Data and Computer Communications

Tenth Edition

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CHAPTER 23

Multiprotocol Label Switching

"No ticket! Dear me, Watson, this is really very singular. According to my experience it is not possible to reach the platform of a Metropolitan train without exhibiting one's ticket."

—The Adventure of the Bruce-Partington Plans

Sir Arthur Conan Doyle

Role of MPLS

- Efficient technique for forwarding and routing packets
- Designed with IP networks in mind
    - Can be used with any link-level protocol
- Fixed-length label encapsulates an IP packet or a data link frame
- MPLS label contains all information needed to perform routing, delivery, QoS, and traffic management functions
- Is connection oriented

MPLS Growth

- Internet Engineering Task Force (IETF) is the lead organization in developing MPLS-related specifications and standards
- Deployed in almost every major IP network
- Reasons MPLS is accepted:

Embraced IP

Built-in flexibility

Protocol neutral

Adapts existing protocols

Is adaptable

Supports metrics

Scales

Background of MPLS

- IP switching (Ipsilon)
- Tag switching (Cisco Systems)
- Aggregate route-based IP switching (IBM)
- Cascade (IP navigator)
- IETF set up the MPLS working group (1997)
  - First set of proposed standards (2001)
  - Key specification is RFC 3031

Connection-Oriented QoS Support

- Connectionless networks cannot provide firm QoS commitments
- Has powerful traffic management and QoS capabilities
- MPLS imposes framework on an IP-based Internet
- Provides the foundation for sophisticated and reliable QoS traffic contracts

Traffic Engineering

- Ability to define routes dynamically, plan resource commitments on the basis of known demand, and optimize network utilization
- Effective use can substantially increase usable network capacity
- ATM provided strong traffic engineering capabilities prior to MPLS
- With basic IP there is a primitive form

MPLS

- Is aware of flows with QoS requirements
- Possible to set up routes on the basis of flows
- Paths can be rerouted intelligently

MPLS Support

Enhancement to the way a connectionless IP-based internet is operated

Can be used on a number of networking technologies

Can coexist with ordinary IP routers

Provides an efficient mechanism for supporting VPNs

Designed to work in ATM and frame relay

Table 23.1 Key MPLS Terms

(Table is on page 779 in textbook)

Forwarding equivalence class (FEC) A group of IP packets that are forwarded in the same manner (e.g., over the same path, with the same forwarding treatment).

Frame merge Label merging, when it is applied to operation over frame-based media, so that the potential problem of cell interleave is not an issue.

Label merging The replacement of multiple incoming labels for a particular FEC with a single outgoing label.

Label swap The basic forwarding operation consisting of looking up an incoming label to determine the outgoing label, encapsulation, port, and other data handling information.

Label swapping A forwarding paradigm allowing streamlined forwarding of data by using labels to identify classes of data packets that are treated indistinguishably when forwarding.

Label switched hop The hop between two MPLS nodes, on which forwarding is done using labels.

Label switched path The path through one or more LSRs at one level of the hierarchy followed by a packets in a particular FEC.

Label switching router (LSR) An MPLS node that is capable of forwarding native L3 packets.

Label stack An ordered set of labels.

Merge point A node at which label merging is done.

MPLS domain A contiguous set of nodes that operate MPLS routing and forwarding and that are also in one Routing or Administrative Domain

MPLS edge node An MPLS node that connects an MPLS domain with a node that is outside of the domain, either because it does not run MPLS, and/or because it is in a different domain. Note that if an LSR has a neighboring host that is not running MPLS, then that LSR is an MPLS edge node.

MPLS egress node An MPLS edge node in its role in handling traffic as it leaves an MPLS domain.

MPLS ingress node An MPLS edge node in its role in handling traffic as it enters an MPLS domain.

MPLS label A short, fixed-length physically contiguous identifier that is used to identify a FEC, usually of local significance. A label is carried in a packet header.

MPLS node A node that is running MPLS. An MPLS node will be aware of MPLS control protocols, will operate one or more L3 routing protocols, and will be capable of forwarding packets based on labels. An MPLS node may optionally be also capable of forwarding native L3 packets.

MPLS Operation

- Label switching routers (LSRs)
  - Nodes capable of switching and routing packets on the basis of label
- Labels define a flow of packets between two endpoints
- Assignment of a particular packet is done when the packet enters the network of MPLS routers
- Connection-oriented technology

Label Assignment

- Based on:

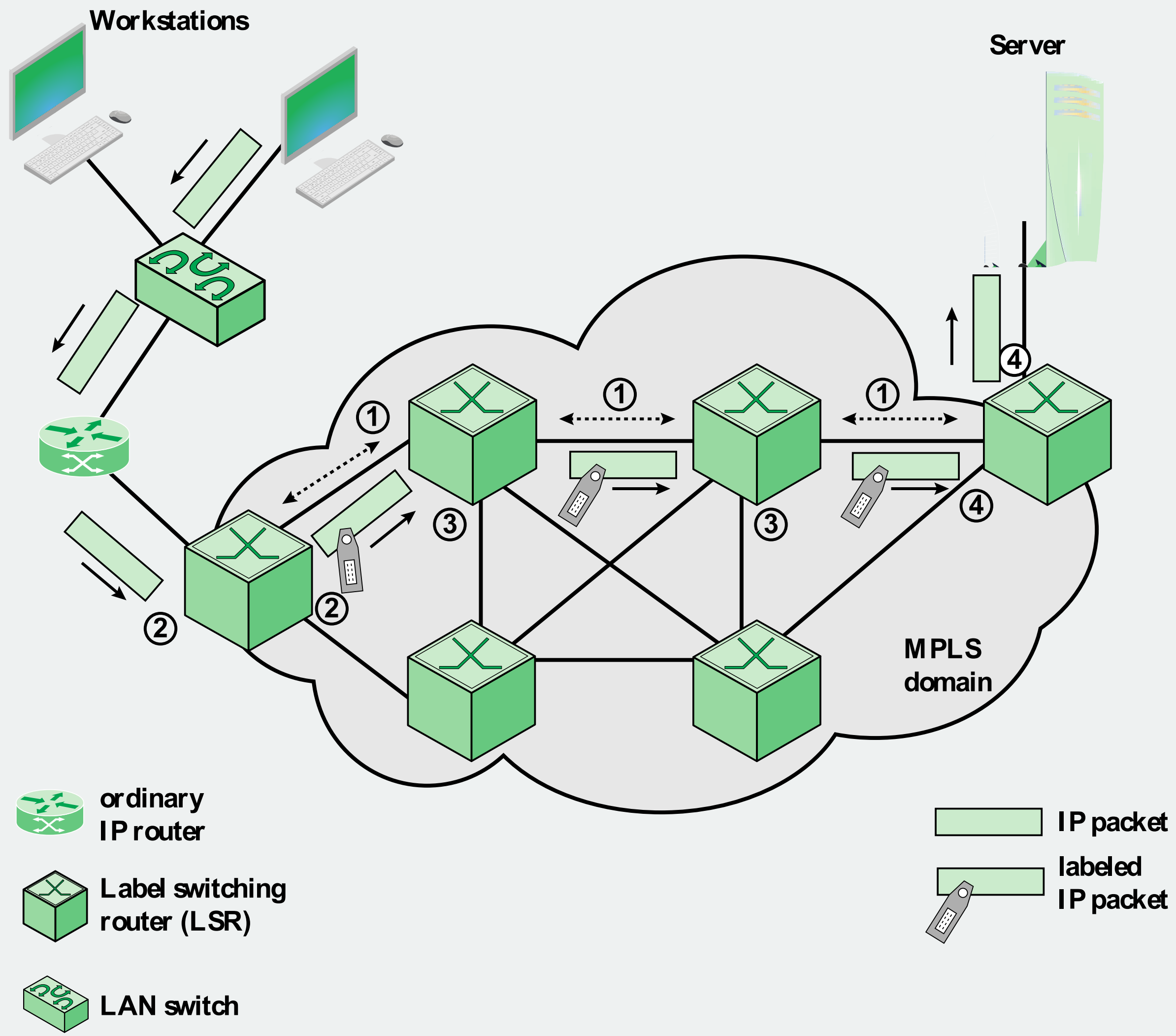


Figure 21.1 MPLS Operation

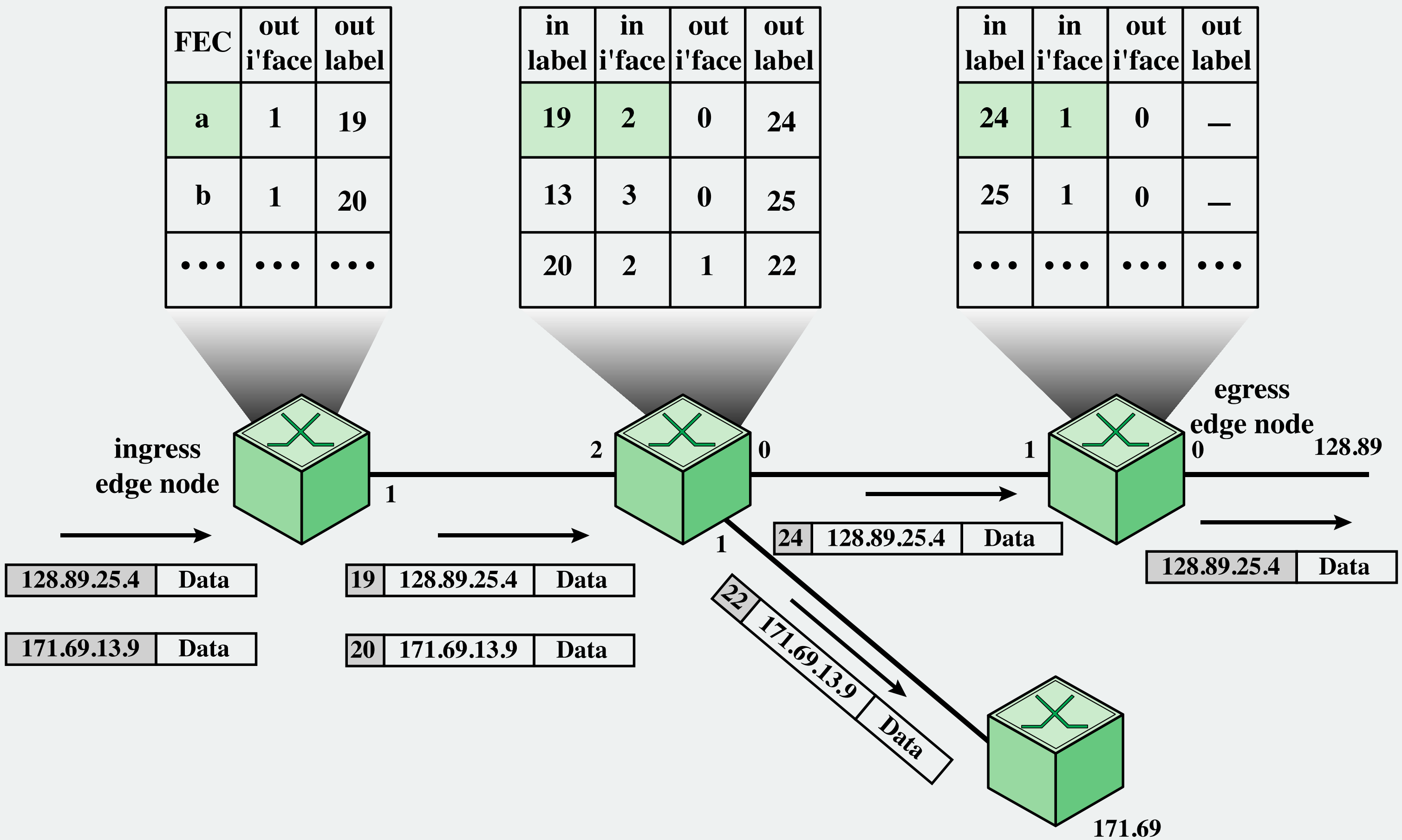


Figure 23.2 MPLS Packet Forwarding

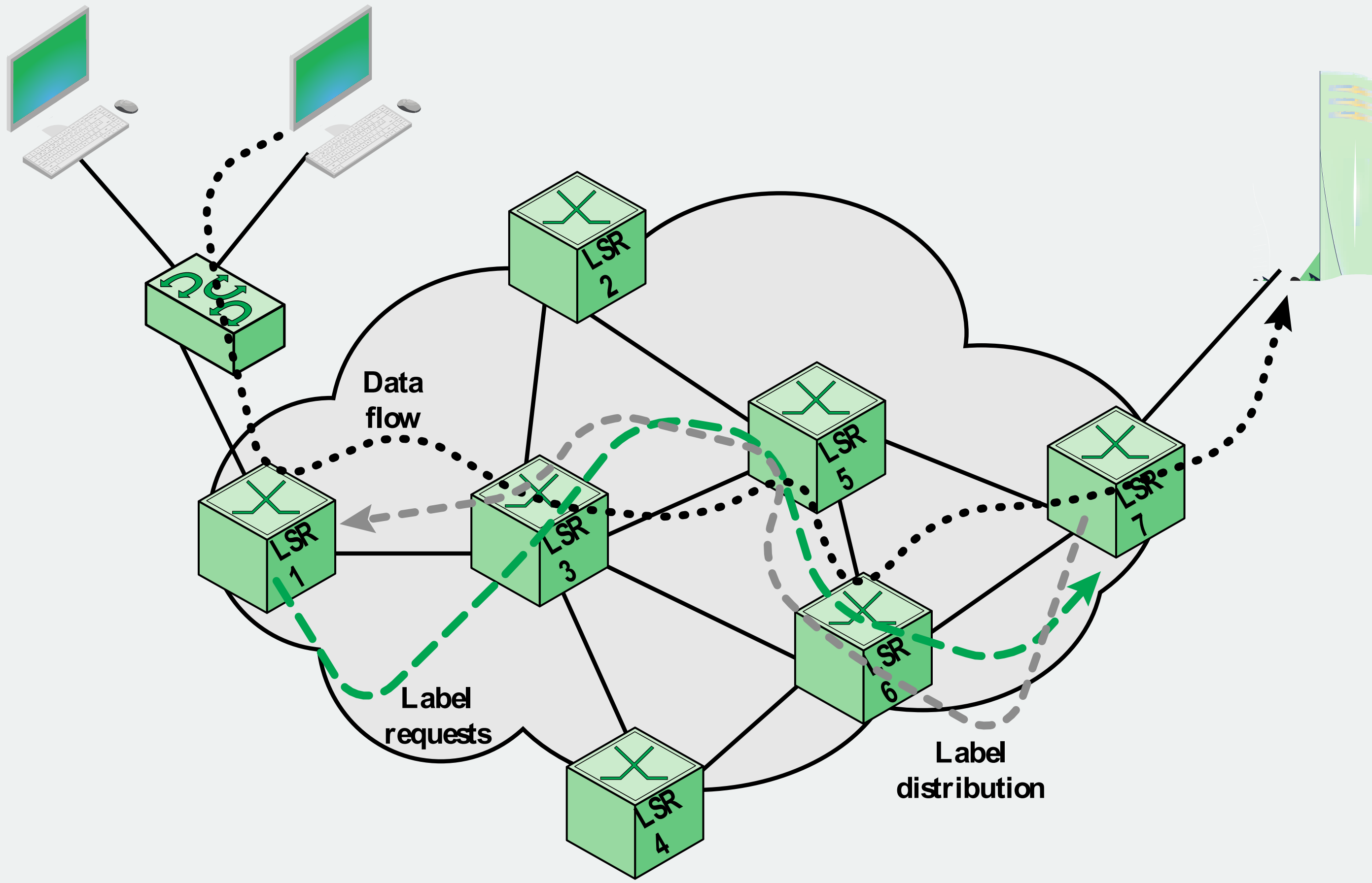


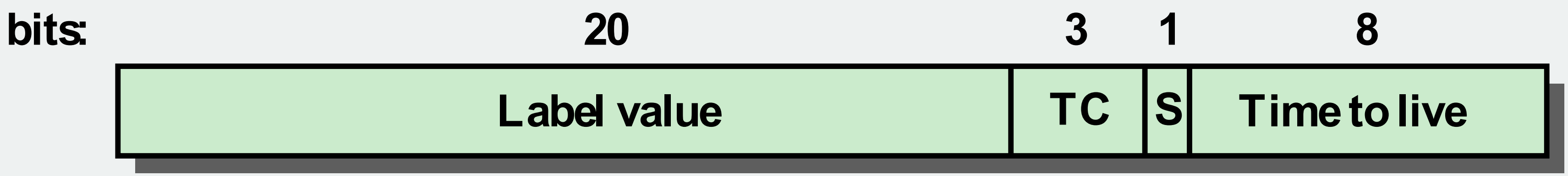
Figure 23.3 LSP Creation and Packet Forwarding through an MPLS Domain

Label Stacking

- One of the most powerful features of MPLS
  - Processing is always based on the top label
  - At any LSR a label may be removed or added
- Allows creation of tunnels
  - Tunnel refers to traffic routing being determined by labels
- Provides considerable flexibility
- Unlimited stacking

UNLIMITED

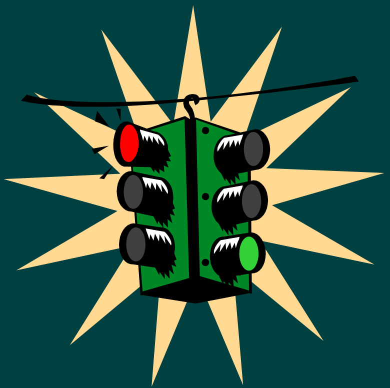
STACKING



TC = traffic class
S = bottom of stack bit

Figure 23.4 MPLS Label Format

Traffic Class (TC)



- RFCs 3270 and 5129
- No unique definition of the TC bits has been standardized
- DS:
  - Assign a unique label value to each DS per-hop-behavior scheduling class
  - Map the drop precedence into the TC field
- ECN:
  - Three possible ECN values are mapped into the TC field

Time to Live Field (TTL)

- Key field in the IP packet header
- Decremented at each router and packet is dropped if the count falls to zero
  - Done to avoid looping
  - Having the packet remain too long in the Internet due to faulty routing
- Included in the label so that the TTL function is still supported

