MPLS

- **Circuit switching**
  - Packet switching vs. circuit switching
  - Virtual circuits

- **MPLS**
  - Labels and label-switching
  - Forwarding Equivalence Classes
  - Label distribution
  - MPLS applications
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

<table>
<thead>
<tr>
<th>Link 7</th>
<th>Link 14</th>
<th>Link 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: 7: 20</td>
<td>20: 14: 78</td>
<td>53: 8: 42</td>
</tr>
<tr>
<td>2: 7: 53</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1: 7: 20 → link 7 → 20: 14: 78
2: 7: 53 → link 8 → 53: 8: 42
Virtual circuits similar to IP datagrams

- Data divided into 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
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

![Diagram of an IP packet encapsulated with an MPLS header]
Pushing, swapping, and popping

- **Pushing**: add the initial “in” label
- **Swapping**: map “in” label to “out” label
- **Popping**: remove the “out” label

Diagram:
- Pushing: add the initial “in” label
- Swapping: map “in” label to “out” label
- Popping: remove the “out” label

Nodes:
- A: IP edge
- B: R1
- C: R4
- D: R3

Connections:
- A to B: IP edge
- B to R1: MPLS core
- R1 to R2: Swapping
- R2 to R3: Popping
- R3 to R4: Pushing
- R4 to C: IP edge
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

Map destinations in 12.1.1.0/24 to out-label 43 and link to R2
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
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