MPLS

- Circuit switching
  - Packet switching vs. circuit switching
  - Virtual circuits
- MPLS
  - Labels and label-switching
  - Forwarding Equivalence Classes
  - Label distribution
  - MPLS applications
- Feedback forms
  - Fill out during last 20 minutes

Packet Switching vs. Circuit Switching

- Packet switching
  - Data traffic divided into packets
    - Each packet contains its own header (with address)
    - Packets sent separately through the network
  - Destination reconstructs the message
  - Example: sending a letter through postal system
- Circuit switching
  - Source first establishes a connection to the destination
    - Each router on the path may reserve bandwidth
  - Source ends data over the connection
    - No destination address, since routers know the path
  - Source tears down the connection when done
  - Example: voice conversation on telephone network

Advantages of Circuit Switching

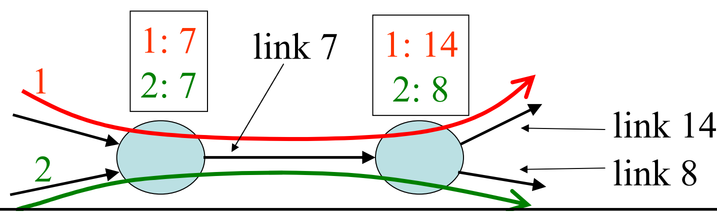
- Guaranteed bandwidth
  - Predictable communication performance
  - Not “best-effort” delivery with no real guarantees
- Simple abstraction
  - Reliable communication channel between hosts
  - No worries about lost or out-of-order packets
- Simple forwarding
  - Forwarding based on time slot or frequency
  - No “longest prefix match” on each packet
- Low per-packet overhead
  - Forwarding based on time slot or frequency
  - No IP (and TCP/UDP) header on each packet

Disadvantages of Circuit Switching

- Wasted bandwidth
  - Bursty traffic leads to idle connection during silent period
  - Unable to achieve gains from statistical multiplexing
- Blocked connections
  - Connection refused when resources are not sufficient
  - Unable to offer “okay” service to everybody
- Connection set-up delay
  - No communication until the connection is set up
  - Unable to avoid extra latency for small data transfers
- Network state
  - Routers must store per-connection information
  - Unable to avoid per-connection storage and state failover

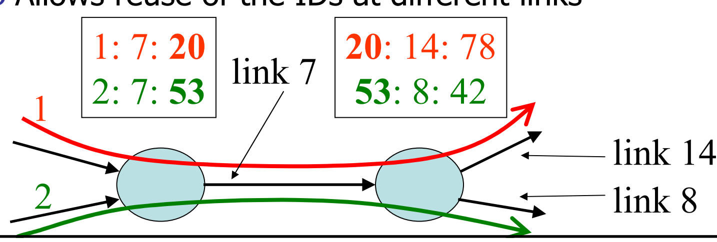
Virtual Circuits

- ❒ Hybrid of packet and circuit switching
  - ❍ Logical circuit between a source and destination
  - ❍ Packets from different VCs multiplex on a link
- ❒ Virtual Circuit Identifier (VC ID)
  - ❍ Source set-up: establish path for the VC
  - ❍ Switch: mapping VC ID to an outgoing link
  - ❍ Packet: fixed length label in the header



Swapping the Label at Each Hop

- ❒ Problem: using VC ID along the whole path
  - ❍ Each virtual circuit consumes a unique ID
  - ❍ Starts to use up all of the ID space in the network
- ❒ Label swapping
  - ❍ Map the VC ID to a new value at each hop
    - Table has old ID, next link, and new ID
  - ❍ Allows reuse of the IDs at different links



Virtual Circuits Similar to IP Datagrams

- Data divided in to packets
  - Sender divides the data into packets
  - Packet has an address (e.g., IP address or VC ID)
- Store-and-forward transmission
  - Multiple packets may arrive at once
  - Need buffer space for temporary storage
- Multiplexing on a link
  - No reservations: statistical multiplexing
    - Packets are interleaved without a fixed pattern
  - Reservations: resources for group of packets
    - Guarantees to get a certain number of "slots"

Virtual Circuits Differ from IP Datagrams

- Forwarding look-up
  - Virtual circuits: fixed-length connection id
  - IP datagrams: destination IP address
- Initiating data transmission
  - Virtual circuits: must signal along the path
  - IP datagrams: just start sending packets
- Router state
  - Virtual circuits: routers know about connections
  - IP datagrams: no state, easier failure recovery
- Quality of service
  - Virtual circuits: resources and scheduling per VC
  - IP datagrams: difficult to provide QoS

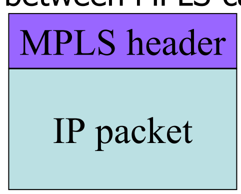
Wide Range of Quality-of-Service Models

- Policies for allocating resources
  - Admission control: whether or not to accept the VC
  - Link scheduling: what order to send packets
  - Buffer management: which packets to drop
- One extreme: best-effort service
  - Accept all connections (unless table is full)
  - Put all packets in a first-in-first-out queue
  - Drop any packet arriving when queue is full
- Another extreme: strict bandwidth guarantees
  - Virtual circuit reserves bandwidth along the path
    - Network edge must shape/police to enforce this rate
  - Each link has a queue for packets from each VC
    - Link schedules the packets using weighted fair queuing