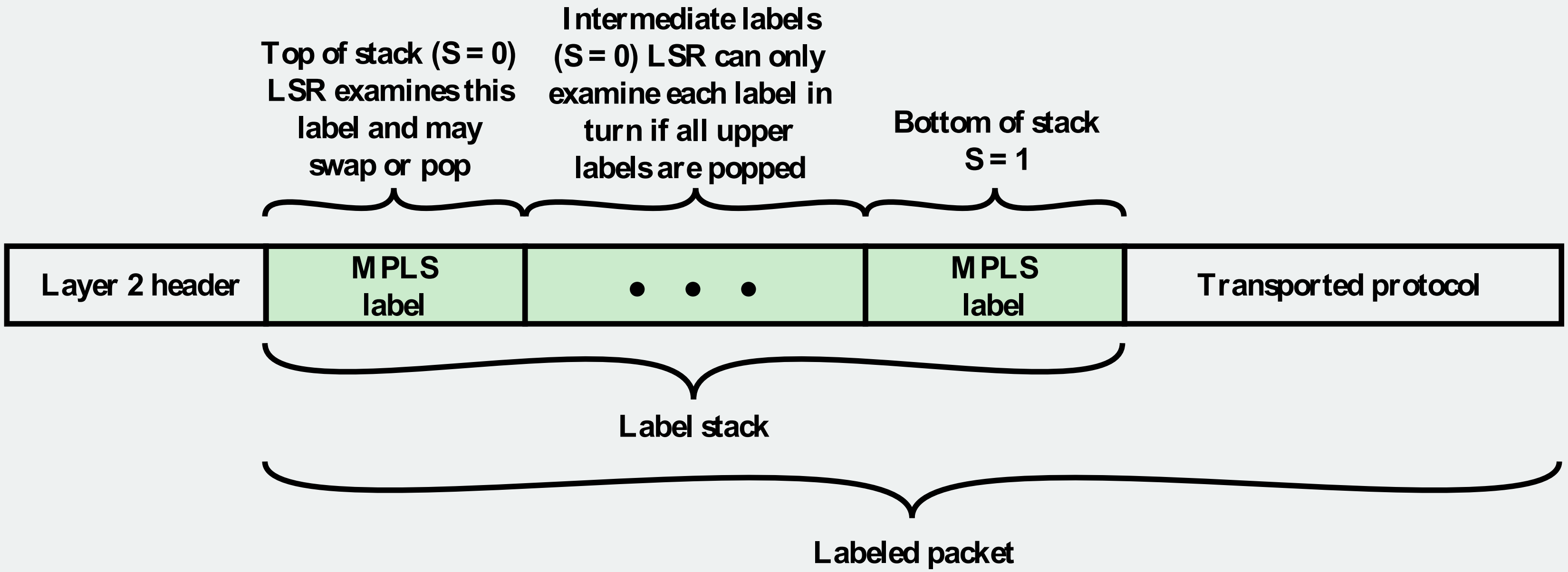


Figure 23.5 Encapsulation for Labeled Packet

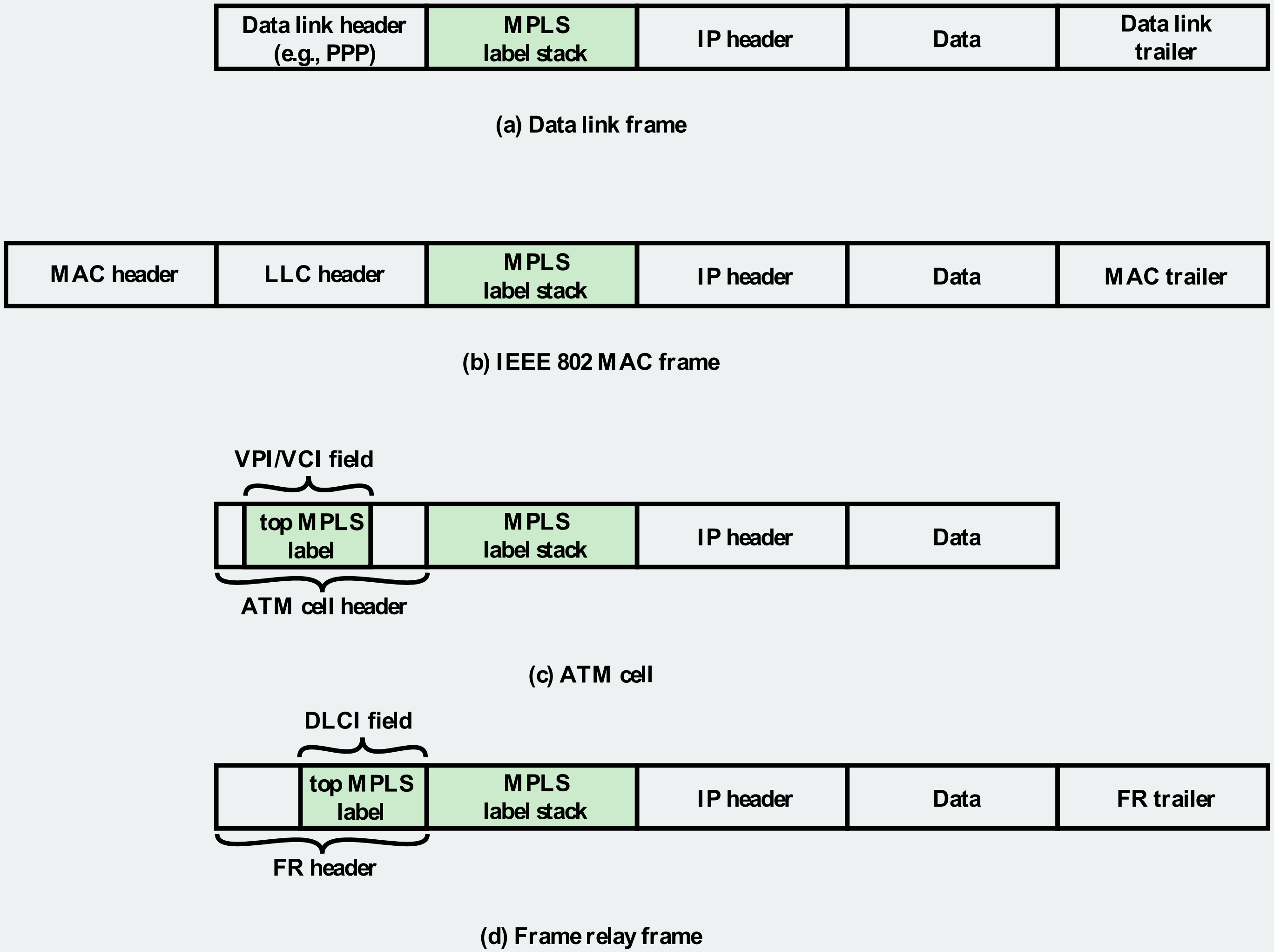


Figure 23.6 Position of MPLS Label Stack

FECs, LSPs, and Labels

Traffic is grouped into FECs

Traffic in an FEC transits an MPLS domain along an LSP

Individual packets in an FEC are uniquely identified

At each LSR each labeled packet is forwarded on the basis of its label value

LSP Topology

- Unique ingress and egress LSR
  - Single path through the MPLS domain is needed
- Unique egress LSR, multiple ingress LSRs
  - Traffic assigned to a single FEC can arise from different sources that enter the network at different ingress LSRs
- Multiple egress LSRs for unicast traffic
  - RFC 3031
- Multicast
  - RFC 5332

