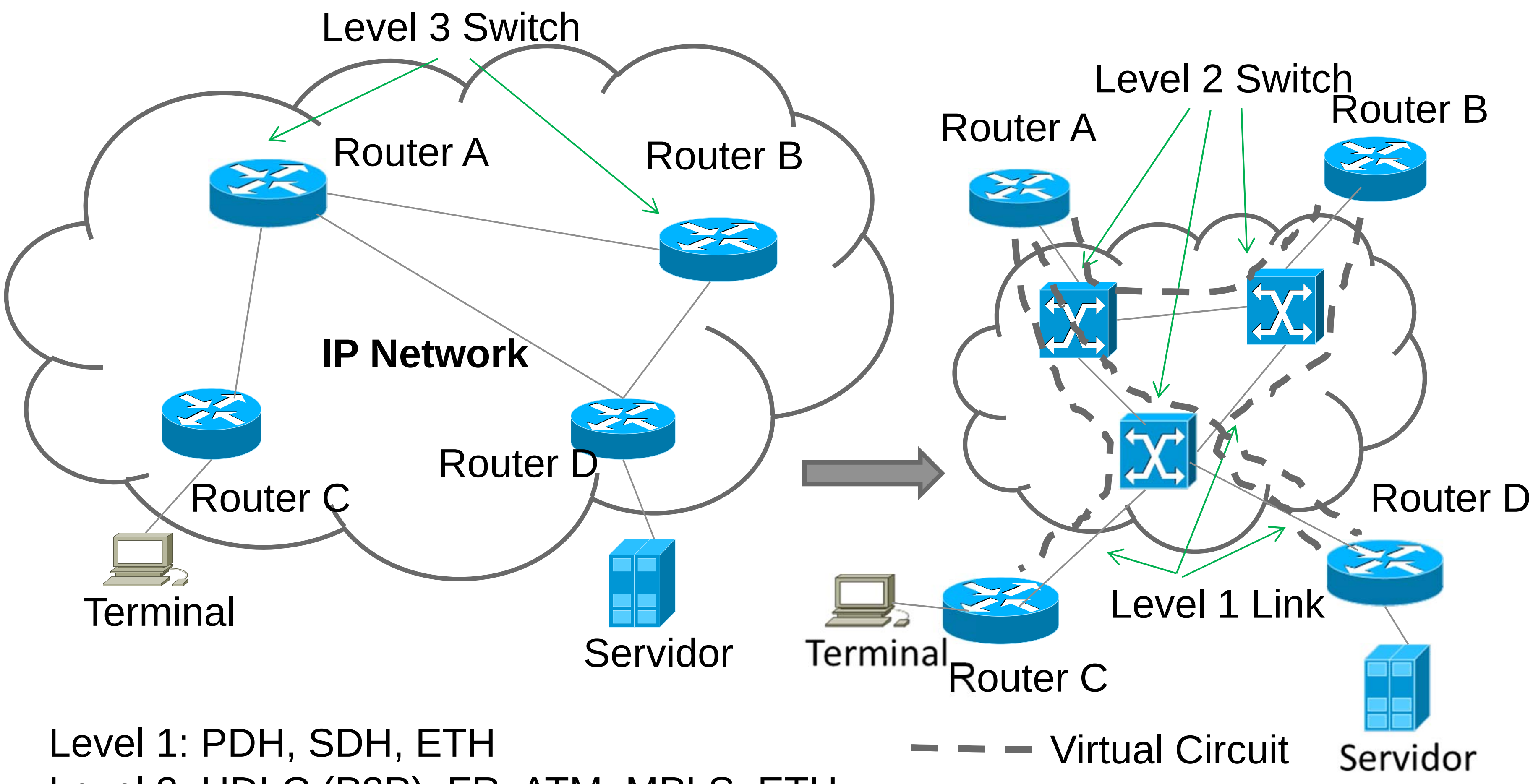
Departament d'Arquitectura de Computadors

Capítol 3. Xarxes troncals

Core (IP) network

Level 3:Datagram
Level 2:Virtual Circuit



Level 1: PDH, SDH, ETH
Level 2: HDLC (P2P), FR, ATM, MPLS, ETH
Level 3: IP

3.1 Commutació de trames
Frame Relay

Source Book: Data and Computer Communication Ed 8. W. Stallings Cap. 10.7

Frame Relay

- Developed to take advantage of high data rates and low error rates
- Operates at data rates of up to 2 Mbps
- Key to achieving high data rates is to strip out most of the overhead involved with error control

Frame relay: LAPF Core

Senyalador	Adreça	Informació	FCS	Senyalador
------1------ byte	-------2-4------	-----------------Variable-----------------	--------2--------	-----1-----

(a) Format de trama

8	7	6	5	4	3	2	1
DLCI superior						C/R	EA 0
DLCI inferior				FECN	BECN	DE	EA 1

(b) Camp d'adreça: 2 bytes (per defecte)

8	7	6	5	4	3	2	1
DLCI superior						C/R	EA 0
DLCI				FECN	BECN	DE	EA 0
DLCI							EA 0
Control DLCI inferior o DL-CORE						D/C	EA 1

(d) Camp d'adreça: 4 bytes

8	7	6	5	4	3	2	1
DLCI superior						C/R	EA 0
DLCI				FECN	BECN	DE	EA 0
Control DLCI interior o DL-CORE						D/C	EA 1

(c) Camp d'adreça: 3 bytes

EA	Bit d'extensió de camp d'adreça
C/R	Bit d'ordre/resposta
FECN	Notificació de congestió explícita cap endavant
BECN	Notificació de congestió explícita cap enrere
DLCI	Identificador de connexió d'enllaç de dades
D/C	Indicador de control DLCI o DL-CORE
DE	Idoneïtat del descart

3.2 Commutació de cel·les ATM

Source: Data and Computer Communication Ed 8. W. Stallings Cap. 11
Data and Computer Communication Ed 10. W. Stallings Cap. 9.6

Asynchronous Transfer Mode (ATM)

- A switching and multiplexing technology that employs small, fixed-length packets called cells
- A fixed-size packet ensures function could be carried out efficiently, with little delay variation
- Small cell size supports delay-intolerant interactive voice service with a small packetization delay
- Designed to provide the performance of a circuit-switching network and the flexibility and efficiency of a packet-switching network
- Standardization effort was to provide a powerful set of tools for supporting a rich QoS capability and a powerful traffic management capability

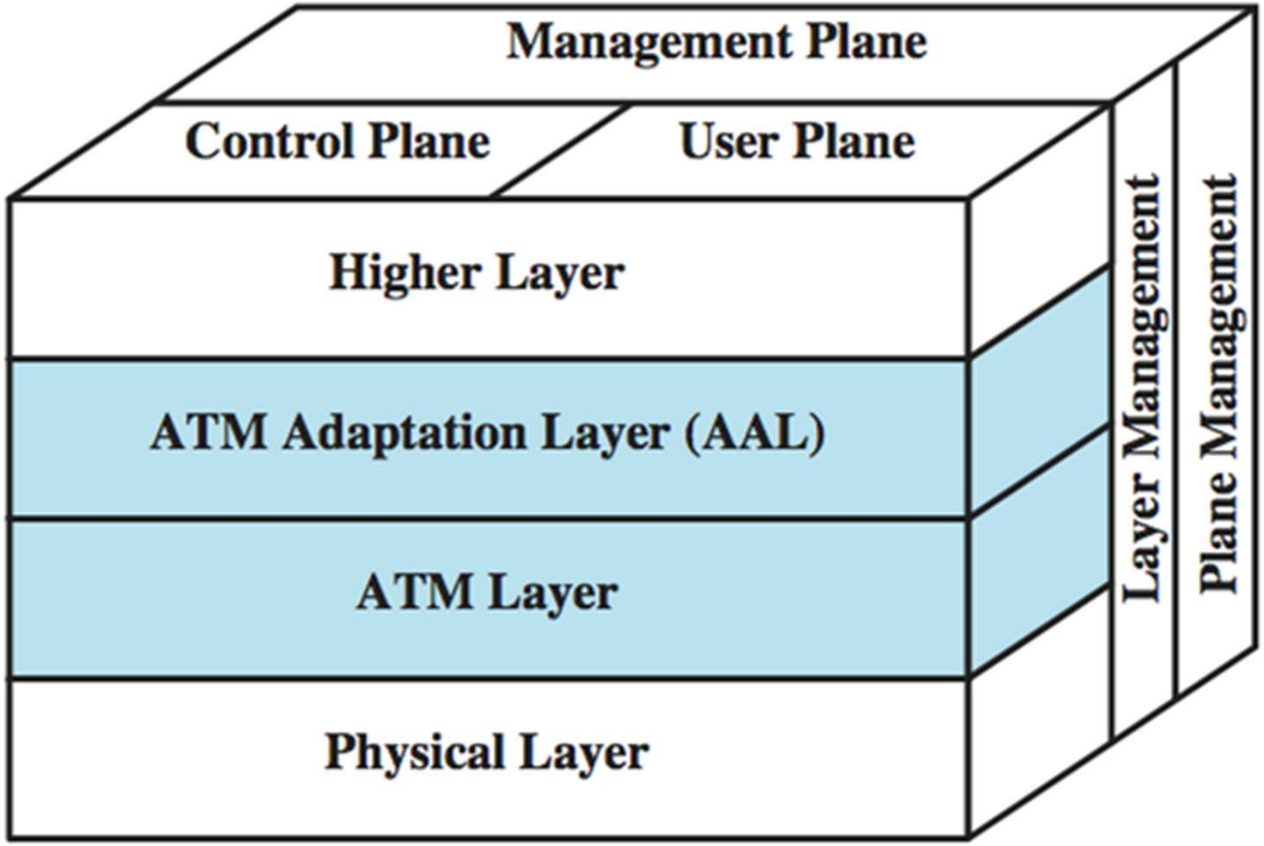
ATM

- Commonly used by telecommunications providers to implement wide area networks
- Used by many DSL implementations
- Used as a backbone network technology in numerous IP networks
- Multiprotocol Label Switching (MPLS) has reduced the role for ATM

Virtual Channel Connection (VCC)

- Logical connection in ATM
- Analogous to a virtual circuit
- Basic unit of switching in an ATM network
- Set up between two end users through the network, and a variable-rate, full duplex flow of fixed-size cells is exchanged over the connection
- Also used for user-network exchange and network-network exchange

Protocol Architecture



Delay in ATM networks

- End to end delay R = Rp + Rt
- Rp (packet delay) = *48x8* / V_{ts}
- Rt (transfer delay) = Tt + Tp + W
  - *Tt (transmission time)* Σt_t $(t_t = 53x8 / V_{tn})$
  - *Tp (propagation time)* Σt_p $(t_p = d / V_p)$
  - *W (queue waiting time)* Σw $(w = nxt_t)$

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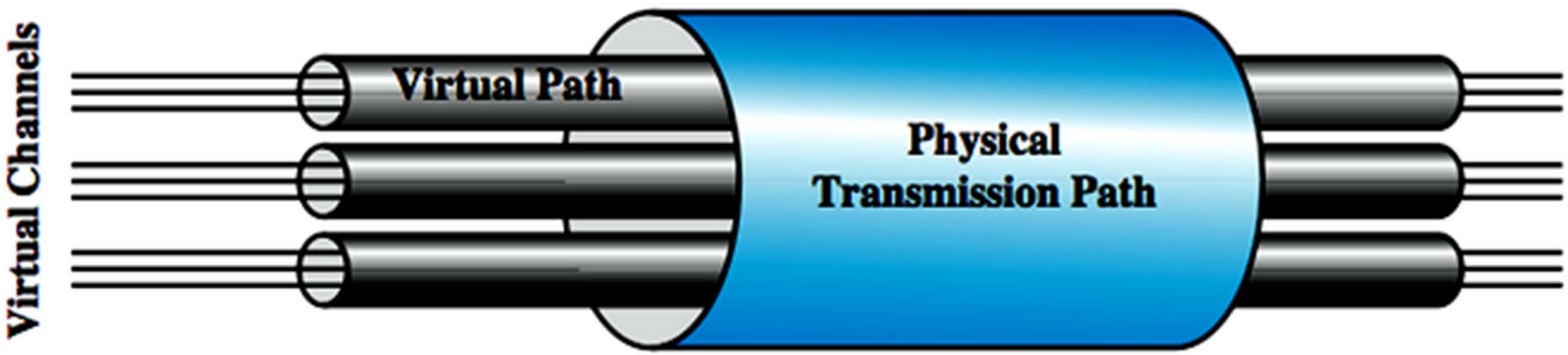
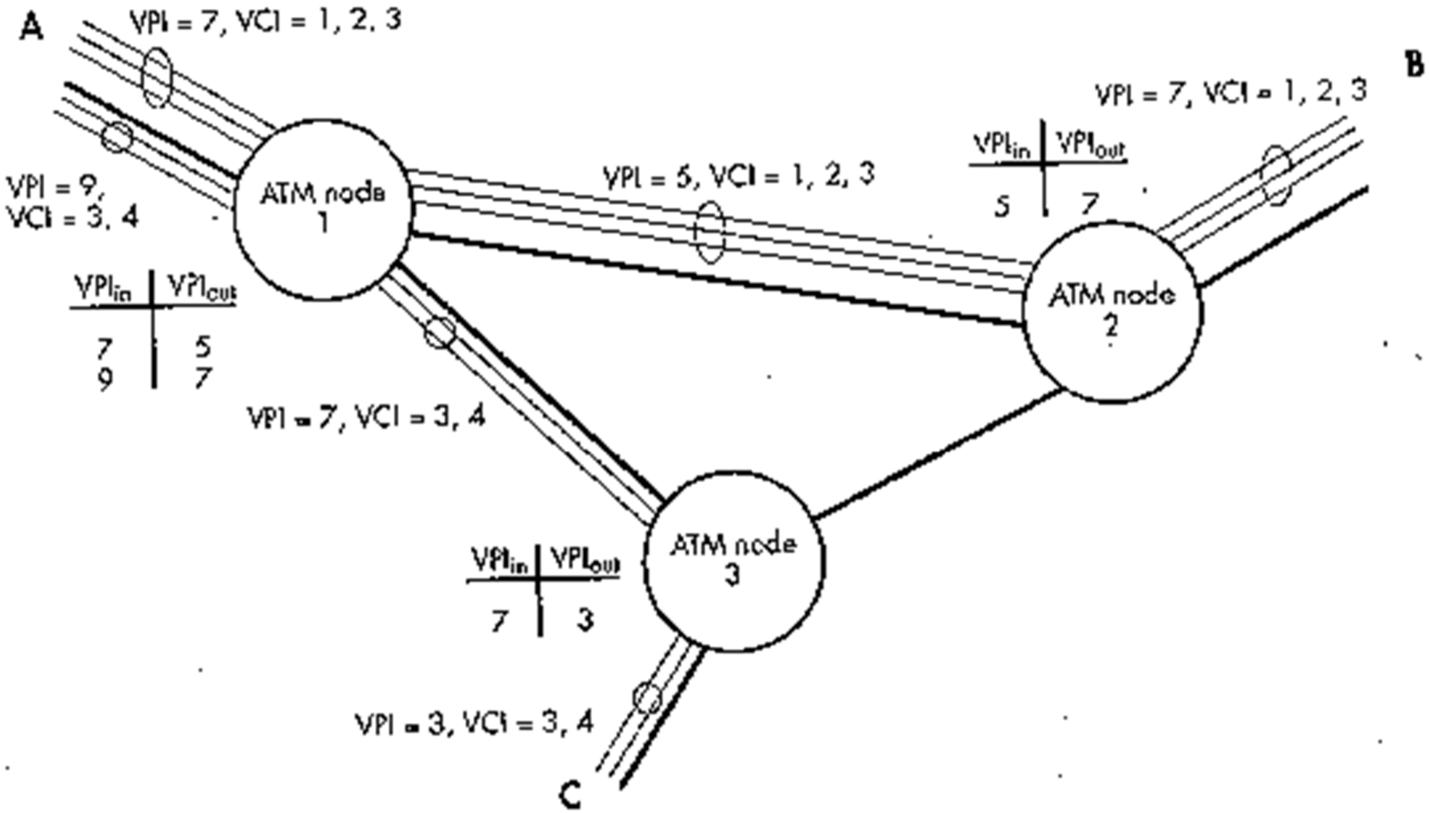
ATM Virtual Path Connection

- virtual path connection (VPC)
  - bundle of VCC with same end points



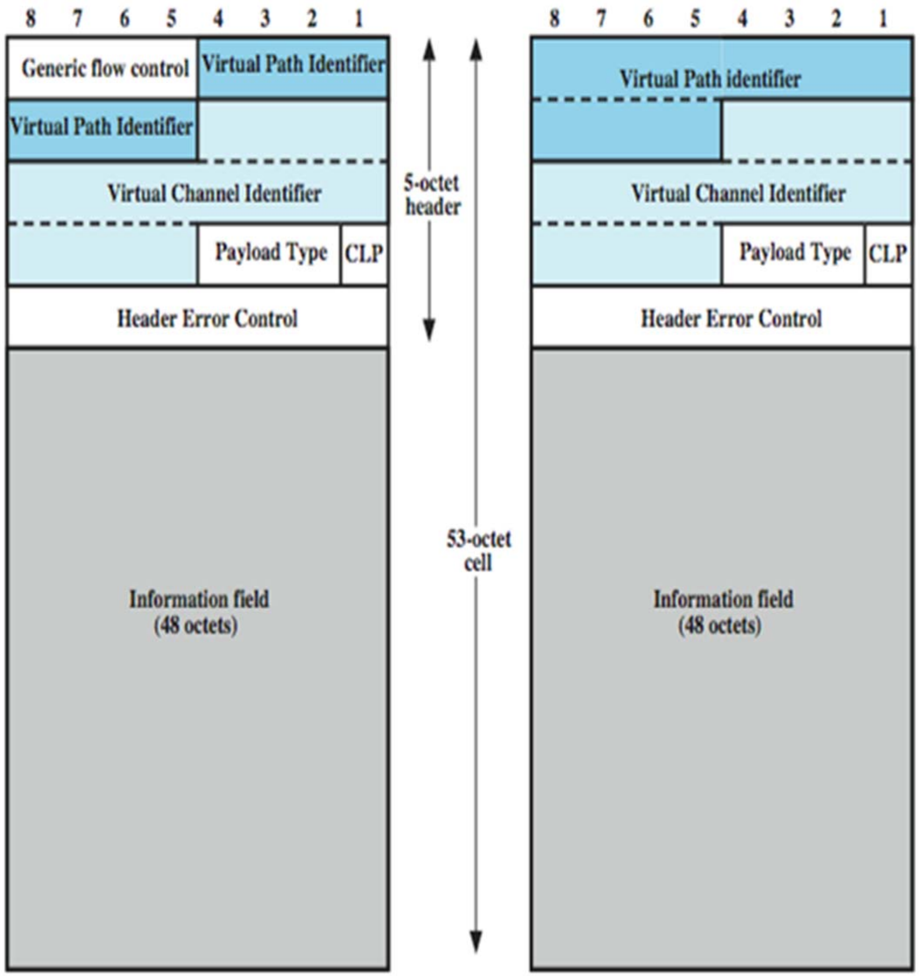
Virtual Channel and Virtual Path

- VPI and VCI relation



VPI Use in an ATM Network

ATM Cells



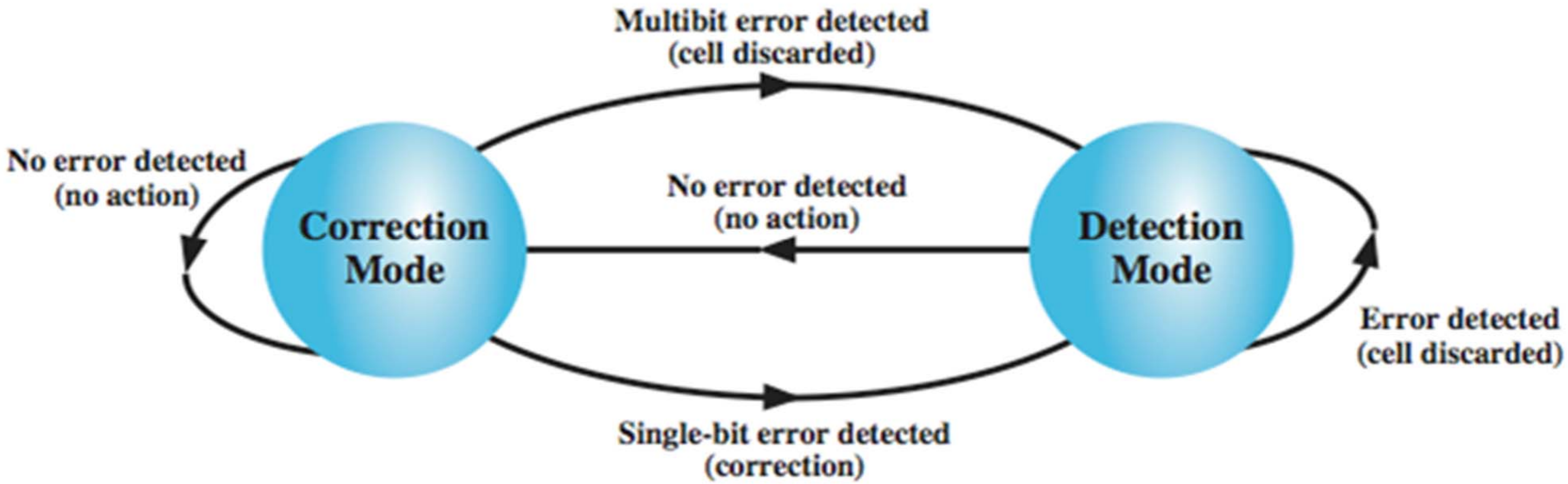
(a) User-network interface (b) Network-network interface

