The Need for Communication

Trends and Advancements

What is taught in this course?

What is NOT taught in this course?

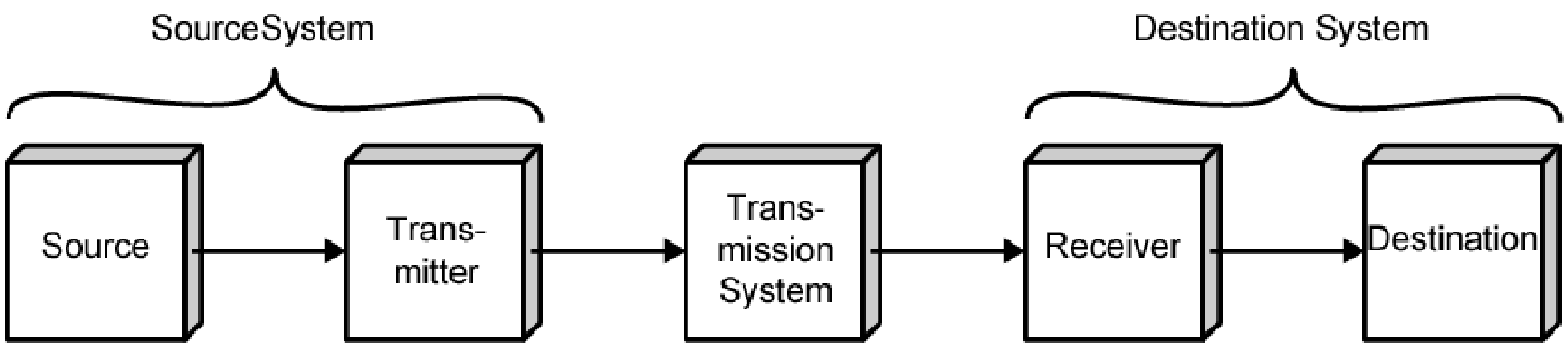
Tips and Tricks to do well

Text and References

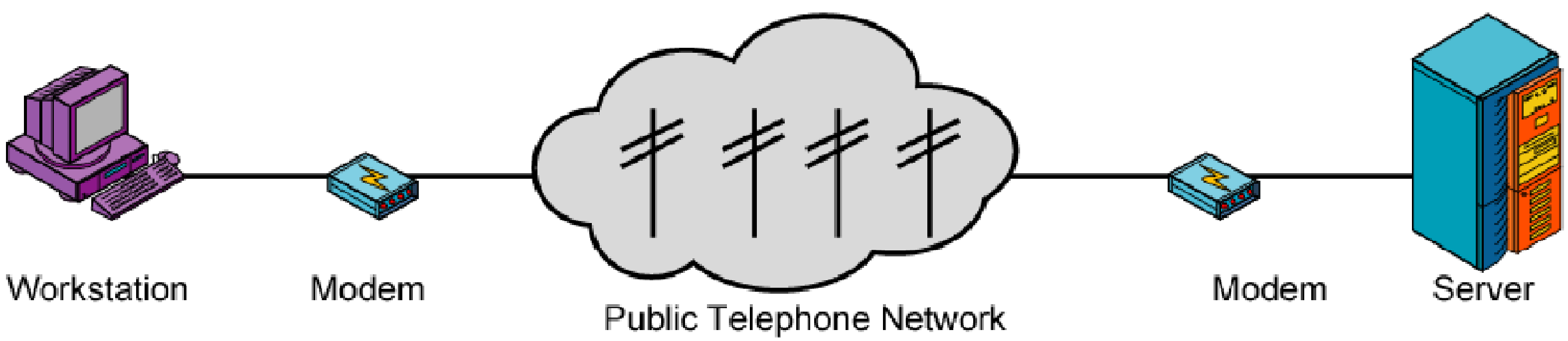
Communication: Sharing of Information (Local or remote)

Telecommunications: Communication at a Distance (includes telephony, telegraph, and television etc.)

Data communications: Exchange of data between two devices via some form of transmission media



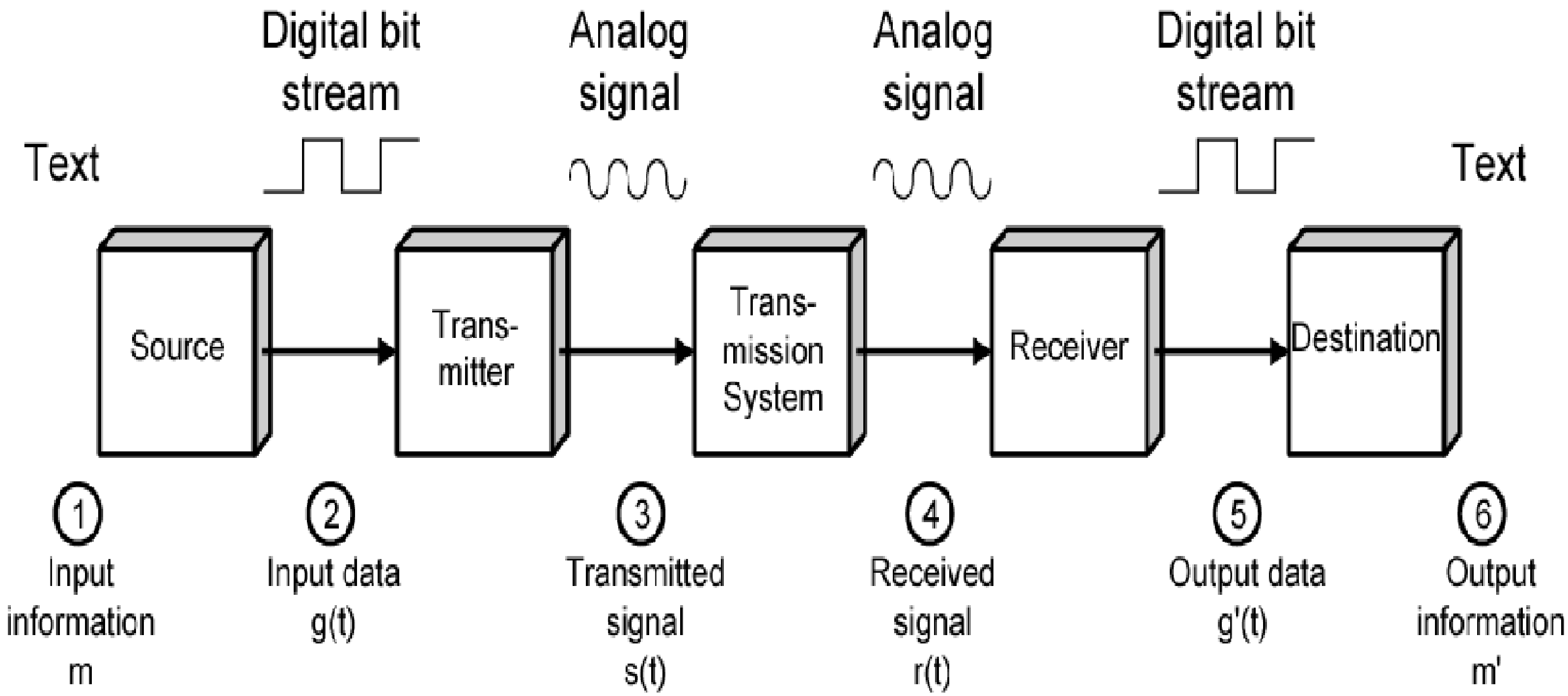
(a) General block diagram



(b) Example

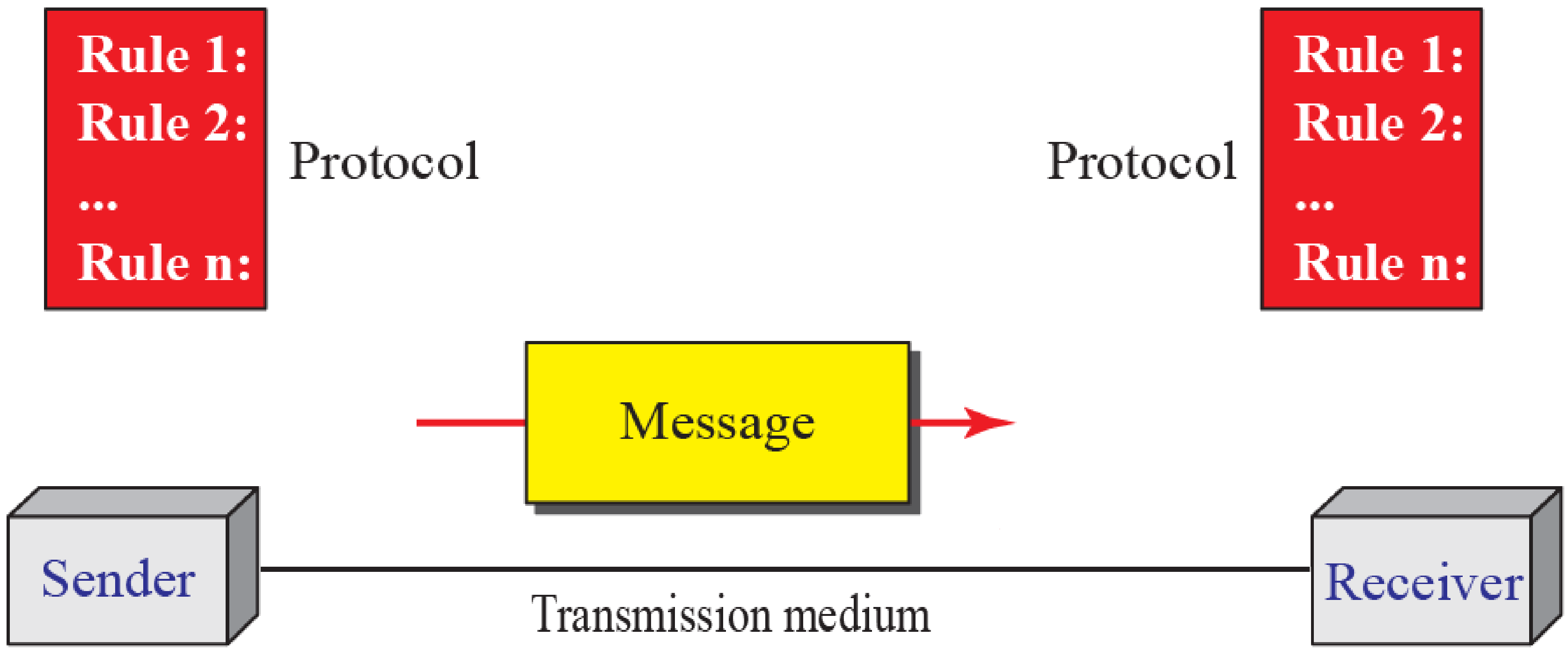
Effectiveness of a Data Communication System:

- **Delivery**
- **Accuracy**
- **Timeliness**
- **Jitter**



Digital bit stream
Analog signal
Analog signal
Digital bit stream
Text
Text
Source
Trans-mitter
Trans-mission System
Receiver
Destination
1
Input information m
2
Input data g(t)
3
Transmitted signal s(t)
4
Received signal r(t)
5
Output data g'(t)
6
Output information m'

A data communications system has five components

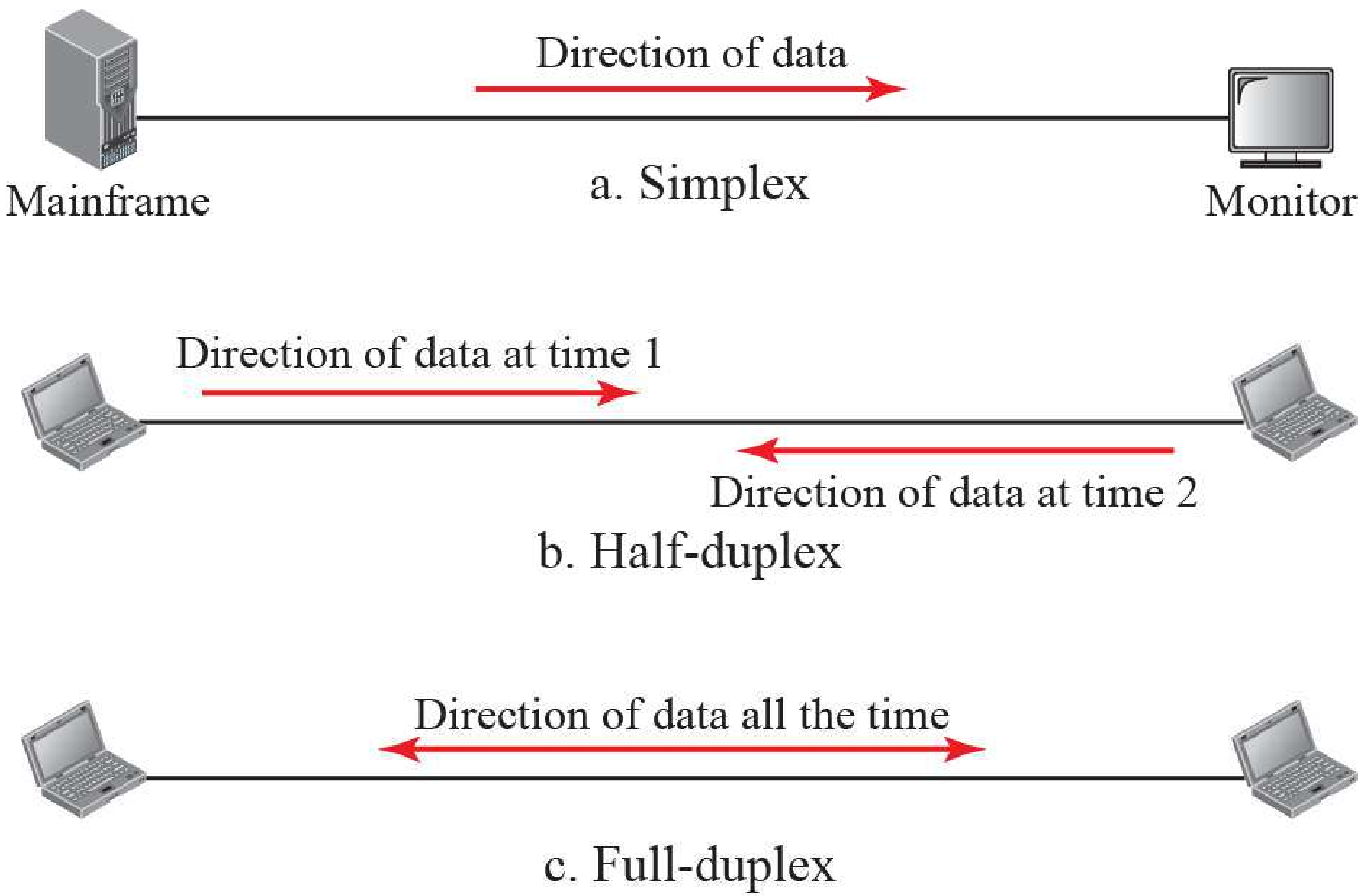

Rule 1:
Rule 2:
...
Rule n:
Protocol
Protocol
Rule 1:
Rule 2:
...
Rule n:
Message
Sender
Transmission medium
Receiver

Forms of Information

- **Text**
- **Numbers**
- **Images**
- **Audio**
- **Video**

Data Flow between two devices:

- **Simplex**
- **Half-Duplex**
- **Full-Duplex**


Direction of data
Mainframe
a. Simplex
Monitor
Direction of data at time 1
Direction of data at time 2
b. Half-duplex
Direction of data all the time
c. Full-duplex

- **Network:**
  Interconnection of a set of devices capable of communication

- **Host**

- **Connecting Device**

A network must be able to meet a certain number of criteria:

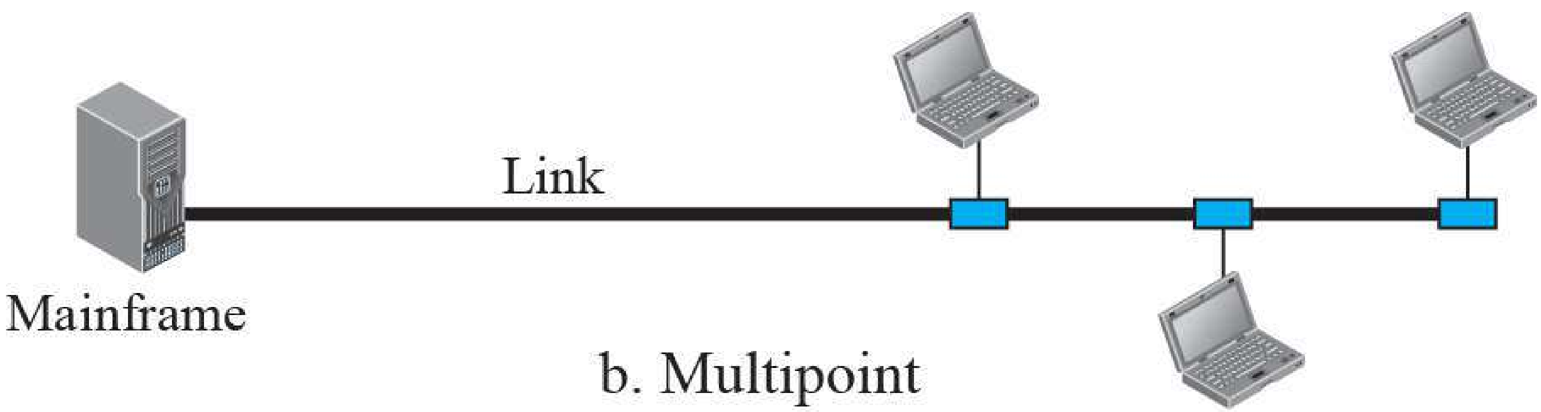
- **Performance**
  - ✓ Throughput
  - ✓ Delay
- **Reliability**
- **Security**

Physical Network Attributes

- **Link**

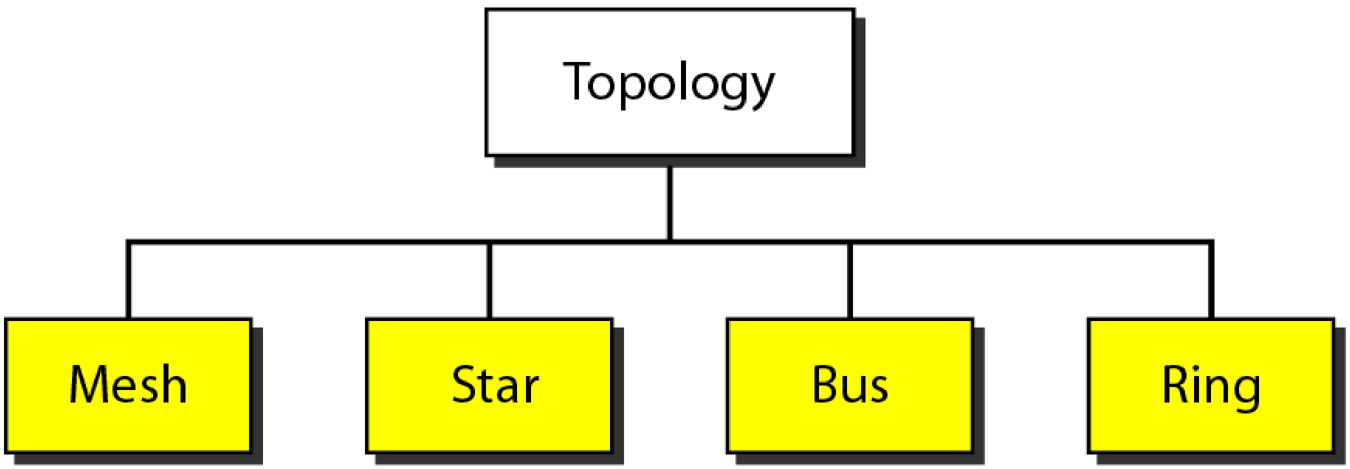
- **Type of Connection**
  - ✓ **Point-to-Point**
  - ✓ **Multipoint**

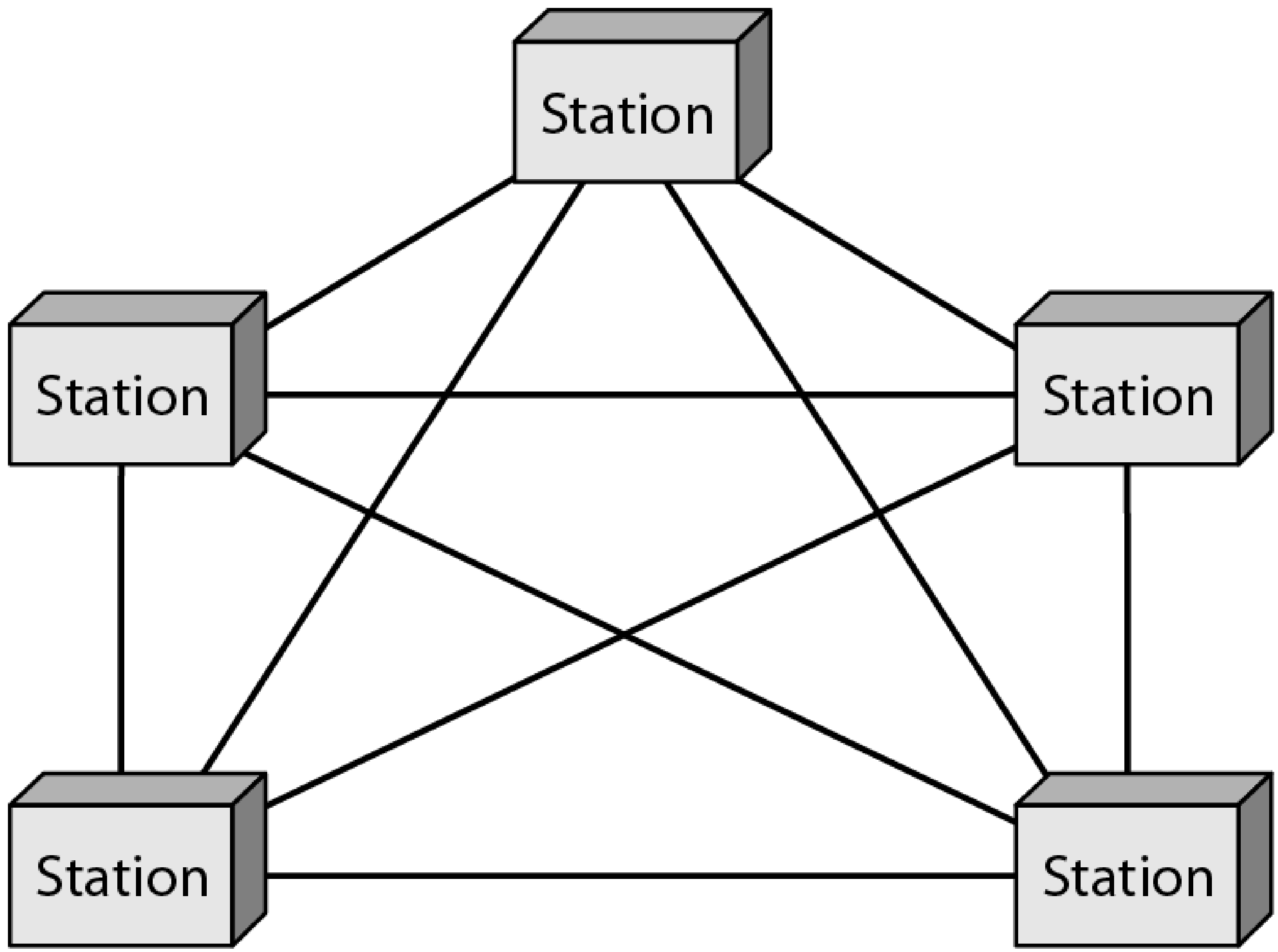
a. Point-to-point

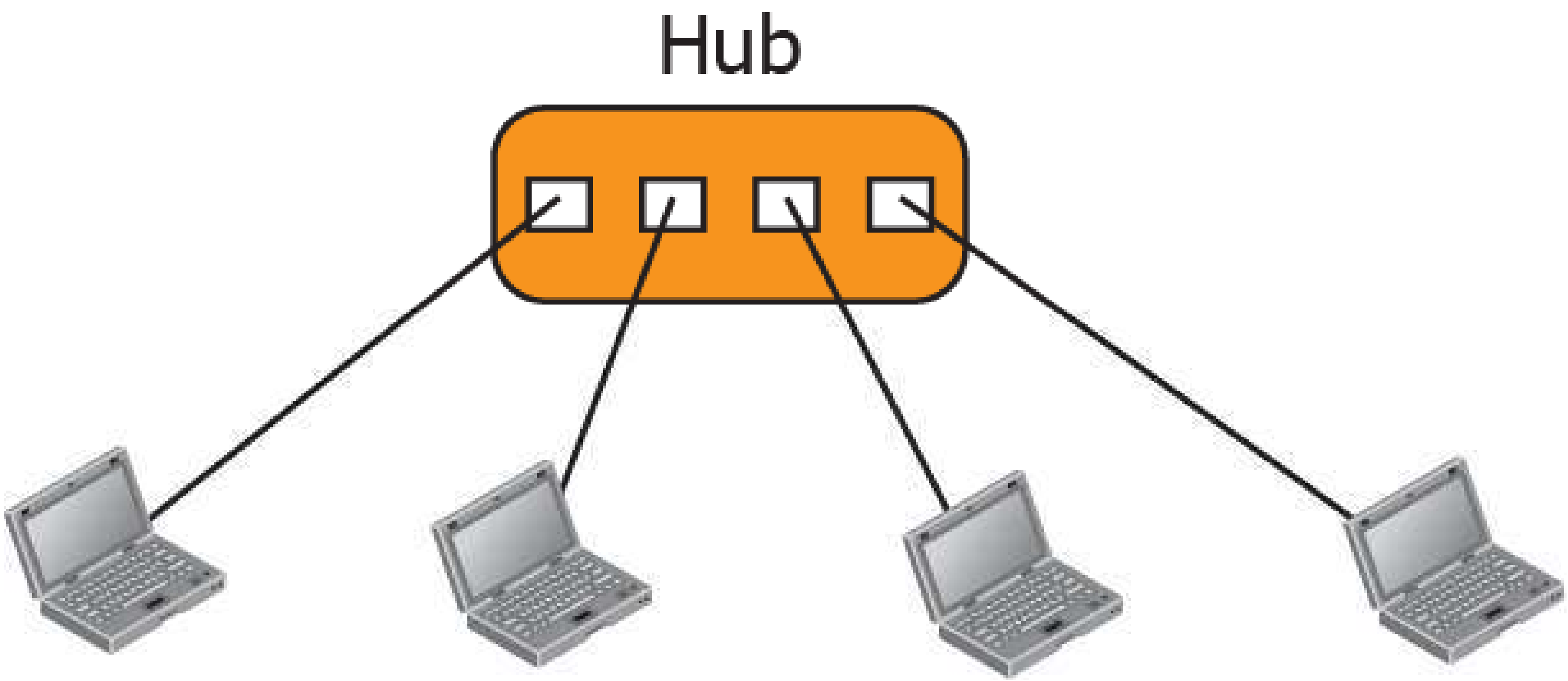


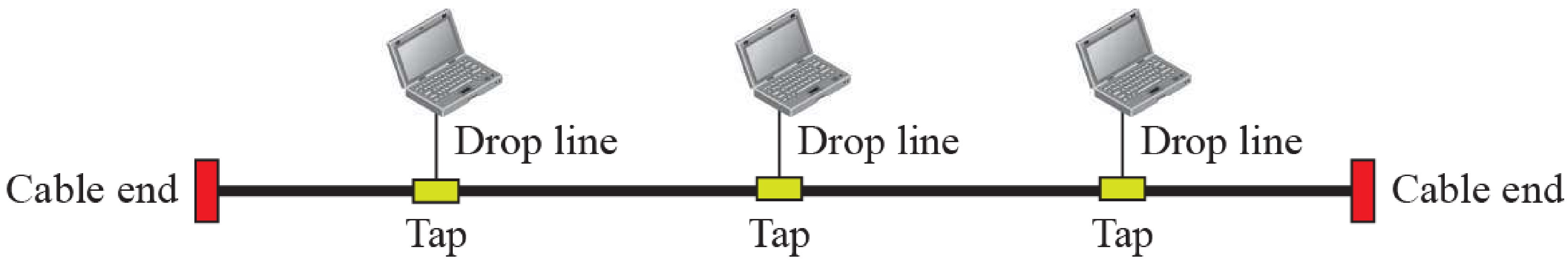
b. Multipoint

- **Physical Layout of Network**
- **Links + Nodes = Topology**
- **Physical Topologies:**
  - ✓ **Mesh**
  - ✓ **Star**
  - ✓ **Bus**
  - ✓ **Ring**

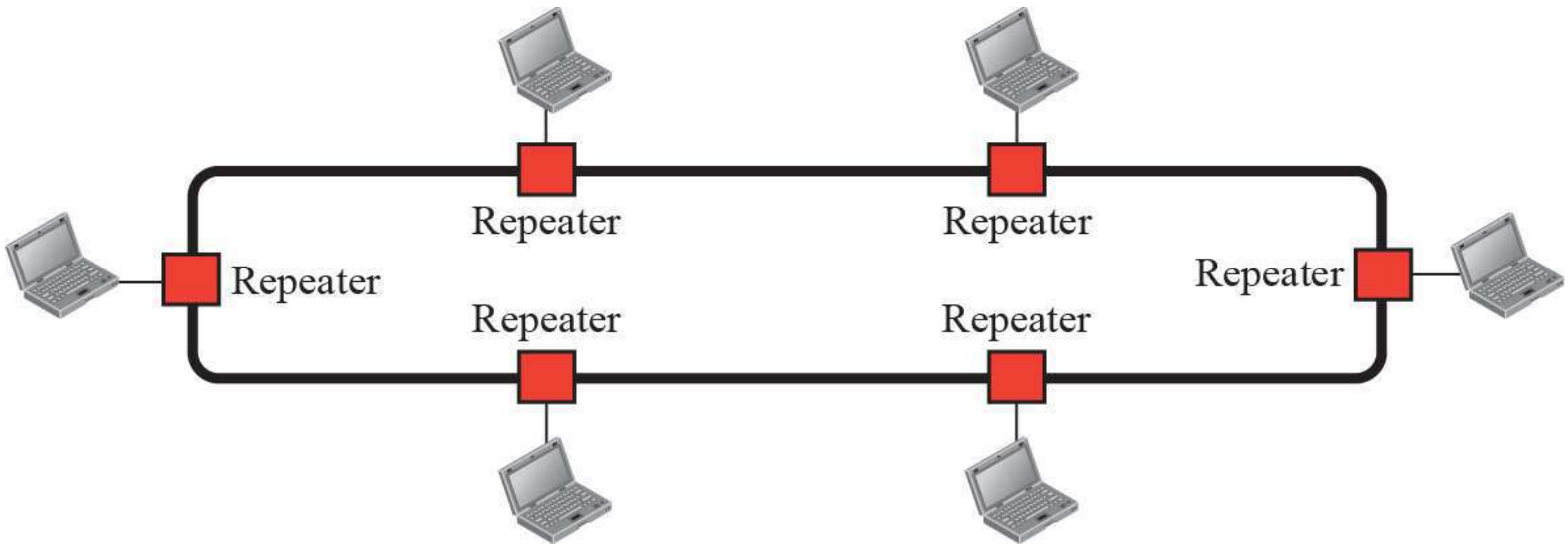

Topology
Mesh
Star
Bus
Ring


Station
Station
Station
Station
Station


Hub

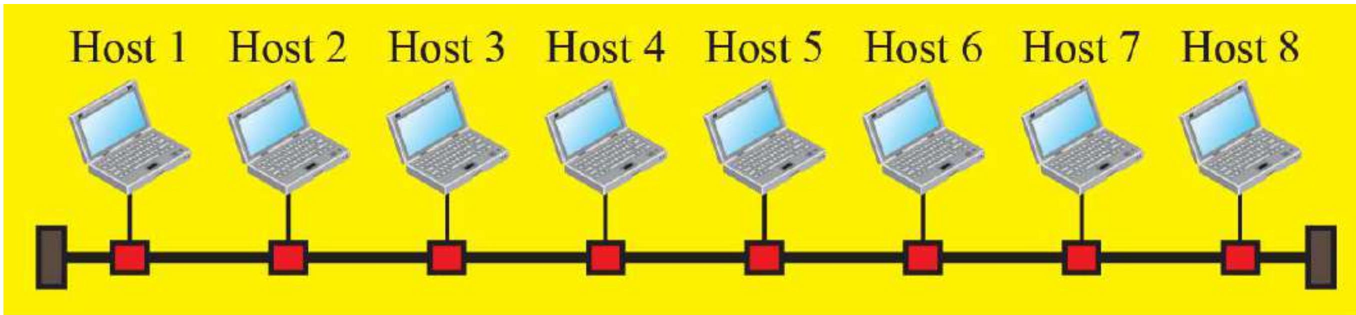


Drop line
Drop line
Drop line
Cable end
Cable end
Tap
Tap
Tap

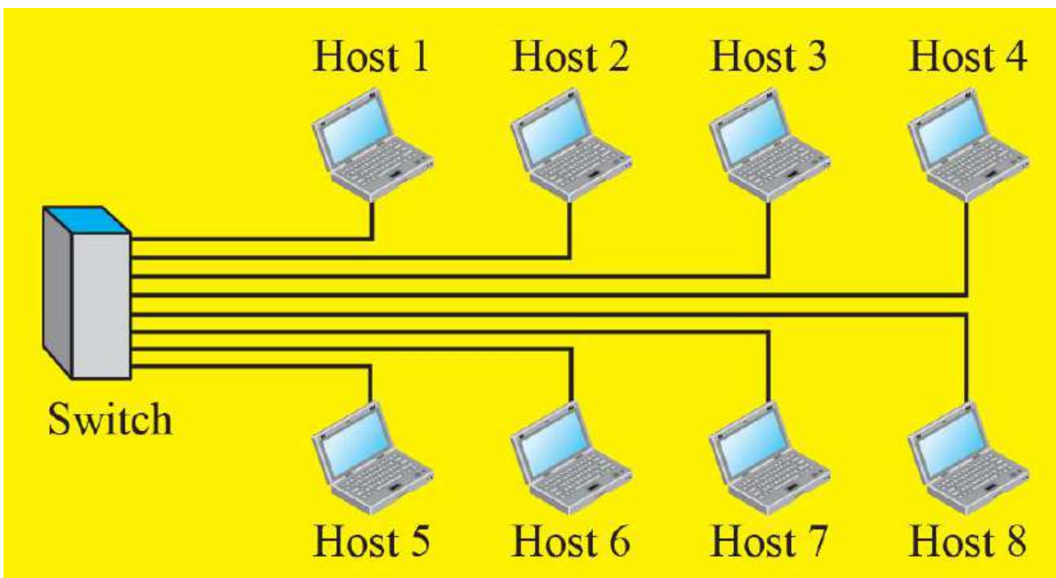

Repeater
Repeater
Repeater
Repeater
Repeater
Repeater

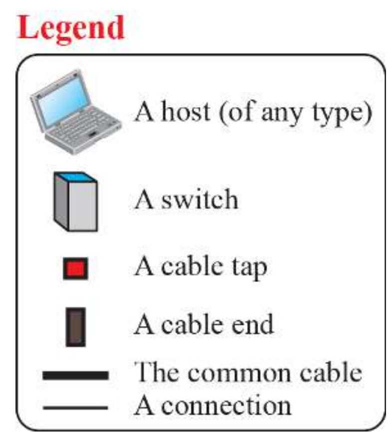
- **Network classification:**
  - ✓ **Size**
  - ✓ **Geographical Coverage**
  - ✓ **Ownership**
- **Local Area Networks (LANs)**
- **Wide Area Networks (WANs)**

- Usually Privately owned
- Connects some hosts in a single office, building, or campus
- Can be as simple as two PCs and a printer in someone's home office
- Can extend throughout a company
- Host Address



a. LAN with a common cable (past)





b. LAN with a switch (today)

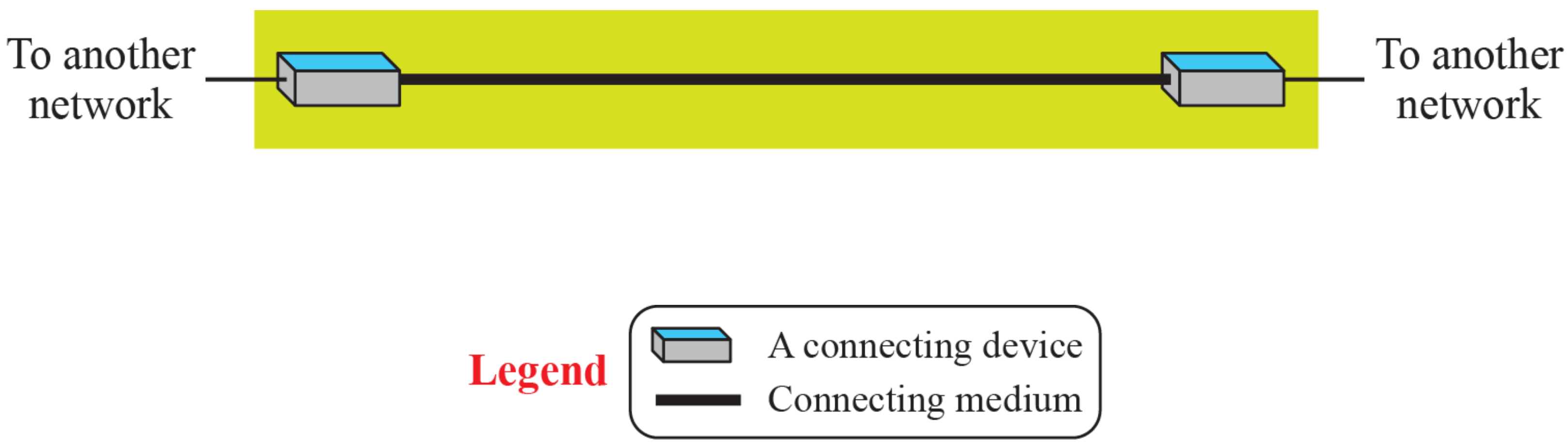
- **Wider geographical span than a LAN**

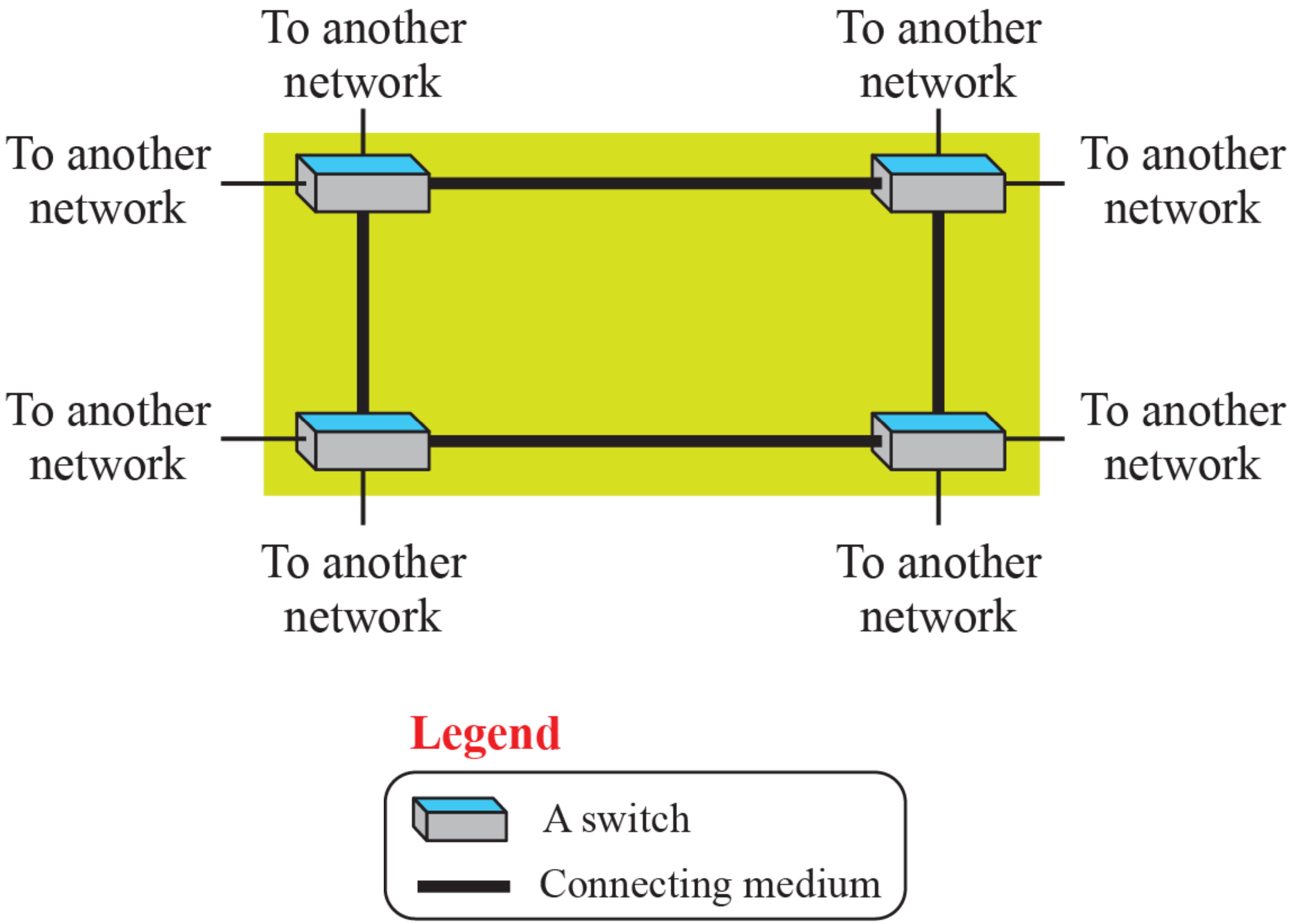
- **Spans a town, a state, a country, or even the world**

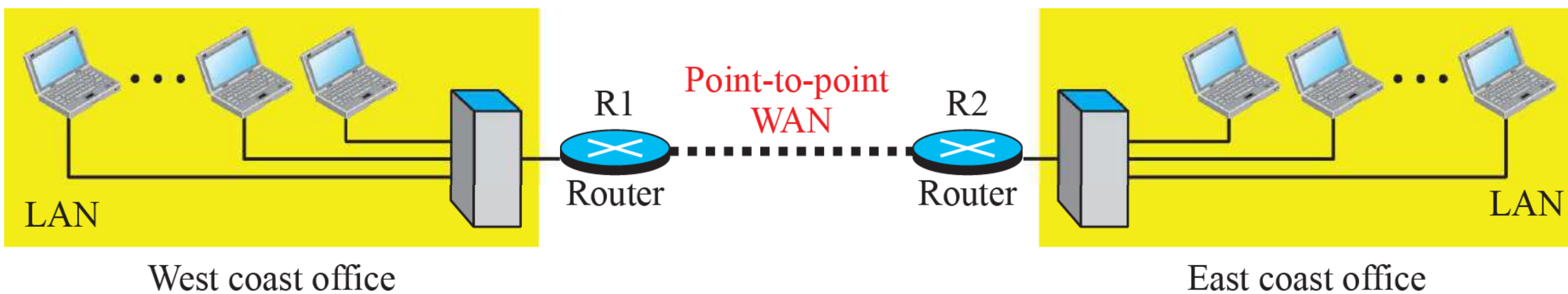
- **Interconnects connecting devices such as switches, routers, or modems**

- **Normally created and run by communication companies**

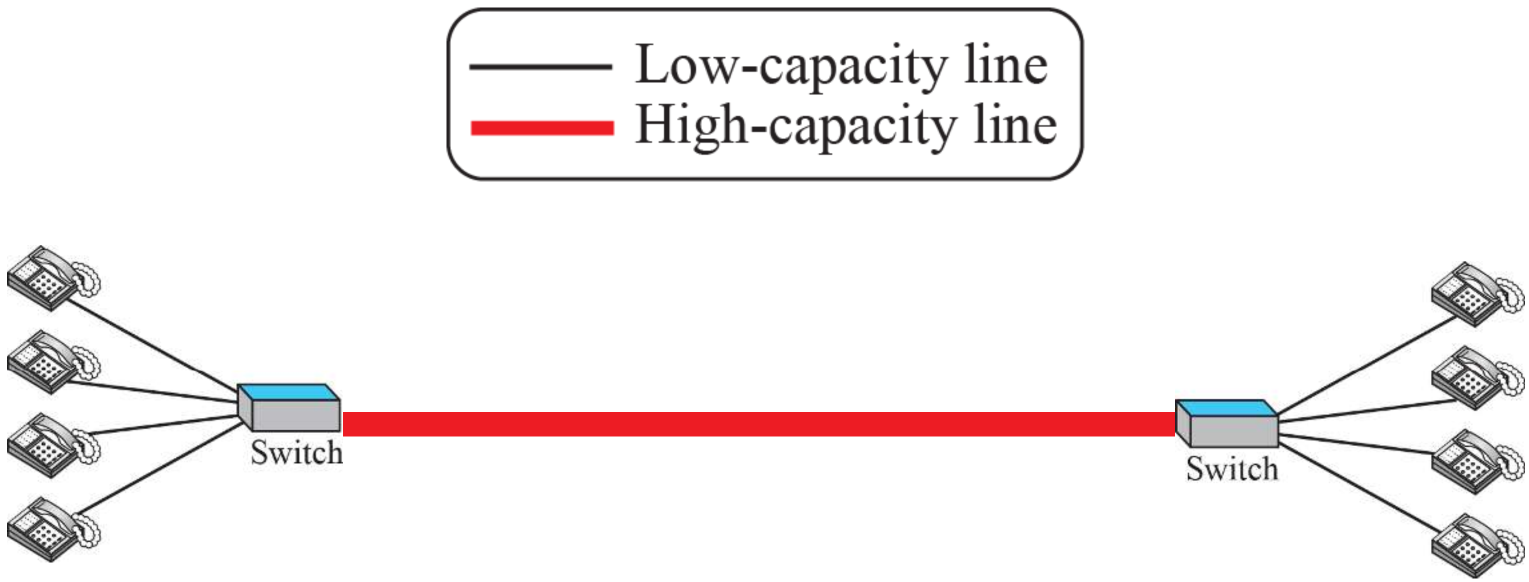
- **Point-to-Point WAN**
- **Switched WAN**
- **Internetwork**


To another network
To another network
Legend
A connecting device
Connecting medium

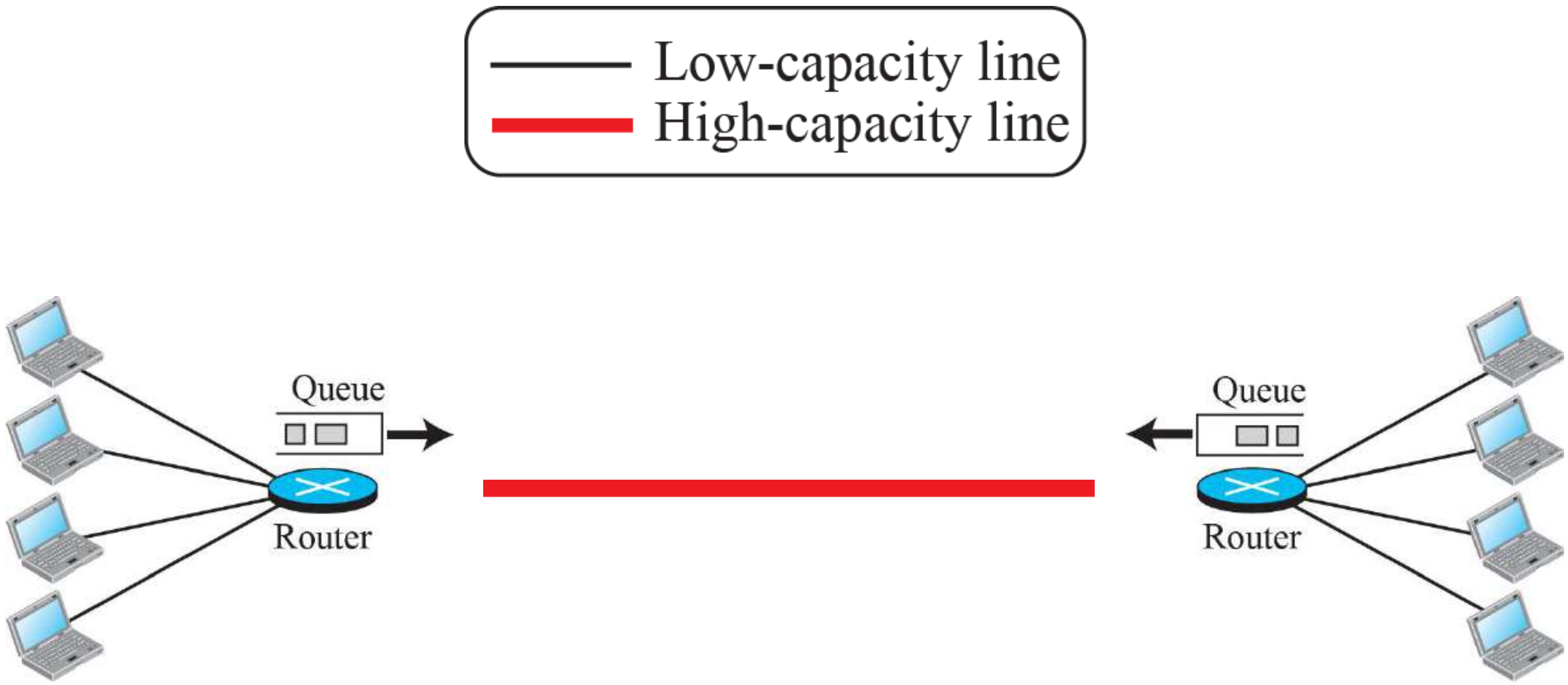

To another network
To another network
To another network
To another network
To another network
To another network
To another network
To another network
Legend
A switch
Connecting medium


LAN
Router
R1
Point-to-point
WAN
R2
Router
LAN
West coast office
East coast office

- **Switching**
  - ✓ **Circuit-Switched Network**
  - ✓ **Packet- Switched Network**