Route Selection

- Refers to the selection of an LSP for a particular FEC
- Supports two options:
  - Hop-by-hop routing
    - Each LSR independently chooses the next hop for each FEC
    - Does not readily support traffic engineering or policy routing
  - Explicit routing
    - A single LSR specifies some or all of the LSRs
    - Can be set up ahead of time or dynamically

Requirements for Label Distribution

- Each LSR on the LSP must do the following:
  - Assign a label to the LSP to be used to recognize incoming packets that belong to the corresponding FEC
  - Inform all potential upstream nodes of the label assigned by this LSR to this FEC, so that these nodes can properly label packets to be sent to this LSR
  - Learn the next hop for this LSP and learn the label that the downstream node has assigned to this FEC; this will enable this LSR to map an incoming label to an outgoing label

Label Distribution

- Label distribution protocol enables two LSRs to learn each other's MPLS capabilities
- RFC 3031 refers to a new label distribution protocol and to enhancements of existing protocols

Hop-by-hop route selection

- No attention is paid to traffic engineering or policy routing concerns
- Ordinary routing protocol is used to determine the next hop by each LSR

Label Distribution Protocol

- Protocols that communicate which label goes with which Forwarding Equivalence Class (FEC)
  - Label Distribution Protocol (LDP; RFC 5036)
  - Resource Reservation Protocol – Traffic Engineering (RSVP-TE; RFC 3209)
  - Multiprotocol BGP as extended for Layer 3 VPNs (L3VPNs; RFC 4364)
  - Once a route is established LDP is used to establish the LSP and assign labels

in label	address prefix	out i'face	out label
—	128.89	1	19
—	171.69	1	20
• • •	• • •	• • •	• • •

in label	address prefix	out i'face	out label
19	128.89	0	24
20	171.69	1	22
• • •	• • •	• • •	• • •

in label	address prefix	out i'face	out label
24	128.89	0	—
• • •	• • •	• • •	• • •

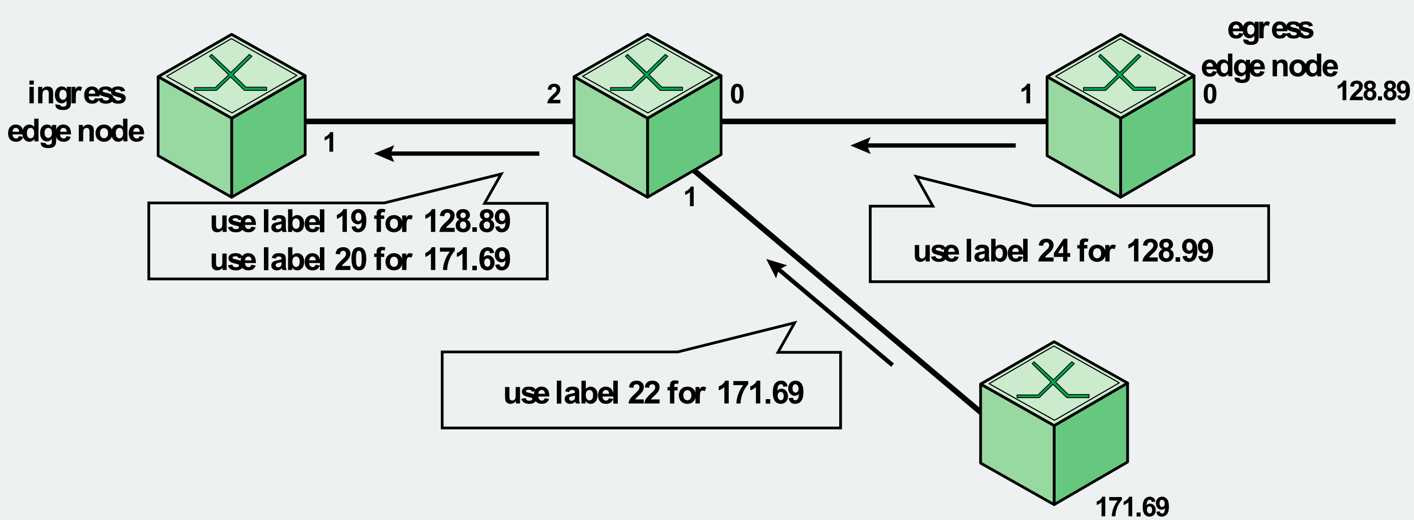


Figure 23.7 Assigning Labels Using LDP Downstream Allocation

LDP Messages

- Discovery
  - Each LSR announces and maintains its presence in a network
    - Hello messages
- Session establishment and maintenance
  - LDP peers
- Advertisement
  - Create, change, and delete label mappings for FECs
- Notification messages
  - Provide advisory information and to signal error information