ATM Cells Format

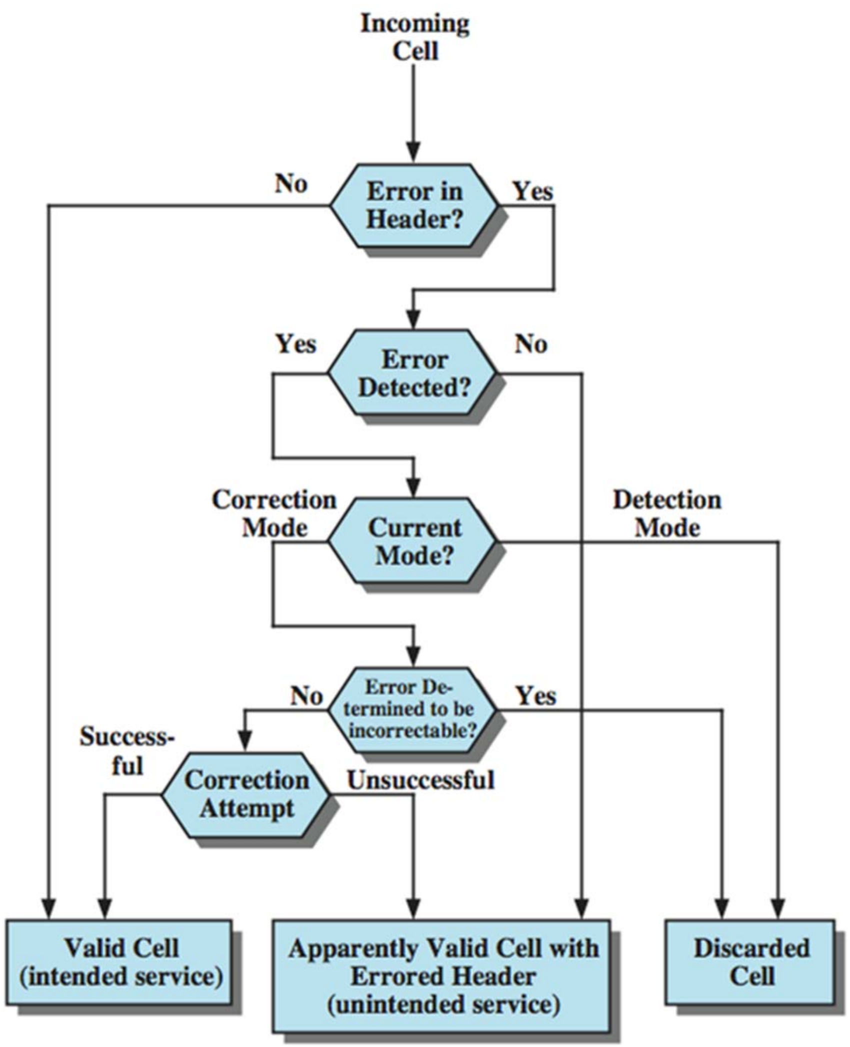
- Payload Type indicator

Payload type	Meaning
000	User data cell, no congestion, cell type 0
001	User data cell, no congestion, cell type 1
010	User data cell, congestion experienced, cell type 0
011	User data cell, congestion experienced, cell type 1
100	Maintenance information between adjacent switches
101	Maintenance information between source and destination switches
110	Resource Management cell (used for ABR congestion control)
111	Reserved for future function

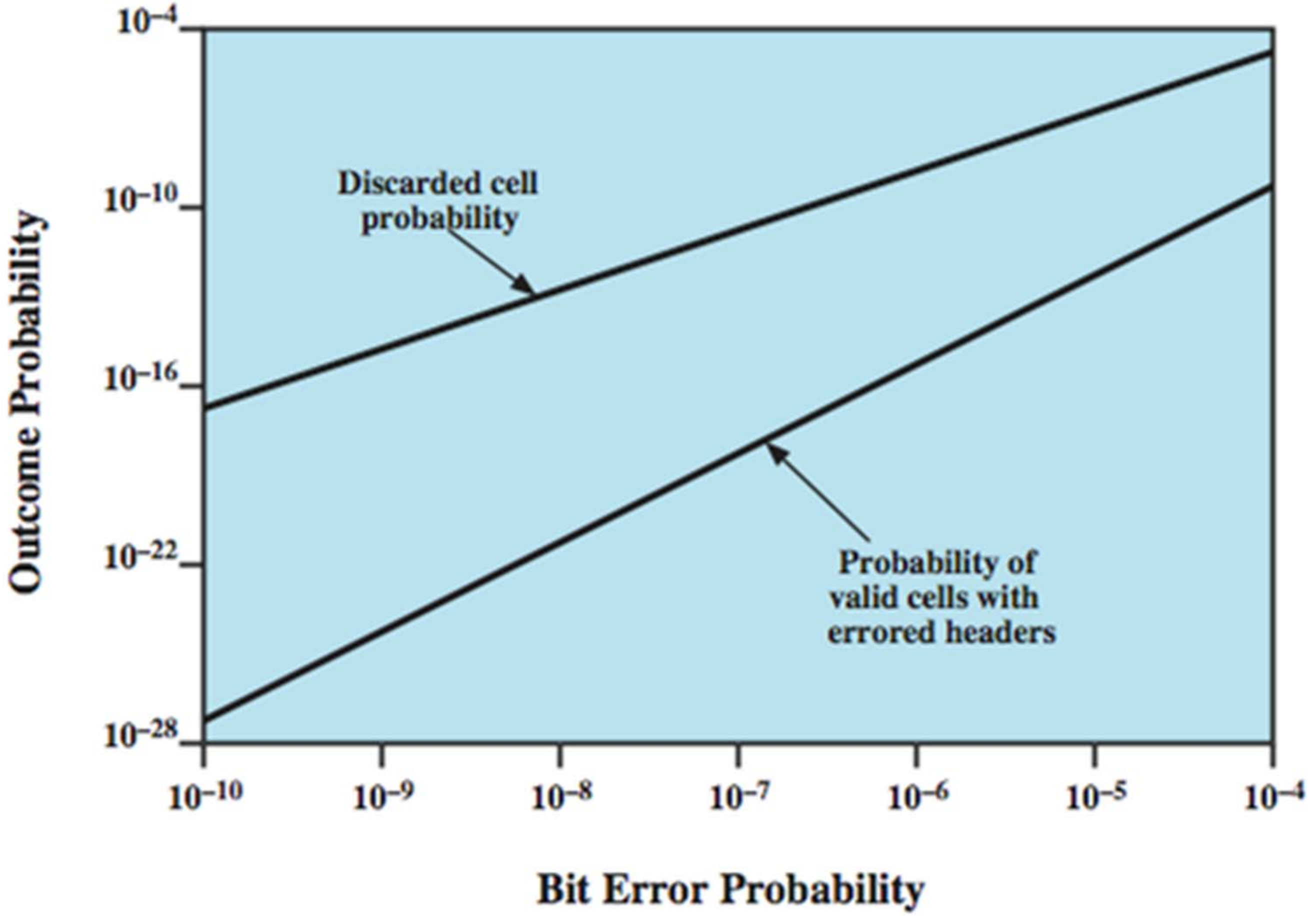
Header Error Control



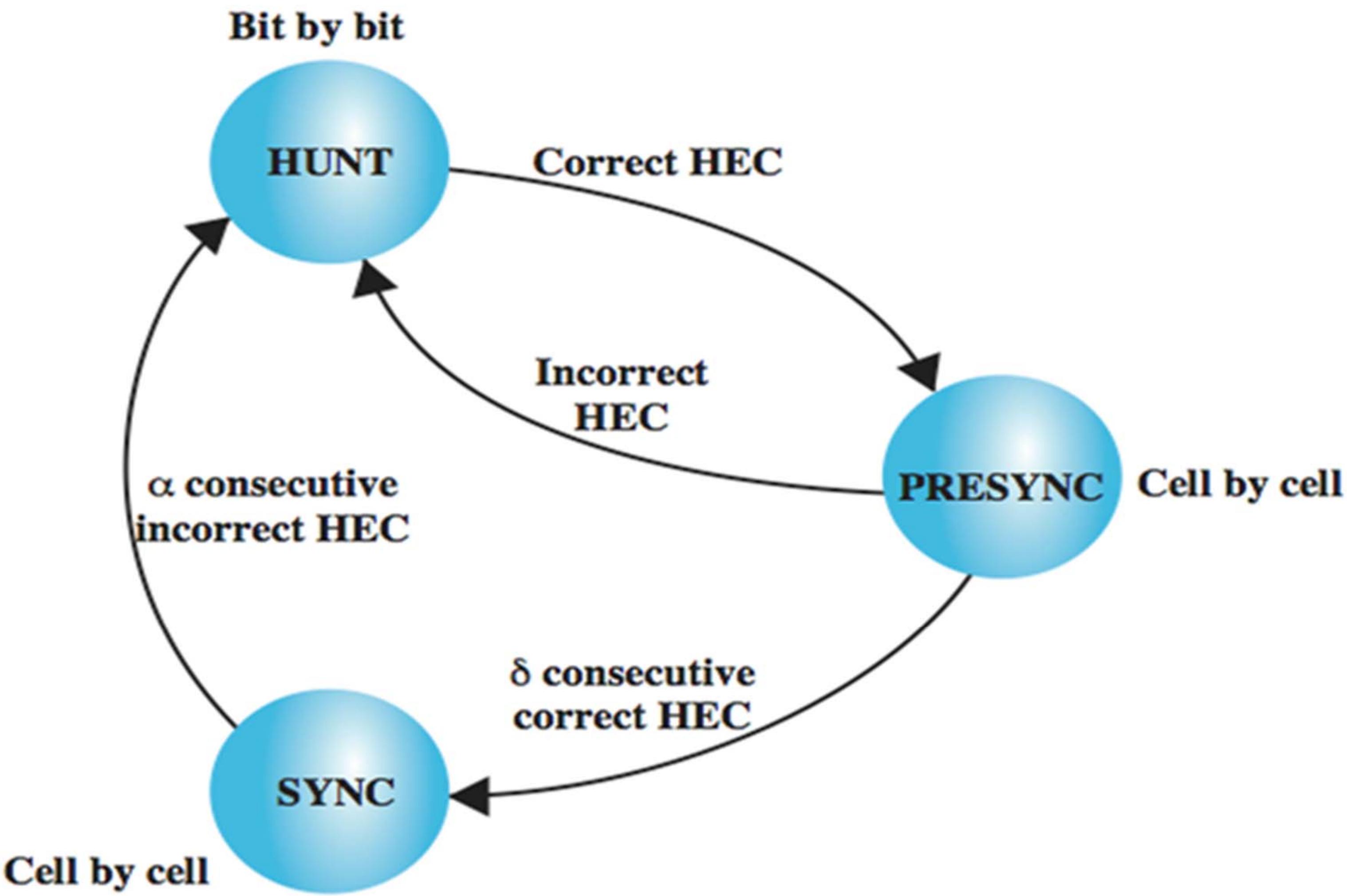
Effect of Error Cell Header



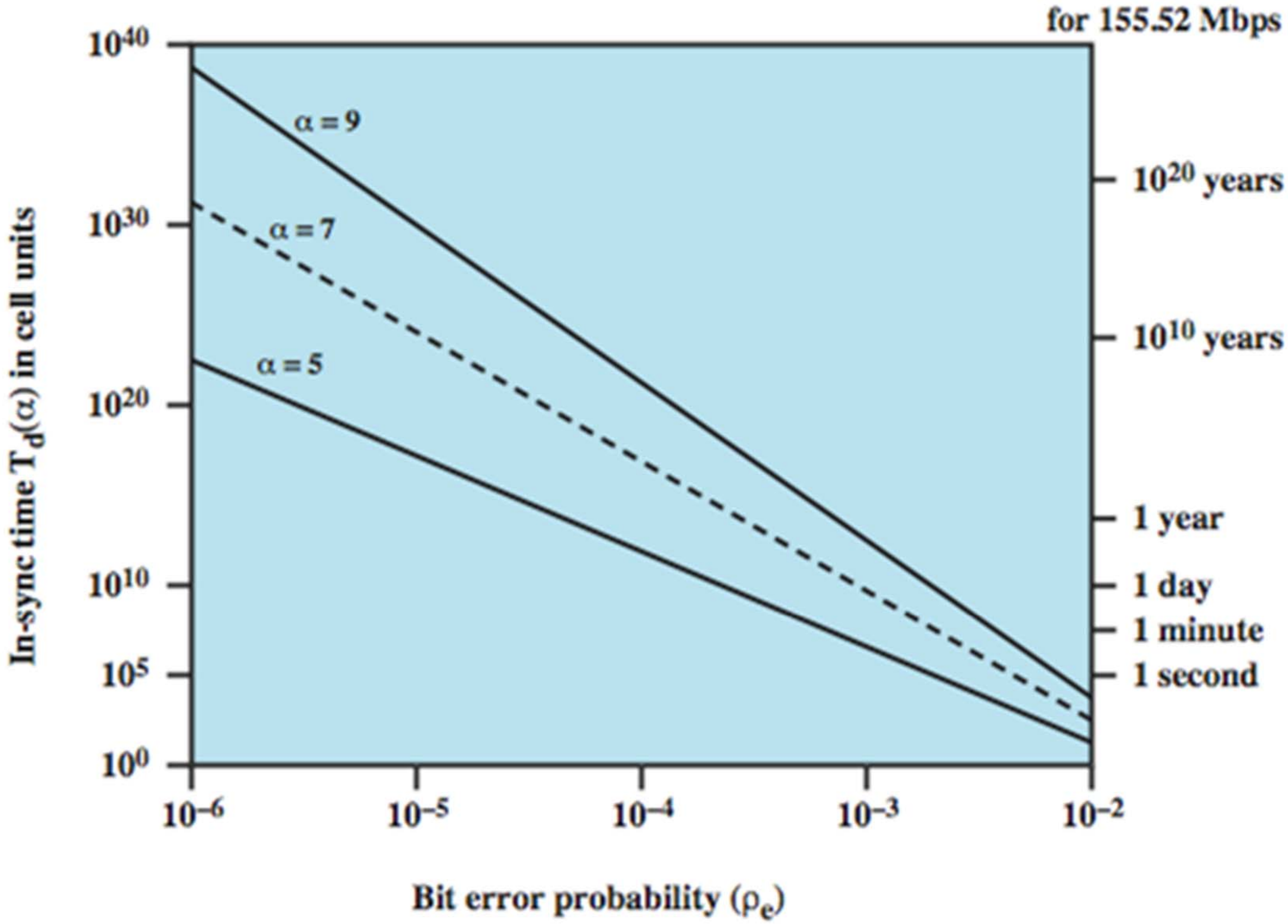
Impact of Random Bit Errors on HEC Performance