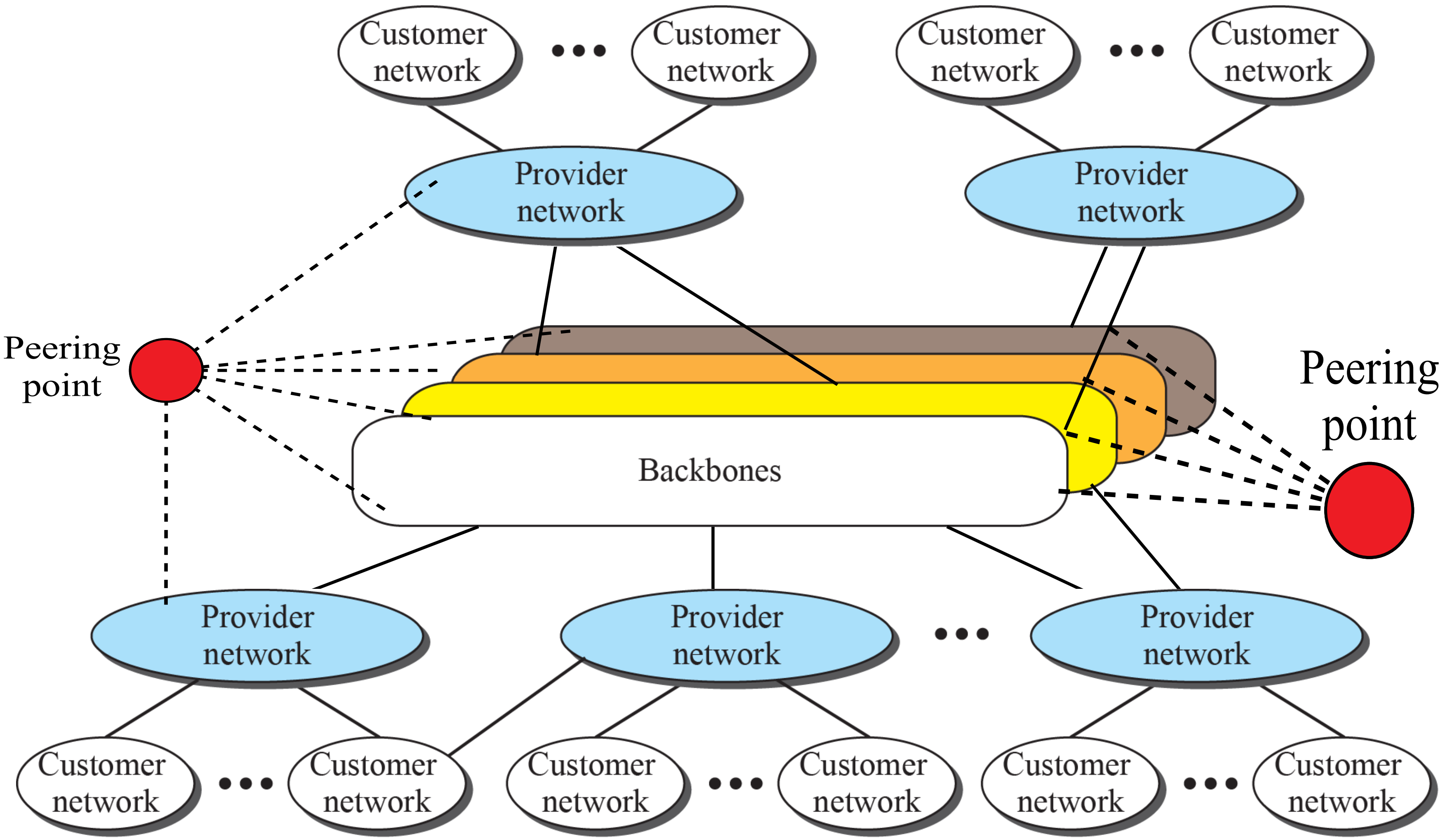


Low-capacity line
High-capacity line
Switch
Switch



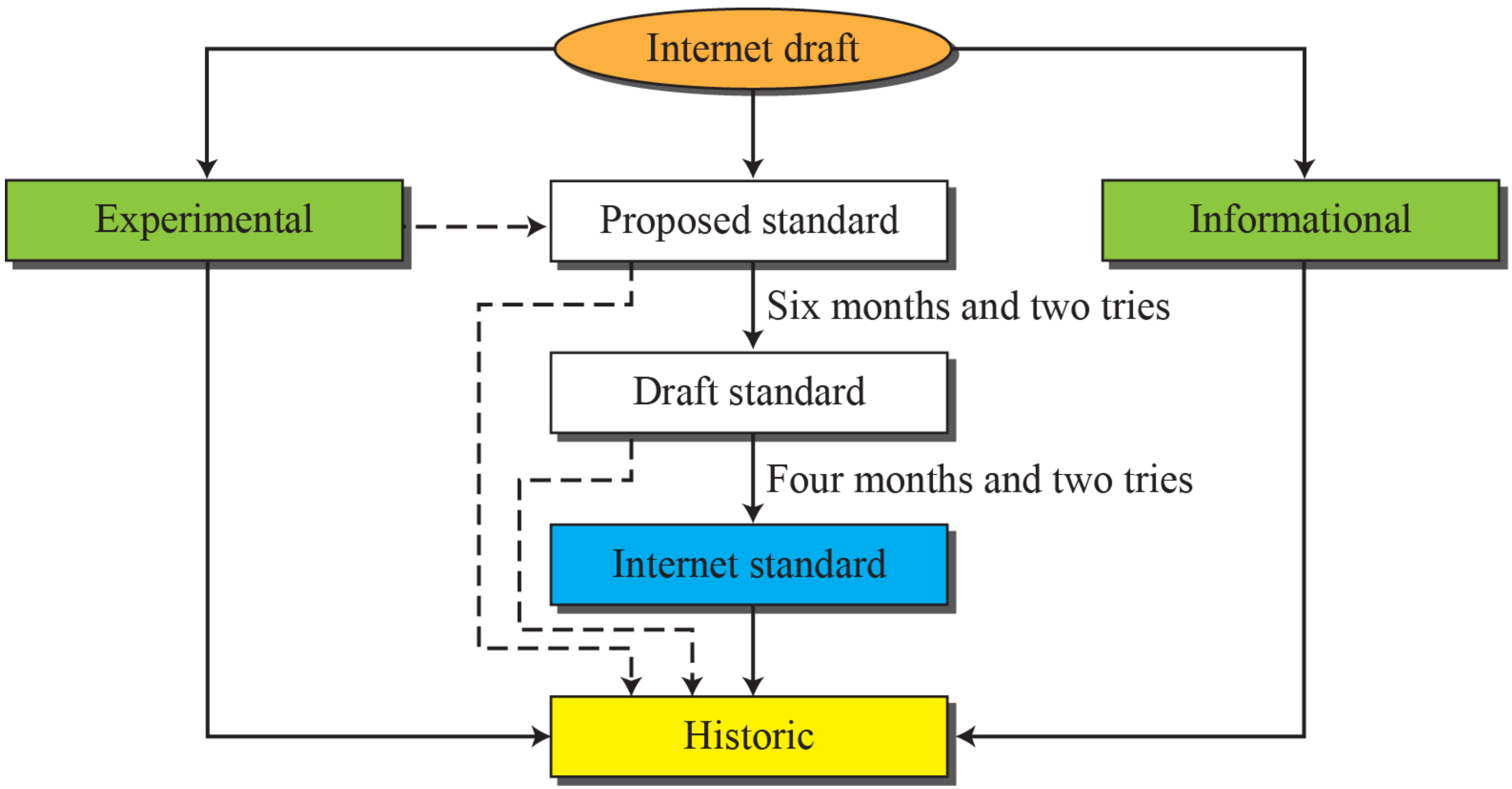
Low-capacity line
High-capacity line
Queue
Router
Queue
Router

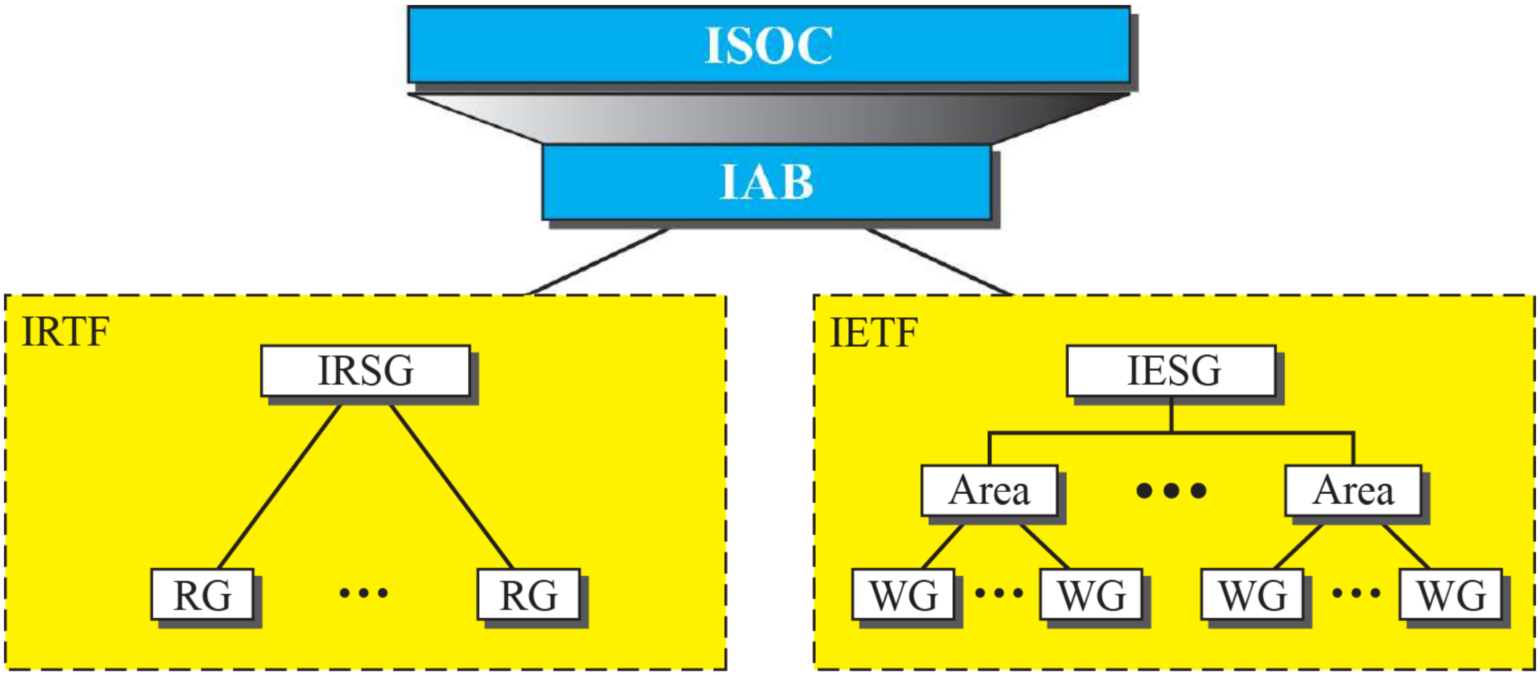
- An internet (note the lowercase i) is two or more networks that can communicate with each other
- The Internet (uppercase I), and is composed of thousands of interconnected networks.
- Accessing the Internet


Customer network
Customer network
Customer network
Customer network
Provider network
Provider network
Peering point
Backbones
Peering point
Provider network
Provider network
Provider network
Customer network
Customer network
Customer network
Customer network
Customer network
Customer network

- **Telegraph and Telephone networks, before 1960:**
  - ✓ **Constant-rate communication only**
- **ARPANET- Packet Switched**
- **Birth of the Internet &TCP/IP**
- **MILNET**
- **CSNET**
- **NSFNET**
- **Internet Today**

- Internet draft
- Request for Comments (RFC)
  - ✓ Proposed Standard
  - ✓ Draft Standard
  - ✓ Internet Standard
  - ✓ Historic
  - ✓ Experimental
  - ✓ Informational


Internet draft
Experimental
Proposed standard
Informational
Six months and two tries
Draft standard
Four months and two tries
Internet standard
Historic

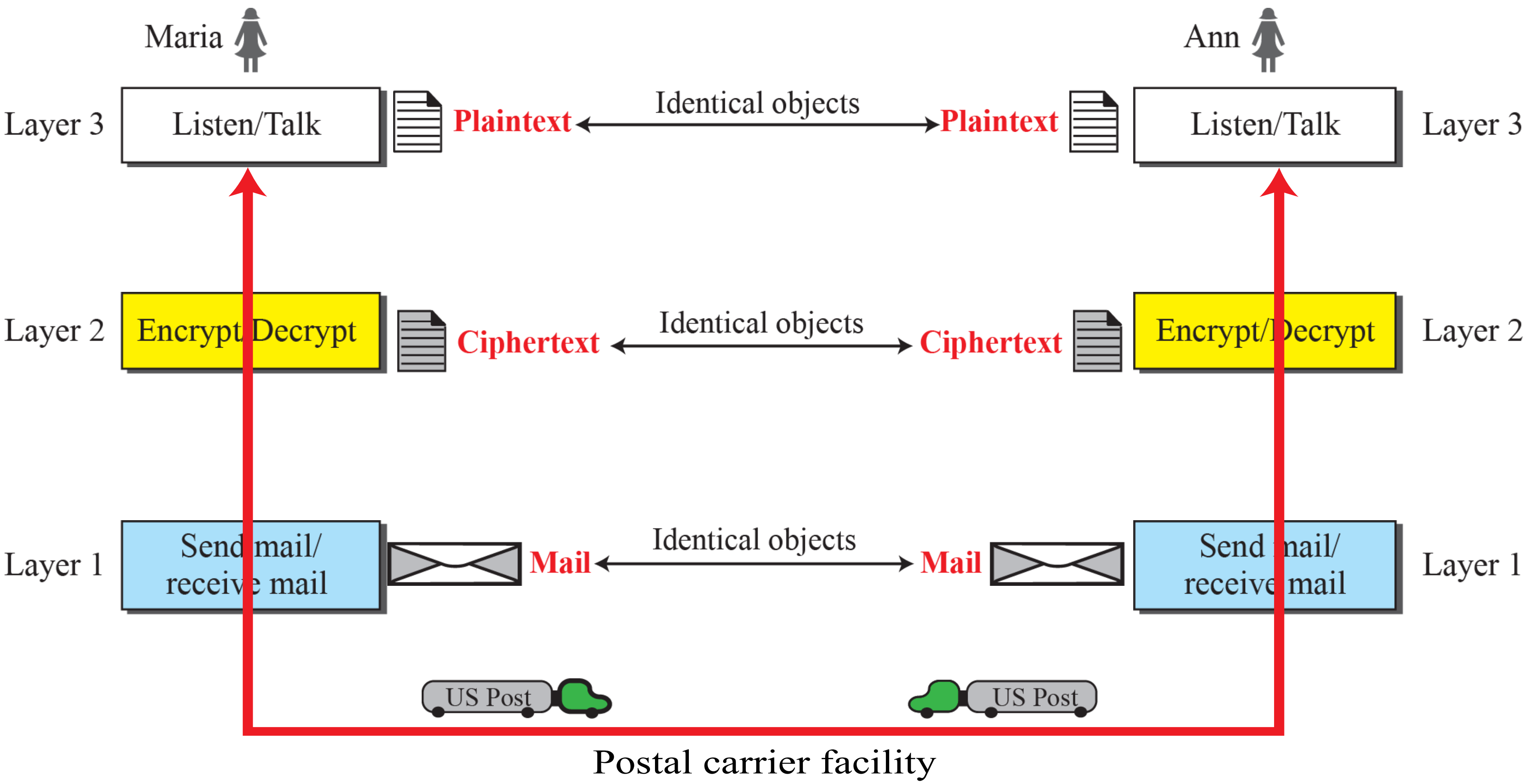

ISOC
IAB
IRTF
IRSG
RG
RG
IETF
IESG
Area
Area
WG
WG
WG
WG

- **Protocol**
  Rules that both the sender and receiver and all intermediate devices need to follow to be able to communicate effectively

- **Protocol Layering**
  Simple Communication: only one simple protocol

  Complex Communication, we need a protocol at each layer, or Protocol Layering


Maria
Ann
Layer 1
Listen/Talk
Listen/Talk
Layer 1
Air



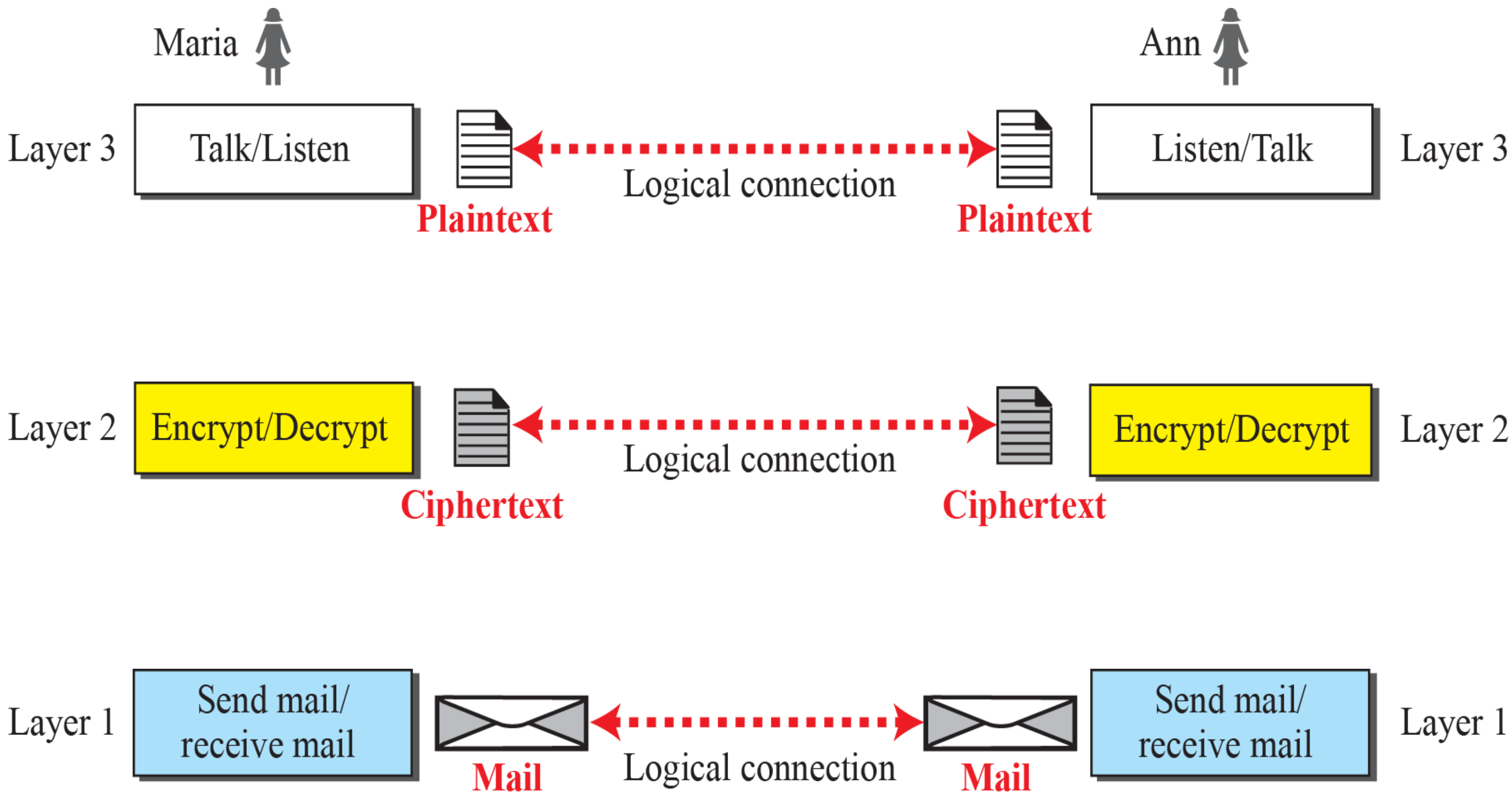
Maria
Ann
Layer 3
Listen/Talk
Plaintext
Identical objects
Plaintext
Listen/Talk
Layer 3
Layer 2
Encrypt/Decrypt
Ciphertext
Identical objects
Ciphertext
Encrypt/Decrypt
Layer 2
Layer 1
Send mail/
receive mail
Mail
Identical objects
Mail
Send mail/
receive mail
Layer 1
US Post
US Post
Postal carrier facility

- **Advantages**
  - ✓ Modularity
  - ✓ Separation of Service & Implementation
  - ✓ Reduced Complexity & Cost

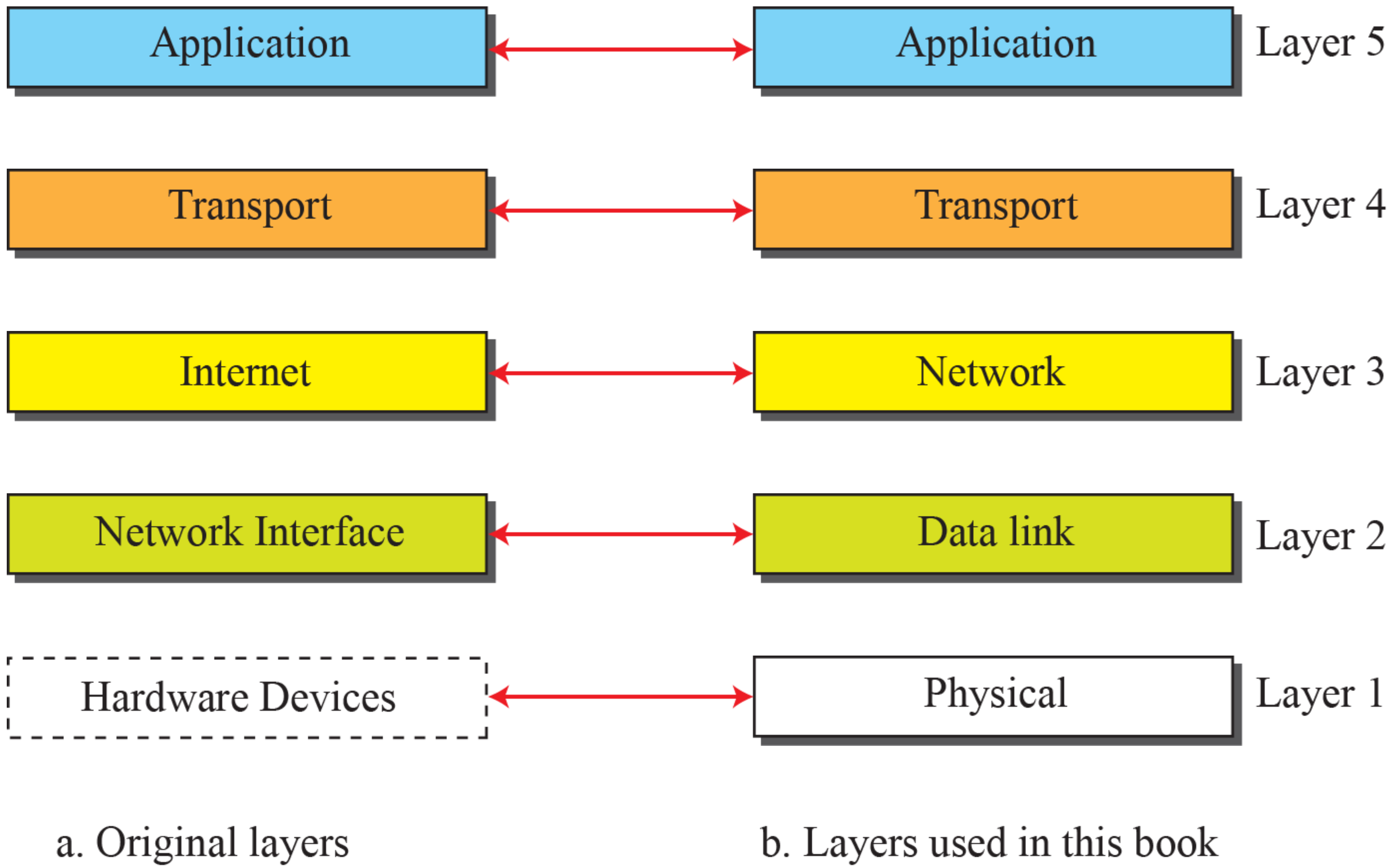
- **Disadvantages**
  - ✓ None Really!

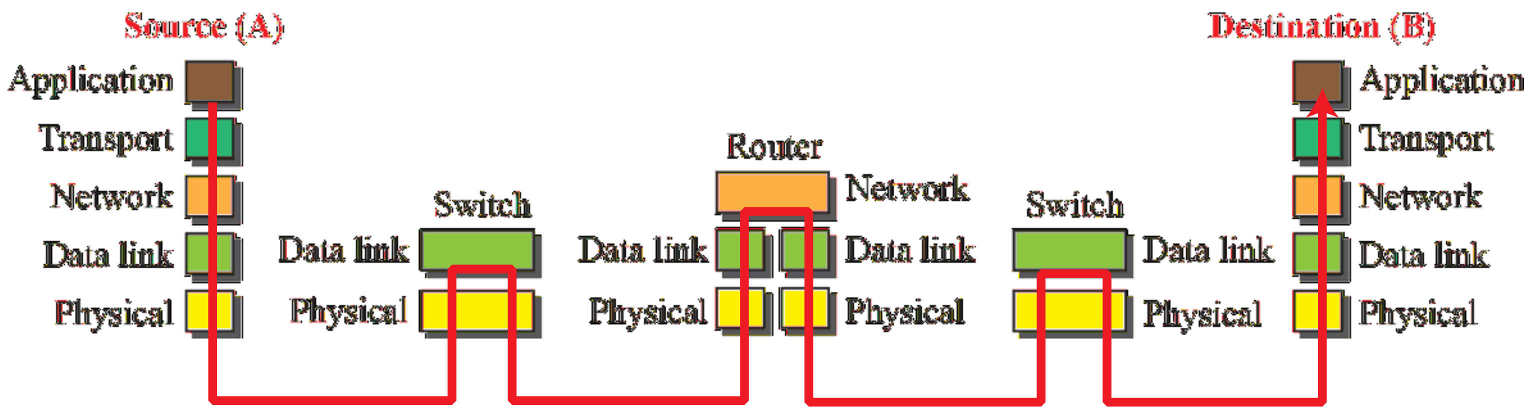
- **Two Principles**
  - ✓ Bidirectional Communication → Each Layer performs two opposite tasks in each direction
  - ✓ Two objects under each layer at both sites should be identical

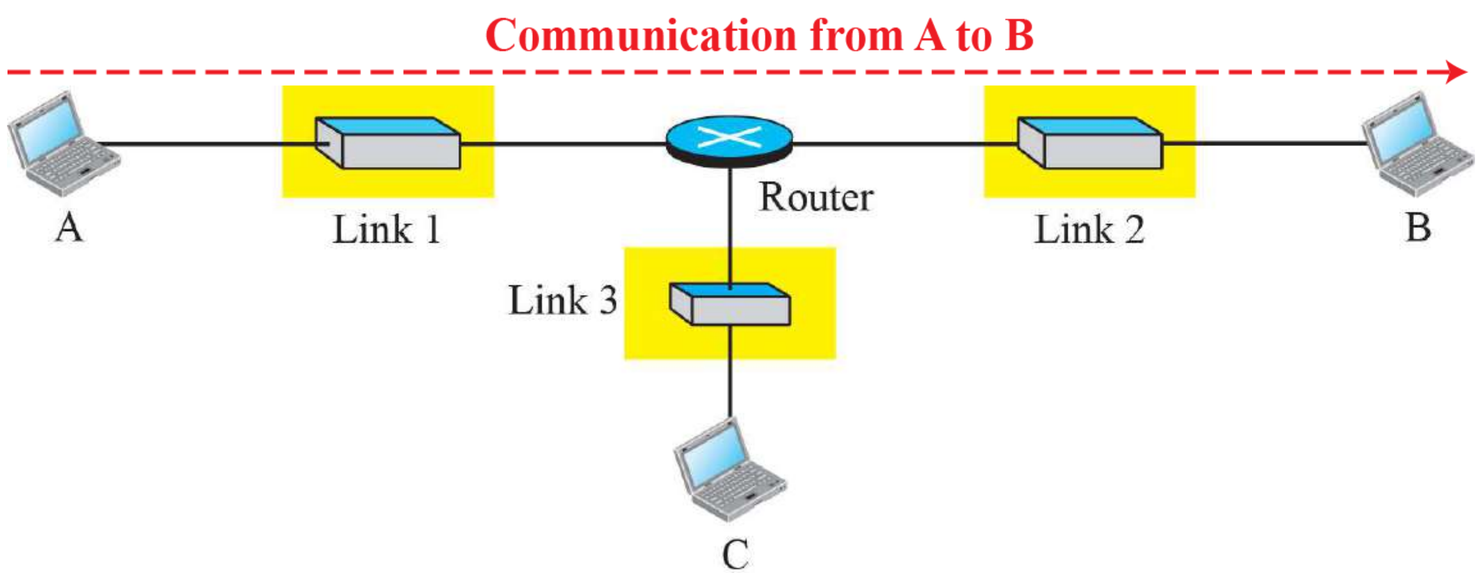
- **Logical Connections**
  - ✓ Imaginary connection between each layer


Maria
Ann
Layer 3
Talk/Listen
Plaintext
Logical connection
Plaintext
Listen/Talk
Layer 3
Layer 2
Encrypt/Decrypt
Ciphertext
Logical connection
Ciphertext
Encrypt/Decrypt
Layer 2
Layer 1
Send mail/
receive mail
Mail
Logical connection
Mail
Send mail/
receive mail
Layer 1

- **TCP/IP Protocol Suite**
  - ✓ Protocol suite used in Internet today
  - ✓ Each Layer provides specific functionality
  - ✓ Hierarchical Protocol
  - ✓ Presented in 1973 and chosen to be the official protocol of Internet in 1983

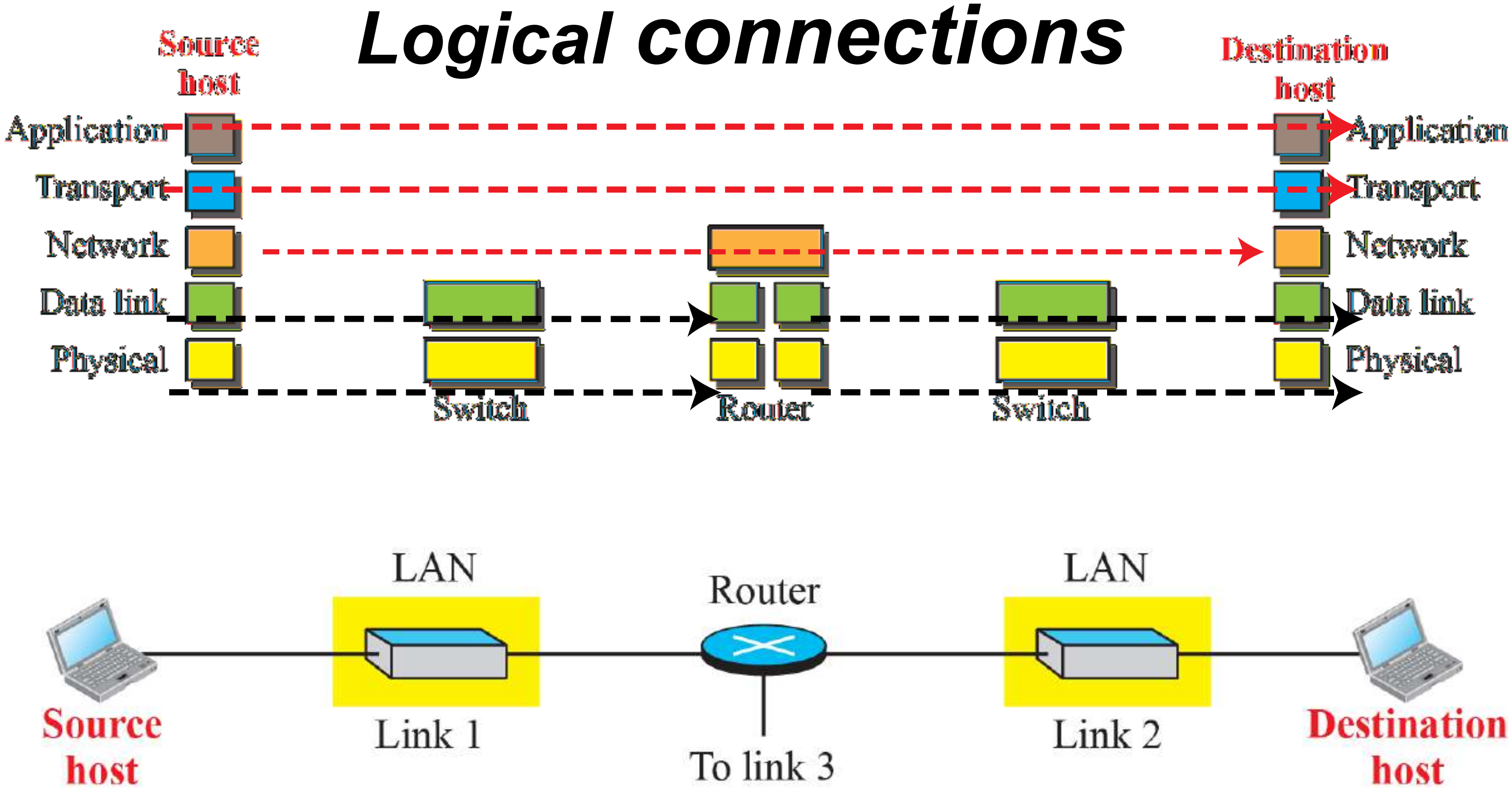

Application
Transport
Internet
Network Interface
Hardware Devices
Application
Transport
Network
Data link
Physical
Layer 5
Layer 4
Layer 3
Layer 2
Layer 1
a. Original layers
b. Layers used in this book


Source (A)
Destination (B)
Application
Transport
Network
Data link
Physical
Switch
Router
Data link
Physical
Network
Data link
Physical
Switch
Data link
Physical
Application
Transport
Network
Data link
Physical

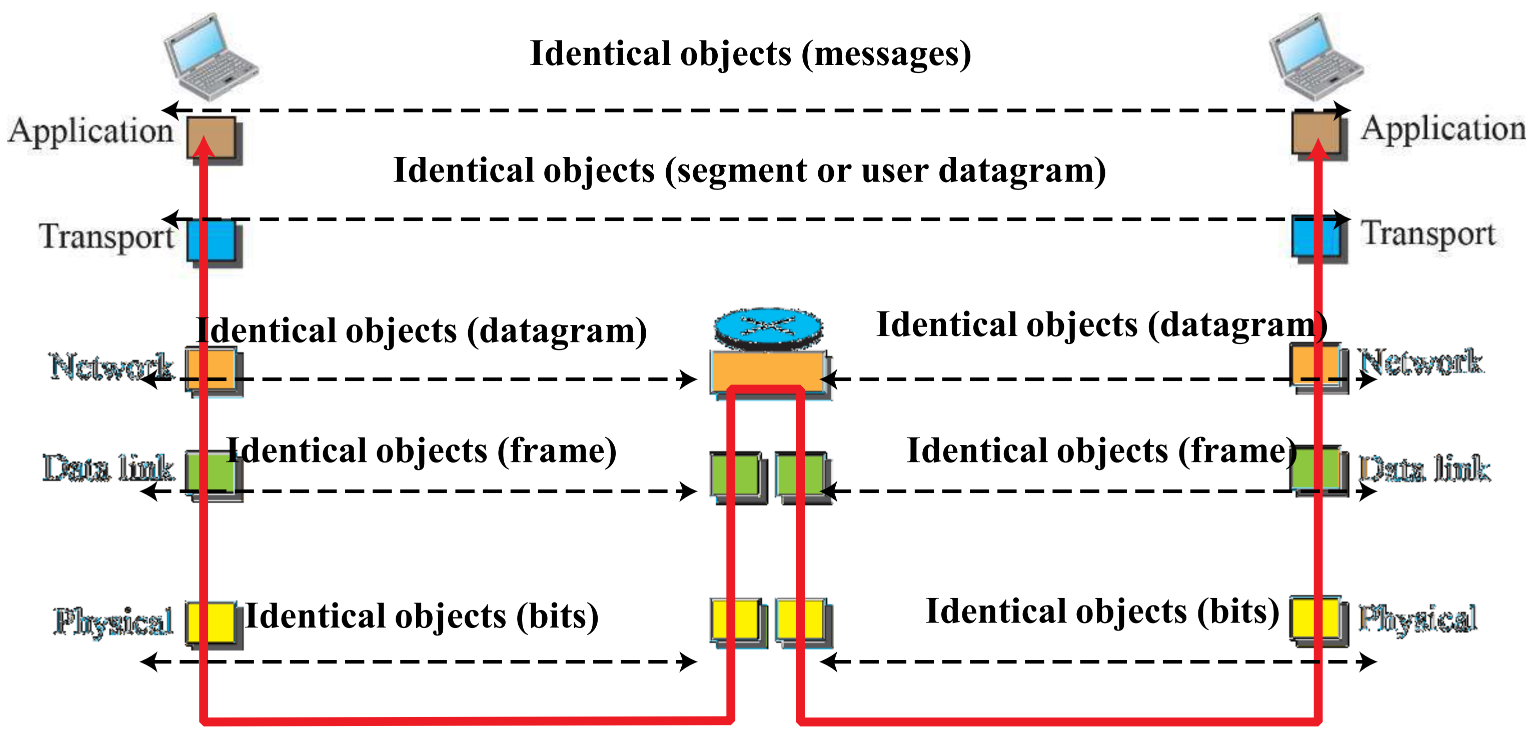

Communication from A to B
A
Link 1
Router
Link 2
B
Link 3
C

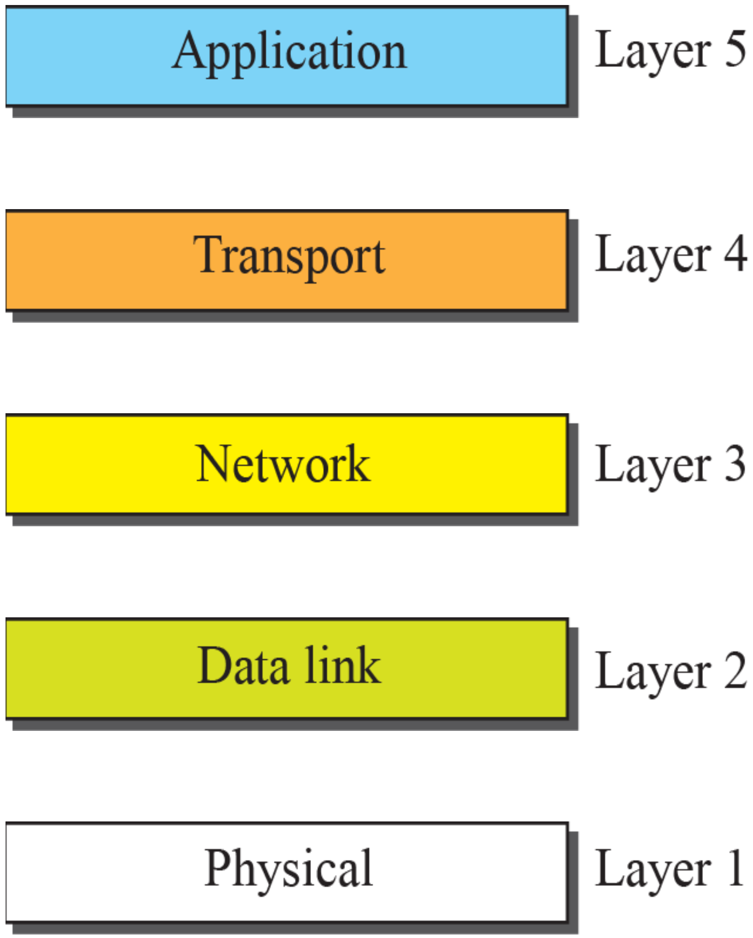
- **Logical Connections between TCP/IP Layers**

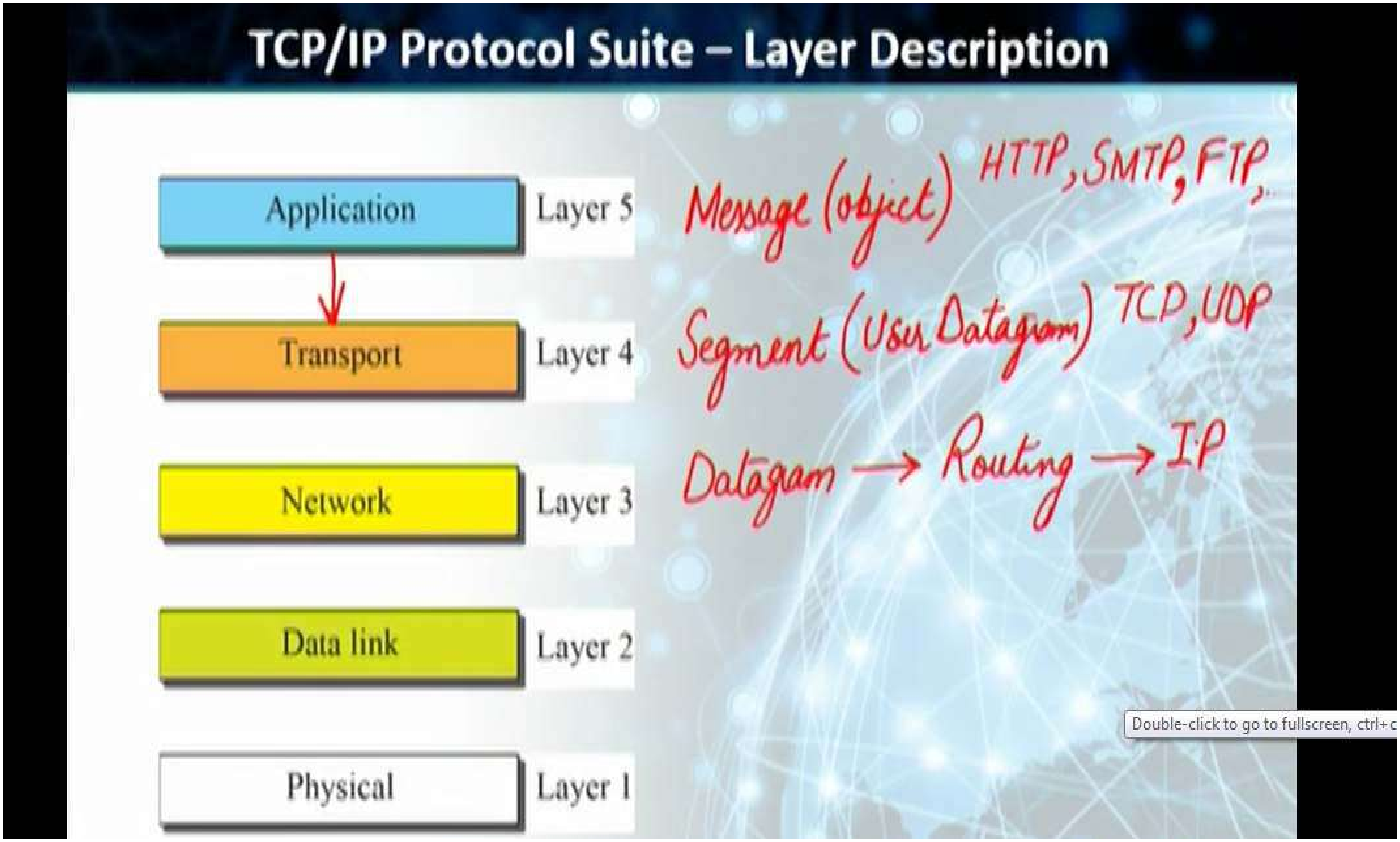
Logical connections



Notes: We have not shown switches because they don't change objects.




Application
Layer 5
Transport
Layer 4
Network
Layer 3
Data link
Layer 2
Physical
Layer 1


TCP/IP Protocol Suite – Layer Description
Application
Layer 5
Transport
Layer 4
Network
Layer 3
Data link
Layer 2
Physical
Layer 1
Message (object) HTTP, SMTP, FTP, ..
Segment (User Datagram) TCP, UDP
Datagram → Routing → IP
Double-click to go to fullscreen, ctrl+c

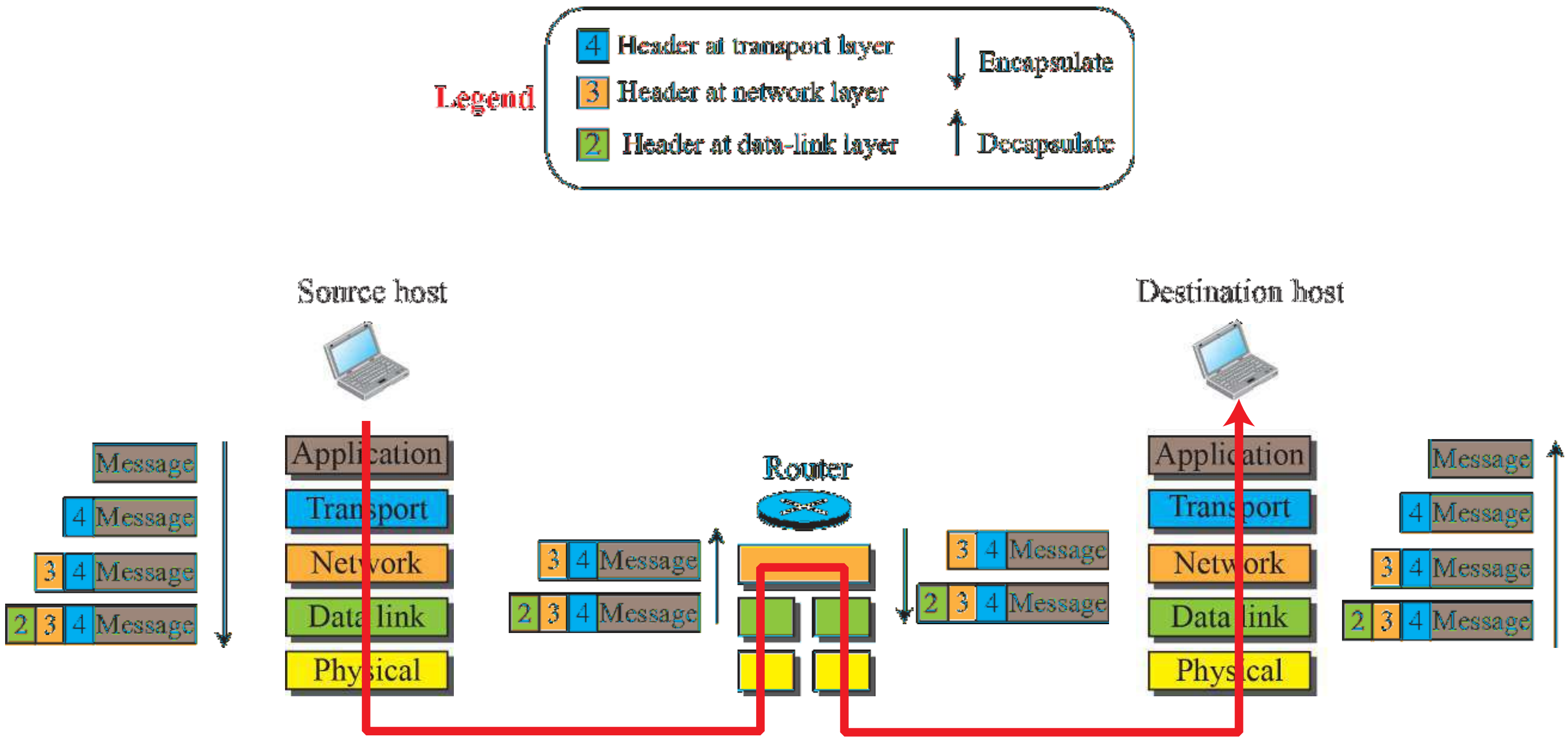
TCP/IP Protocol Suite – Layer Description

Application	Layer 5	Message (object) HTTP, SMT
Transport	Layer 4	Segment (User Datagram) TC
Network	Layer 3	Datagram → Routing →
Data link	Layer 2	Frame (object) Standard,
Physical	Layer 1	Bits (object)

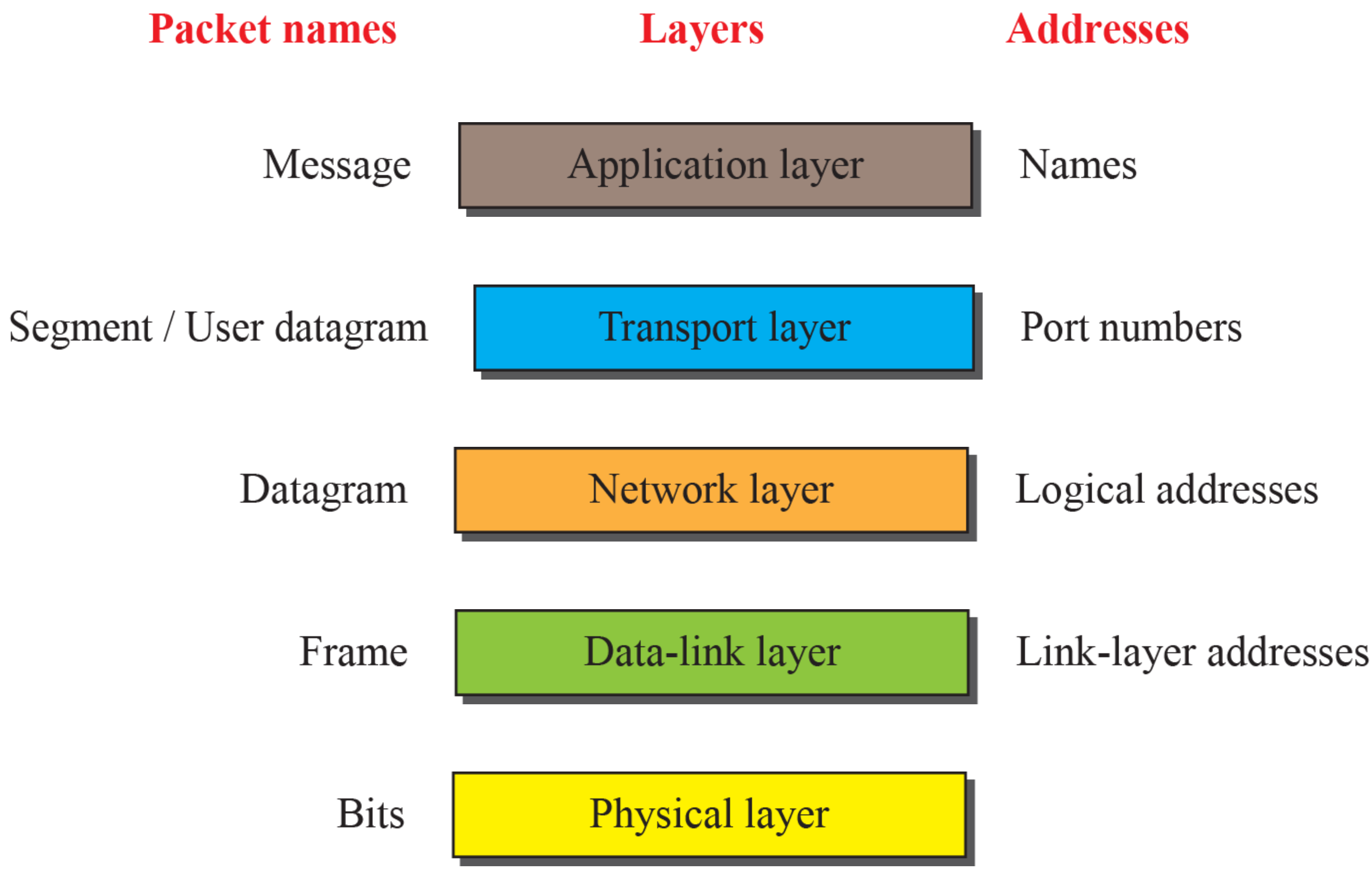
TM

- **Important Concept in Internet Protocol Layering**

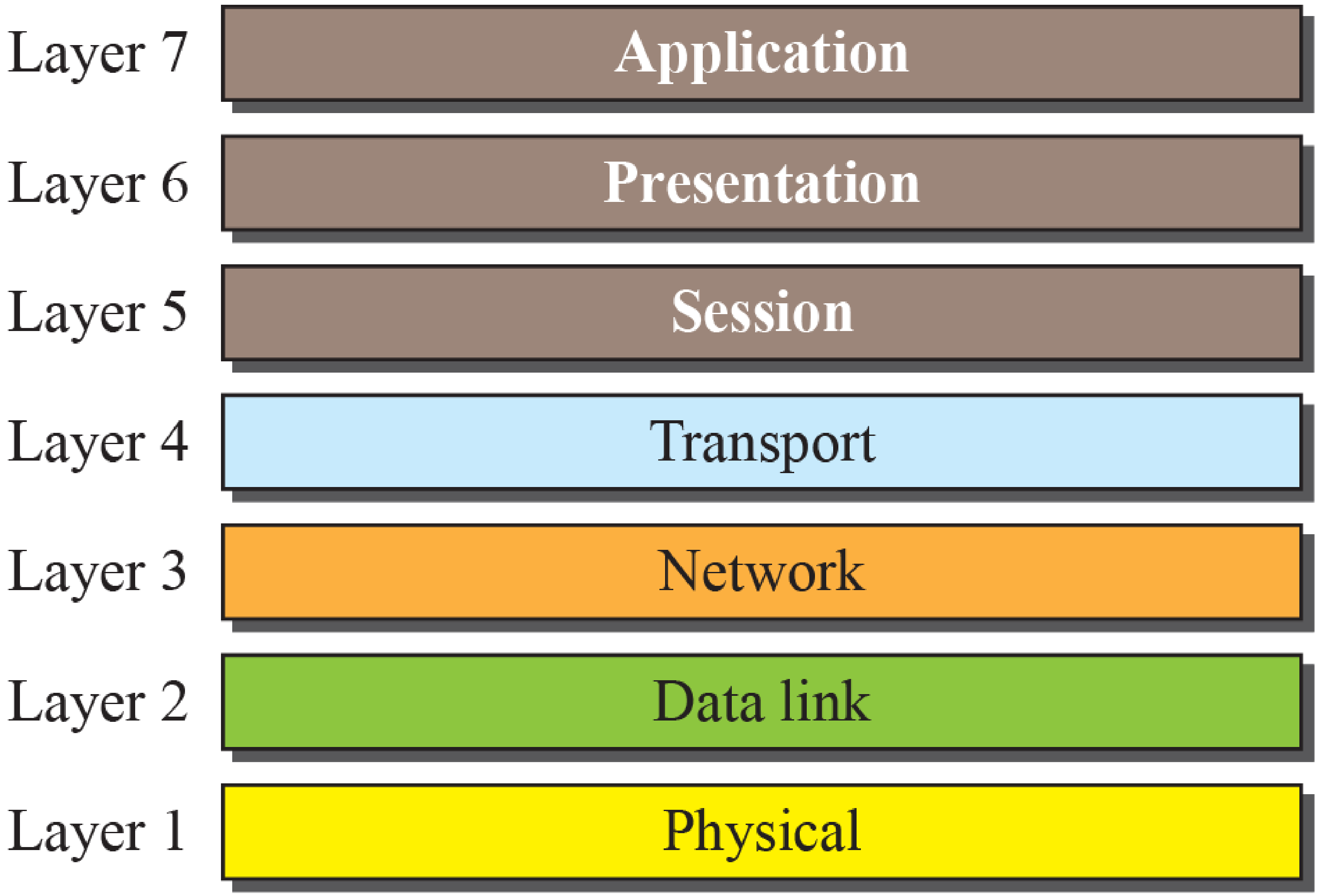
- **Layer Header**


Legend
4 Header at transport layer
3 Header at network layer
2 Header at data-link layer
Encapsulate
Decapsulate
Source host
Destination host
Router
Application
Transport
Network
Data link
Physical
Message
4 Message
3 4 Message
2 3 4 Message