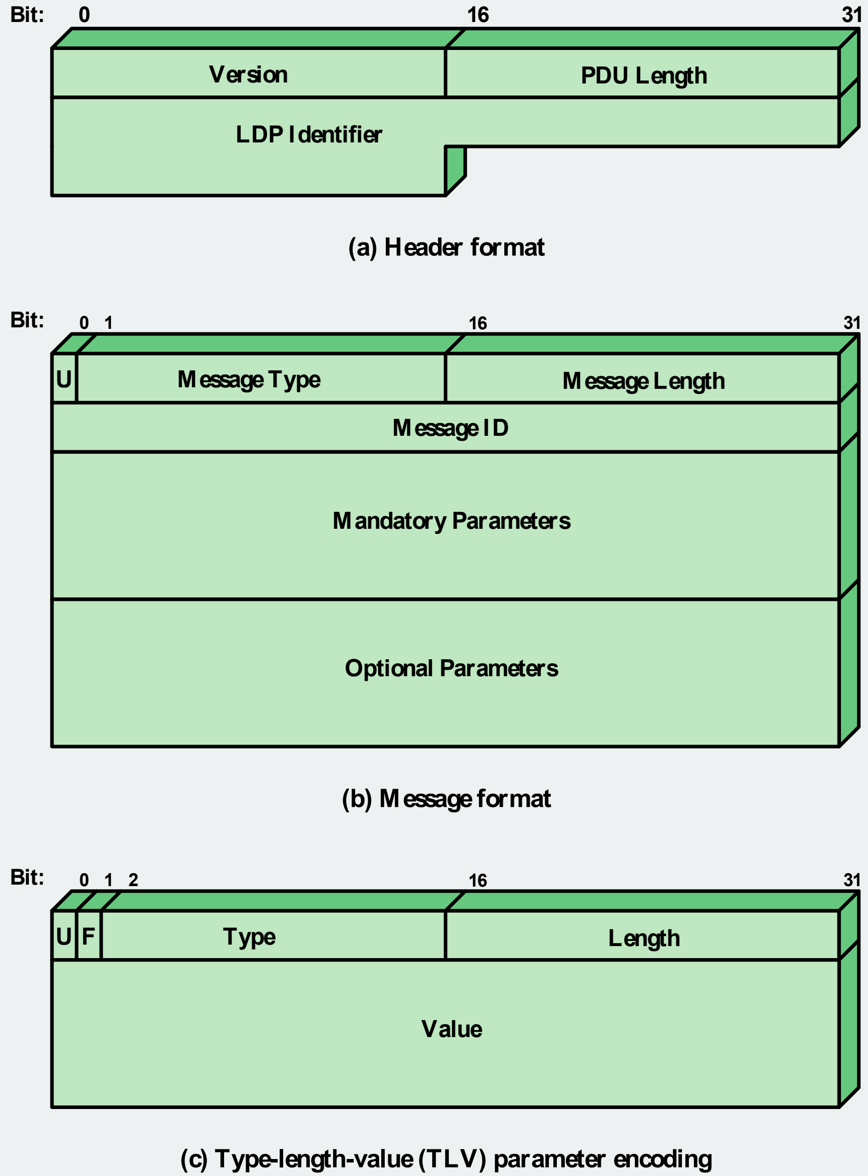
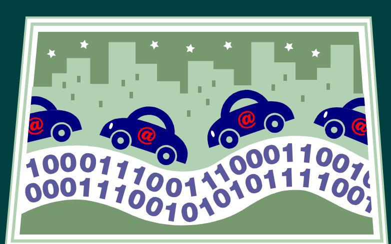
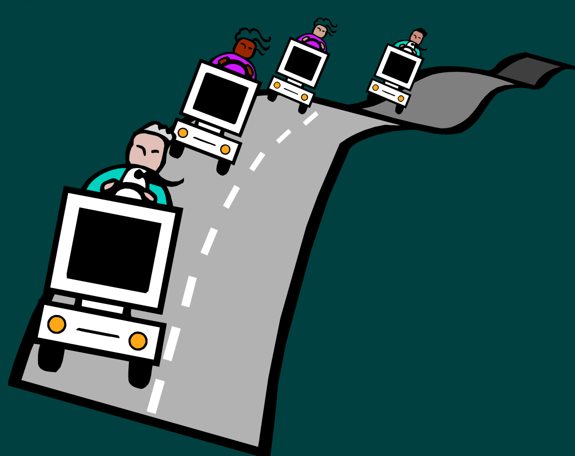


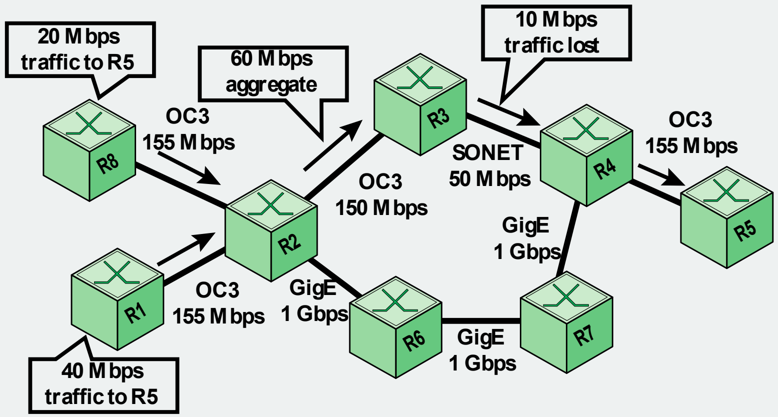
Figure 23.8 LDP PDU Formats

Traffic Engineering

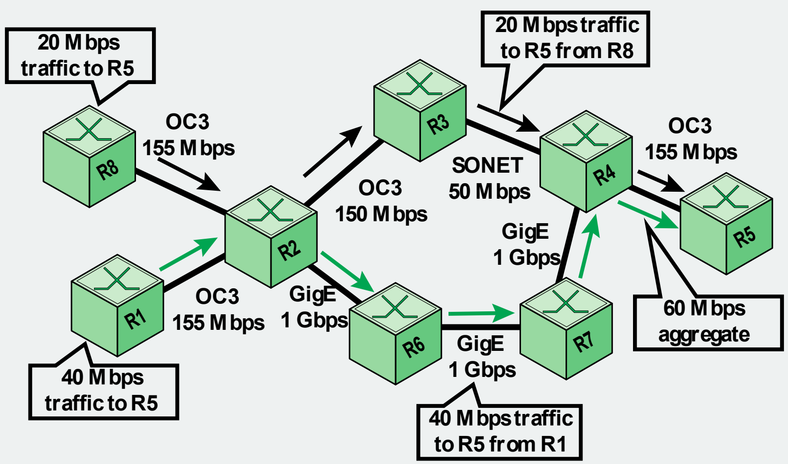
- RFC 2702
- Allocate traffic to the network to maximize utilization of the network capacity
- Ensure the most desirable route through the network while meeting QoS requirements