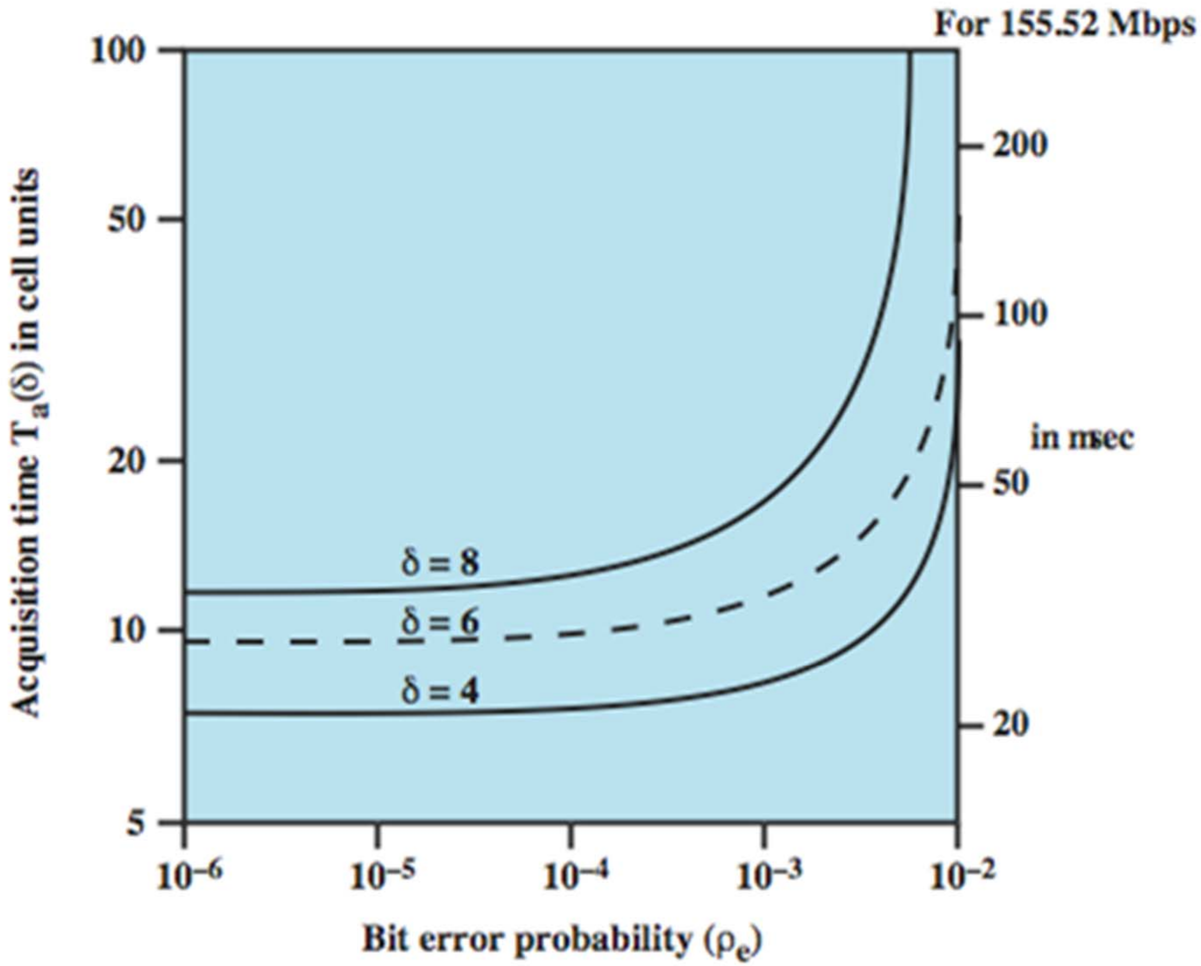
Cell Delineation State Diagram



Impact of Random Bit Errors on Cell Delineation Performance



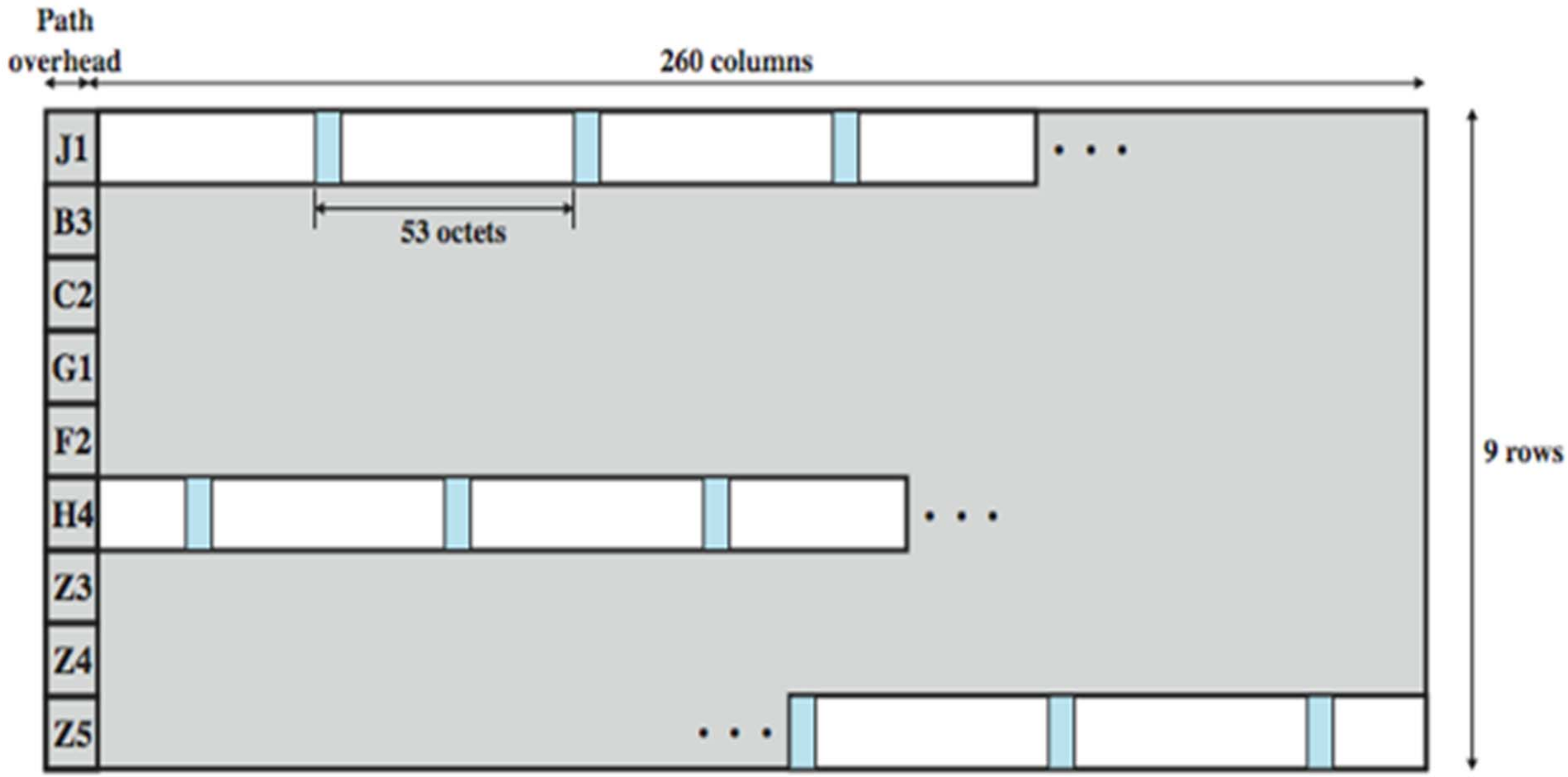
Acquisition Time vs. Bit Error Rate



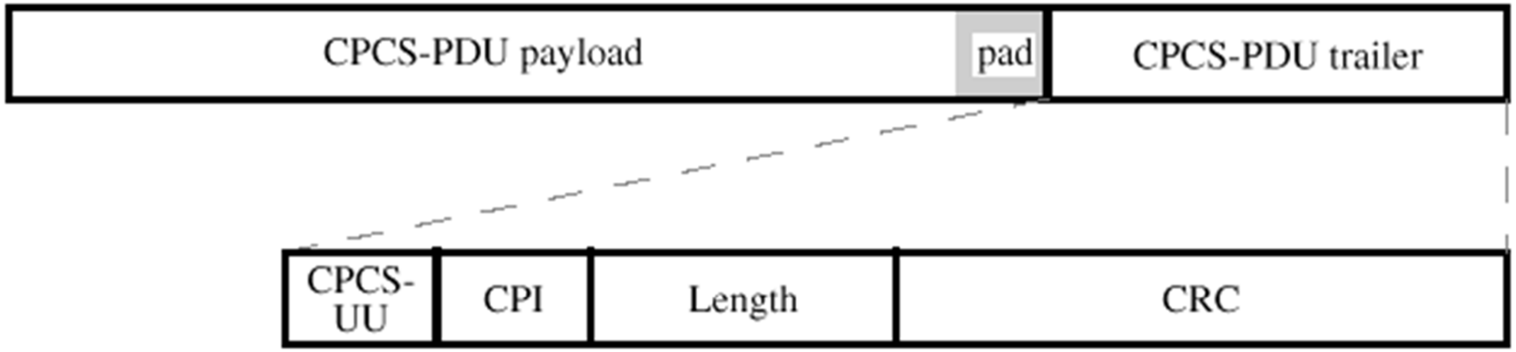
SDH Based Physical Layer

- imposes structure on ATM stream
  - eg. for 155.52Mbps
  - use STM-1 (STS-3) frame
- can carry ATM and STM payloads
- specific connections can be circuit switched using SDH channel
- SDH multiplexing techniques can combine several ATM streams

STM-1 Payload for SDH-Based ATM Cell Transmission

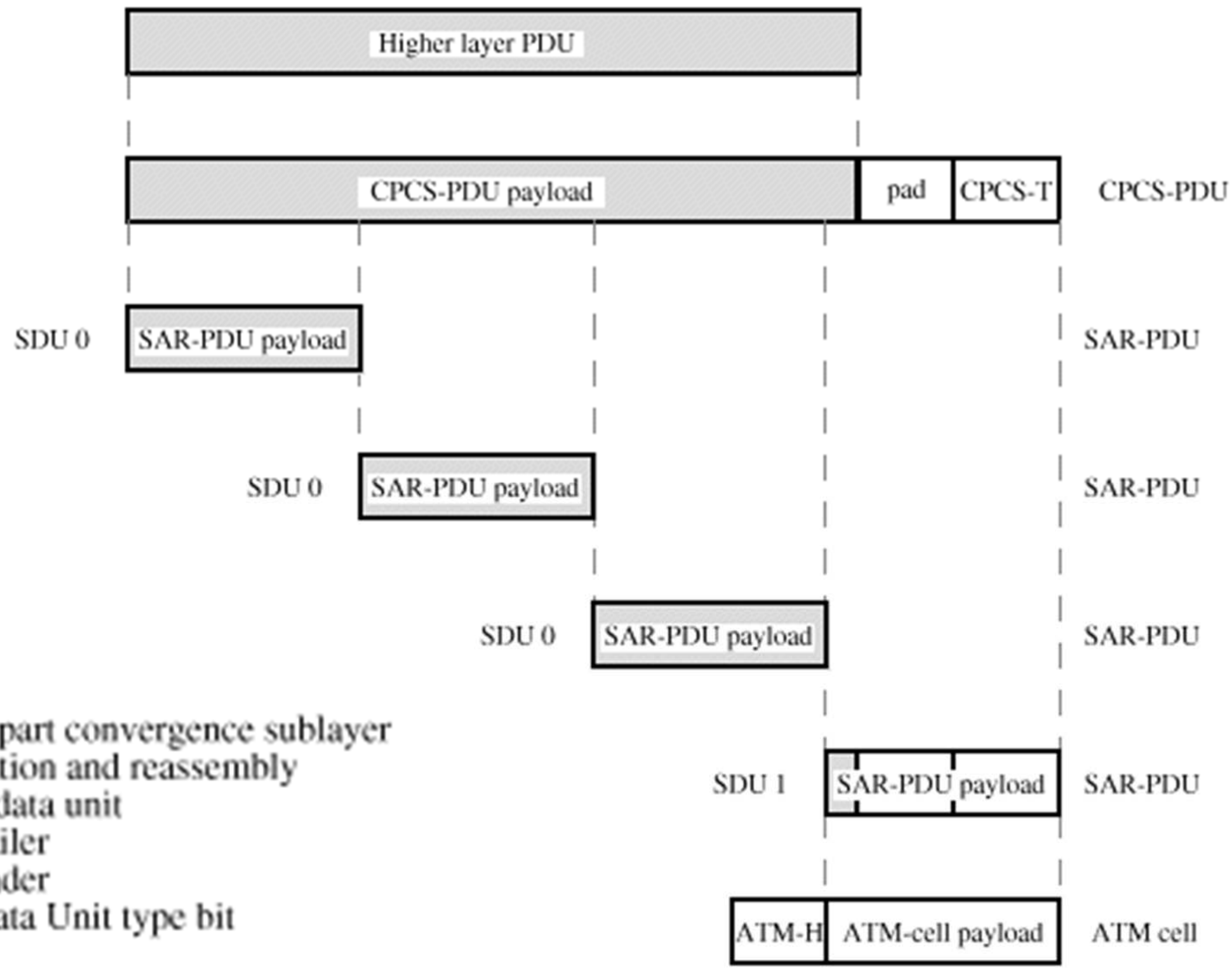


AAL5 CPCS-PDU



CPCS-UU	=	CPCS user-to-user indication (1 octet)
CPI	=	common part indicator (1 octet)
Length	=	length of CPCS-PDU payload (2 octets)
CRC	=	cyclic redundancy check (4 octets)

AAL5 transmission



CPCS = common part convergence sublayer
SAR = segmentation and reassembly
PDU = protocol data unit
CPCS-T = CPCS trailer
ATM-H = ATM header
SDU = Service Data Unit type bit

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ATM Service Categories

Real time - limit amount/variation of delay

- Constant bit rate (CBR)
- Real time variable bit rate (rt-VBR)

Non-real time - for bursty traffic

- Non-real time variable bit rate (nrt-VBR)
- Available bit rate (ABR)
- Unspecified bit rate (UBR)
- Guaranteed frame rate (GFR)

3.3 Commutació d'etiquetes MPLS

Source book: Data and Computer Communication Ed 10. W. Stallings Cap. 23

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

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

Key MPLS Terms

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.

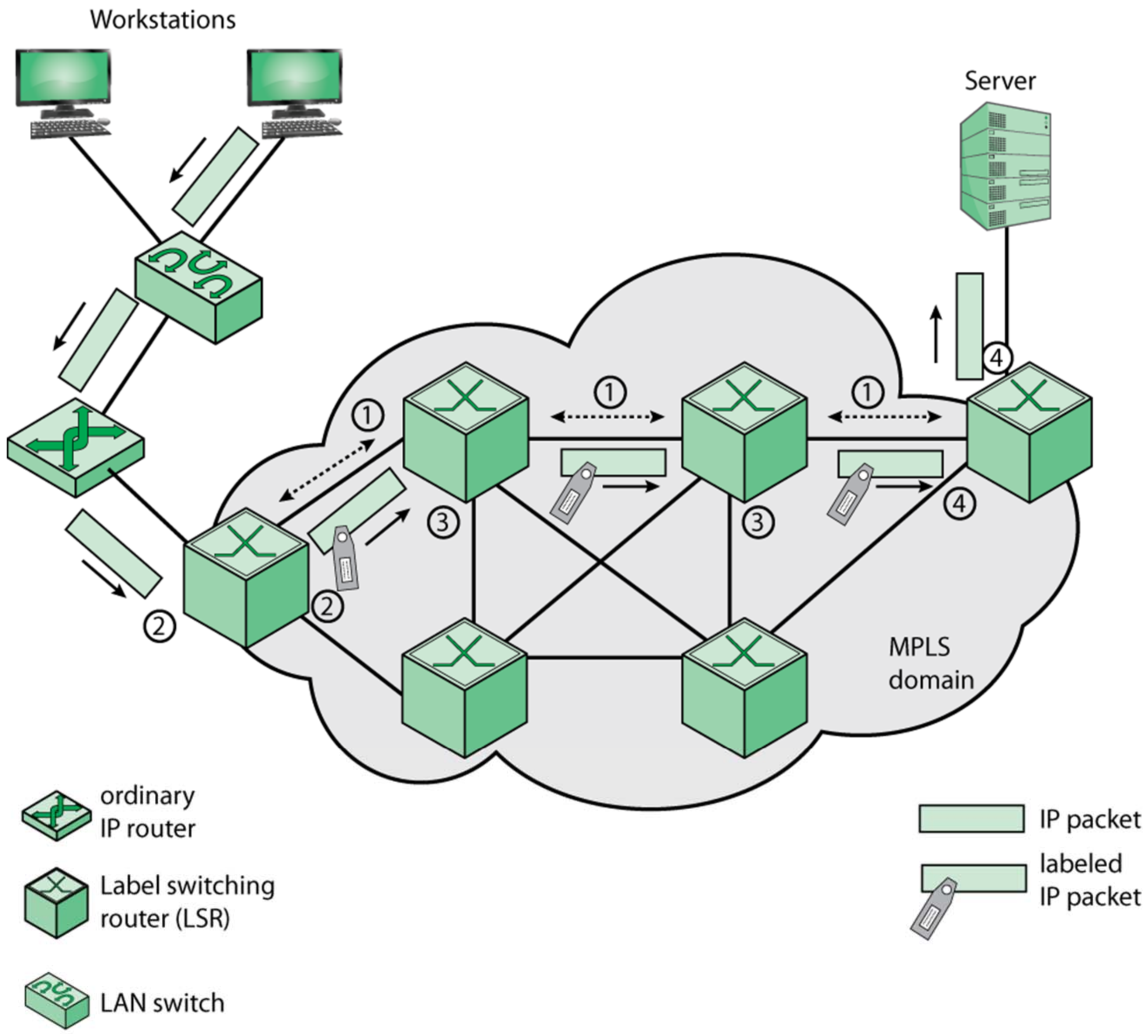
MPLS label A short, fixed-length physically contiguous identifier that is used to identify a FEC, usually of local significance. A label is carried in a packet header.

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.

