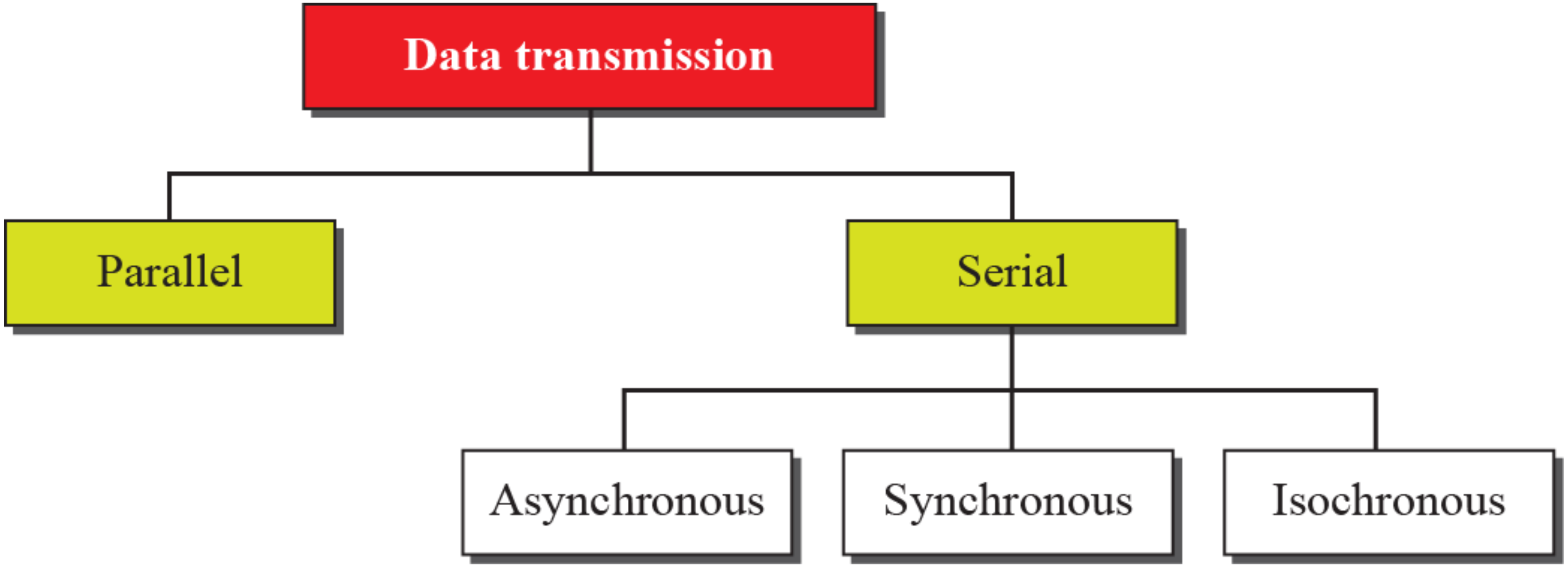
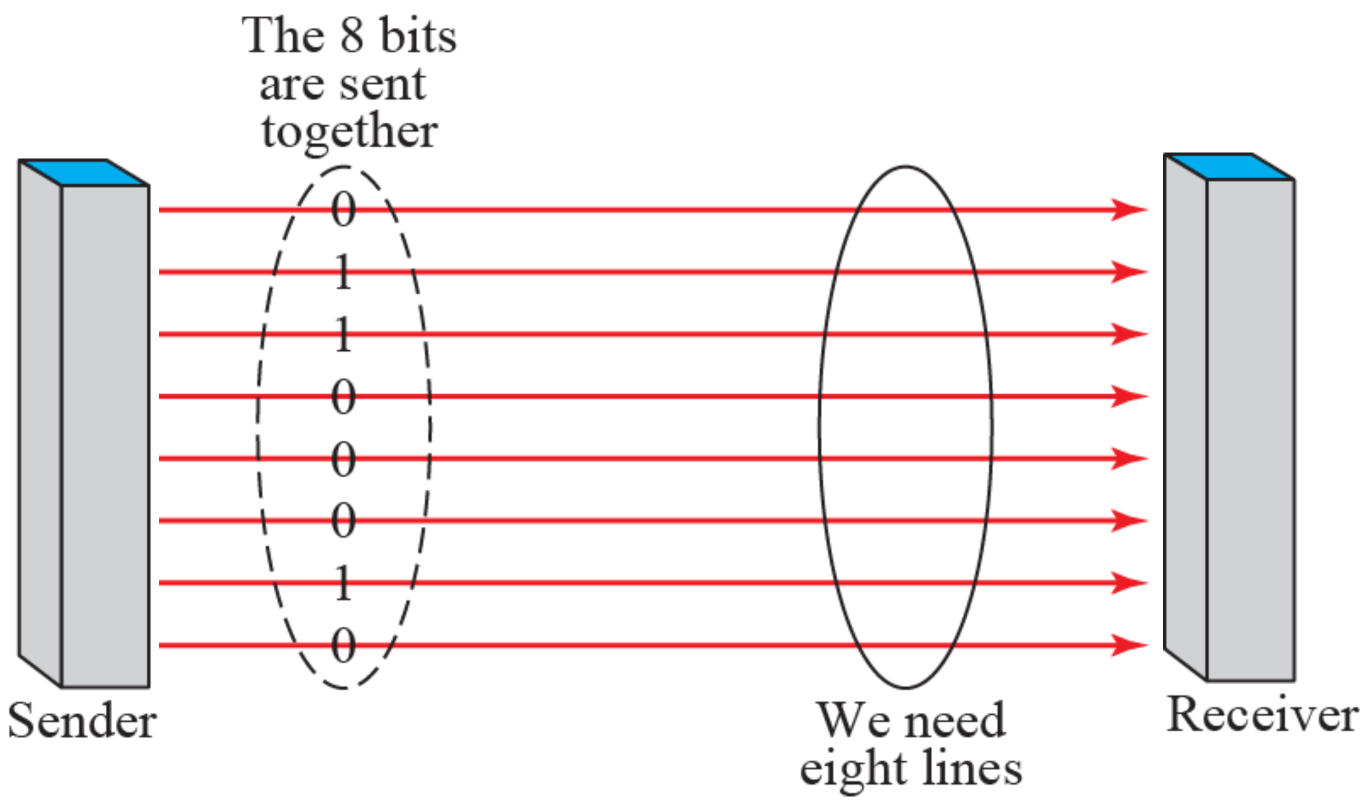
Layer 1 and 2

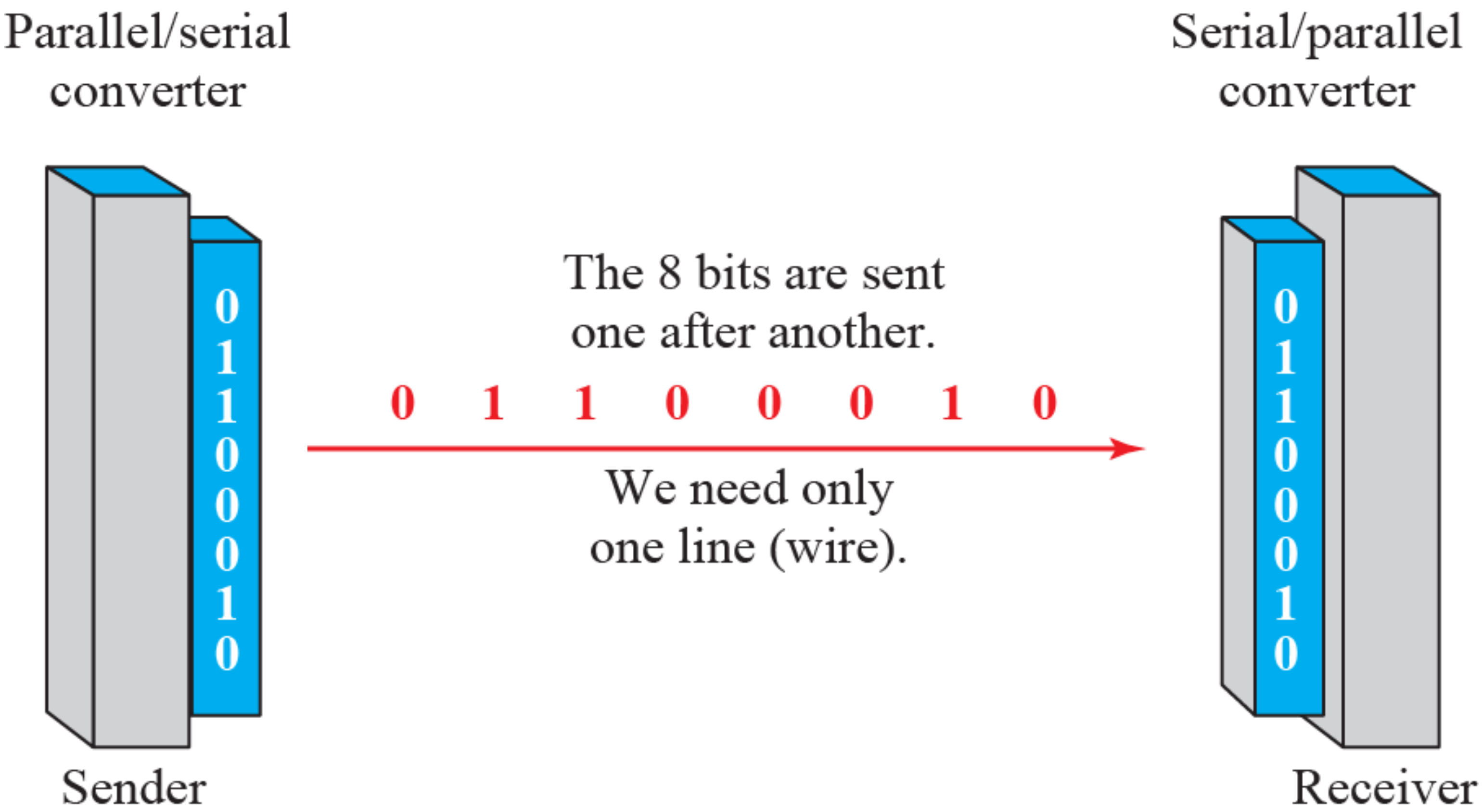
Transmission modes



Parallell transmission

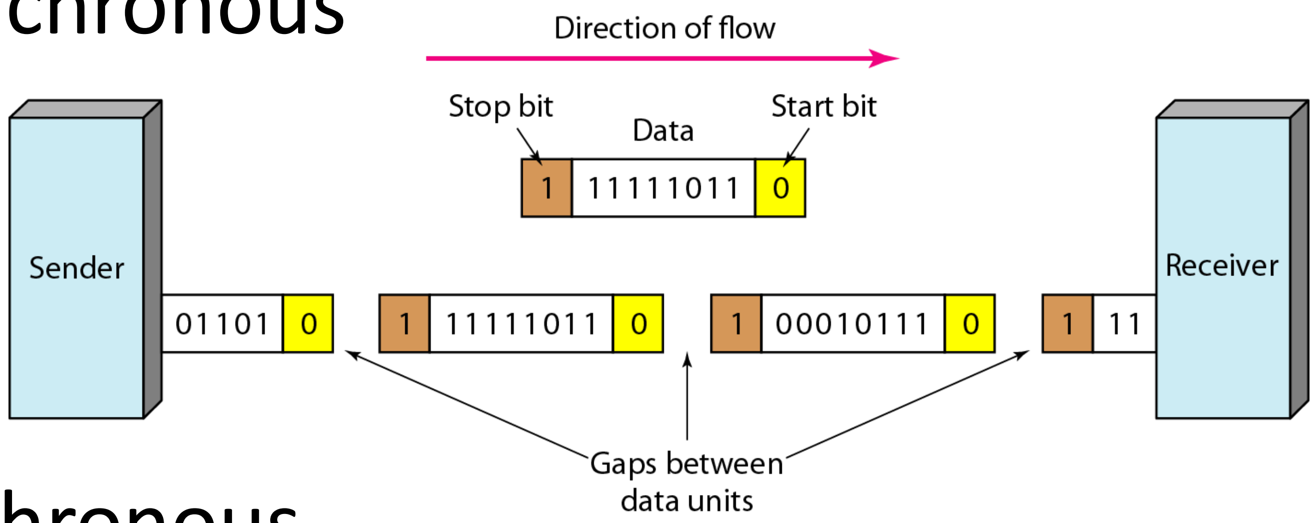


Serial transmission

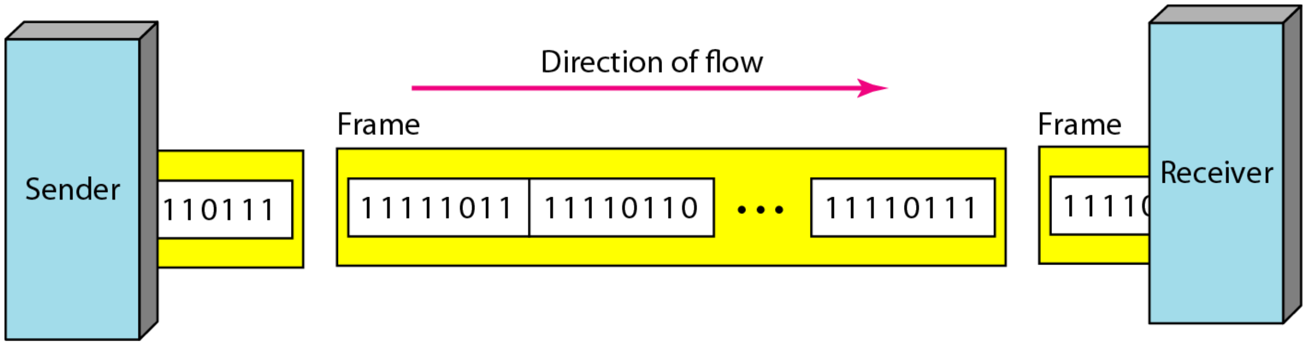


Transmission modes

- Asynchronous



- Synchronous



Multiplexing, principle

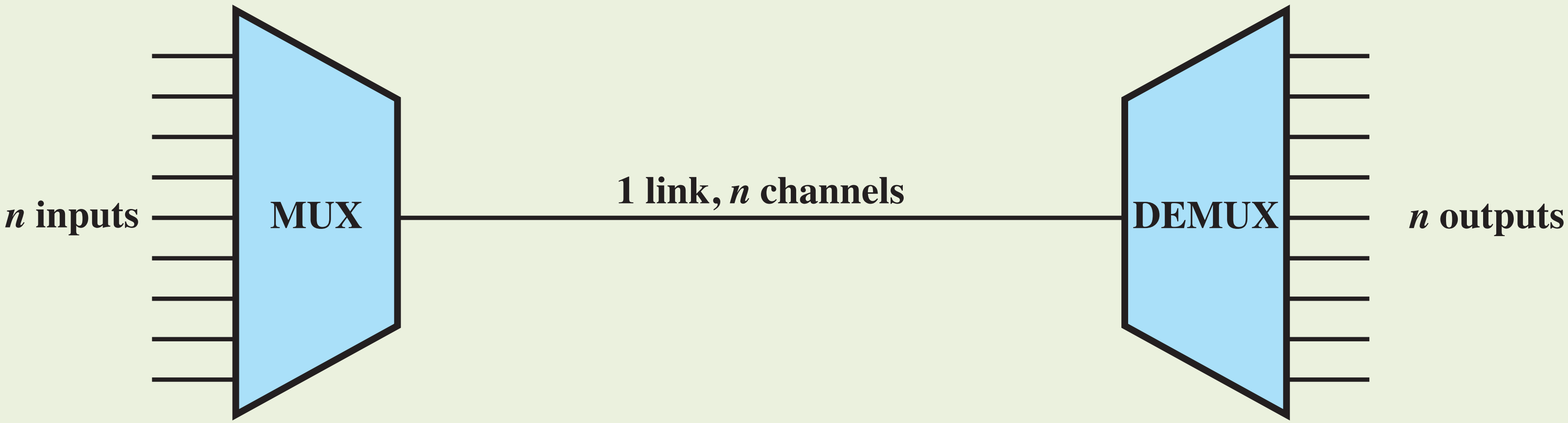
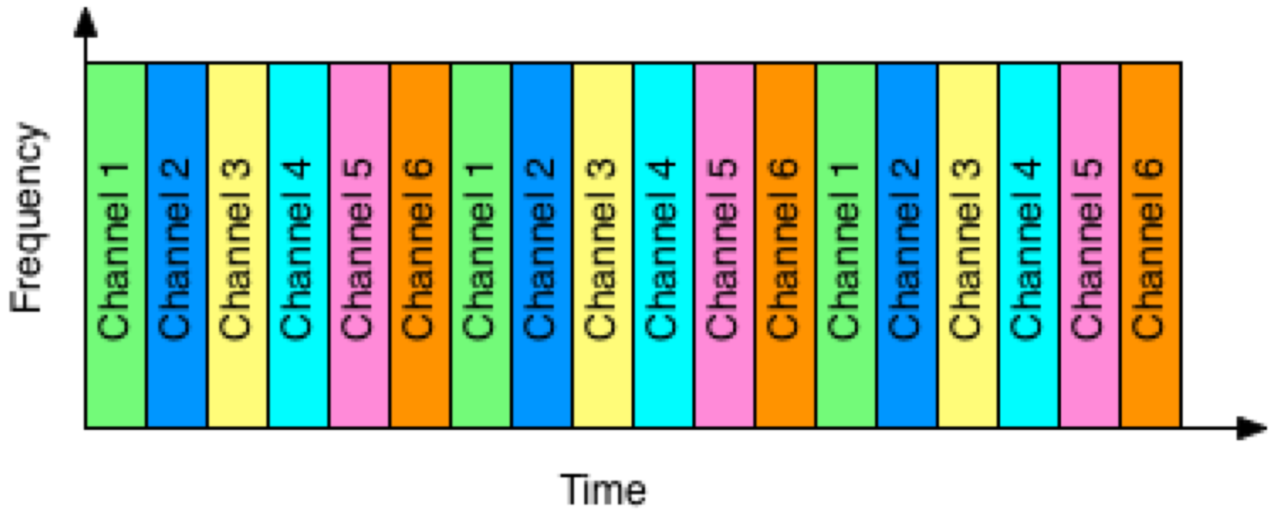


