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# **MPLS**

## Multiprotocol Label Switching

IETF working group:

<http://www.ietf.org/html.charters/mpls-charter.html>

# References

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- C. Metz, “Ingredients for Better Routing? Read the Label,” *IEEE Internet Computing*, Sept/Oct. 1998, pp. 10-15.
- RFC 3031, January 2001: “Multiprotocol Label Switching Architecture”.
  - Read sections 1, 2 and 3.
- RFC 3032, January 2001: “MPLS Label Stack Encoding”.
  - Read sections 1, 2 and 3.

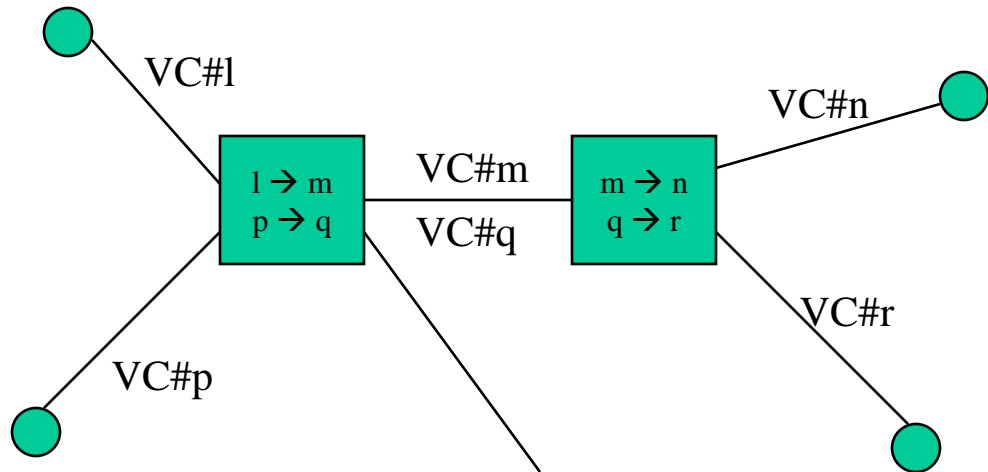
# Motivation

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- To improve the efficiency of routers to match that of virtual-circuit switches.
- To provide greater routing flexibility:  
such that routing is not constrained to traditional destination-based shortest paths
  - traffic engineering and provisioning
  - constraint-based routing (QoS routing)

# Virtual Circuit Routing

- Connection-oriented
- VC established from source to destination prior to transmission of traffic
- VC# refers to a particular connection
- Efficient switching by simple VC table lookup