- **Every communication needs at least two addresses:**
  - ✓ **Source Address &**
  - ✓ **Destination Address**
- **Addressing by Layer**
- **Physical Layer is an exception**

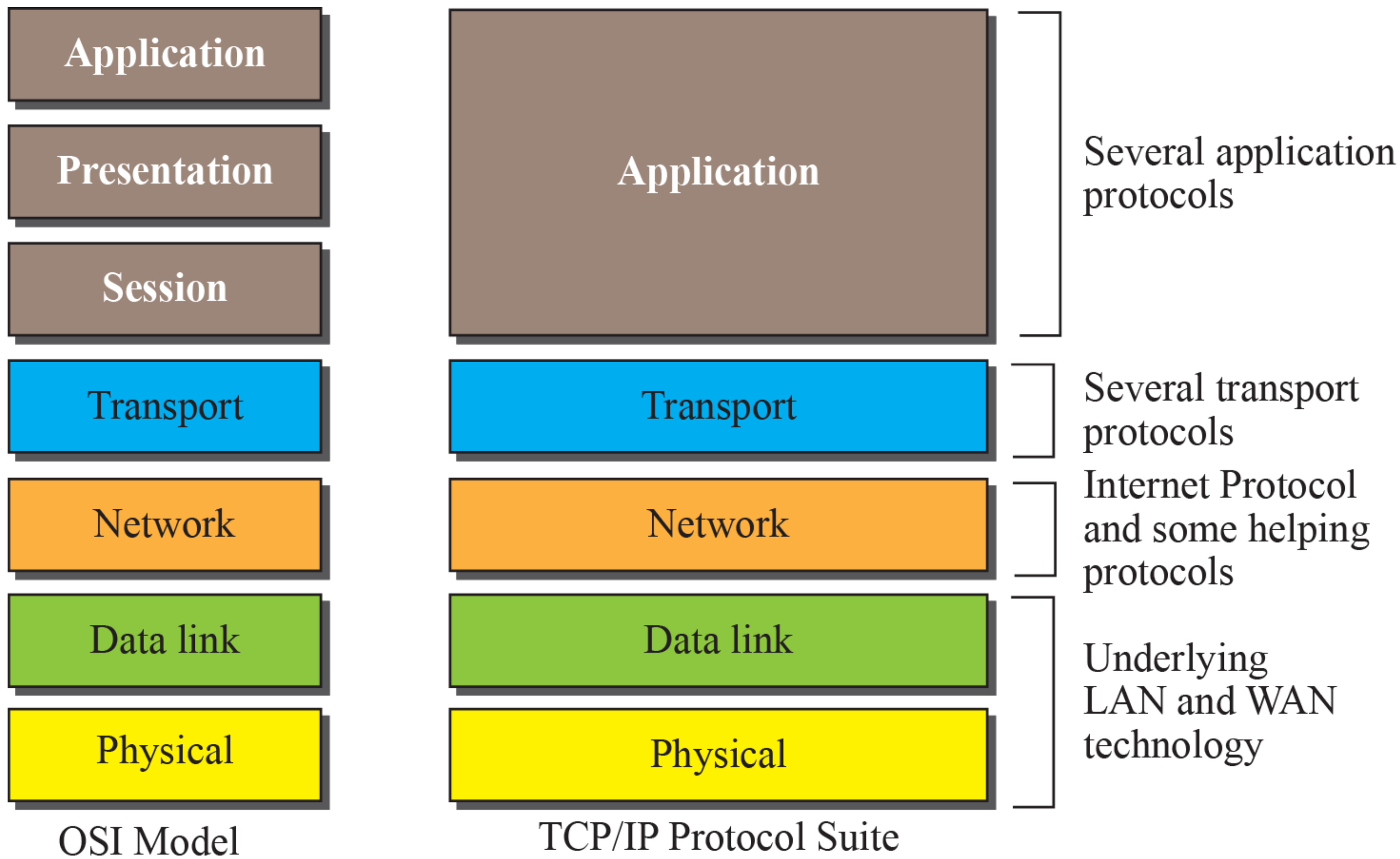

Packet names
Layers
Addresses
Message
Application layer
Names
Segment / User datagram
Transport layer
Port numbers
Datagram
Network layer
Logical addresses
Frame
Data-link layer
Link-layer addresses
Bits
Physical layer

- International Organization for Standardization (ISO)
- ISO established in 1947
- Close to three-fourths of countries represented
- Introduced OSI Model in late 1970s
- OSI: a 7-Layer Model


Layer 7
Application
Layer 6
Presentation
Layer 5
Session
Layer 4
Transport
Layer 3
Network
Layer 2
Data link
Layer 1
Physical

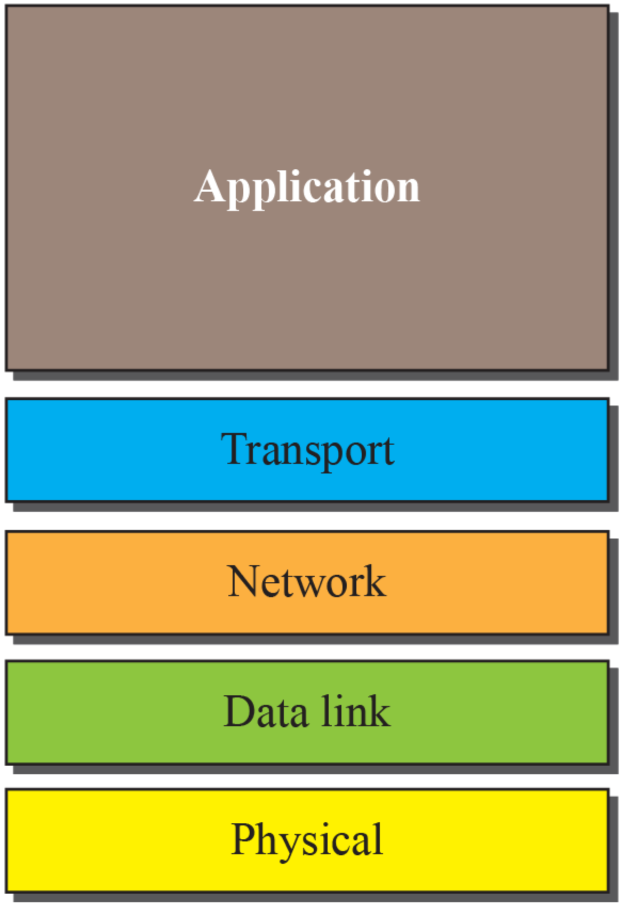
- **Two Layers of OSI missing from TCP/IP**

- **Application (TCP/IP) = Application + Presentation + Session (OSI)**

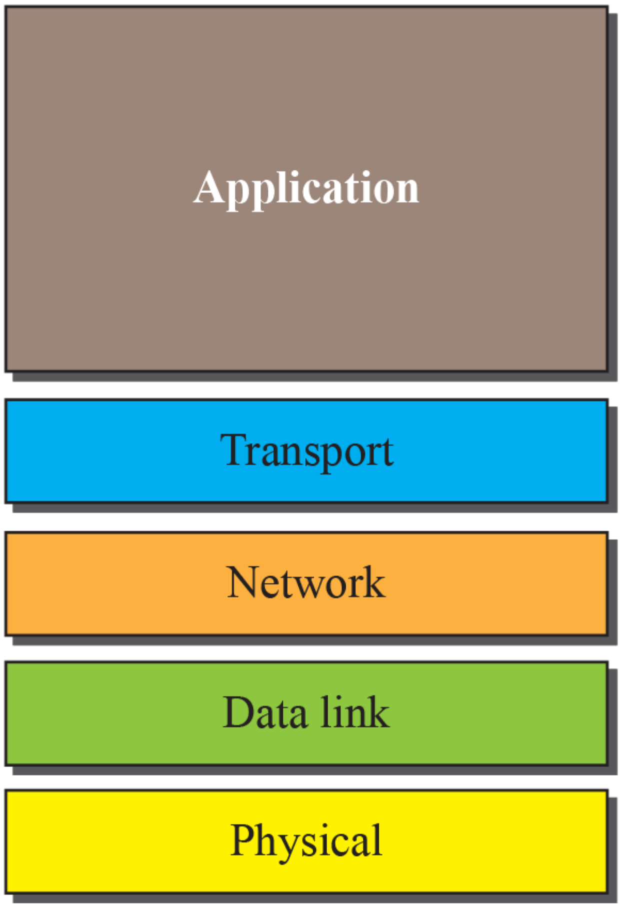


Application
Presentation
Session
Transport
Network
Data link
Physical
OSI Model
Application
Transport
Network
Data link
Physical
TCP/IP Protocol Suite
Several application protocols
Several transport protocols
Internet Protocol and some helping protocols
Underlying LAN and WAN technology

- **Three reasons OSI did not replace TCP/IP:**
  - ✓ **OSI was completed when TCP/IP was fully in place**
  - ✓ **Some layers in OSI not fully defined**
  - ✓ **Performance of TCP/IP better than that of OSI**

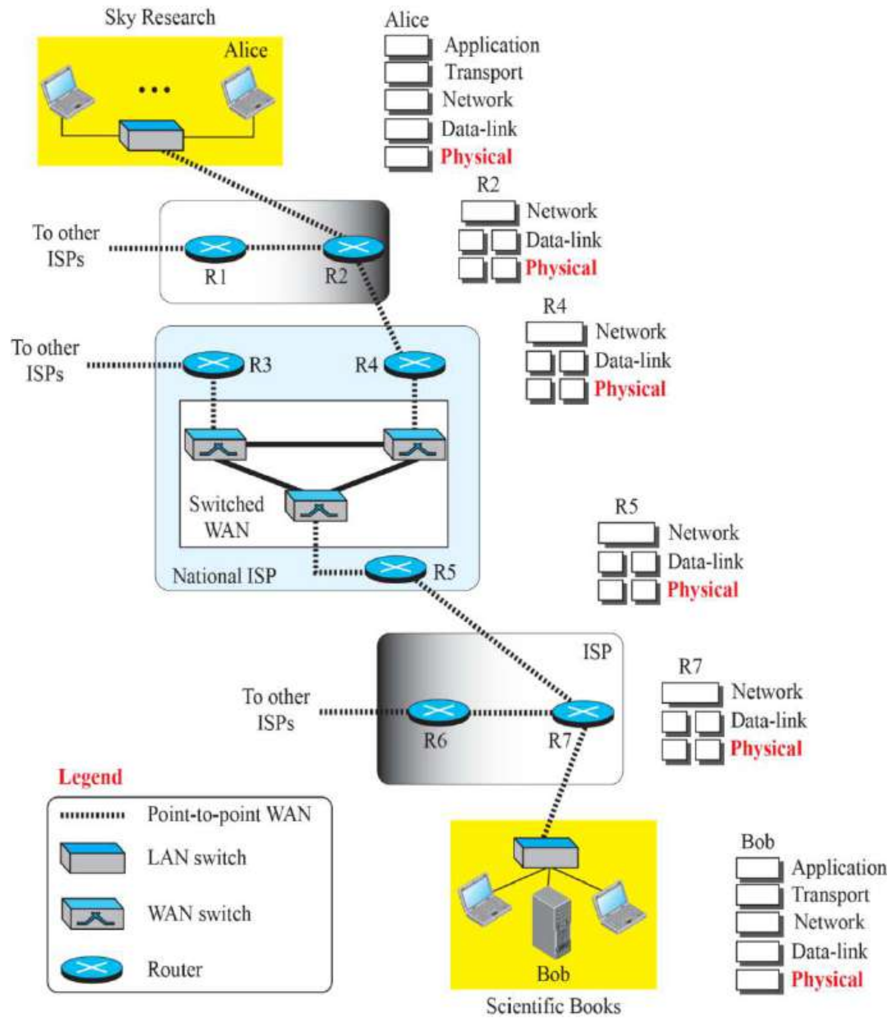


TCP/IP Protocol Suite



TCP/IP Protocol Suite

- **Analog & Digital Transmission**
- **Transmission Media**
- **Switching**
- **Error Detection and Correction**
- **Media Access and Data Link Control**
- **Wired and Wireless LANs**



Sky Research
Alice
Alice
Application
Transport
Network
Data-link
Physical
R2
Network
Data-link
Physical
To other ISPs
R1
R2
R4
Network
Data-link
Physical
To other ISPs
R3
R4
Switched WAN
National ISP
R5
R5
Network
Data-link
Physical
ISP
R7
Network
Data-link
Physical
To other ISPs
R6
R7
Legend
Point-to-point WAN
LAN switch
WAN switch
Router
Bob
Scientific Books
Bob
Application
Transport
Network
Data-link
Physical

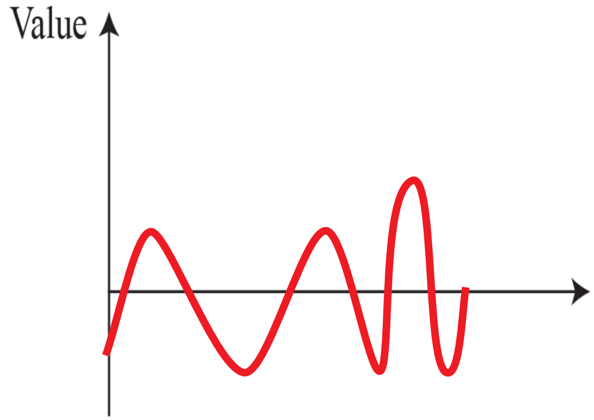
- Data → Analog or Digital
- Analog Data → Continuous
- Digital Data → Discrete
- Examples: Analog Clock vs. Digital Clock
- Human voice vs. Data in Computer

- **Signals represent Data**

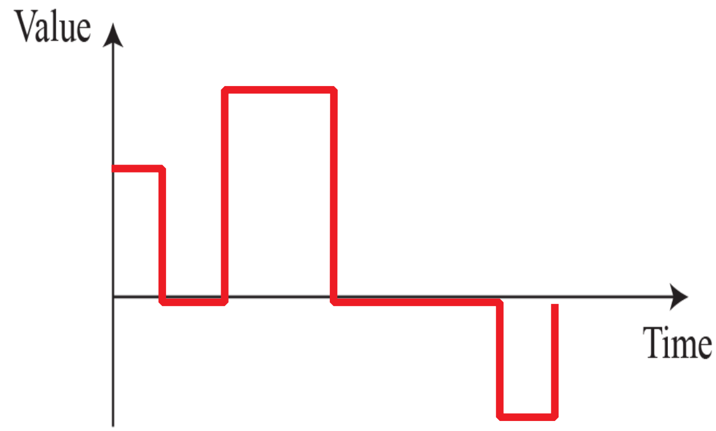
- **Signals → Analog or Digital**

- **Analog Signal → Infinite Levels of Intensity over time**

- **Digital Signal → Limited number of defined values**



a. Analog signal



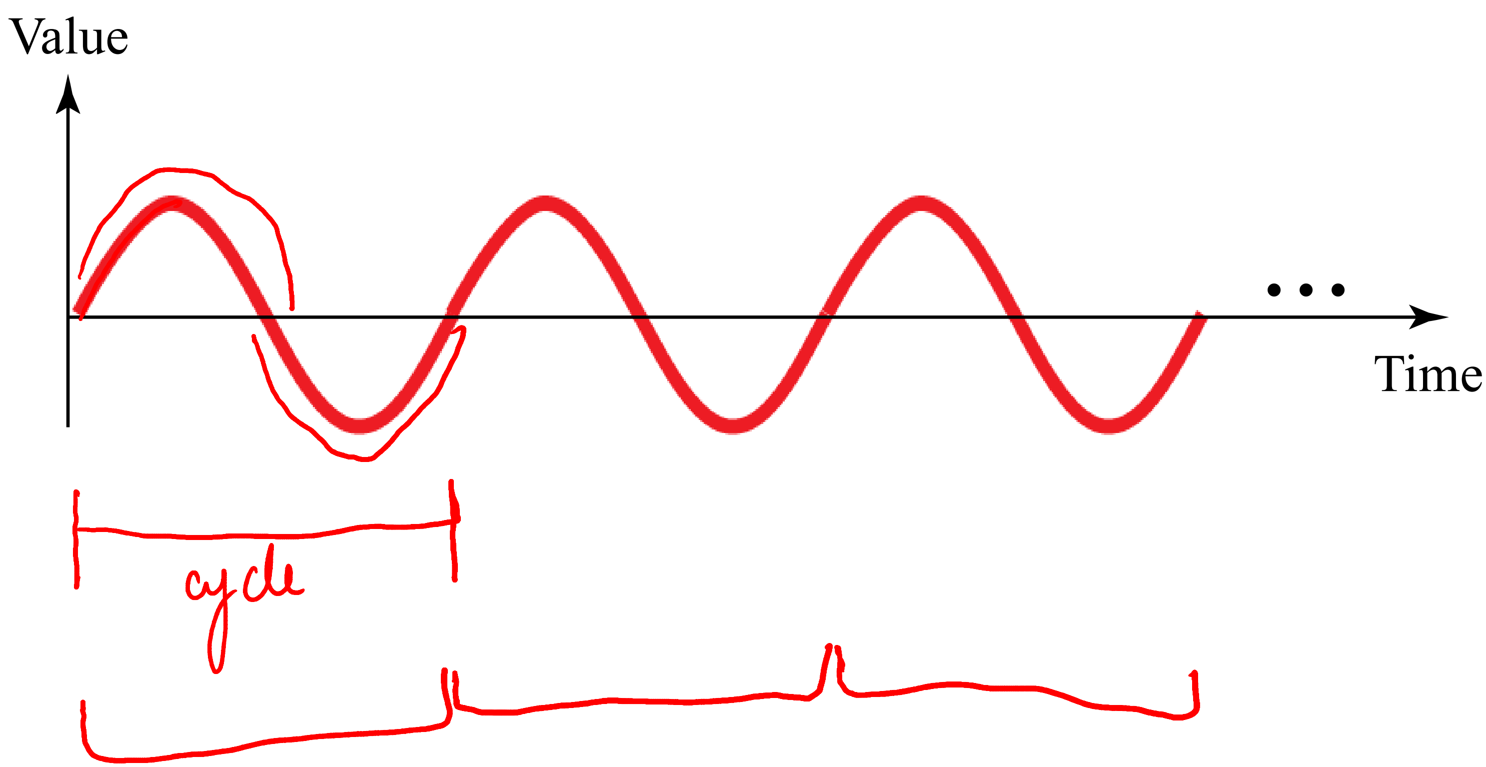
b. Digital signal

- **Analog/Digital Signal → Periodic or Non-periodic**
- **Periodic Signal → Pattern**
- **Period and Cycle**
- **Non-Periodic → No Pattern**
- **Periodic ANALOG Signals and Non-periodic DIGITAL Signals**

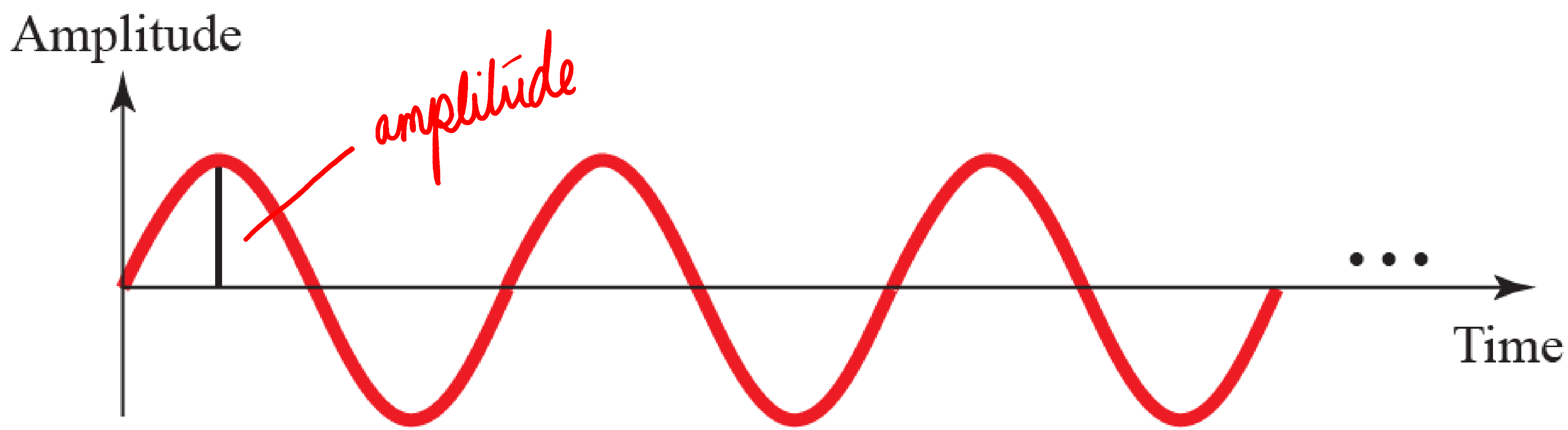
- **Periodic Analog Signals → Simple or Composite**

- **Simple Periodic Analog signal→ Sine wave**

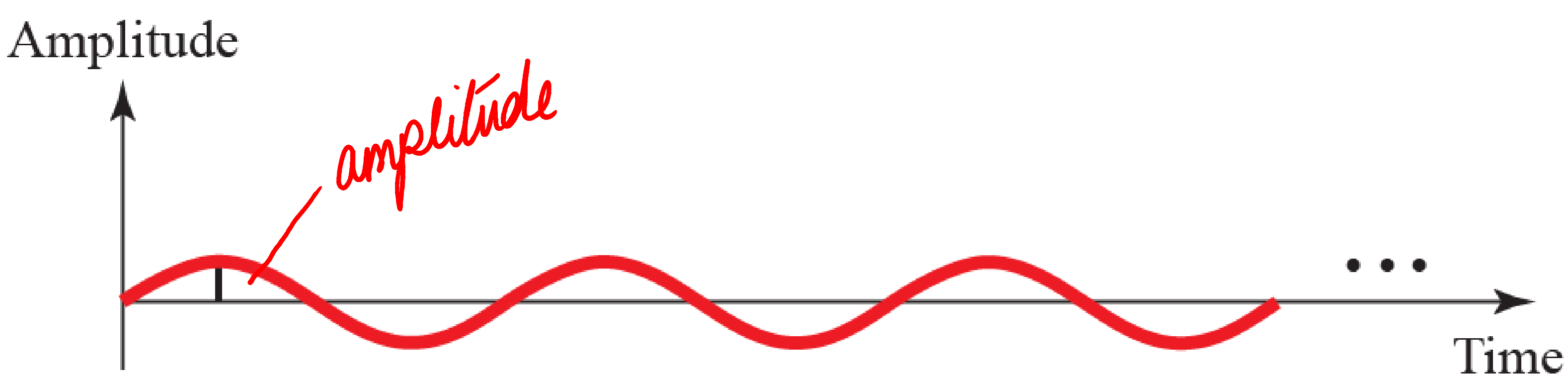
- **Composite Periodic Analog signal→ Composed of multiple sine waves**



Value
Time
cycle



a. A signal with high peak amplitude



b. A signal with low peak amplitude

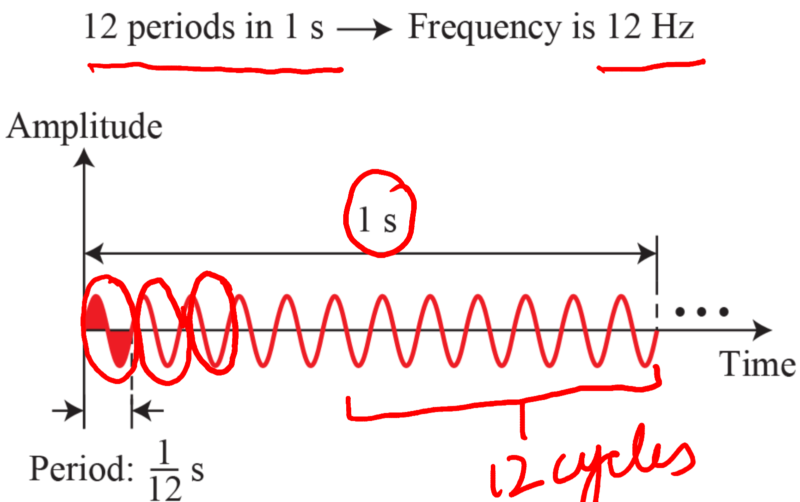
- **Period (T) → Amount of time required to complete 1 cycle**

- **Frequency (f) → No. of Periods in 1 sec**

- **$f = 1/T$ or $T = 1/f$**

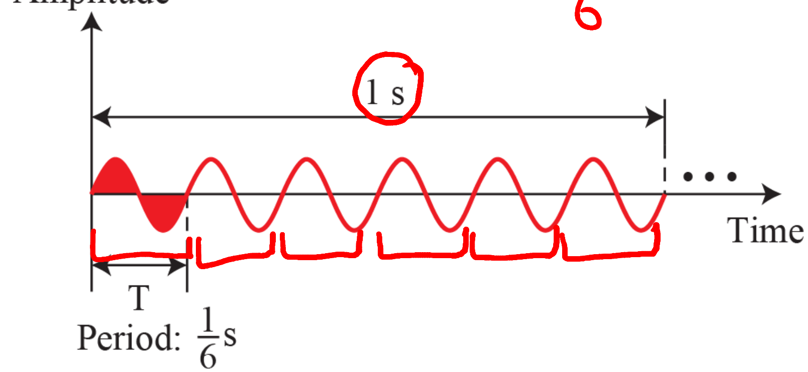
$$Hz = \text{cycles/sec}$$

$$T = \frac{1}{f} = \frac{1}{12}\ \text{sec}$$



a. A signal with a frequency of 12 Hz

$$T = \frac{1}{6}\ \text{sec}$$



b. A signal with a frequency of 6 Hz

Period		*Frequency*	
Unit	*Equivalent*	*Unit*	*Equivalent*
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3} Hz
Microseconds (μs)	10^{-6} s	Megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

The power we use at home has a frequency of 60 Hz. The period of this sine wave can be determined as follows:

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166 \text{ sec}$$

$$= 16.6 \text{ msec}$$

The period of a signal is 100 ms. What is its frequency in kilohertz?.

$$T = 100\,ms \Rightarrow 100 \times 10^{-3}\,sec = 10^{-1}\,sec$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} = 10\,Hz$$

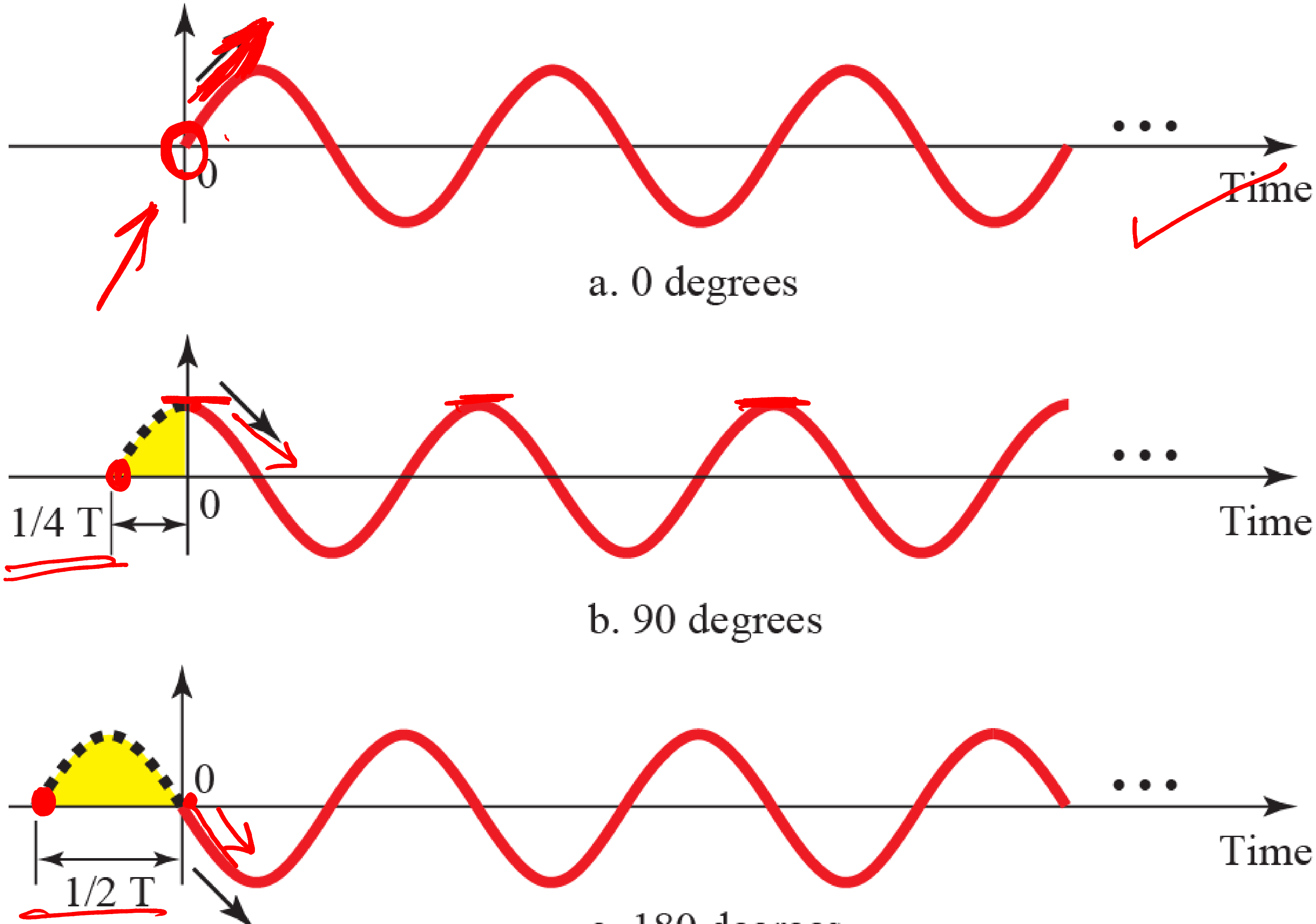
$$10 \times 10^{-3}\,kHz$$

$$= \underline{\underline{10^{-2}\,kHz}}$$

- **Position of waveform relative to time 0**
- **Phase describes the amount of shift of the wave**
- **Indicates start of the first cycle**

$$360^\circ = 2\pi \text{ radians}$$

$$1^\circ = \frac{2\pi}{360} \text{ rad}$$



a. 0 degrees

b. 90 degrees

c. 180 degrees

A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?

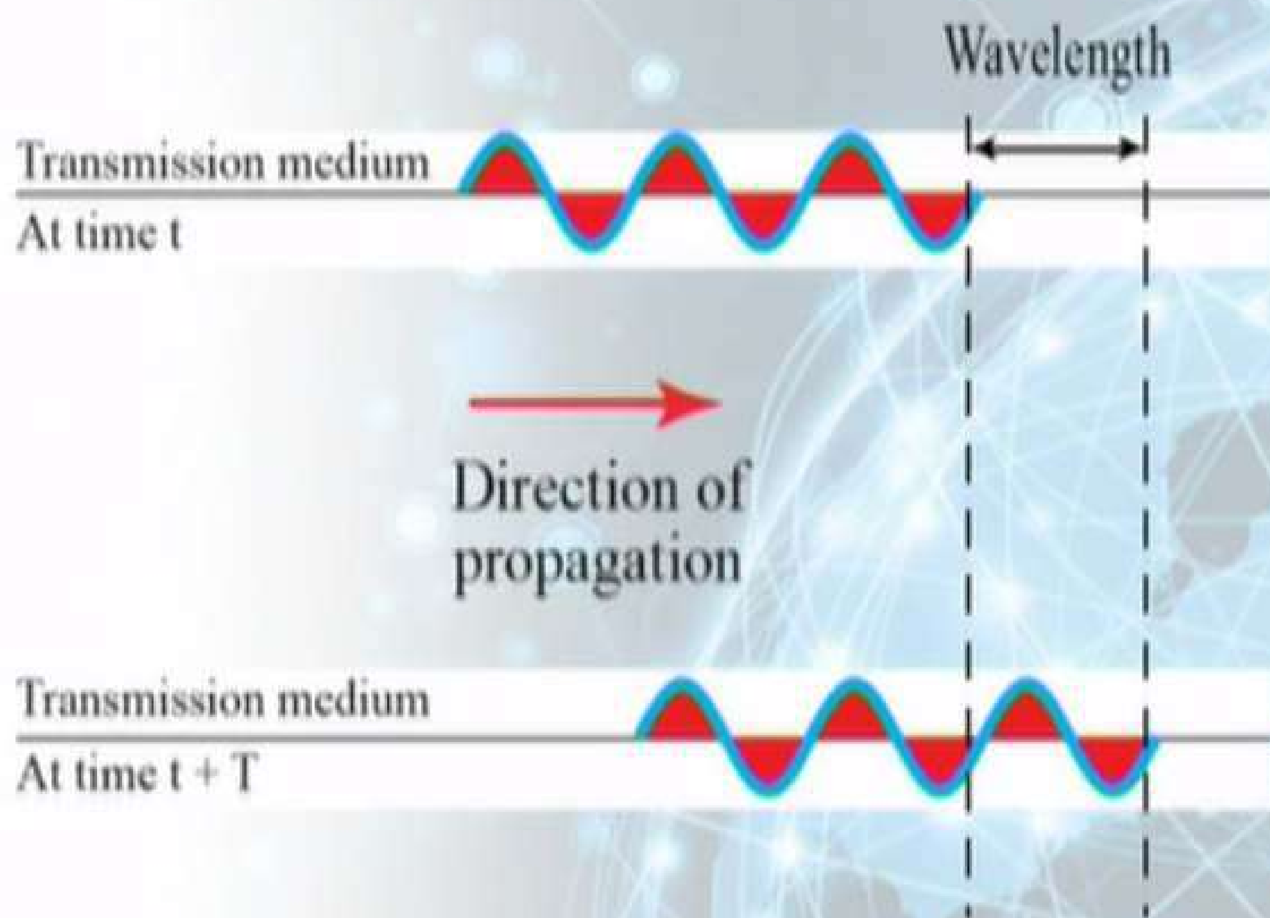
$$\frac{1}{6} \times 360^\circ = \underline{\underline{60^\circ}}$$

$$60 \times \frac{2\pi}{360} = 1.046 \text{ rad}$$

$$1^\circ = \frac{2\pi}{360} \text{ rad}$$

Wavelength is another characteristic of a signal traveling through a transmission medium. Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium (see Figure 3.7).

Figure 3.7


Wavelength
Transmission medium
At time t
Direction of propagation
Transmission medium
At time t + T

Prop. Speed = c = Light (speed)

frequency = f

Wavelength = λ

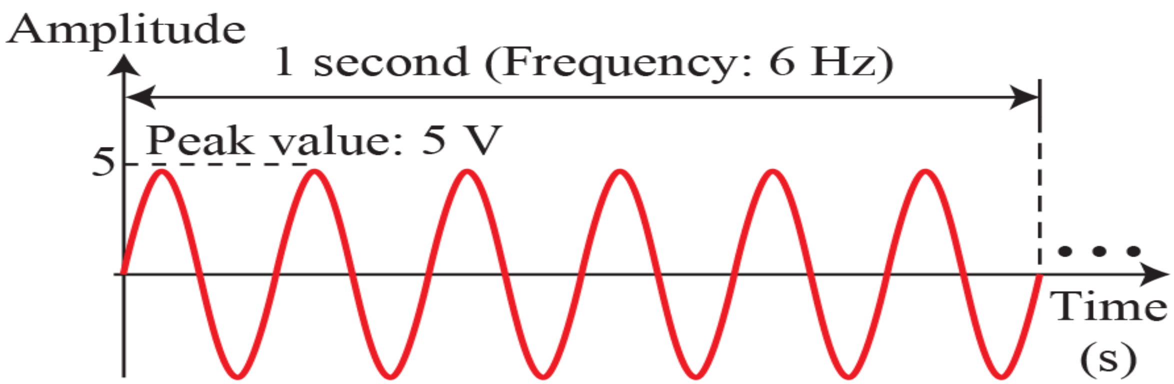
$$\lambda = \frac{c}{f} = \frac{3 \times 10^{8} \text{ m/sec}}{f}$$

$$\lambda = \frac{3 \times 10^{8}}{4 \times 10^{14}}$$

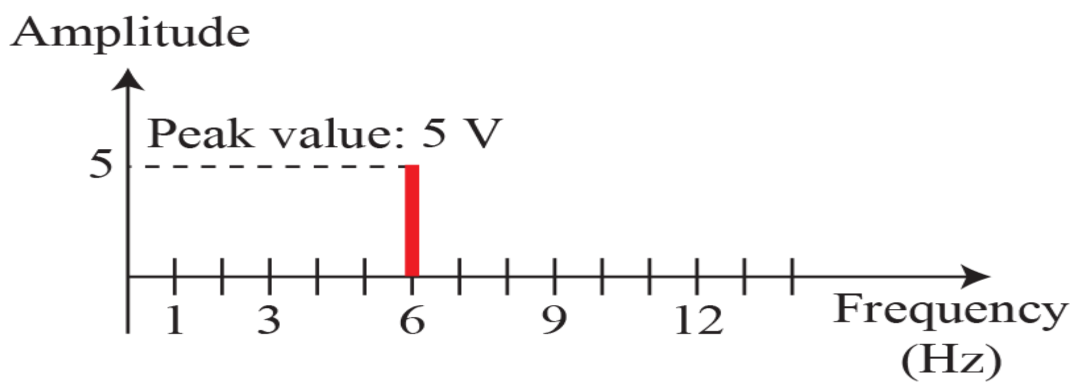
$$\lambda = 0.75 \times 10^{-6}\, m$$

$$= 0.75\, \mu m$$

A sine wave is comprehensively defined by its amplitude, frequency, and phase. We have been showing a sine wave by using what is called a time domain plot. The time-domain plot shows changes in signal amplitude with respect to time (it is an amplitude-versus-time plot). Phase is not explicitly shown on a time-domain plot.



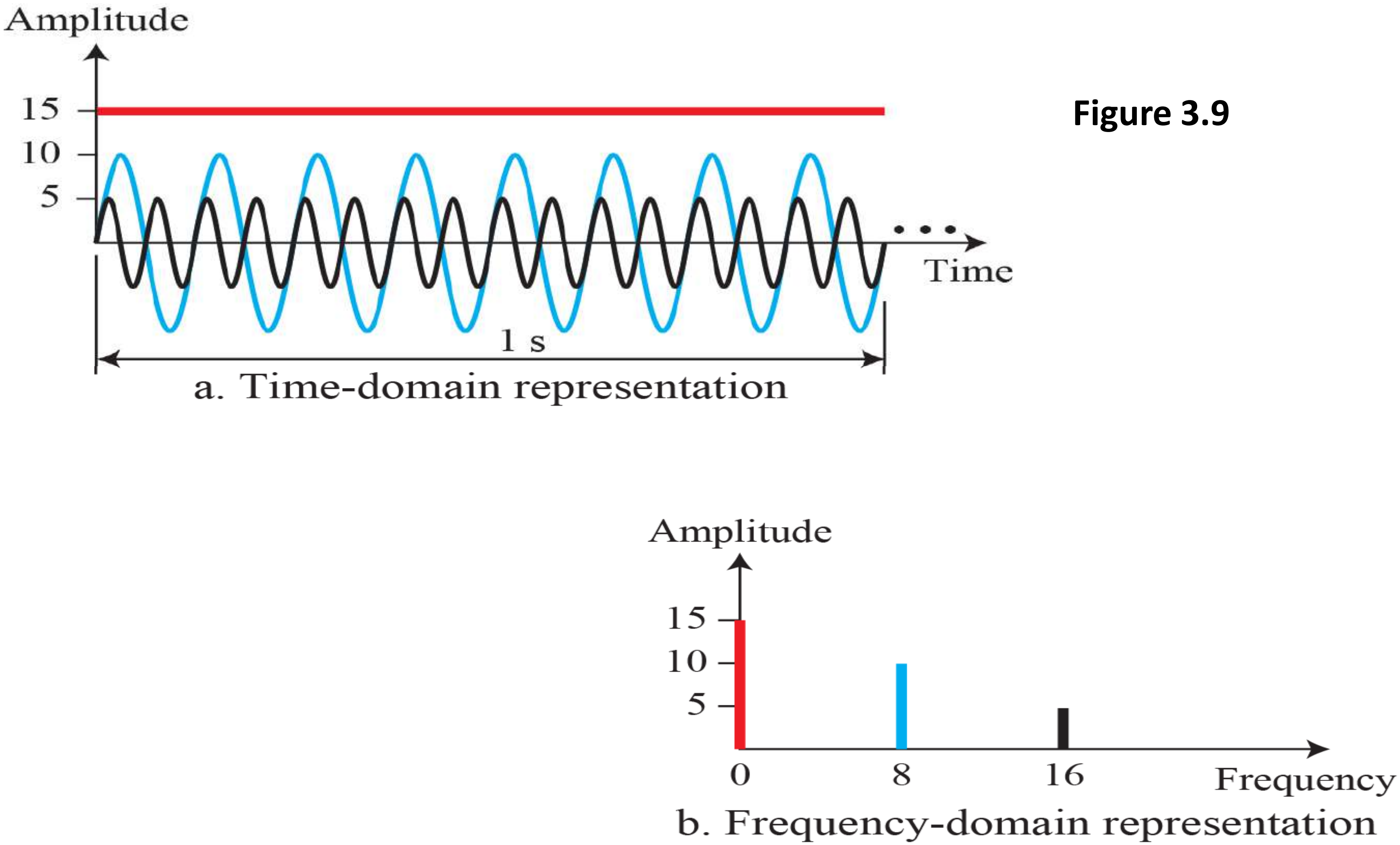
a. A sine wave in the time domain



b. The same sine wave in the frequency domain

The frequency domain is more compact and useful when we are dealing with more than one sine wave. For example, Figure 3.9 shows three sine waves, each with different amplitude and frequency. All can be represented by three spikes in the frequency domain.

Figure 3.9

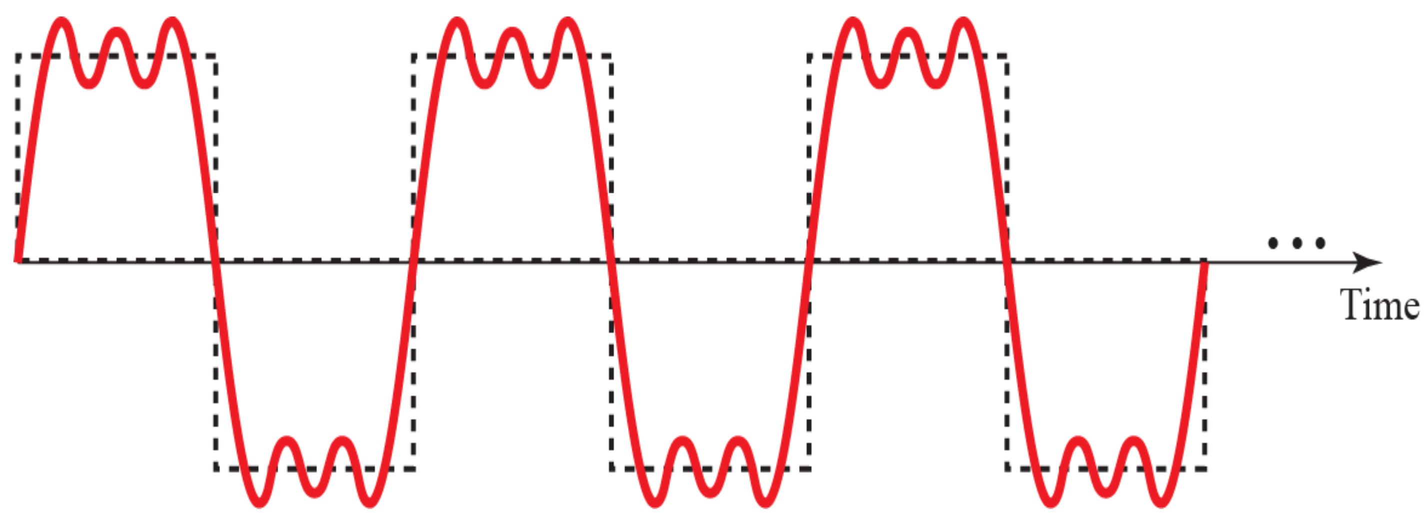

Amplitude
15
10
5
Time
1 s
a. Time-domain representation
Amplitude
15
10
5
0
8
16
Frequency
b. Frequency-domain representation

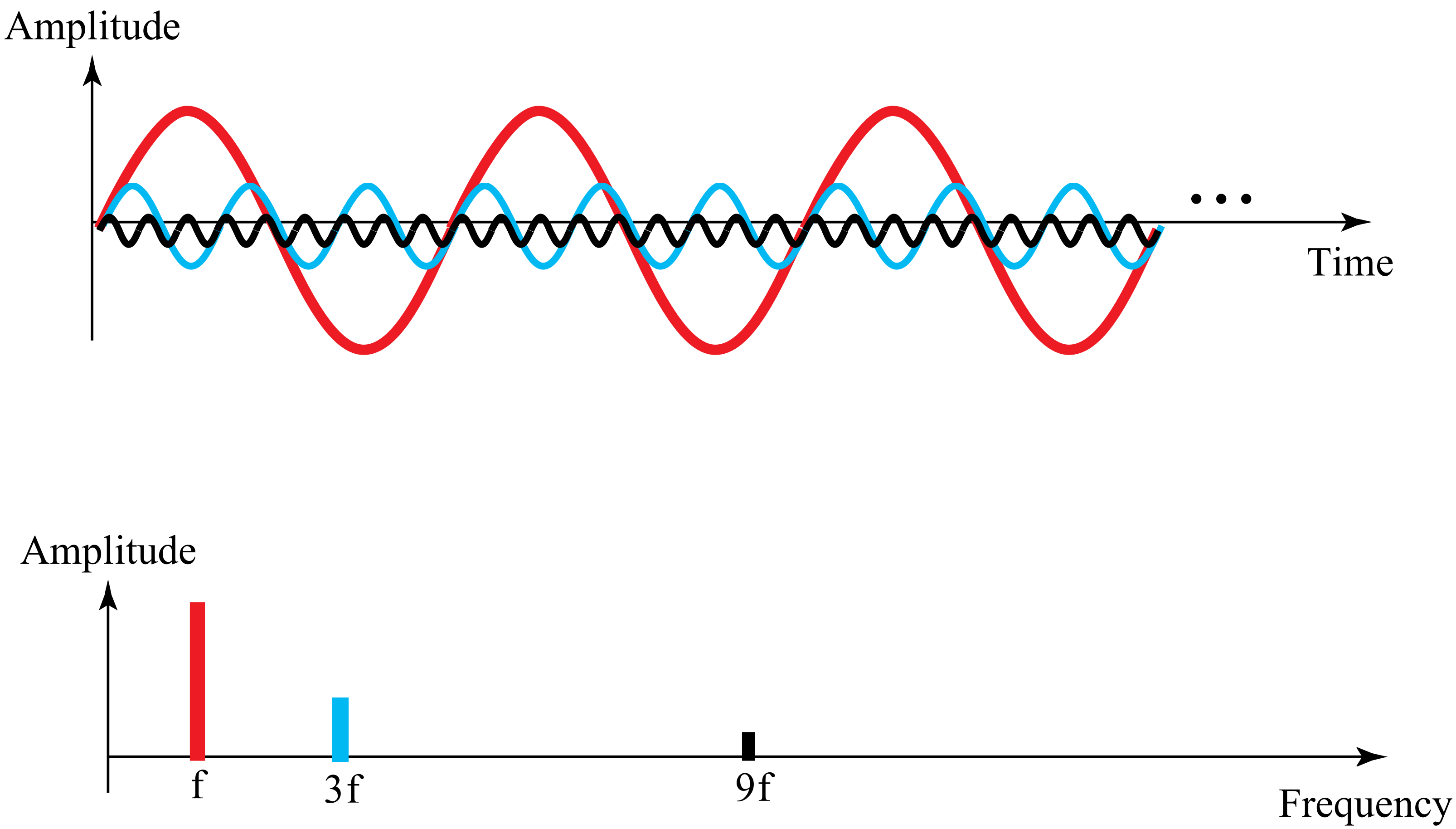
So far, we have focused on simple sine waves. Simple sine waves have many applications in daily life. We can send a single sine wave to carry electric energy from one place to another. For example, the power company sends a single sine wave with a frequency of 60 Hz to distribute electric energy to houses and businesses.

- **Single Sine Wave can only carry limited information**

- **Composite Signal is made up of multiple simple sine waves**

- **Can be periodic or non-periodic**

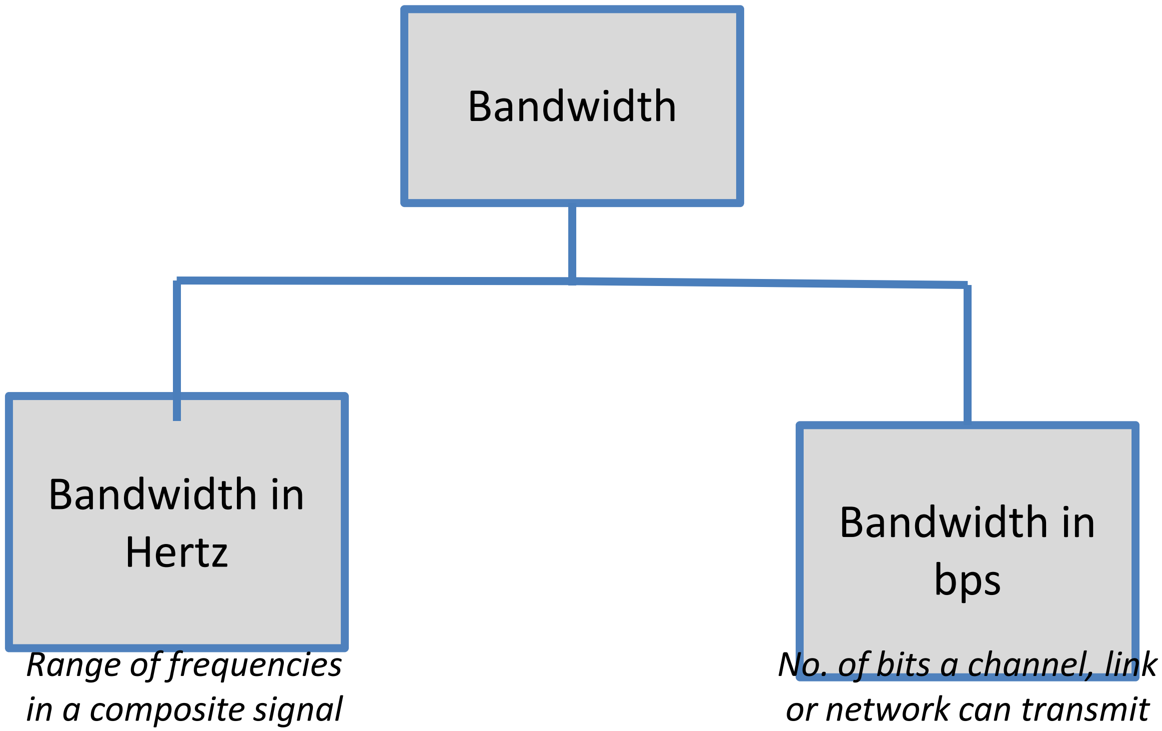

Time



b. Frequency-domain decomposition of the composite signal

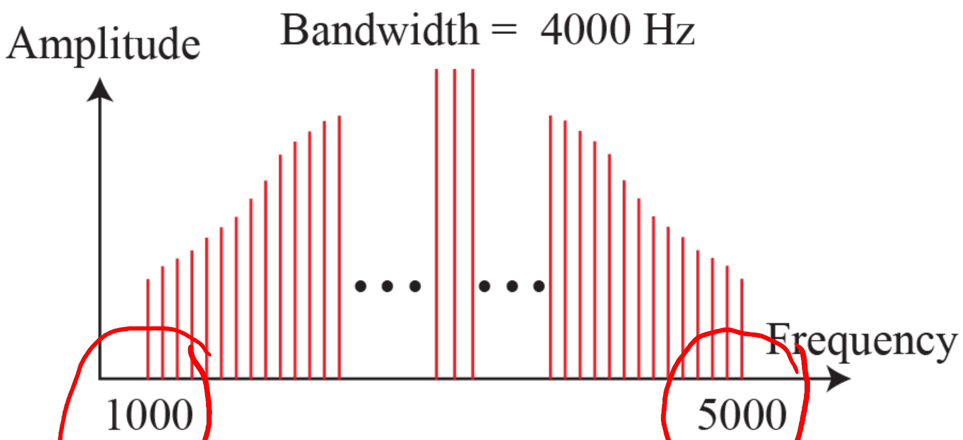
- An important characteristic that measures Network Performance

- Bandwidth can be used in two different contexts with two different measuring values:
  - Bandwidth in Hertz
  - Bandwidth in bits per second


Bandwidth
Bandwidth in Hertz
Bandwidth in bps
Range of frequencies in a composite signal
No. of bits a channel, link or network can transmit

- **Range of frequencies contained in a Composite Signal**

- **The bandwidth is normally a difference between two frequencies (the highest and the lowest)**

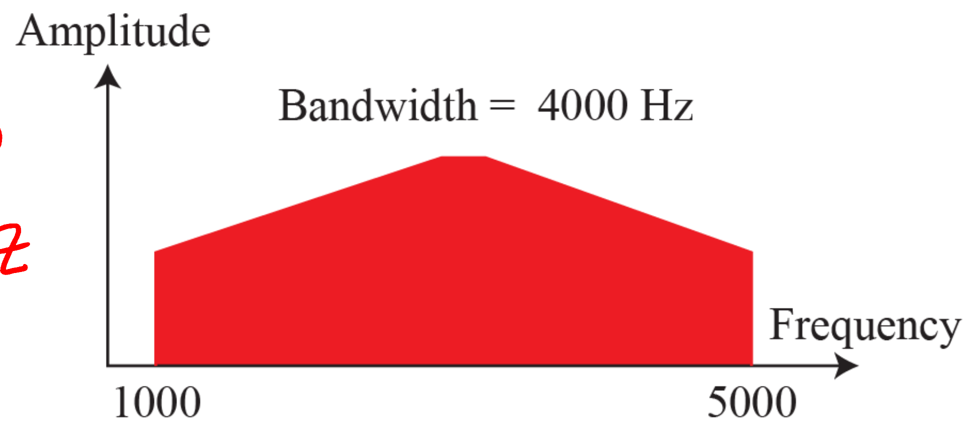


a. Bandwidth of a periodic signal

$$B = f_h - f_l$$
$$= 5000 - 1000$$
$$= 4000\ \text{Hz}$$

$5000 - 1000$

$B = 4000\ \text{Hz}$

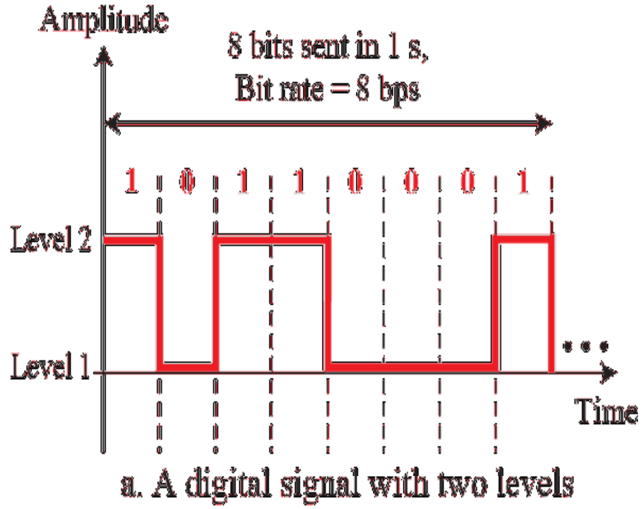


b. Bandwidth of a nonperiodic signal

If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V.