Figure 8.1 Multiplexing

Multiplexing in time/frequency

FDM Frequency Division Multiplexing

TDM Time Division Multiplexing



Synchronous TDM

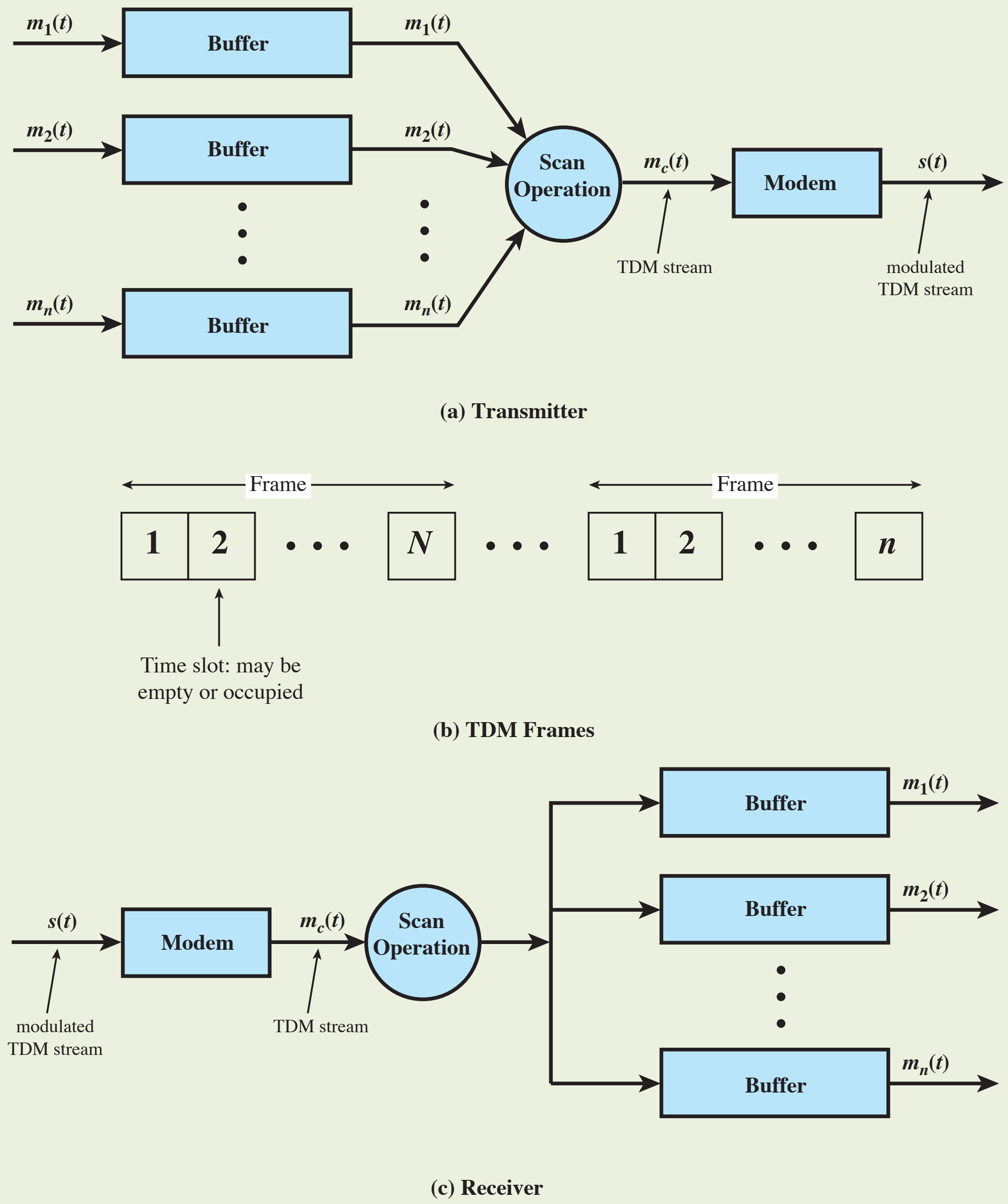


Figure 8.6 Synchronous TDM System

TDM Link Control

- Data link control protocols not needed
  - Time is control parameter
  - No headers and trailers
- Flow control
  - Data rate of multiplexed line is fixed
  - If one channel receiver can not receive data, the others must carry on. The corresponding source must be turned off, leaving empty slots for a while.
- Error control
  - Errors handled on individual channel

Synchronisation

- Problem of synchronizing various data sources
  - E.g. variation or drift in clocks
- Common solution: Pulse stuffing
  - Outgoing data rate higher than sum of incoming rates
  - Stuff extra pulses (or bits) at predefined positions in the outgoing sequence
  - Pulses identified at the receiver, which can be used to synchronize with the transmitter.

Control of transmission

Simplex

- One way transmission

Half duplex

- Two way transmission, but not simultaneously

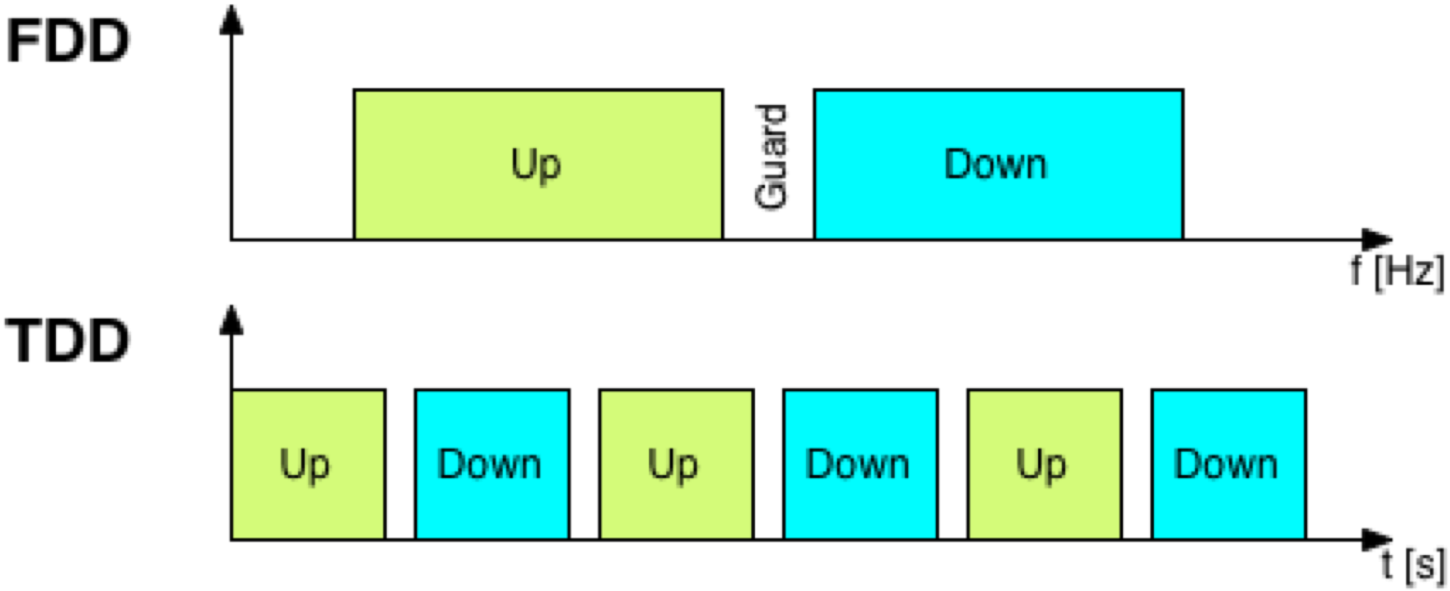
Full duplex

- Two way transmission

Duplexing

- FDD (Frequency Division Duplexing)
  - Separate Up-link and Down-link in frequency band
- TDD (Time Division Duplexing)
  - Separate Up-link and Down-link in time slots
- Wavelength duplexing
  - Up and Down signals separated by wavelength (optical networks)

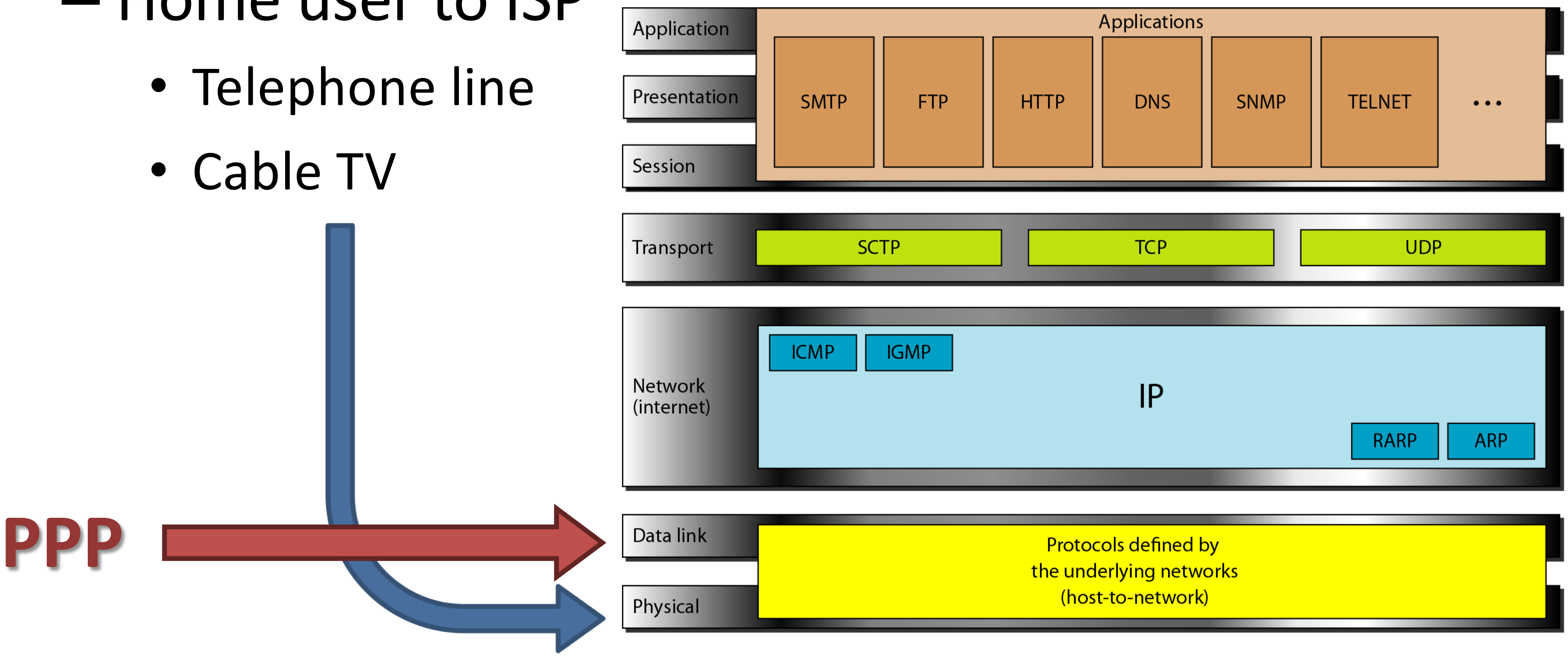
Duplexing



Wavelength like frequency

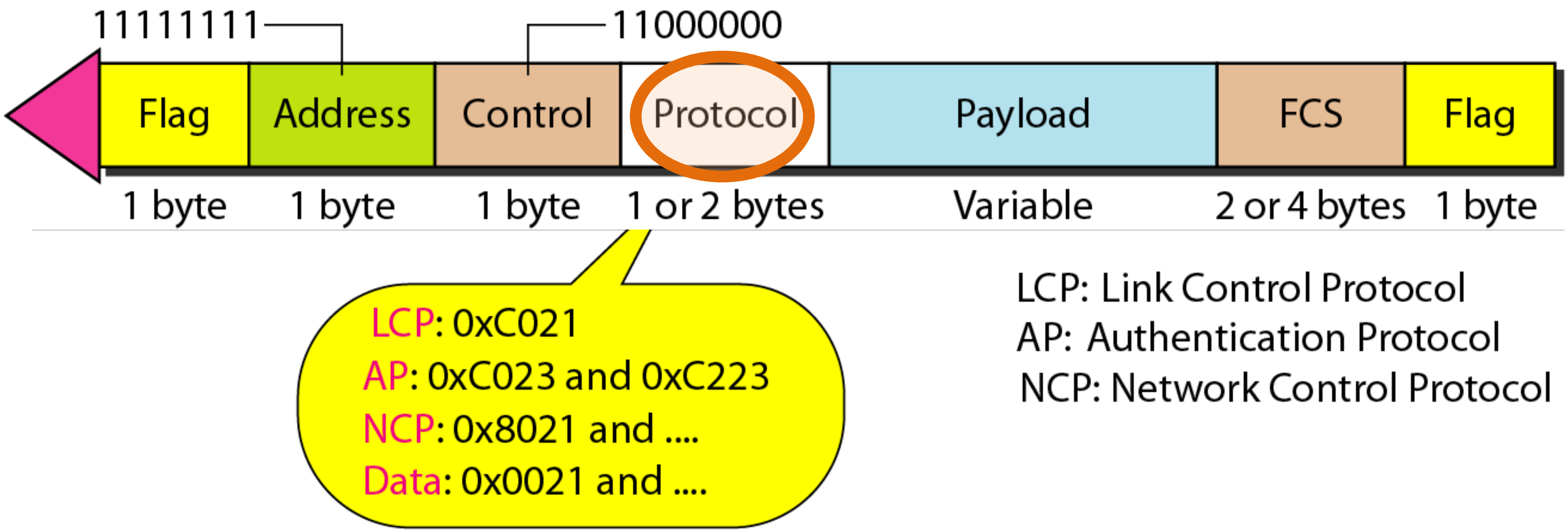
Point-to-point protocol (PPP)

- Direct connection between two nodes
  - Internet access
  - Home user to ISP
    - Telephone line
    - Cable TV



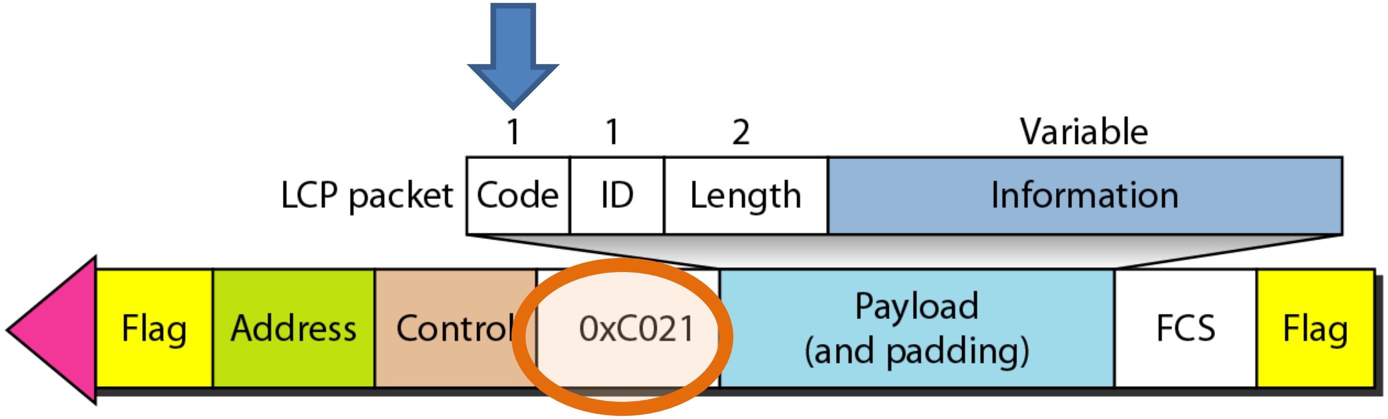
PPP frame format

- Support for several (sub)protocols
- Address & control not used
- Maximum payload 1500 bytes



Link control protocol (LCP)