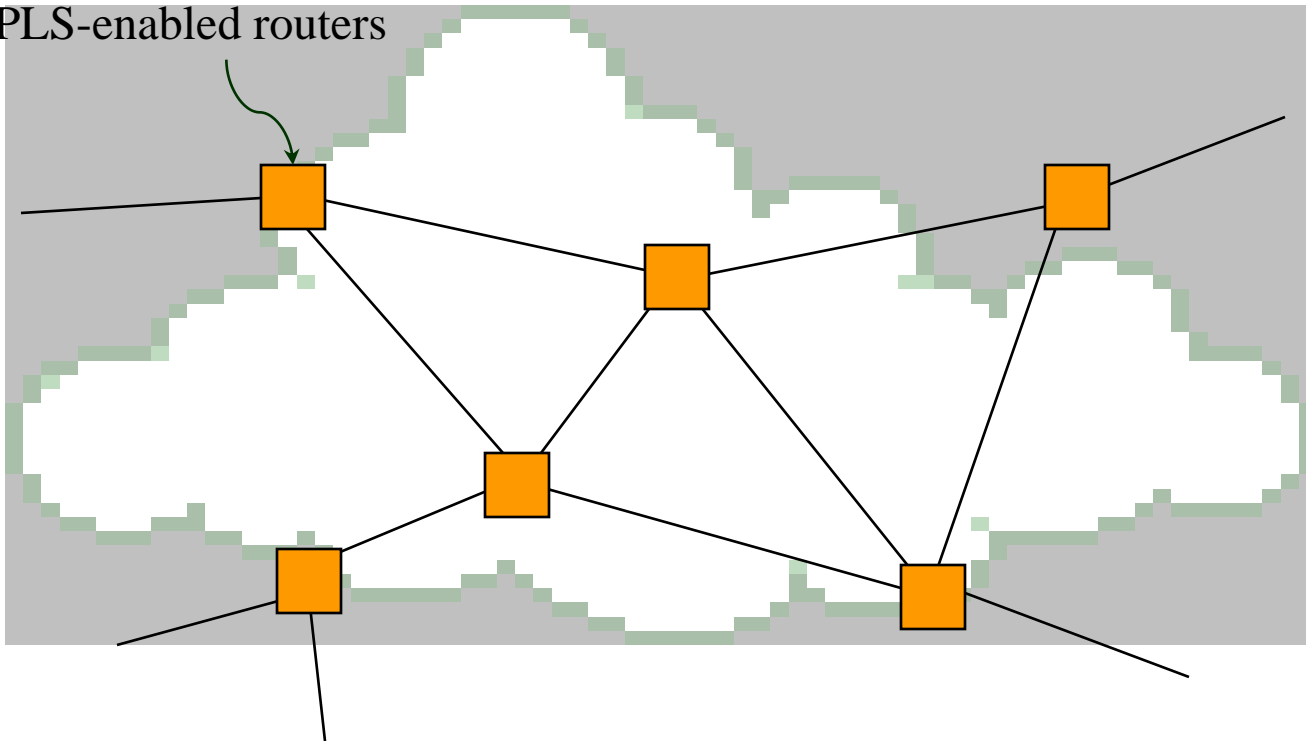
# Today's IP Routing Model

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- Each router makes independent forwarding decisions based on destination IP address.
- Routing tables created based on routing protocol used
- Complex table lookup
  - Large tables
  - Longest prefix match determines next hop.
- MPLS applies concept of VC routing to certain flows to gain efficiency (like caching the route)

# Consider an MPLS domain

Label Switching Routers (LSRs)  
= MPLS-enabled routers



# ***FEC classification***

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- Identify groups of IP packets that require the same forwarding treatment:
  - in the path traversed
  - in QoS treatment
- For example, all of the best-effort packets going to the same destination.
- Call each such group a "Forwarding Equivalence Class" (FEC).

# Labeling and Switching

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- FEC determination is done once at the ingress to the MPLS domain. The packet is then "labeled" to identify its FEC.
- All subsequent forwarding by LSRs is done using label swapping:
  - look up incoming label
  - determine outgoing port, outgoing label, QoS treatment, etc.
  - forward with outgoing label

# ***Label Switched Paths***

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- The path through the LSRs followed by the packets in an FEC is called a label switched path (LSP)
- Each LSP maps to an FEC. Multiple FECs may share the same LSP.

# Switched Path Types

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- point-to-point
  - Connects an ingress node to an egress node for unicast traffic
  - $O(n^2)$ , where  $n$  = number of edge MPLS devices
- multipoint-to-point
  - Each egress node reachable via a single multipoint-to-point switched path.
  - Data units are merged into a single label at intermediate nodes
  - $O(n)$ , where  $n$  = number of egress nodes

# Switched Path Types (cont.)

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- point-to-multipoint
  - For distributing multicast traffic
  - The switched path tree mirrors the multicast distribution tree (as determined by the multicast routing protocol)
- multipoint-to-multipoint
  - Combines multicast traffic from multiple sources into a single multicast distribution tree.
  - Advantage: multicast tree shared by multiple sources

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# MPLS Mechanisms

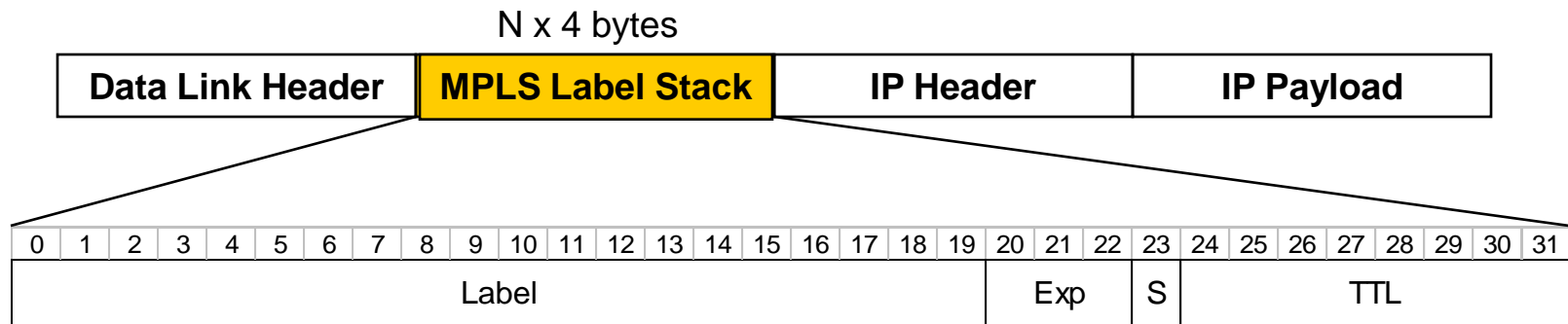
- Labels and label stack
- Label assignment (*when* they are assigned)
- Packet forwarding
- Label distribution