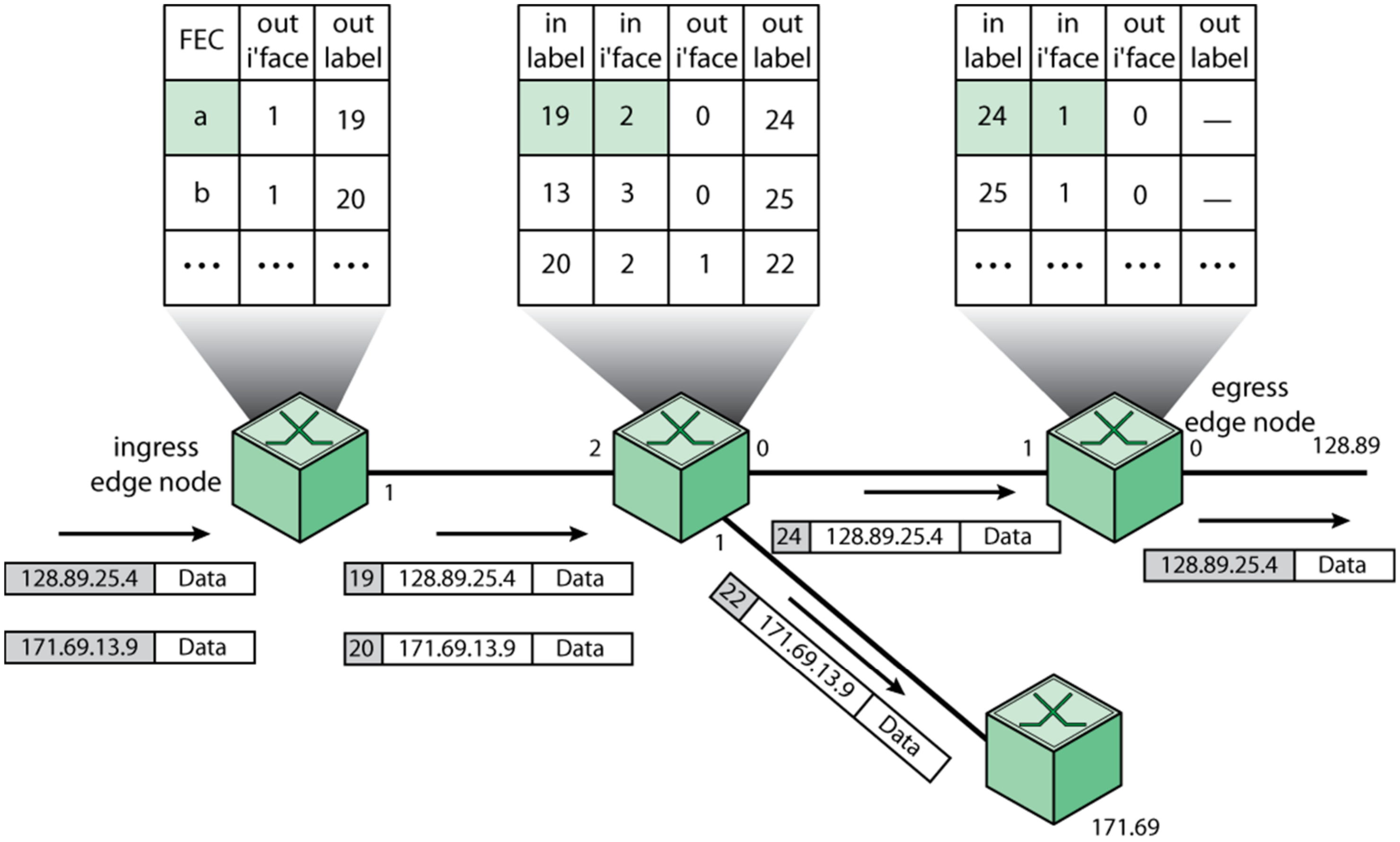
MPLS Operation

- 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

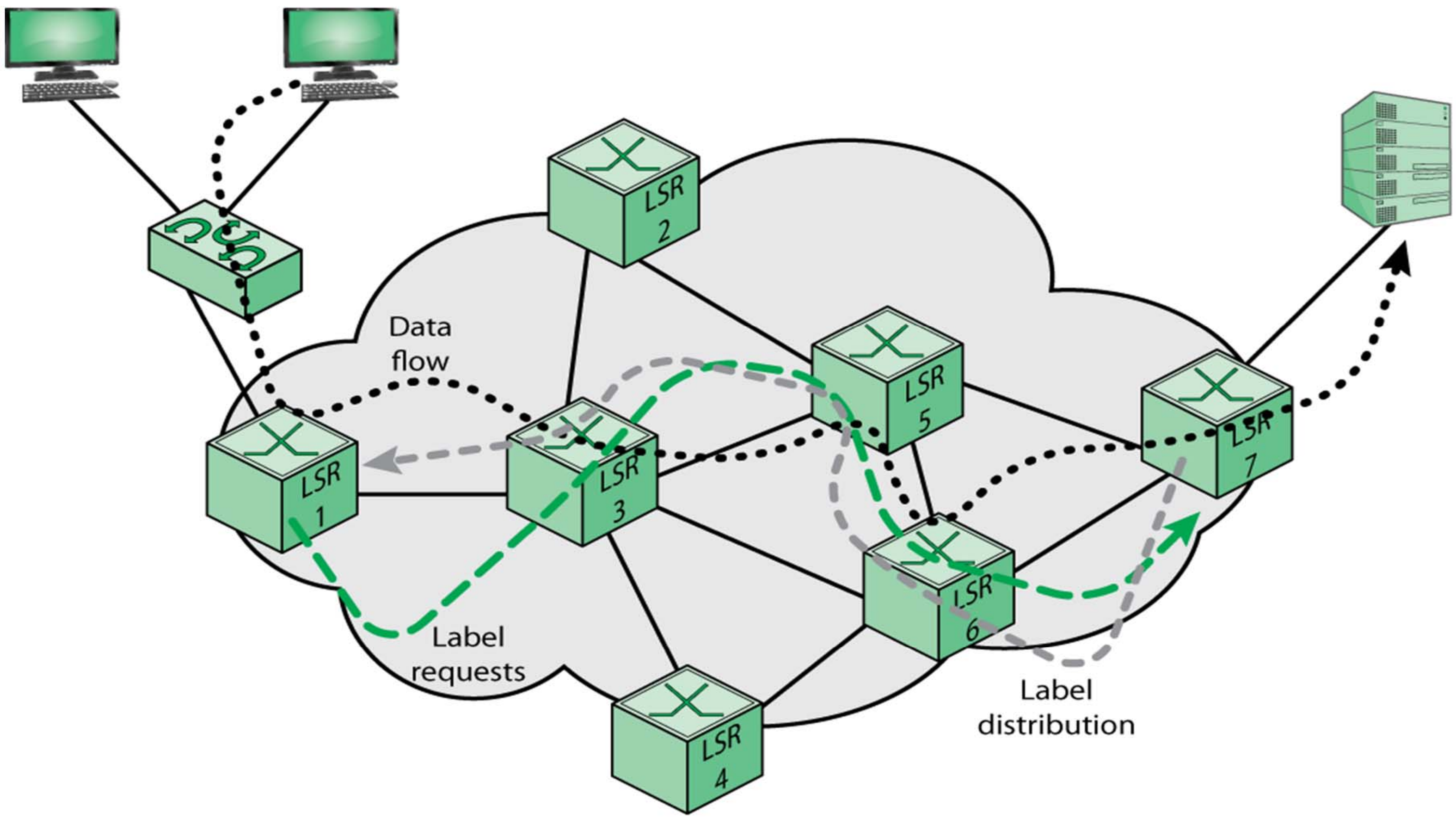
MPLS Operation



MPLS Packet Forwarding



LSP Creation and Packet Forwarding



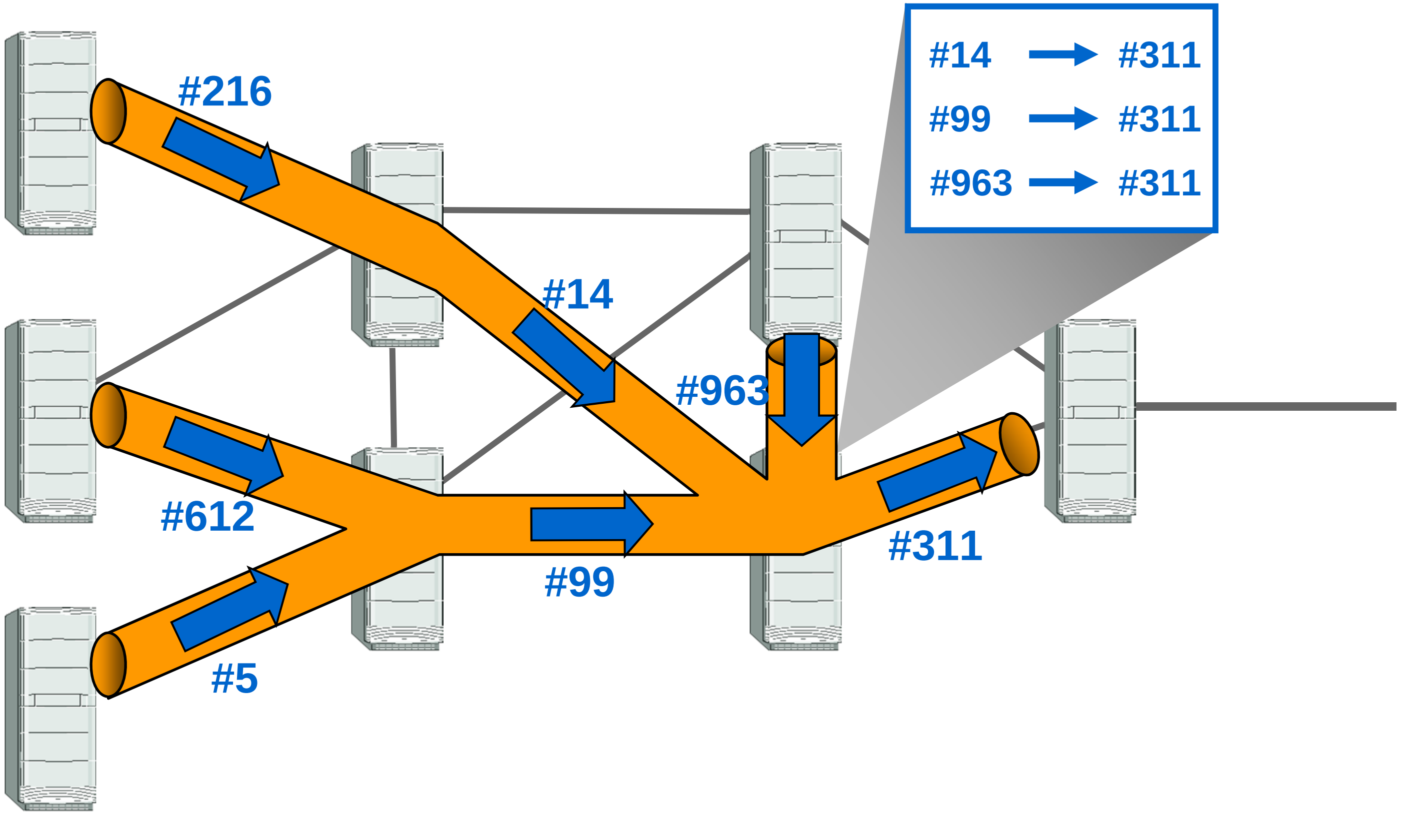
Label Stacking

- 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

Merging LSP



Label Format

- defined in RFC 3032
- 32-bit field consisting of:
  - Label value
  - Traffic class (TC)
  - S
  - Time to live (TTL)

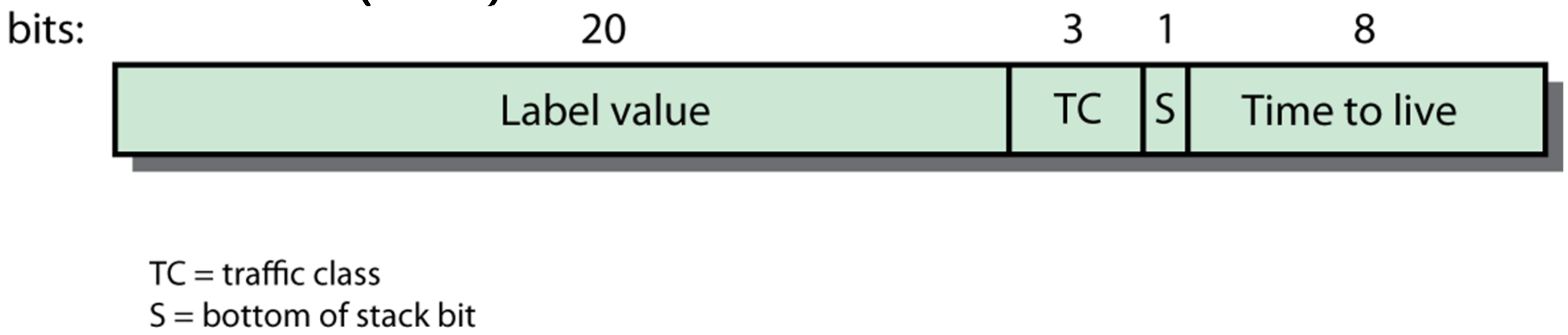


Figure 21.4 MPLS Label Format

Label Placement

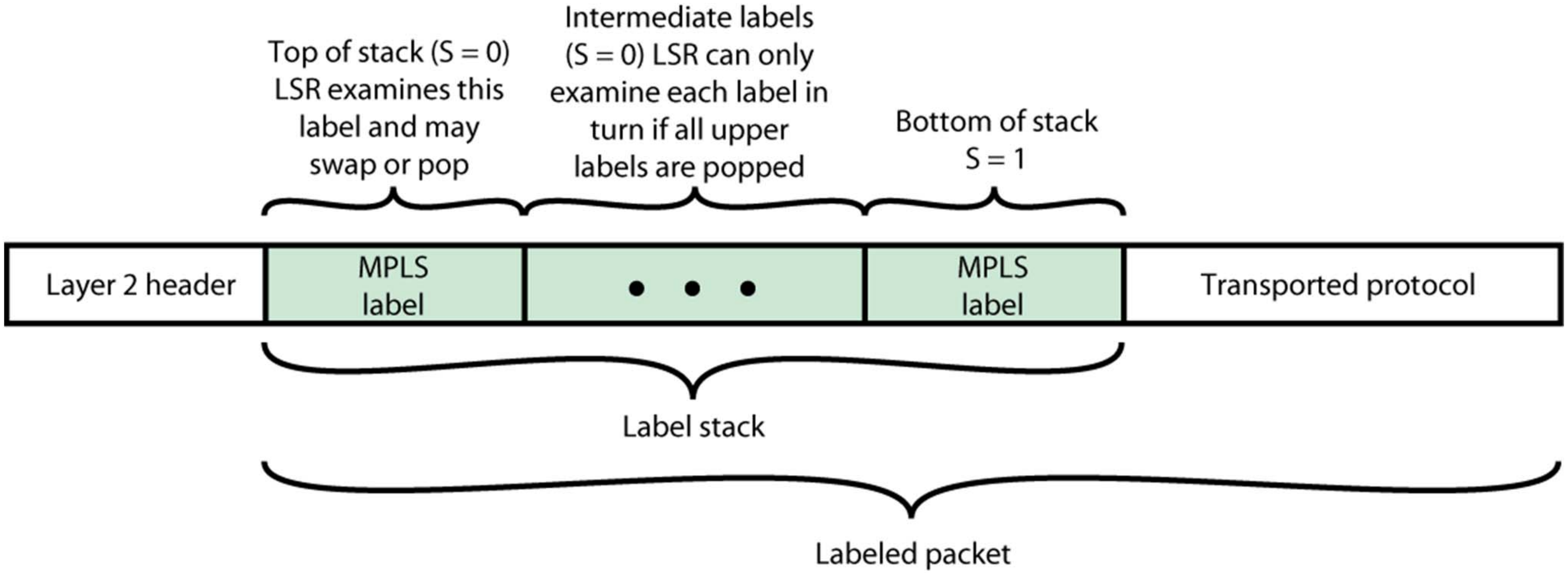
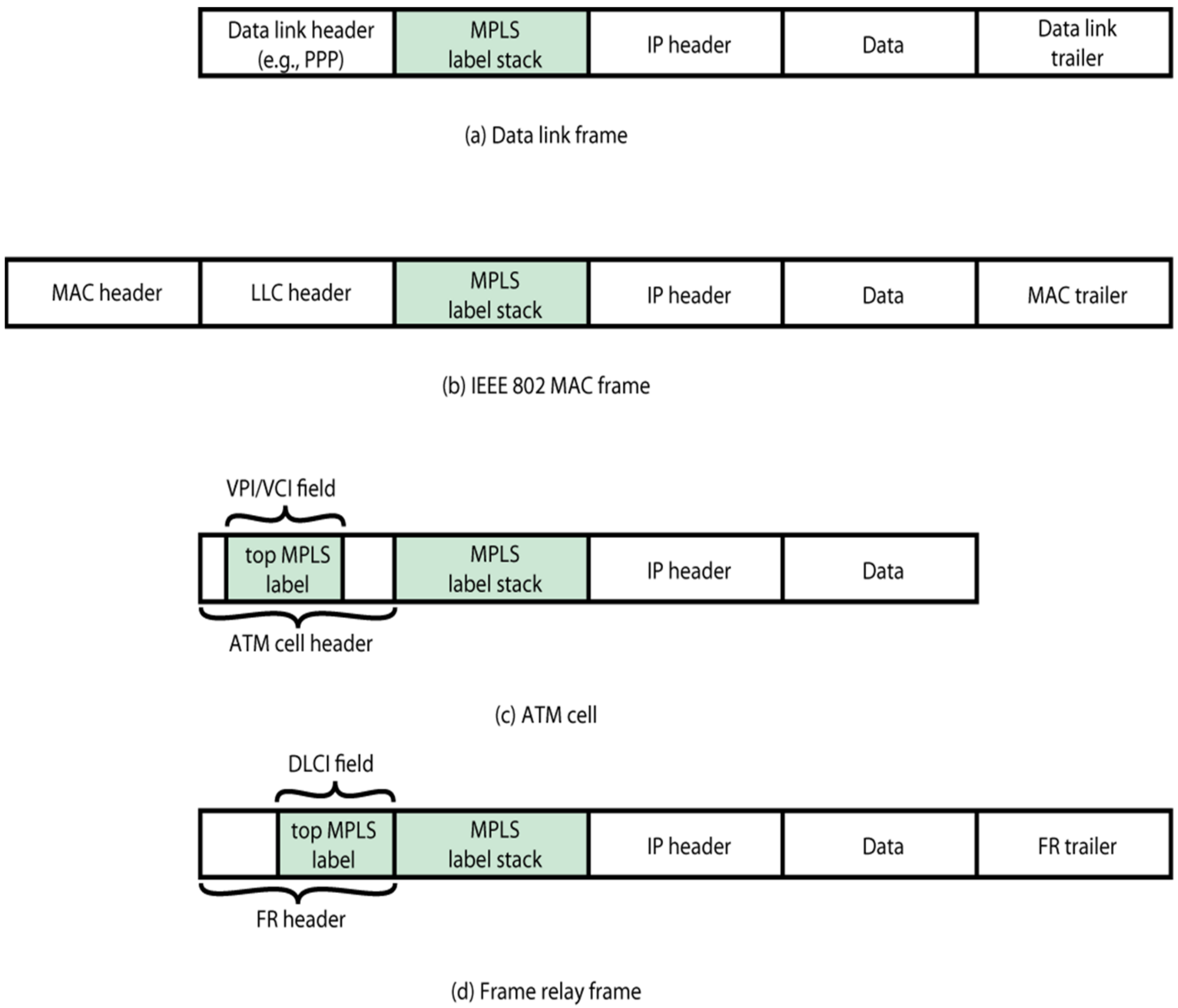


Figure 21.5 Encapsulation for Labeled Packet

Label Stack


Data link header (e.g., PPP)
MPLS label stack
IP header
Data
Data link trailer
(a) Data link frame
MAC header
LLC header
MPLS label stack
IP header
Data
MAC trailer
(b) IEEE 802 MAC frame
VPI/VCI field
top MPLS label
MPLS label stack
IP header
Data
ATM cell header
(c) ATM cell
DLCI field
top MPLS label
MPLS label stack
IP header
Data
FR trailer
FR header
(d) Frame relay frame

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 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)

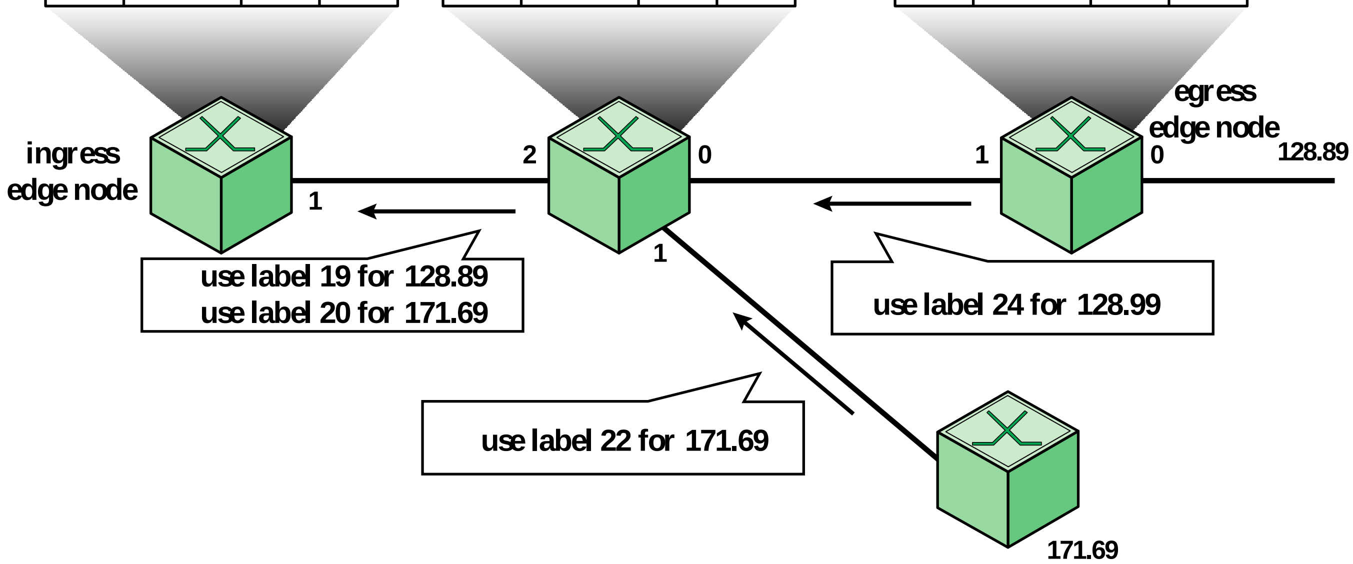
➢ Once a route is established LDP is used to establish the LSP and assign labels

Assigning 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
...	...	...	...

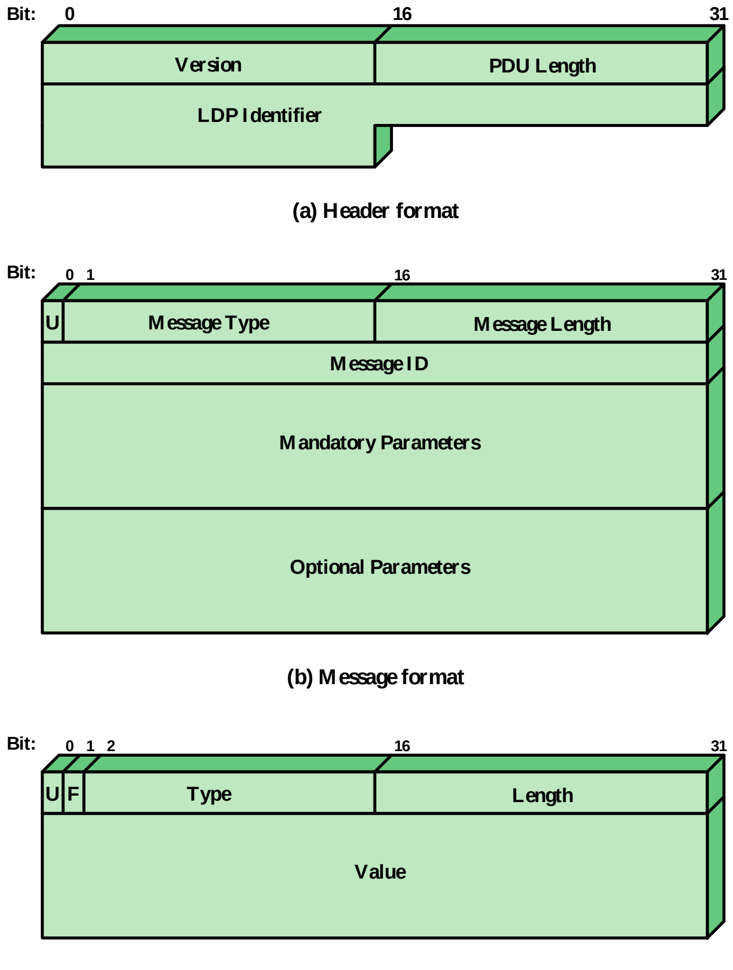
in label	address prefix	out i'face	out label
24	128.89	0	—
...	...	...	...



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

LDP messages format

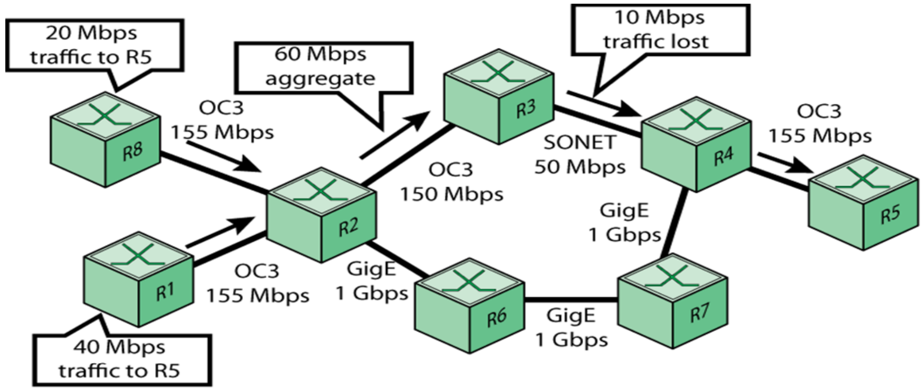


(c) Type-length-value (TLV) parameter encoding

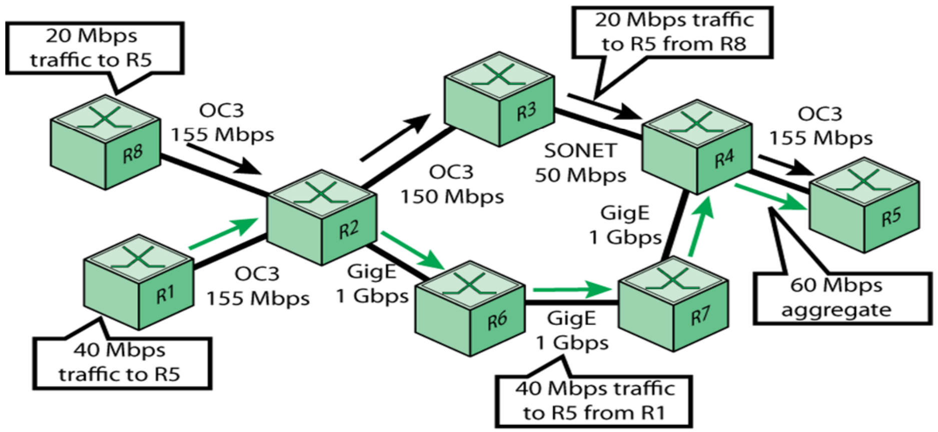
Traffic Engineering

- 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

Example of Traffic Engineering



(a) A shortest-path solution

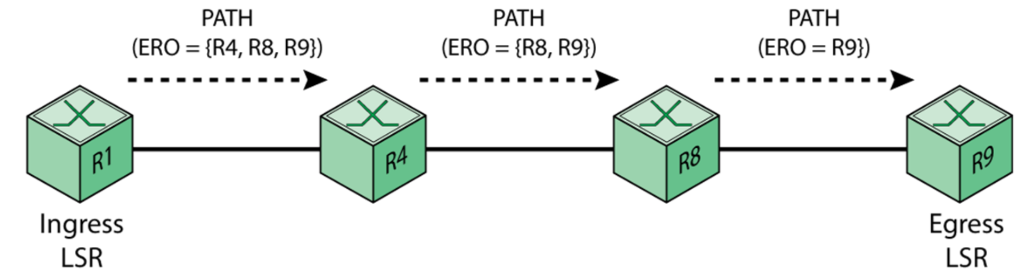


(b) A traffic-engineered solution

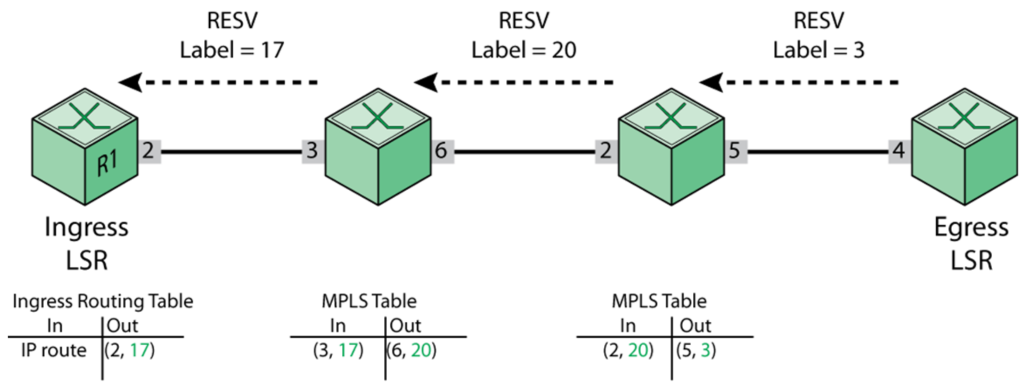
Elements of MPLS Traffic Engineering (MPLS TE)