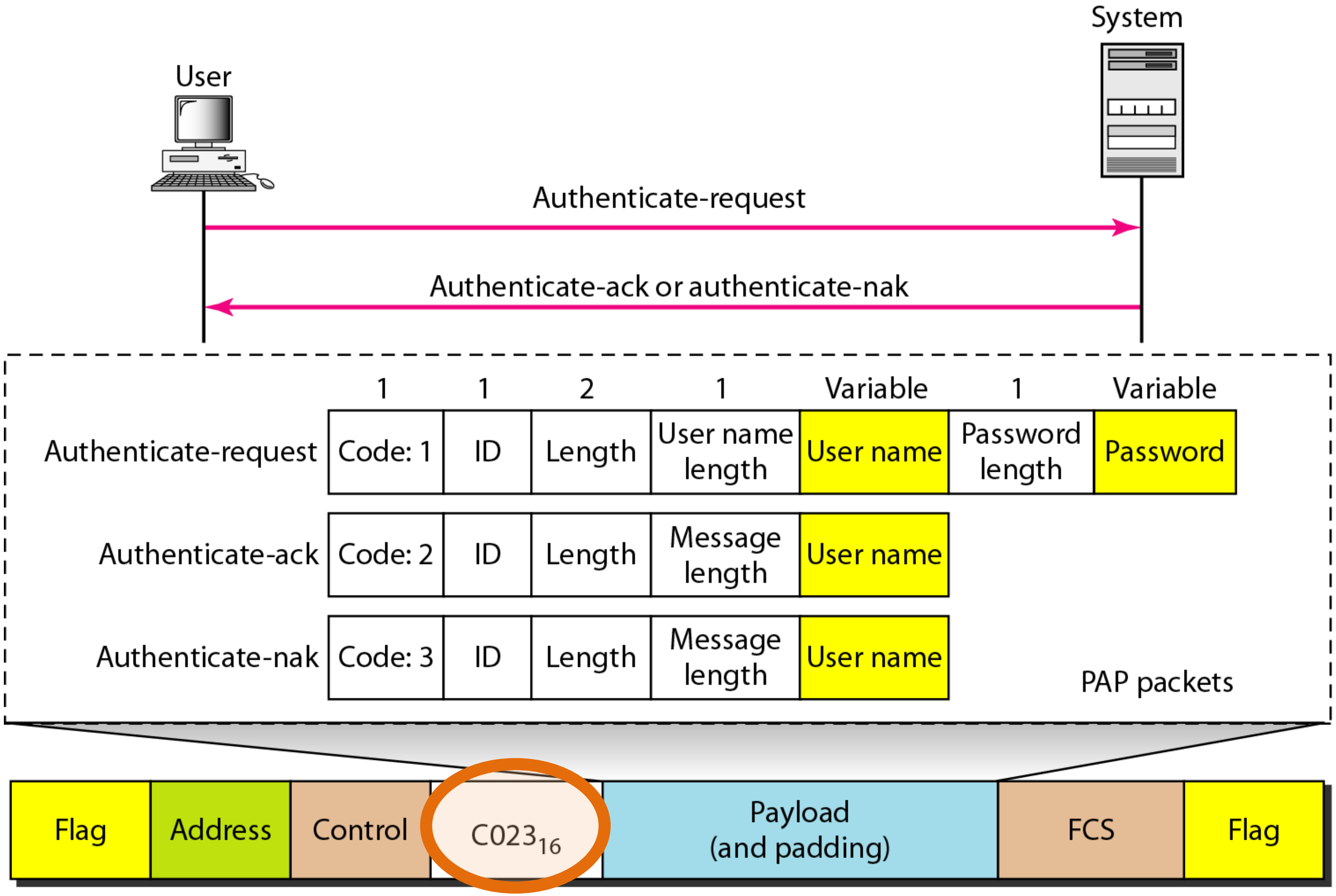
- Establish
- Configure
- Terminate



	Code	Packet Type	Description
Link Configuration	0x01	Configure-request	Contains the list of proposed options and their values
	0x02	Configure-ack	Accepts all options proposed
	0x03	Configure-nak	Announces that some options are not acceptable
	0x04	Configure-reject	Announces that some options are not recognized
Link Termination	0x05	Terminate-request	Request to shut down the line
	0x06	Terminate-ack	Accept the shutdown request
Monitoring and Debugging	0x07	Code-reject	Announces an unknown code
	0x08	Protocol-reject	Announces an unknown protocol
	0x09	Echo-request	A type of hello message to check if the other end is alive
	0x0A	Echo-reply	The response to the echo-request message
	0x0B	Discard-request	A request to discard the packet

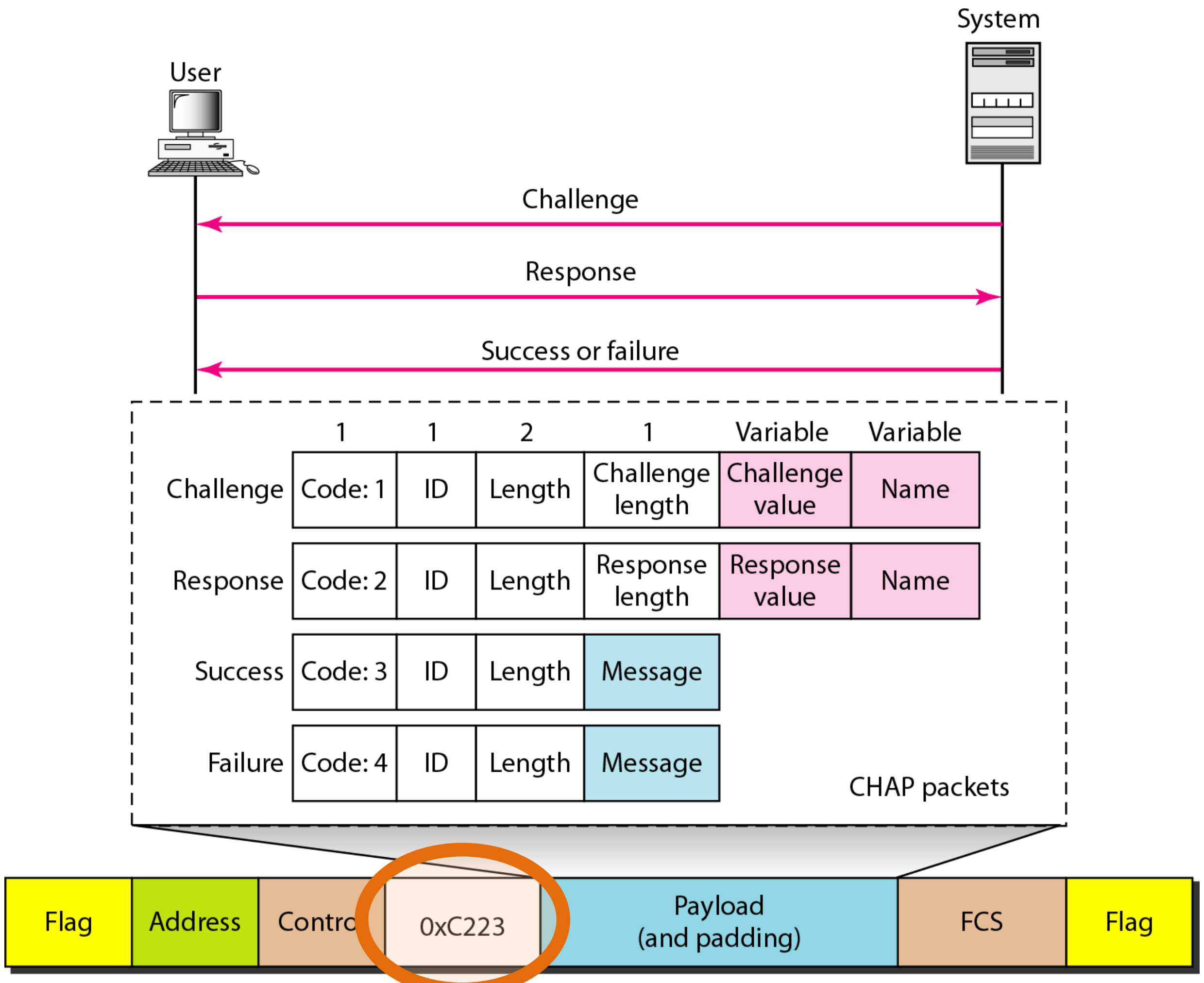
Authentication protocols (AP)

- Password authentication (PAP)



Authentication protocols (AP)

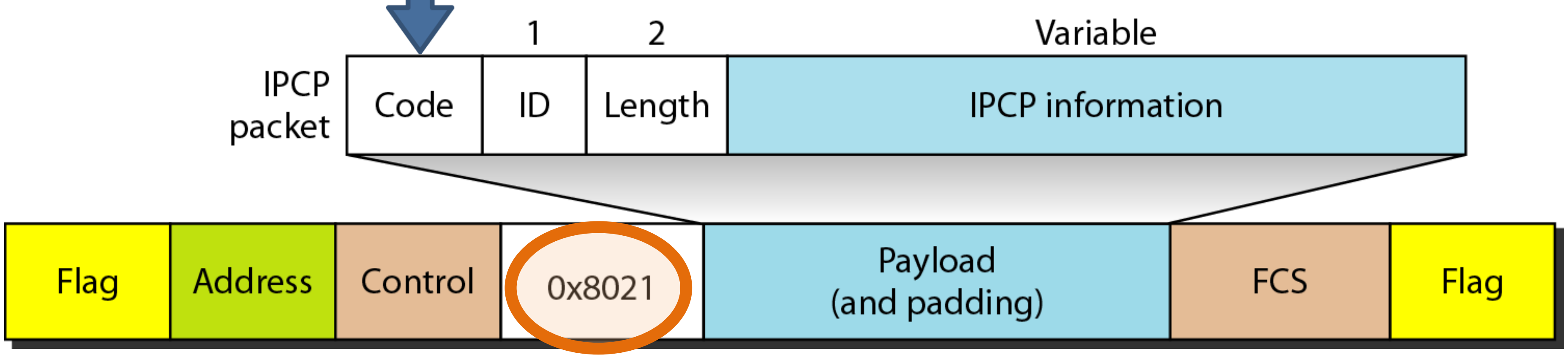
- Challenge handshake authentication (CHAP)



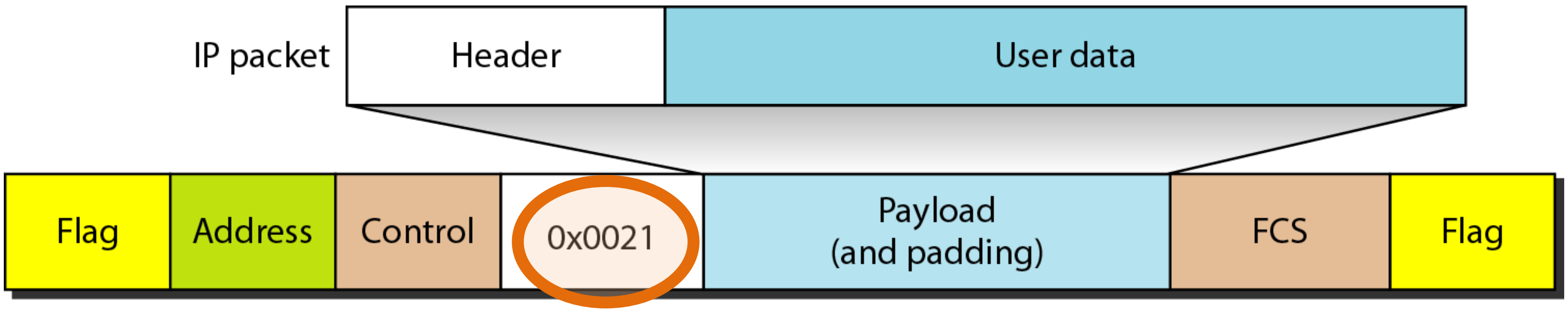
Network control protocols (NCP)

- Preparations for the network layer
  - IPCP for Internet

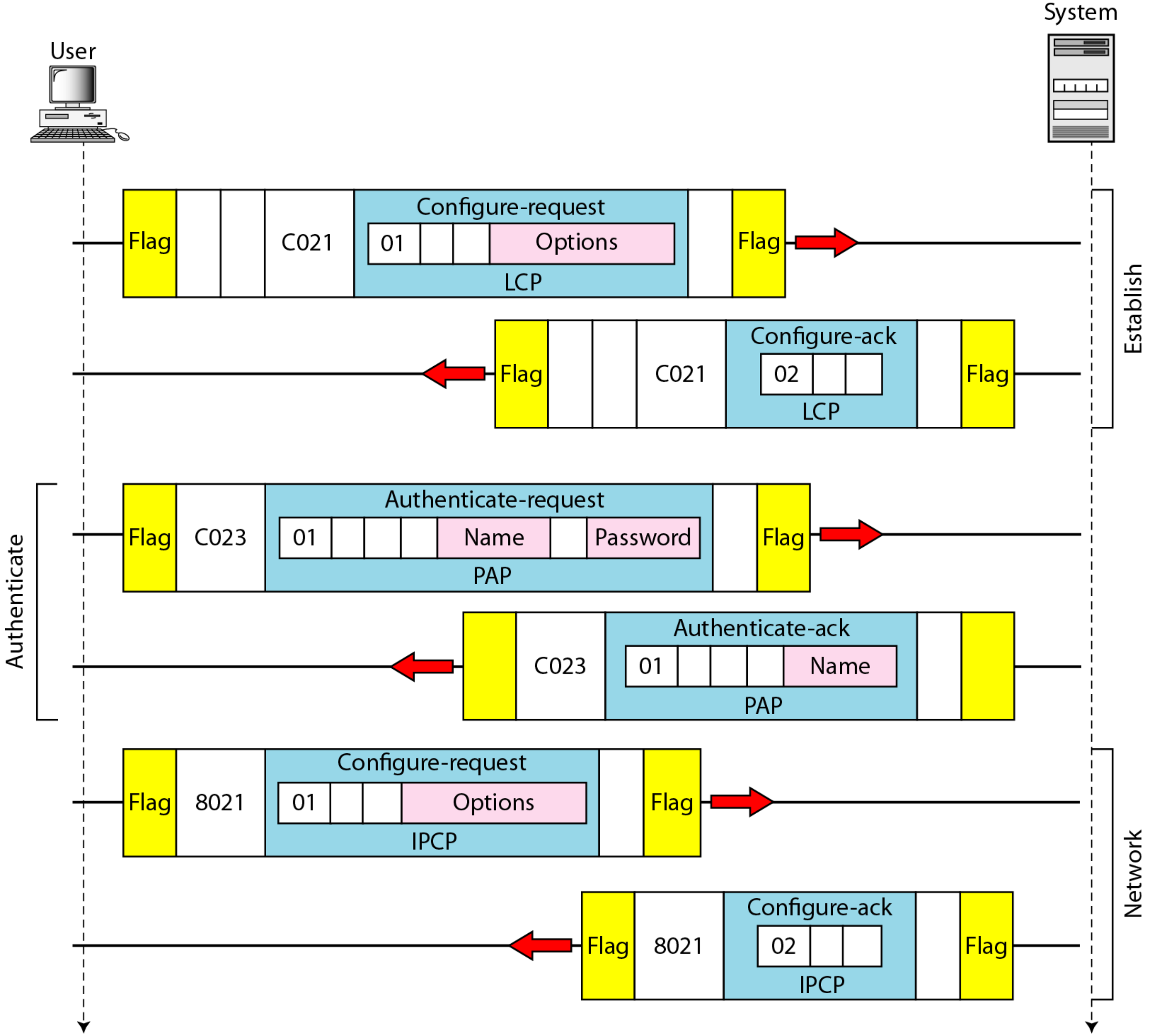
Code	*IPCP Packet*
0x01	Configure-request
0x02	Configure-ack
0x03	Configure-nak
0x04	Configure-reject
0x05	Terminate-request
0x06	Terminate-ack
0x07	Code-reject



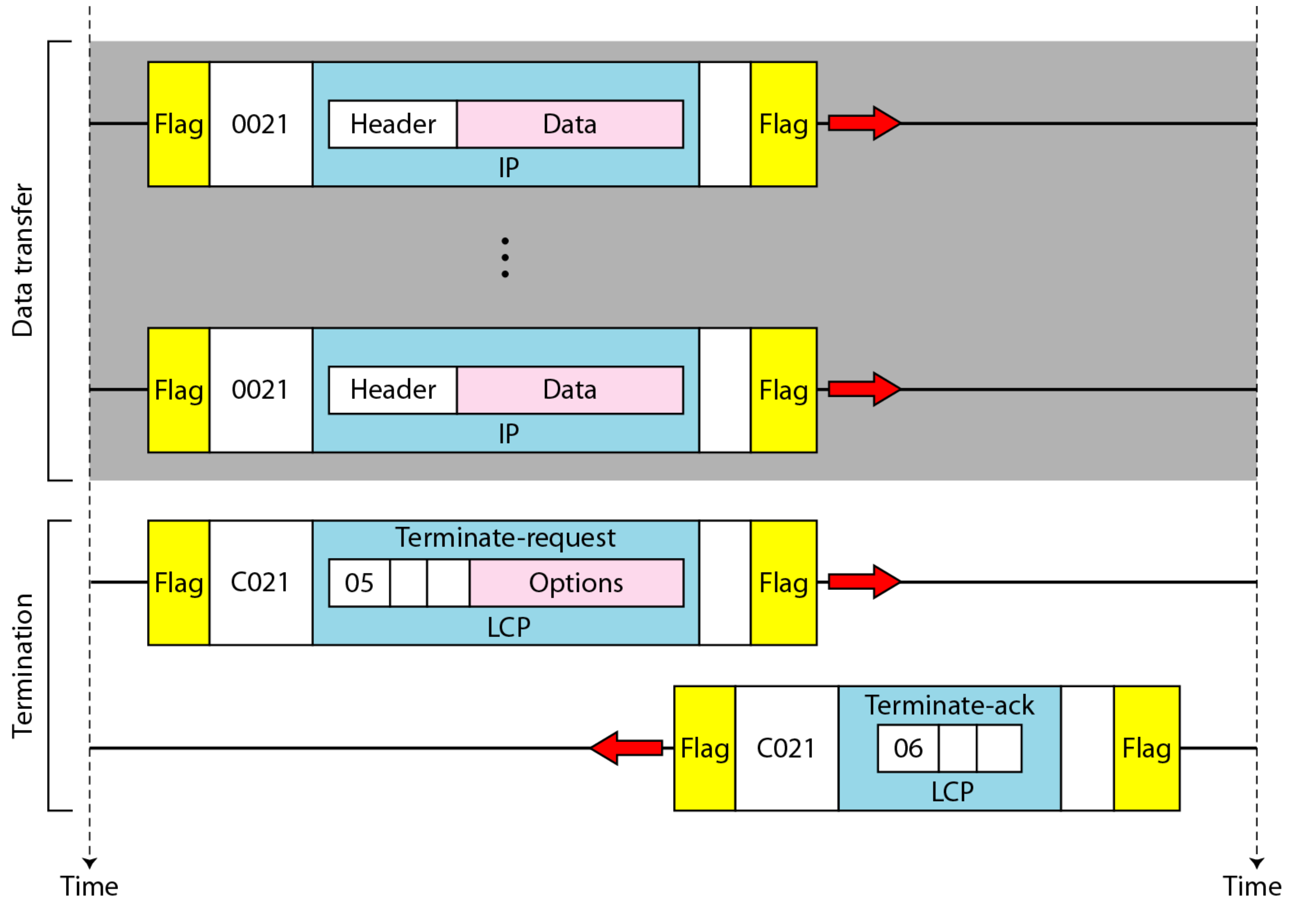
IP datagram encapsulation in PPP



PPP session example



PPP session example (cont'd)