In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels.

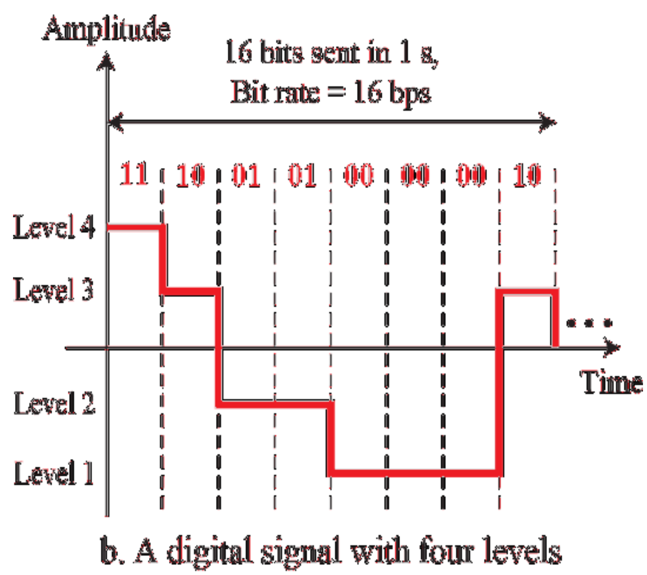
- Information can also be represented by a digital signal
- For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage
- A digital signal can have more than two levels so that we can send more than one bit for each level



a. A digital signal with two levels

In general, if a signal has L levels, each level needs $\log_2 L$ bits. So, we can send $\log_2 2 = 1$ bit per level

$\log_2 4 = 2$ bits



b. A digital signal with four levels

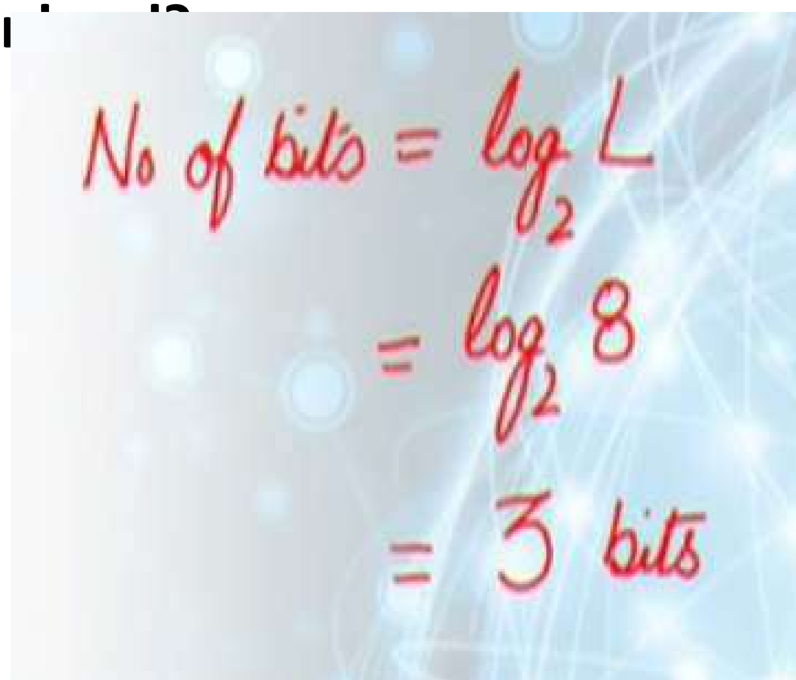
In this case, we can send more than 1 bit for each level. Figure 3.17 shows two signals, one with two levels and the other with four.

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the following formula. Each

$$\text{Number of bits per level} = \log_2 8 = 3$$

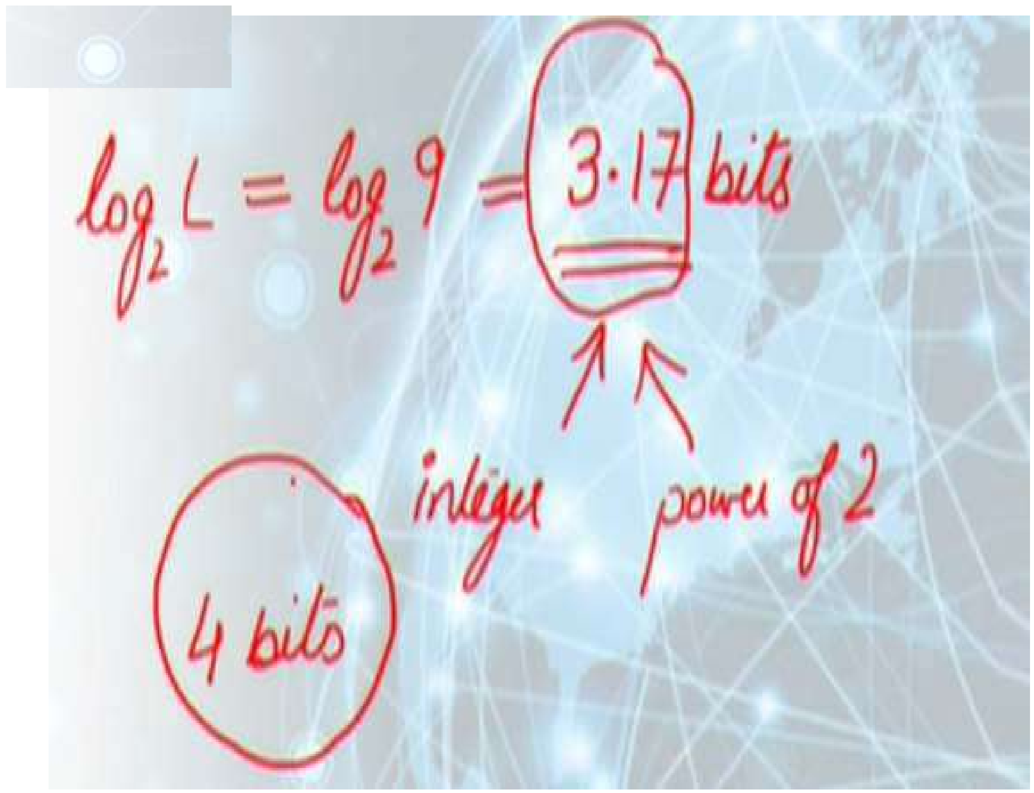
bits.

A digital signal has eight levels. How many bits are needed per

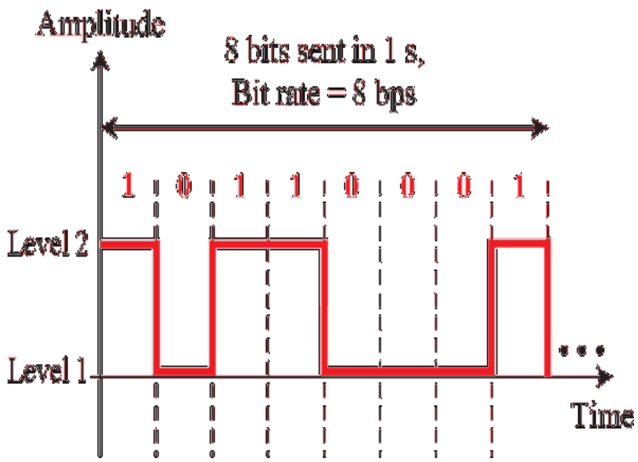


A digital signal has nine levels. How many bits are needed per level? We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

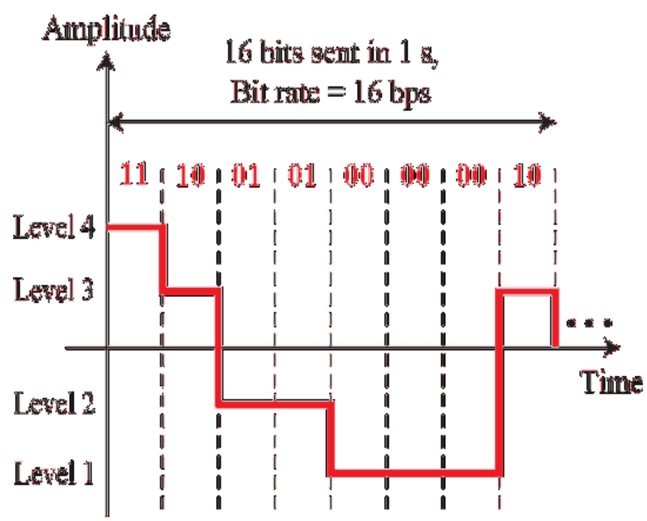
A digital signal has nine levels. How many bits are needed per level? We calculate the number of bits by using the formula.



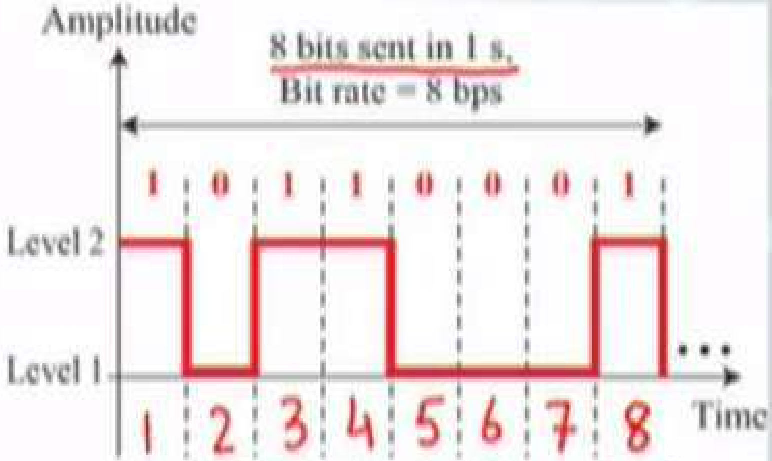
- **Number of bits sent in 1 second**
- **Bit Rate is expressed in bits per second (bps)**
- **Most digital signals are non-periodic, and thus period and frequency are not appropriate characteristics**



a. A digital signal with two levels



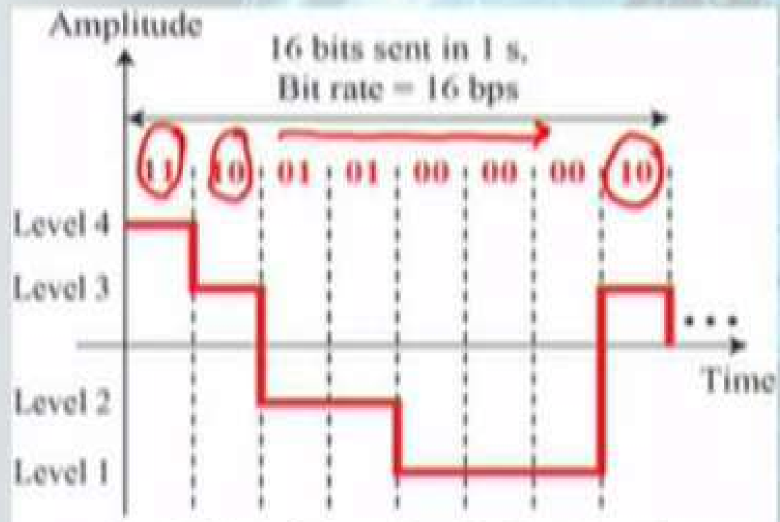
b. A digital signal with four levels



a. A digital signal with two levels

Bit Rate = 8bps

BR = 1



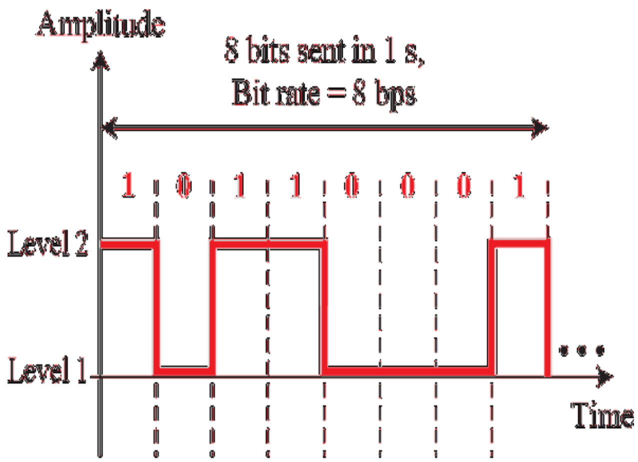
b. A digital signal with four levels

Most digital signals are nonperiodic, and thus period and frequency are not appropriate characteristics. Another term—bit rate (instead of frequency)—is used to describe digital signals. The bit rate is the number of bits sent in 1s, expressed in bits per second (bps). Figure 3.17 shows the bit rate for two signals.

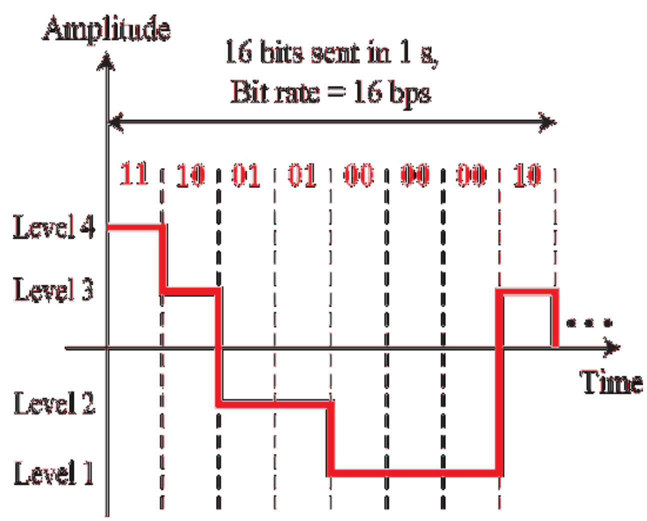
- **Number of bits sent in 1 second**

- **Bit Rate is expressed in bits per second (bps)**

- **Most digital signals are non-periodic, and thus period and frequency are not appropriate characteristics**



a. A digital signal with two levels



b. A digital signal with four levels

Assume we need to download text documents at the rate of 100 pages per second. What is the required bit rate of the ch

1 page = 24 lines

1 line = 80 characters

1 ch = 8 bits

$$\text{Bit Rate} = 100 \times 24 \times 80 \times 8$$

$$= \underline{\underline{1.536}}\ \text{Mbps}$$

Solution

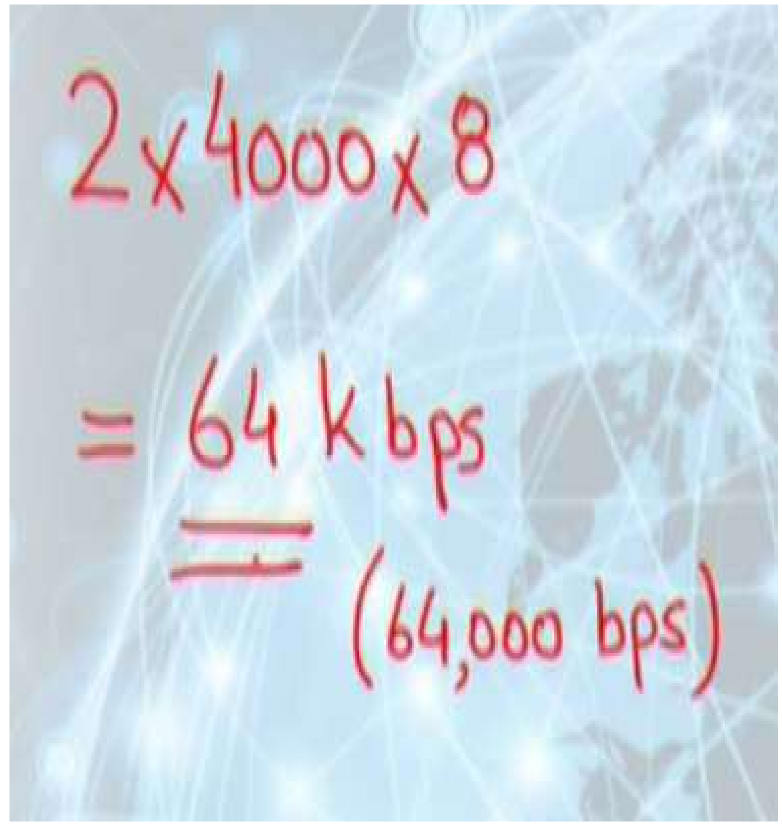
From Table 3.1 we find the equivalents of 1 ms (1 ms is 10–3 s) and 1 s (1 s is 106 μs). We make the

$$100 \times 24 \times 80 \times 8 = 1{,}536{,}000 \text{ bps}$$

subst

$$= 1.536 \text{ Mbps}$$

A digitized voice channel is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?



Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires

$$2 \times 4000 \times 8 = 64{,}000 \text{ bps}$$

$$= 64 \text{ kbps}$$

What is the bit rate for high-definition TV (HDTV)?

Solution

HDTV uses digital signals to broadcast high quality video signals. The HDTV screen is normally a ratio of 16 : 9 (in contrast to 4 : 3 for regular TV), which means the screen is wider. There are 1920 by 1080 pixels per screen, and the screen is renewed 30 times per second.

Solution

Twenty-four bits represents one color pixel. We can calculate the bit rat

$$1920 \times 1080 \times 30 \times 24$$

$$= 1{,}492{,}992{,}000 \approx 1.5 \text{ Gbps}$$

The TV stations reduce this rate to 20 to 40 Mbps through compression.

We discussed the concept of the wavelength for an analog signal: the distance one cycle occupies on the transmission medium. We can define something similar for a digital signal: the bit length. The bit length is the distance one bit occupies on the transmission medium.

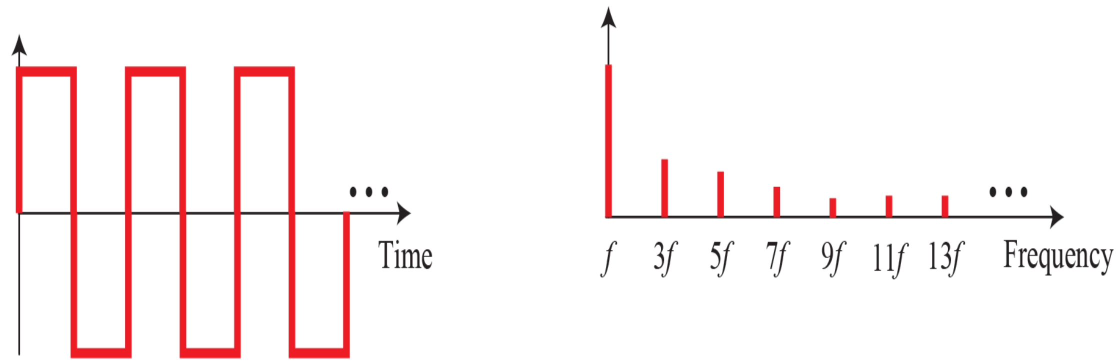
$$\text{Bit length} = \text{propagation speed} \times \text{bit duration}$$

- **Based on Fourier analysis, a digital signal is a composite analog signal**

- **A digital signal, in the time domain, comprises connected vertical and horizontal line segments**

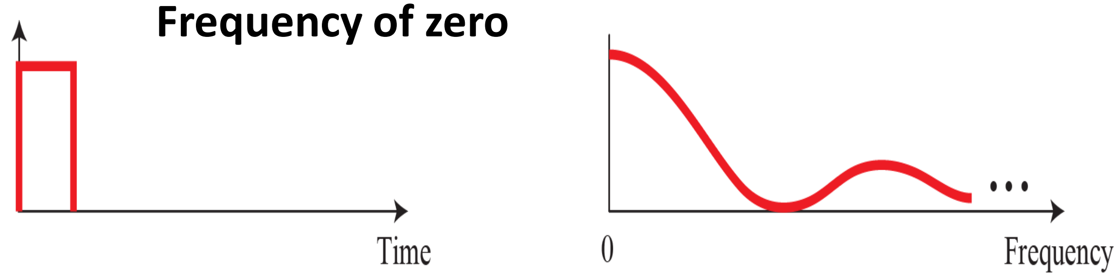
- **Infinite Bandwidth**

A vertical line in the time domain means a frequency of infinity: a horizontal line in the time domain means a frequency of zero. Going from a frequency of zero to a frequency of infinity implies all frequencies in between are part of the domain.

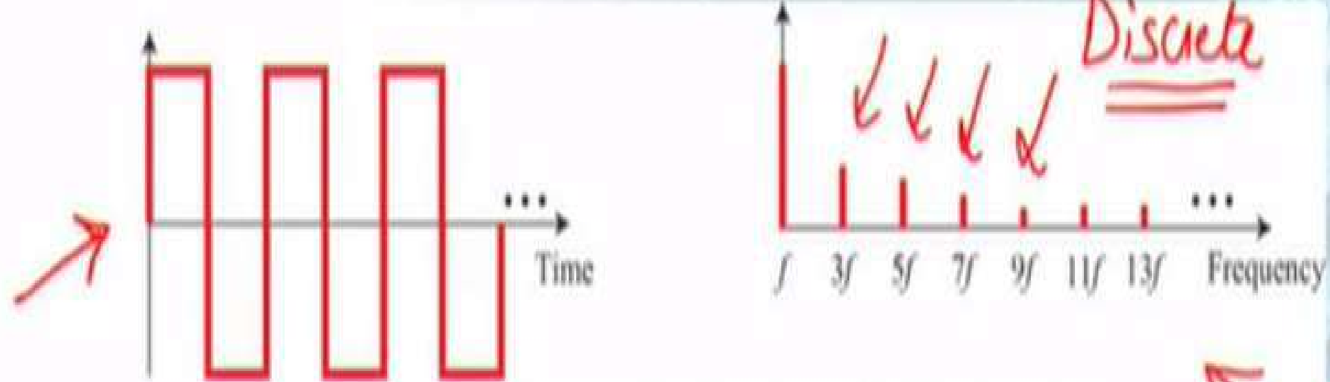


a. Time and frequency domains of periodic digital signal

Vertical line in the time domain:
Frequency of infinity
Horizontal line in the time domain:
Frequency of zero



b. Time and frequency domains of nonperiodic digital signal



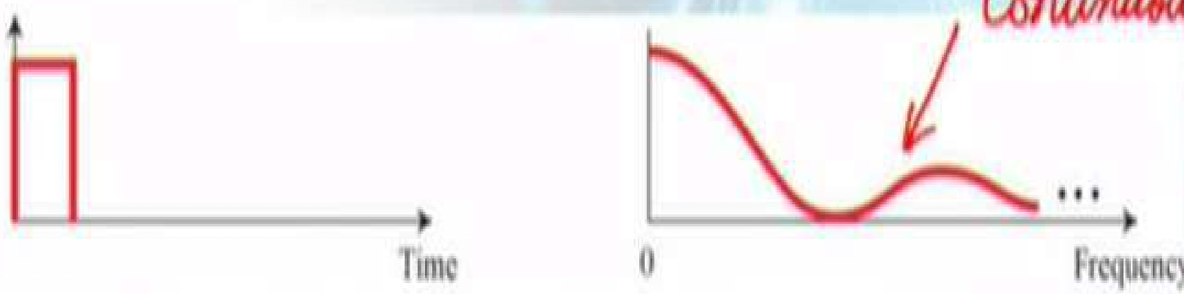
a. Time and frequency domains of periodic digital signal

Vertical line in the time domain: Frequency of infinity $f\infty$

Horizontal line in the time domain: Frequency of zero $f0$

$f = \frac{1}{T}$

Continuous

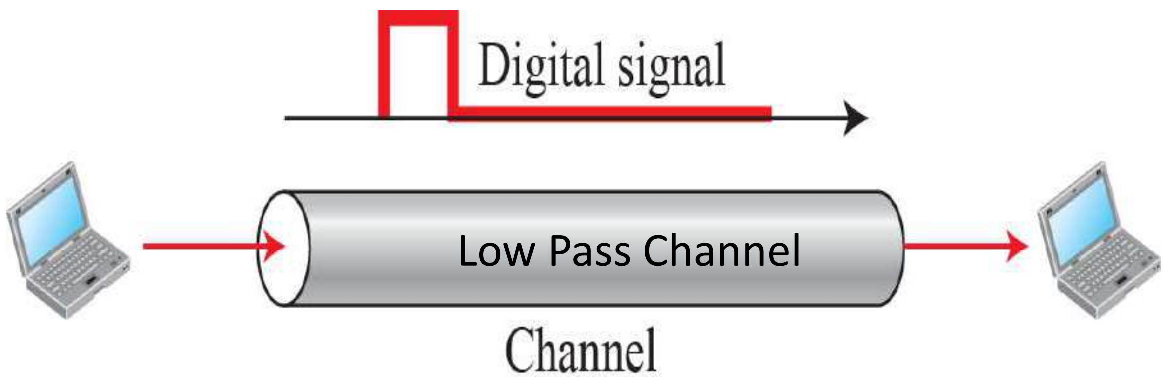


b. Time and frequency domains of nonperiodic digital signal

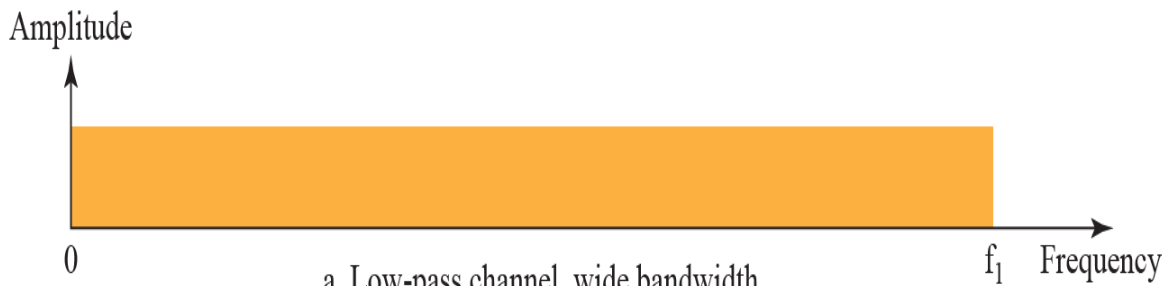
- **Digital signal, periodic or non-periodic, is a composite analog signal with frequencies between zero and infinity (Infinite Bandwidth)**

- **Two approaches for transmission:**
  - ✓ **Baseband Transmission**
  - ✓ **Broadband Transmission**

A vertical line in the time domain means a frequency of infinity: a horizontal line in the time domain means a frequency of zero. Going from a frequency of zero to a frequency of infinity implies all frequencies in between are part of the domain.

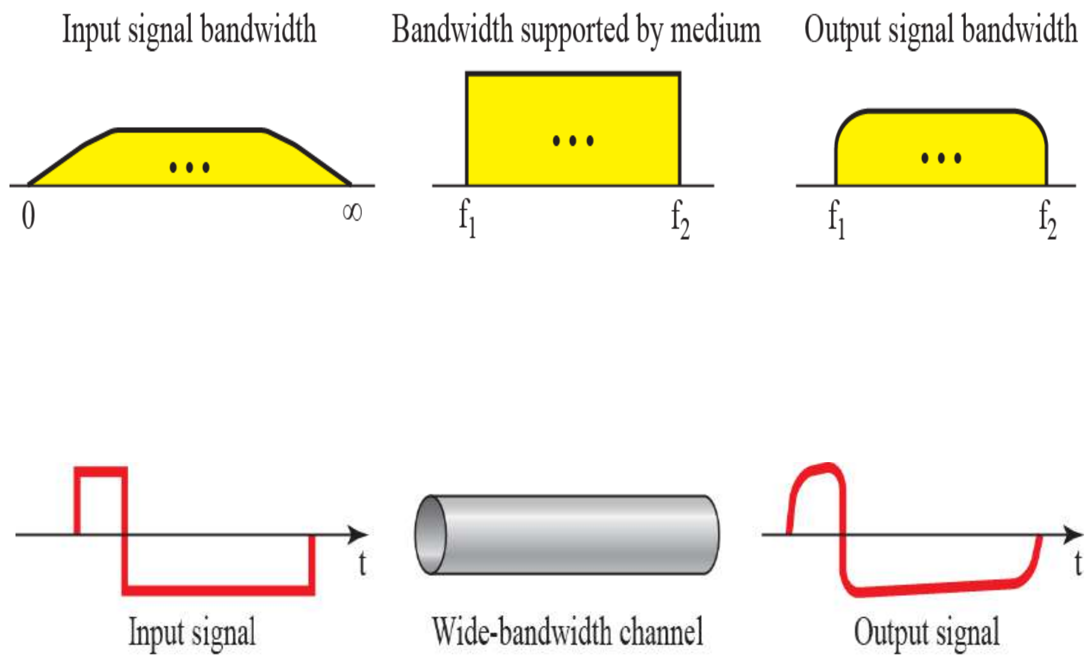


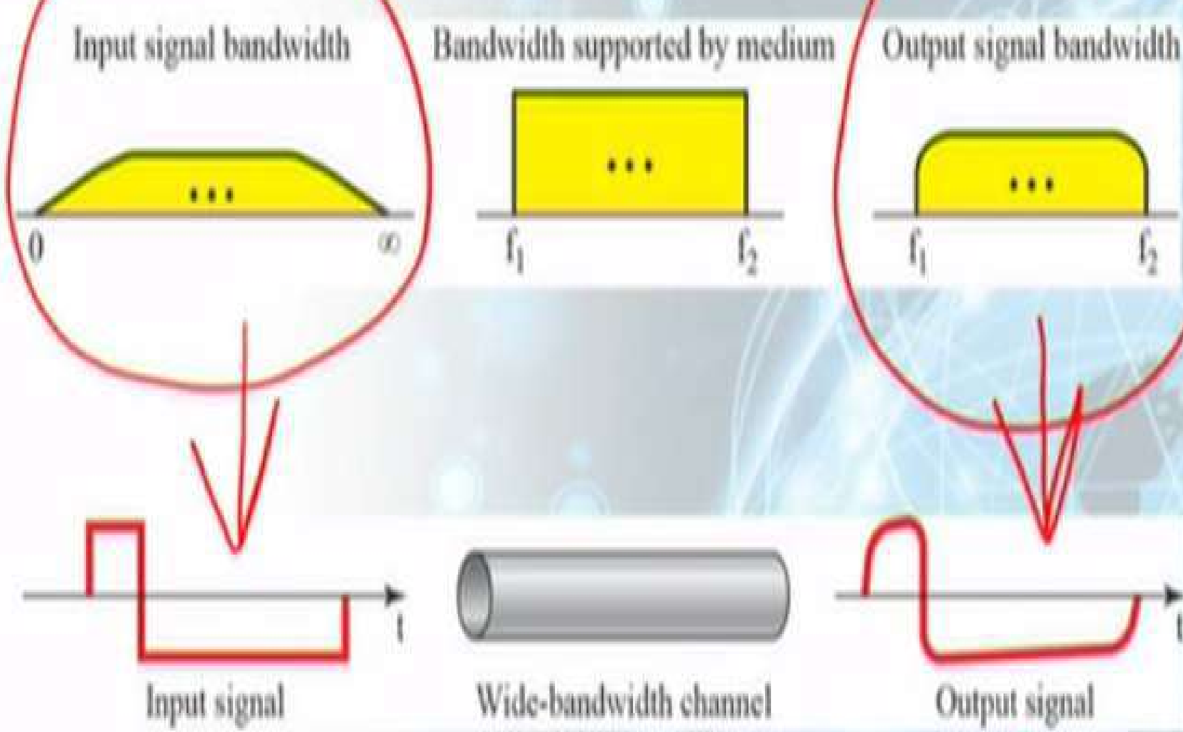
Sending a **Digital Signal** without changing it to an **Analog Signal**



a. Low-pass channel, wide bandwidth

b. Low-pass channel, narrow bandwidth


Input signal bandwidth
Bandwidth supported by medium
Output signal bandwidth
0
∞
f_1
f_2
f_1
f_2
t
t
Input signal
Wide-bandwidth channel
Output signal

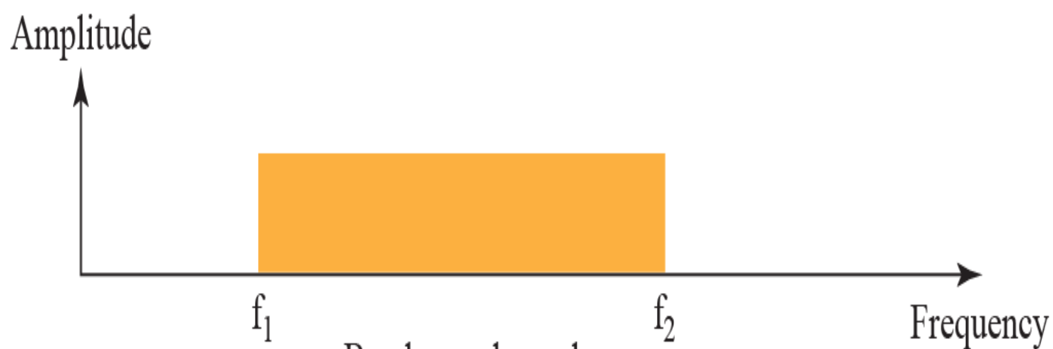


Input signal bandwidth
0
∞
Bandwidth supported by medium
f1
f2
Output signal bandwidth
f1
f2
t
Input signal
Wide-bandwidth channel
t
Output signal

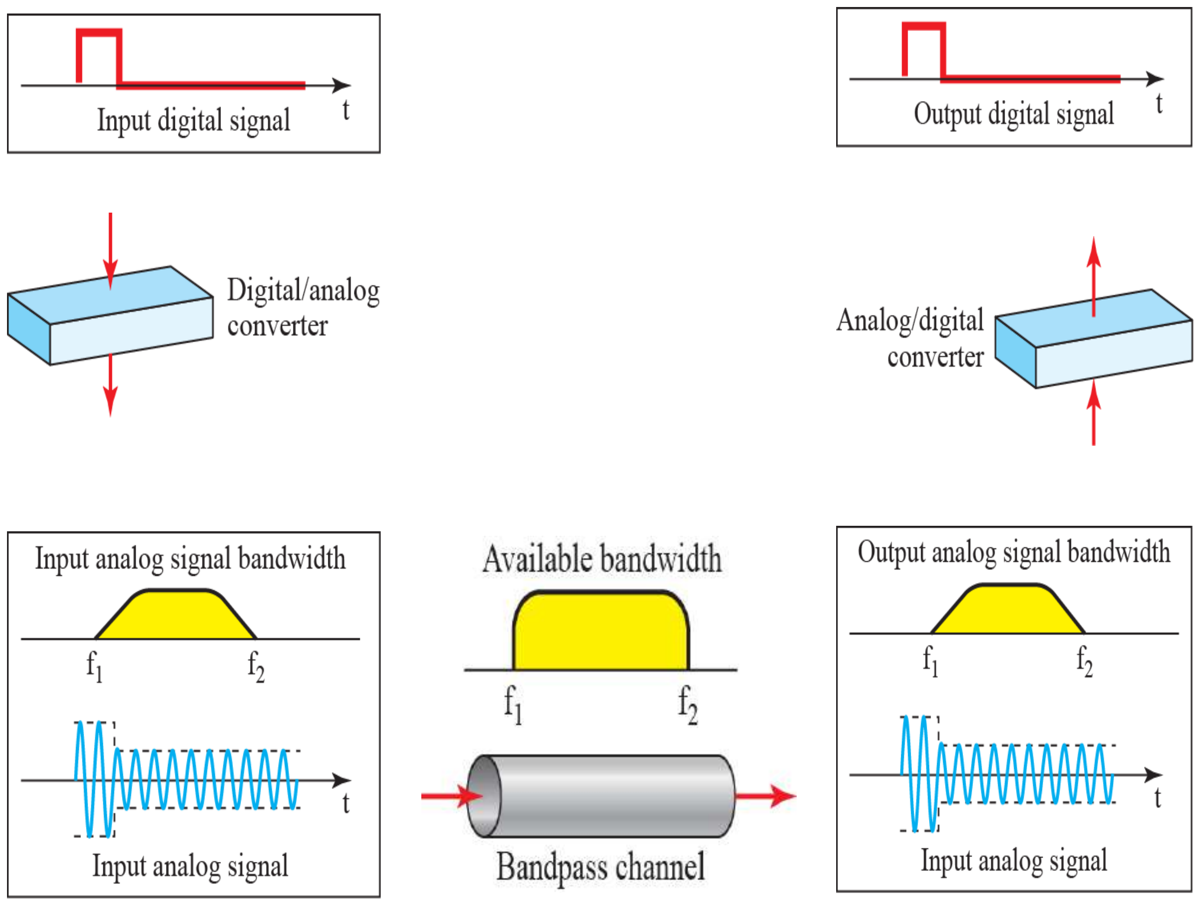
- Changing the Digital signal to an Analog signal for transmission

- Modulation allows us to use a bandpass channel—a channel with a bandwidth that does not start from zero

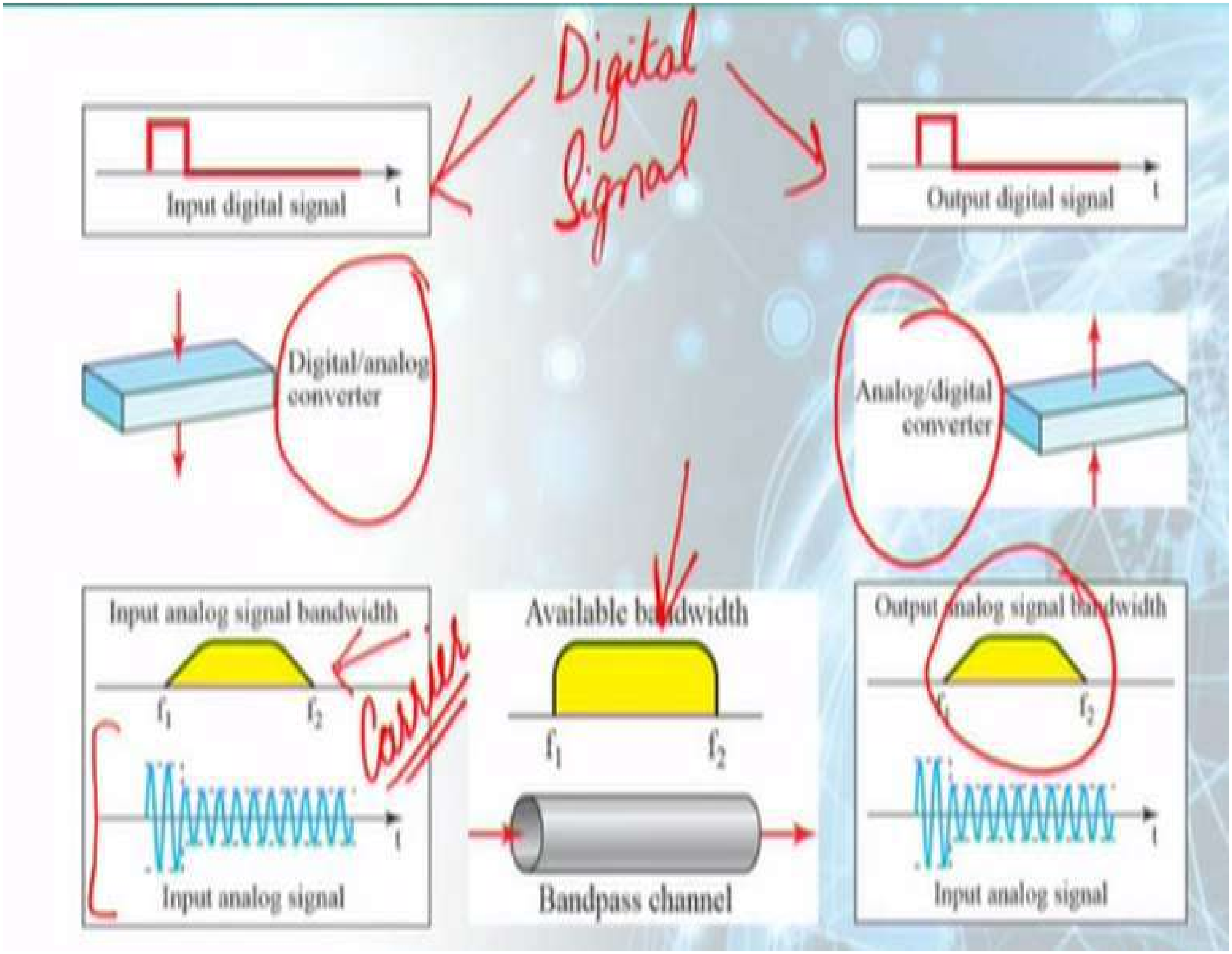
- More available than a low-pass



Bandpass channel



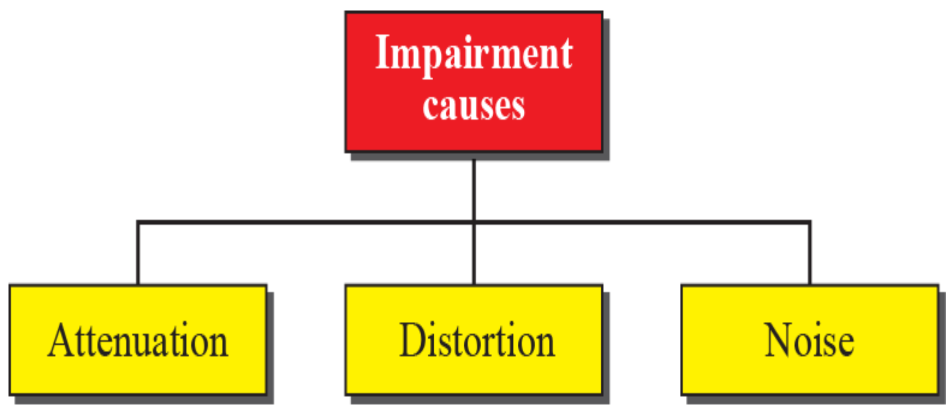
Input digital signal
t
Digital/analog
converter
Input analog signal bandwidth
f1
f2
t
Input analog signal
Available bandwidth
f1
f2
Bandpass channel
Output digital signal
t
Analog/digital
converter
Output analog signal bandwidth
f1
f2
t
Input analog signal


Digital Signal
Input digital signal
t
Output digital signal
t
Digital/analog converter
Analog/digital converter
Input analog signal bandwidth
f_1
f_2
Carrier
Input analog signal
Available bandwidth
f_1
f_2
Bandpass channel
Output analog signal bandwidth
f_1
f_2
Input analog signal

- **Transmission media are not perfect**

- **Cause Signal impairments**

- **Signal sent is not the same as the signal received**


Impairment causes
Attenuation
Distortion
Noise

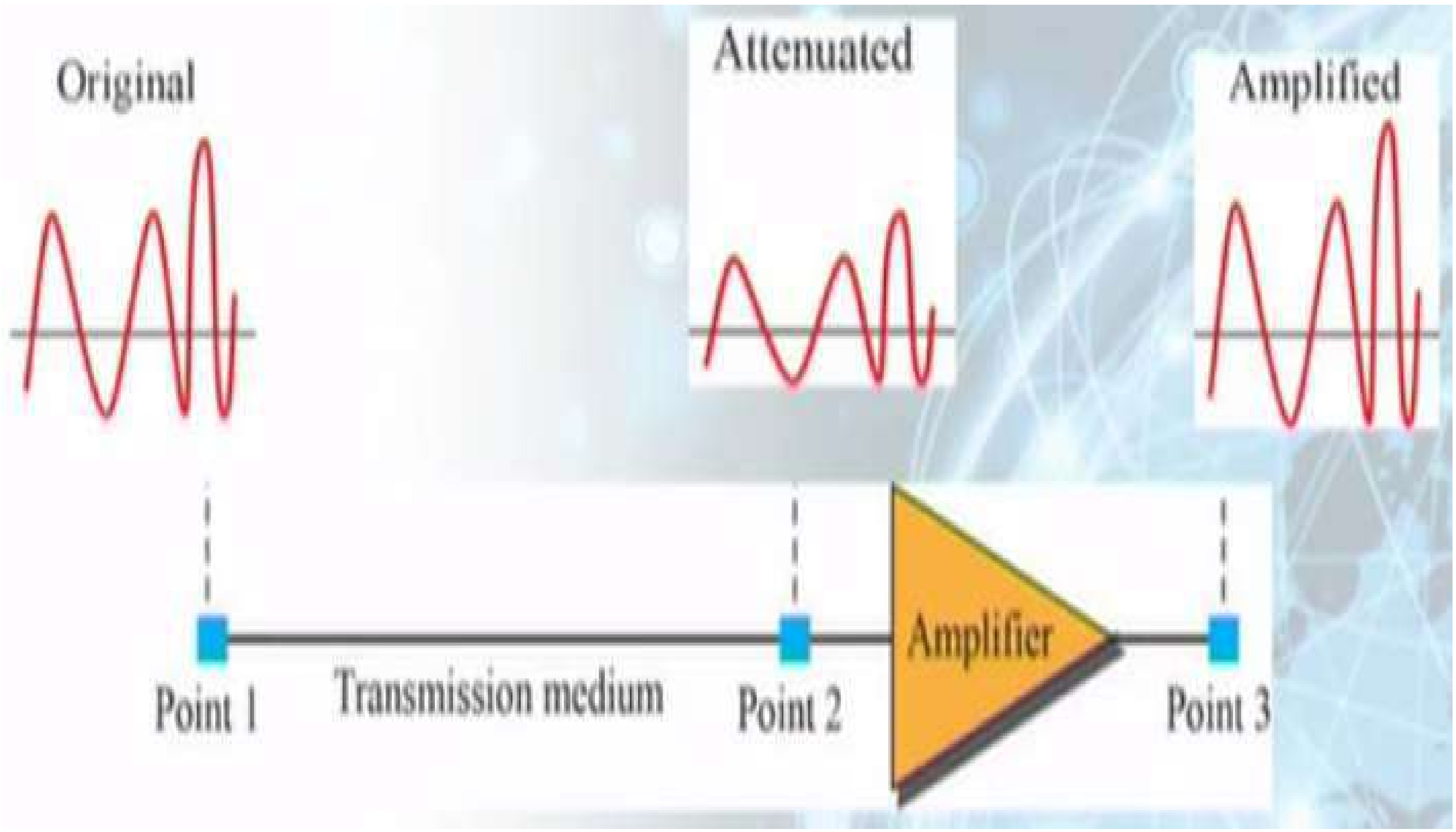
What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise (see Figure 3.26).

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium.

Attenuation means a loss of energy. When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium. That is why a wire carrying electric signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat.

To compensate for this loss, amplifiers are used to amplify the signal. Figure 3.27 shows the effect of attenuation and amplification..

Figure 3.27


Original
Attenuated
Amplified
Amplifier
Point 1
Transmission medium
Point 2
Point 3

Suppose a signal travels through a transmission medium and its power is reduced to one half. This means that P2 = 0.5 P1. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} P_2/P_1 = 10 \log_{10} (0.5\, P_1)/P_1$$
$$= 10 \log_{10} 0.5 = 10 \times (-0.3) = -3 \text{ dB}.$$

A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

A signal travels through an amplifier, and its power is increased 10 times. This means that P_2 = 10P1. In this case, the amplification

$$10 \log_{10}\frac{P_2}{P_1} = 10 \log_{10}\frac{10P_1}{P_1} =$$

$$10 \log_{10} 10 = 10(1) = 10 \text{ dB}$$

One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In Figure 3.28 a signal travels from point 1 to point 4. The signal is attenuated by the time it reaches point 2.

Between points 2 and 3, the signal is amplified. Again, between points 3 and 4, the signal is attenuated. We can find the resultant decibel value for the signal just by adding the decibel measurements between each set of points. In this case, the decibel value can be calculated as

$$dB = -3 + 7 - 3 = +1$$

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as dBm = 10 log10 Pm, where Pm is the power in milliwatts. Calculate the power of a signal if its $dB_m = -30$.

Solution

We can calculate the power in the signal as

$$dB_m = 10\log_{10} \longrightarrow dB_m = -30 \longrightarrow$$

$$\log_{10} P_m = -3 \longrightarrow P_m = 10^{-3}\,\text{mW}$$

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as dBm = 10 log10 Pm, where Pm is the power in milliwatts. Calculate the power of a signal if its $dB_m = -30$.