(a) A shortest-path solution

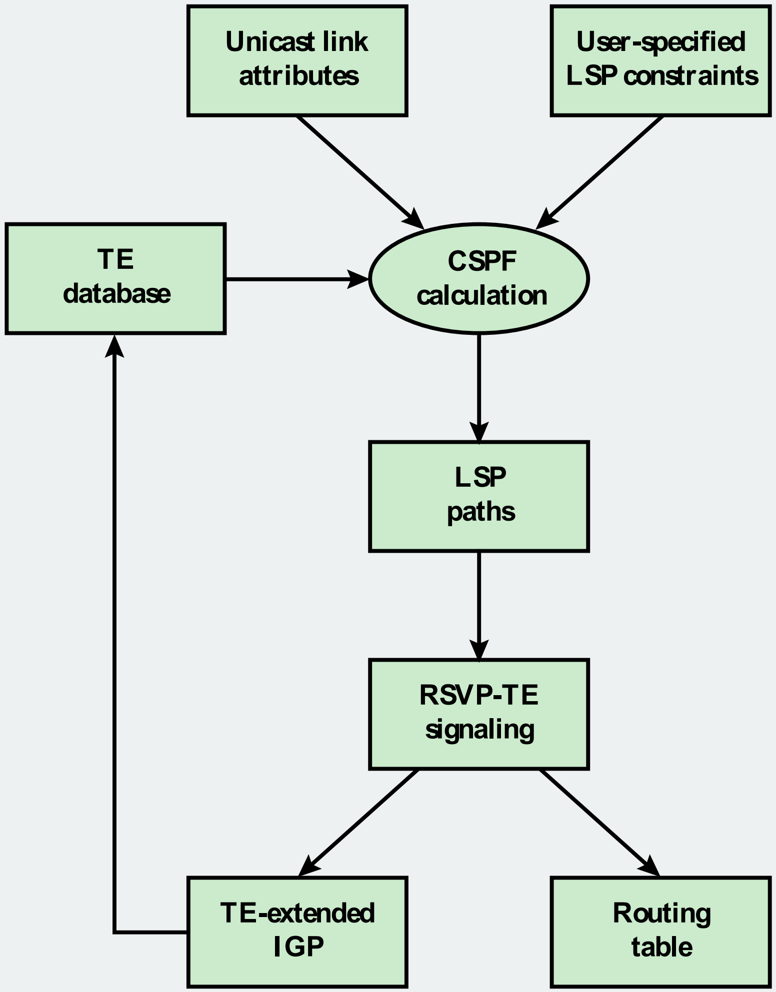


(b) A traffic-engineered solution

Figure 23.9 Traffic Engineering Example

Elements of MPLS Traffic Engineering (MPLS TE)

- Information distribution
  - A link state protocol is necessary to discover the topology of the network
- Path calculation
  - Shortest path through a network that meets the resource requirements of the traffic flow
- Path setup
  - Signaling protocol to reserve the resources for a traffic flow and to establish the LSP
- Traffic forwarding
  - Accomplished with MPLS using the LSP



RSVP-TE= Resource Reservation Protocol - Traffic Engineering
CSPF = Constrained shortest-path first
IGP = Interior gateway protocol (interior routing protocol; e.g., OSPF)
LSP = Label switching path
TE = traffic engineering

Figure 23.10 CSPF Flowchart

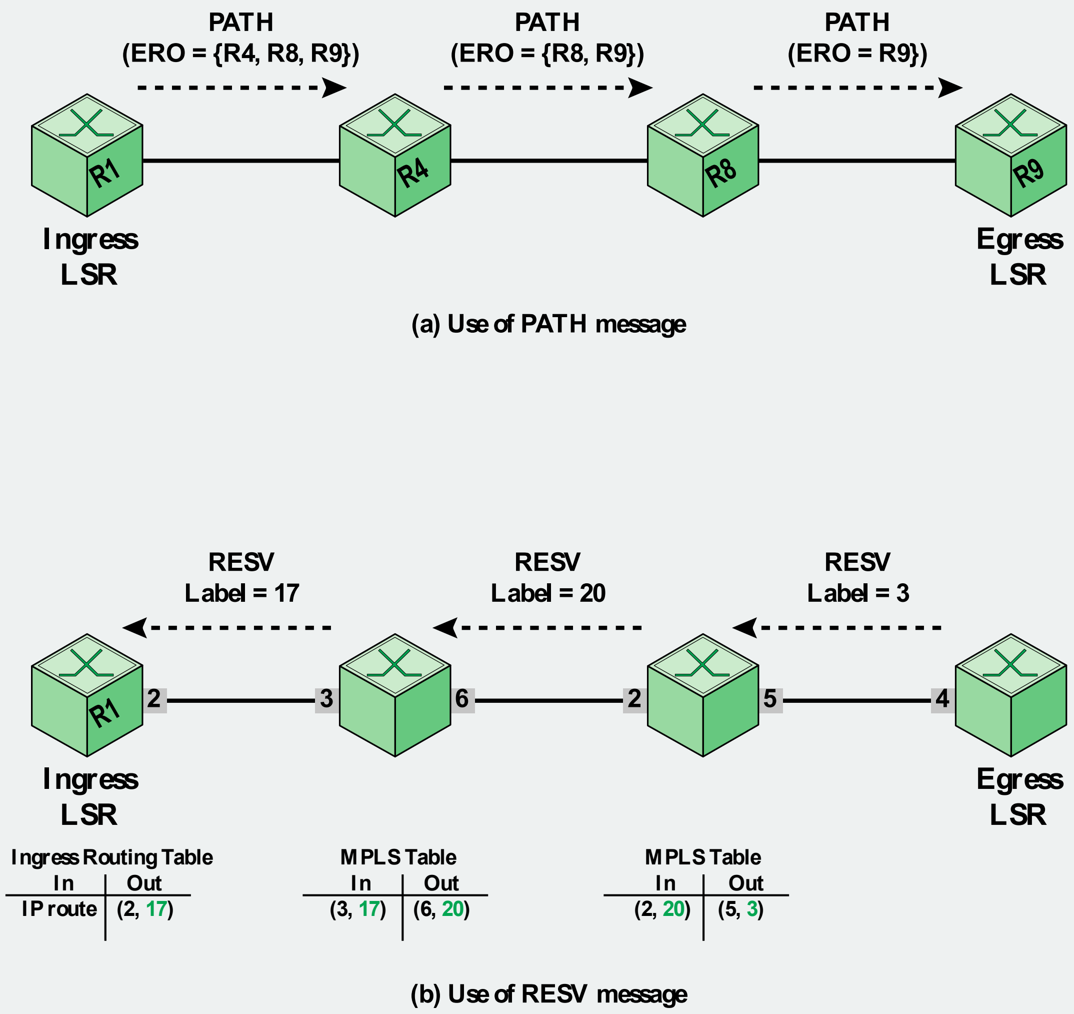


Figure 23.11 RSVP-TE Operation

Virtual Private Network (VPN)

- Private network configured within a public network in order to take advantage of management facilities of larger networks
- Traffic designated as VPN traffic can only go from a VPN source to a destination in the same VPN

Widely used by enterprises to:

- Create wide area networks (WANs)
- Provide site-to-site communications to branch offices
- Allow mobile user to dial up their company LANs

Table 23.2

VPN Terminology

Attachment circuit (AC) In a Layer 2 VPN the CE is attached to PE via an AC. The AC may be a physical or logical link.