SONET/SDH

- Synchronous Optical Network (ANSI)
- Synchronous Digital Hierarchy (ITU-T)
- High speed capability of optical fiber
- Defines hierarchy of signal rates
    - Synchronous Transport Signal level 1 (STS-1) or Optical Carrier level 1 (OC-1) is 51.84Mbps
    - Carries one DS-3 or multiple (DS1 DS1C DS2) plus ITU-T rates (e.g., 2.048Mbps)
    - Multiple STS-1 combine into STS-N signal
    - ITU-T lowest rate is 155.52Mbps (STM-1)

Digital hierarchy on optical links

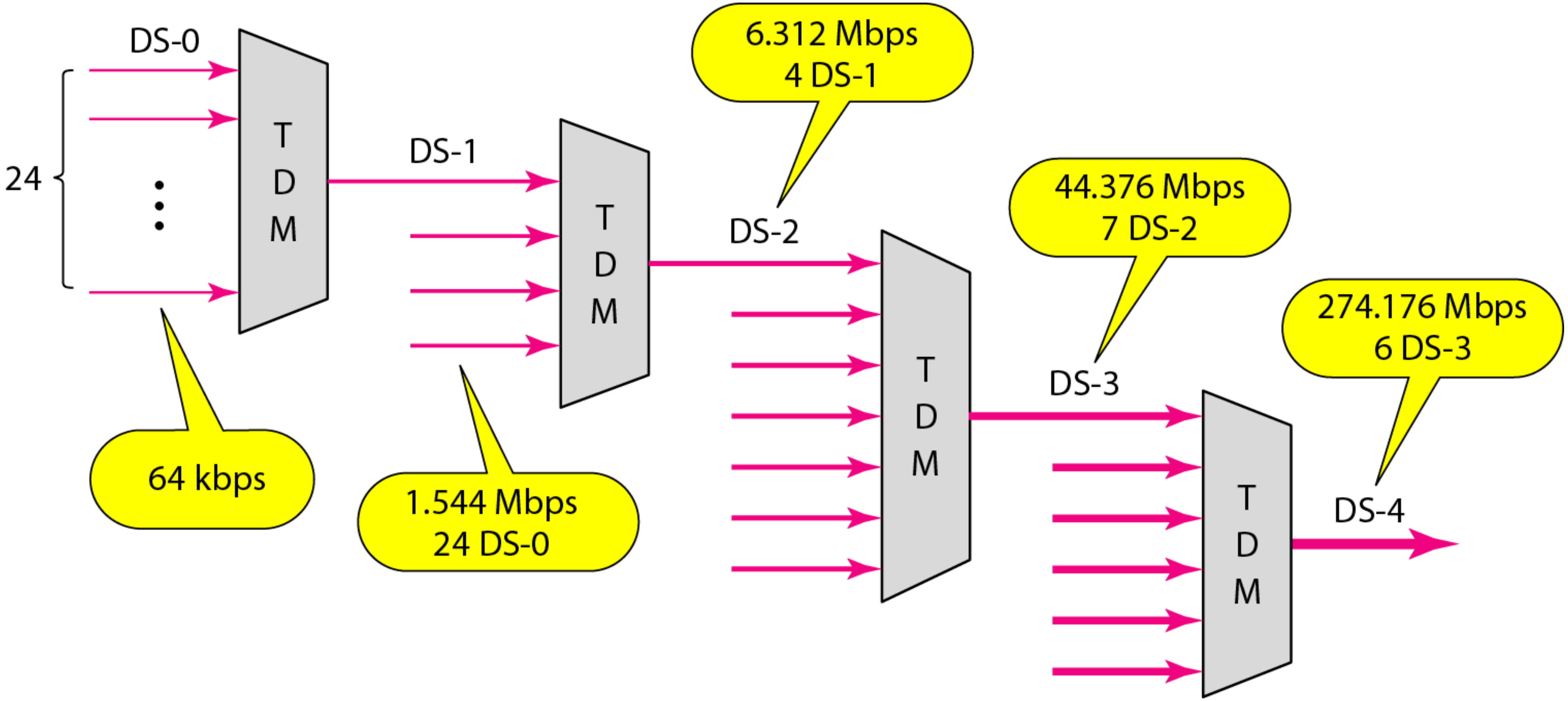


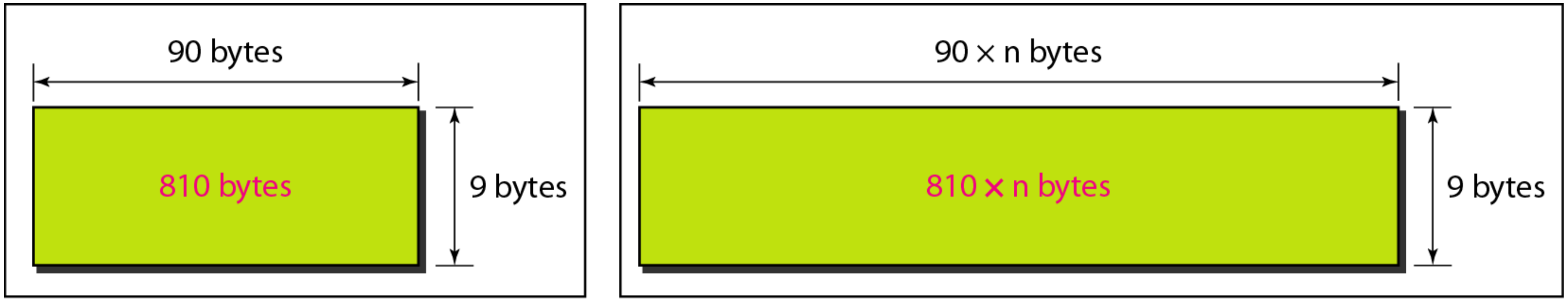
Table 8.4
SONET/SDH Signal Hierarchy

SONET Designation	ITU-T Designation	Data Rate	Payload Rate (Mbps)
STS-1/OC-1		51.84 Mbps	50.112 Mbps
STS-3/OC-3	STM-1	155.52 Mbps	150.336 Mbps
STS-12/OC-12	STM-4	622.08 Mbps	601.344 Mbps
STS-48/OC-48	STM-16	2.48832 Gbps	2.405376 Gbps
STS-192/OC-192	STM-64	9.95328 Gbps	9.621504 Gbps
STS-768	STM-256	39.81312 Gbps	38.486016 Gbps
STS-3072		159.25248 Gbps	153.944064 Gbps

SONET frames

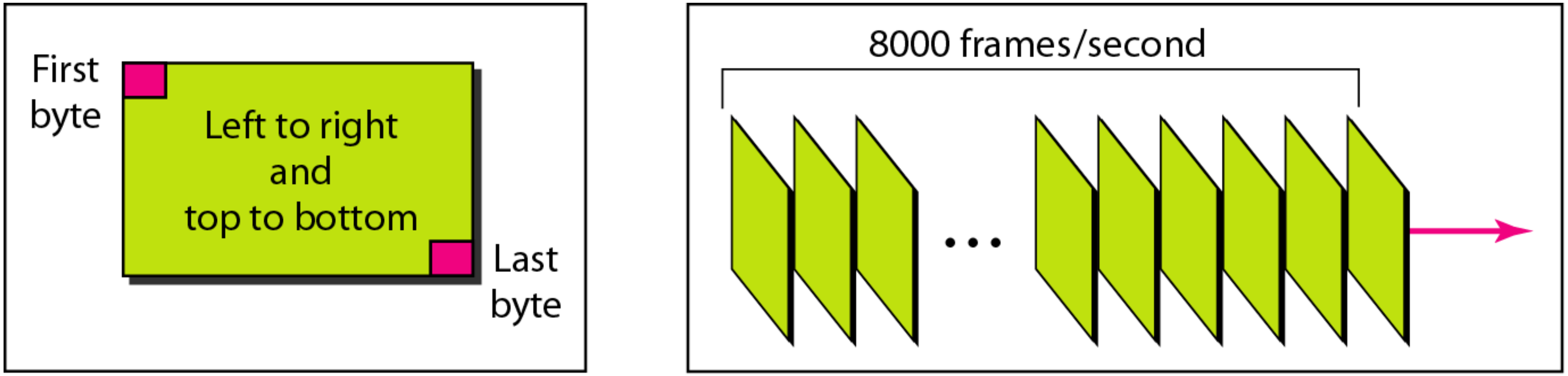
- Proportional to data rates

STS	*OC*	*Rate (Mbps)*	*STM*
STS-1	OC-1	51.840	
STS-3	OC-3	155.520	**STM-1**
STS-9	OC-9	466.560	**STM-3**
STS-12	OC-12	622.080	**STM-4**
STS-18	OC-18	933.120	**STM-6**
STS-24	OC-24	1244.160	**STM-8**
STS-36	OC-36	1866.230	**STM-12**
STS-48	OC-48	2488.320	**STM-16**
STS-96	OC-96	4976.640	**STM-32**
STS-192	OC-192	9953.280	**STM-64**