Solution

The loss in the cable in decibels is $5 \times (-0.3) = -1.5$ dB. We can calculate

$$dB = 10 \log_{10} (P_2 / P_1) = -1.5$$

$$\longrightarrow \quad (P_2 / P_1) = 10^{-0.15} = 0.71$$

$$P_2 = 0.71 P_1 = 0.7 \times 2 \text{ mW} = 1.4 \text{ mW}$$

- Unit of Signal strength is Decibel or dB
- Decibel (dB) measures the relative strengths of two signals or one signal at two different points

$$10 \log_{10} P_2/P_1$$

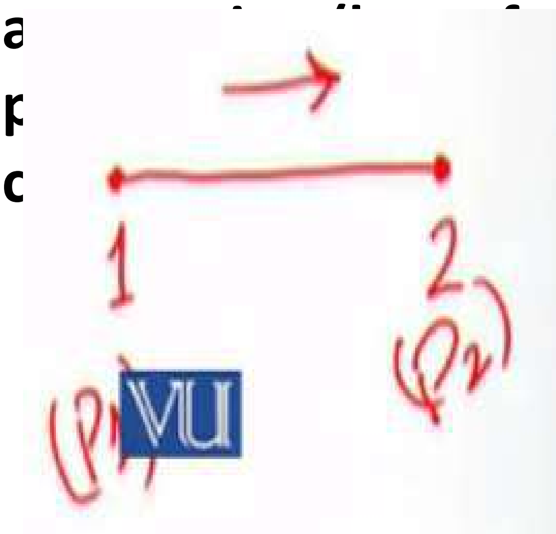
- Decibel is negative if a signal is attenuated and positive if signal is amplified

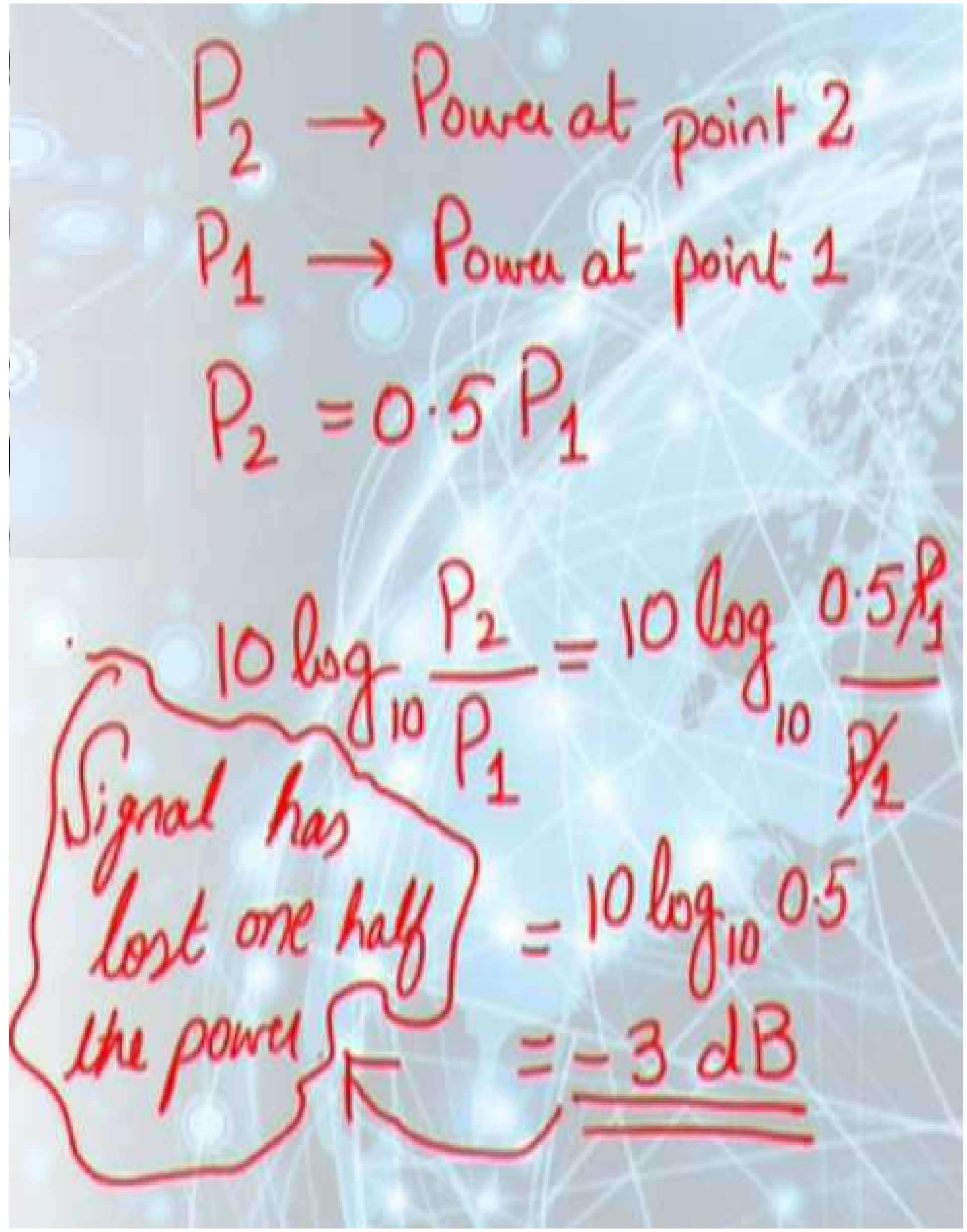
Suppose a signal travels through a transmission medium and its power is reduced to one half. This means that P2 = 0.5 P1. In this case, the

a

p

c





A signal travels through an amplifier, and its power is increased 10 times. This means that P_2 = 10P1. In this case, the amplification (gain of power) can be calculated as

$$P_2 = 10\,P_1$$

$$10 \log_{10} \frac{P_2}{P_1}$$

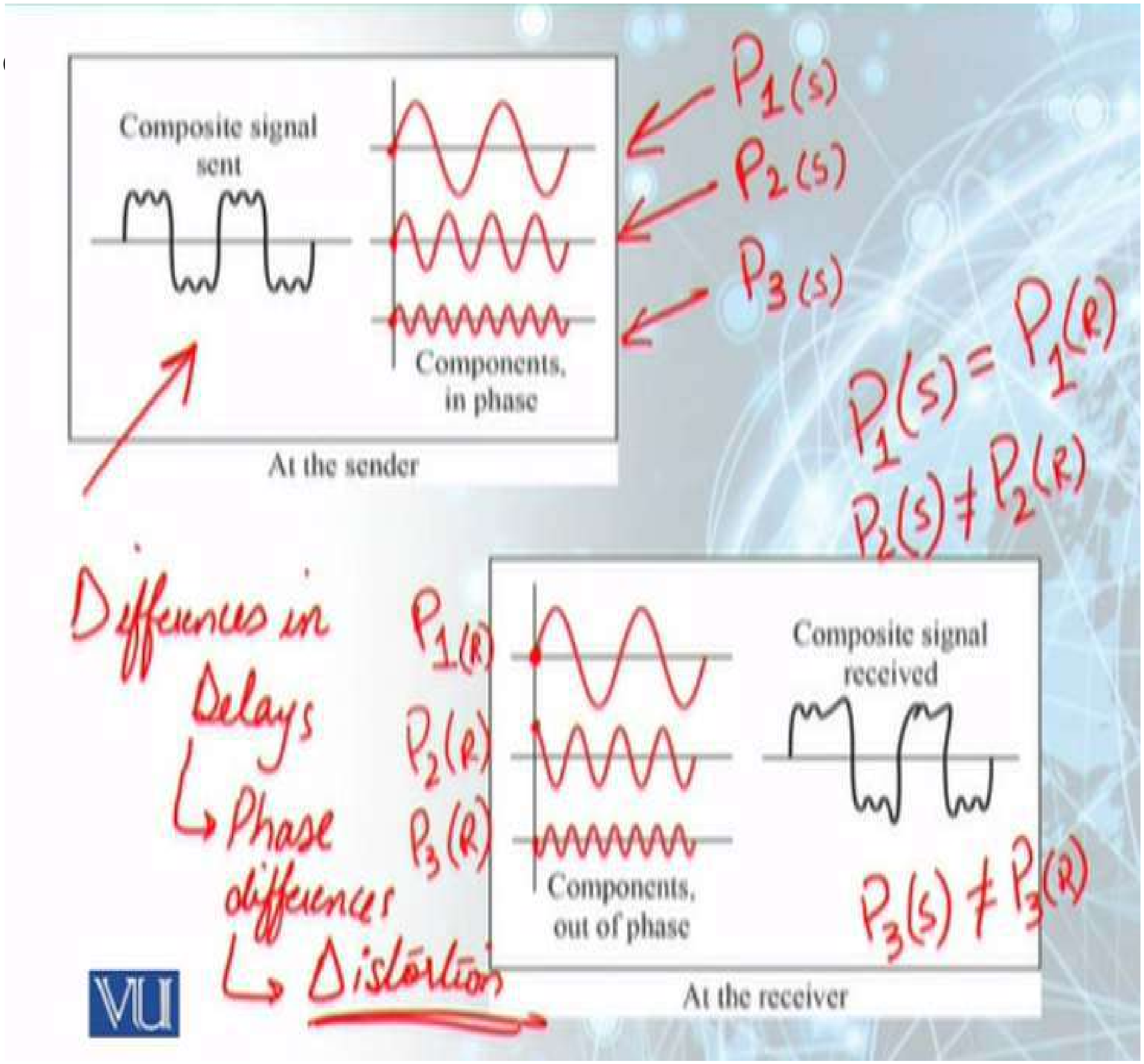
$$= 10 \log_{10} \frac{10\cancel{P_1}}{\cancel{P_1}}$$

$$= 10\,\mathrm{dB}$$

- **Distortion means that the signal changes its form or shape.**
- **Distortion can occur in a composite signal made of different frequencies.**
- **Each signal component has its own propagation speed (see the next section) through a medium and, therefore, its own delay in arriving at the final destination.**

Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.

Figure 3.2



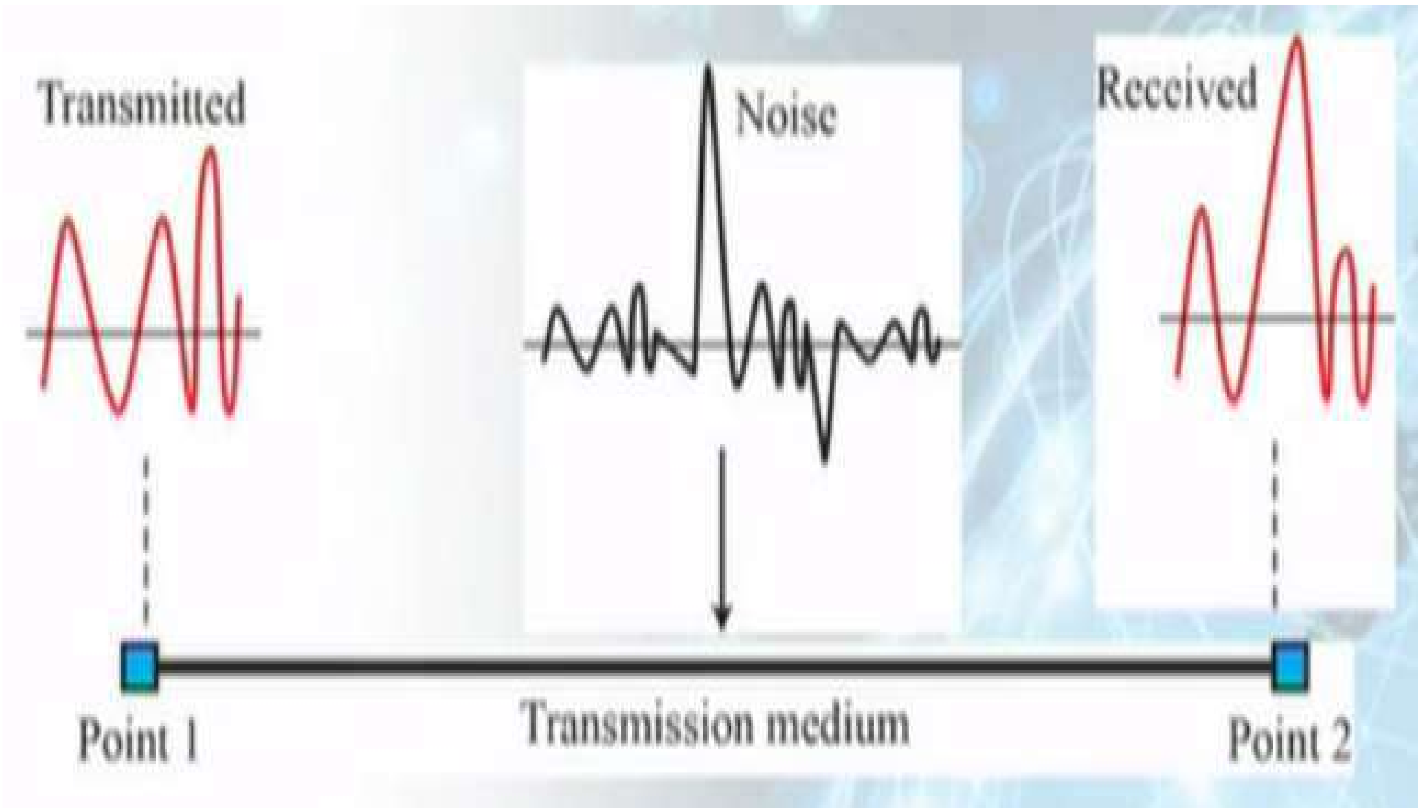
Composite signal sent
Components, in phase
At the sender
$P_1(s)$
$P_2(s)$
$P_3(s)$
$P_1(s) = P_1(R)$
$P_2(s) \neq P_2(R)$
Differences in Delays
↳ Phase differences
↳ Distortion
$P_1(R)$
$P_2(R)$
$P_3(R)$
Components, out of phase
Composite signal received
$P_3(s) \neq P_3(R)$
At the receiver
VU

- Noise is another cause of impairment.
- Several types of noise, such as thermal noise, induced noise, crosstalk, and impulse noise, may corrupt the signal.

- Thermal noise is the random motion of electrons in a wire, which creates an extra signal not

- **Induced noise comes from sources such as motors.**

- **Crosstalk is the effect of one wire on the other.**

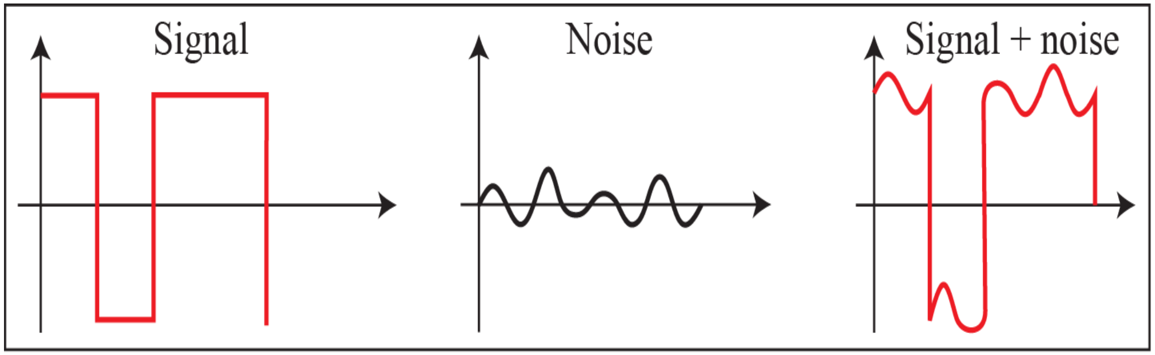


Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

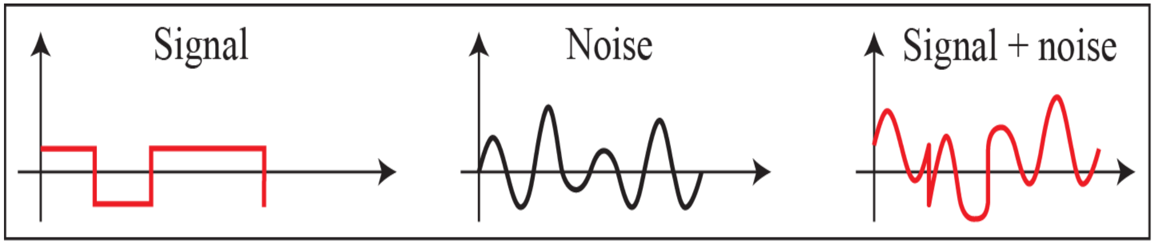
Figure 3.31

- **Signal to Noise Ratio (SNR) is used to find the theoretical bit rate limit of a signal**

$$\mathrm{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$$



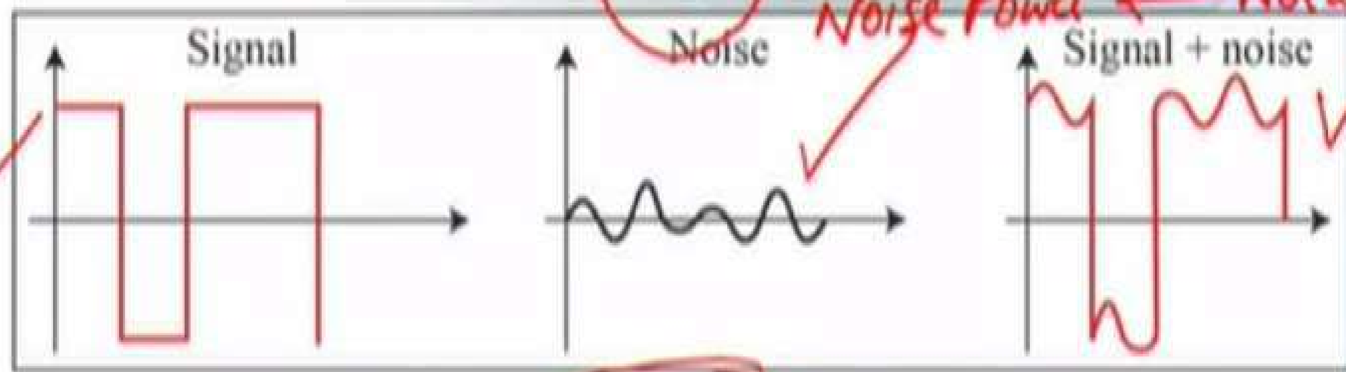
a. High SNR



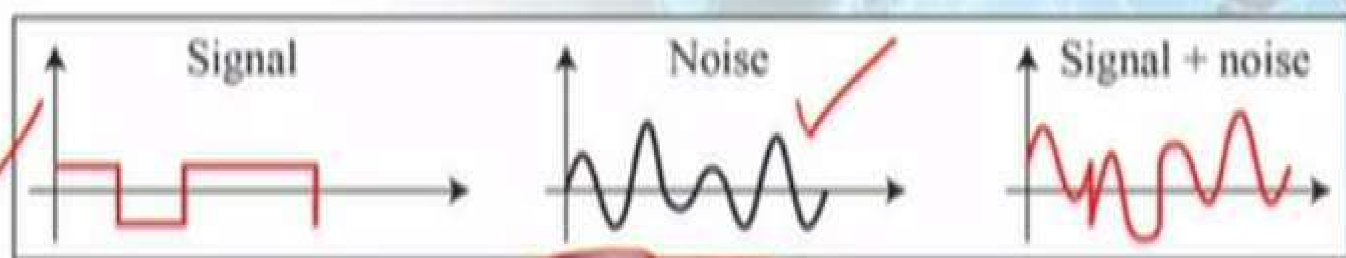
b. Low SNR

Noise – Signal to Noise Ratio (SNR)

$$SNR = \frac{\text{Signal Power} \leftarrow \text{wanted}}{\text{Noise Power} \leftarrow \text{Not wanted}}$$



a. High SNR ✓ less corrupted

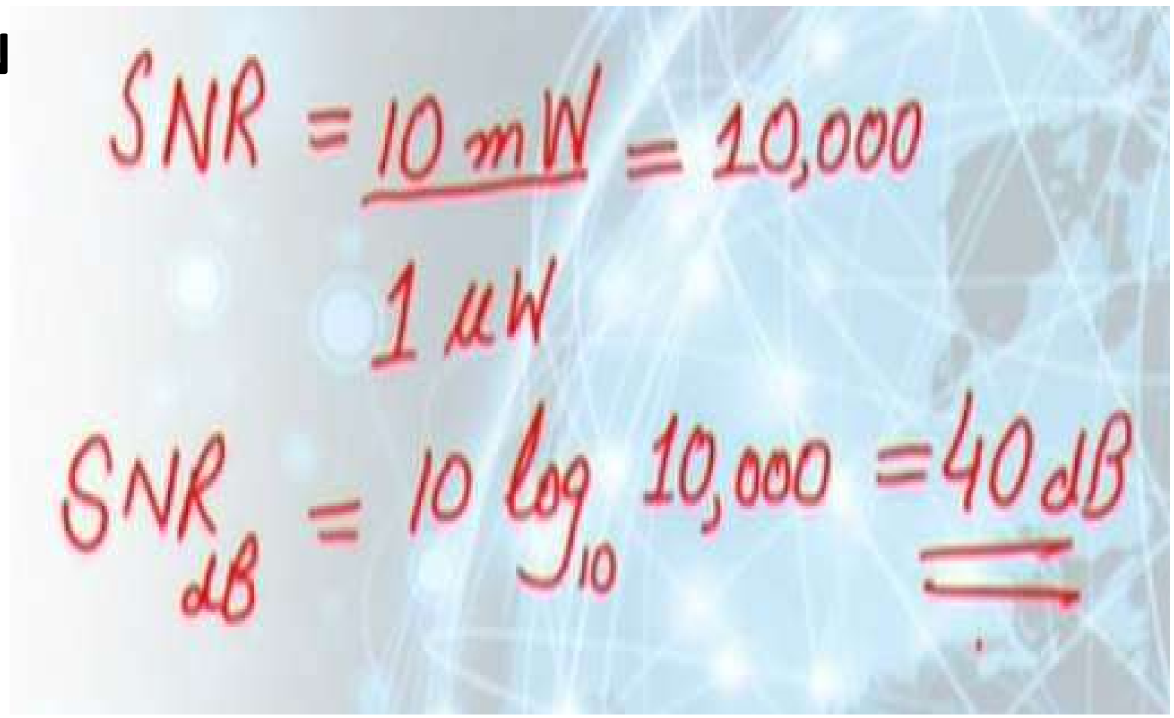


$$SNR_{dB} = 10 \log_{10} SNR$$

b. Low SNR ✓ more corrupted

VU

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SN



The values of SNR and SNR_{dB} for a noiseless channel are calculated as

Noise = 0

↳ NOT a real life scenario

$$SNR = \frac{(\text{Sig. Power})}{0} = \infty$$

$$= 10 \log_{10} \infty = \infty$$

Not Real

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and $SNR_{dB?}$

Solution

The values of SNR and SNR_{dB} can be calculated as

$$SNR = (10{,}000\ \mu w) / (1\ \mu w) = 10{,}000 \quad SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

The values of SNR and SNR_{dB} for a noiseless channel are

Solution

The values of SNR and SNRdB for a noiseless channel are

$$SNR = (\text{signal power}) / 0 = \infty$$

$$\longrightarrow \quad SNR_{dB} = 10 \log_{10} \infty = \infty$$

We can never achieve this ratio in real life; it is an ideal.

- How fast we can send data, in bits per second, over a channel?

- Data Rate depends on 3 factors:
  - ✓ The Bandwidth available
  - ✓ The level of the signals we use
  - ✓ The level of noise

- **Two theoretical formulas developed to calculate the data rate:**

    - ✓ **one by Nyquist for a noiseless channel**

    - ✓ **another by Shannon for a noisy channel**

$$\text{Bit Rate} = 2 \times \text{Bandwidth} \times \log_2 L$$

BW = BW of channel

L = No. of Signal levels

BR = bps

$$\boxed{\text{Bit Rate} \propto L}$$

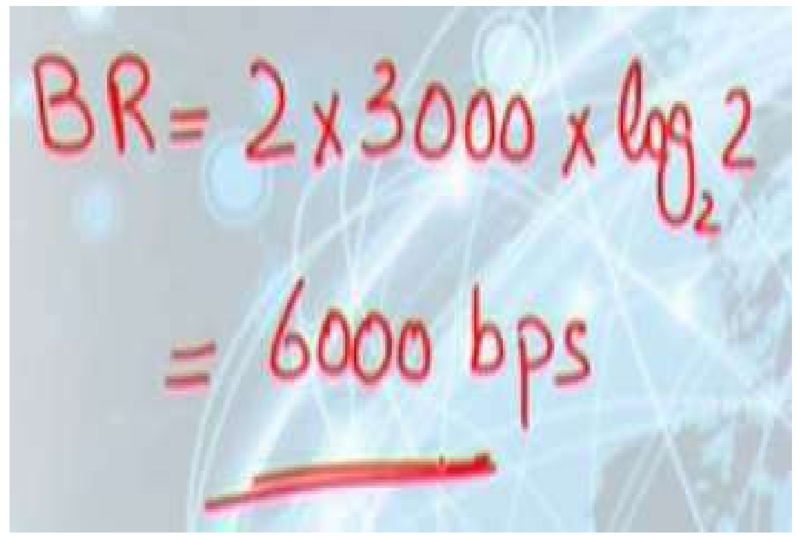
$$L\uparrow \Longrightarrow \text{Bit Rate}\uparrow$$

$(L \Rightarrow 0, 1)$ $\underline{L = 2 \text{ levels}}$

- **For a noiseless channel, the Nyquist bit rate formula defines the theoretical maximum bit rate**

- **Finding balance between Bit rate**
  m
  y

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as



Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The

n

c

a

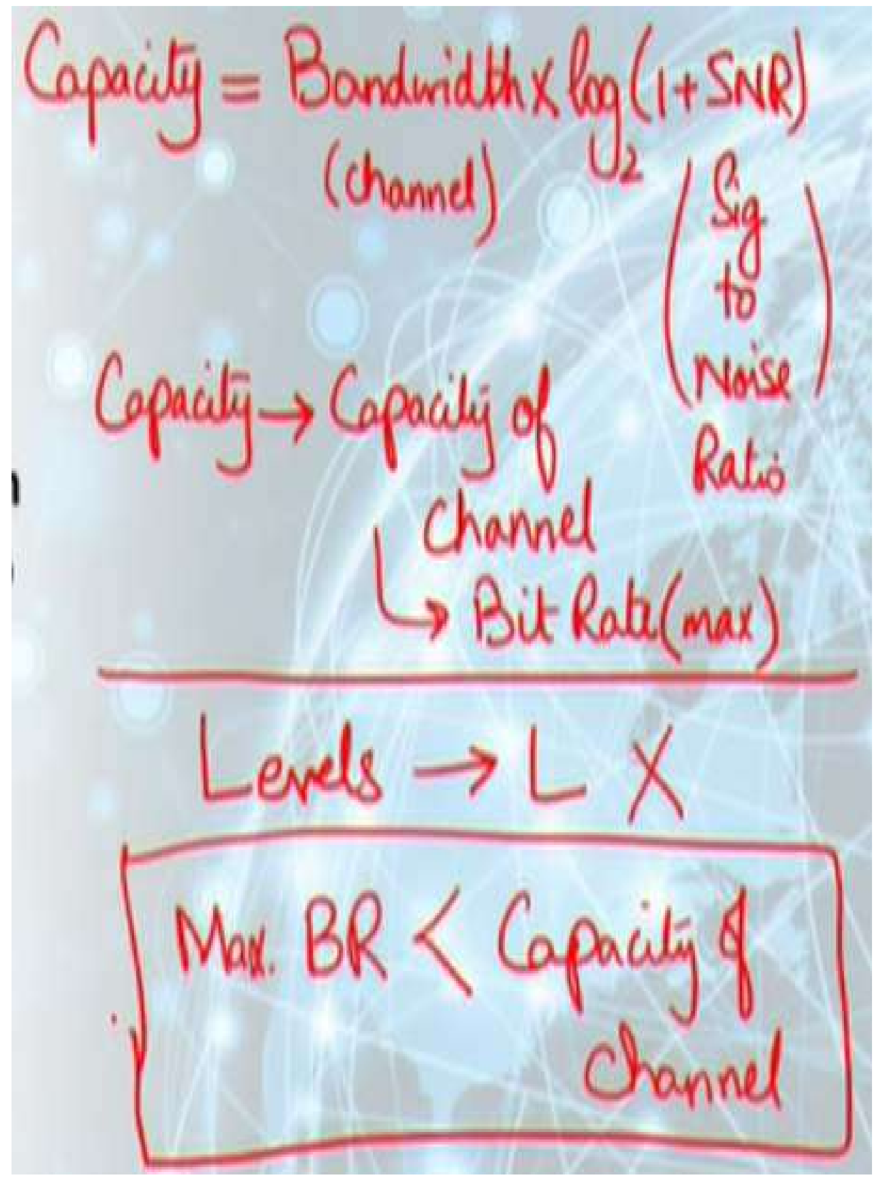
$BR \propto L$

$$BR = 2 \times 3000 \times \log_2 4$$

$$= 12{,}000 \text{ bps}$$

(Reliability)

- **In reality, we cannot have a noiseless channel; the channel is always noisy**
- **In 1944, Claude Shannon introduced a formula, to determine the theoretical highest data rate for a noisy**



Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

$$SNR \simeq \text{zero}$$

$$C = B \log_2(1+SNR)$$

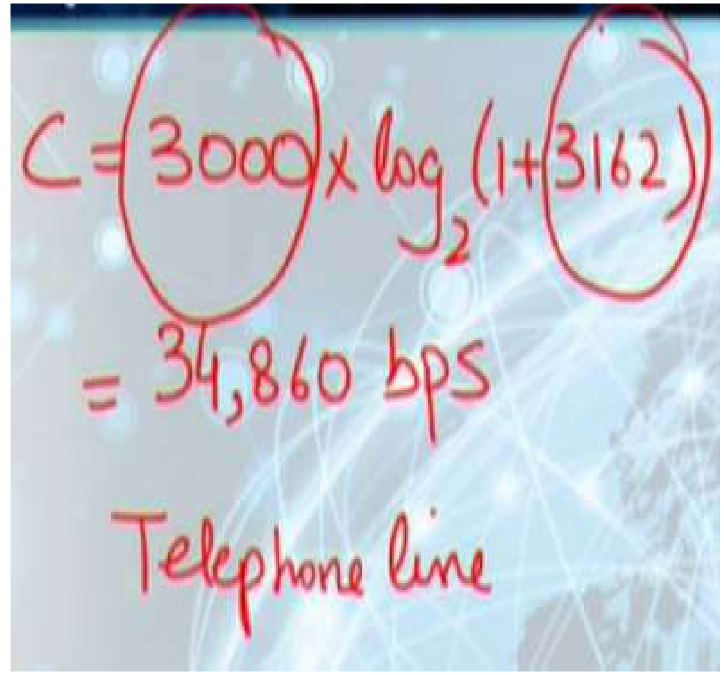
$$= B \log_2 1$$

$$= B \times \text{zero}$$

$$\boxed{C = \text{zero}}$$

→ Cannot receive any data through channel.

Theoretical highest bit rate of a Telephone line with a Bandwidth of 3000 Hz assigned for data communication. SNR is usually 3162. The capacity is calculated as:



- **In practice, we need to use both methods to find the limits and signal levels**

- **Shannon's formula gives us the upper limit while the Nyquist formula gives us the signal levels**

Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this

$$C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0)$$

cha

$$= B \log_2 1 = B \times 0 = 0$$

capacity C is calculated as

This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel.

This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot r

t

ch

$$C = B \log_2 (1 + \text{SNR}) =$$

$$3000 \log_2(1 + 3162) =$$

$$3000 \times 11.62 = 34{,}860 \text{ bps}$$

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

The signal-to-noise ratio is often given in decibels. Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR \longrightarrow$$

$$SNR = 10^{SNR_{dB}/10} \longrightarrow$$

$$SNR = 10^{3.6} = 3981$$

$$C = B \log_2(1 + SNR) =$$

$$2 \times 10^6 \times \log_2 3982$$

$$= 24 \text{ Mbps}$$

When the SNR is very high, we can assume that SNR + 1 is almost the same as SNR. In these cases, the theoretical channel capacity can be simplified to C 5 B 3 $SNR_{dB.}$ For example, we can calculate the

$$C = 2\ \text{MHz} \times (36 / 3) = 24\ \text{Mbps}$$

of the previous example as

In practice, we need to use both methods to find the limits and signal levels. Let us show this with an example.

We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Solution

First, we use the

$$C = B \log_2(1 + \text{SNR}) =$$ **a to**

mit

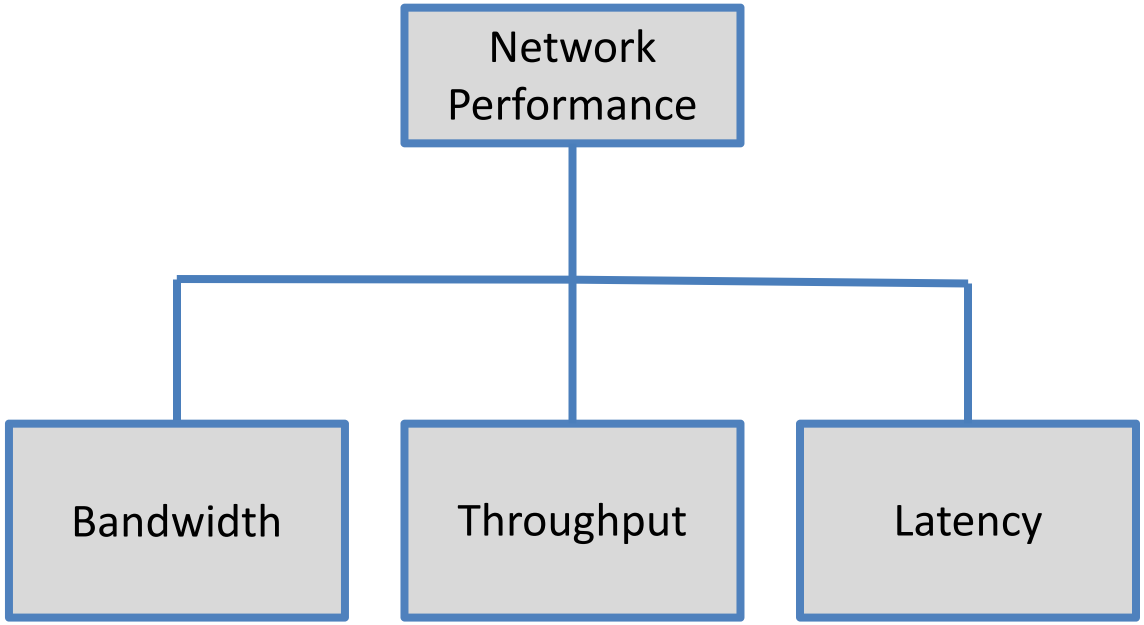
$$10^6 \log_2(1 + 63) = 10^6 \log_2 64 =$$

$$6 \text{ Mbps}$$

The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps. Then we use the Nyquist formu … the numb … al levels

$$4\ \text{Mbps} = 2 \times 1\ \text{MHz} \times \log_2 L \longrightarrow L = 4$$

- **Data transmission (in form of Signal) over a network and how network behaves is important**
- **More important is the performance of the network**
- **How good is our network?**



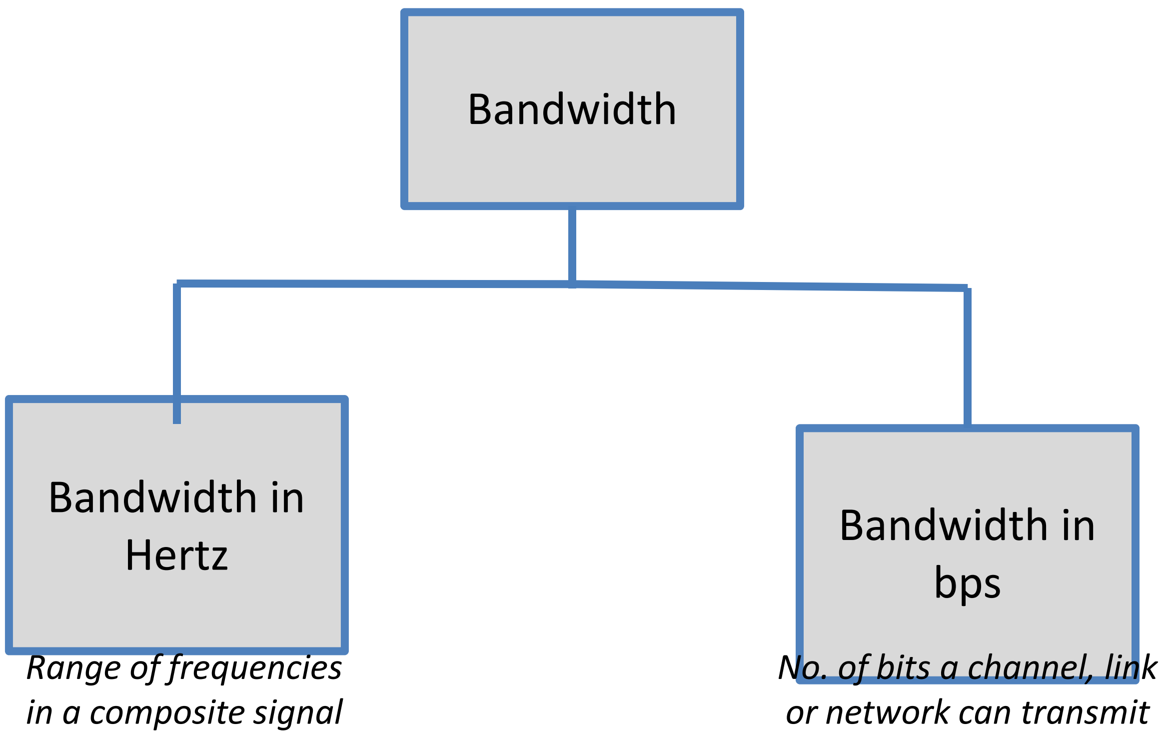
- **There are 3 characteristics of network performance**

- An important characteristic that measures Network Performance

- Bandwidth can be used in two different contexts with two different measuring values:
  - Bandwidth in Hertz
  - Bandwidth in

The bandwidth of a subscriber line is 4 kHz for voice or data. The bandwidth of this line for data transmission can be up to 56,000 bps using a sophisticated modem to change the digital signal to analog.

If the telephone company improves the quality of the line and increases the bandwidth to 8 kHz, we can send 112,000 bps by using the same technology as mentioned in Example 3.42.


Bandwidth
Bandwidth in Hertz
Bandwidth in bps
Range of frequencies in a composite signal
No. of bits a channel, link or network can transmit

- **Measure of how fast we can actually send data through a network.**

- **Bandwidth is not the same as Throughput**

- **A link may have a bandwidth of B bps, but we can only send T bps through this**

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput network?

$$T = \frac{(12{,}000 \times 10{,}000)}{60}$$

$$= 2\,\text{Mbps}$$

$$\boxed{\begin{aligned} T &= 2\,\text{Mbps} \\ B &= 10\,\text{Mbps} \end{aligned}}$$

The throughput is a measure of how fast we can actually send data through a network. Although, at first glance, bandwidth in bits per second and throughput seem the same, they are different. A link may have a bandwidth of B bps, but we can only send T bps through this link with T always less than B.

The latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.

We can say that latency is made of four components: propagation time, transmission time, queuing time and processing delay.

Latency = propagation time + transmission time + queuing time + processing delay

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

Throughput =

(12,000X10,000)/60 = 2Mbps

The throughput is almost one-fifth of the bandwidth in this case.

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4 × 108 m/s in cable.

Solution

We can calculate the propagation time as

Propagation time = (12,000X10,000)/(2.4X2^8)=

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

What are the propagation time and the transmission time for a 2.5-KB (kilobyte) message if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 108 m/s.

Solution

We can calculate the propagation and transmission time as

Propagation time = (12,000 X 1000)/ (2.4X 10^8) = 50 ms

Transmission time = (2500 X 8) / 10^9 = 0.020 ms

Solution

Note that in this case, because the message is short and the bandwidth is high, the dominant factor is the propagation time, not the transmission time.

What are the propagation time and the transmission time for a 5-MB (megabyte) message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 108

Solution

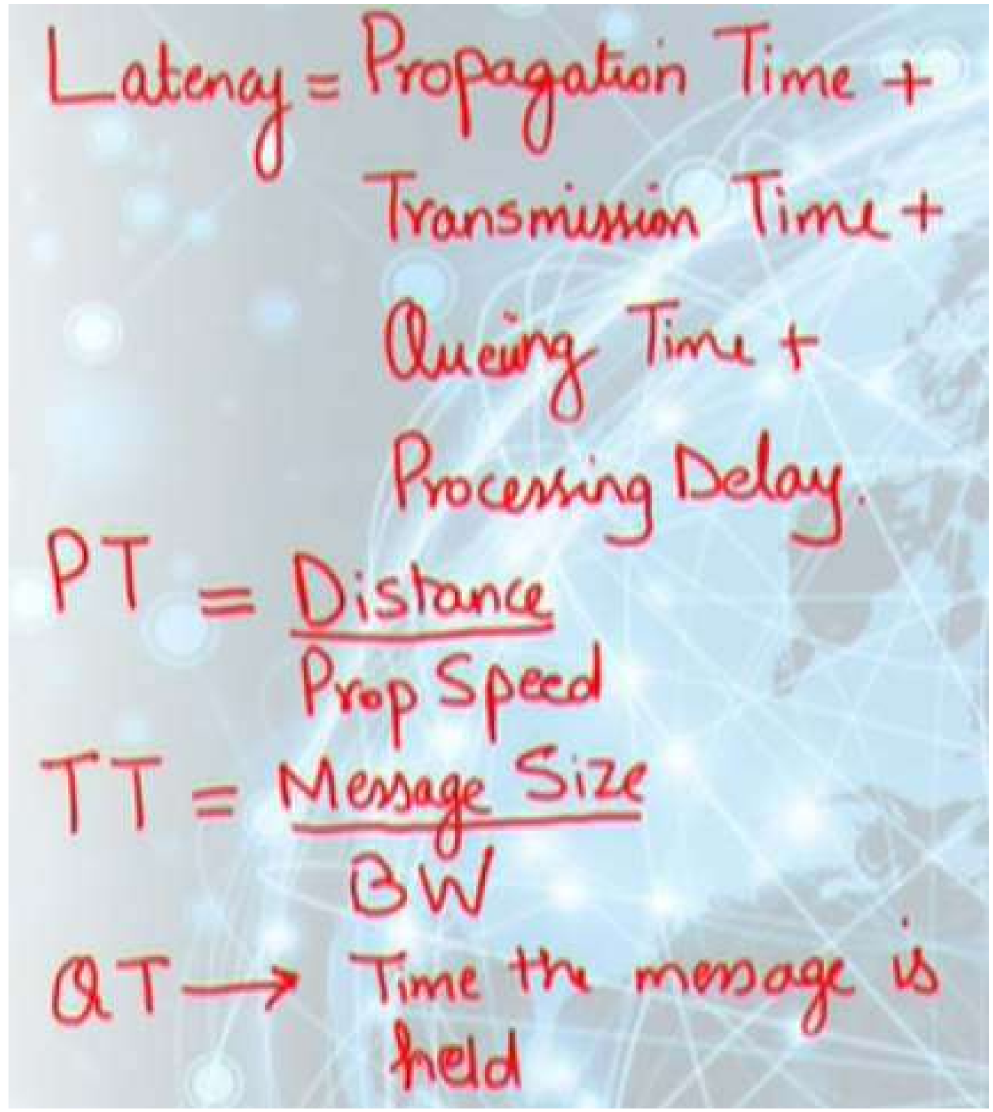
We can calculate the propagation and transmission times as

Propagation time = (12,000 X 1000) / (2.4 X 10^8) = 50 ms

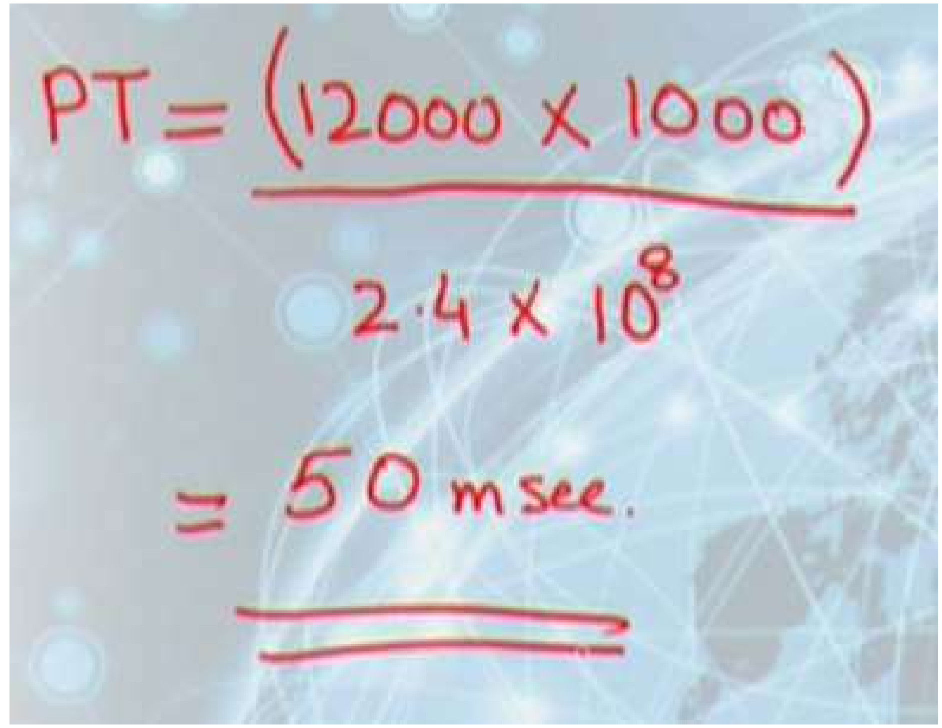
Transmission time = (5,000,000 X 8) / 106 = 40s

We can calculate the propagation and transmission

- **Latency or delay defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source**



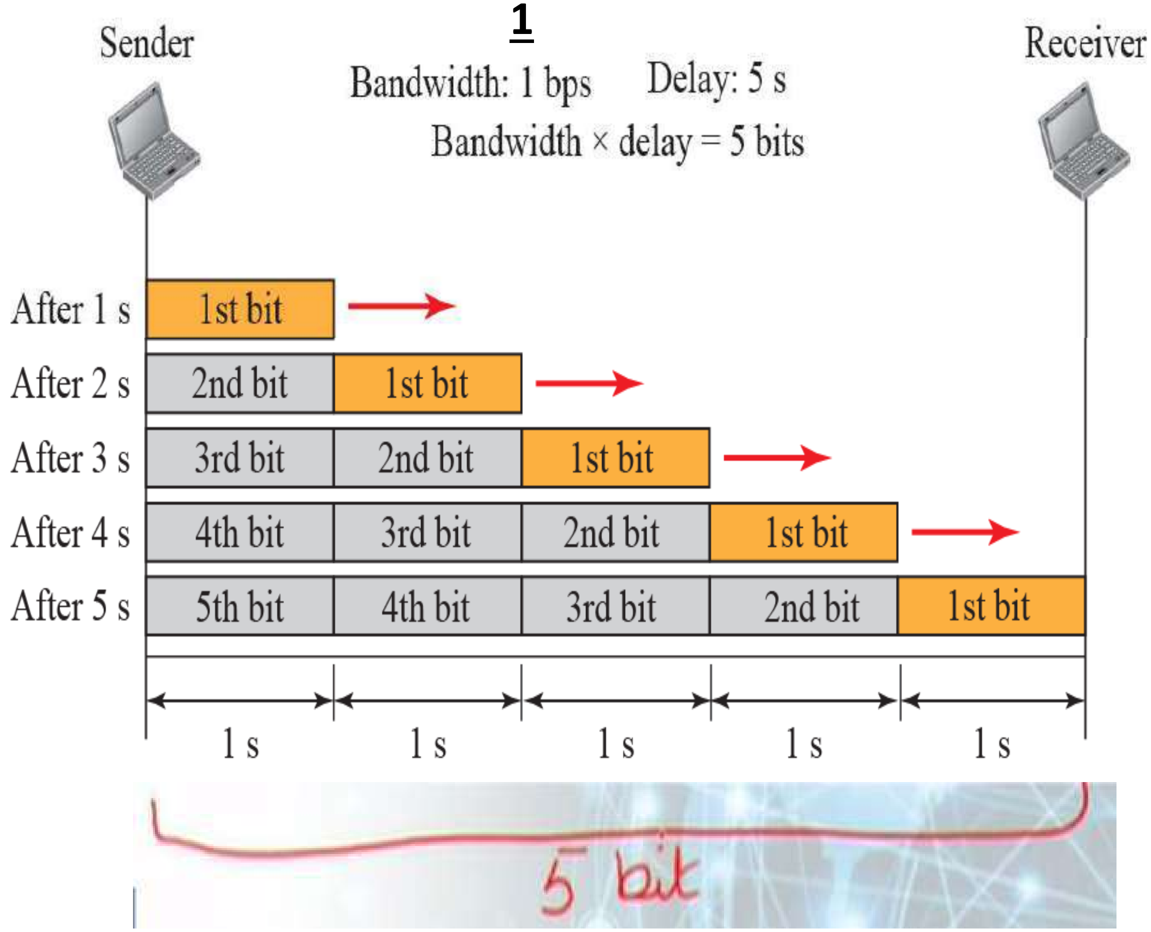
What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4×10^8 m/s in cable.