# Labels

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- A relatively short, fixed-length identifier used to identify an FEC
- Usually assigned based (completely or partially) on network layer destination address
- Encapsulated either
  - between link layer and network layer ("shim" layer), or
  - within an existing data link or network header (e.g., the VCI/VPI pair with ATM)

# Example: “shim” layer



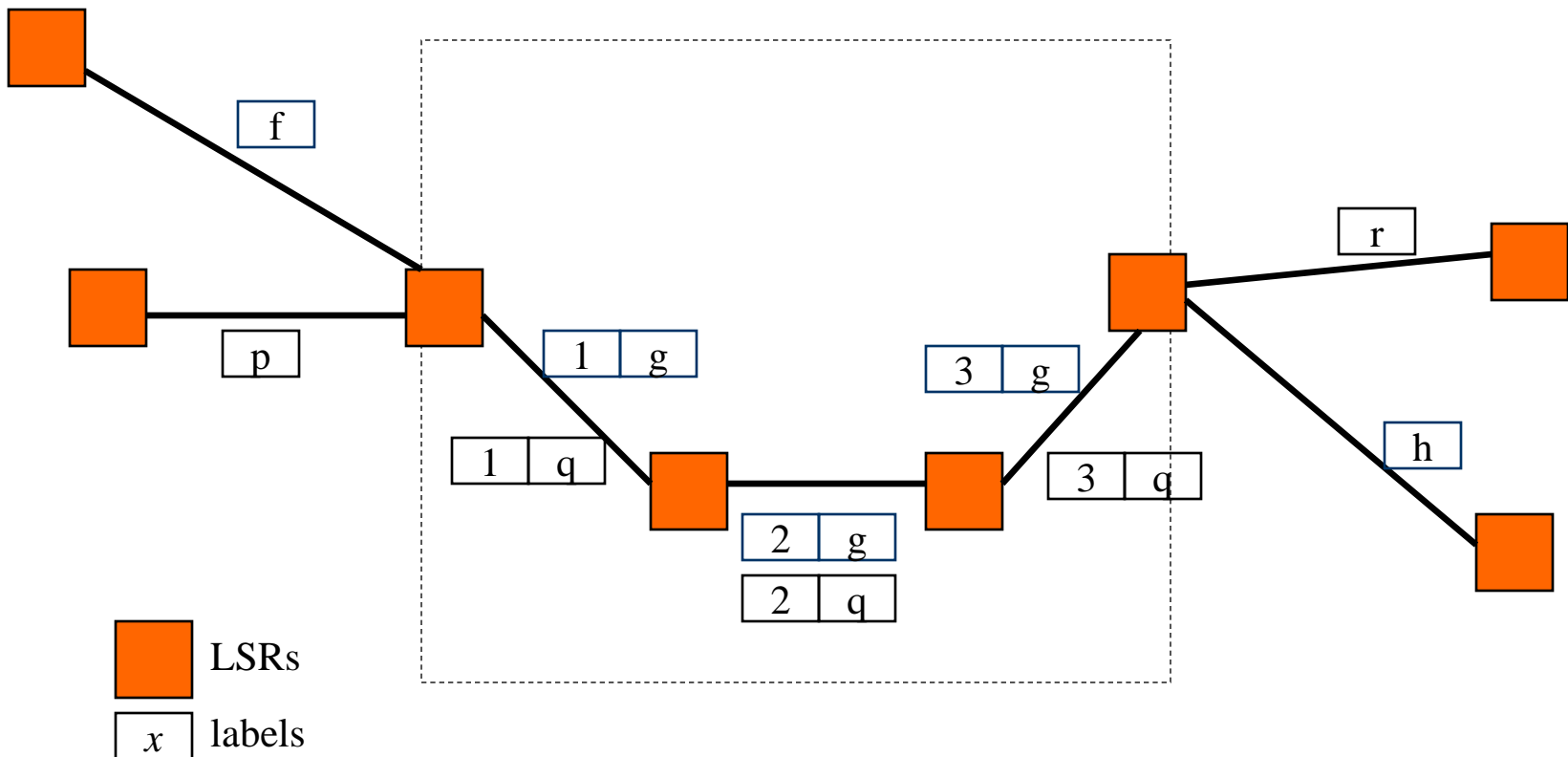
- **Label:** Numeric value of the label; values 0-3 have special meaning, 4-15 are reserved.
- **Exp:** Experimental use.
- **S:** When set, indicates bottom of stack (last label).
- **TTL:** Time-To-Live. Number of hops this packet can take. Initially set to the TTL of the packet. Has significance only on the top of the stack.

