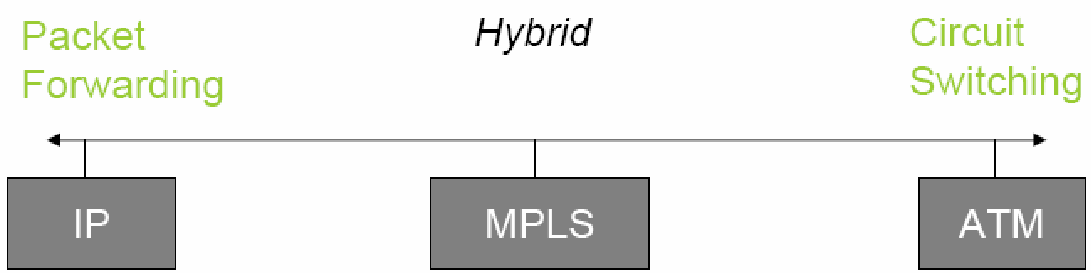
Multi-Protocol Label Switching

- The concept behind MPLS:

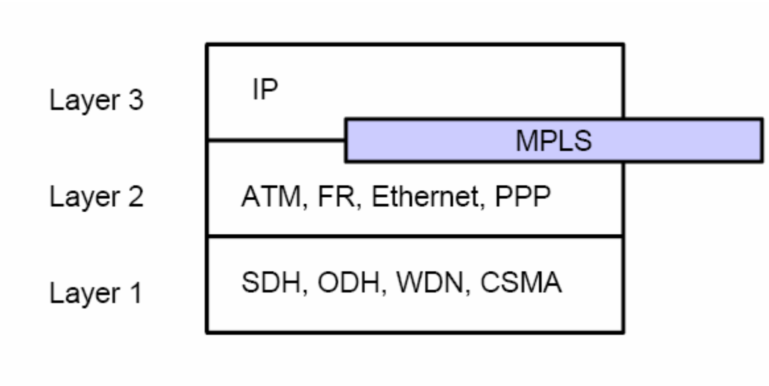
- Combine the forwarding algorithm used in ATM with IP
- Route IP datagrams over ATM hardware switches

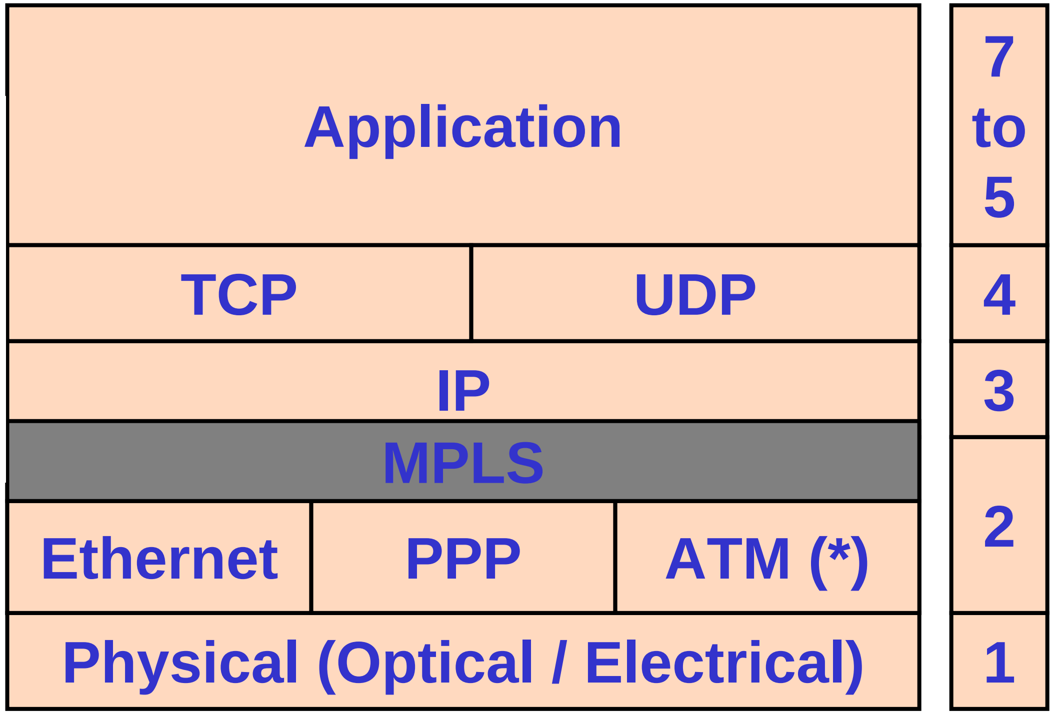
- History:

- The main application of ATM: IP over ATM
- In 1995 Ipsilon advanced a method of routing IP datagrams over ATM hardware
- In 1997 Cisco ``embraced and extended'' the work with tag switching which then became MPLS



MPLS in the Stack





* ATM without addressing is considered a layer 2 protocol

MPLS Characteristics

- MPLS improves internet scalability by eliminating the need for each router and switch in a packet's path to perform traditionally redundant address lookups and route calculation

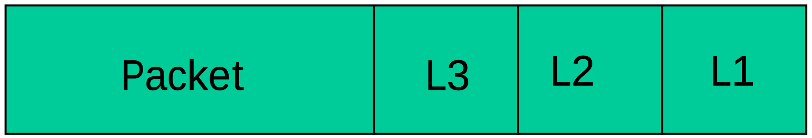
- Improves scalability through better traffic engineering

- MPLS also permits explicit backbone routing, which specifies in advance the hops that a packet will take across the network
- This should allow more deterministic, or predictable, performance that can be used to guarantee QoS
- Is independent of layer 2 and layer 3 protocols

- Maps IP addresses to fixed length labels
- Interfaces to existing routing protocols (BGP, OSPF)
- Supports ATM, Frame-Relay and Ethernet

MPLS Label Stack

- Label stack carries a number of labels organized as a last-in, first out stack
- The processing is always based on the top label
- An unlabeled packet can be thought as a packet whose label stack is empty

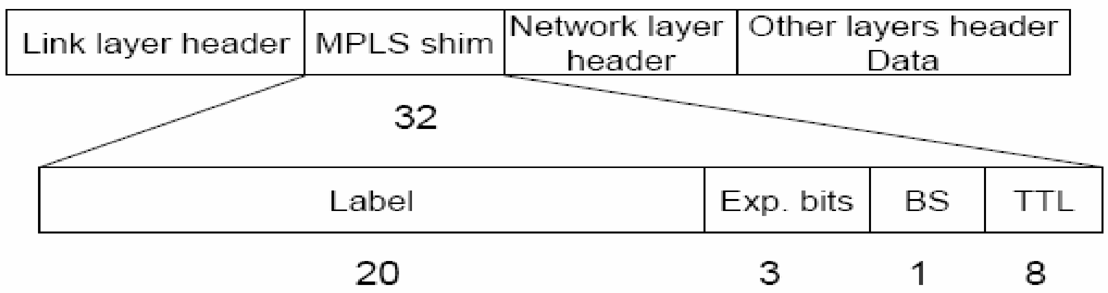


MPLS Shim Header

• Label: A short, fixed length, locally significant identifier used to identify a packet with a path