a. STS-1 frame b. STS-n frame

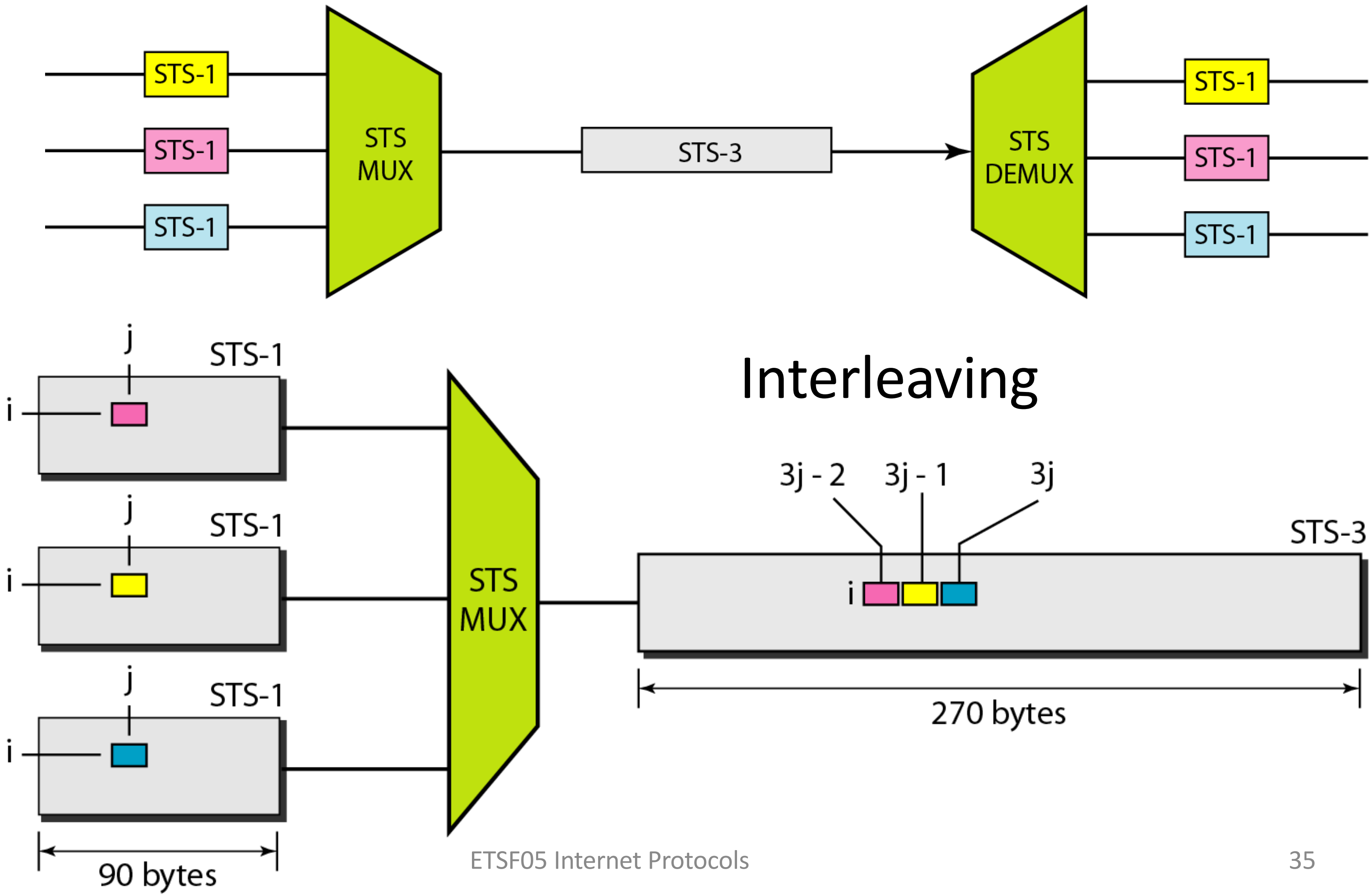
SONET frames in transmission



a. Byte transmission

b. Frame transmission

Multiplexing and byte interleaving



Network architecture

- Devices and connections

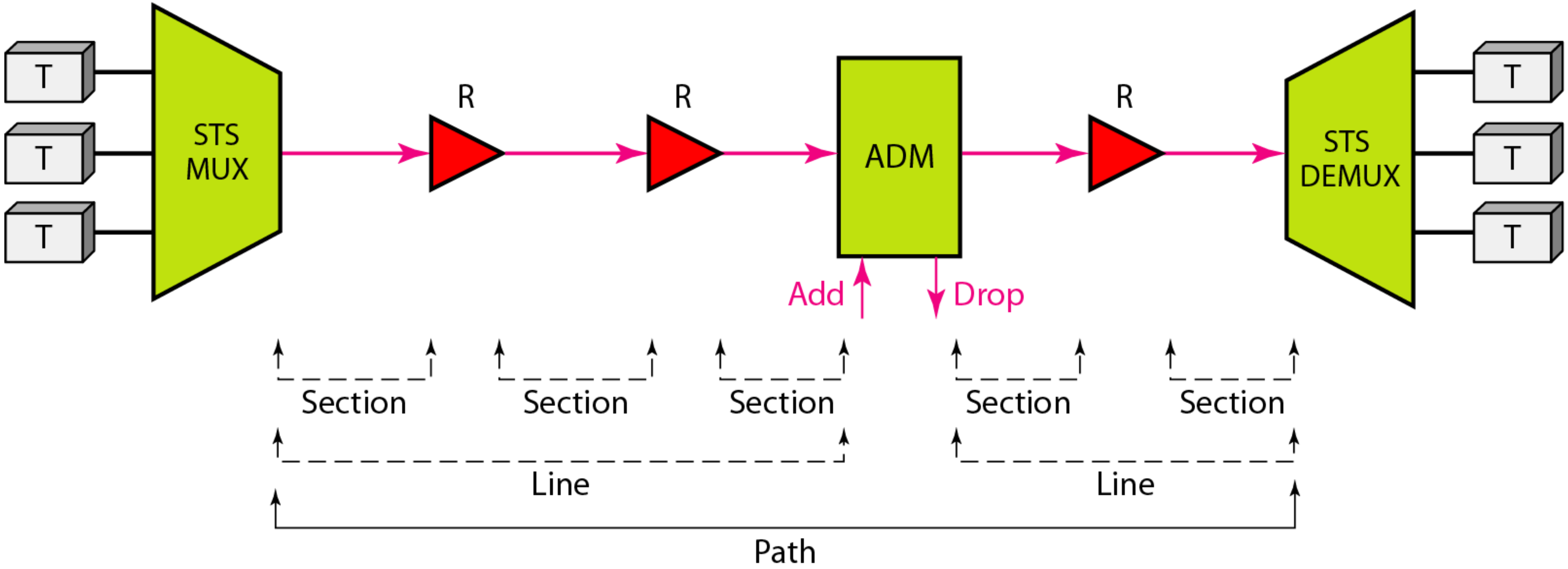
ADM: Add/drop multiplexer

STS MUX: Synchronous transport signal multiplexer

STS DEMUX: Synchronous transport signal demultiplexer

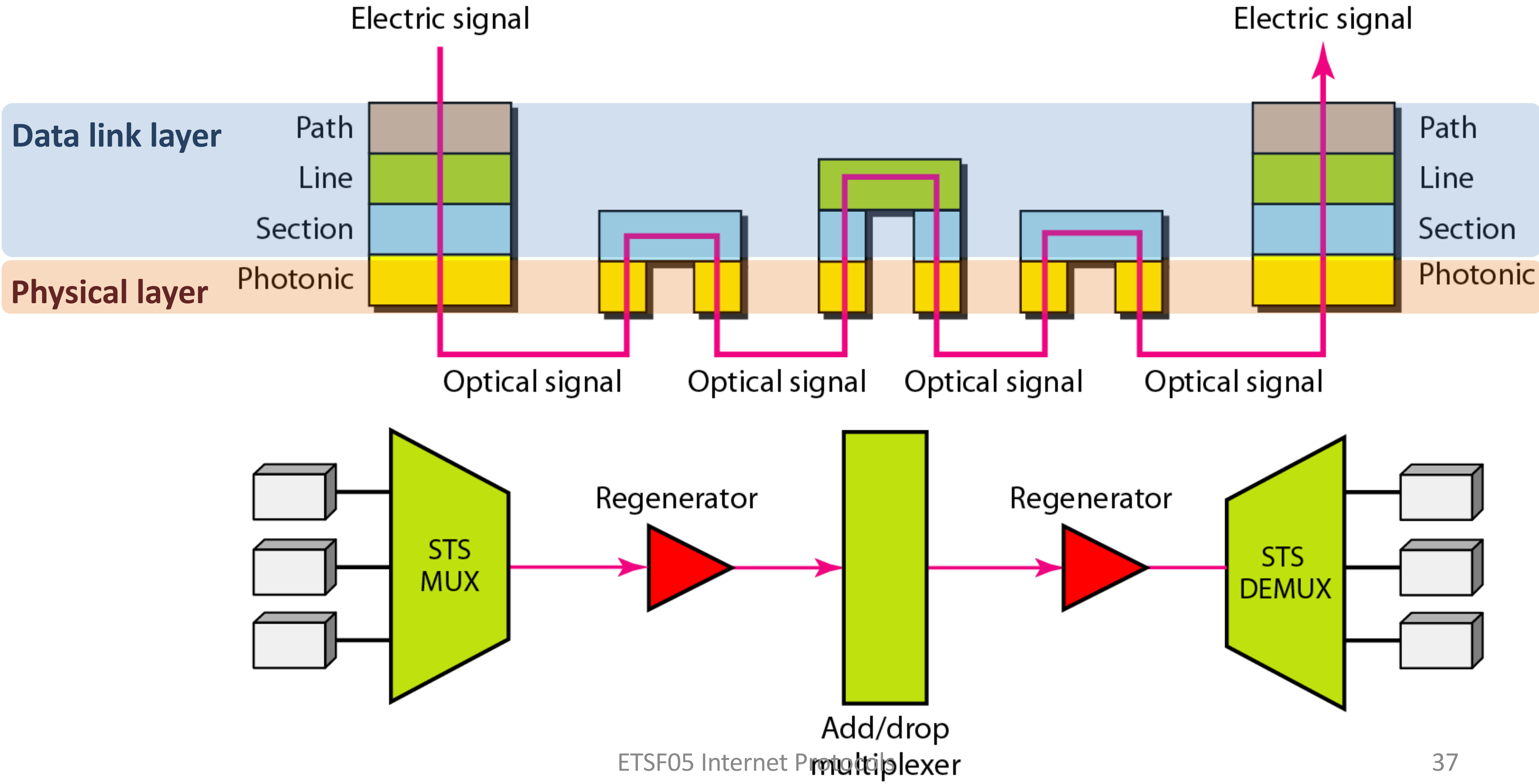
R: Regenerator

T: Terminal



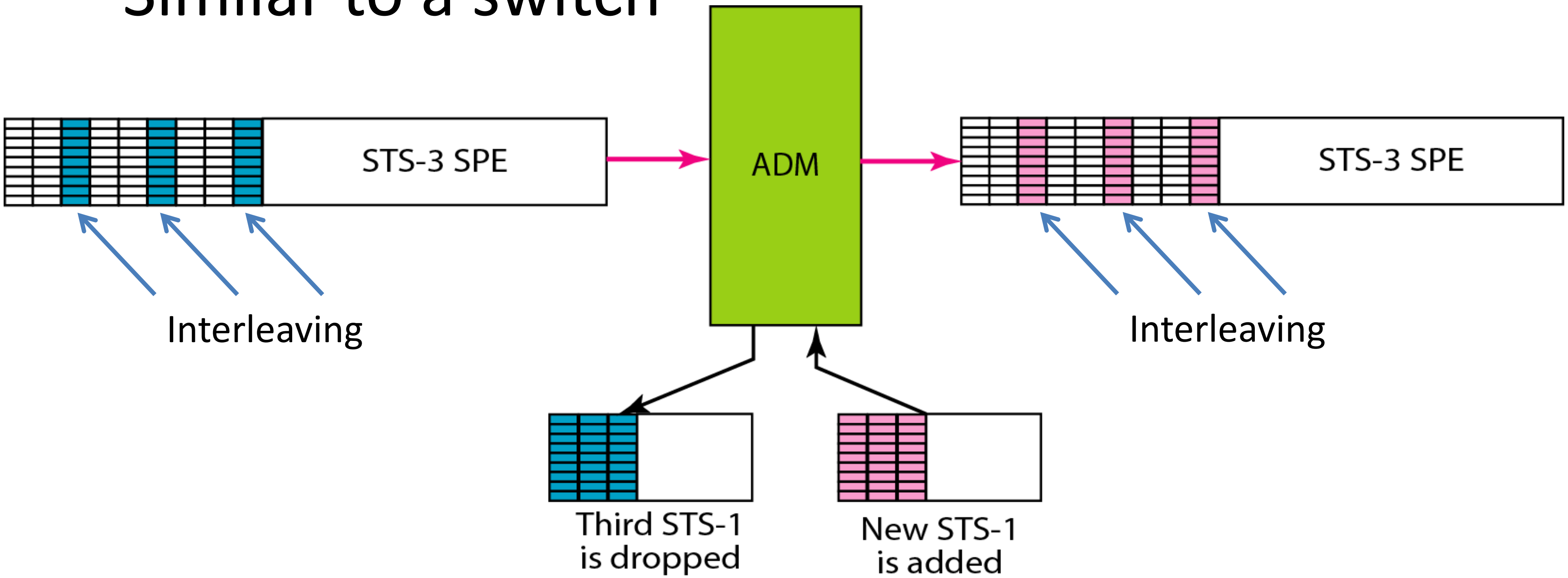
Network architecture

- Devices and layers



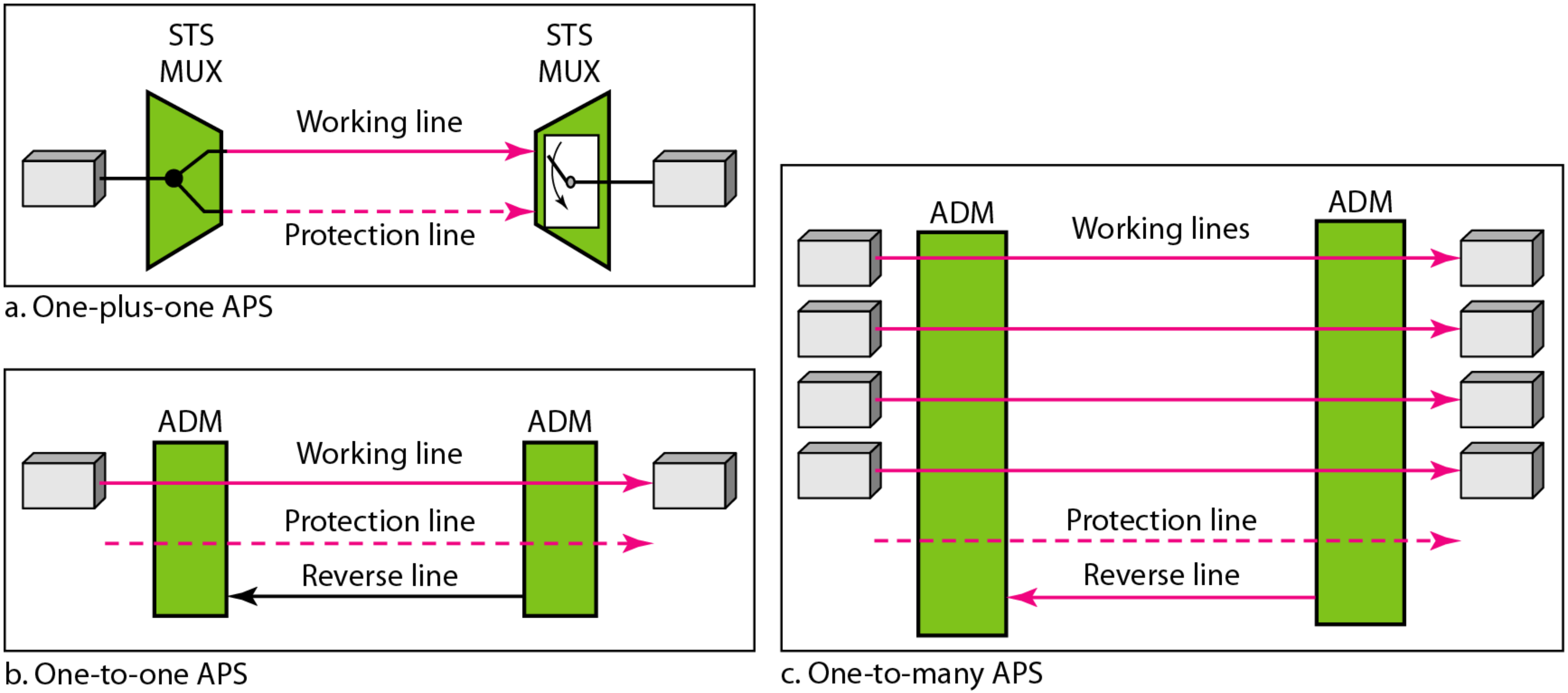
SONET add/drop multiplexer

- Replaces a signal with another one
- Operates at line layer
- Similar to a switch