Multi-Protocol Label Switching

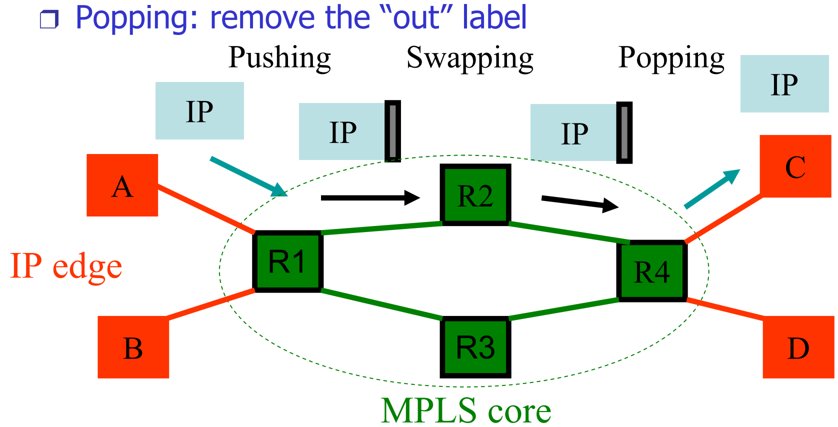
Multi-Protocol Label Switching

- Multi-Protocol
  - Encapsulate a data packet
    - Could be IP, or some other protocol (e.g., IPX)
  - Put an MPLS header in front of the packet
    - Actually, can even build a stack of labels…
- Label Switching
  - MPLS header includes a label
  - Label switching between MPLS-capable routers



Pushing, Swapping, and Popping

- Pushing: add the initial "in" label
- Swapping: map "in" label to "out" label
- Popping: remove the "out" label



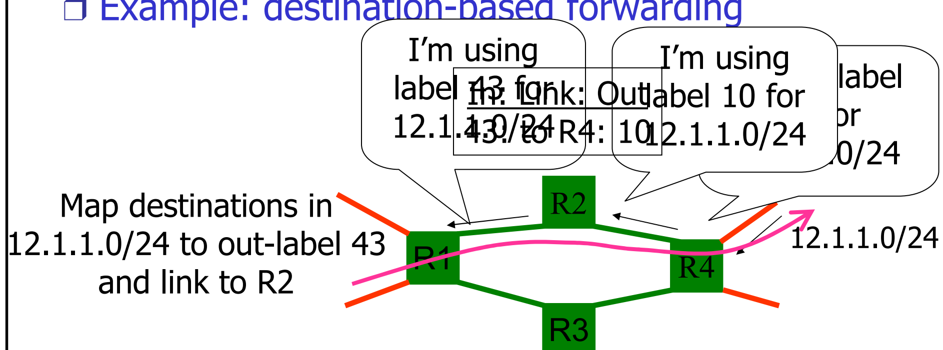
Forwarding Equivalence Class (FEC)

- Rule for grouping packets
  - Packets that should be treated the same way
  - Identified just once, at the edge of the network
- Example FECs
  - Destination prefix
    - Longest-prefix match in forwarding table at entry point
    - Useful for conventional destination-based forwarding
  - Src/dest address, src/dest port, and protocol
    - Five-tuple match at entry point
    - Useful for fine-grain control over the traffic
  - Sent by a particular customer site
    - Incoming interface at entry point
    - Useful for virtual private networks

A label is just a locally-significant identifier for a FEC

Label Distribution Protocol

- Distributing labels
  - Learning the mapping from FEC to label
  - Told by the downstream router
- Example: destination-based forwarding



Supporting Explicitly-Routed Paths

- Explicitly routing from ingress to egress
  - Set an explicit path (e.g., based on load)
  - Perhaps reserve resources along the path
- Extend a protocol for resource reservation
  - Start with ReSource Reservation Protocol (RSVP)
    - Used for reserving resources along an IP path
  - Extensions for label distribution & explicit routing
- Extend a protocol for distributing labels
  - Start with Label Distribution Protocol (LDP)
  - Extensions for explicit routing & reservation
- Two competing proposed standards