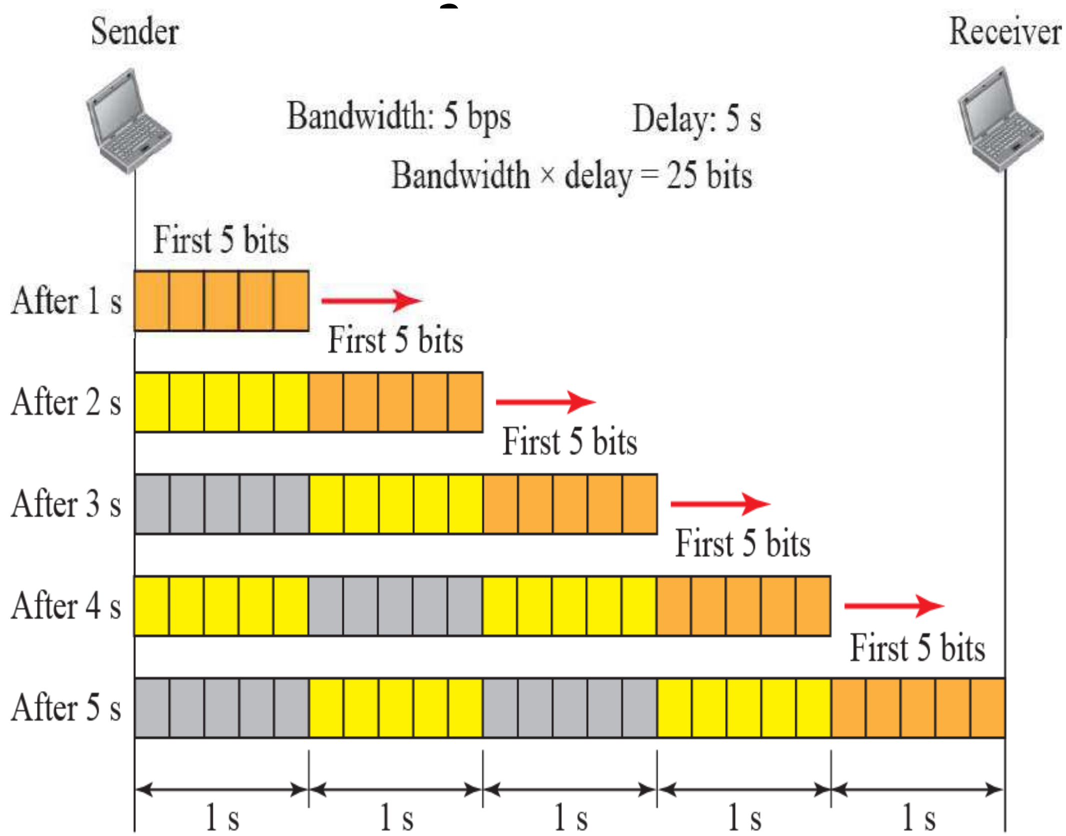
- **Bandwidth and delay are two performance metrics of a link**

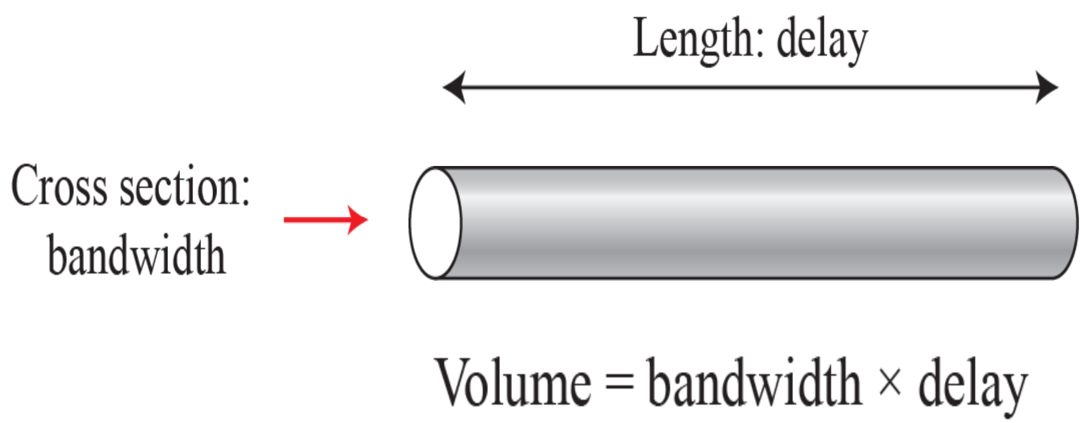
- **Product of the two, The Bandwidth-Delay Product defines the number of bits that can fill a link**

Case 1


Sender
Receiver
Bandwidth: 1 bps
Delay: 5 s
Bandwidth × delay = 5 bits
After 1 s
After 2 s
After 3 s
After 4 s
After 5 s
1st bit
2nd bit
3rd bit
4th bit
5th bit
1 s
5 bit

Case


Sender
Receiver
Bandwidth: 5 bps
Delay: 5 s
Bandwidth × delay = 25 bits
First 5 bits
After 1 s
First 5 bits
After 2 s
First 5 bits
After 3 s
First 5 bits
After 4 s
First 5 bits
After 5 s
1 s
1 s
1 s
1 s
1 s

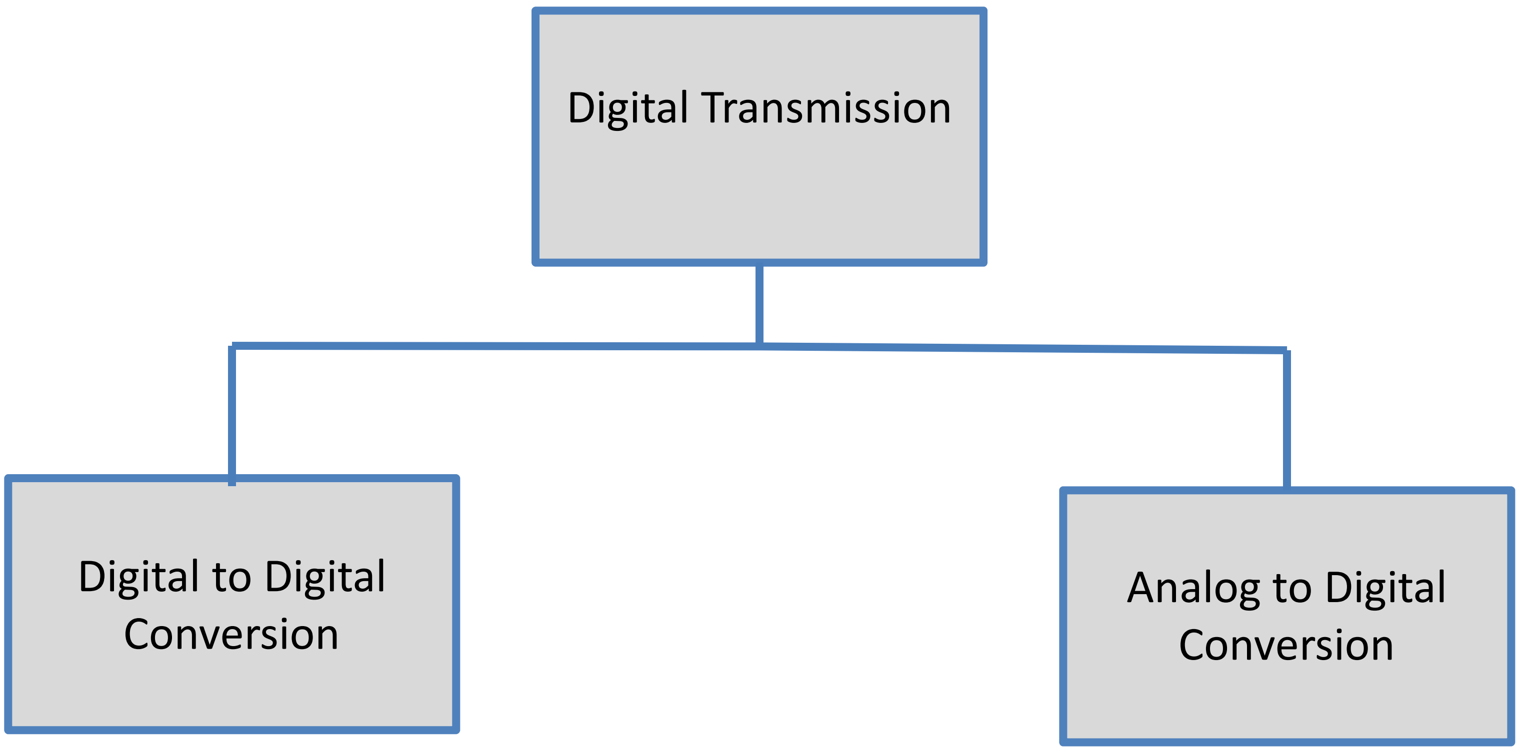

Length: delay
Cross section:
bandwidth
Volume = bandwidth × delay

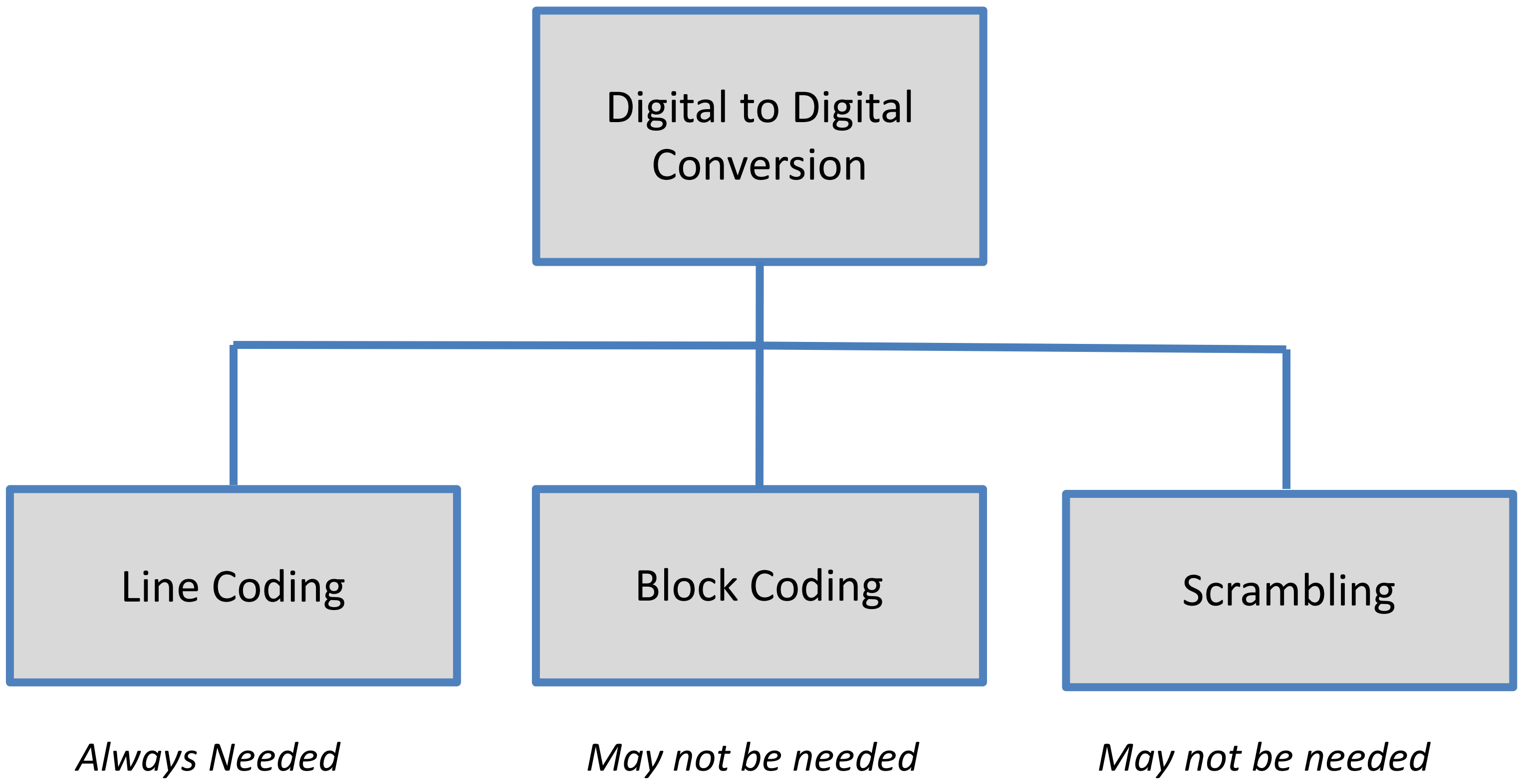
We can think about the link between two points as a pipe. The cross section of the pipe represents the bandwidth, and the length of the pipe represents the delay. We can say the volume of the pipe defines the bandwidth-delay product, as shown in Figure 3.34.

- **Jitter is a problem if different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive (audio and video data, for example)**

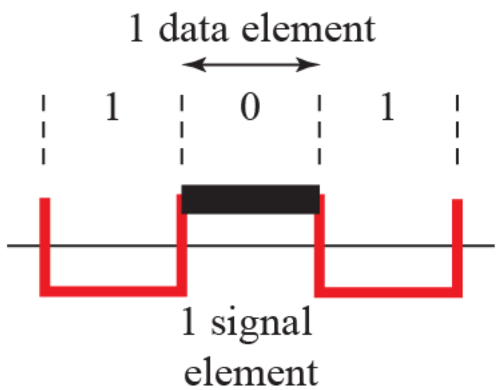
- **Delay for first packet is 20 ms for the second is 45 ms, and for the third is 40 ms, then the real-time application that uses the packets endures jitter**

- **Data → Analog or Digital**
- **Signals → Analog or Digital**
- **Digital Transmission**
- **Analog Transmission**

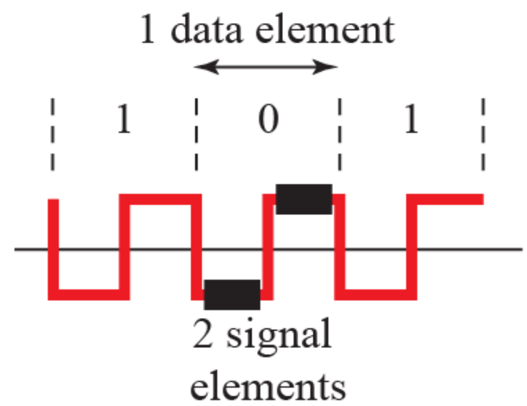

Digital Transmission
Digital to Digital Conversion
Analog to Digital Conversion


Digital to Digital Conversion
Line Coding
Block Coding
Scrambling
Always Needed
May not be needed
May not be needed

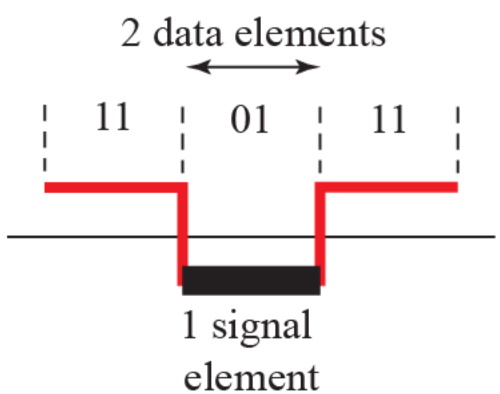
- **A Data element is the smallest entity that can represent a piece of information → Bit**
- **A Signal element is the shortest unit of a digital signal**
- **Data Elements: Carried**
- **Signal Elements: Carriers**



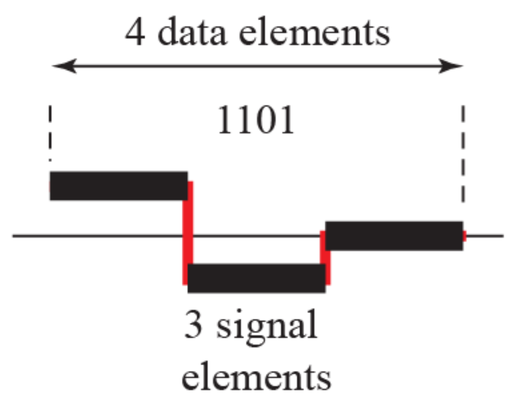
a. One data element per one signal element ($r = 1$)



b. One data element per two signal elements $\left(r = \frac{1}{2}\right)$



c. Two data elements per one signal element ($r = 2$)



d. Four data elements per three signal elements $\left(r = \frac{4}{3}\right)$

$S \rightarrow$ Signal Rate

$D \rightarrow$ Data Rate

$r \rightarrow$ No. of data elements carried by signal element

$$S = \frac{D}{r}$$

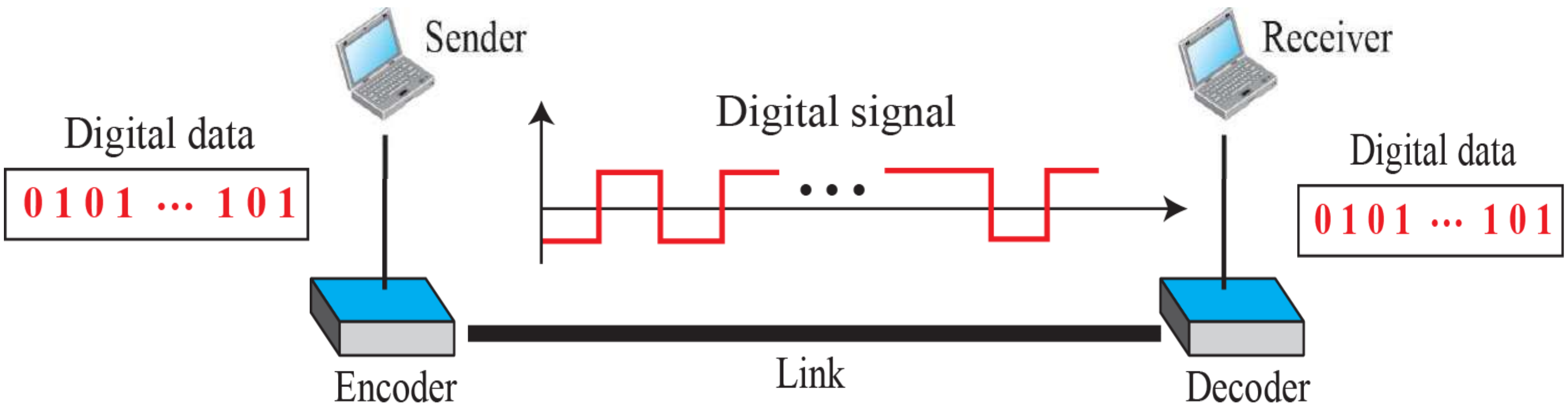
- **Data Rate is number of data elements sent in 1 sec (bps)**
- **Signal Rate is number of signal elements sent in 1 sec (baud)**
- **Data Rate → Bit Rate** ↑
- **Signal Rate → Pulse Rate, Modulation Rate or Baud Rate** ↓

A signal has a signal rate of 100 bauds. What is the Data rate if one data element is carried per signal element?

- **Digital data to Digital signals**

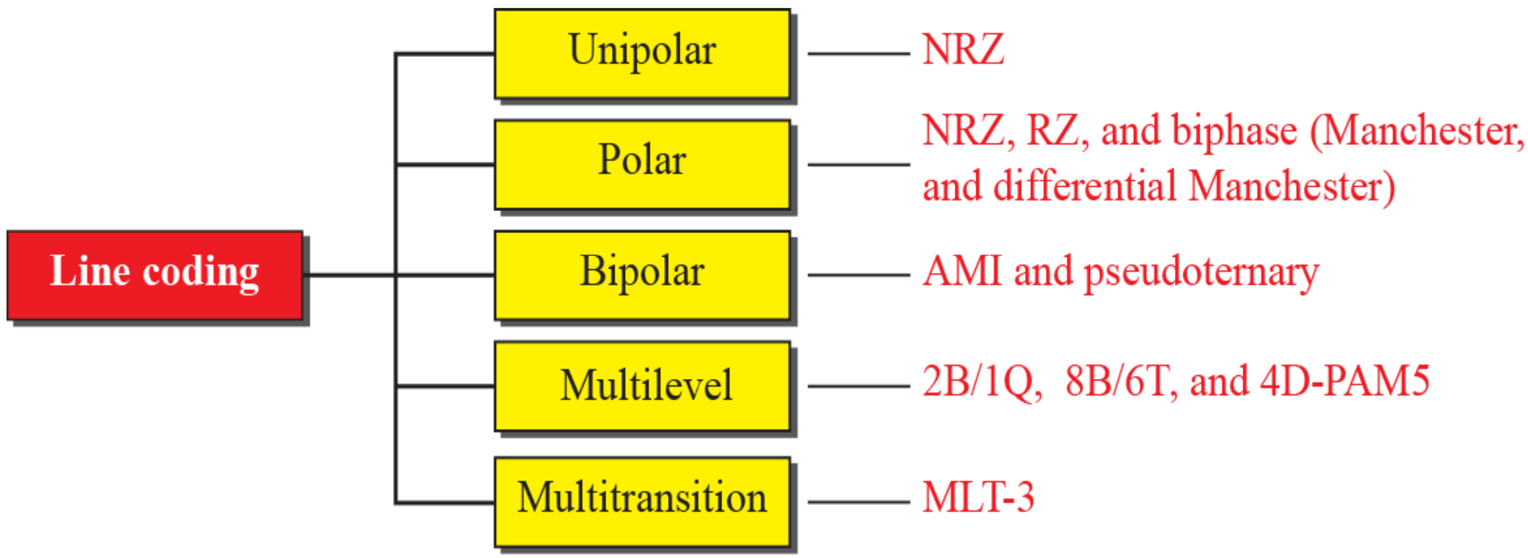
- **Data (Text, Numbers, Pictures, Audio, or Video) is stored in computer memory as sequences of bits**

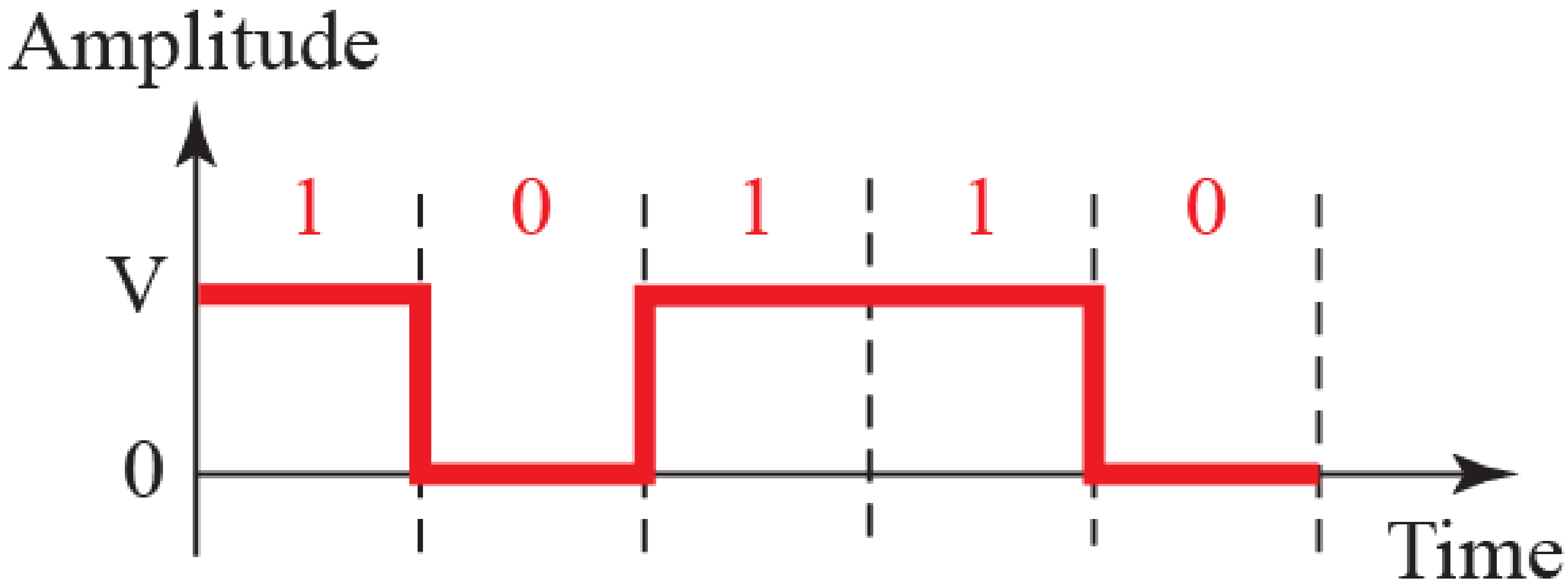
- **Line coding converts a sequence of Bits to a Digital Signal**



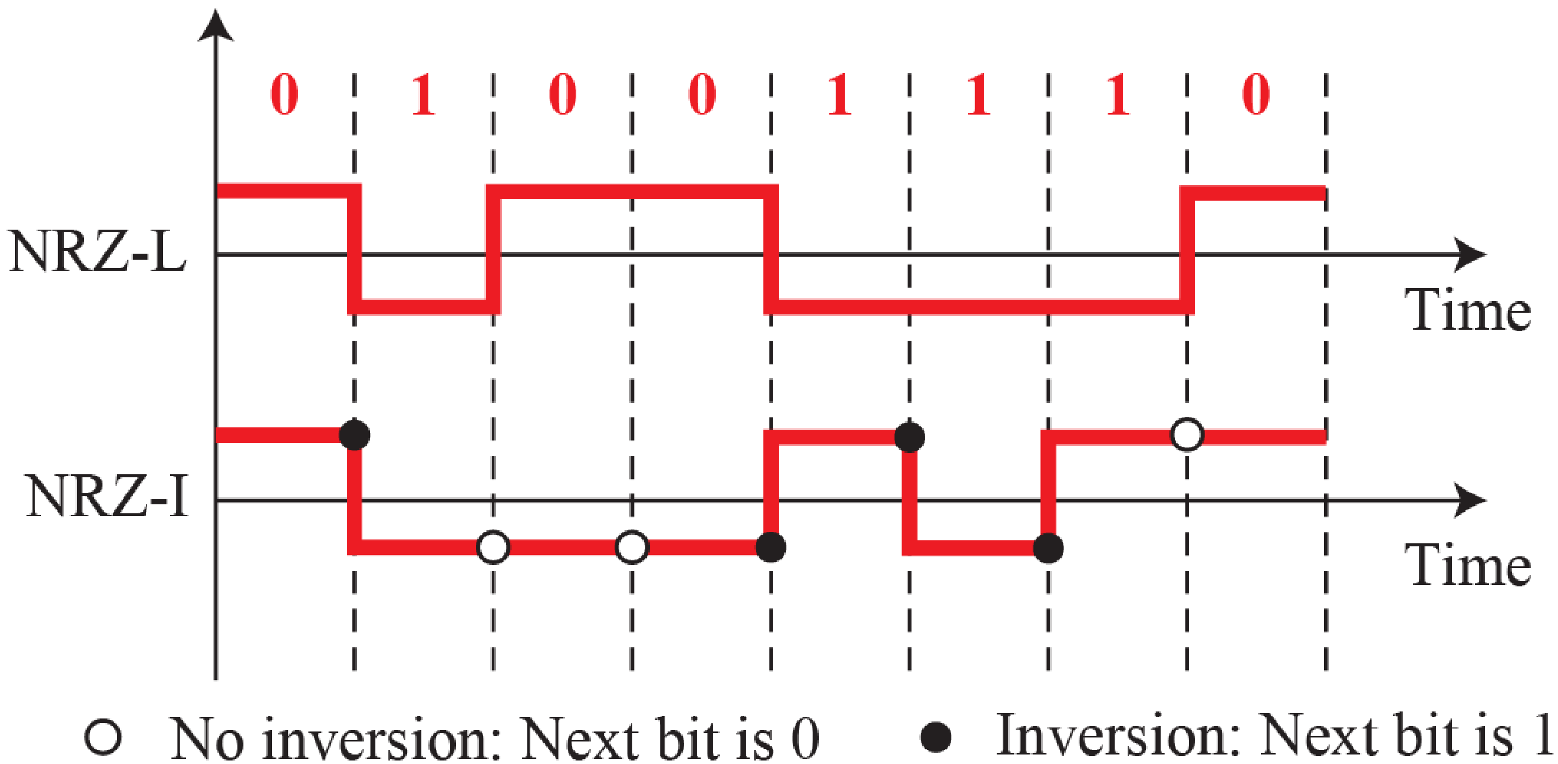
Sender
Receiver
Digital data
0 1 0 1 ··· 1 0 1
Digital signal
Digital data
0 1 0 1 ··· 1 0 1
Encoder
Link
Decoder

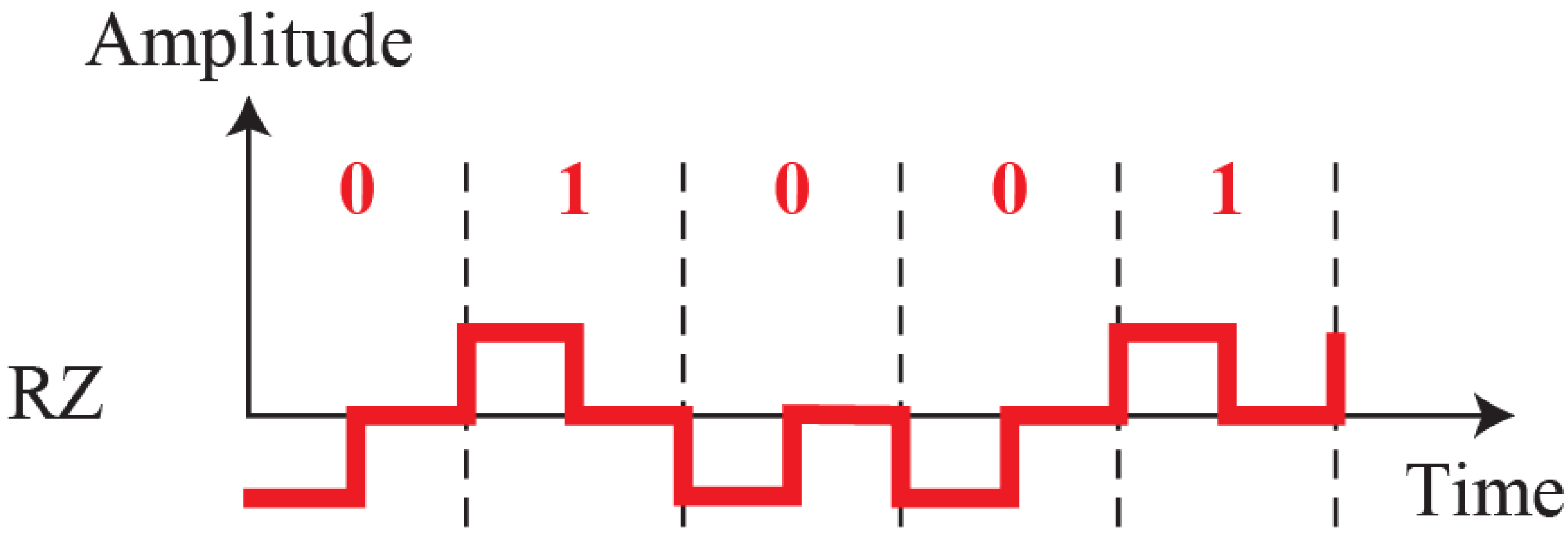
- **We can roughly divide line coding schemes into five broad categories**


Line coding
Unipolar
Polar
Bipolar
Multilevel
Multitransition
NRZ
NRZ, RZ, and biphase (Manchester, and differential Manchester)
AMI and pseudoternary
2B/1Q, 8B/6T, and 4D-PAM5
MLT-3



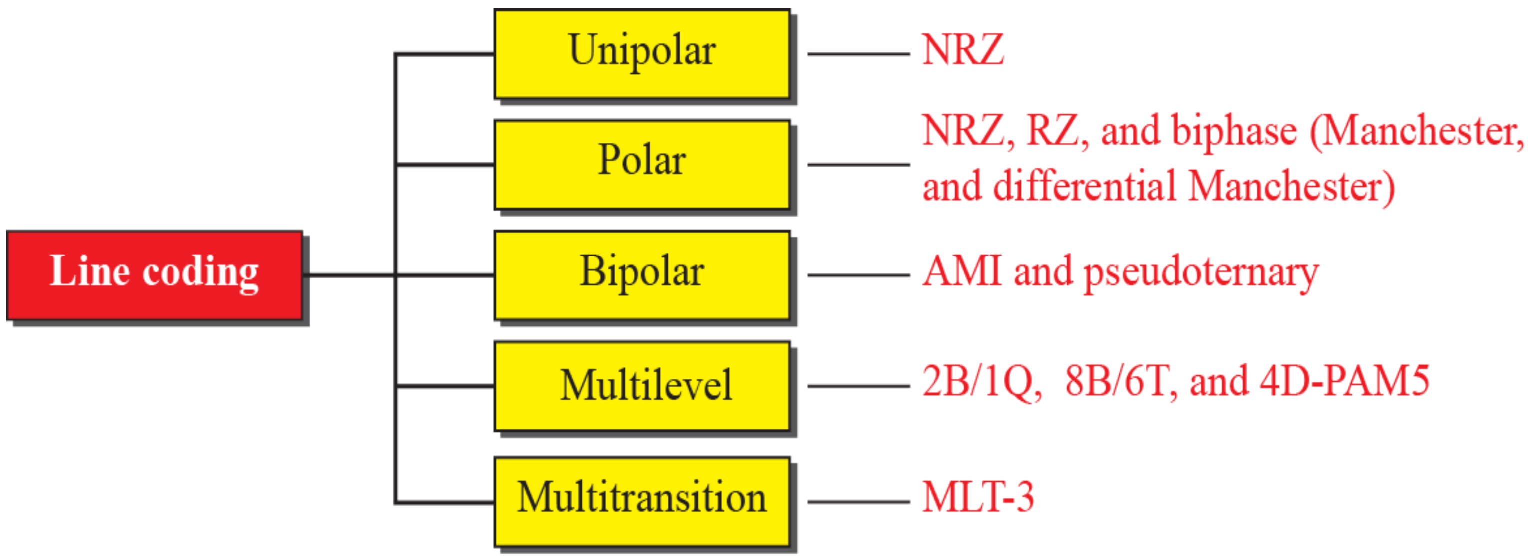
Amplitude
1
0
1
1
0
V
0
Time

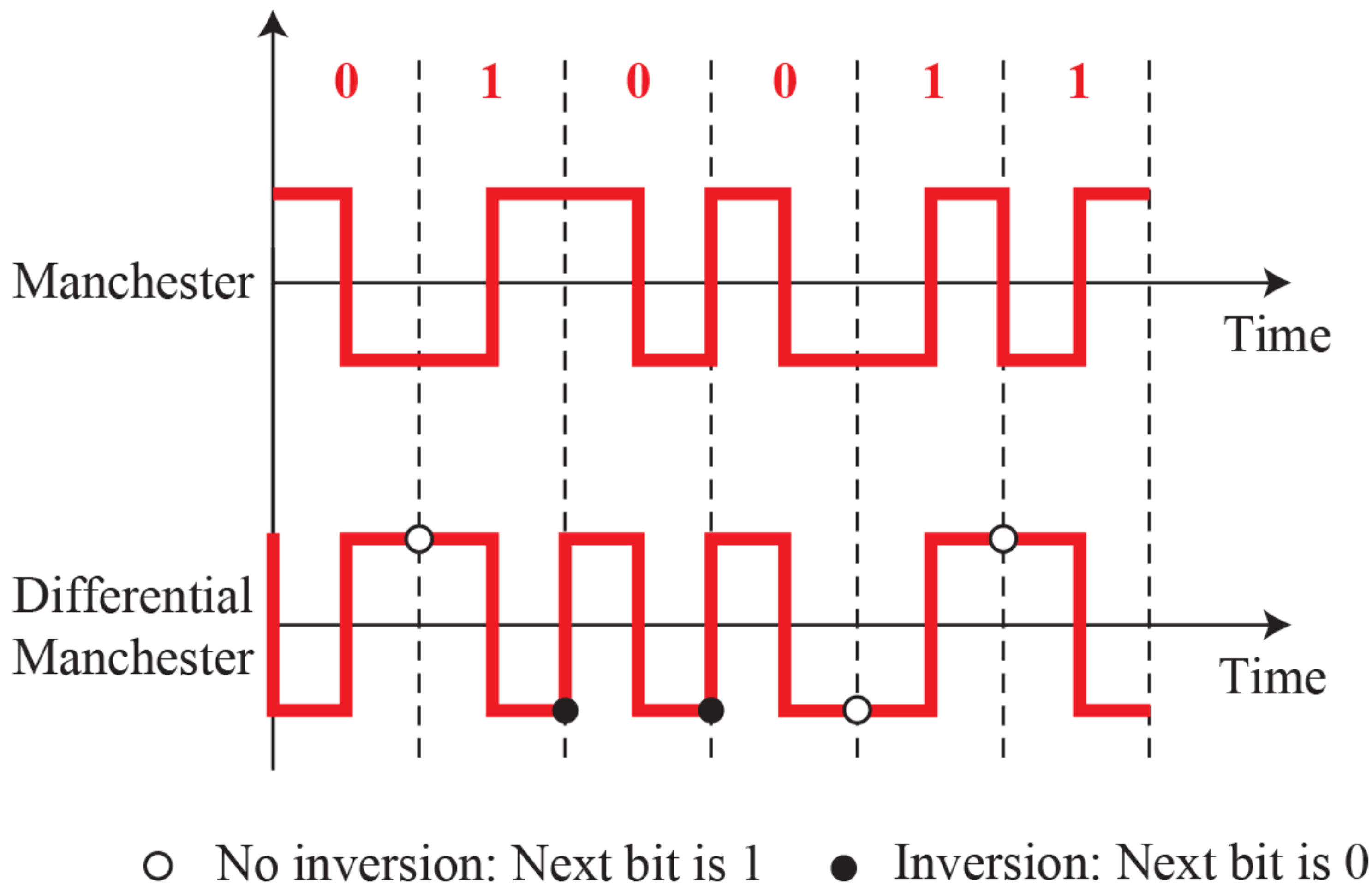

0 1 0 0 1 1 1 0
NRZ-L
Time
NRZ-I
Time
No inversion: Next bit is 0
Inversion: Next bit is 1



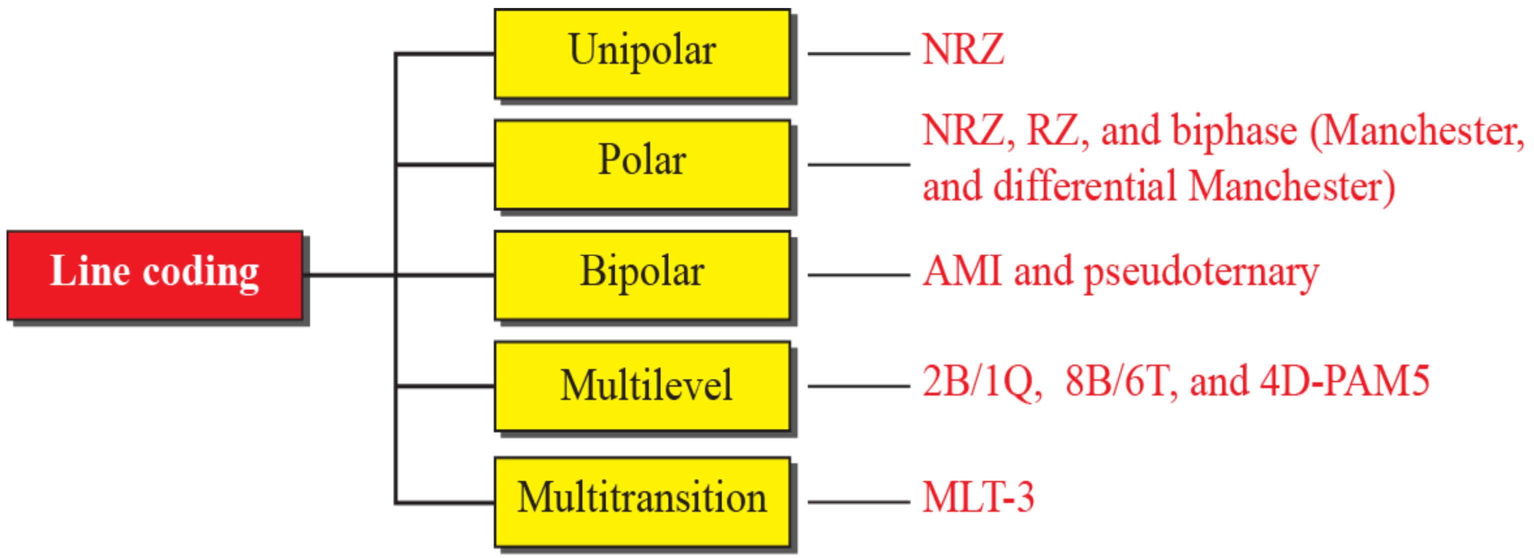
Amplitude
RZ
0
1
0
0
1
Time

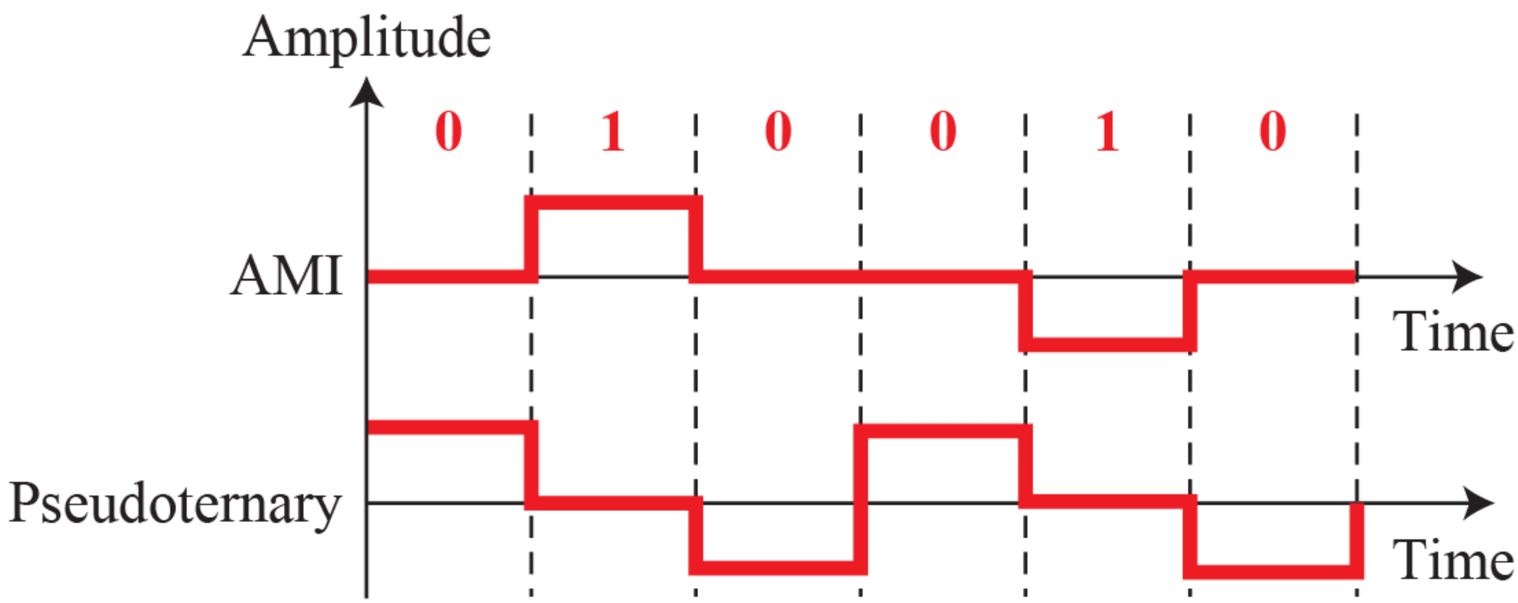
- **We can roughly divide line coding schemes into five broad categories**


Line coding
Unipolar
Polar
Bipolar
Multilevel
Multitransition
NRZ
NRZ, RZ, and biphase (Manchester, and differential Manchester)
AMI and pseudoternary
2B/1Q, 8B/6T, and 4D-PAM5
MLT-3

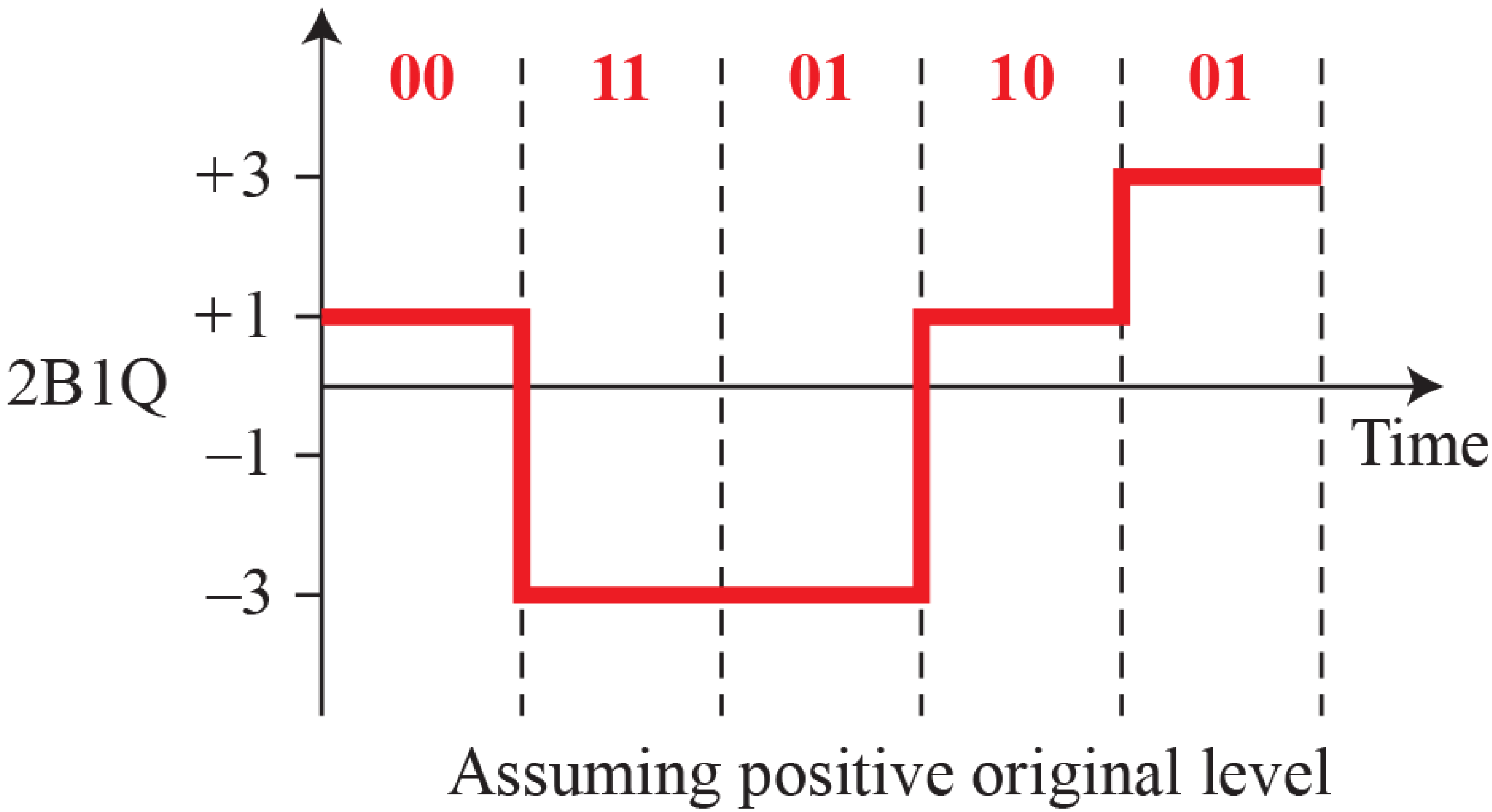

0
1
0
0
1
1
Manchester
Time
Differential Manchester
Time
No inversion: Next bit is 1
Inversion: Next bit is 0

- **We can roughly divide line coding schemes into five broad categories**


Line coding
Unipolar
Polar
Bipolar
Multilevel
Multitransition
NRZ
NRZ, RZ, and biphase (Manchester, and differential Manchester)
AMI and pseudoternary
2B/1Q, 8B/6T, and 4D-PAM5
MLT-3



Amplitude
0
1
0
0
1
0
AMI
Time
Pseudoternary
Time



00
11
01
10
01
+3
+1
2B1Q
–1
–3
Time
Assuming positive original level

Category	*Scheme*	*Bandwidth (average)*	*Characteristics*
Unipolar	NRZ	$B = N/2$	Costly, no self-synchronization if long 0s or 1s, DC
Polar	NRZ-L	$B = N/2$	No self-synchronization if long 0s or 1s, DC
	NRZ-I	$B = N/2$	No self-synchronization for long 0s, DC
	Biphase	$B = N$	Self-synchronization, no DC, high bandwidth
Bipolar	AMI	$B = N/2$	No self-synchronization for long 0s, DC
Multilevel	2B1Q	$B = N/4$	No self-synchronization for long same double bits
	8B6T	$B = 3N/4$	Self-synchronization, no DC
	4D-PAM5	$B = N/8$	Self-synchronization, no DC
Multitransition	MLT-3	$B = N/3$	No self-synchronization for long 0s

- Block coding changes a block of ‘m’ bits into a block of ‘n’ bits (n>m)

- mB/nB encoding technique

- We need Redundancy to ensure Synchronization

- Block coding gives us redundancy and improves line coding performance

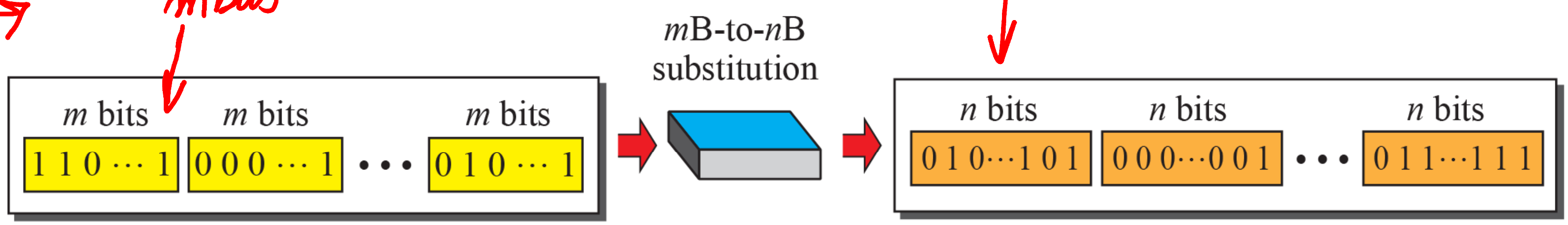
Division

Substitution

Combination

Stream

m bits



Division of a stream into *m*-bit groups

Combining *n*-bit groups into a stream

mB/nB

$$\underbrace{n > m}_{\text{Redundant bits}}$$

Redundancy

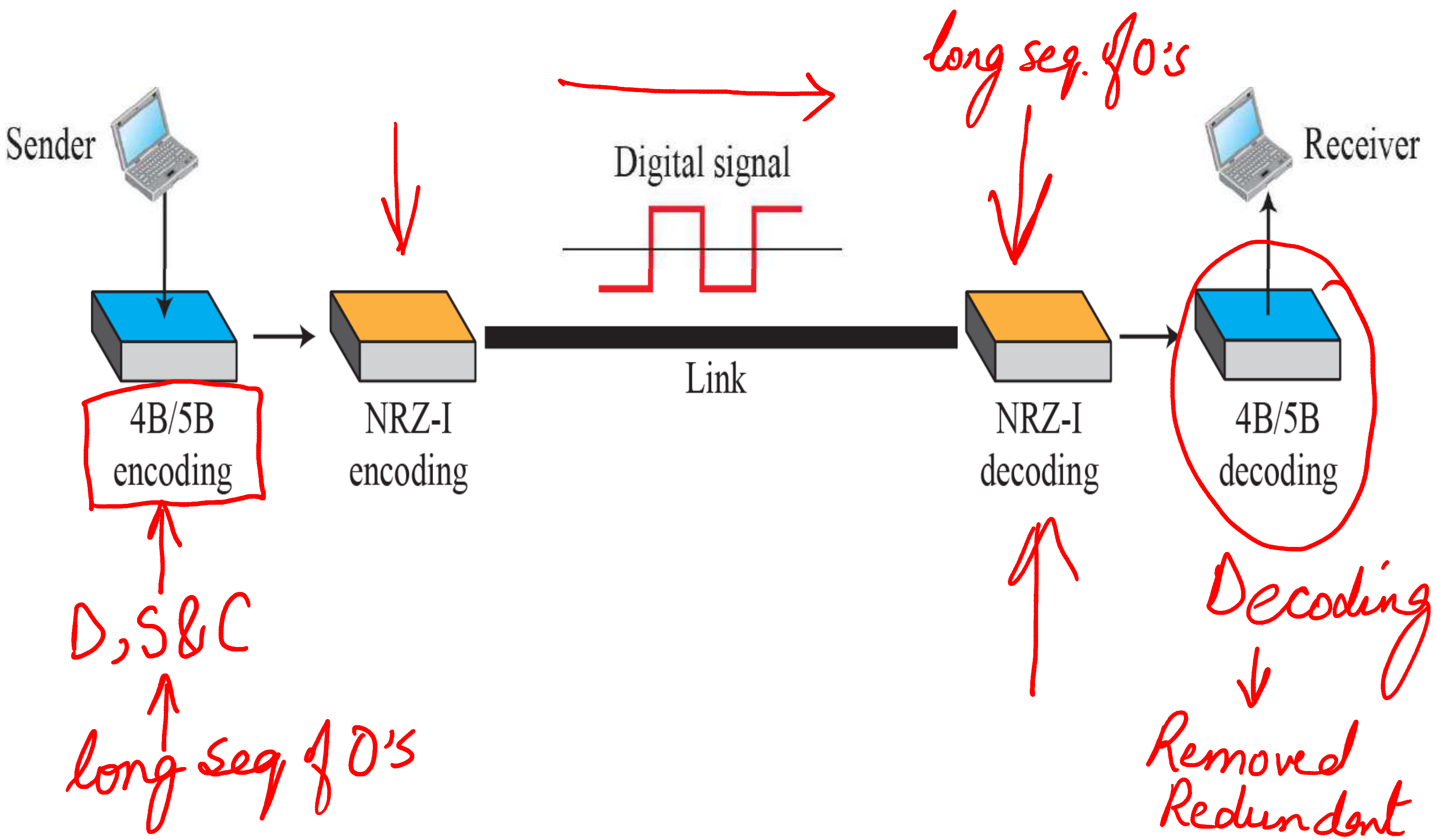
- **Block coding changes a block of ‘m’ bits into a block of ‘n’ bits (n>m)**

- **mB/nB encoding technique**

- **We need Redundancy to ensure Synchronization**

- **Block coding gives us redundancy and improves line coding performance**

4B/5B $\Rightarrow m=4 \quad n=5 \quad n>m$



- **Block coding changes a block of ‘m’ bits into a block of ‘n’ bits (n>m)**

- **mB/nB encoding technique**

- **We need Redundancy to ensure Synchronization**

- **Block coding gives us redundancy and improves line coding performance**

$2^4 = 16$ $2^5 = 32$ groups

Data Sequence	Encoded Sequence	Control Sequence	Encoded Sequence
1 0000	11110	Q (Quiet)	00000
2 0001	01001	I (Idle)	11111
3 0010	10100	H (Halt)	00100
0011	10101	J (Start delimiter)	11000
0100	01010	K (Start delimiter)	10001
0101	01011	T (End delimiter)	01101
0110	01110	S (Set)	11001
0111	01111	R (Reset)	00111
1000	10010		
1001	10011		
1010	10110		
1011	10111		
1100	11010		
1101	11011		
1110	11100		
16 1111	11101		

- Block coding changes a block of ‘m’ bits into a block of ‘n’ bits (n>m)
- mB/nB encoding technique
- We need Redundancy to ensure Synchronization
- Block coding gives us redundancy and improves line coding performance

We need to send data at a 1-Mbps rate. What is the minimum required bandwidth, using a combination of 4B/5B and NRZ-I or Manchester coding?