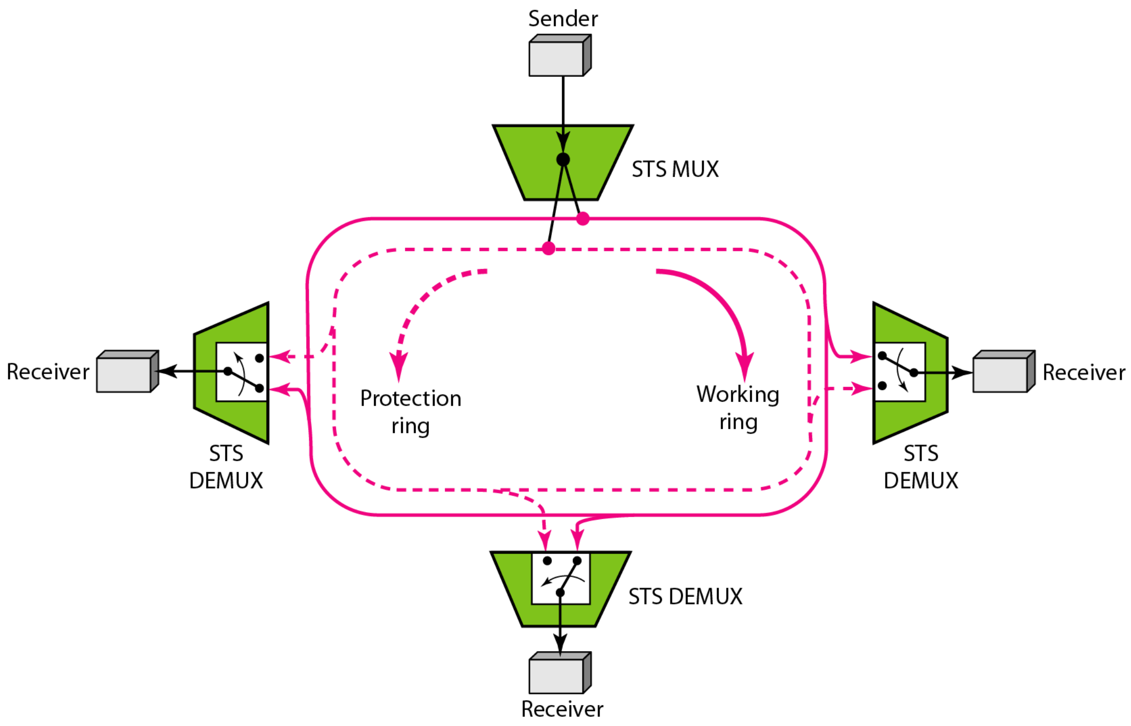


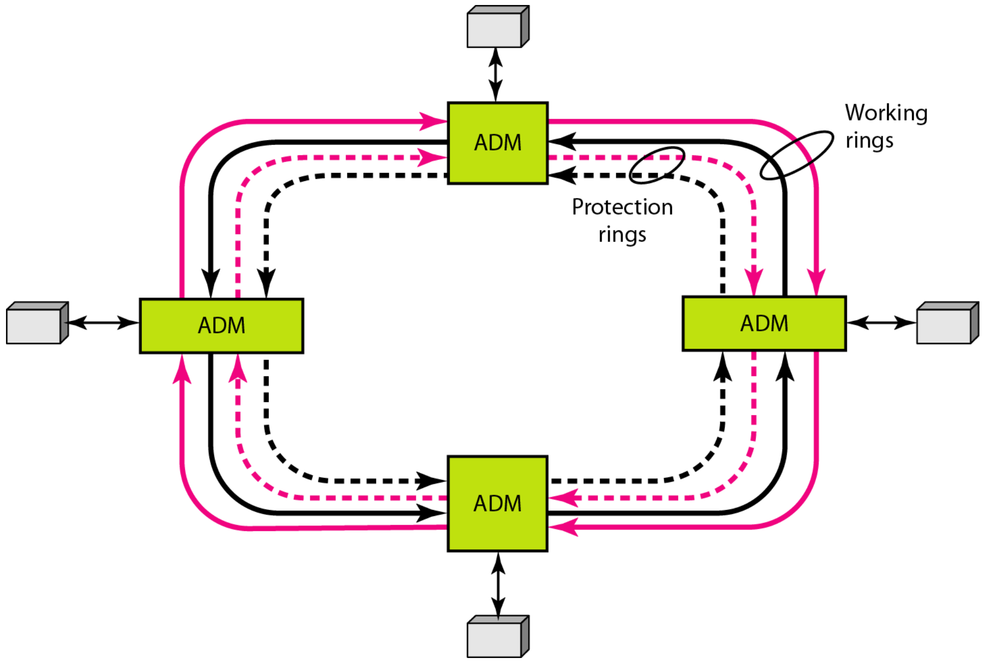
Automatic protection switching

- Failure protection through line redundancy



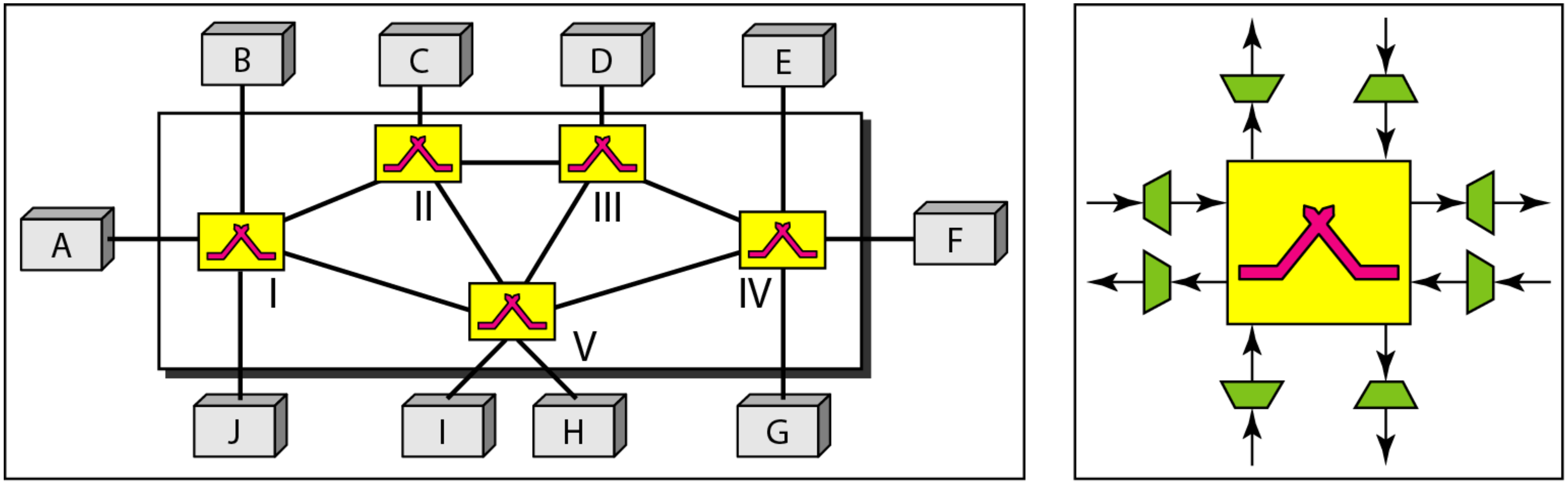
Ring SONET topology





Mesh SONET topology

- Better scalability
  - Multiplexing/demultiplexing at switches



a. SONET mesh network

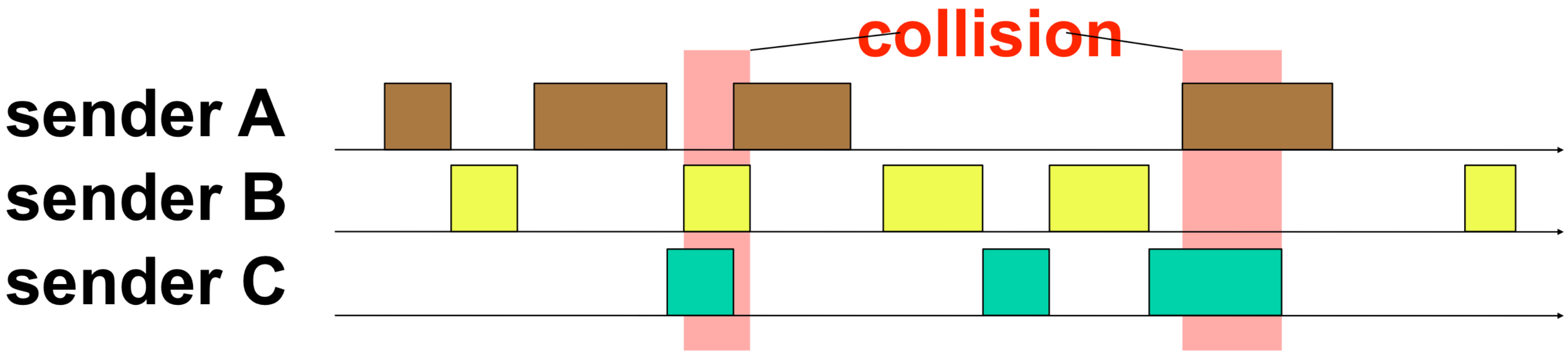
b. Cross-connect switch

Random Access Techniques

- No one “owns” resources
- Equal share of resources
- No central coordination

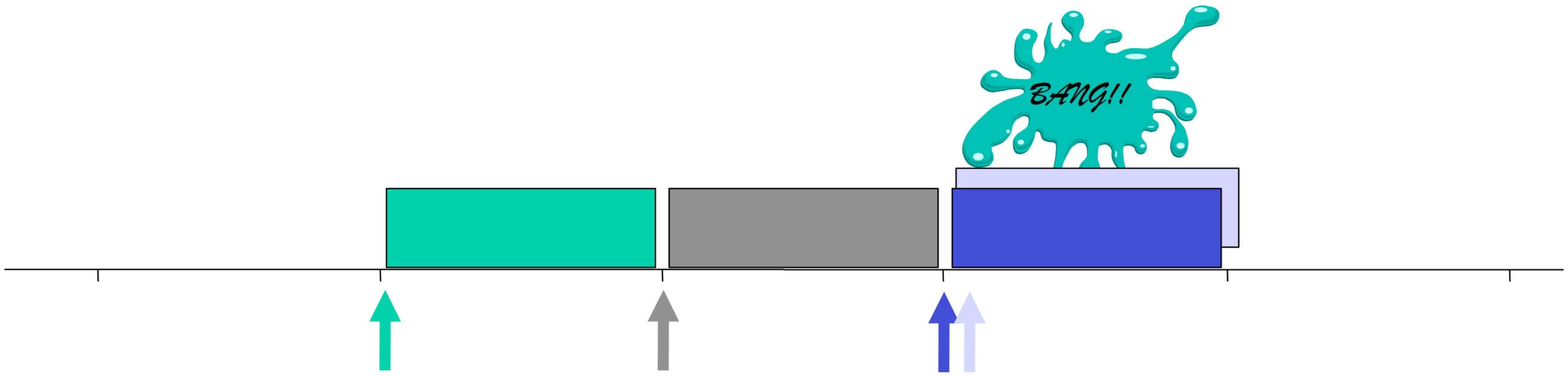
PURE ALOHA

- Whenever a station has something to send, it sends.
- When a packet is received by the central, an acknowledgement (ack) is sent back in broadcast.
- If the sending station does not receive an “ack” within a set time, a collision is assumed.
- When a collision, retransmit within a random time slot, 200-1500 ms.



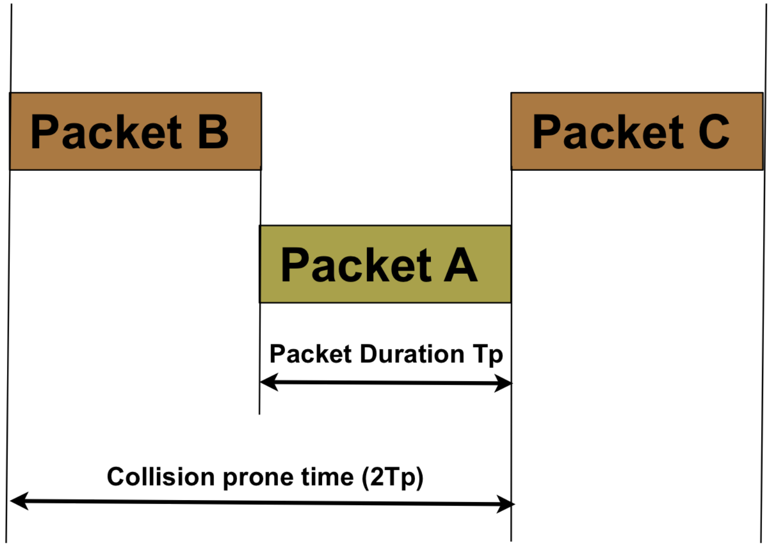
SLOTTED ALOHA

- Packets may just be transmitted within time slots.
- If a station has started to transmit in a time slot, other station who wish to transmit within this time slot can not interfere.
- This principle leads to a much better utilization of the channel.



ALOHA Performance

- Assumptions:
- Random independent packet generation
- Packet length Tp, Normalised packet generation rate $0 \geq \lambda_p \geq 1$



Aloha performance

- Packet generation process is Poisson distributed with:
  Probability n packets generated during time t

$$Pr(n,t) = \frac{(\lambda_p t)^n e^{(-\lambda_p t)}}{n!}$$

Probability zero packets generated during time t

$$Pr(0,t) = e^{(-\lambda_p t)}$$

Effective throughput = Rate x P_{succ} =

$$T_{put} = \lambda_p T_p e^{(-2\lambda_p T_p)}$$

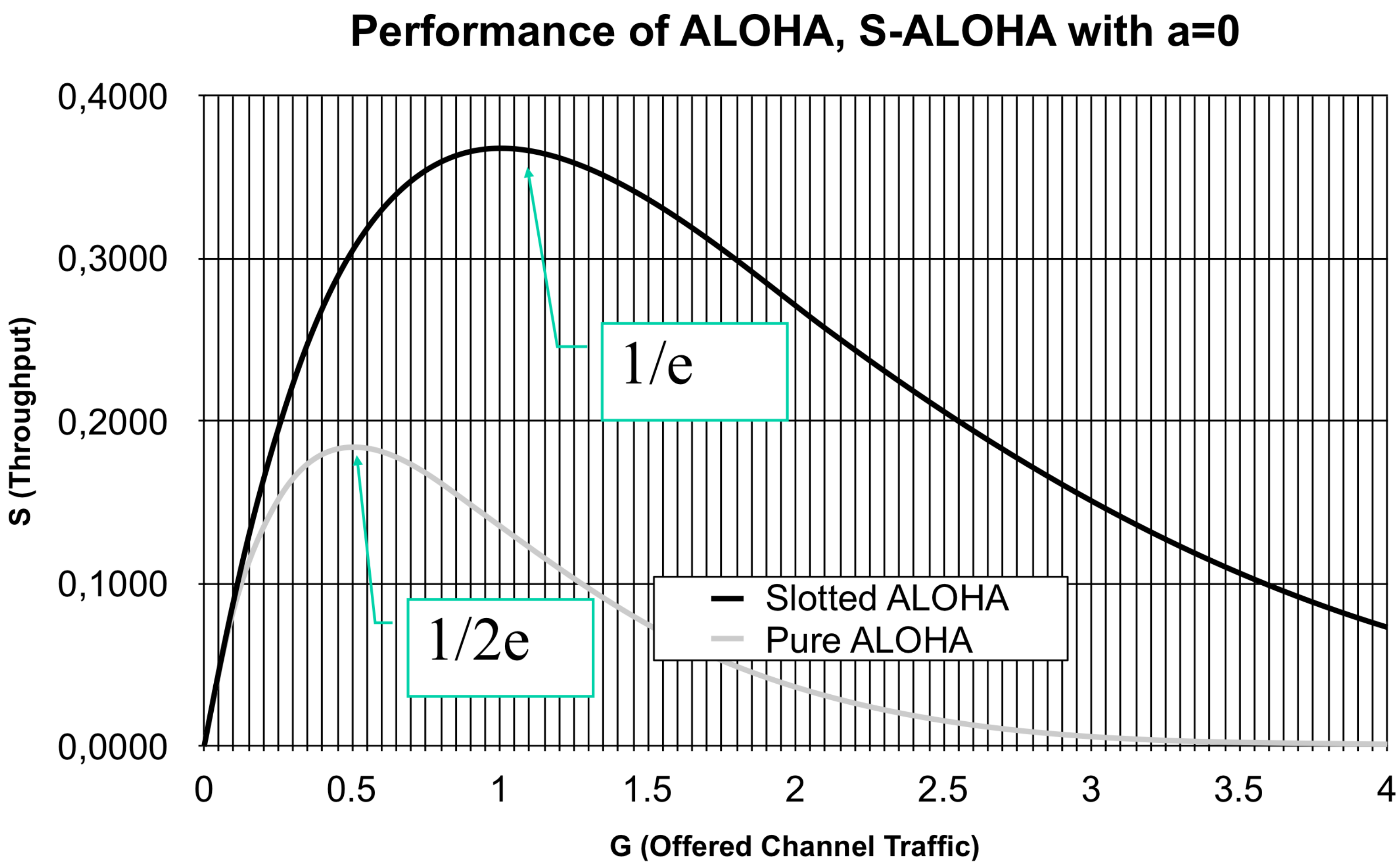
Maximum found at:

$$\frac{\partial}{\partial x} T_{put} = 0 => \frac{1}{2e}$$

For slotted Aloha, t = Tp

$$\frac{\partial}{\partial x} T_{put} = 0 => \frac{1}{e}$$

ALOHA PERFORMANCE



CSMA/CD

check carrier to see if cable busy **(CSMA)**

if yes

  wait for idle

  transmit (persistence scheme)

else

  transmit and listen for collision **(CD)**

  if collision

    backoff randomly and try again N times

  else wait min idle time - give others nodes a chance

  (distributed fairness, time slot == 51.2us for 10mbit)

CSMA/CD Persistence

- Aggressiveness after idle is detected
  - 1-persistence
    - Transmit as soon as possible
  - Non-persistence
    - If busy, wait random time then sense channel again
  - P-persistence
    - If busy, wait for idle and transmit with probability P

Persistence performance

- Definitions: G = Offered Load; S = throughput

$$S_1 = \frac{Ge^{-G}1+G}{G+e^{-G}} \qquad S_n = \frac{G}{1+G} \qquad S_p = \frac{Ge^{-G}1+pGx}{G+e^{-G}}$$

- Where: $x = \sum_{k=0}^{\infty} \frac{(qG)^k}{(1-q^{k+1})!}$ see (Kleinrock and Tobagi 1975)

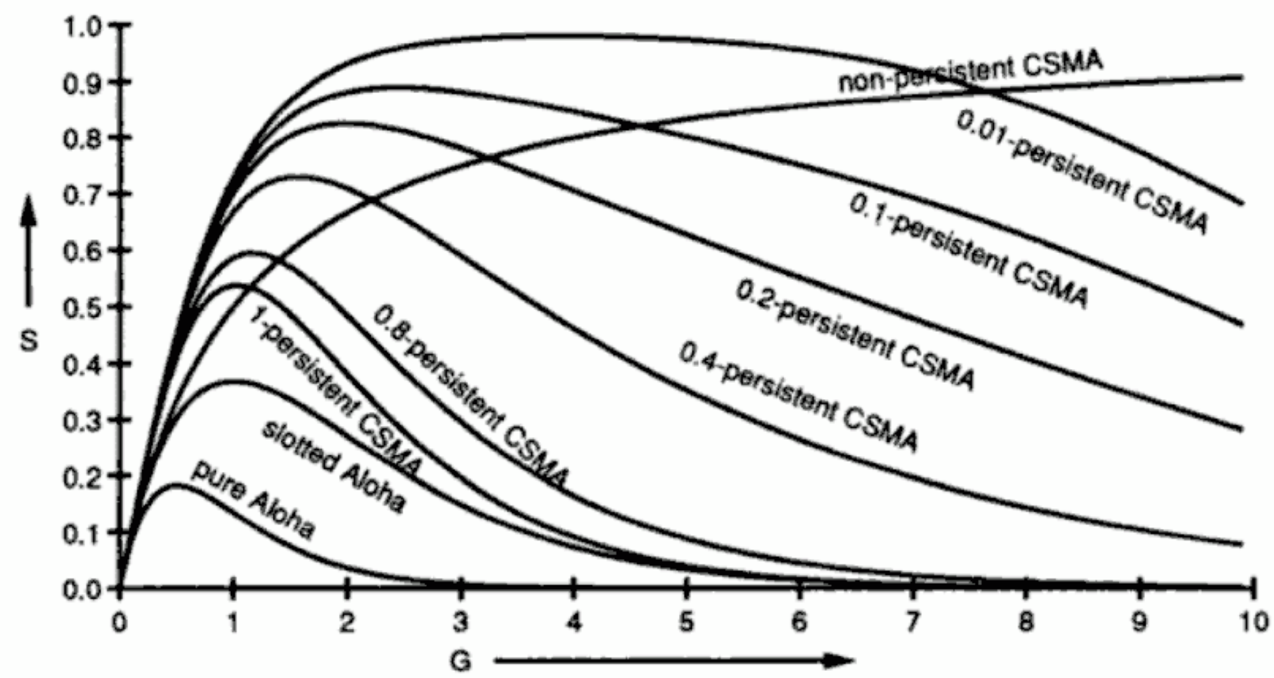


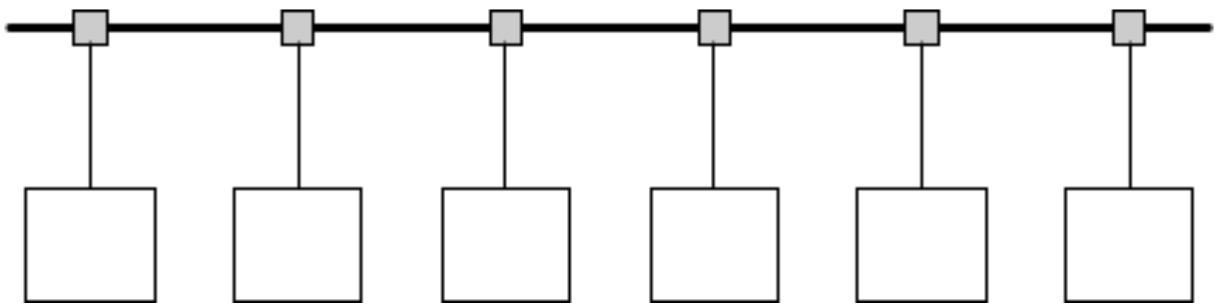
Fig 3.11. Channel Throughput: Aloha and CSMA

Collision Detection / Retransmission

- N tries, say 16
- if collision, must send jam signal, random backoff and retransmit
- jam == 512 bits (64 bytes), make sure end nodes hear collision, hence enet min frame is 64 bytes (46 data)
- backoff is "binary exponential algorithm"
- wait 1, 2, 4, 8 time-slots, etc * a random delay, max 1023

Ethernet

- IEEE 802.3
- Original: 10BASE-5
  - 1983
  - 10Mbps, Baseband, 500 meters
  - Coax as shared resource (collision domain)



Ethernet Properties

- broadcast bus
- distributed access control; i.e., no central “master” saying you may or may not
- hw gets every packet, may not pass it on
- CSMA/CD - carrier sense multiple access with collision detection

Ethernet Header

- Preamble = Phy synchronisation
- Addresses: Sender and Dest. MAC

Preamble	Destination Address	Source Address	Frame Type	Frame Data	CRC
8 octets	6 octets	6 octets	2 octets	46–1500 octets	4 octets

Ethernet Addressing

- each controller has ***UNIQUE*** (!) ethernet or MAC address, assigned via IEEE in its “brains” (rom, flash memory, whatever)
- 48-bit integer, 6 unsigned char bytes
  - unicast address: **00:00:C0**:01:02:03
- first 3 bytes are manufacturer code
  - Intel: 00:AA:00
  - Sun: 08:00:20
- standards.ieee.org/db/oui/index.html - IEEE web page for MAC lookup

Address types

- **unicast** - physical address of controller
- **broadcast**: *ff:ff:ff:ff:ff:ff*
- **multicast**: *01:xx:xx:xx:xx:xx*

Errors

- Enet uses CRC, 32 bit “hash code”
- all bit errors are caught by CRC? (no)
  - ethernet crc is better than IP checksum though
- most are caught? (yes)
- that your packet will arrive for sure ? (no)
  - collisions or output i/f may toss as too busy
  - routers are busy and throw packets out (congestion)
  - “noise” causes CRC error, therefore packet is tossed
- if you have 10 routers end to end, CRC is enough to guarantee reliability? (no way)