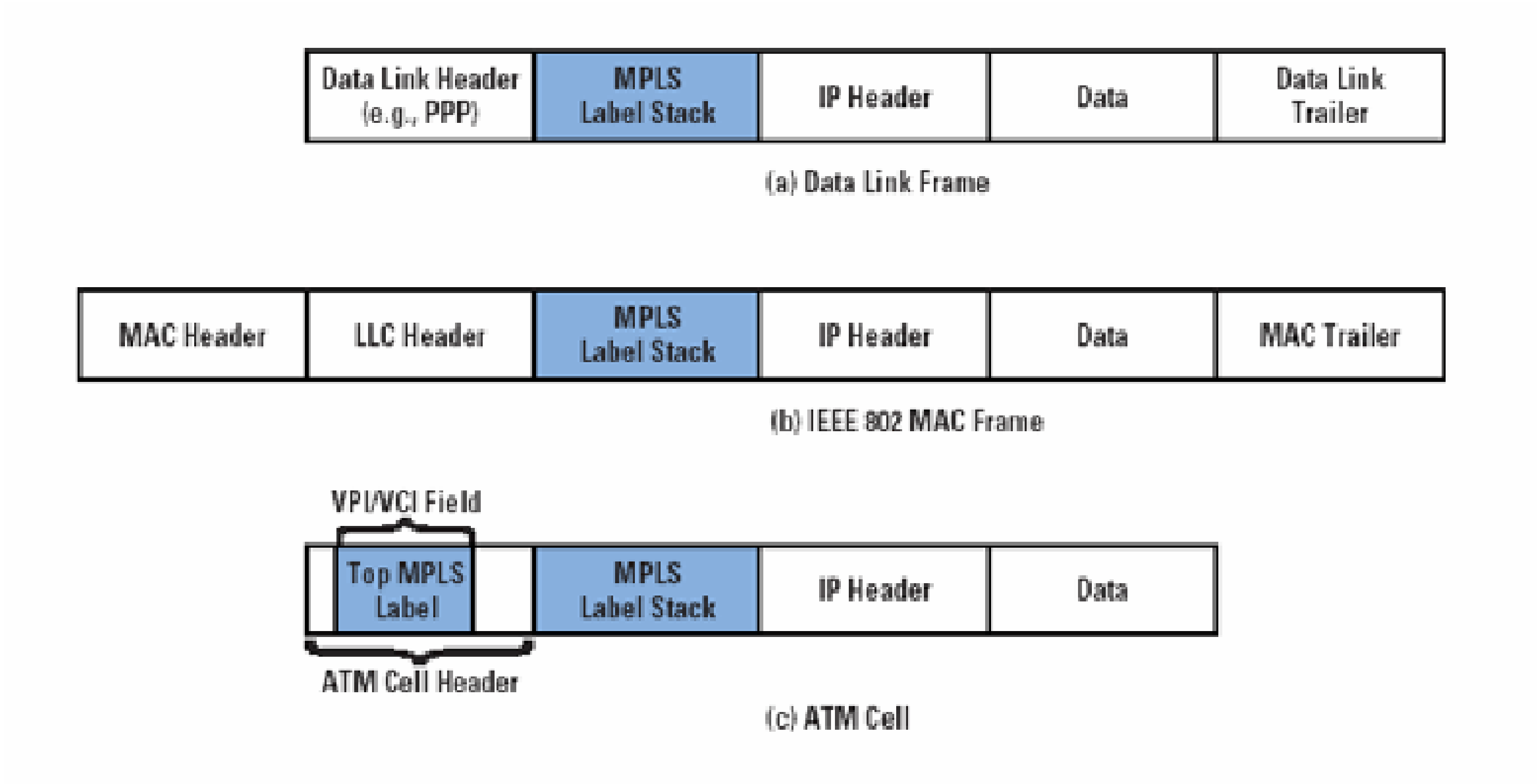
- The label must be identifiable by a layer 2 technology

- E.g.: VPI/VCI field for ATM



Exp.bits:	Experimental Bits, often used for Class of Service
BS:	Bottom of Stack bit, is set if no label follows
TTL:	Time To Leave, used in the same way like in IP

Labeled Packet



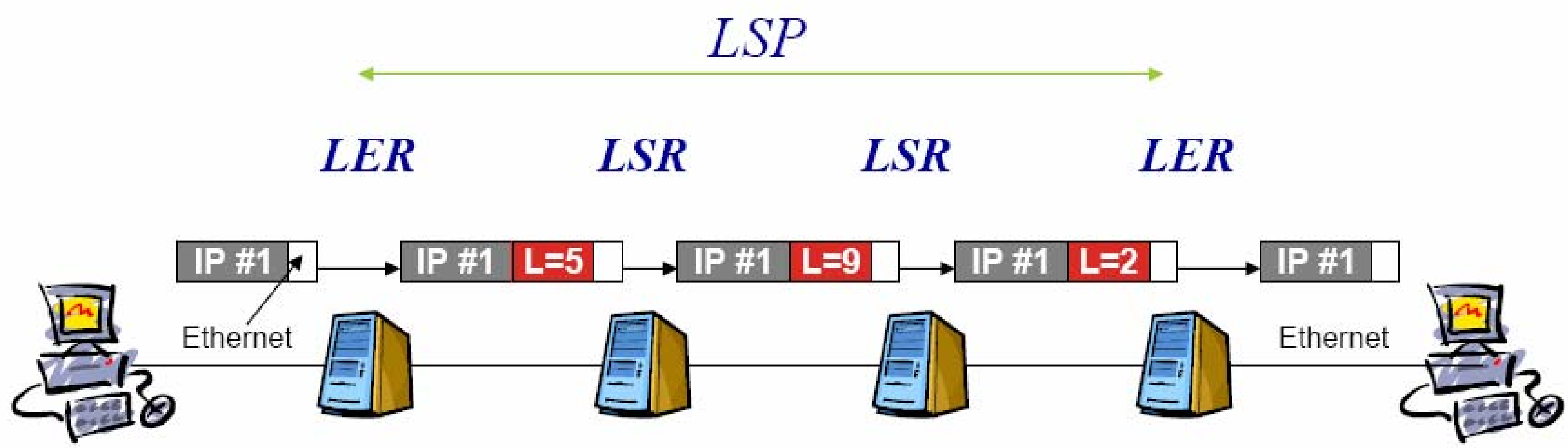
Label Edge Routers (LERs)