- 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 Operation



(a) Use of PATH message



(b) Use of RESV message

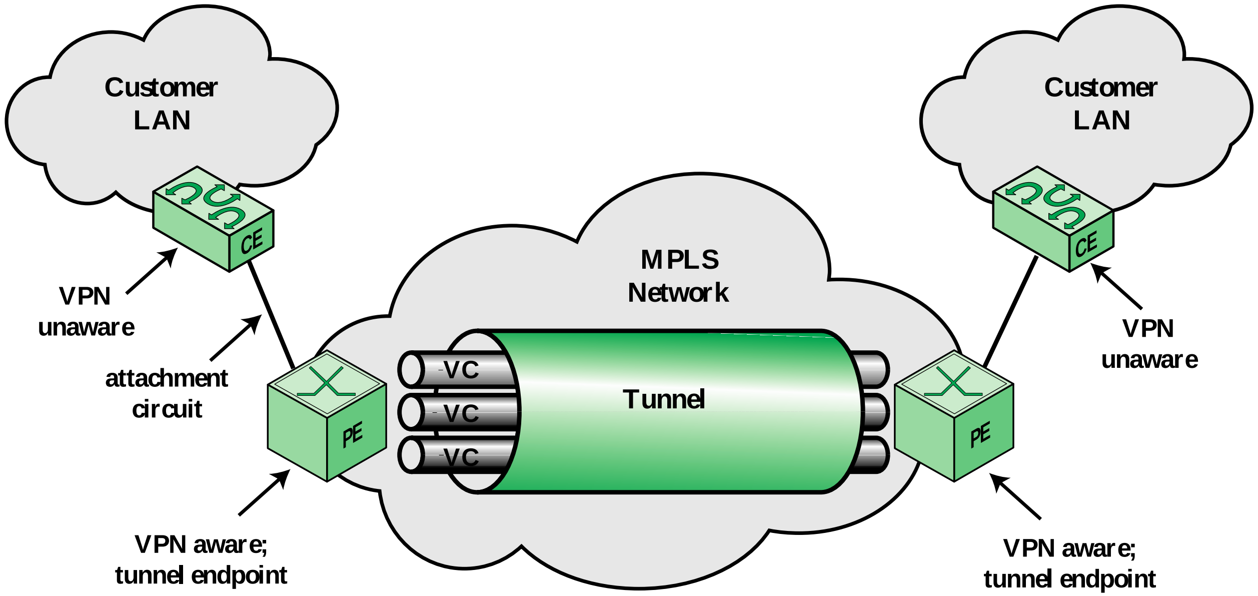
Virtual Private Network (VPN)

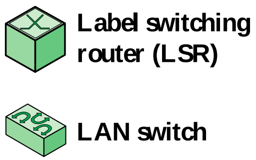
- Private network configured within a public network in order to take advantage of management facilities of larger networks
- Traffic designated as VPN traffic can only go from a VPN source to a destination in the same VPN

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

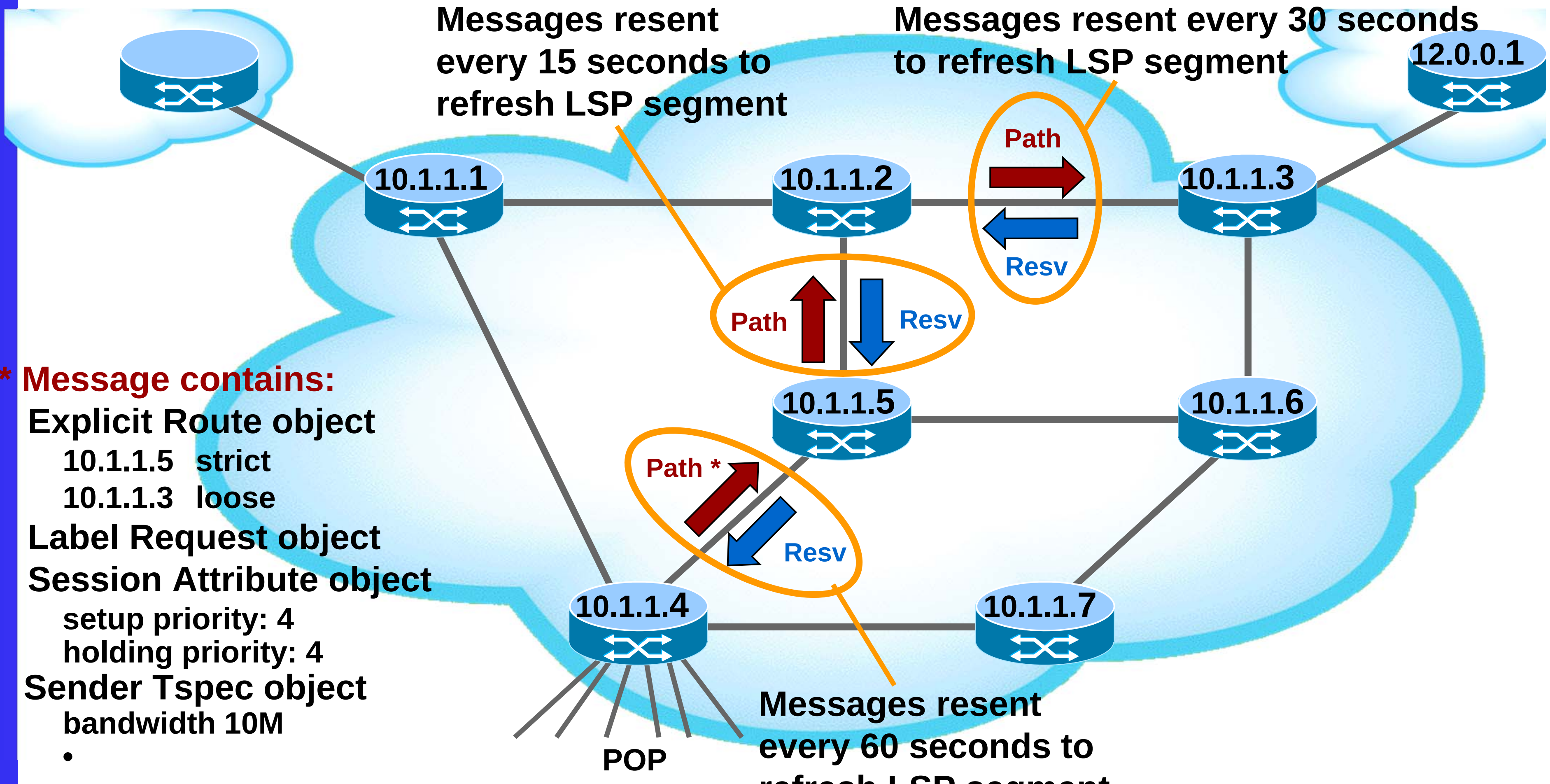
Layer 2 VPN





CE = customer edge
PE = provider edge
VC = virtual channel
VPN = virtual private network

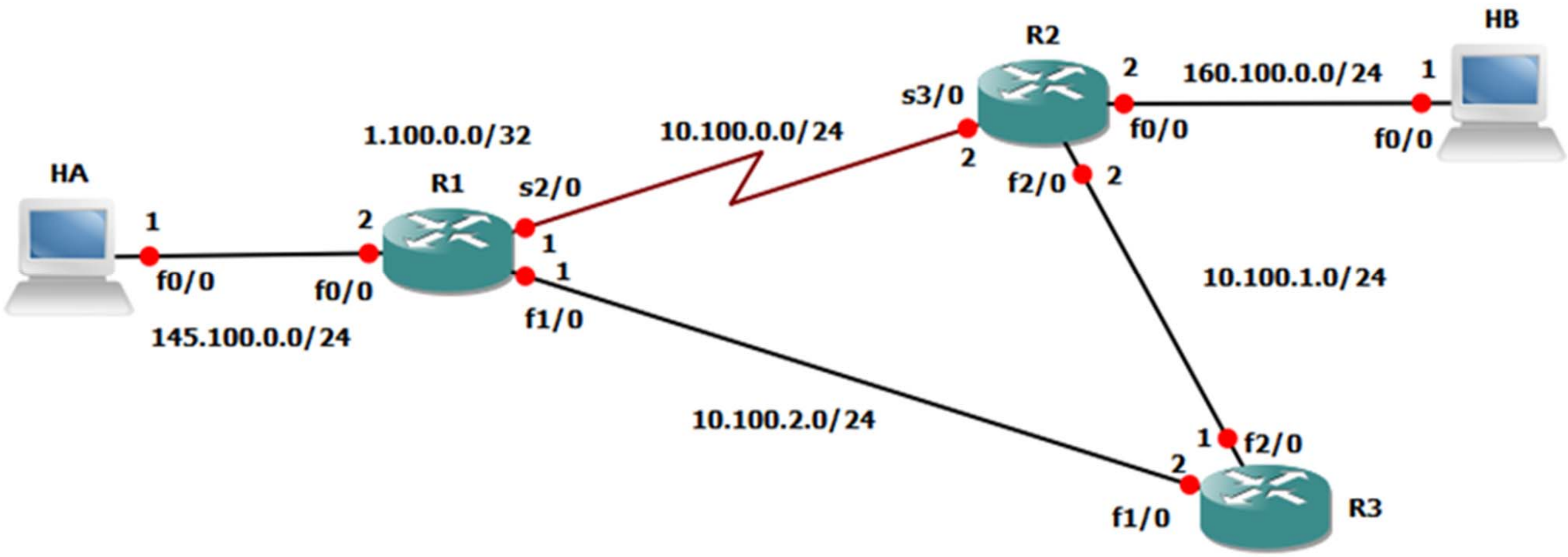
RSVP-TE details: Example



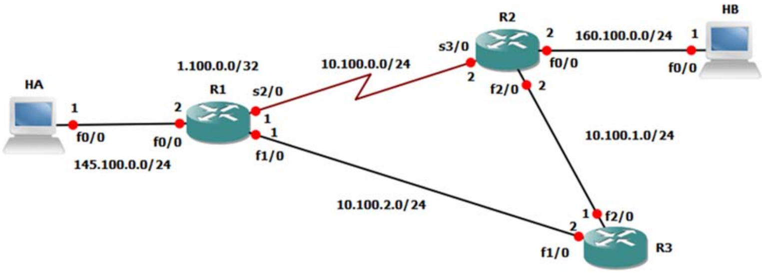
* Message contains:

- Explicit Route object
  - 10.1.1.5 strict
  - 10.1.1.3 loose
- Label Request object
- Session Attribute object
  - setup priority: 4
  - holding priority: 4
- Sender Tspec object
  - bandwidth 10M
  - •
  - •
  - •

Real example MPLS



Programació Router



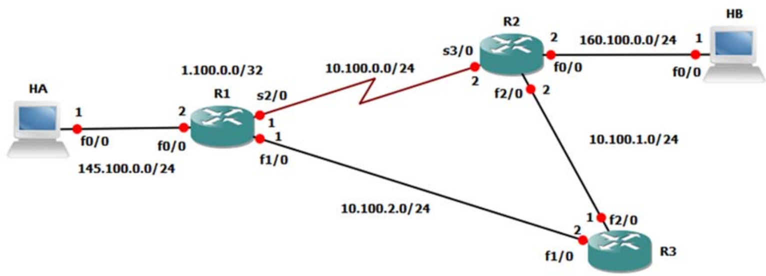
R1

```
ip cef
mpls label protocol ldp
interface Loopback0
 ip address 1.100.1.1 255.255.255.255
interface FastEthernet0/0
 ip address 145.100.0.2 255.255.255.0
interface FastEthernet1/0
 ip address 10.100.2.1 255.255.255.0
mpls ip
interface Serial2/0
 ip address 10.100.0.1 255.255.255.0
 mpls ip
router ospf 1
passive-interface FastEthernet0/0
 network 1.100.1.1 0.0.0.0 area 0
 network 10.100.0.0 0.0.0.255 area 0
 network 10.100.2.0 0.0.0.255 area 0
 network 145.100.0.0 0.0.0.255 area 0
```

R2

```
ip cef
mpls label protocol ldp
interface Loopback0
 ip address 1.100.1.2 255.255.255.255
interface FastEthernet0/0
 ip address 160.100.0.2 255.255.255.0
interface FastEthernet2/0
 ip address 10.100.1.2 255.255.255.0
mpls ip
interface Serial3/0
 ip address 10.100.0.2 255.255.255.0
 mpls ip
router ospf 1
 passive-interface FastEthernet0/0
 network 1.100.1.2 0.0.0.0 area 0
 network 10.100.0.0 0.0.0.255 area 0
 network 10.100.1.0 0.0.0.255 area 0
 network 160.100.0.0 0.0.0.255 area 0
```

Routing table MPLS



R1#show ip route

1.0.0.0/32 is subnetted, 3 subnets

C 1.100.1.1 is directly connected, Loopback0

O 1.100.1.2 [110/3] via 10.100.2.2, 00:00:59, FastEthernet1/0

O 1.100.1.3 [110/2] via 10.100.2.2, 00:00:59, FastEthernet1/0

145.100.0.0/24 is subnetted, 1 subnets

C 145.100.0.0 is directly connected, FastEthernet0/0

160.100.0.0/24 is subnetted, 1 subnets

O 160.100.0.0 [110/3] via 10.100.2.2, 00:00:59, FastEthernet1/0

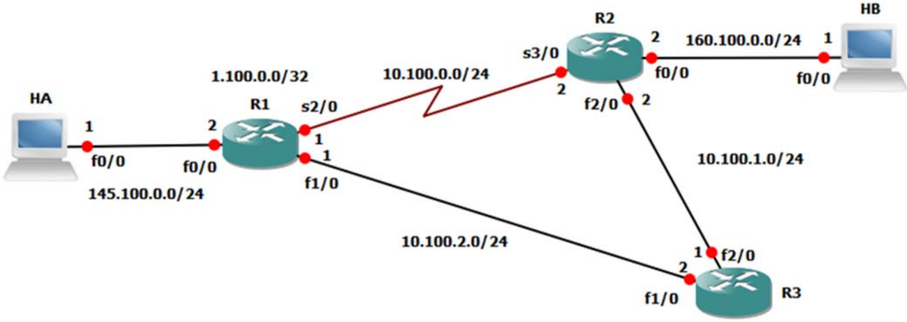
10.0.0.0/24 is subnetted, 3 subnets

C 10.100.2.0 is directly connected, FastEthernet1/0

C 10.100.0.0 is directly connected, Serial2/0

O 10.100.1.0 [110/2] via 10.100.2.2, 00:00:59, FastEthernet1/0

Label table MPLS

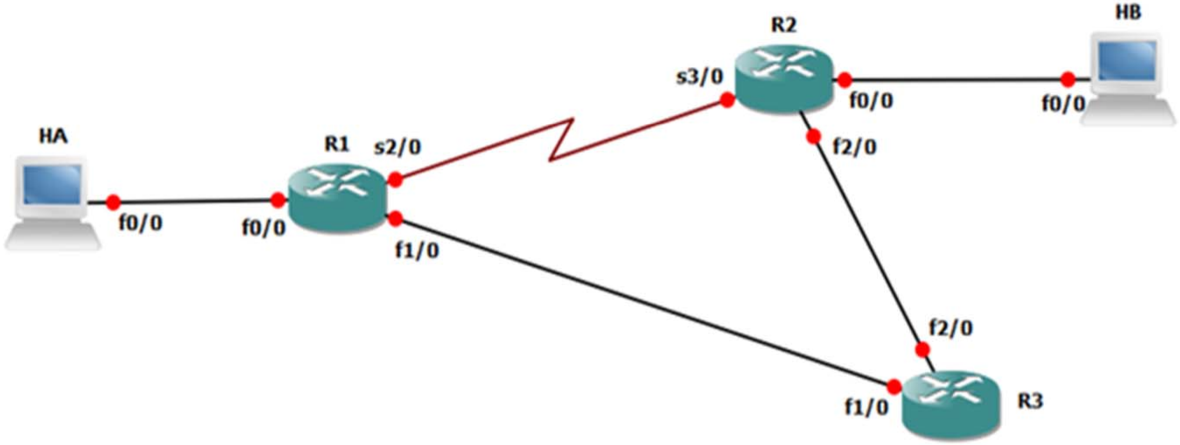


R1#show mpls forwarding-table

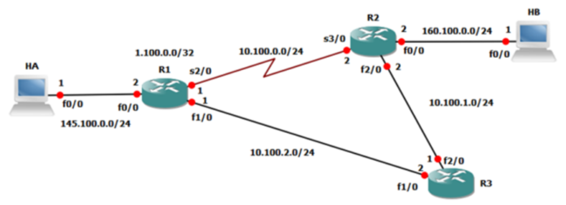
Local tag	Outgoing tag or VC	Prefix or Tunnel Id	Bytes tag switched	Outgoing interface	Next Hop
16	17	1.100.1.2/32	0	Fa1/0	10.100.2.2
17	Pop tag	10.100.1.0/24	0	Fa1/0	10.100.2.2
18	20	160.100.0.0/24	0	Fa1/0	10.100.2.2
19	Pop tag	1.100.1.3/32	0	Fa1/0	10.100.2.2

MPLS TE example

Tunel1 entre R1 y R2 a 50 Kbps dynamic. esto quiere decir que pasará por donde le diga OSPF. Seguramente R1-R3-R2. Si quiero que pase por R1-R2 deberé ponerlo explícito.
Tunel 2 entre R2-R3-R1 a 100 Kbps explícito por lo que pasará siempre R2-R3-R1
Se puede ver con "show ip route" en cada router