Customer edge (CE) A device or set of devices on the customer premises that attaches to a provider provisioned VPN.

Layer 2 VPN (L2VPN) An L2VPN interconnects sets of hosts and routers based on Layer 2 addresses.

Layer 3 VPN (L3VPN) An L3VPN interconnects sets of hosts and routers based on Layer 3 addresses.

Packet switched network (PSN) A network through which the tunnels supporting the VPN services are set up.

Provider edge (PE) **A** device or set of devices at the edge of the provider network with the functionality that is needed to interface with the customer.

Tunnel Connectivity through a PSN that is used to send traffic across the network from one PE to another. The tunnel provides a means to transport packets from one PE to another. Separation of one customer's traffic from another customer's traffic is done based on tunnel multiplexers

Tunnel multiplexer An entity that is sent with the packets traversing the tunnel to make it possible to decide which instance of a service a packet belongs to and from which sender it was received. In an MPLS network, the tunnel multiplexor is formatted as an MPLS label.

Virtual channel (VC) A VC is transported within a tunnel and identified by its tunnel multiplexer. In an MPLS-enabled IP network, a VC label is an MPLS label used to identify traffic within a tunnel that belongs to a particular VPN; i.e., the VC label is the tunnel multiplexer in networks that use MPLS labels.

Virtual private network (VPN) A generic term that covers the use of public or private networks to create groups of users that are separated from other network users and that may communicate among them as if they were on a private network.

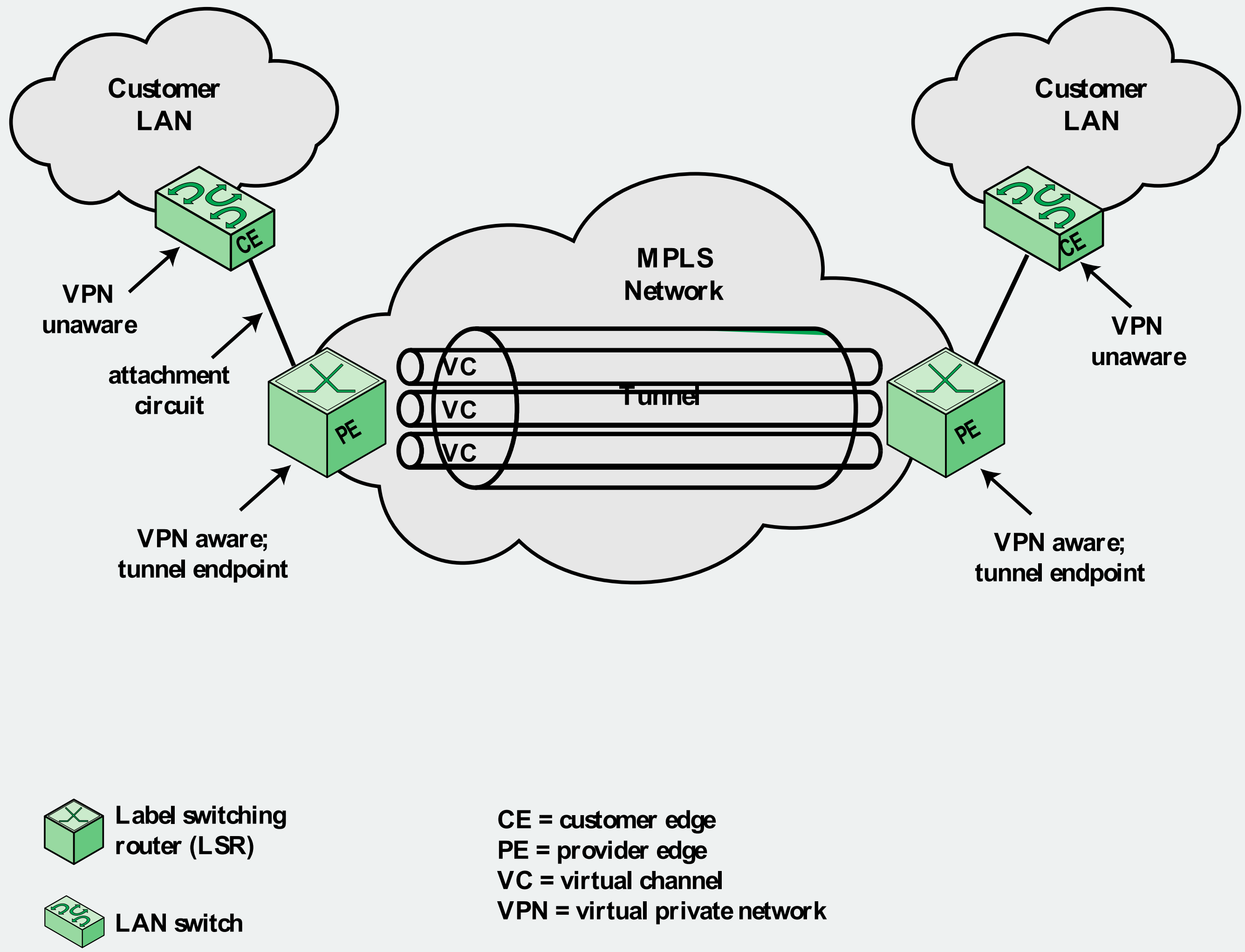


Figure 23.12 Layer 2 VPN Concepts

Layer 3 VPN

- Based on VPN routes between CEs based on IP addresses
- CE implements IP and is thus a router
- CE routers advertise network to provider
- Provider uses an enhanced version of BGP to establish VPNs between CEs
- MPLS tools establish routes

Summary

- The role of MPLS
- Background
  - Connection-oriented QoS support
  - Traffic engineering
  - VPN support
  - Multiprotocol support
- MPLS operation
- Labels
  - Label stacking
  - Label format
  - Label placement
- FECs, LSPs, and labels
  - Route selection
- Label distribution
  - Requirements
  - Protocol
  - LDP messages
  - LDP message format
- Traffic engineering
  - Elements of MPLS traffic engineering
  - Constrained shortest-path first algorithm
  - RSVP-TE
- VPNs
  - Layer 2 VPN
  - Layer 3 VPN