- Reside at the edge of an MPLS network and assign and remove the labels from the packets
- Support multiple ports connected to dissimilar networks (such as ATM and Ethernet)

Label Switching Routers (LSRs)

- High speed routers in the core of an MPLS network
- ATM switches can be used as LSRs without changing their hardware
- MPLS label switching is equivalent to VPI/VCI label switching

Positions of LERs and LSRs



IP Addr	Out Label
192.4/16	5
Layer 2 Transport	**Assign init label**

In Label	Out Label
5	9
Label Swapping	

In Label	Out Label
9	2
Label Swapping	

In Label	Next Hop
2	192.4/16
Remove Label	Layer 2 Transport

“ROUTE AT EDGE, SWITCH IN CORE”

Forward Equivalence Class (FEC)

- Is a representation of a group of packets that share the same requirements for their transport
- The assignment of a particular packet to a particular FEC is done just once (when the packet enters the MPLS network)
- Label Switched Paths (LSPs):

 - A path is established before the data transmission starts

 - A path is a representation of an FEC

Path Establishment

- MPLS provides two options to set up an LSP

 - Hop-by-hop routing:

 * Each LSR independently selects the next hop for a given FEC

 * LSRs support any available routing protocols (OSPF, ATM, etc.)

 - Explicit routing:

 * Similar to source routing

 * The ingress LSR specifies the list of nodes through which the packet traverses

- The LSP setup for an FEC is unidirectional
- The return traffic must take another LSP

Label Distribution Protocol (LDP)

- An application layer protocol for the distribution of label binding information to LSRs
  - It is used to map FECs to labels, which, in turn, create LSPs
  - LDP sessions are established between LDP peers in the MPLS network (not necessarily adjacent)
- LDP message types:
  - <u>Discovery</u>: Announce and maintain the presence of an LSR in a network
  - <u>Session</u>: Establish, maintain, and terminate sessions between LDP peers
  - <u>Advertisement</u>: Create, change, and delete label mappings for FECs
  - <u>Notification</u>: Provide advisory information and signal error information

MPLS Operation

- The following steps must be taken for a data packet to travel through an MPLS network

 - Label creation and distribution

 - Table creation at each router

 - Label-switched path creation

 - Label insertion/table lookup

 - Packet forwarding

MPLS Operation: Step 1

- Label creation and label distribution:

- Before any traffic begins the routers make the decision to bind a label to a specific FEC and build their tables
- With LDP, downstream routers initiate the distribution of labels and the label/FEC binding
- In addition, traffic-related characteristics and MPLS capabilities are negotiated using LDP
- A reliable transport protocol should be used for LDP signaling

MPLS Operation: Step 2

- Table creation:

- On receipt of label bindings each LSR creates entries in the Label Information Base (LIB)
- The contents of the table will specify the mapping between a label and an FEC
- The entries are updated whenever renegotiation of the label bindings occurs

Input Port	Incoming Port Label	Output Port	Outgoing Port Label
1	3	3	6
2	9	1	7

MPLS Operation: Step 3

- Label switched path creation:

  - The LSPs are created in the reverse direction to the creation of entries in the LIBs

MPLS Operation: Step 4

- Label insertion/table-lookup:

  - The first router (LER) uses the LIB table to find the next hop and request a label for the specific FEC