Programació Routers

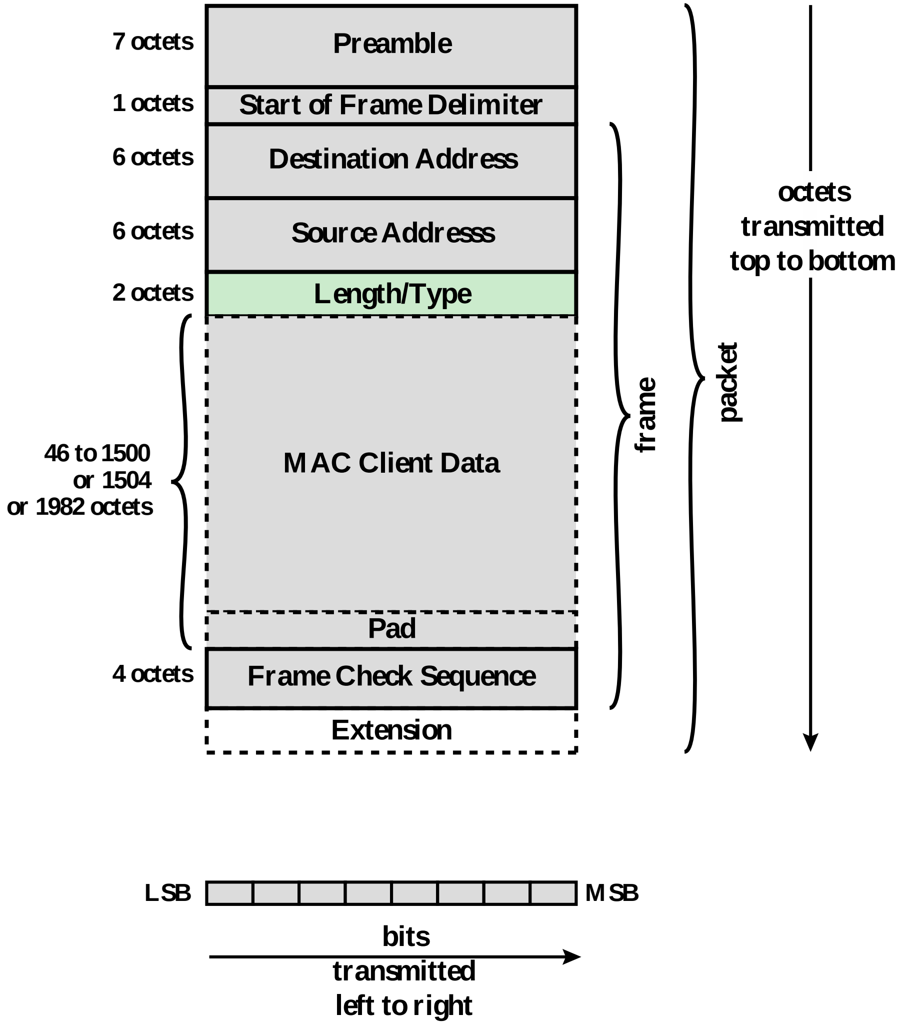


R1
ip cef
mpls label protocol ldp
mpls traffic-eng tunnels
interface Loopback0
 ip address 1.100.1.1 255.255.255.255
interface Tunnel1
 ip unnumbered Loopback0
 tunnel destination 1.100.1.2
 tunnel mode mpls traffic-eng
 tunnel mpls traffic-eng autoroute announce
 tunnel mpls traffic-eng bandwidth 50
 tunnel mpls traffic-eng path-option 1 dynamic
interface FastEthernet0/0
 ip address 145.100.0.2 255.255.255.0
interface FastEthernet1/0
 ip address 10.100.2.1 255.255.255.0
 mpls ip
 mpls traffic-eng tunnels
 ip rsvp bandwidth 1000
interface Serial2/0
 ip address 10.100.0.1 255.255.255.0
 mpls ip
 mpls traffic-eng tunnels
 clock rate 56000
 ip rsvp bandwidth 100
router ospf 1
 mpls traffic-eng router-id Loopback0
 mpls traffic-eng area 0
passive-interface FastEthernet0/0
 network 1.100.1.1 0.0.0.0 area 0
 network 10.100.0.0 0.0.0.255 area 0
 network 10.100.2.0 0.0.0.255 area 0
 network 145.100.0.0 0.0.0.255 area 0

2.4 Carrier Ethernet

Source book: Data and Computer Communication Ed 10. W. Stallings Cap. 12

Ethernet MAC Frame format



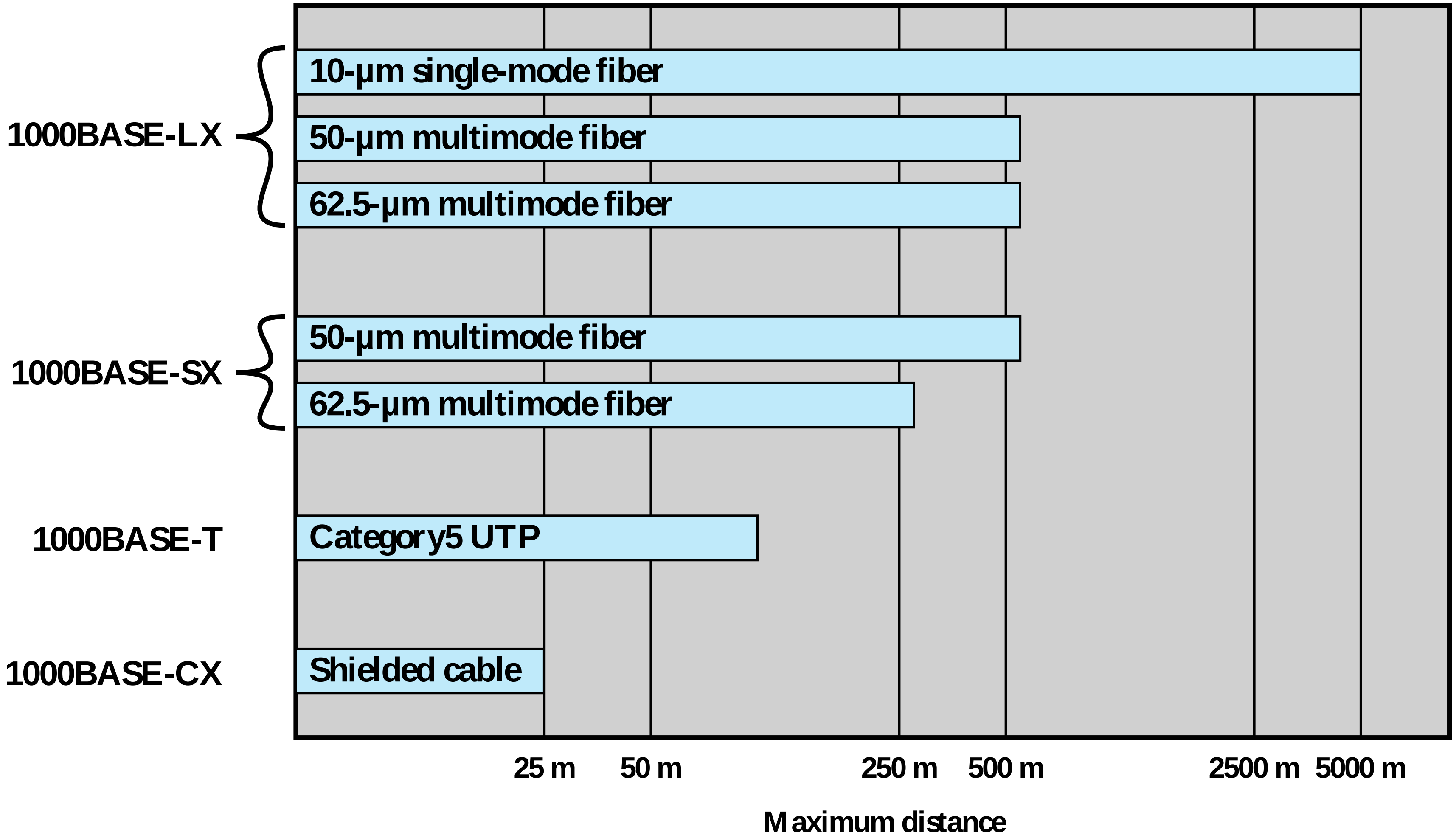
Full Duplex Operation

- Traditional Ethernet half duplex
- Using full-duplex, station can transmit and receive simultaneously
- 100-Mbps Ethernet in full-duplex mode, giving a theoretical transfer rate of 200 Mbps
- Stations must have full-duplex adapter cards
- And must use switching hub
  - Each station constitutes separate collision domain
  - CSMA/CD algorithm no longer needed
  - 802.3 MAC frame format used

Gigabit Ethernet for carrier

- Carrier extension
  - At least 4096 bit-times long (512 for 10/100)
- Frame bursting
- Not needed if using a switched hub to provide dedicated media access

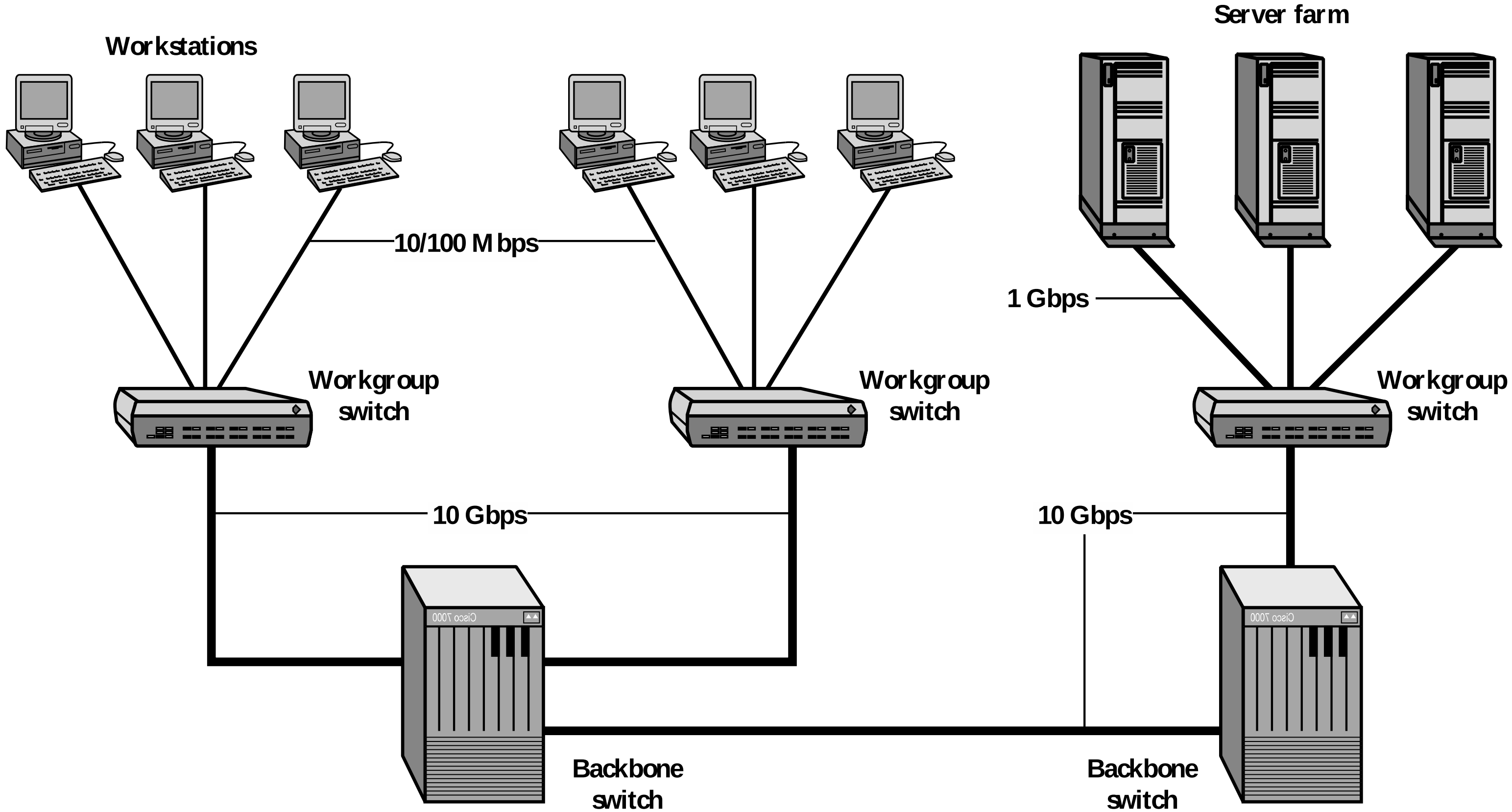
Gigabit Ethernet Medium Options



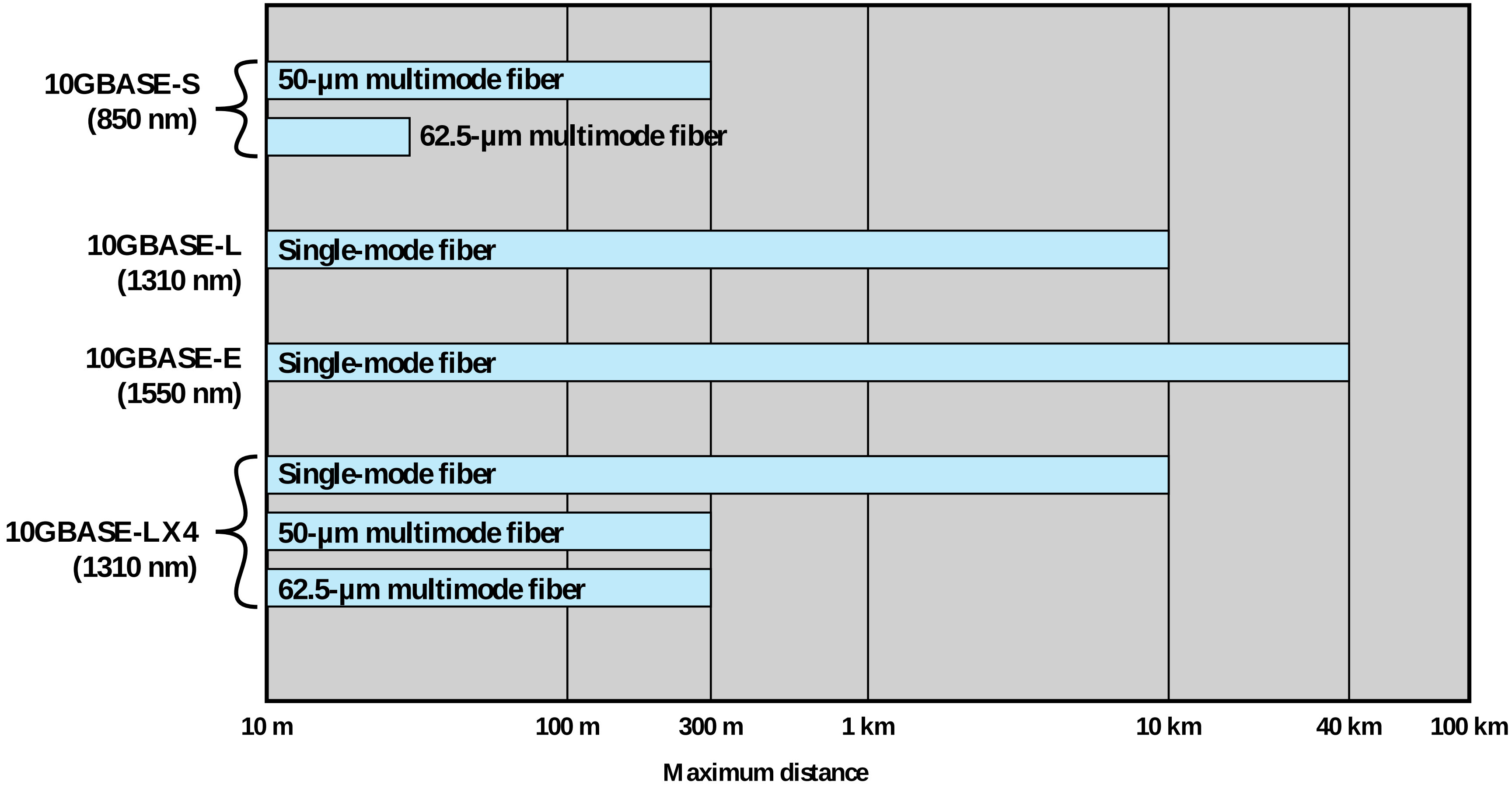
10Gbps Ethernet

- Growing interest in 10Gbps Ethernet
  - High-speed backbone use
  - Future wider deployment
- Alternative to ATM and other WAN technologies
- Uniform technology for LAN, MAN, or WAN
- Advantages of 10Gbps Ethernet
  - No expensive, bandwidth-consuming conversion between Ethernet packets and ATM cells
  - IP and Ethernet together offers QoS and traffic policing approach ATM
  - Have a variety of standard optical interfaces

10Gbps Ethernet exemple



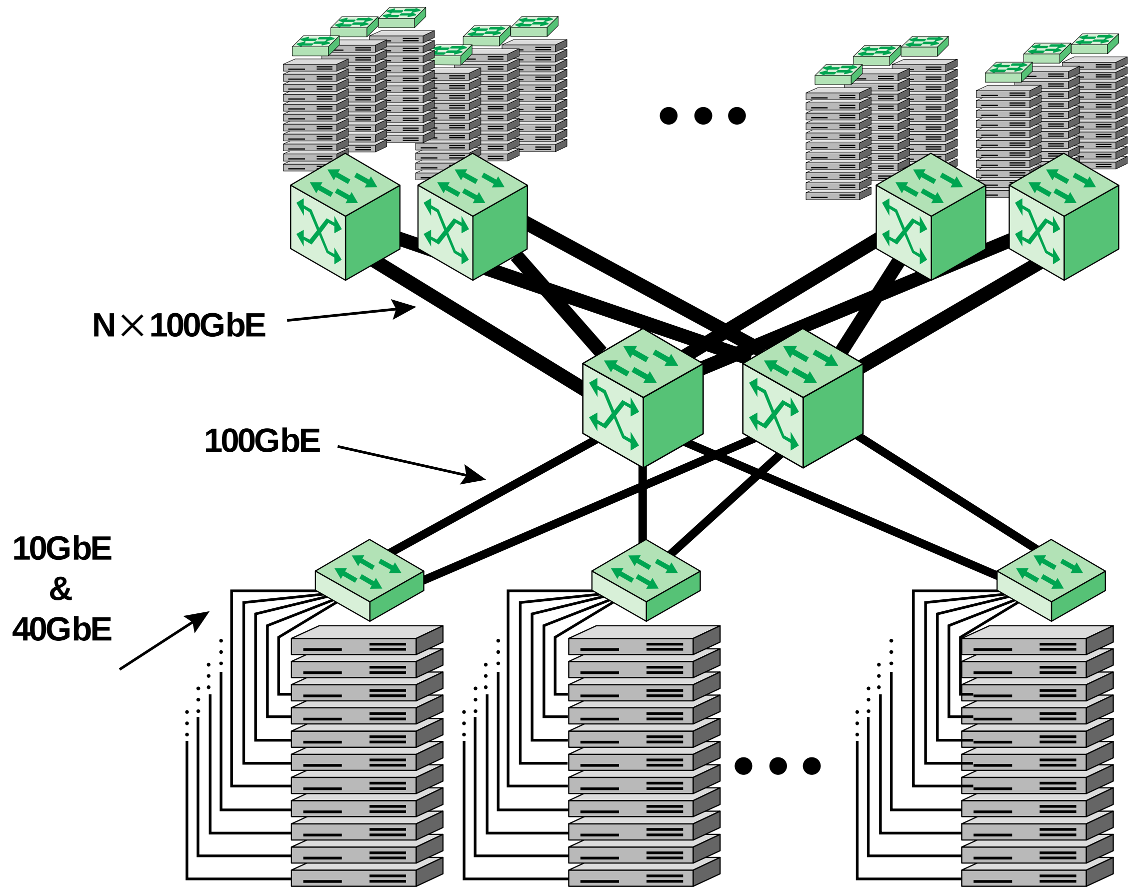
10 Gbps Ethernet Distance Options



100-Gbps Ethernet

- Preferred technology for wired LAN
- Preferred carrier for bridging wireless technologies into local Ethernet networks
- Cost-effective, reliable and interoperable
- Popularity of Ethernet technology:
  - Availability of cost-effective products
  - Reliable and interoperable network products
  - Variety of vendors

Example 100 Gbps Ethernet



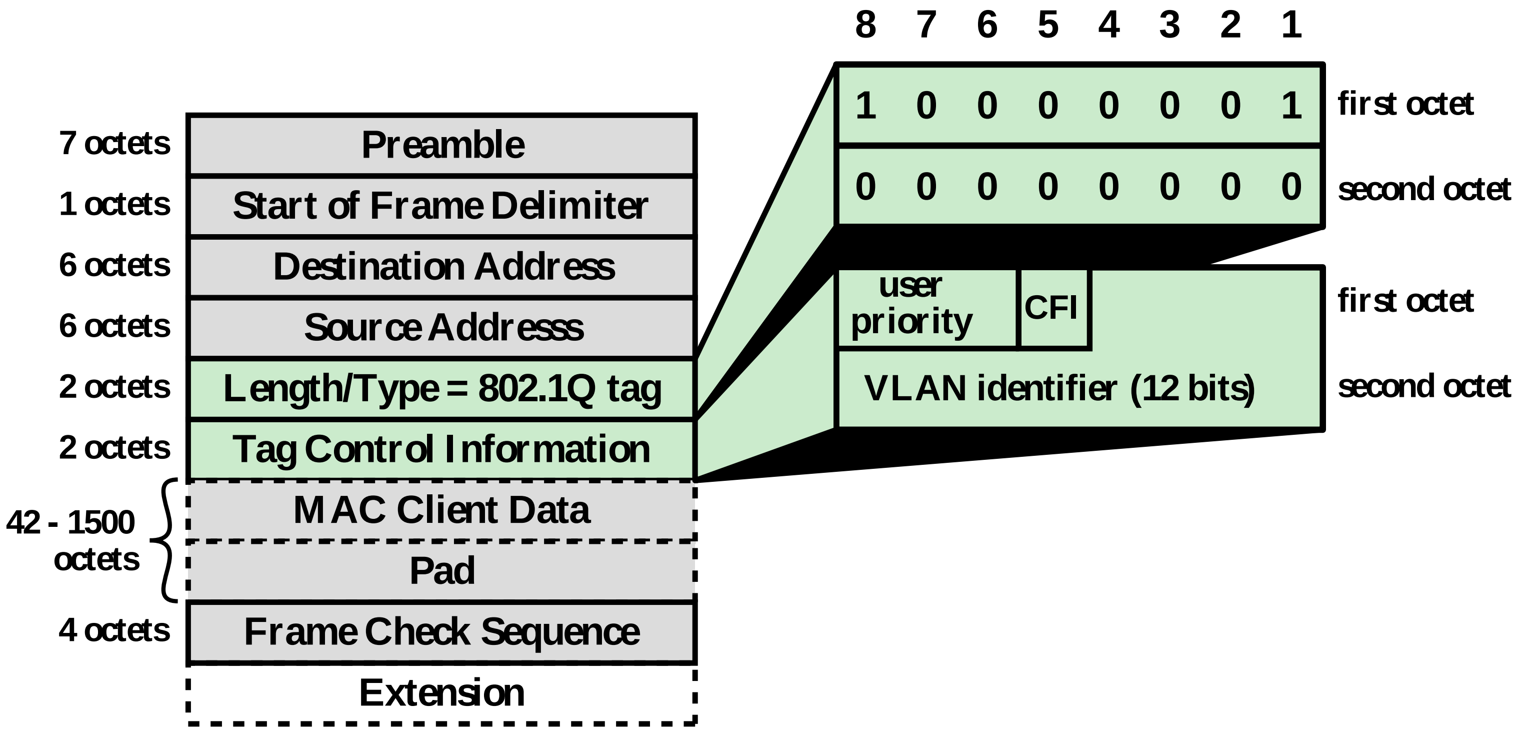
Media Options for 40-Gbps and 100-Gbps Ethernet