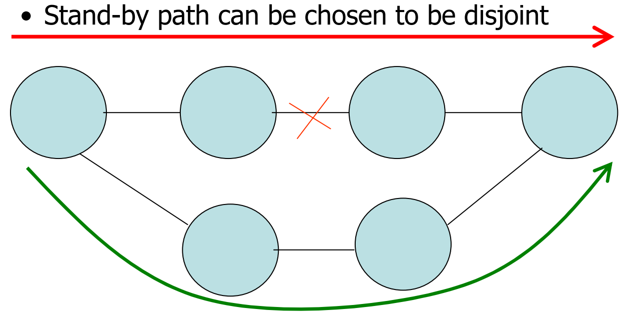
Applications of MPLS

TE With Constraint-Based Routing

- Path calculation
  - Constrained shortest-path first
  - Compute shortest path based on weights
    - But, exclude paths that do not satisfy constraints
    - E.g., do not consider links with insufficient bandwidth
- Information dissemination
  - Extend OSPF/IS-IS to carry the extra information
    - E.g., link-state attributes for available bandwidth
- Path signaling
  - Establish label-switched path on explicit route
- Forwarding: MPLS labels

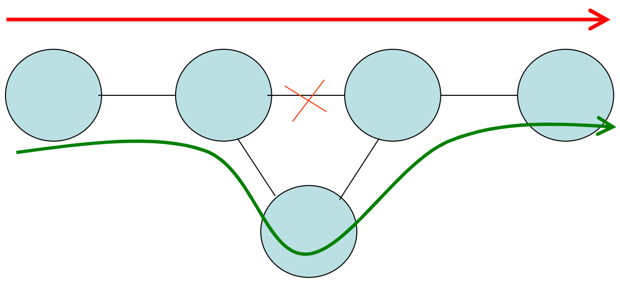
Surviving Failures: Path Protection

- Path protection
  - Reserve bandwidth on an alternate route
    - Protect a label-switched path by having a stand-by
  - Much better than conventional IP routing
    - Precise control over where the traffic will go
    - Stand-by path can be chosen to be disjoint

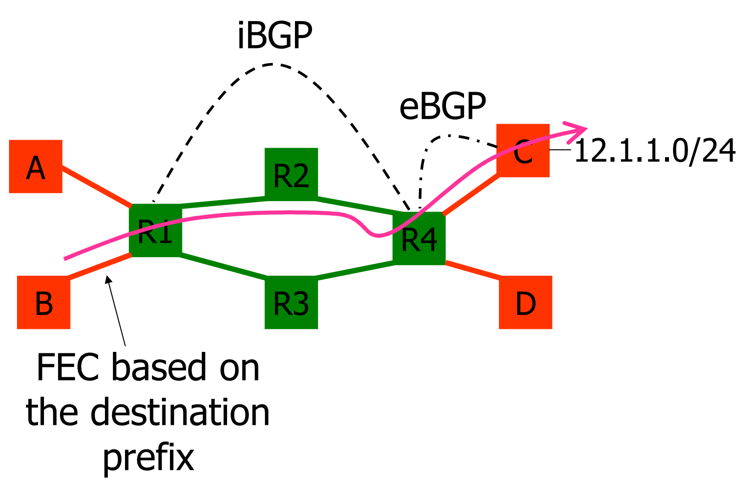


Surviving Failures: Fast Reroute

- Ensure fast recovery from a link failure
  - Protect a link by having a protection sub-path
- Much faster recovery than switching paths
  - Affected router can detect the link failure
  - … and start redirecting to the protection sub-path

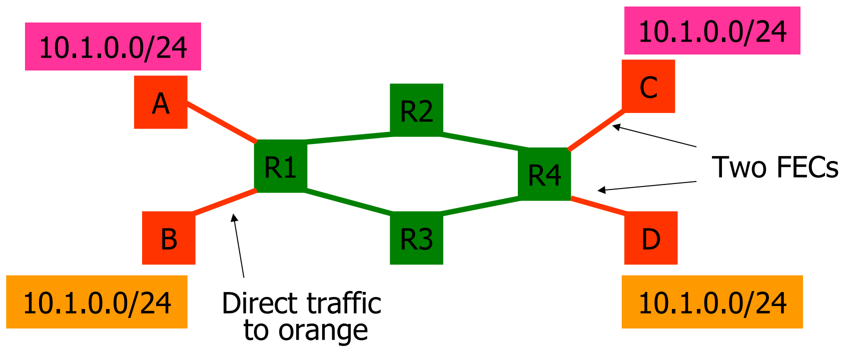


BGP-Free Core



Routers R2 and R3 don't need to speak BGP

VPNs With Private Addresses



MPLS tags can differentiate green VPN from orange VPN.

Status of MPLS

- Deployed in practice
  - BGP-free core
  - Virtual Private Networks
  - Traffic engineering
- Challenges
  - Protocol complexity
  - Configuration complexity
  - Difficulty of collecting measurement data
- Continuing evolution
  - Standards
  - Operational practices and tools

Conclusion

- MPLS is an overlay
  - Tunneling on top of the network
    - Built on top of an underlying routing algorithm
  - Flexibility in mapping traffic to paths
    - Associating packets with FECs, and then labels
  - New protocols for creating label-switching tables
    - Binding FECs to labels across a path
    - Establishing explicit routes
- Many open questions
  - Makes operations easier vs. harder?
  - Trade-offs in exploiting the flexibility?
  - Interdomain routing with MPLS?