Data Rate = 1 Mbps

4B/5B Block Coding

↳ 4 bit group ⇔ 5 bit group

Data Rate = 1.25 Mbps

$\boxed{\text{Signal Rate} \uparrow}$

Synchronisation ⇒ ✓

Signal Rate ↑ ⇒ BW ↑ ✓

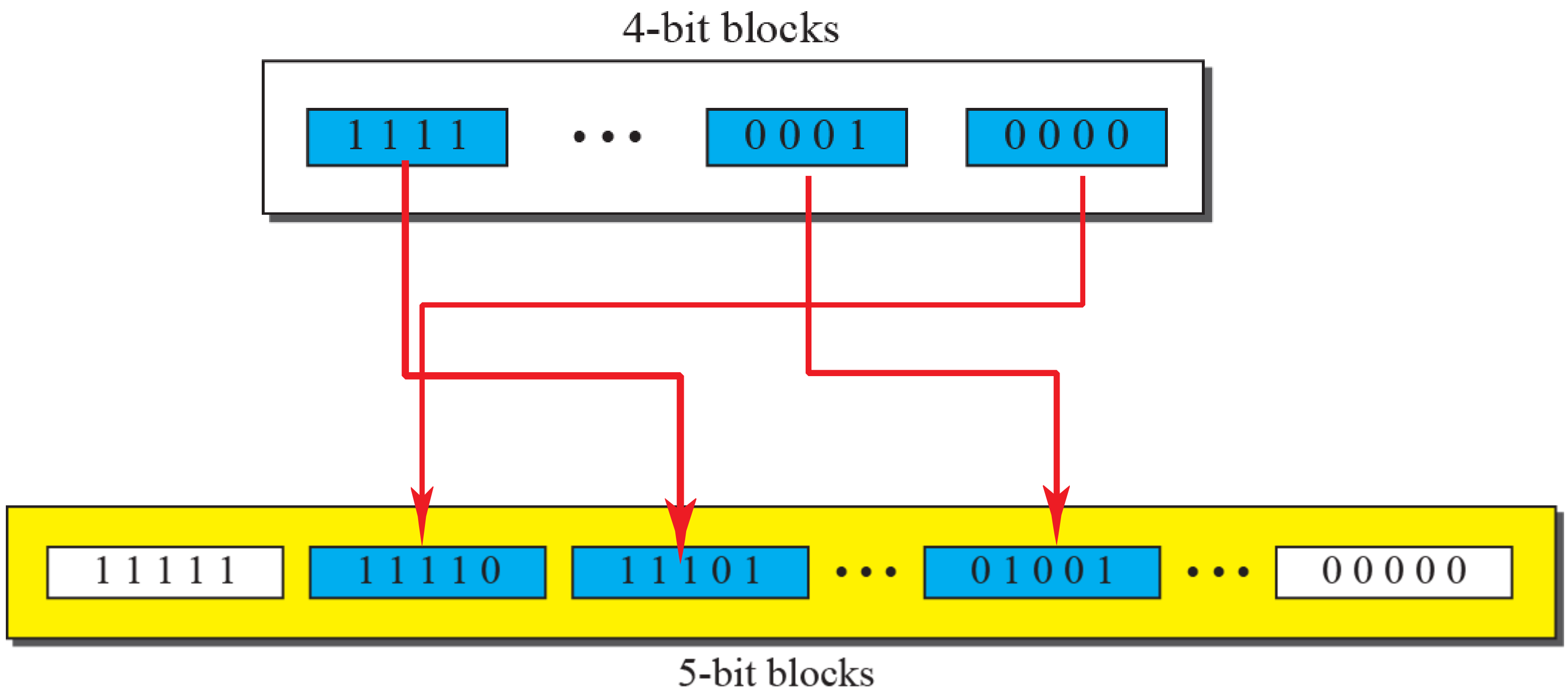
$BW_{NRZ\text{-}I} < BW_{Manchester}$

DC-component ✗

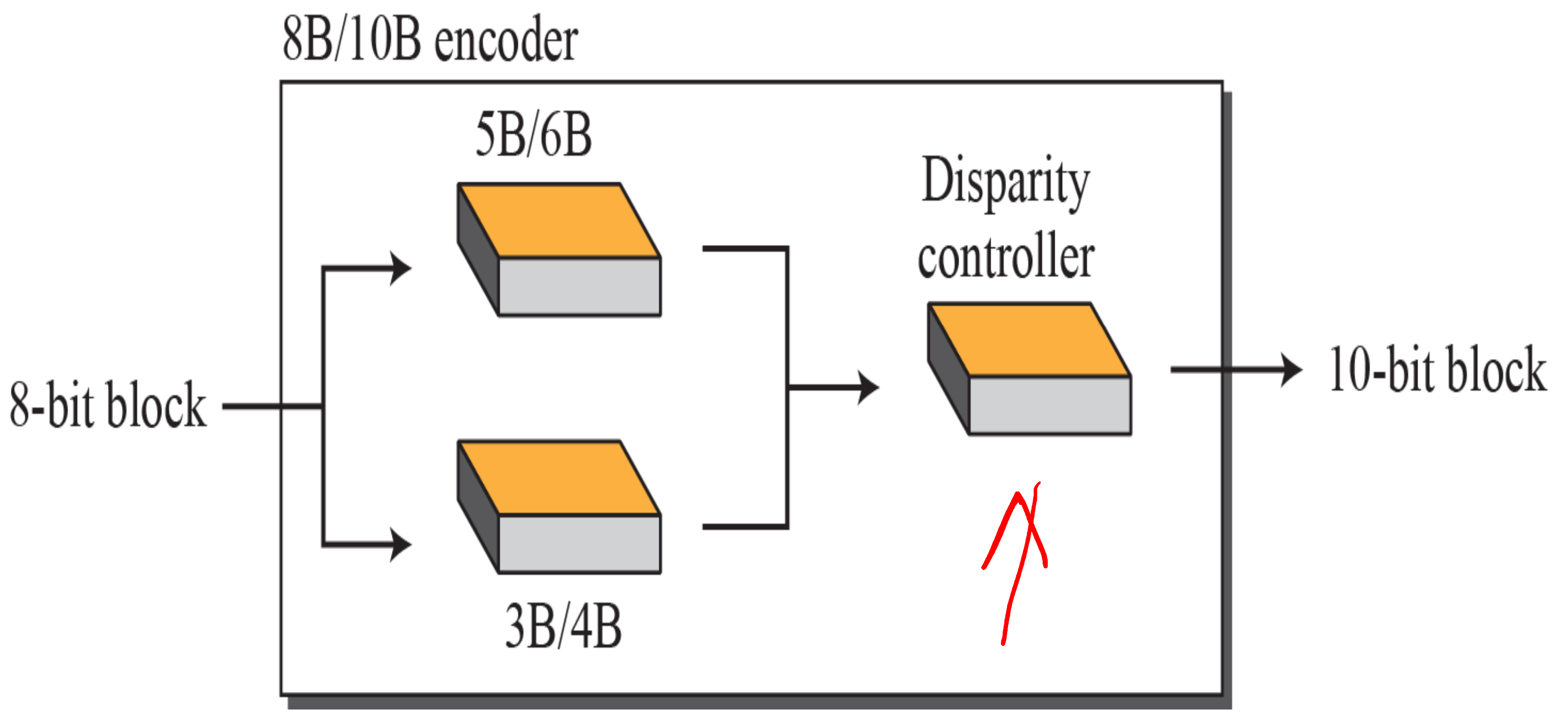
$$NRZ\text{-}I = \frac{N}{2} = \frac{1.25\,\text{Mbps}}{2}$$

$$= 625\ \text{kHz}$$

Manchester ⇒ 1 MHz


4-bit blocks
1 1 1 1
• • •
0 0 0 1
0 0 0 0
1 1 1 1 1
1 1 1 1 0
1 1 1 0 1
• • •
0 1 0 0 1
• • •
0 0 0 0 0
5-bit blocks

$m=8 \quad n=10$

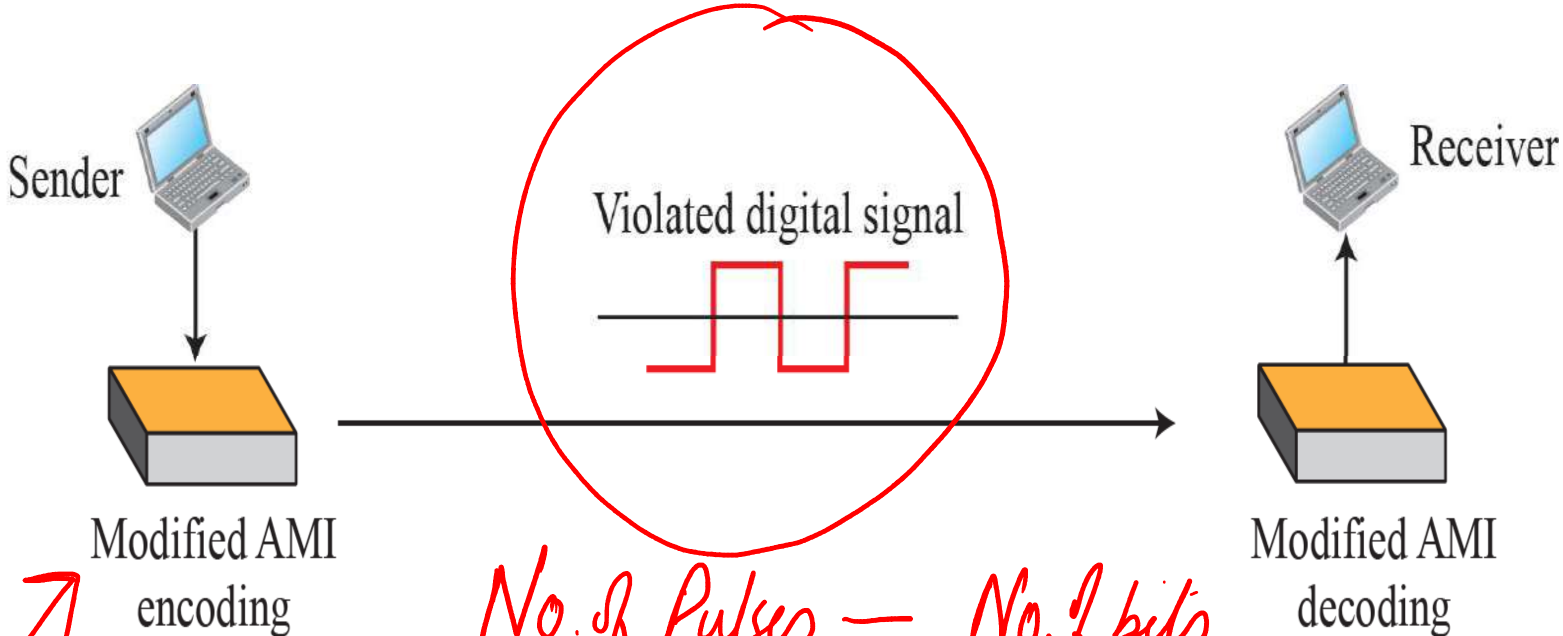

8B/10B encoder
5B/6B
Disparity controller
8-bit block
10-bit block
3B/4B

- **Biphase schemes suitable for LAN but not for Long Distance**

- **Block Coding + NRZ-I solves synch issue but has DC component**

- **Bipolar AMI has a narrow bandwidth (no DC Component) but synch issue (long series of 0s)**

- **The system needs to insert the required pulses based on the defined scrambling rules**



No. of Pulses = No. of bits in sequence of 0s

- **Two common scrambling techniques are B8ZS and HDB3**

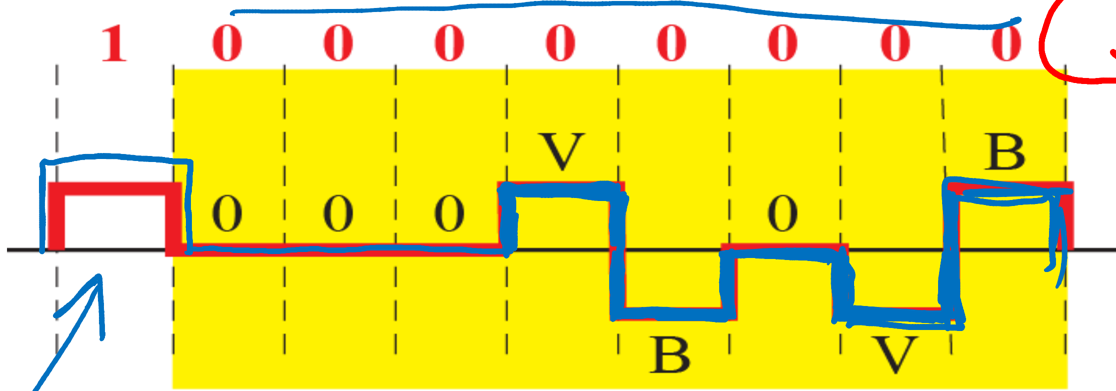
- **Bipolar with 8-Zero Substitution (B8ZS)**

- **High-density bipolar 3-zero (HDB3)**

00000000
→ 000VB0VB

V → violation

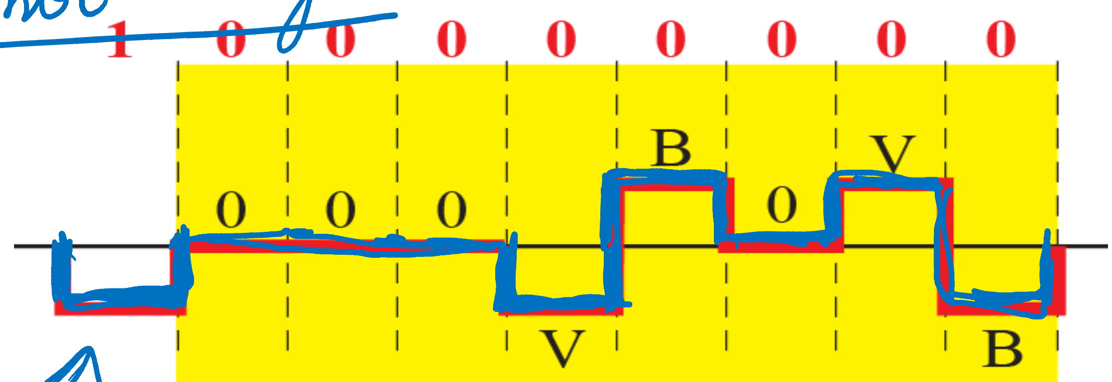
B → Bipolar



a. Previous level is positive.

Bit Rate doesnot change

DC Balance

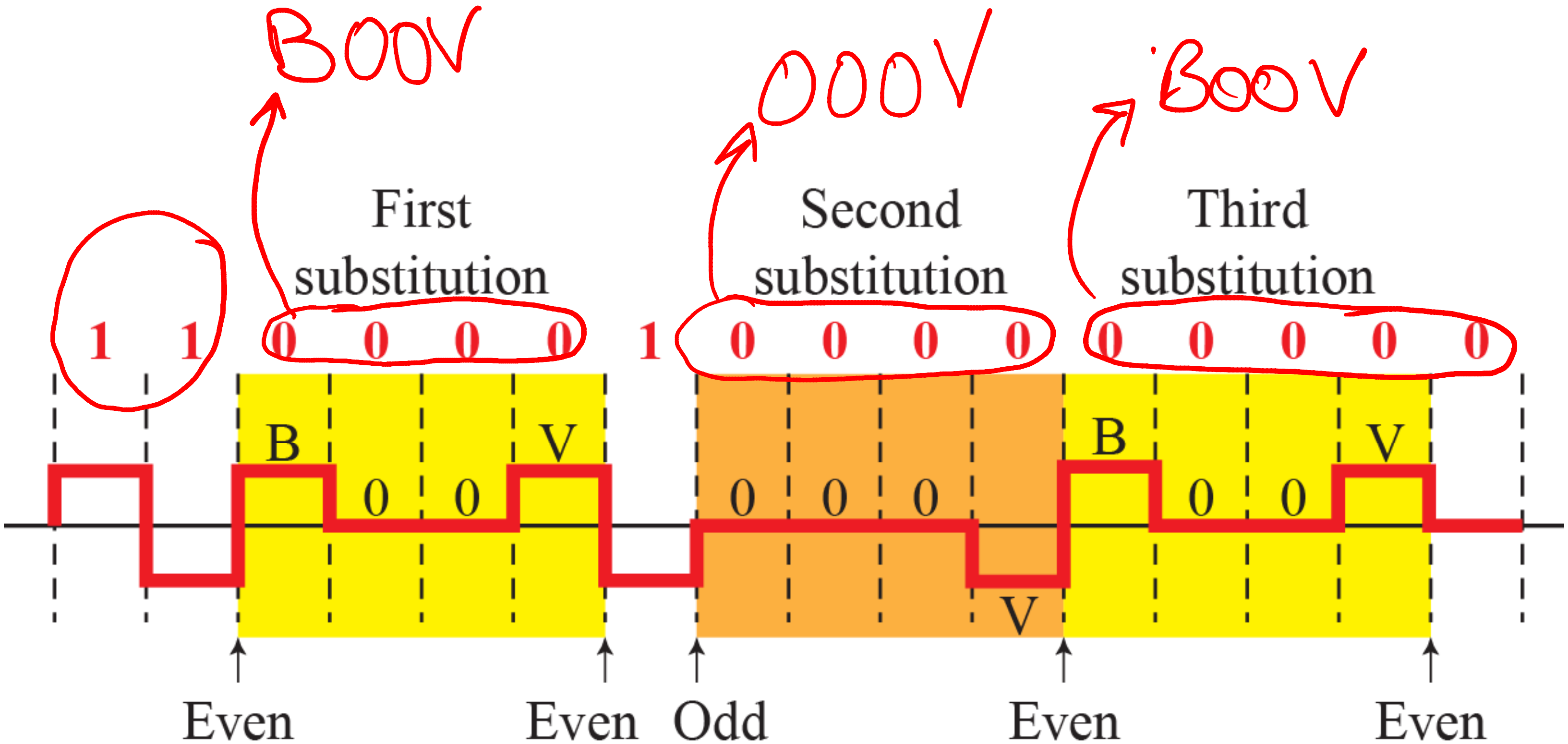


b. Previous level is negative.

- **Two common scrambling techniques are B8ZS and HDB3**

- **Bipolar with 8-Zero Substitution (B8ZS)**

- **High-density bipolar 3-zero (HDB3)**



Rule 1: Non-zero pulses → odd

0000 → $\boxed{000V}$

Rule 2: Non-zero pulses → even

0000

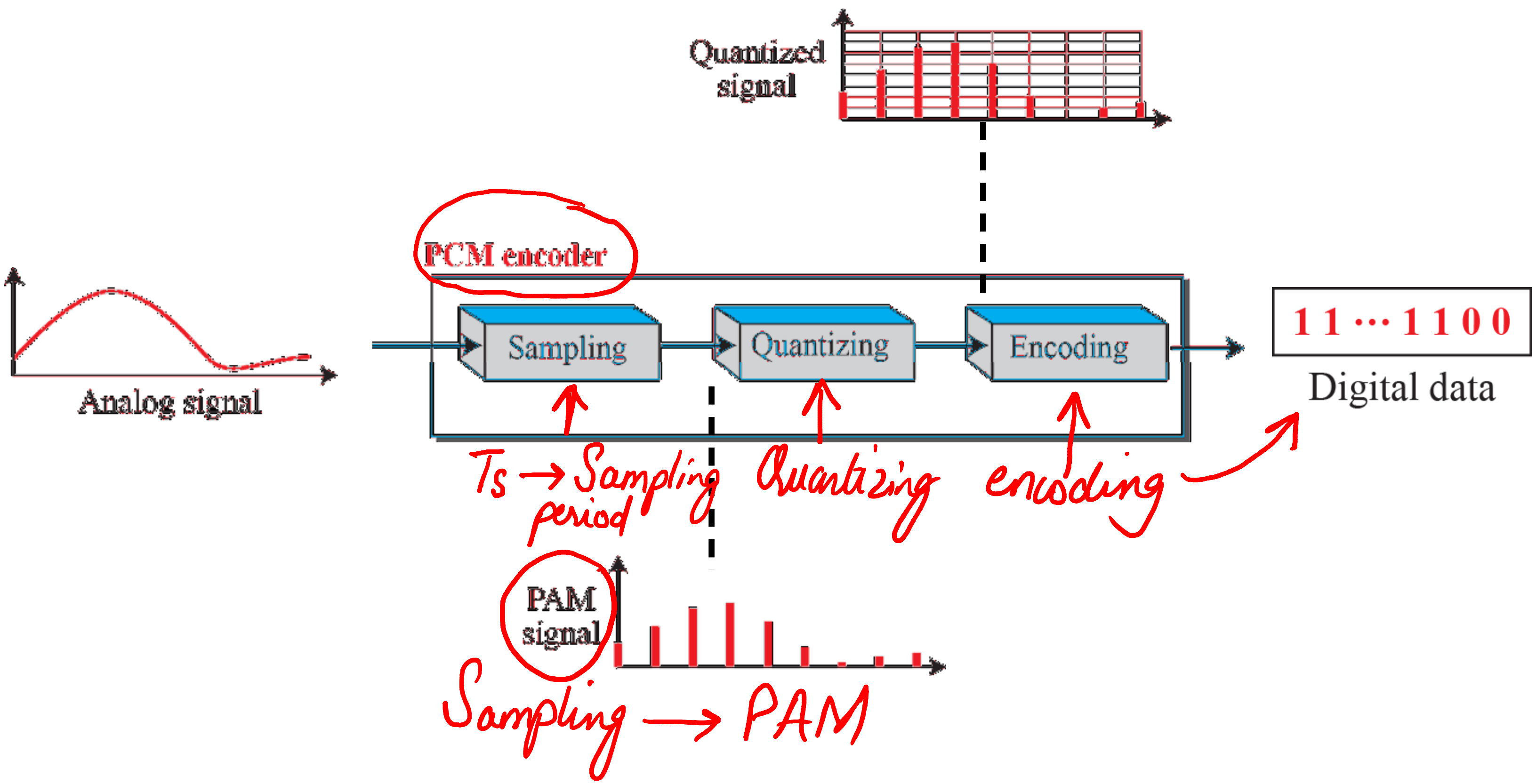
$\boxed{B00V}$

- **Analog Data to Digital Data**

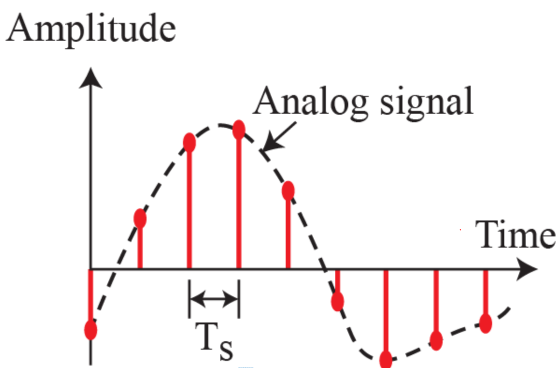
- **Process of Digitization**

- **Two techniques:**
  - ✓ **Pulse Code Modulation (PCM)**

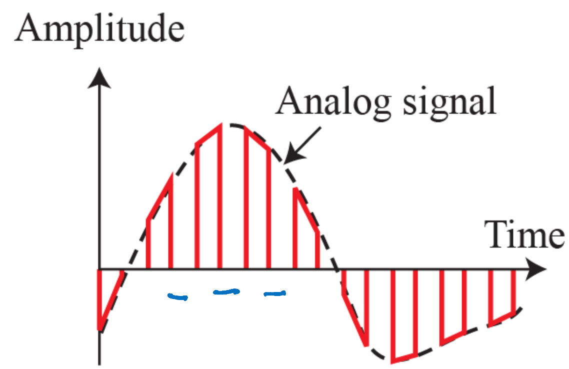
  - ✓ **Delta Modulation (DM)**


Quantized signal
PCM encoder
Sampling
Quantizing
Encoding
1 1 ··· 1 1 0 0
Digital data
Analog signal
Ts → Sampling period
Quantizing
encoding
PAM signal
Sampling → PAM

- **Sampling**
- **Quantization**
- **Encoding**



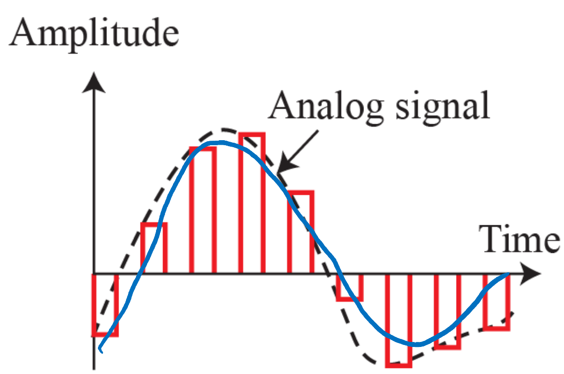
a. Ideal sampling



b. Natural sampling

Sampling
↳ Pulse Amplitude Modulation

T_s → Sampled interval or Sample period



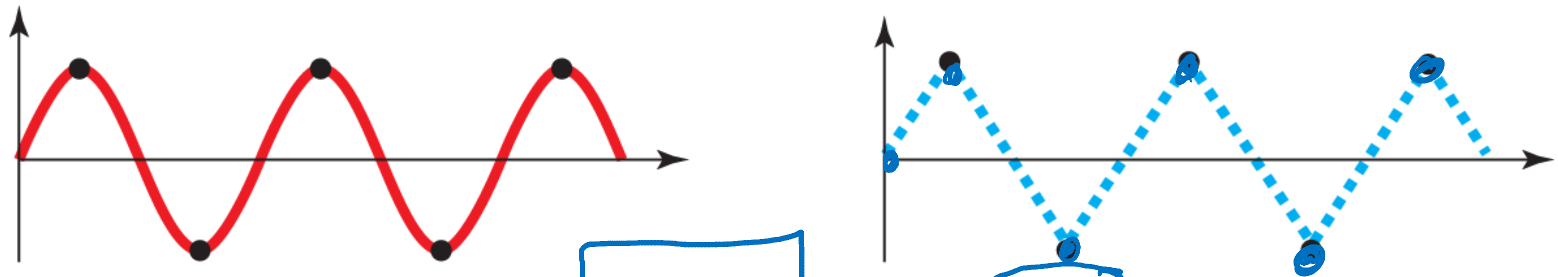
c. Flat-top sampling

Sample and Hold

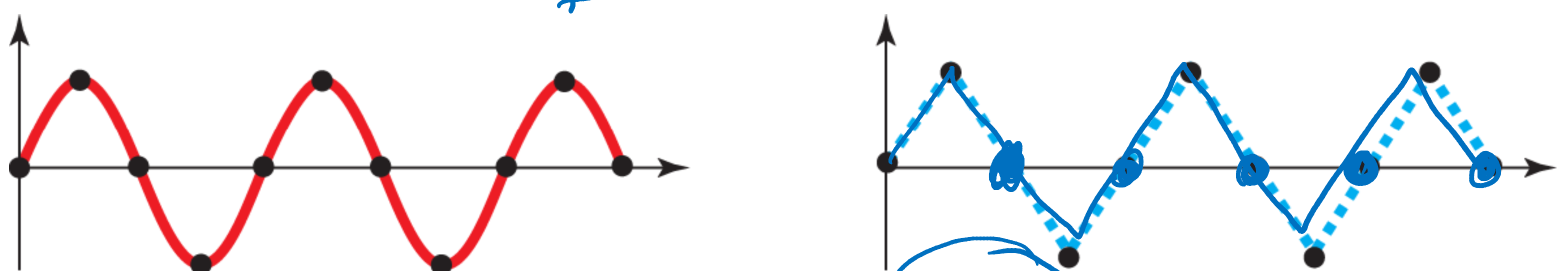
- **Nyquist → $f_s = 2f_h$**

- **Sampling sine wave at three sampling rates:**

  - ✓ **$f_s = 4f$ (2 times the Nyquist rate)**
  - ✓ **$f_s = 2f$ (Nyquist rate)**
  - ✓ **fs = f (one-half the Nyquist rate)**

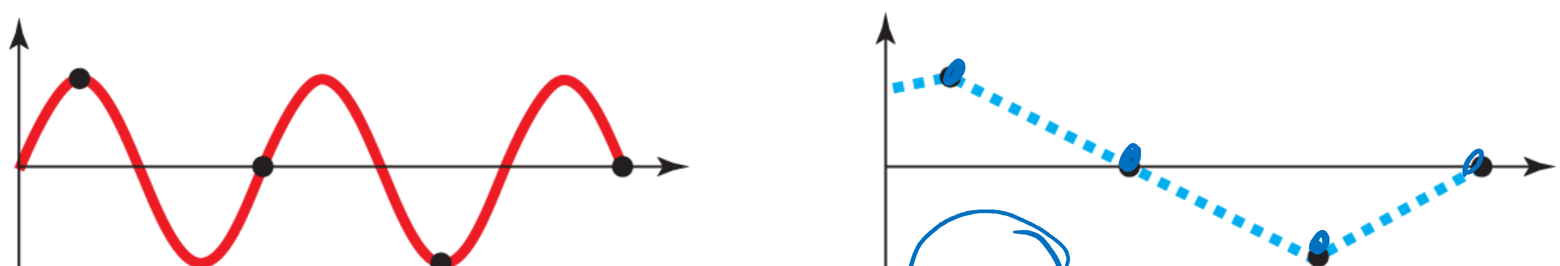


a. Nyquist rate sampling: $f_s = 2\text{ f}$



b. Oversampling: $f_s = 4\text{ f}$

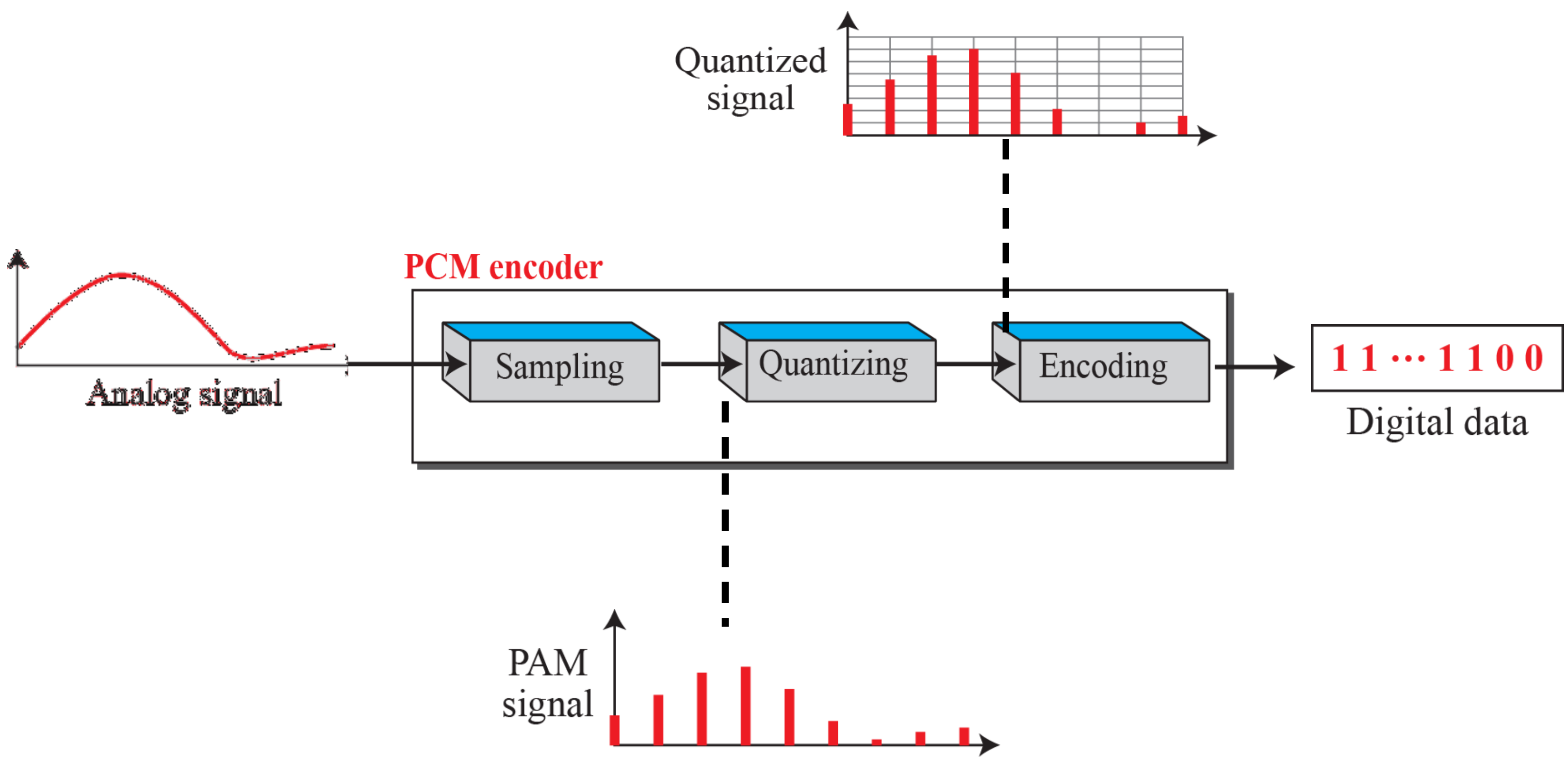
Double Nyquist rate



c. Undersampling: $f_s = \text{ f}$

Half the Nyquist rate

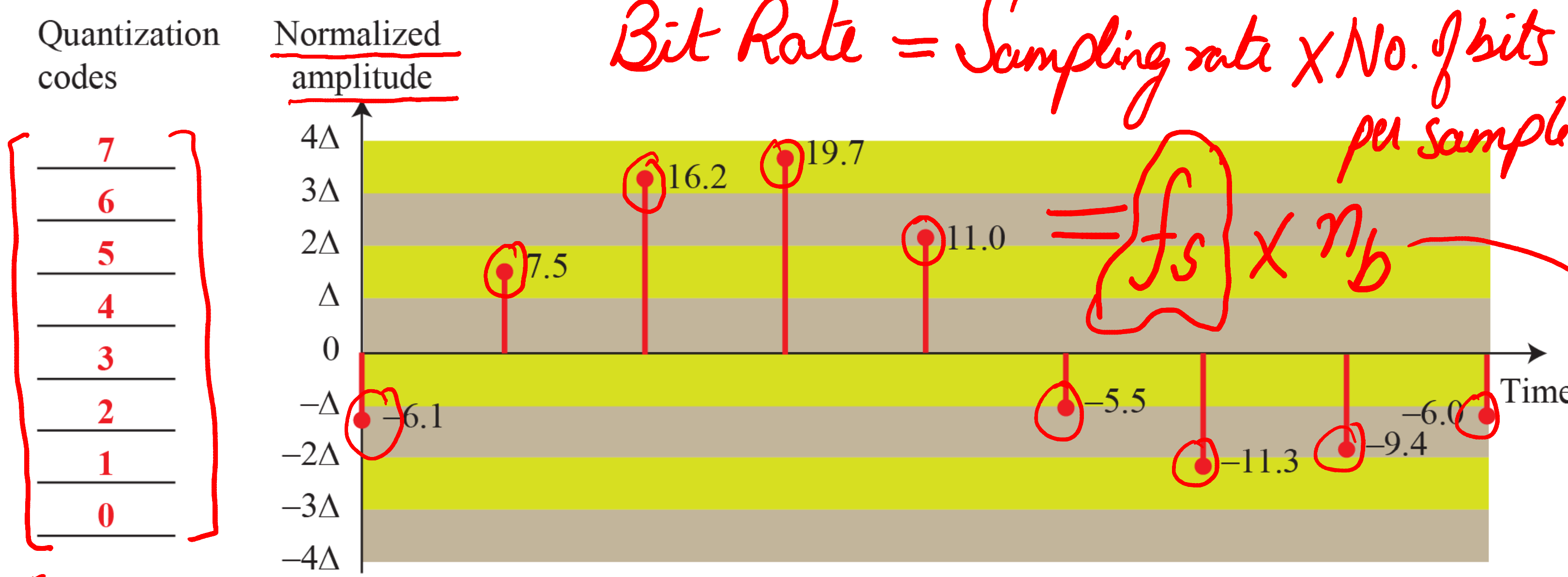
- **Most common technique**
- **Employs a PCM Encoder**
- **A PCM encoder has three processes:**
  - ✓ **Sampling**
  - ✓ **Quantization**
  - ✓ **Encoding**


Quantized
signal
PCM encoder
Sampling
Quantizing
Encoding
Analog signal
1 1 ··· 1 1 0 0
Digital data
PAM
signal

- **Sampling**
- **Quantization**
- **Encoding**

- Sampling → Series of pulses with amplitude values between min and max signal amplitude
- Infinite set with non-integral values not suitable for encoding
- We quantize the sampling output into certain levels based on range of amplitudes and how much accuracy is needed

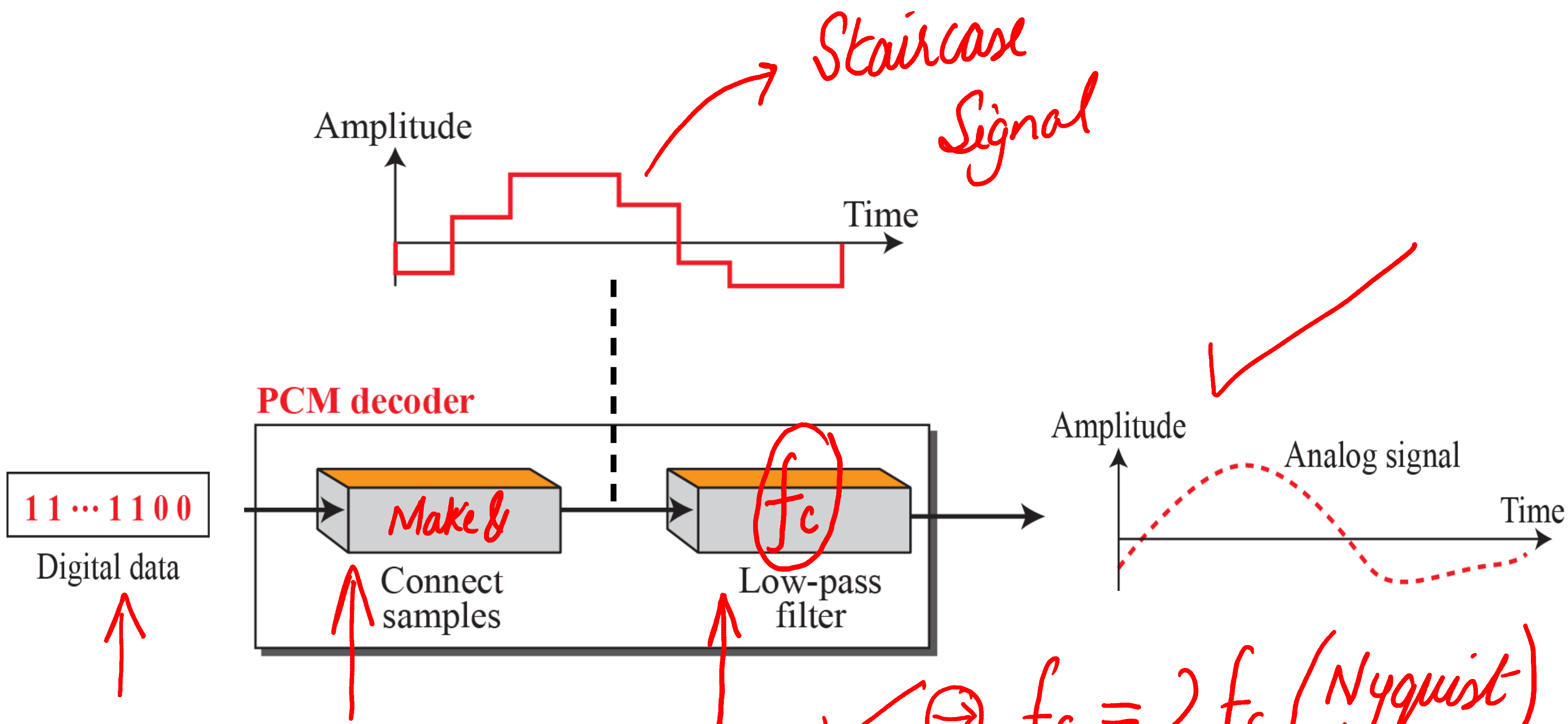
Bit Rate = Sampling rate × No. of bits per sample $= f_s \times n_b$



Normalized PAM values	–1.22	1.50	3.24	3.94	2.20	–1.10	–2.26	–1.88	–1.20
Normalized quantized values	–1.50	1.50	3.50	3.50	2.50	–1.50	–2.50	–1.50	–1.50
Normalized error	–0.28	0	+0.26	–0.44	+0.30	–0.40	–0.24	+0.38	–0.30
Quantization code	2	5	7	7	6	2	1	2	2
Encoded words	010	101	111	111	110	010	001	010	010

$n_b = \log_2 L$ $\quad L \rightarrow$ Quantization Level

- **Encoding**
    - ✓ **Sampling**
    - ✓ **Quantization**
    - ✓ **Encoding**
- **Decoding**



$\checkmark$ ⊖ $f_s = 2 f_c$ (Nyquist Rate)

$\checkmark$ ⊖ $L \rightarrow$ Quantization Levels

$\checkmark$ ⊖ Amplification

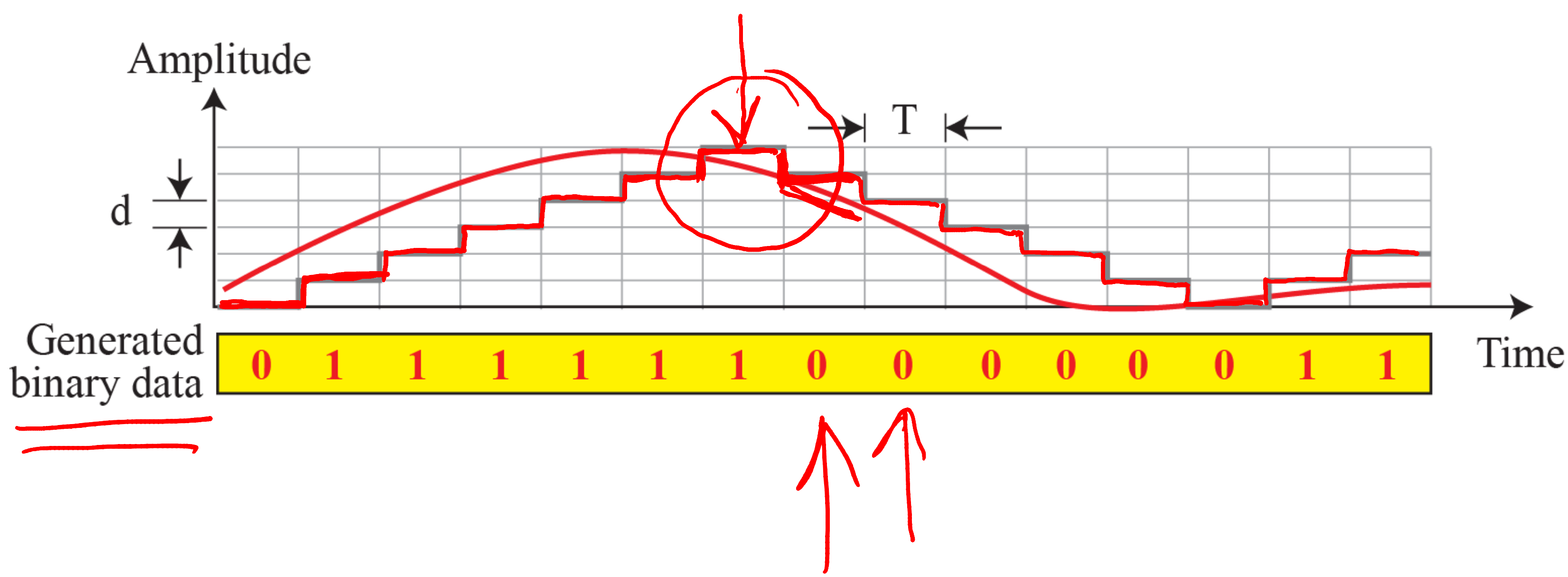
- **Analog Data to Digital Data**

- **Process of Digitization**

- **Two techniques:**
  - ✓ **Pulse Code Modulation (PCM)**

  - ✓ **Delta Modulation (DM)**

- PCM is a very complex technique
- Delta modulation is a simpler technique
- PCM finds the value of the signal amplitude for each sample; DM finds the change from the previous sample
- No code words



Amplitude
d
T
Time
Generated binary data
0 1 1 1 1 1 1 0 0 0 0 0 0 1 1

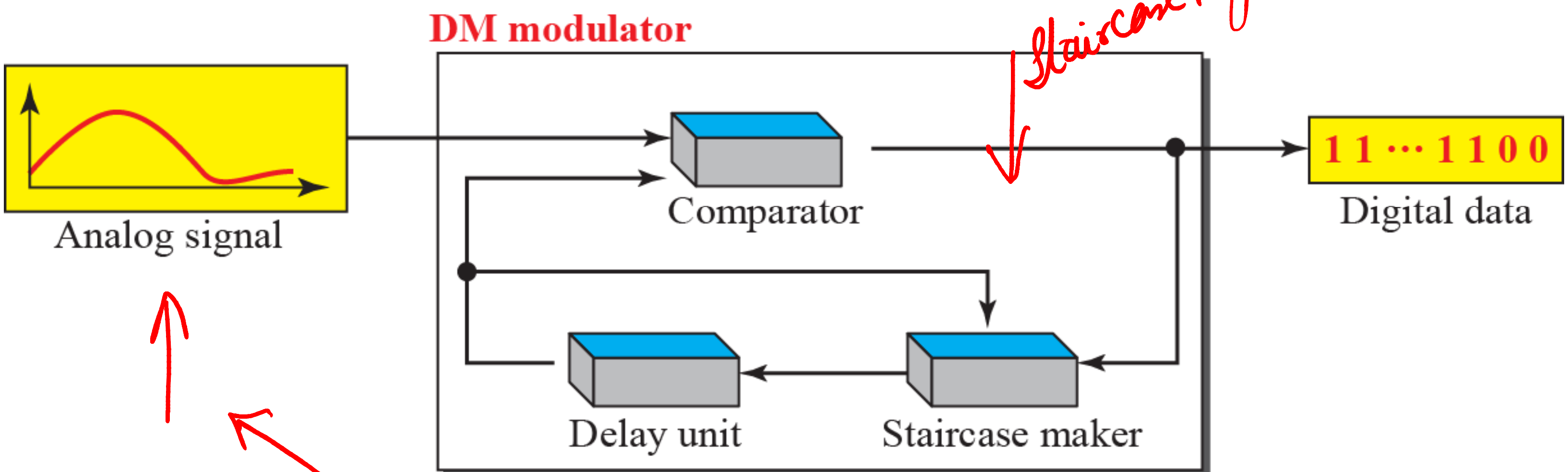
- **Delta modulation is a simpler technique**
- **DM finds the change from the previous sample**
- **No code words**

Delta → δ

+δ → 1

−δ → 0

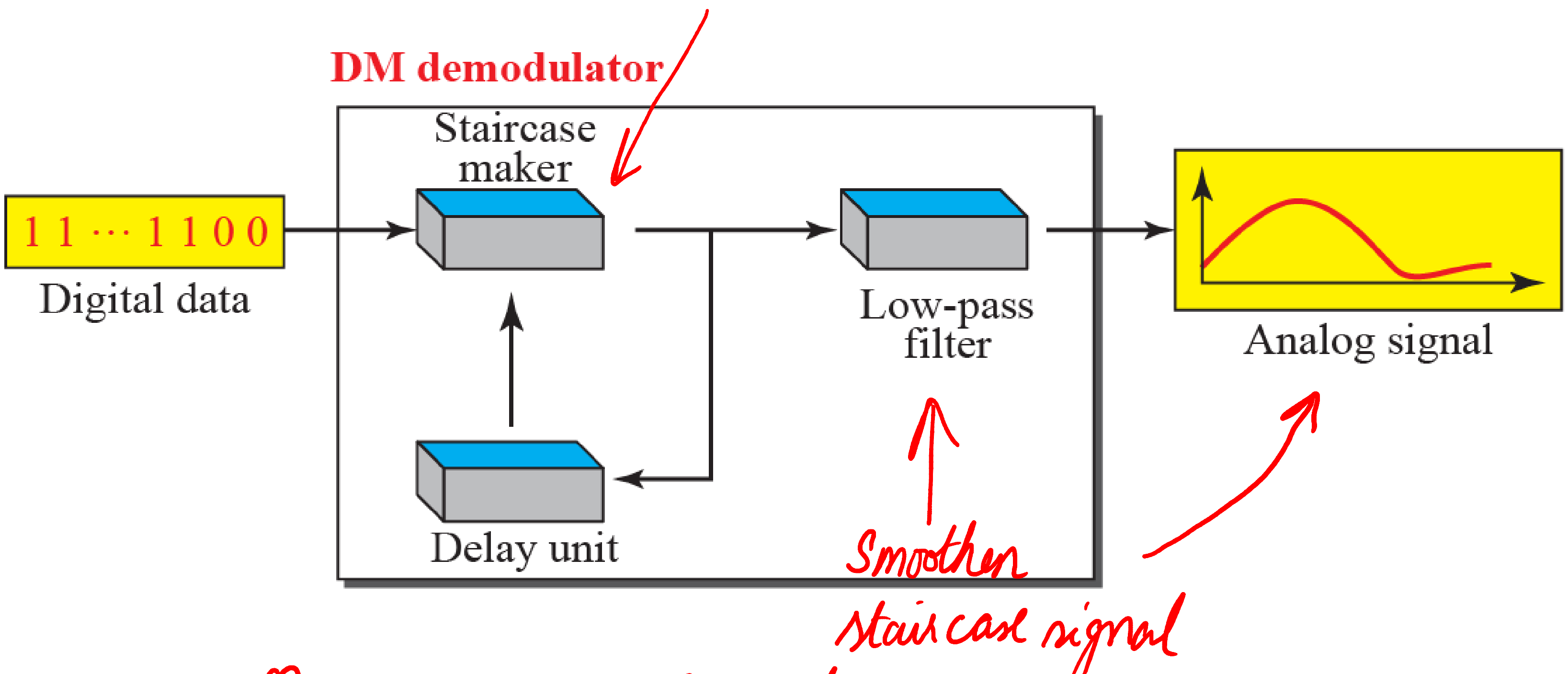
Staircase signal



Compare → Comparator

Staircase signal

Adaptive DM $\rightarrow$ δ is not fixed $\rightarrow$ Performance $\uparrow$



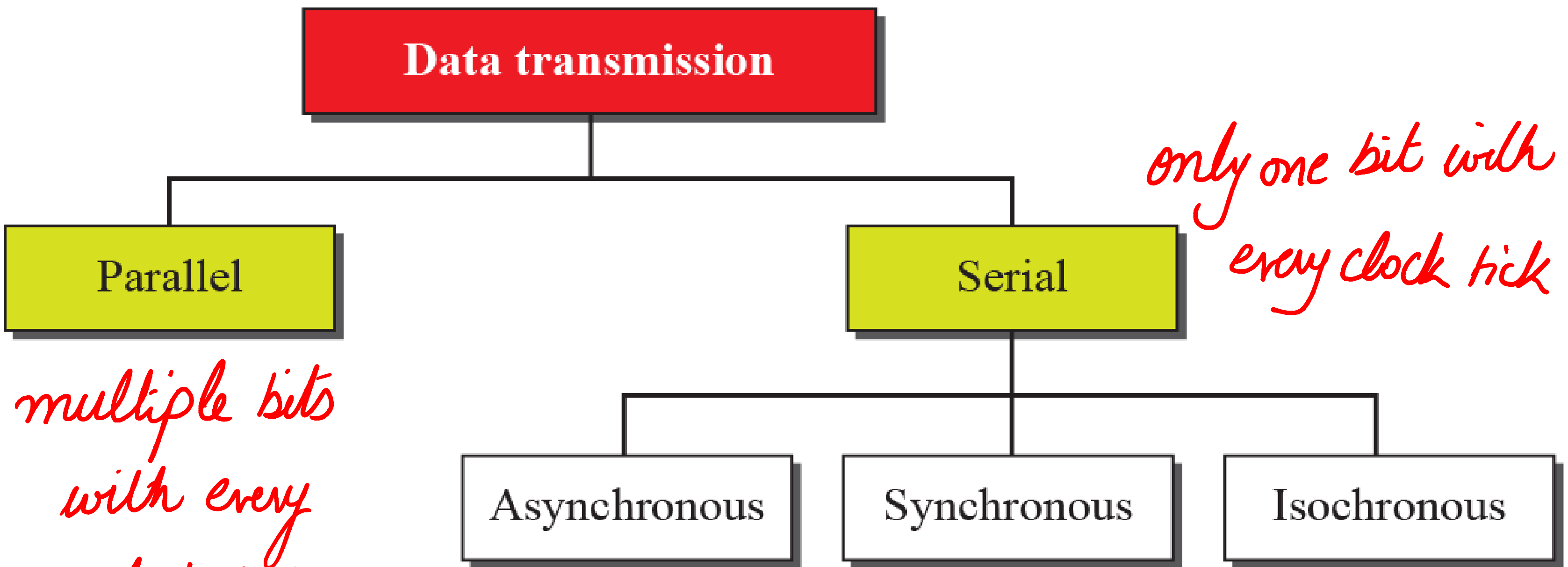
Quantization Error (QE)

$QE_{DM} < QE_{PCM}$.