	40 Gbps	100 Gbps
1m backplane	40GBASE-KR4	
10 m copper	40GBASE-CR4	1000GBASE-CR10
100 m multimode fiber	40GBASE-SR4	1000GBASE-SR10
10 km single mode fiber	40GBASE-LR4	1000GBASE-LR4
40 km single mode fiber		1000GBASE-ER4

Naming nomenclature:

Copper: K = backplane; C = cable assembly
Optical: S = short reach (100m); L - long reach (10 km); E = extended long reach (40 km)
Coding scheme: R = 64B/66B block coding
Final number: number of lanes (copper wires or fiber wavelengths)

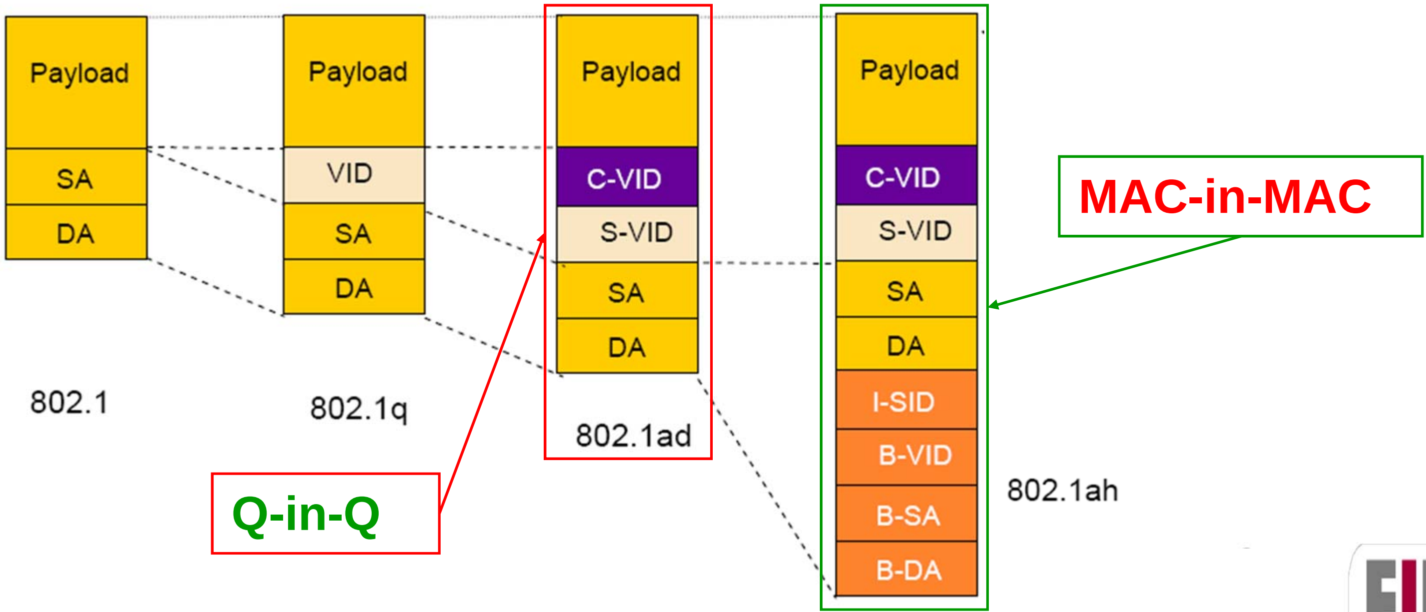
Tagged IEEE 802.3 MAC Frame Format



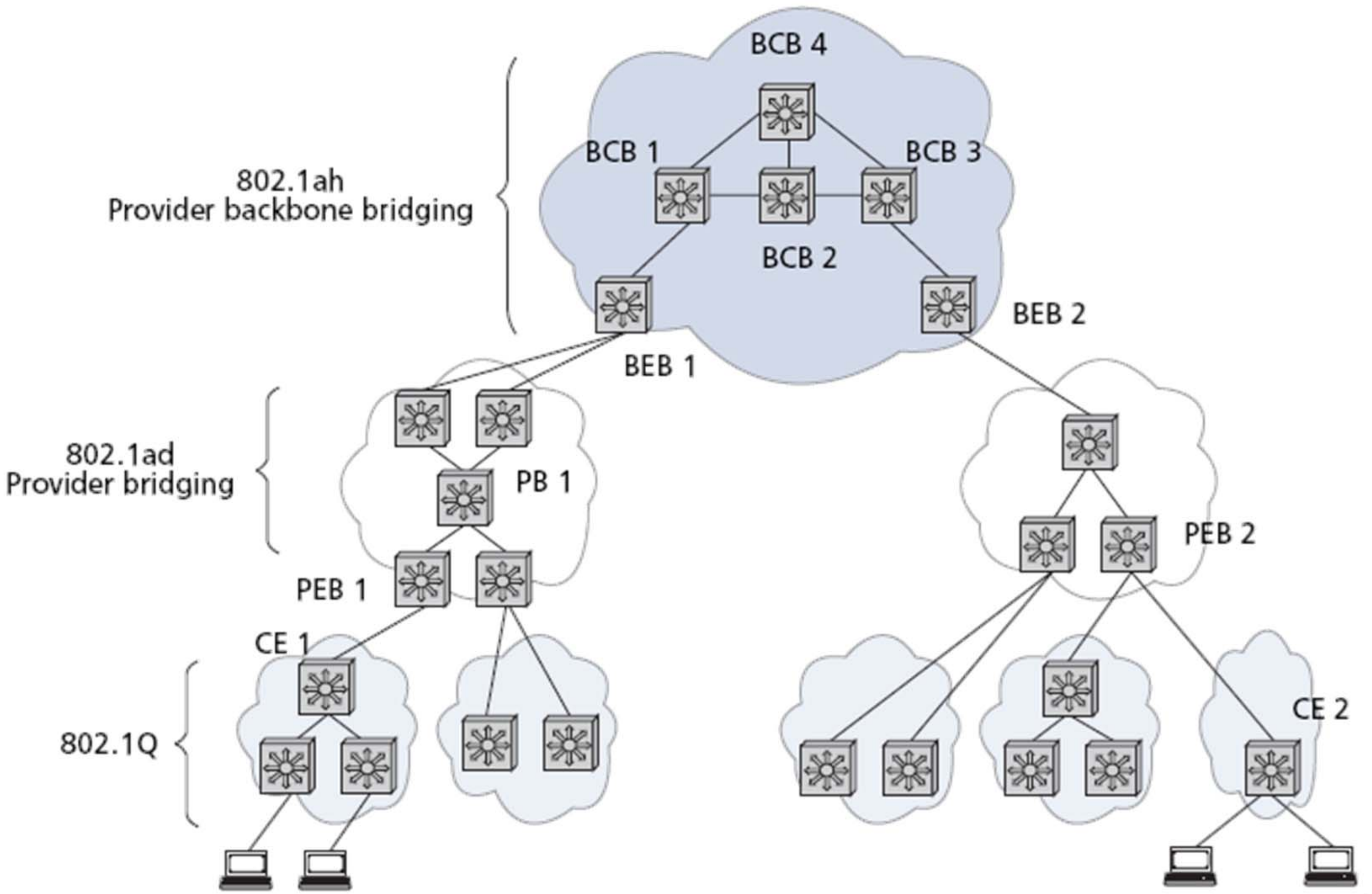
CFI = Canonical Format Indicator
VLAN = virtual local area network

Provider Backbone Bridge Traffic Engineering (PBB-TE)

- **IEEE has developed a number of standards providing enhancements to the original Ethernet standards. PBB-TE adapts Ethernet technology to carrier class transport networks**
  - **802.1Q**: Virtual LAN
  - **802.1ad**: Provider Bridging
  - **802.1ah**: Provider Backbone Bridging
  - **802.1ag**: Connectivity Fault Management (OAM)



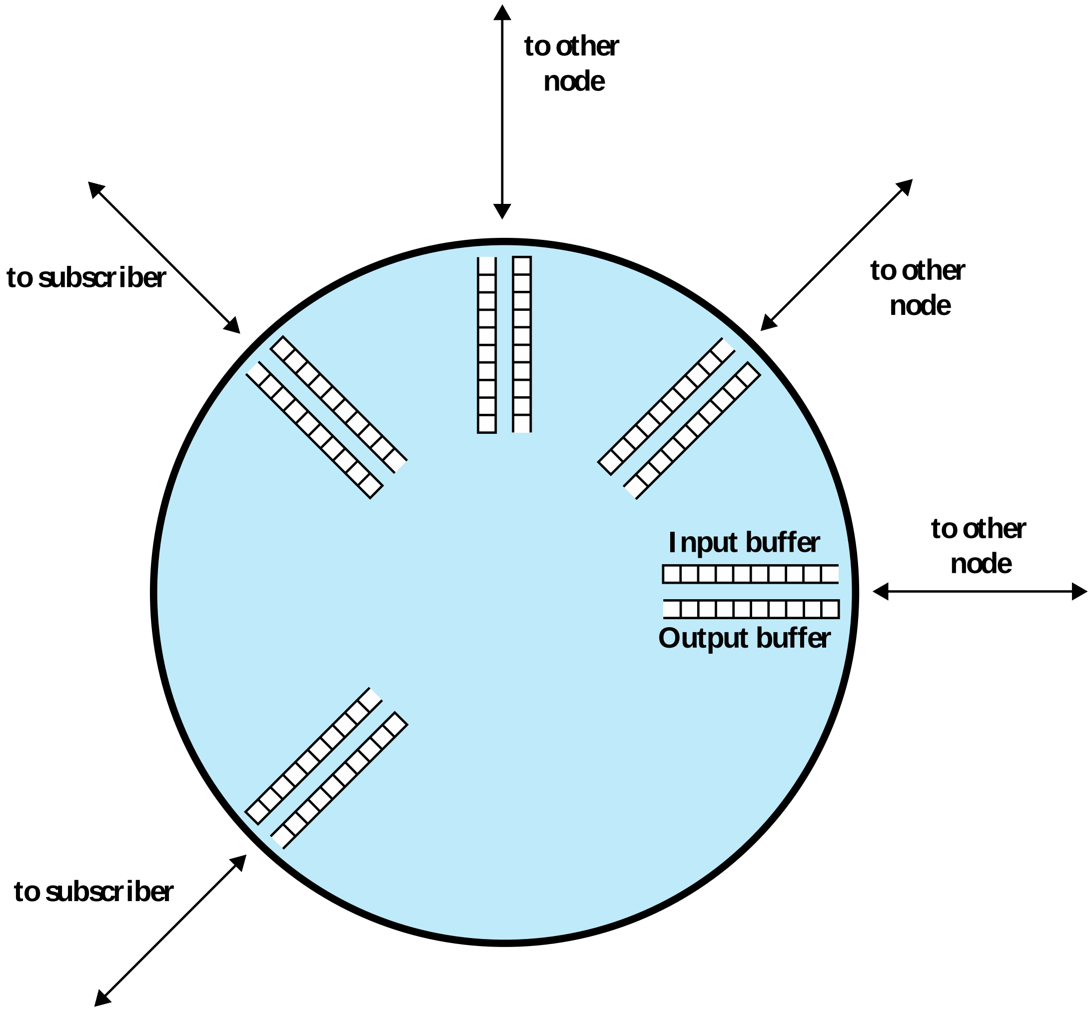
The way to PBB-TE



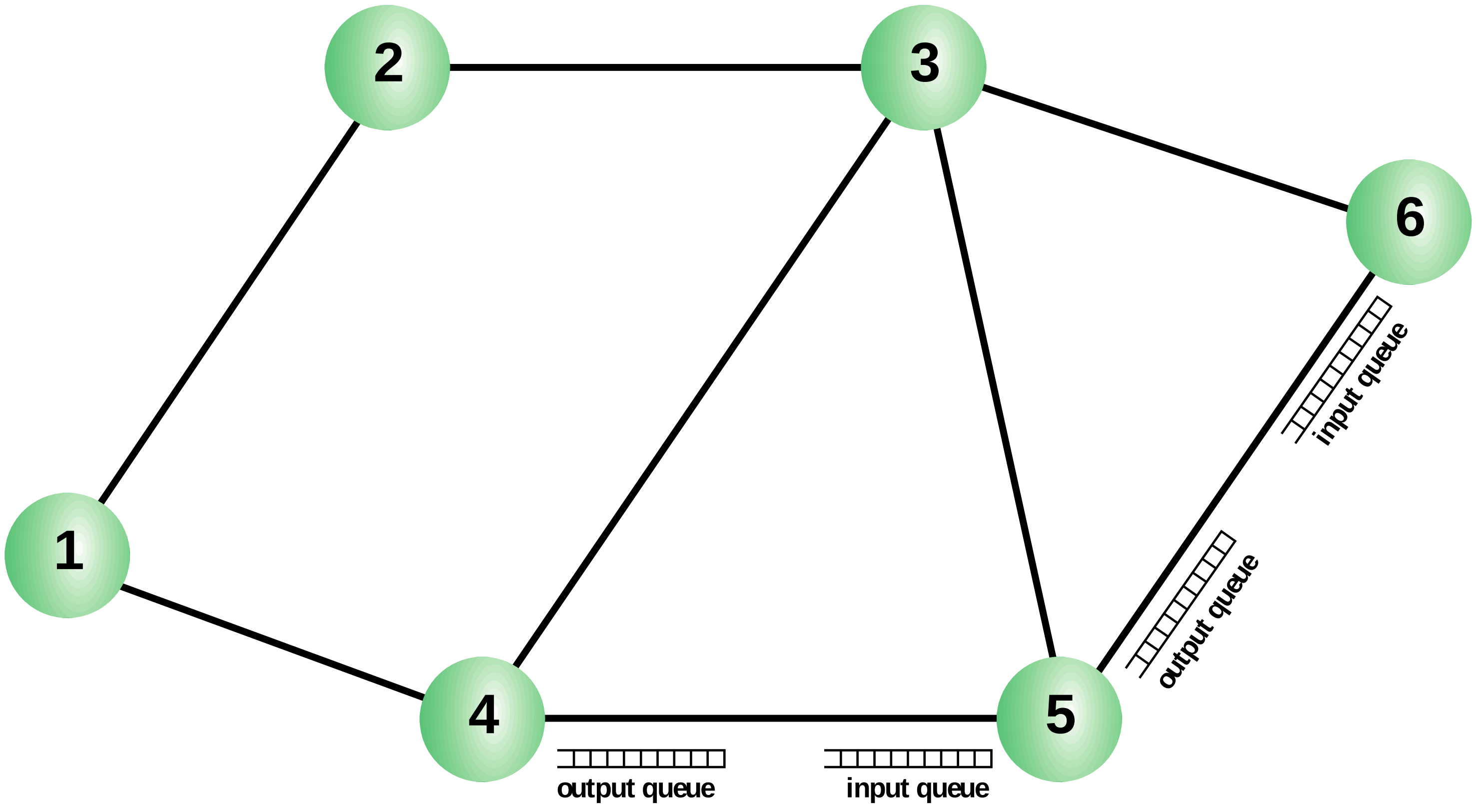
2.5 Control de la congestió en xarxes de commutació nivell 2

Source book: Data and Computer Communication Ed 10. W. Stallings Cap. 20
: Data and Computer Communication Ed 8. W. Stallings Cap. 13