# *Hierarchical Label Stack*

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- MPLS supports a LIFO stack hierarchy, called a label stack
- Processing occurs only at top level label
- Examples of use:
  - Having an IGP label and a BGP label allows interior routers to be free of BGP information.  
The IGP label is used to steer the packet through the AS, while the BGP label is used to switch between ASes.
  - Tunnels for virtual private networks

# Hierarchical Label Stack (cont)



# Forwarding Operations

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- Label swapping occurs at each node
- For a labeled packet:
  - Map the incoming label at top of label stack to a Next Hop Label Forwarding Entry (NHLFE), which contains
    - the packet's next hop
    - the operation to perform on the packet's label stack (replace with a specified new label, pop label stack, etc)
  - Perform the specified operation on label stack
  - Forward with new label

# Forwarding Operations (cont.)

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- For an unlabeled packet
  - Analyze packet header to determine the packet's FEC
  - Map the FEC to an NHLFE
  - Perform the specified operation on label stack
  - Forward with new label
- Note that there could be more than one NHLFE corresponding to a label or FEC.
  - One of the NHLFEs must be chosen
  - This could be useful for load balancing

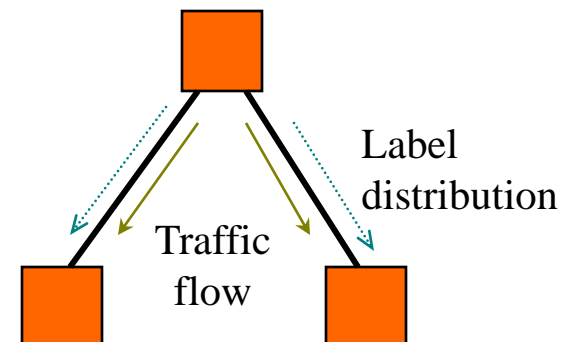
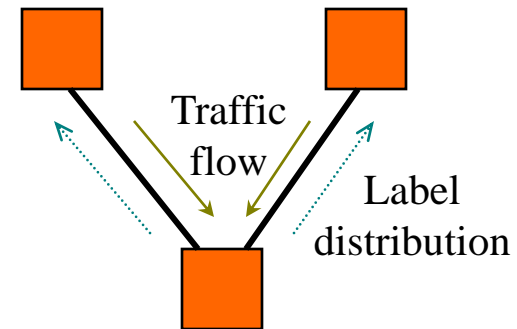
# ***Label distribution***

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- LSRs learn about each other's labels through label distribution
  - Communicates the "meaning" (i.e., FEC) of the label between two adjacent LSRs
  - MPLS does not assume the presence of one particular mechanism

# Label distribution direction

- Allocation by downstream LSR
  - Rationale: downstream LSR is the one examining/interpreting the label, so it should specify the label
  - Most natural method for unicast traffic
- Allocation by upstream LSR
  - Rationale: in multicast, there may be efficiency gains by using the same label on all output ports for a particular multicast packet



# Label assignment schemes

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- Topology driven label assignment:
  - Labels are generally pre-assigned based on normal routing protocol control traffic
  - Computational/bandwidth overhead is a function of size of network
- Request driven label assignment:
  - Path creation triggered by control protocols (such as RSVP)
  - Number of labels/overhead of distribution depends on number of flows