  - Subsequent routers just use the label to find the next hop

  - Once the packet reaches the egress LSR (LER), the label is removed and the packet is supplied to the destination

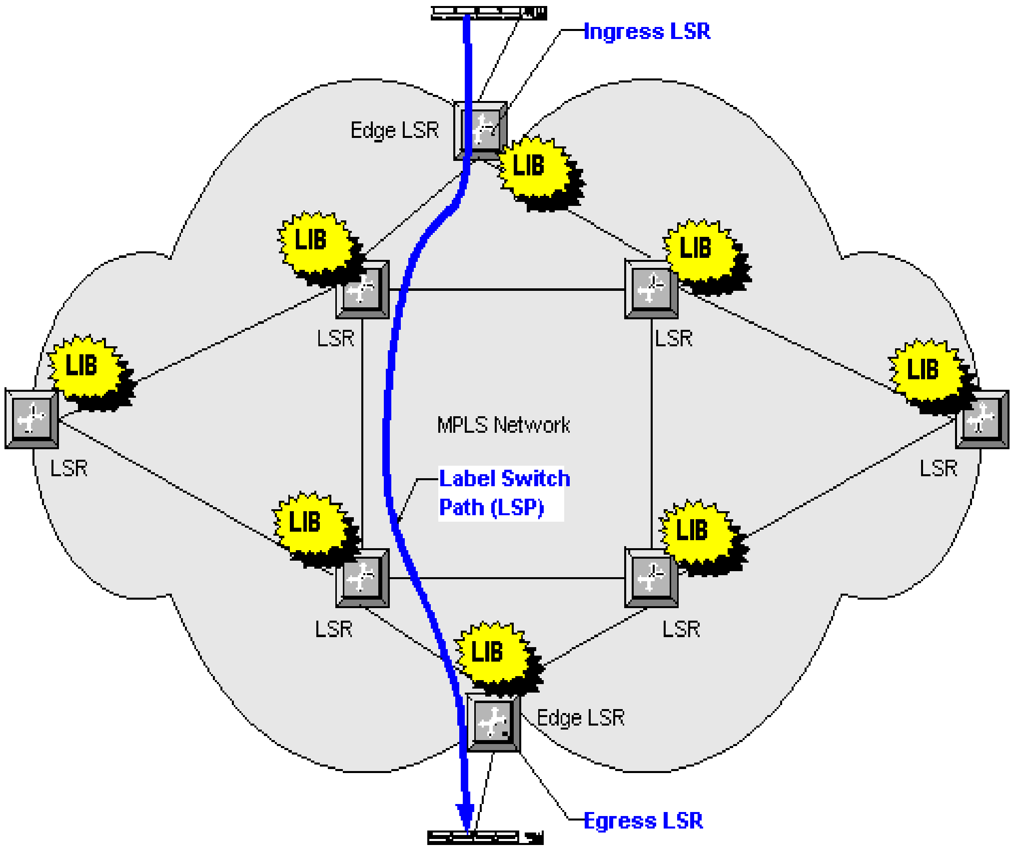
MPLS Operation: Step 5 (1/2)

- Packet forwarding:

- A LER may not have any labels for this packet as it is the first occurrence of this request
- In an IP network, it will use traditional routing to find the next hop
- Let an LSR be the next hop for this LER
  * The LER will initiate a label request toward the LSR
  * This label request will propagate through the MPLS network
  * The LSP will be set up in the reverse direction
- The LER will insert the label and forward the packet to the first LSR

MPLS Operation: Step 5 (2/2)

- Each subsequent LSR will examine the label in the received packet, replace it with the outgoing label and forward it
- When the packet reaches the egress LER, it will remove the label because the packet is departing from an MPLS network and deliver it to the destination



MPLS Outlook

- The label switched path acts like a ``shortcut'' across the core network
- Keeps core operation simple and efficient
- Uses the LSPs to offer controlled quality of service links
- Becoming very important for optical networks -- where the LSP is implemented optically

  - The LSRs are optical cross-connects
  - The ``label'' is implicit in the wavelength used
- Future networks will be:

  - All IP -- speech network will be subsumed
  - Optically switched at the core
  - Electrically switched below 10 Gbps
  - Down to DSL or Ethernet at the edge .. 1 Mbps – 50 Mbps