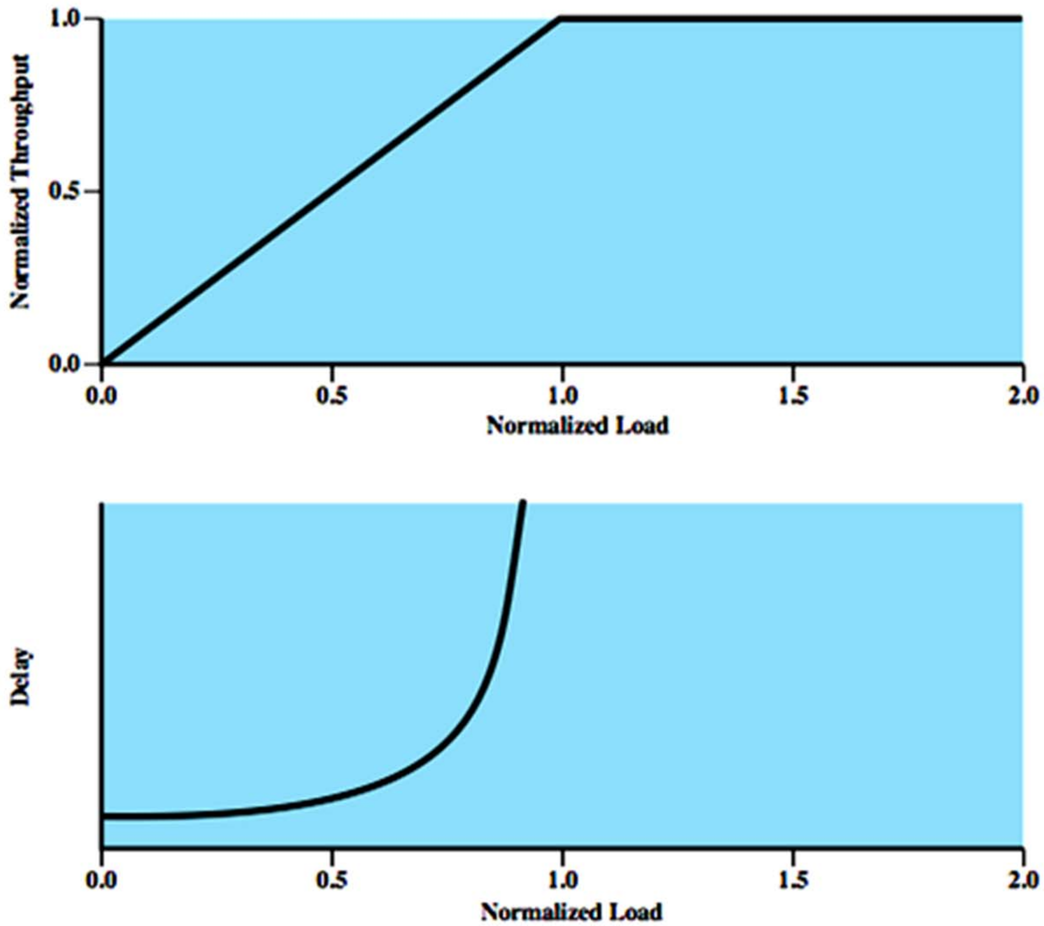
Queues at Node



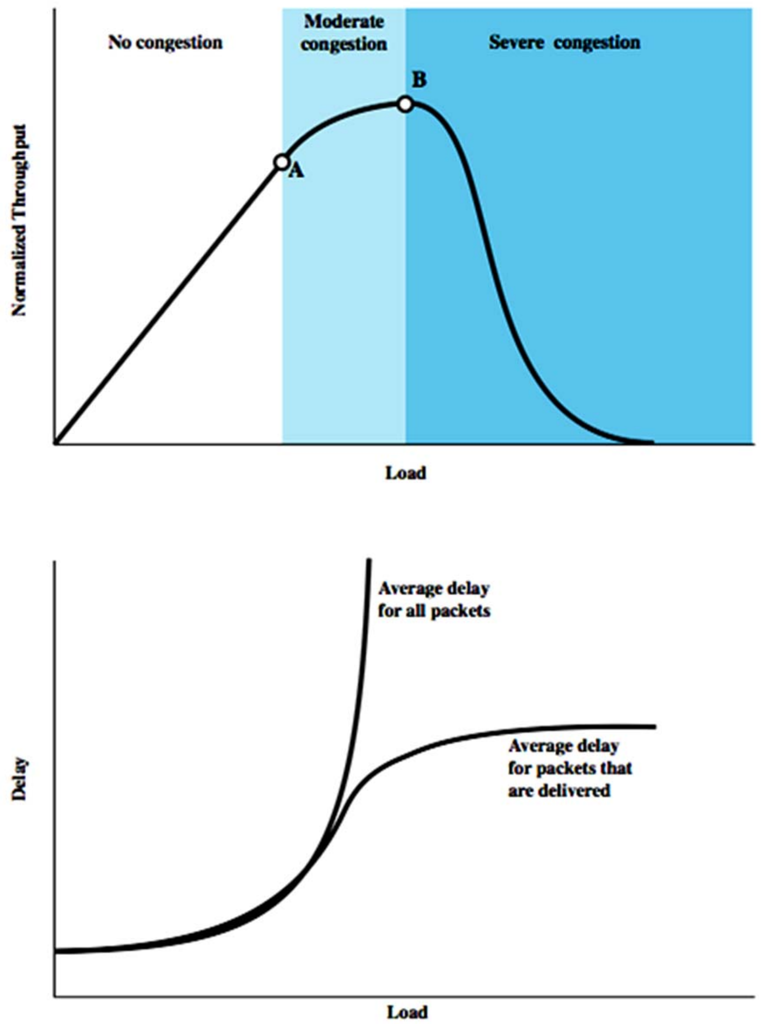
Interaction of Queues in a data network



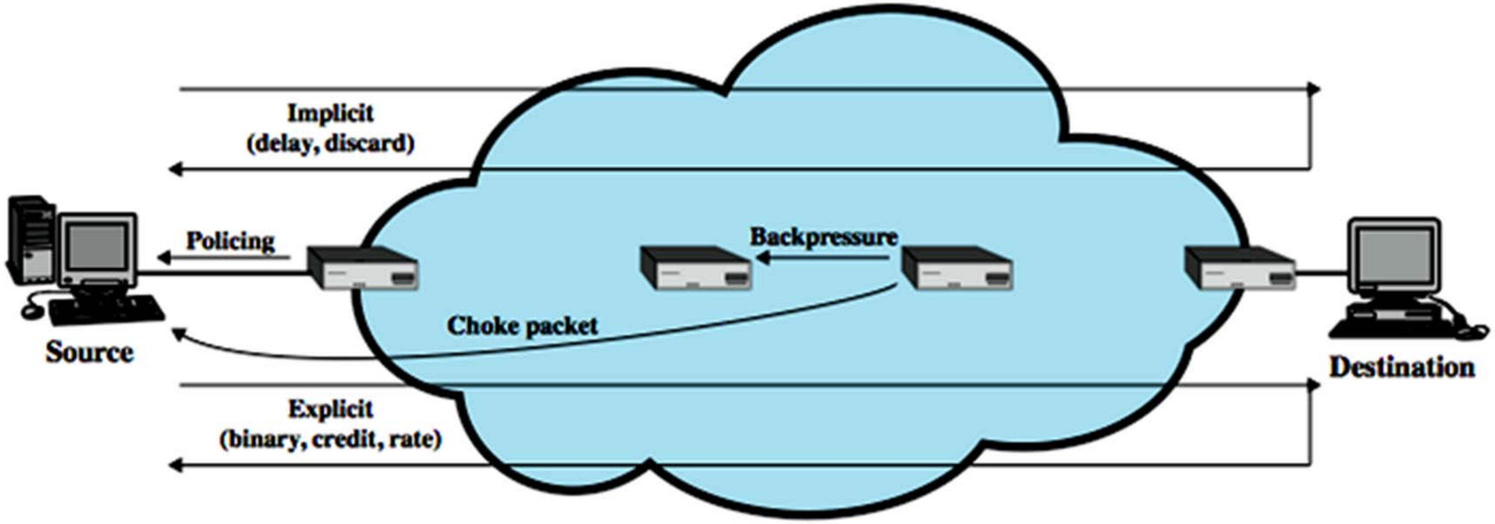
Ideal Network Utilization



Effects of Congestion - No Control



Mechanisms for Congestion Control



Backpressure

- If node becomes congested it can slow down or stop flow of packets from other nodes
- Can be exerted on the basis of links or logical connections
- Flow restriction propagates backward to sources, which are restricted in the flow of new packets into the network
- Can be selectively applied to logical connections so that the flow from one node to the next is only restricted or halted on some connections

Choke Packet

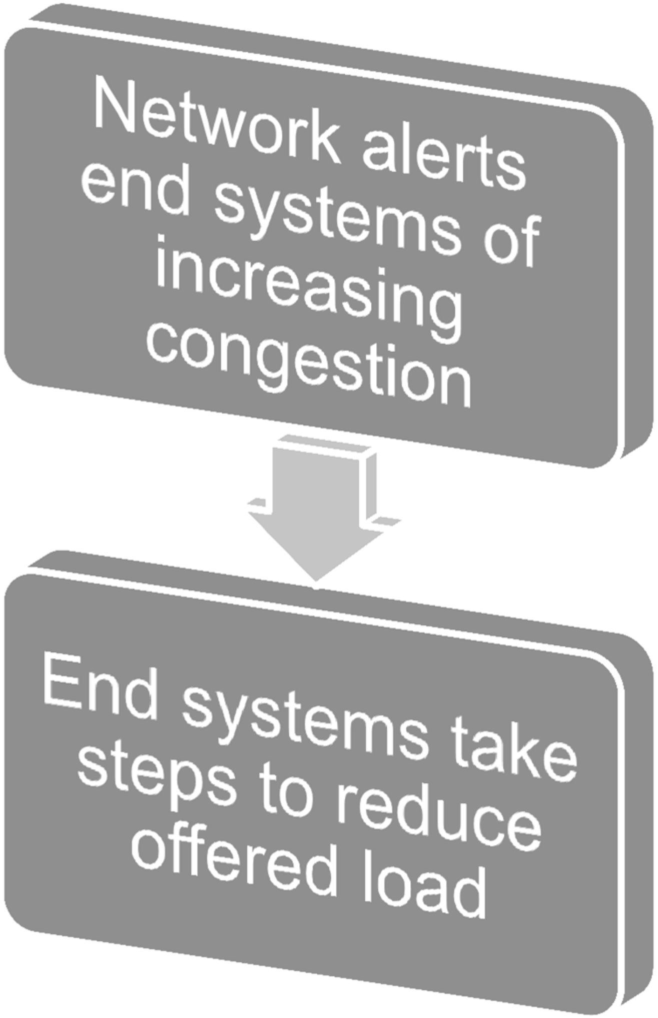
- A control packet
  - Generated at congested node
  - Sent back to source node
- An example is the Internet Control Message Protocol (ICMP) Source Quench packet
  - *From router or destination end system*
  - *Source cuts back until it no longer receives quench messages*
  - *Message is issued for every discarded packet*
  - *Message may also be issued for anticipated congestion*
- Is a crude technique for controlling congestion

Implicit Congestion Signaling

- With network congestion:
  - Transmission delay increases
  - Packets may be discarded
- Source can detect congestion and reduce flow
- Responsibility of end systems
- Effective on connectionless (datagram) networks
- Also used in connection-oriented networks
  - LAPF control is capable of detecting lost frames

Explicit Congestion Signaling

- Backward
  - Congestion avoidance notification in opposite direction to packet required
- Forward
  - Congestion avoidance notification in same direction as packet required



Explicit Signaling Categories

Binary

- A bit set in a packet indicates congestion

Credit based

- Indicates how many packets source may send
- Common for end-to-end flow control

Rate based

- Supply explicit data rate limit
- Nodes along path may request rate reduction

Traffic Management

Fairness

- Provide equal treatment of various flows

Quality of service

- Different treatment for different connections

Reservations

- Traffic contract between user and network
- Excess traffic discarded or handled on a best-effort basis

Traffic Shaping/Traffic Policing

- Two important tools in network management:
  - Traffic shaping
    - *Concerned with traffic leaving the switch*
    - *Reduces packet clumping*
    - *Produces an output packet stream that is less burst and with a more regular flow of packets*
  - Traffic policing
    - *Concerned with traffic entering the switch*
    - *Packets that don’t conform may be treated in one of the following ways:*
      - *Give the packet lower priority compared to packets in other output queues*
      - *Label the packet as nonconforming by setting the appropriate bits in a header*
      - *Discard the packet*

Token Bucket / Leaky Bucket

- Widely used traffic management tool
- Advantages:
  - Many traffic sources can be defined easily and accurately
  - Provides a concise description of the load to be imposed by a flow, enabling the service to determine easily the resource requirement
  - Provides the input parameters to a policing function

Token bucket

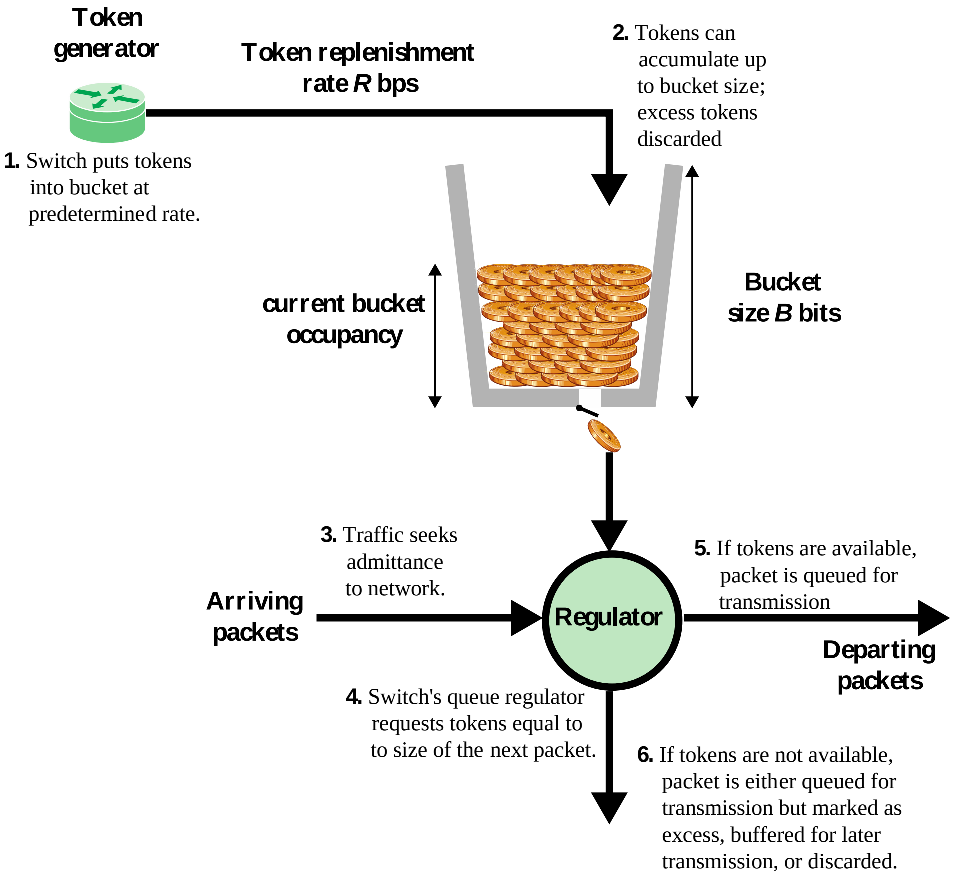


Figure 20.6 Token Bucket Scheme

Leaky bucket

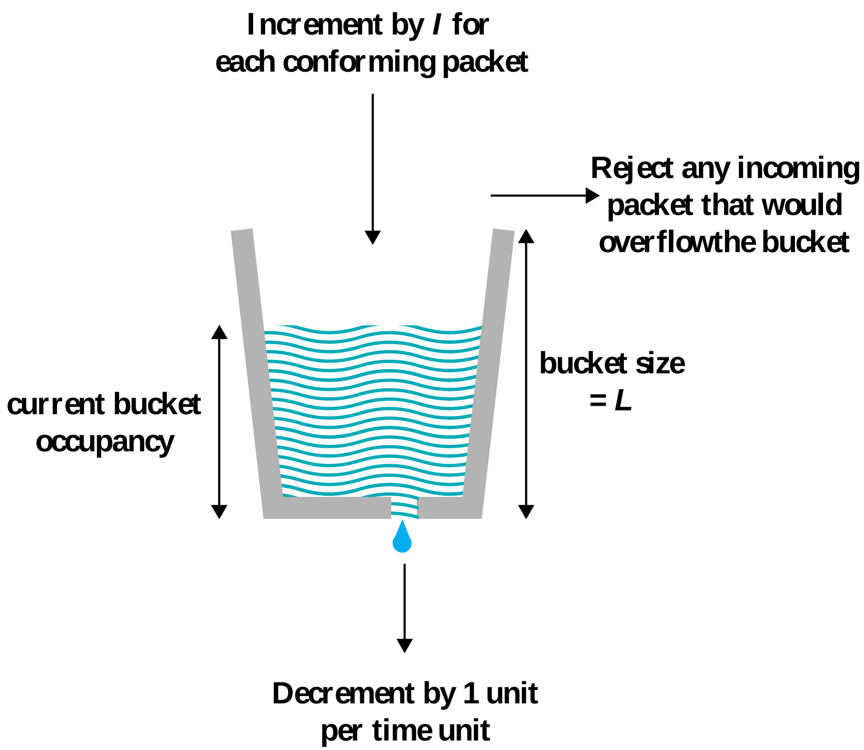
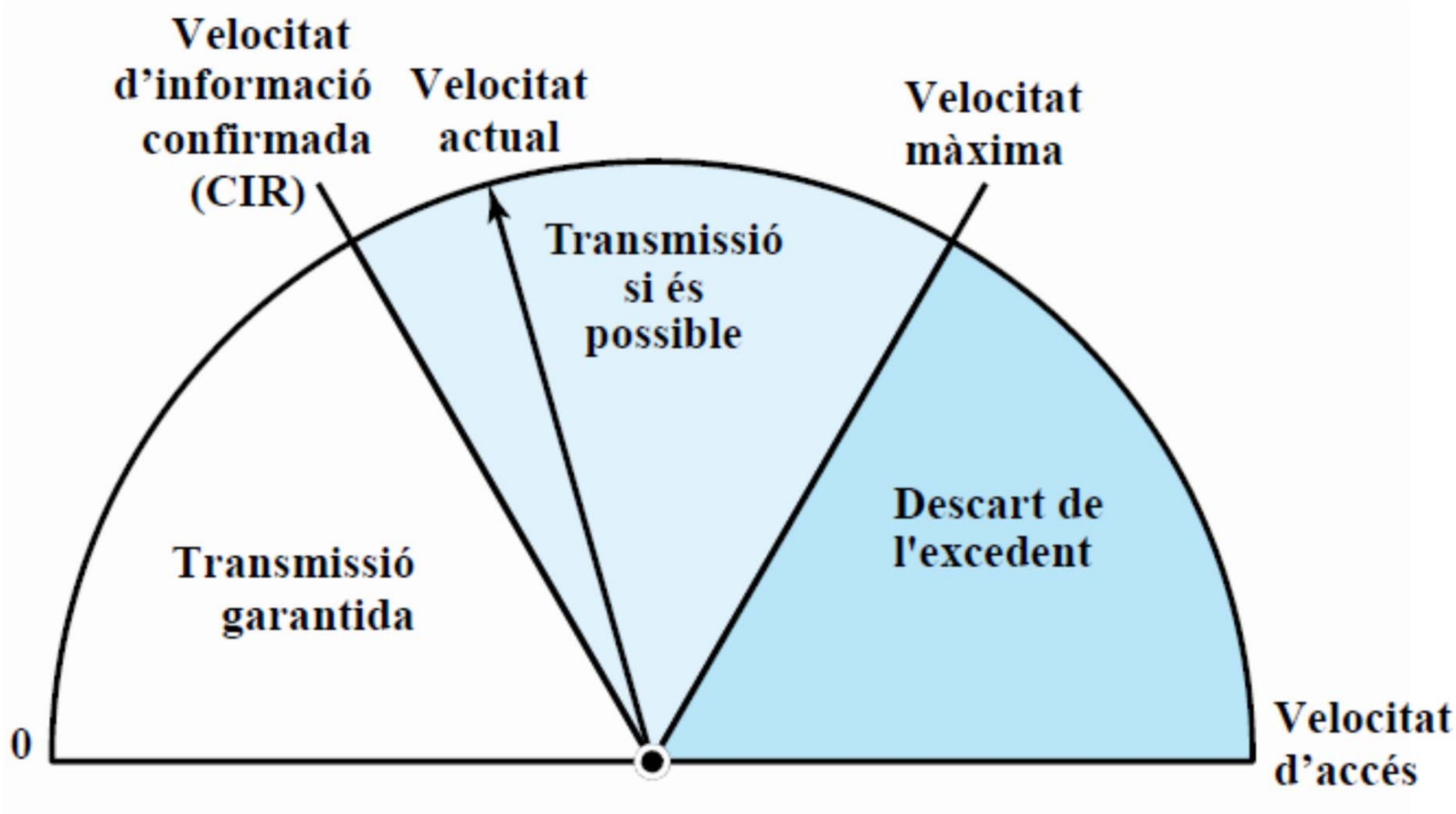


Figure 20.7 Leaky Bucket Algorithm

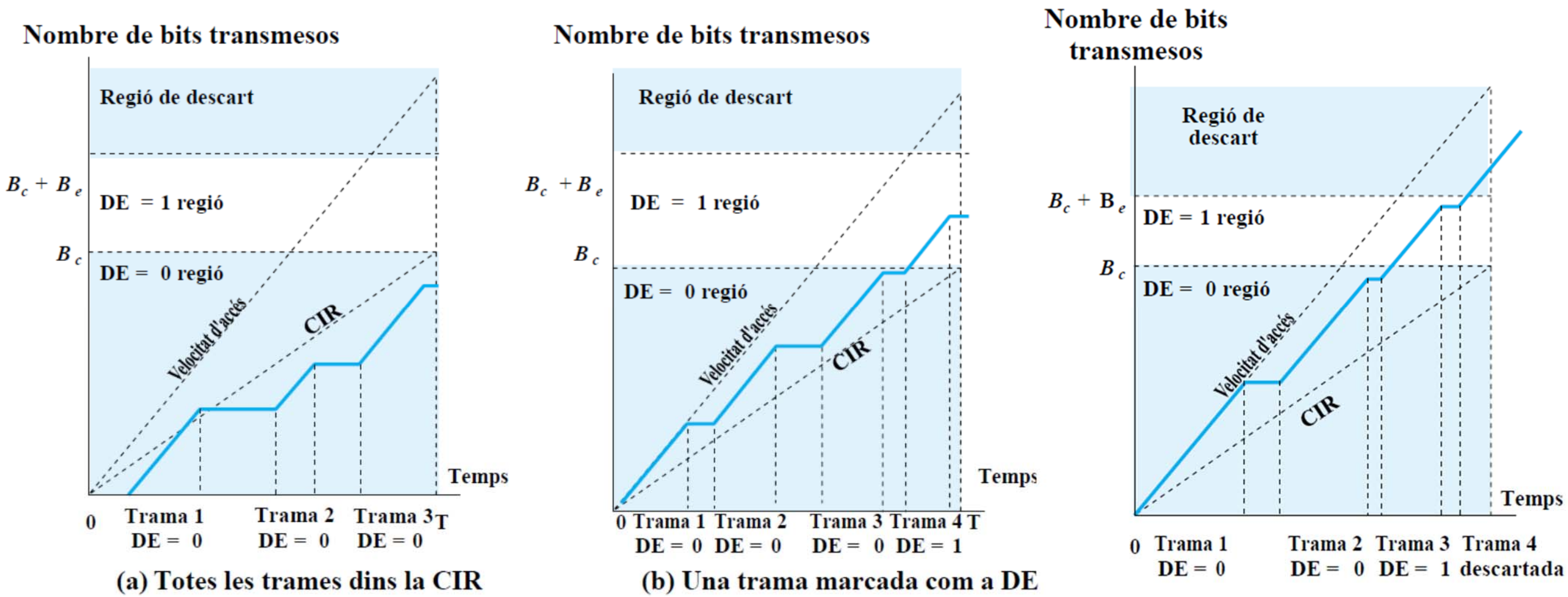
Example: FR congestion control

Tècnica	Tipus	Funció	Elements clau
Control de descart	Estratègia de descart	Proporciona una guia per a la xarxa sobre les trames que cal descartar	Bit DE
Notificació de la congestió explícita cap enrere	Elusió de la congestió	Proporciona una guia per als sistemes finals sobre la congestió a la xarxa	Bit BECN o missatge CLLM
Notificació de la congestió explícita cap endavant	Elusió de la congestió	Proporciona una guia per als sistemes finals sobre la congestió a la xarxa	Bit FECN
Notificació de la congestió implícita	Recuperació de la congestió	El sistema final infereix la congestió de la pèrdua de trames	Números de seqüència a PDU de capa superior

CIR strategy



Congestion control



$$T = \frac{B_c}{CIR}$$