WLAN and WiFi

- IEEE 802.11
- ”Wireless Ethernet”
- Three types of configuration

Single accesspoint

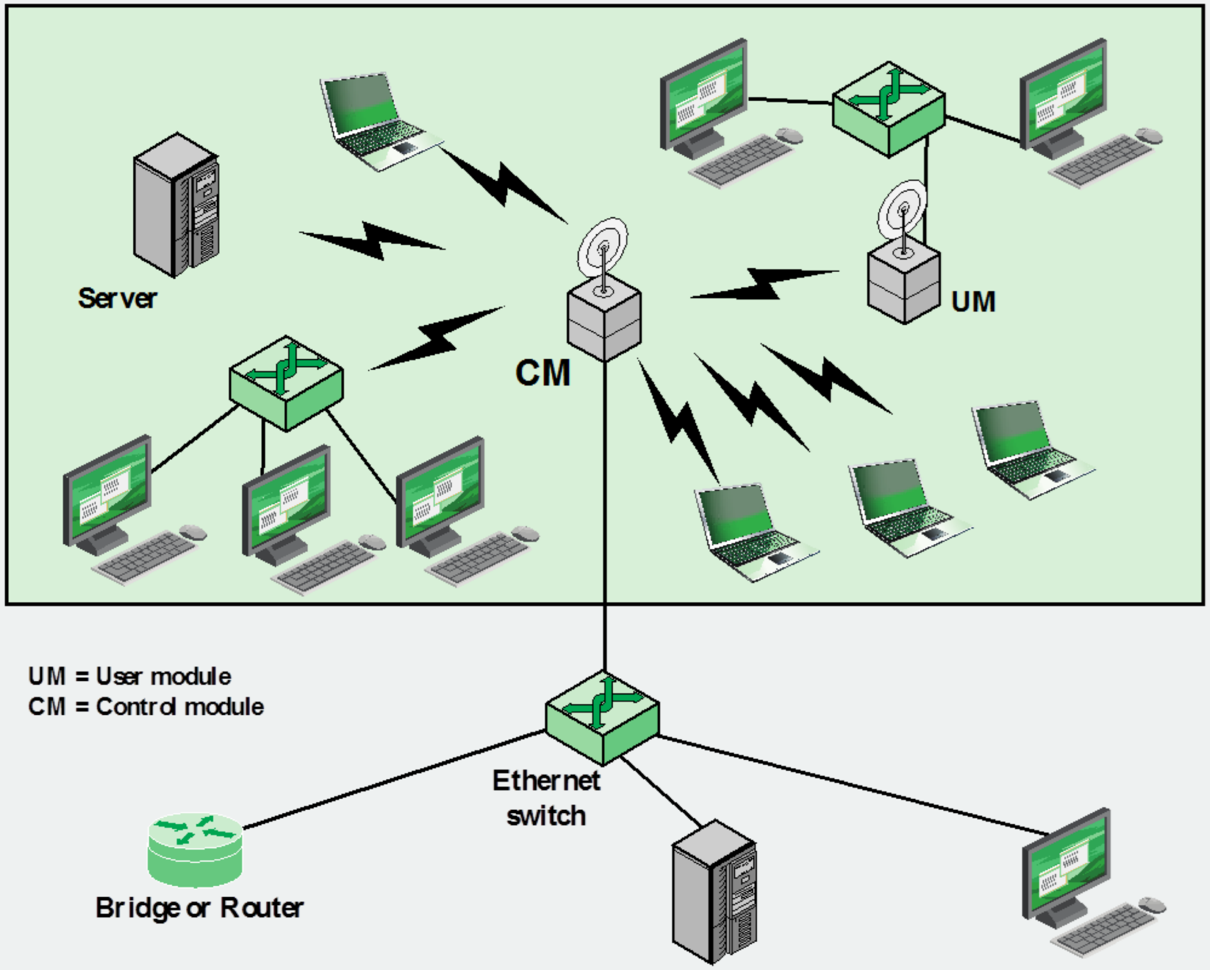


Figure 13.1 Example Single-Cell Wireless LAN Configuration

Multiple accesspoints

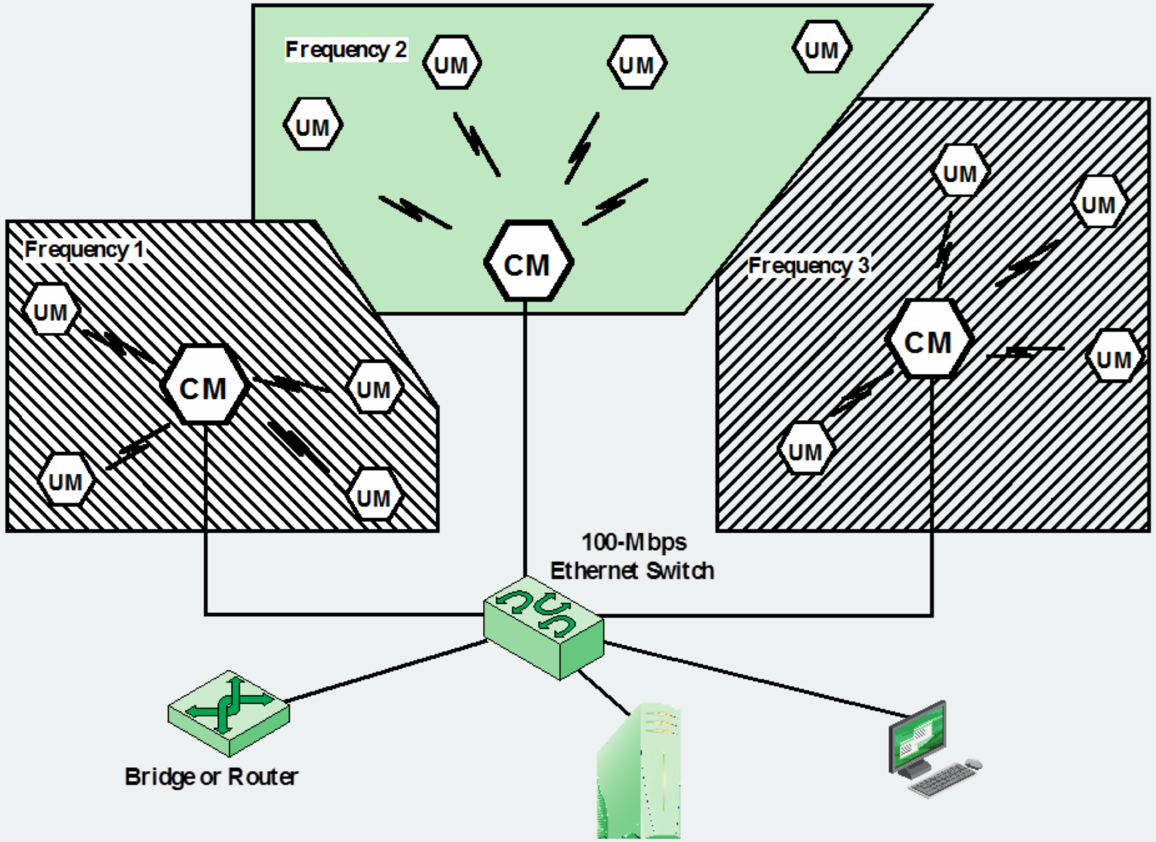


Figure 13.2 Example Multiple-Cell Wireless LAN Configuration

Ad Hoc (no accesspoint)

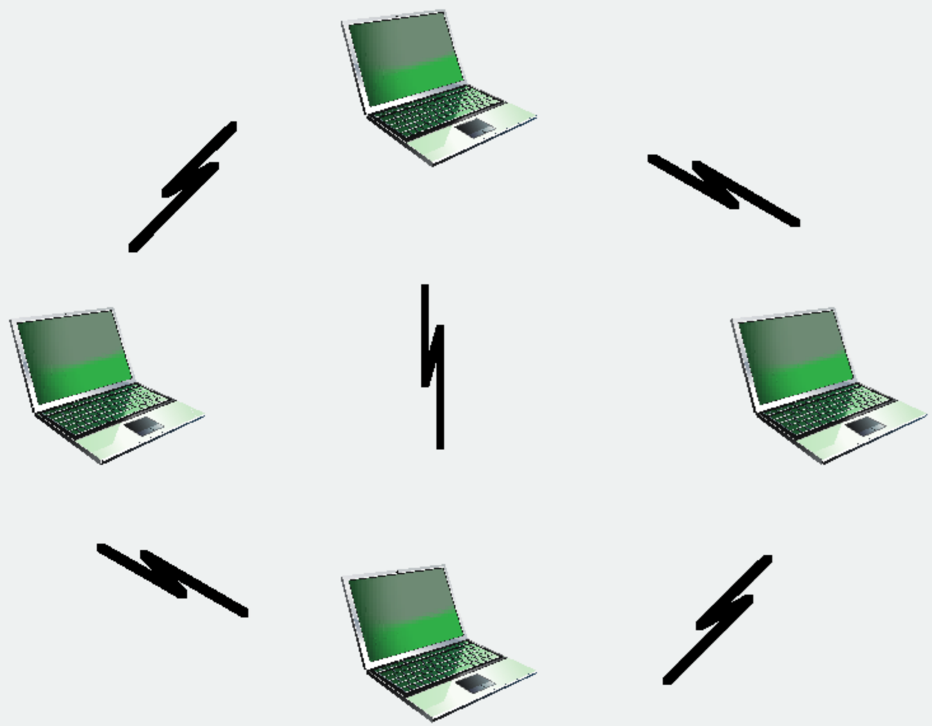


Figure 13.3 Ad Hoc Wireless LAN Configuration

Wireless LAN Considerations

- Throughput
- Number of nodes
- Connection to backbone LAN
- Service area (typical diameter 100-300 m)
- Battery power consumption
- Transmission robustness and security
- Collocated network operation (overlap)
- License-free operation (2.4 GHz and 5 GHz)
- Hand over/roaming
- Dynamic configuration

Wi-Fi Alliance

- Need for standardization
- Wireless Ethernet Compatibility Alliance (WECA)
  - Industry consortium formed in 1999
- Renamed the Wi-Fi (Wireless Fidelity) Alliance
  - Created a test suite to certify interoperability for 802.11 products

Table 13.1
Key IEEE 802.11 Standards

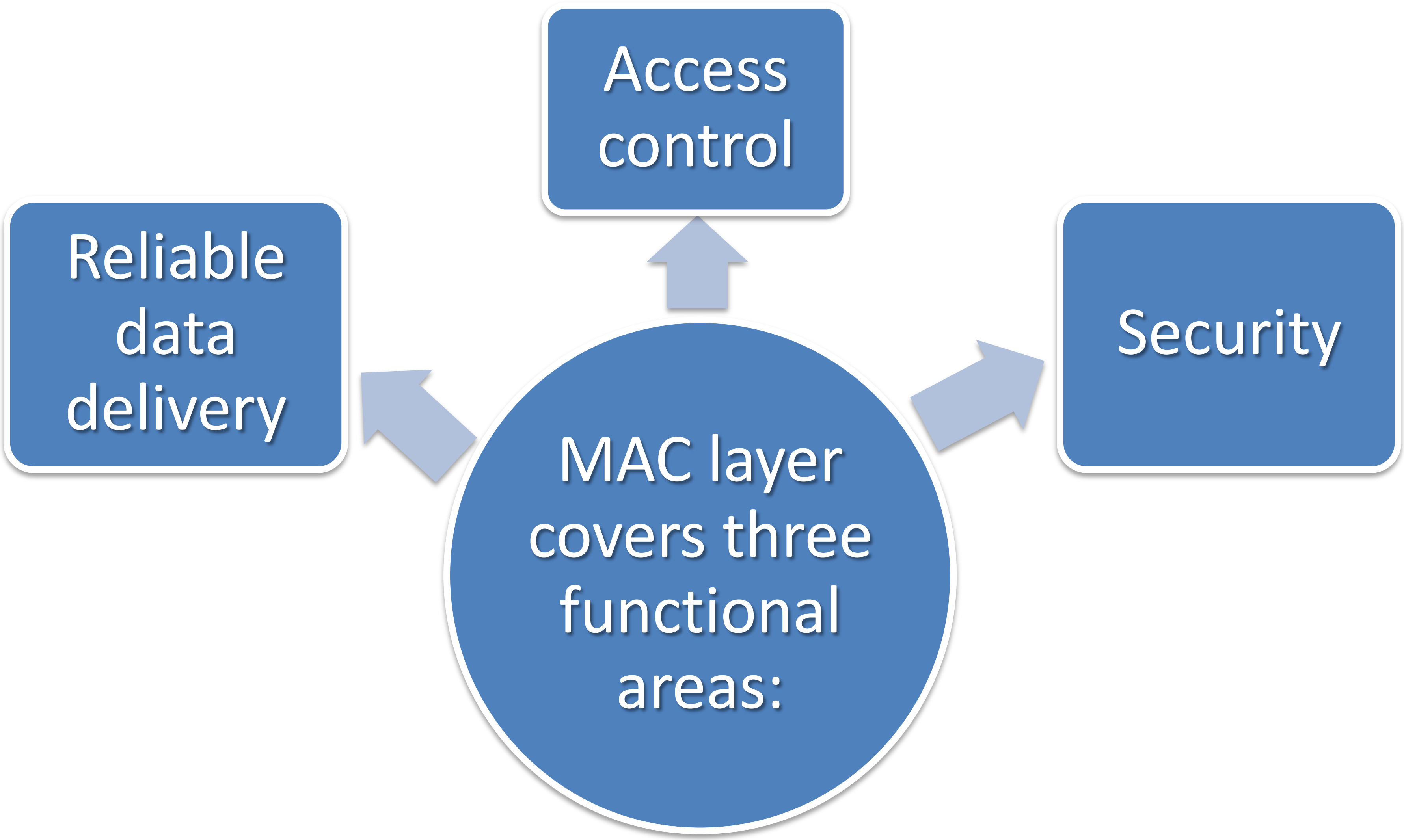
Standard	Scope
IEEE 802.11a	Physical layer: 5-GHz OFDM at rates from 6 to 54 Mbps
IEEE 802.11b	Physical layer: 2.4-GHz DSSS at 5.5 and 11 Mbps
IEEE 802.11c	Bridge operation at 802.11 MAC layer
IEEE 802.11d	Physical layer: Extend operation of 802.11 WLANs to new regulatory domains (countries)
IEEE 802.11e	MAC: Enhance to improve quality of service and enhance security mechanisms
IEEE 802.11g	Physical layer: Extend 802.11b to data rates >20 Mbps
IEEE 802.11i	MAC: Enhance security and authentication mechanisms
IEEE 802.11n	Physical/MAC: Enhancements to enable higher throughput
IEEE 802.11T	Recommended practice for the evaluation of 802.11 wireless performance
IEEE 802.11ac	Physical/MAC: Enhancements to support 0.5–1 Gbps in 5-GHz band
IEEE 802.11ad	Physical/MAC: Enhancements to support ≥ 1 Gbps in the 60-GHz band

(Table can be found on page 424 in the textbook)

Table 13.2
IEEE 802.11 Terminology

Access point (AP)	Any entity that has station functionality and provides access to the distribution system via the wireless medium for associated stations
Basic service set (BSS)	A set of stations controlled by a single coordination function
Coordination function	The logical function that determines when a station operating within a BSS is permitted to transmit and may be able to receive PDUs
Distribution system (DS)	A system used to interconnect a set of BSSs and integrated LANs to create an ESS
Extended service set (ESS)	A set of one or more interconnected BSSs and integrated LANs that appear as a single BSS to the LLC layer at any station associated with one of these BSSs
Frame	Synonym for MAC protocol data unit
MAC protocol data unit (MPDU)	The unit of data exchanged between two peer MAC entities using the services of the physical layer
MAC service data unit (MSDU)	Information that is delivered as a unit between MAC users
Station	Any device that contains an IEEE 802.11 conformant MAC and physical layer

Medium Access Control



Reliable Data Delivery

- Can be dealt with at a higher layer
- More efficient to deal with errors at MAC level
- 802.11 includes frame exchange protocol
  - Station receiving frame returns acknowledgment (ACK) frame
  - Exchange treated as atomic unit
  - If no ACK within short period of time, retransmit
- 802.11 physical and MAC layers unreliable
  - Includes a CRC
  - Error detection results in loss of frames