# ***Label assignment schemes (cont.)***

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- Traffic driven label assignment:
  - At an LSR, the arrival of data recognized as a flow triggers label assignment
  - Bindings are established dynamically based on traffic measurements
  - There is latency from appearance of flow to its labeling
  - Overhead depends on traffic patterns

# ***Label distribution protocols: Explicit and Piggybacking***

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- Label mappings can be communicated by:
  - Explicit label distribution:
    - utilize a protocol designed specifically for label distribution.
  - Piggybacking on other control messages:
    - modifies existing protocols, e.g., OSPF, BGP, RSVP, PIM.
    - Same mechanism distributes both routing/control information and label information
    - avoids situation where label for a specific destination uses an outdated path

# ***LDP: Label Distribution Protocol***

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- Explicit label distribution protocol proposed by MPLS WG, published as RFC 3036.
- Associates an FEC with each label it distributes
- Each FEC is specified as a set of one or more FEC elements.

Types of FEC elements currently defined in LDP are:

- address prefix
- host address
- Has mechanism to discover potential LDP peers

# ***LDP: Label Distribution Protocol (cont.)***

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- LDP sessions (using TCP) are established to negotiate parameters and for label distribution
- Advertisement messages create, change, and delete label mappings for FECs
- Two methods for label distribution:
  - Downstream on Demand: an LSR explicitly requests, from its next hop for a particular FEC, a label binding for that FEC.
  - Downstream Unsolicited: an LSR distributes bindings to upstream LSRs that have not explicitly requested them.

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# *Applying MPLS*

# Constraint-based Routing

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- In constraint-based routing, the information used to set up paths extends beyond what the routing protocol offers; e.g., a path can be set up given certain QoS constraints
- Explicit routing is a subset of constraint-based routing where the constraint is the explicit route
- An extension to the LDP specification for supporting constraint-based routing is defined in draft *Constraint-based LSP Setup using LDP*

# Traffic Engineering

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- Traffic engineering seeks to optimize network performance through proper mapping of traffic flows onto the physical network topology
  - to balance the load on various links, routers, switches;
  - to avoid congested paths.
- Without T.E., only the shortest path is used.
- Need a packet-forwarding mechanism to move traffic along the explicit path chosen: MPLS provides this
- Need a signaling mechanism to reserve resources and establish path state in network nodes along explicit path: RSVP extensions for MPLS provides this

# RSVP extensions for MPLS

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## Base RSVP

- Signaling between pairs of hosts
- State applies to single host-to-host flow
- Scalability, latency, overhead concerns

## Extended RSVP

- Signaling between pairs of routers (the ingress and egress points)
- State applies to a collection of flows sharing a common path & network resources
- Extensions reduce the number of refresh messages and the message processing requirements
- Helps distribute MPLS labels

# Supporting DiffServ over an MPLS Network

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- DiffServ Behavior Aggregates can be mapped onto MPLS labels
- MPLS allows the precedence/ class of service to be inferred from the label
- Example: multiple LSPs can be provisioned between each pair of edge LSRs.  
Each LSP can be engineered to provide different performance and bandwidth guarantees

# Benefits of using MPLS

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- Facilitates forwarding
  - Simplified forwarding: Exact match (rather than longest prefix match) for shorter label. Shorter list of labels.
  - Facilitates complex mappings from IP packet to FEC (e.g., based on source and destination address, incoming interface, etc). Complexity can increase without impact on core routers.
  - Partitions control and forwarding functions: heavy processing takes place on the edges of the network; pure label based forwarding in core.

## ***Benefits of using MPLS (cont.)***

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- Allows finer control in routing
  - Efficiency in explicit routing; otherwise, packet needs to carry with it an encoding of its route.
  - Ingress router may differentiate packets based on information other than destination address, or even based on information not contained in network layer header.
  - Traffic engineering: selecting appropriate paths to balance traffic load
  - QoS Routing: Each stream may need to be individually routed to provide QoS guarantees. Identify flows/classes by tags.
  - Virtual Private Networks (VPNs): labels can isolate traffic between VPNs.

# ***Benefits of using MPLS (cont.)***

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- Single forwarding paradigm
  - Supports multiple types of service (IP, frame relay, ATM, IP tunneling, VPNs, etc.) on same network
  - Unicast and multicast handled with same forwarding algorithm