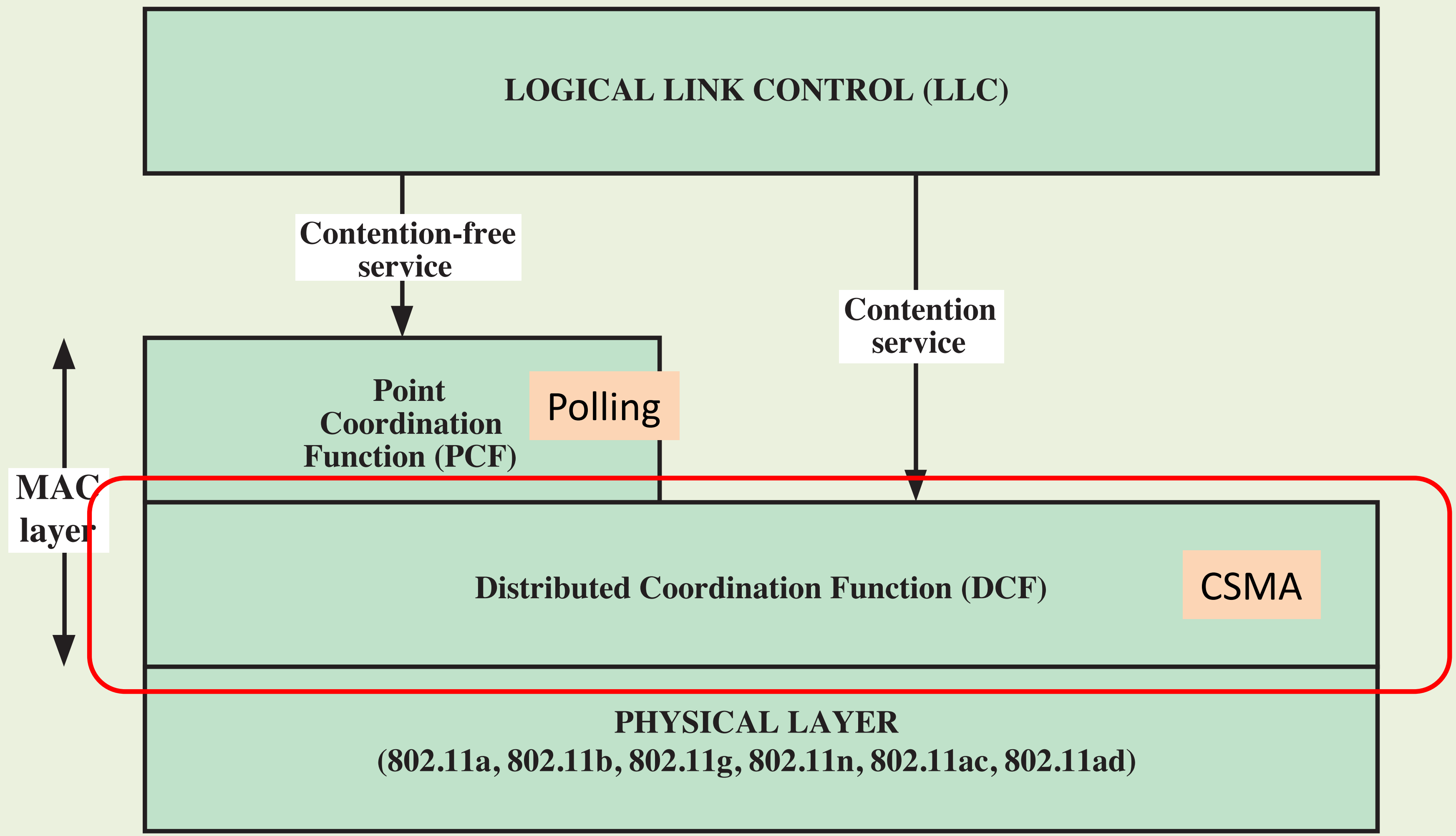
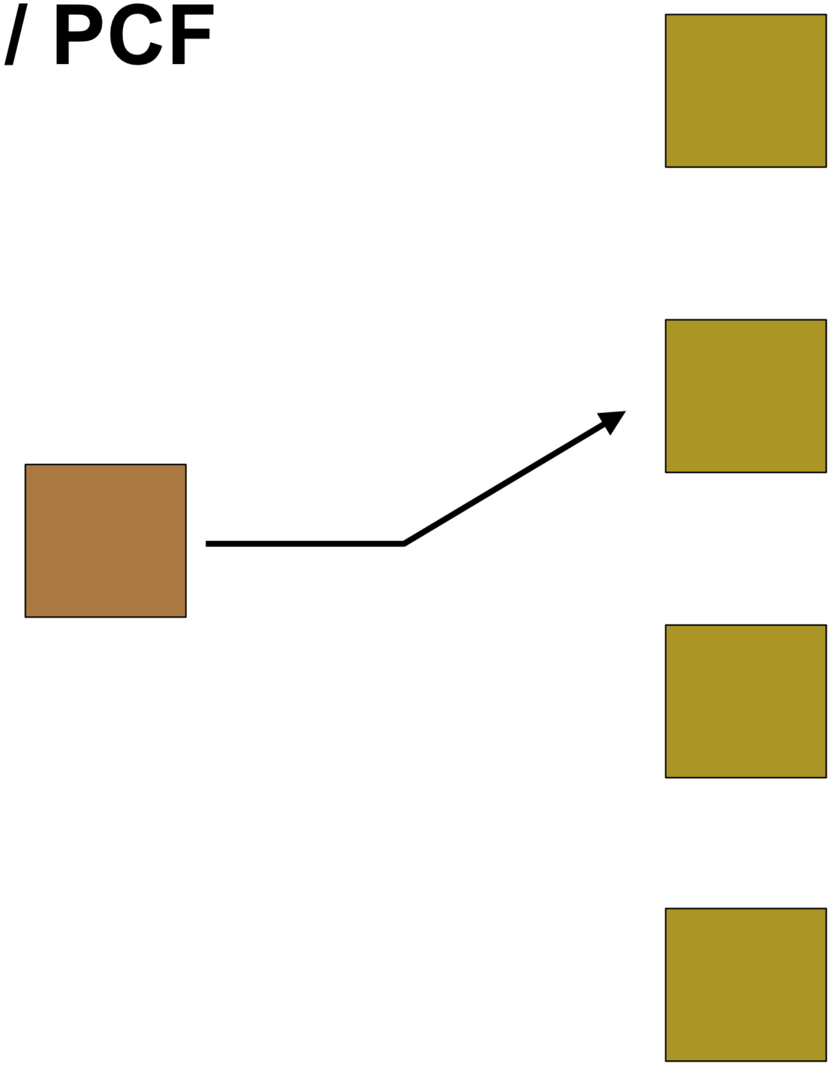


Figure 13.5 IEEE 802.11 Protocol Architecture

Polling / PCF



Distributed Coordination Function (DCF)

- DCF sublayer uses CSMA-CA algorithm
- Does not include a collision detection function because it is not practical on a wireless network
- Includes a set of delays that amounts as a priority scheme

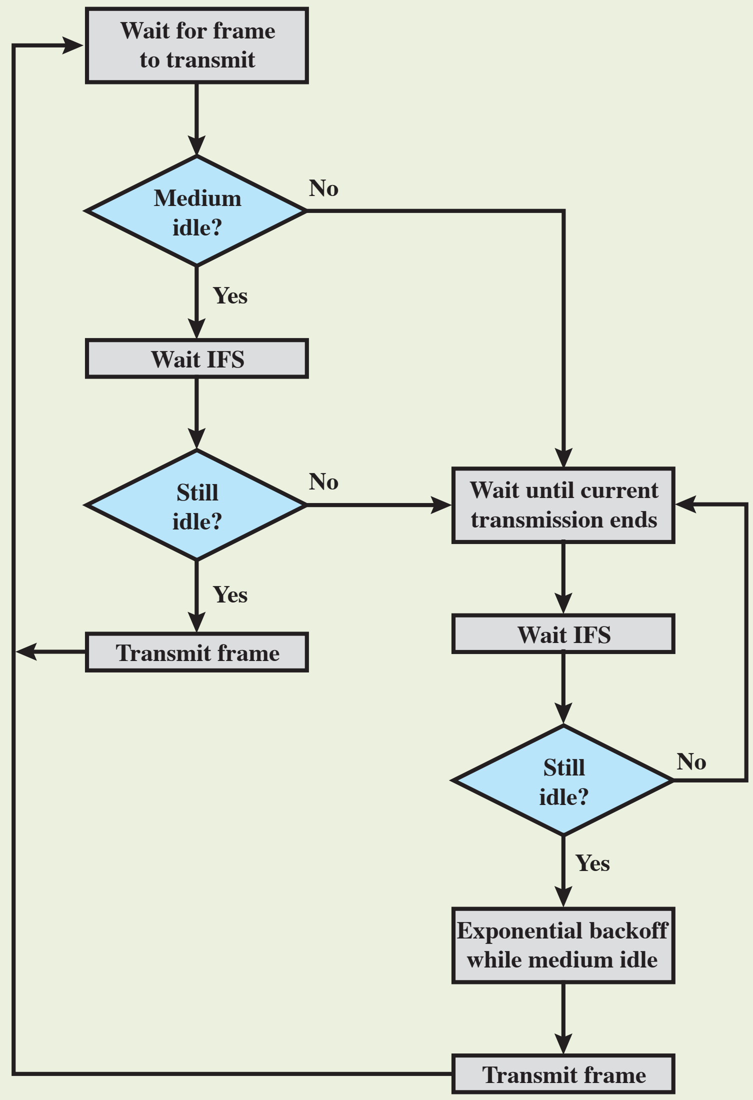


Figure 13.6 IEEE 802.11 Medium Access Control Logic

Contention Window

- When time to transmit, generate random number of slot times to wait
  - Spreads transmission attempts further
  - Lowers chance of collision
  - Since we cannot use collision detection

Priority IFS Values

SIFS

(short IFS)

For all immediate response actions

PIFS

(point coordination function IFS)

Used by the centralized controller in PCF scheme when issuing polls

DIFS

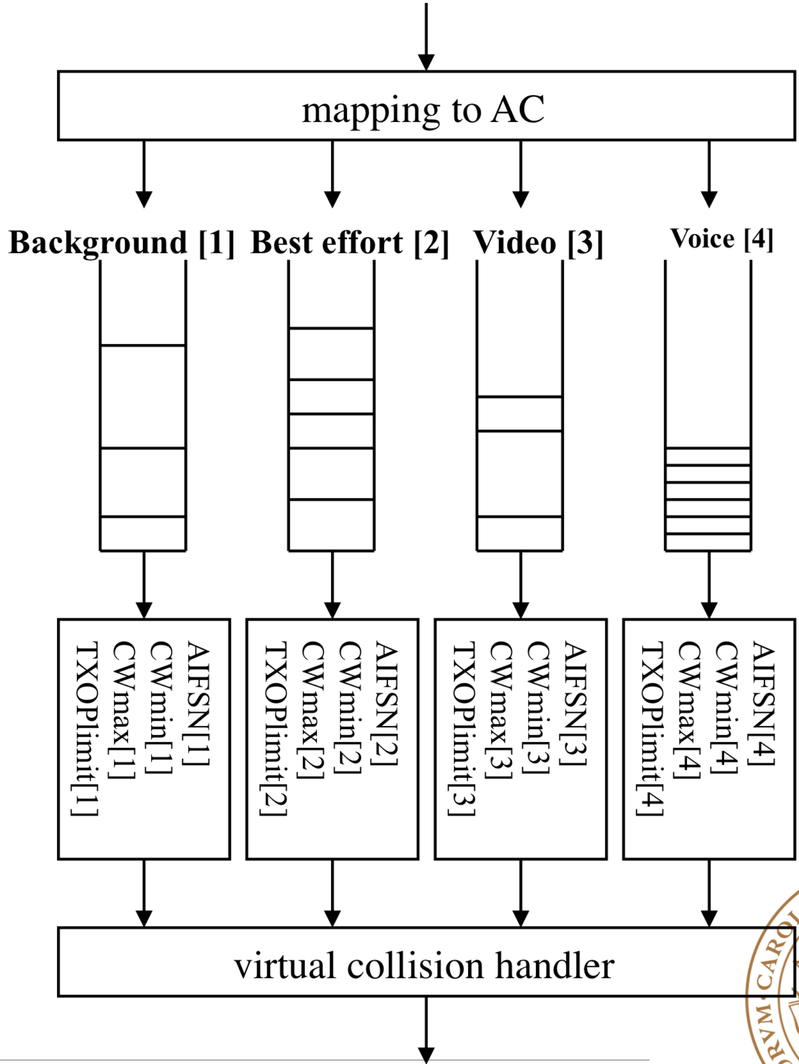
(distributed coordination function IFS)

Used as minimum delay for asynchronous frames contending for access

Enhanced Distributed Channel Access (EDCA)

- Contention-based "Enhanced DCF"
  - access category (AC): Each station has **four ACs** ("transmission queues"). Each AC contends for TXOPs independently of the other ACs
  - Service differentiation is realized by varying
    - CWmin[AC]/CWmax[AC]
    - AIFSN[AC]
    - TXOPlimit[AC]

    No Guarantees Possible, only statistical behaviour!



802.11 MAC frame format

Two types
- Control
- Data

Four adress fields!
- Source MAC
- AP MAC
- Router MAC
- Ad-Hoc address
- BSSID (name AP)

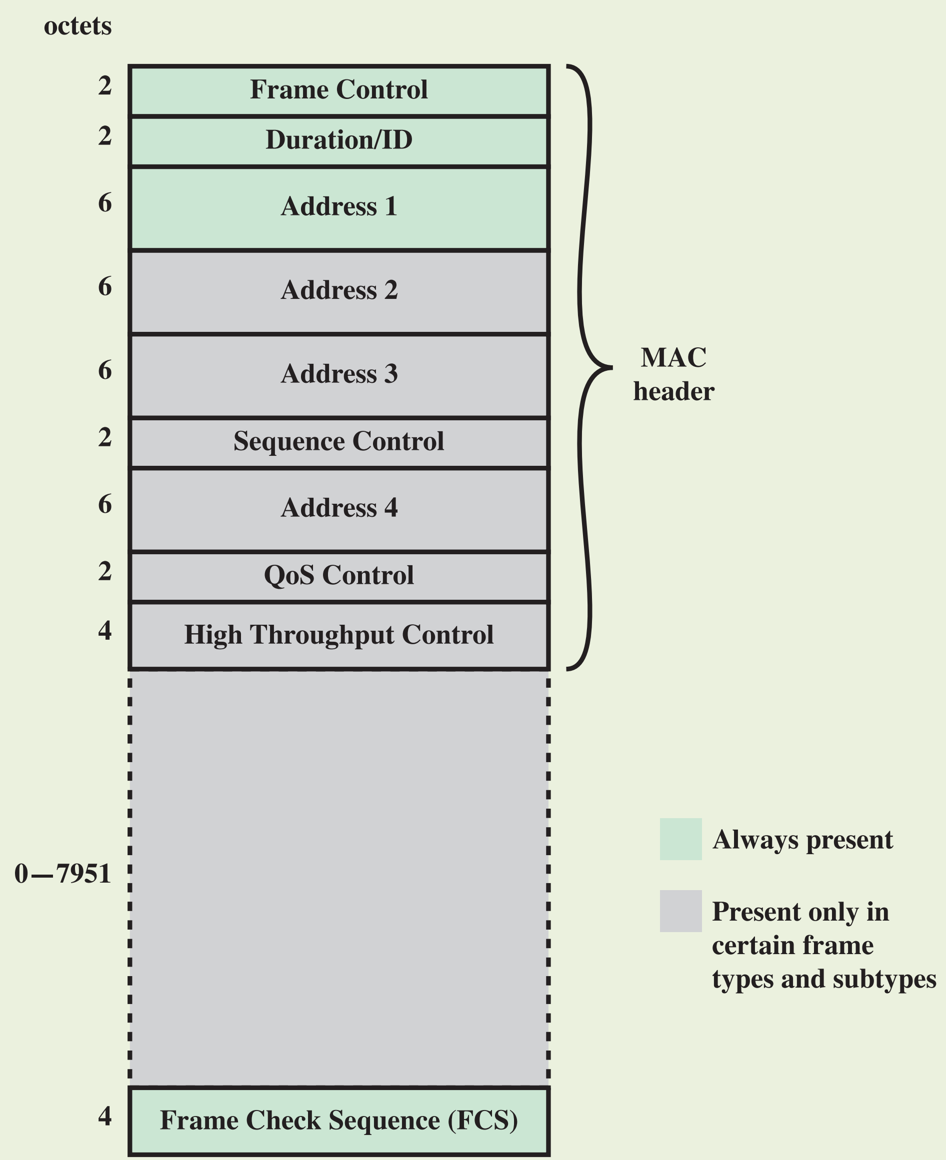
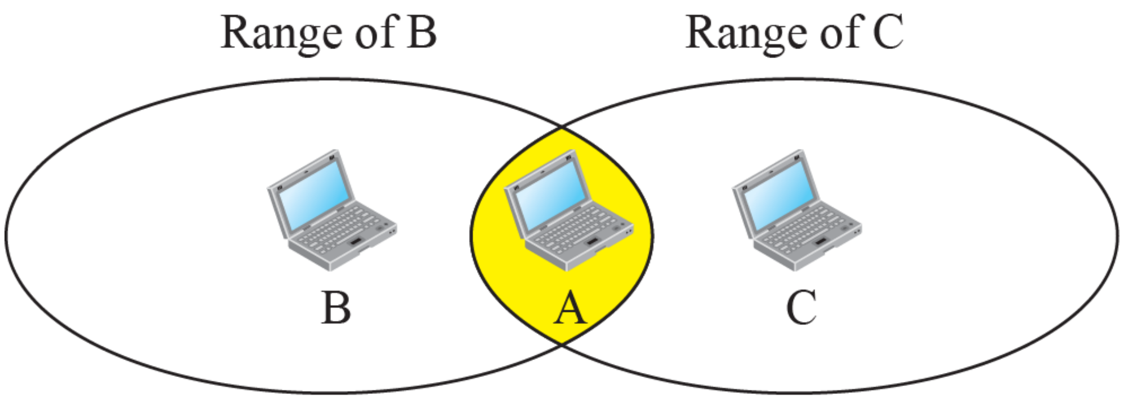
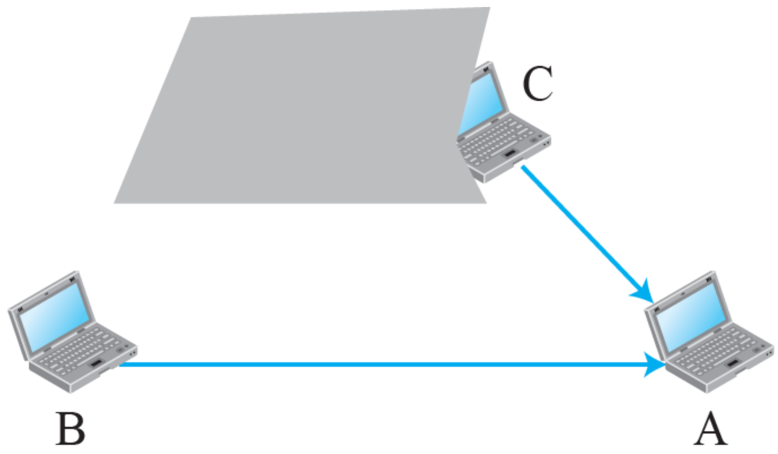


Figure 13.8 IEEE 802.11 MAC Frame Format

Hidden Node/Station Problem



a. Stations B and C are not in each other's range.



b. Stations B and C are hidden from each other.

Four Frame Exchange

- RTS alerts all stations within range of source that exchange is under way
- CTS alerts all stations within range of destination
- Other stations don’t transmit to avoid collision
- RTS/CTS exchange is a required function of MAC but may be disabled
- Can use four-frame exchange for better reliability