- **Transmission of Data:**
  - ✓ **Wiring**
    - ➢ **Data Stream**

- **Do we send 1 bit at a time; or do we group bits into larger groups and, if so, how?**

- **Parallel or Serial Transmission**



only one bit with every clock tick

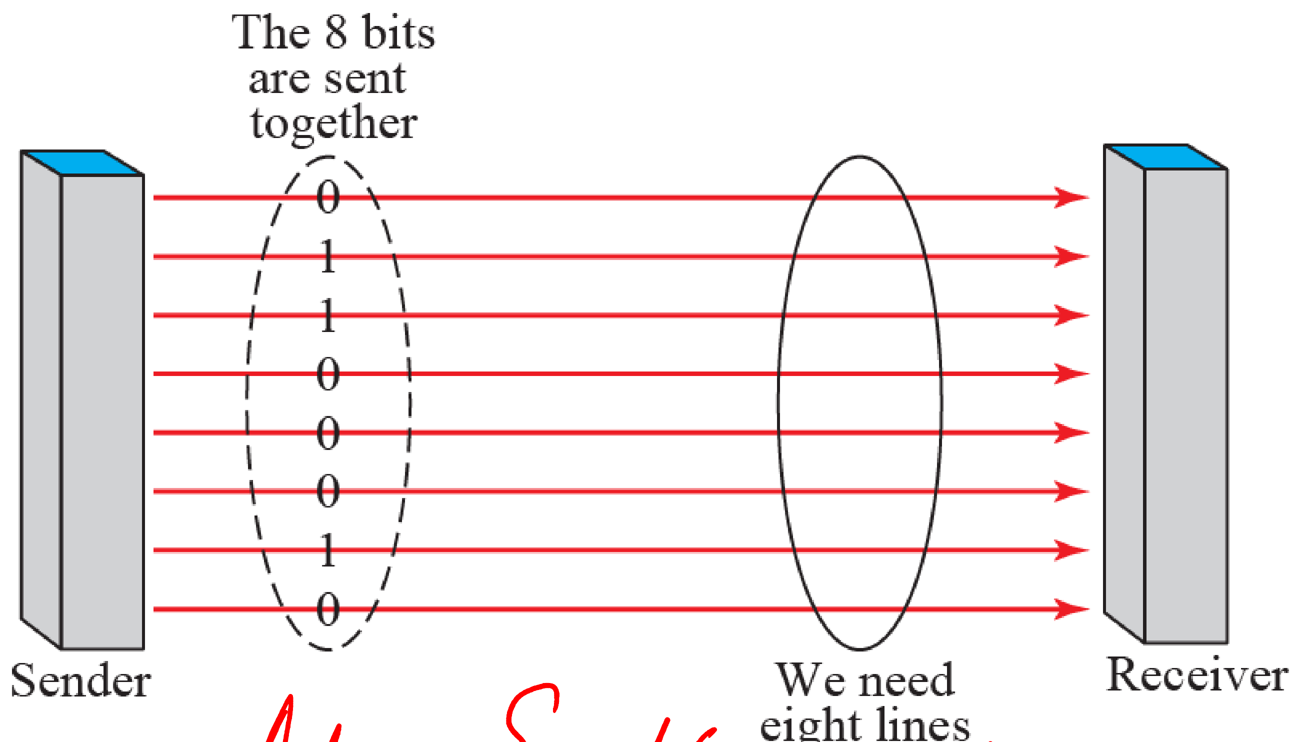
multiple bits with every clock tick

- **Binary data (1s ad 0s) organized in groups of ‘n’ bits**

- **We send ‘n’ bits at a time instead of just one**

- **‘n’ wires required to send ‘n’ bits at one time**

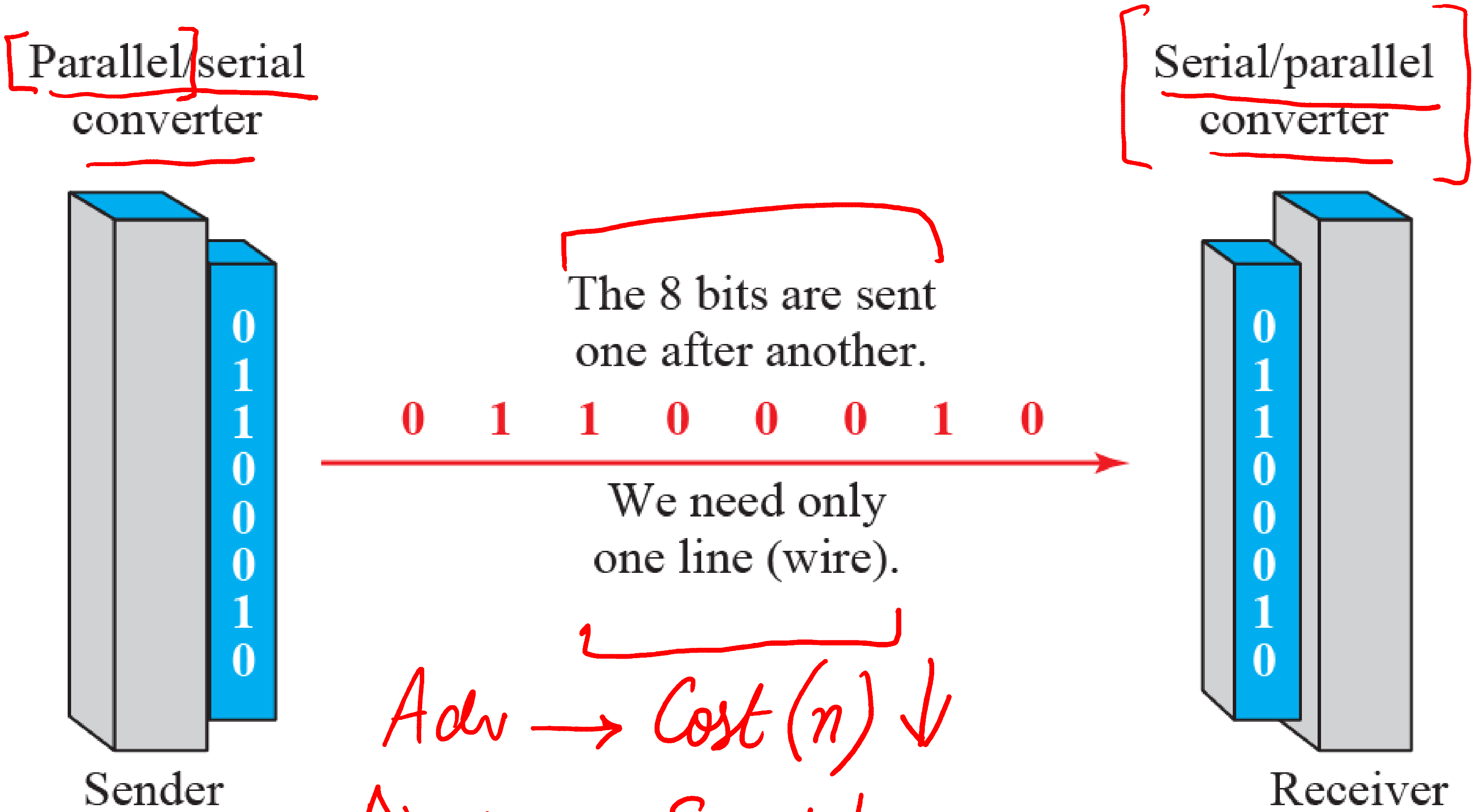
$n = 8$



Adv → Speed (factor of n)

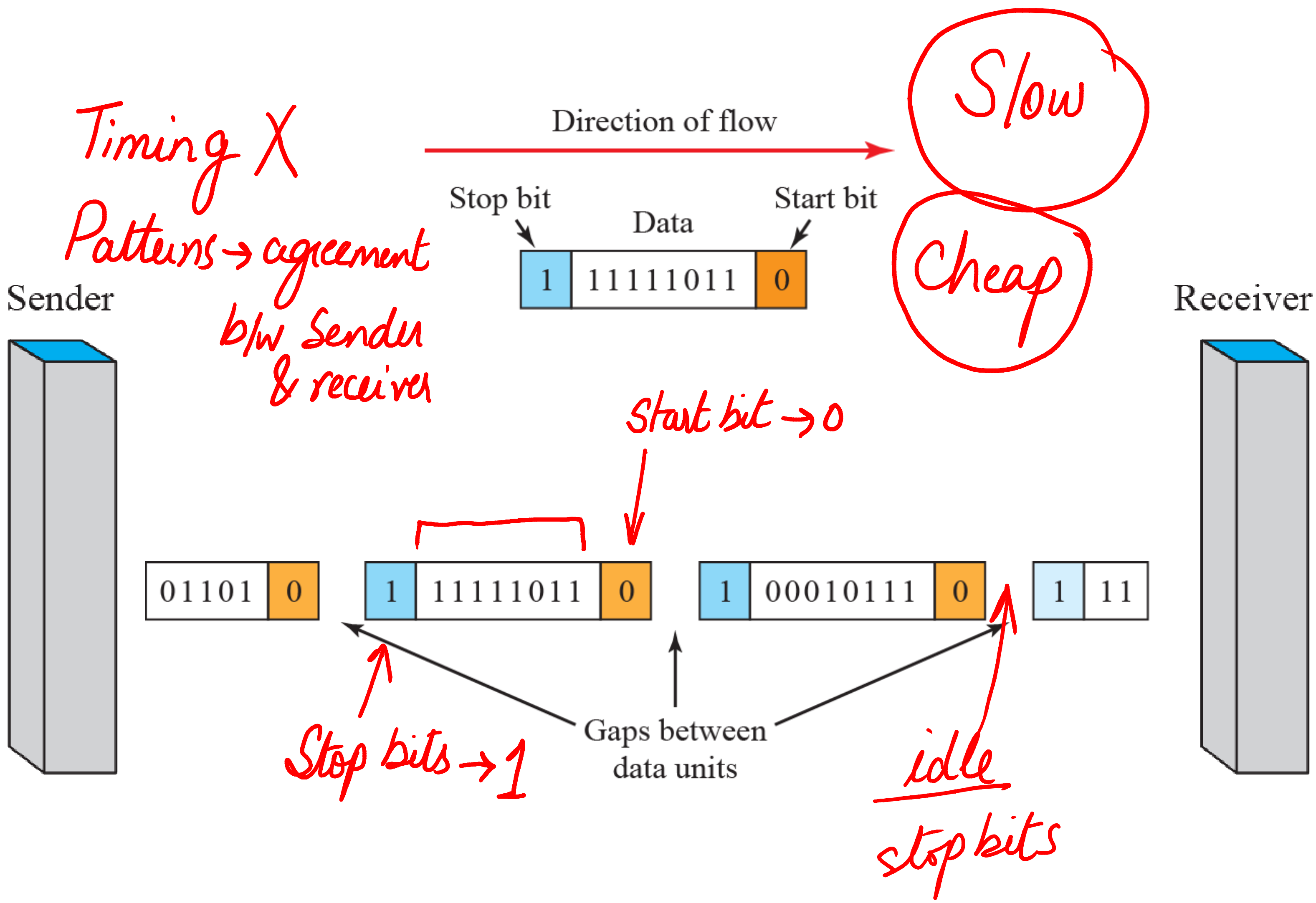
Disadv → Cost (n wires) → Short Distances

- **In serial transmission one bit follows another**
- **Only one communication channel rather than ‘n’ to transmit data**



Adv → Cost (n) ↓

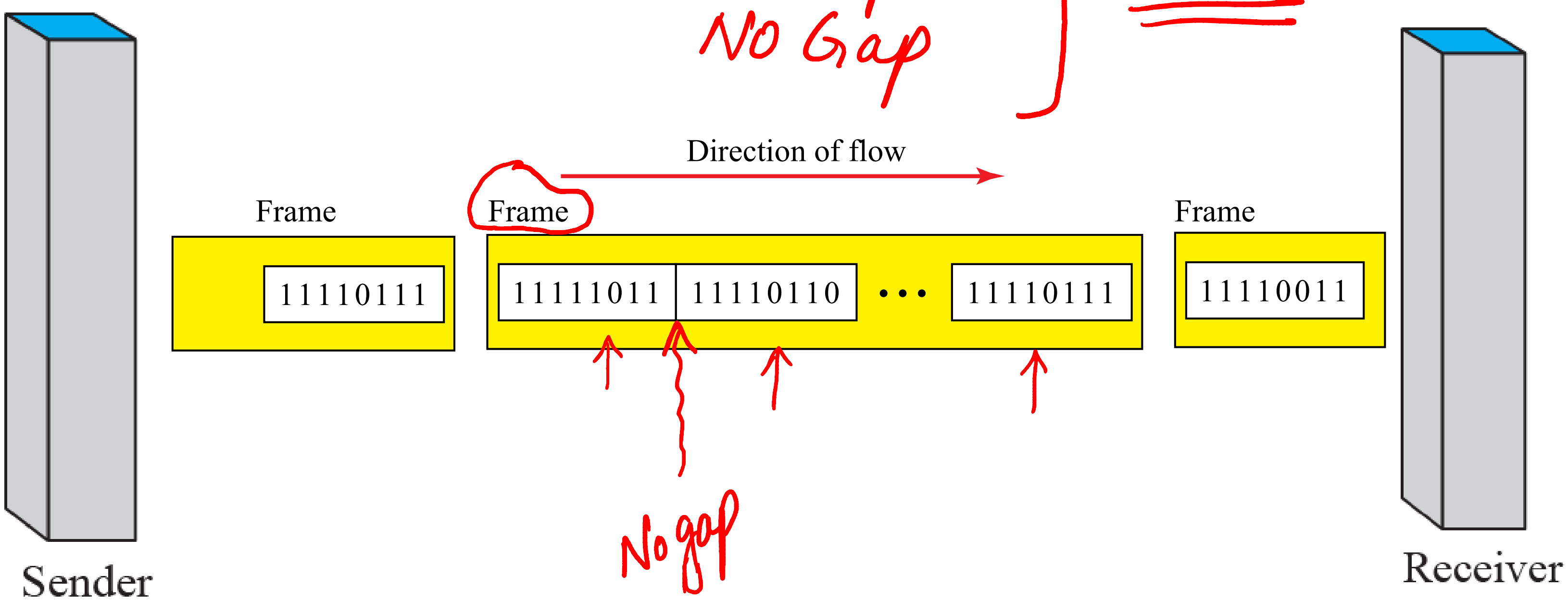
Disadv → Speed ↓


Timing X
Patterns → agreement
b/w Sender
& receiver
Direction of flow
Slow
Cheap
Stop bit
Data
Start bit
1
11111011
0
Sender
Receiver
Start bit → 0
01101
0
1
11111011
0
1
00010111
0
1
11
Stop bits → 1
Gaps between
data units
idle
stop bits

- **In serial transmission one bit follows another**
- **Only one communication channel rather than ‘n’ to transmit data**

No start bits
No stop bits
No Gap

Timing



Adv → Speed

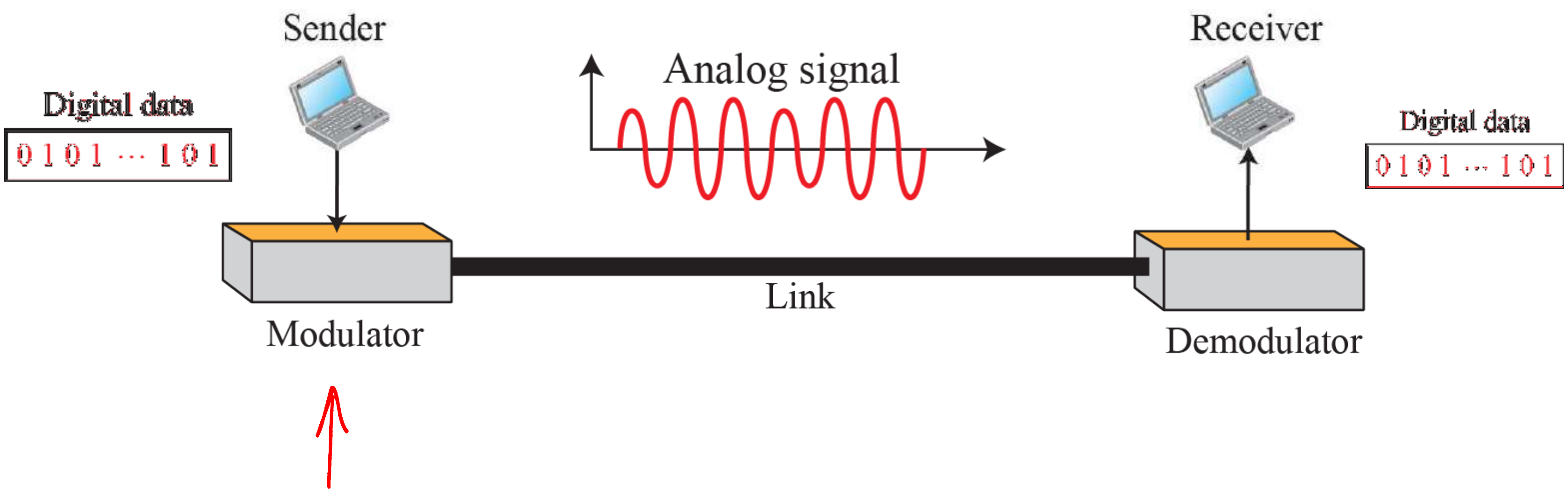
Accurate count of bits

- Real time Audio and Video
- Synchronization between characters is not enough
- Entire stream should be synchronized
- Isochronous guarantees fixed rate data

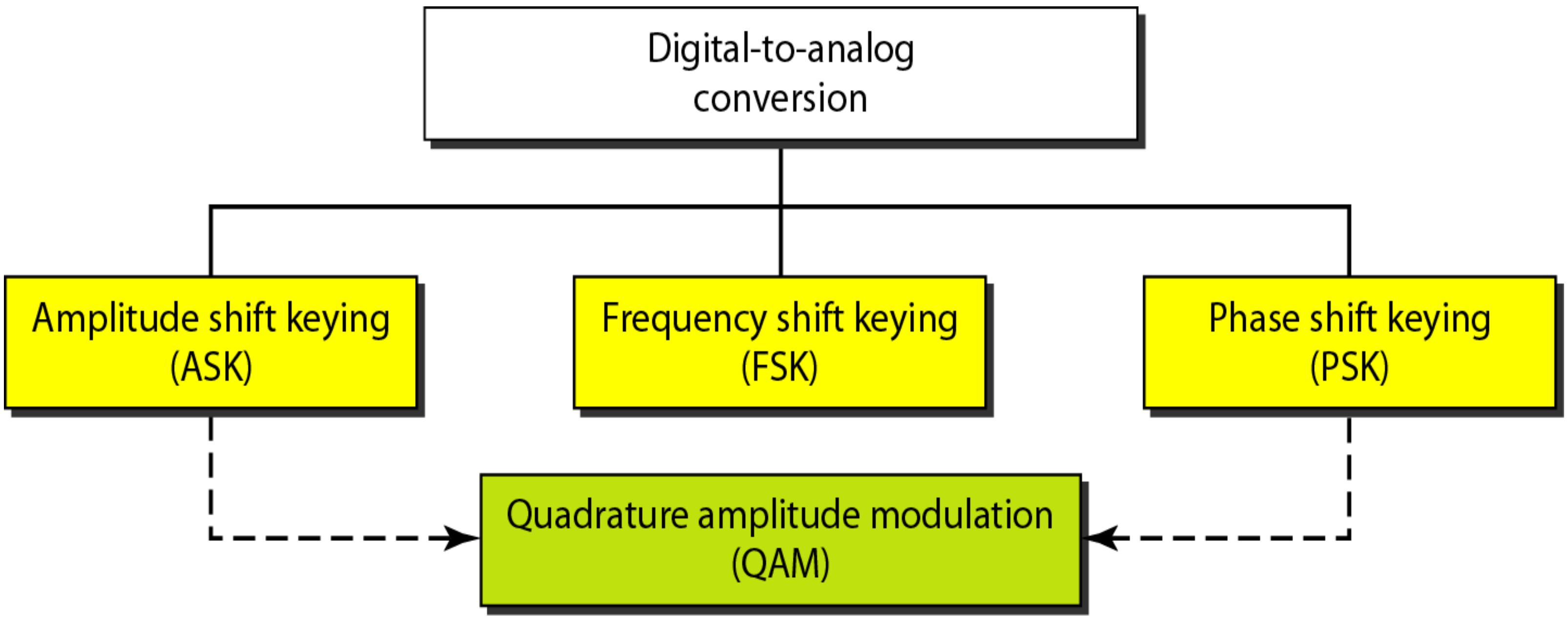
- **Process of changing one of the characteristics of analog signal based on the information in digital data**

- **A sine wave is defined by 3 characteristics:**
  - ✓ **Amplitude**
  - ✓ **Frequency**
  - ✓ **Phase**

- **By changing one of these characteristics, we can use it to represent a digital signal**



Sender
Analog signal
Receiver
Digital data
0 1 0 1 ··· 1 0 1
Digital data
0 1 0 1 ··· 1 0 1
Link
Modulator
Demodulator


Digital-to-analog conversion
Amplitude shift keying (ASK)
Frequency shift keying (FSK)
Phase shift keying (PSK)
Quadrature amplitude modulation (QAM)

- **Before we discuss specific methods of digital-to-analog modulation, two basic issues must be reviewed:**

  - ✓ **Bit and Baud rates and**
  - ✓ **The Carrier Signal**

- In Analog Transmission of Digital Data, Baud Rate is less than or equal to the Bit Rate
  - ✓ Data Element vs. Signal Element ✓
  - ✓ Data Rate vs. Signal Rate
- Bandwidth Required ∝ Signal Rate (except FSK)
- Carrier Signal / Modulation (Shift Keying)

Data Element → bit

Signal Element → smallest unit of signal (constant)

$$S = \frac{N}{r} \Rightarrow r = \log_2 L$$

Carrier Signal

Sender → high freq. signal

↳ base of information signal

- **Before we discuss specific methods of digital-to-analog modulation, two basic issues must be reviewed:**

  - ✓ **Bit and Baud rates and**
  - ✓ **The Carrier Signal**

An analog signal carries 4 bits per signal element. If 1000 signal elements are sent per second, find the bit rate?

$r = 4 \quad S = 1000$

$N = ?$

$$S = \frac{N}{r} \Rightarrow N = S \times r$$

$$N = 1000 \times 4$$

$$= 4000 \text{bps}$$

An analog signal has a bit rate of 8000 bps and a baud rate of 1000 baud. How many data elements are carried by each signal element? How many signal elements do we need?

$N = 8000 \text{ bps}$

$S = 1000 \text{ baud}$

$L = ?$

$r = ?$

$$S = \frac{N}{r} \Rightarrow r = \frac{N \text{ (bits)}}{S \text{ (bauds)}}$$

$\longrightarrow r = 8 \text{ bits/baud}$

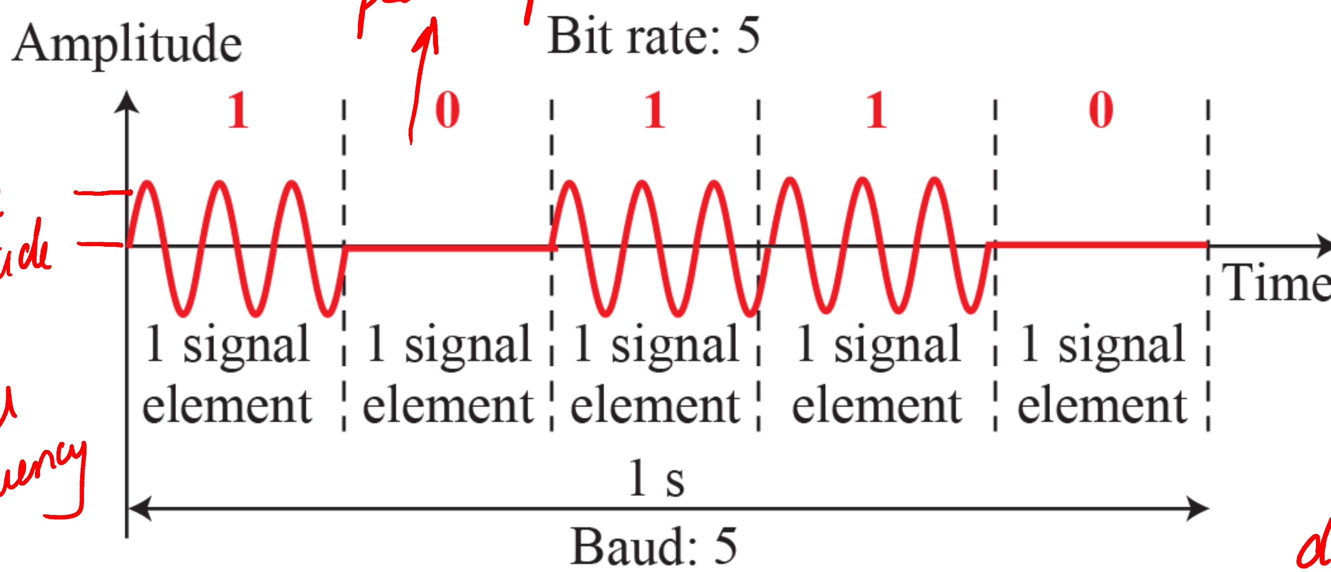
$r = \log_2 L$

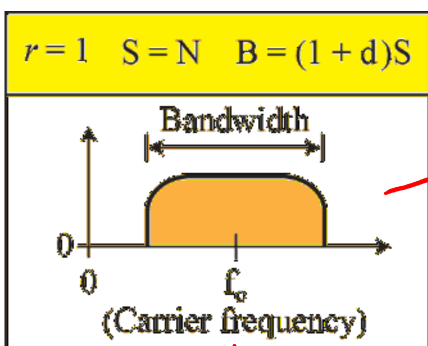
$\longrightarrow L = 2^r = 2^8 = 256$

- The amplitude of the carrier signal is varied to create signal elements
- Both frequency and phase remain constant while the amplitude changes
- Binary ASK or On-Off Keying (OOK)

peak amplitude is zero

Same amplitude as carrier frequency





non periodic composite signal

BW $\propto$ Signal Rate

$d = 0 \rightarrow$ min

$d = 1 \rightarrow$ max

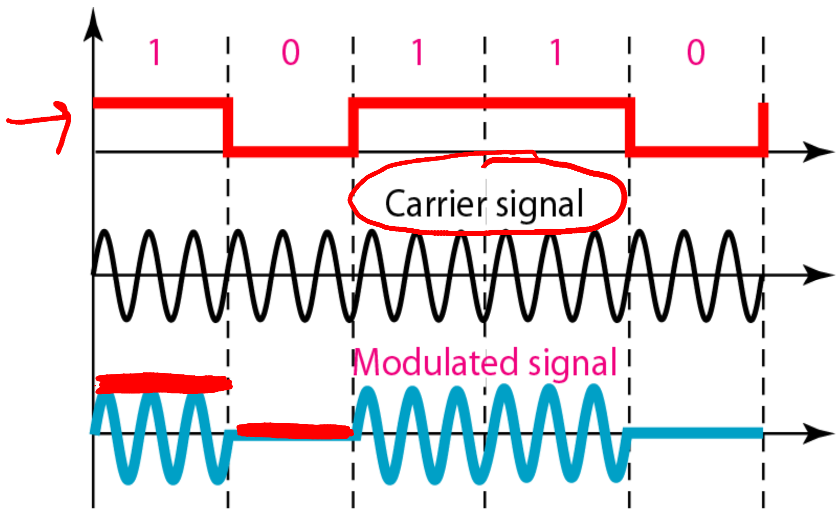
$$B = (1 + d)S$$

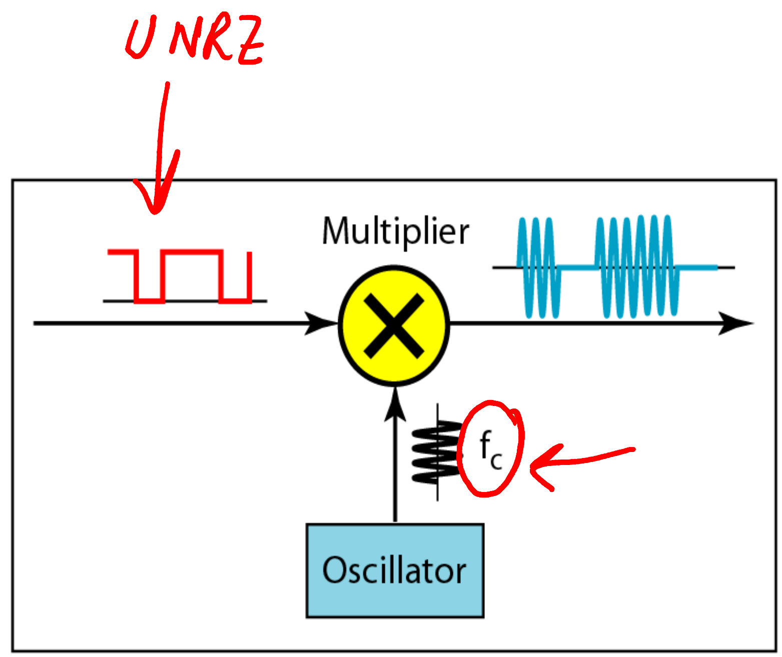
$d \rightarrow$ modulation & filtering process

$(0 \rightarrow 1)$

- **The amplitude of the carrier signal is varied to create signal elements**
- **Both frequency and phase remain constant while the amplitude changes**
- **Binary ASK or On-Off Keying (OOK)**

Unipolar NRZ → HV = 1
LV = 0





1 ⟶ maintaining amplitude of carrier
0 ⟶ zero amplitude

We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What are the carrier frequency and the bit rate if we modulated our data by using ASK with d = 1?

$r = 1$

$f_c = 250\,kHz$

$B = (1+d)S$

$B = (1+1)S$

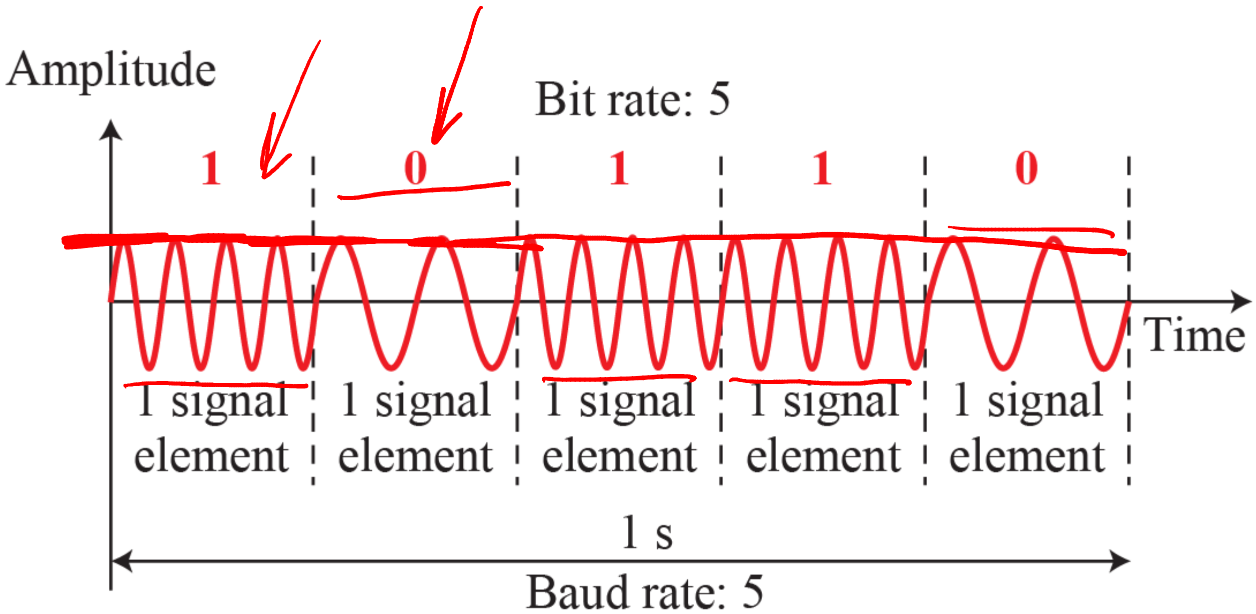
$B = 2S$

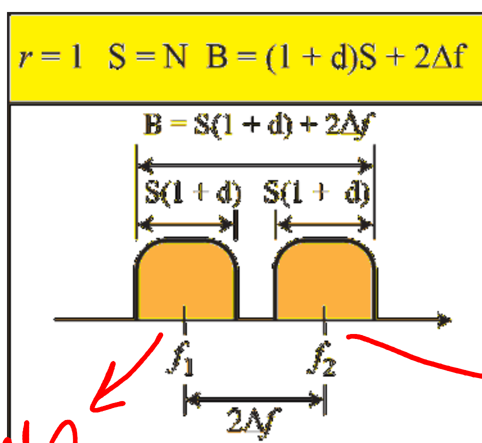
$B = 2\left(\frac{N}{r}\right)$

$B = 2N \quad (r = 1)$

$N = \frac{B}{2} = \frac{100\,kHz}{2} = 50\,kbps$

- **The frequency of the carrier signal is varied to represent data**
- **The frequency of the modulated signal is constant for the duration of one signal element, but changes for the next signal element if the data element changes**
- **Both peak amplitude and phase remain constant**





zero

one

$$f_2 - f_1 = 2\Delta f$$

$$B = (1+d)S + 2\Delta f$$

$$\boxed{B \propto S}$$

- **The frequency of the carrier signal is varied to represent data**

- **Both peak amplitude and phase remain constant**

We have an available bandwidth of 100 kHz which spans from 200 to 300 kHz. What should be the carrier frequency and the bit rate if we modulated our data by using FSK with d = 1?

$$B = (1+d) \times S + 2\Delta f$$

$$\Delta f = 50 kHz$$

$$\underline{\underline{B}} = 2S + 50$$

$$2S + 50 = 100$$

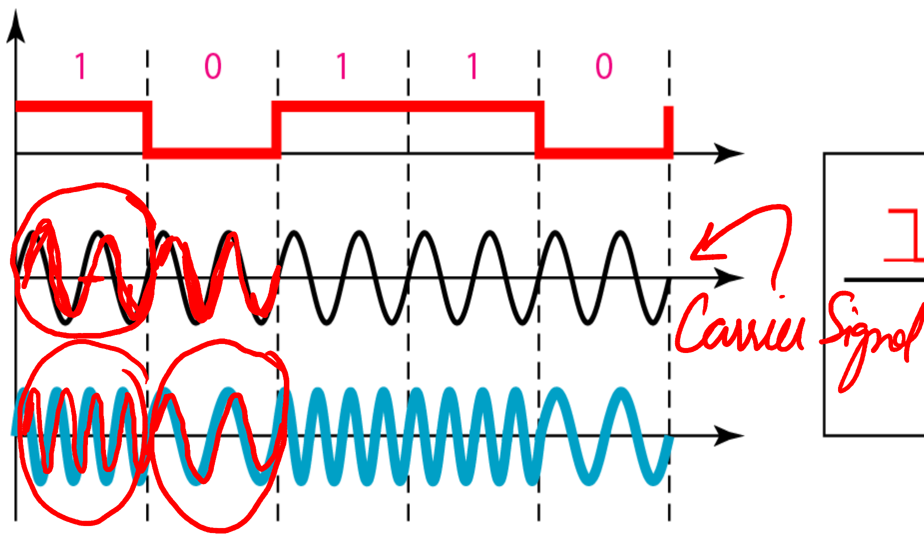
$$2S = 50 kHz$$

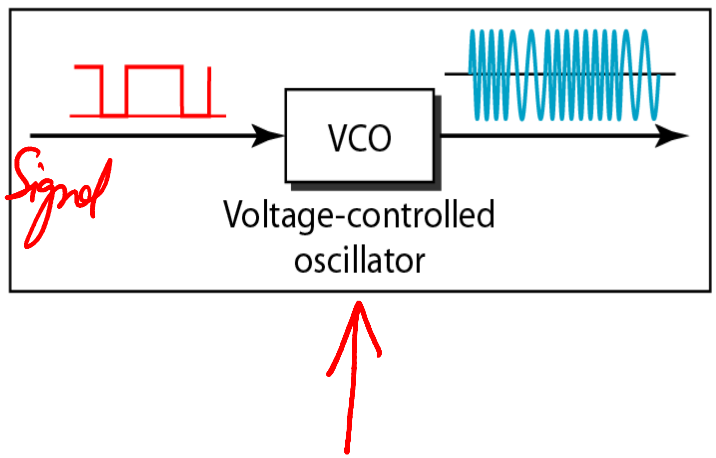
$$S = 25 \text{ kbaud}$$

$$N = S$$

$$\underline{N = 25 \text{ kbps}}$$

Unipolar NRZ



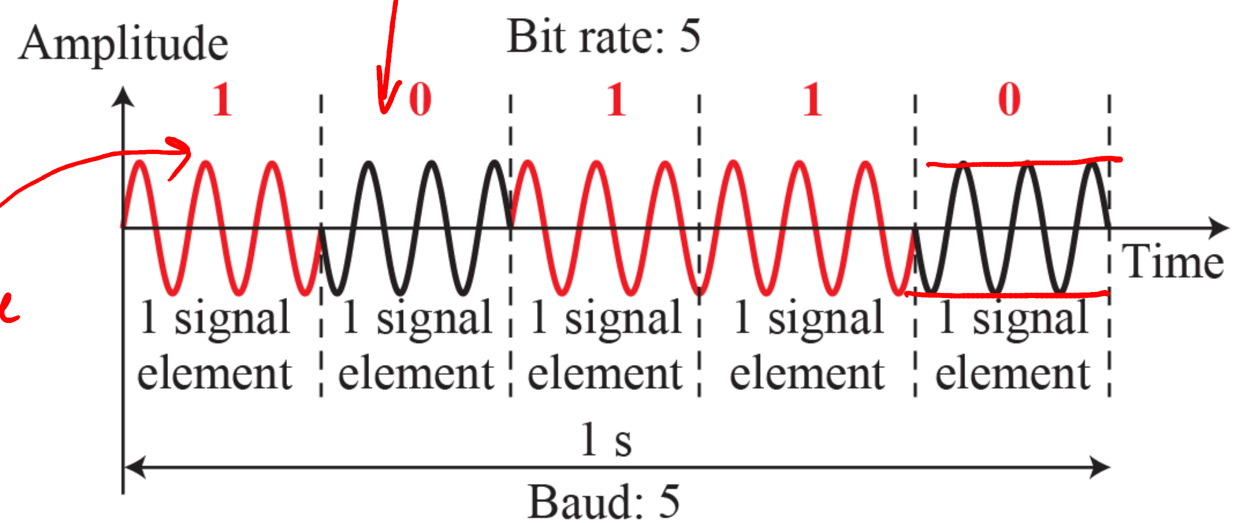


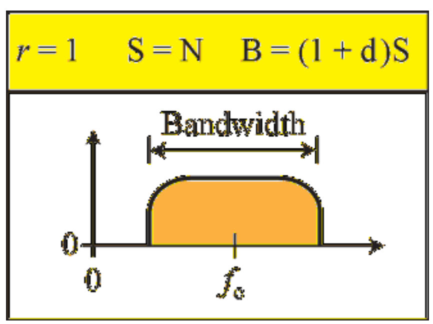
- **The phase of the carrier is varied to represent two or more different signal elements**

- **Both peak amplitude and frequency remain constant**

- **PSK is relatively common than ASK or FSK** phase of 180°

phase of 0°

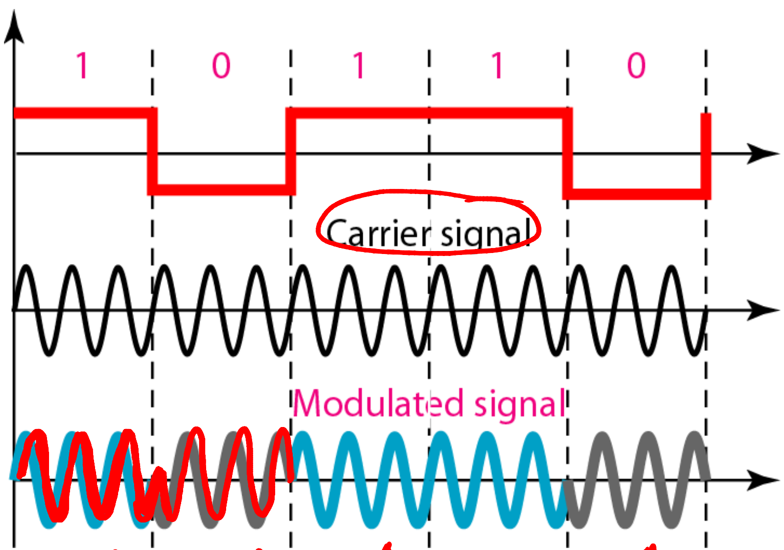




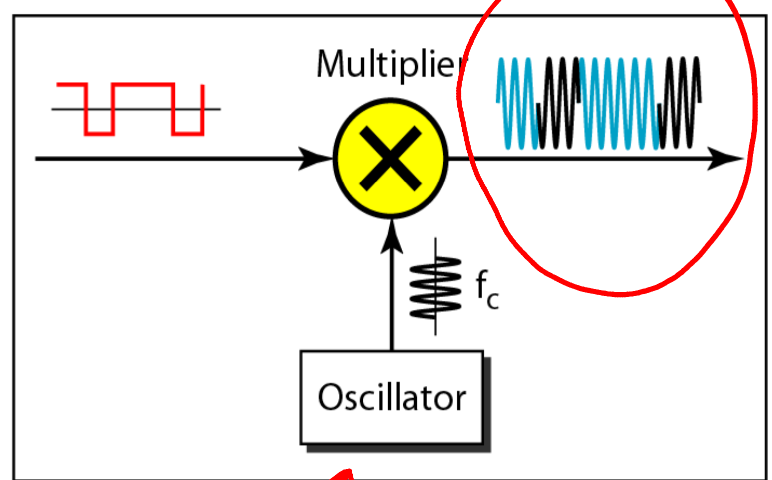
$$B = (1+d)S$$

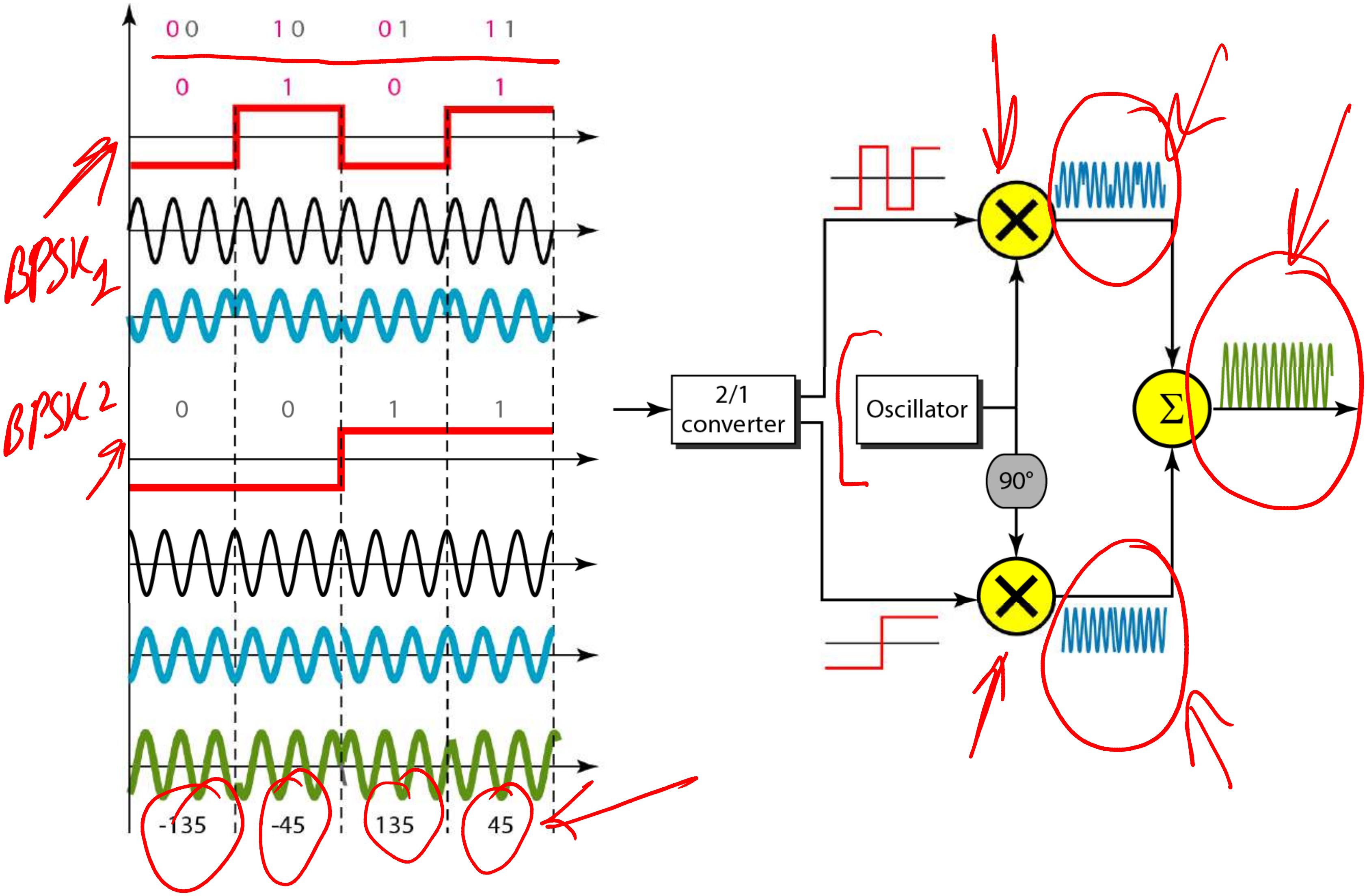
$$B_{PSK} = B_{ASK}$$

Polar NRZ



0° 180° 0° 0° 180°





0 0
1 0
0 1
1 1
0
1
0
1
BPSK 1
BPSK 2
0
0
1
1
-135
-45
135
45
2/1 converter
Oscillator
90°
Σ

Find the bandwidth for a signal transmitting at 12 Mbps for QPSK. The value of d = 0.

$$r = 2$$

$$S = \frac{N}{r}$$

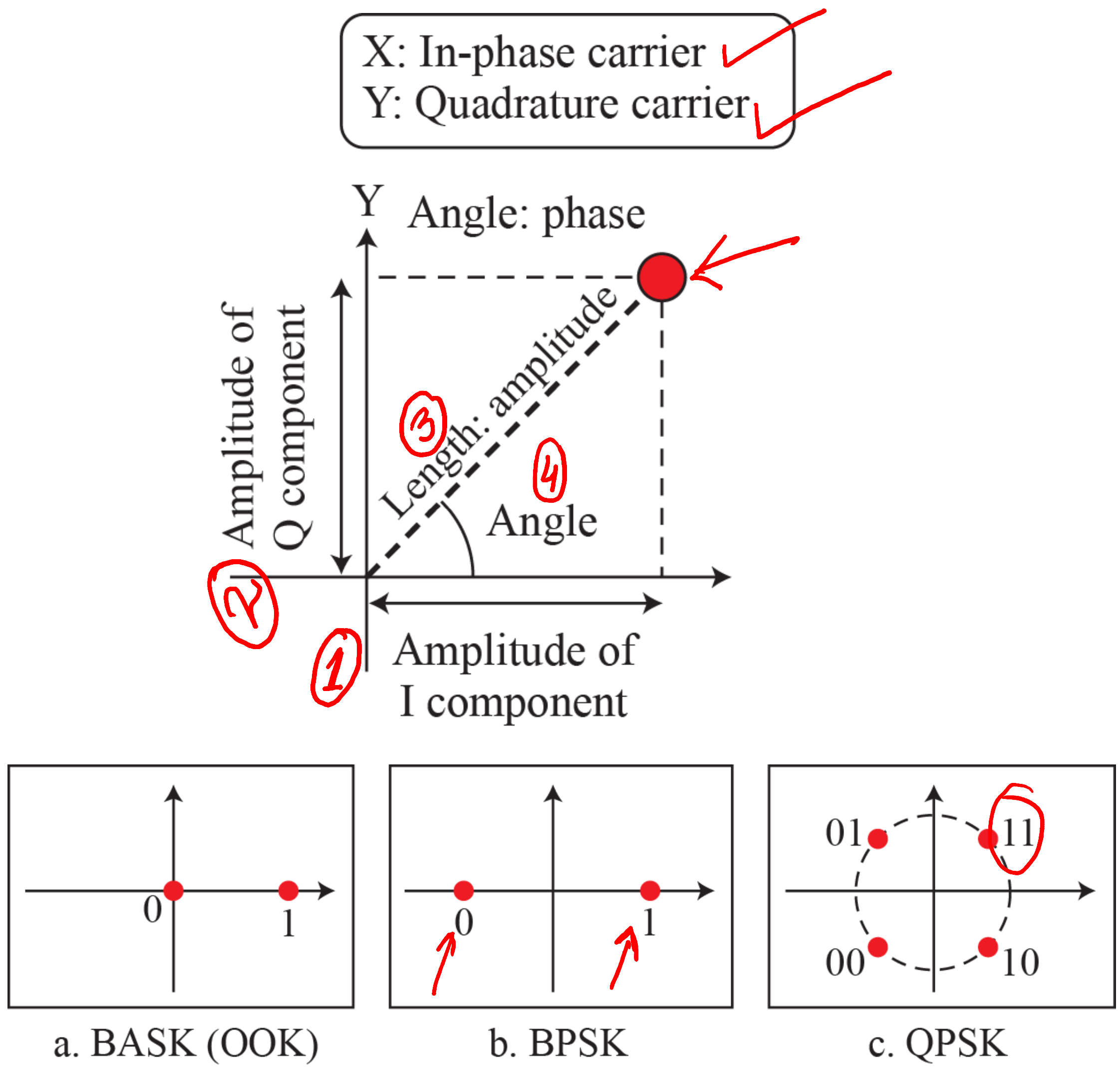
$$= \frac{12\,\text{Mbps}}{2}$$

$$= 6\,\text{Mbaud}.$$

$$d = 0 \longrightarrow B = S = \underline{\underline{6\,\text{MHz}}}$$

- **Helps us define the phase and amplitude of a signal element when we are using two carriers (one in phase and other in quadrature)**

- **Signal element is represented as a dot**

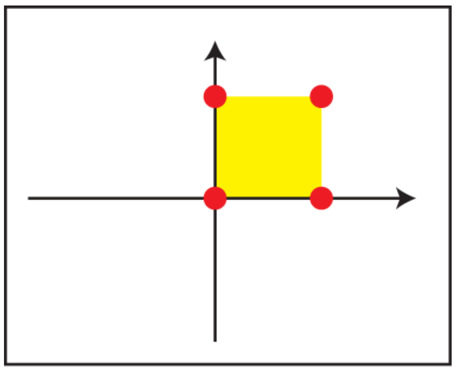


X: In-phase carrier
Y: Quadrature carrier
Y
Angle: phase
Amplitude of Q component
Length: amplitude
Angle
Amplitude of I component
1
2
3
4
0
1
0
1
01
11
00
10
a. BASK (OOK)
b. BPSK
c. QPSK

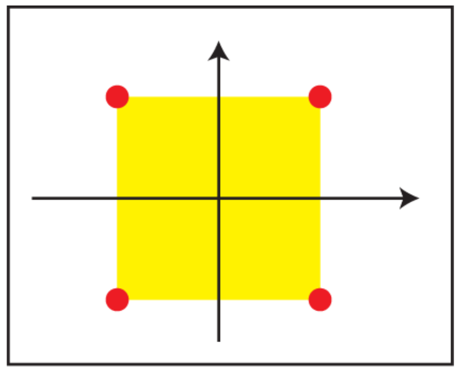
- **PSK is limited by the ability of the equipment to distinguish small differences in phase which limits its potential bit rate**

- **We have been altering only one of the three characteristics of a sine wave at a time; but what if we alter two?**

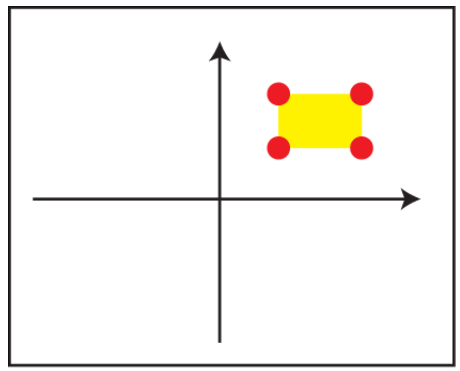
- **Why not combine ASK and PSK?**



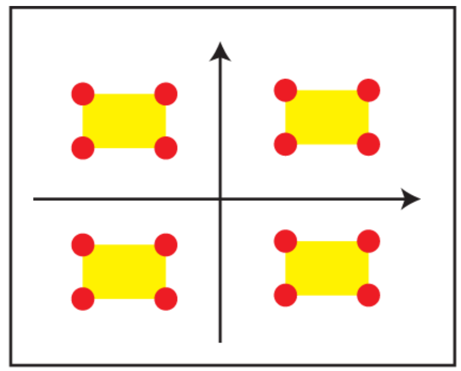
a. 4-QAM



b. 4-QAM

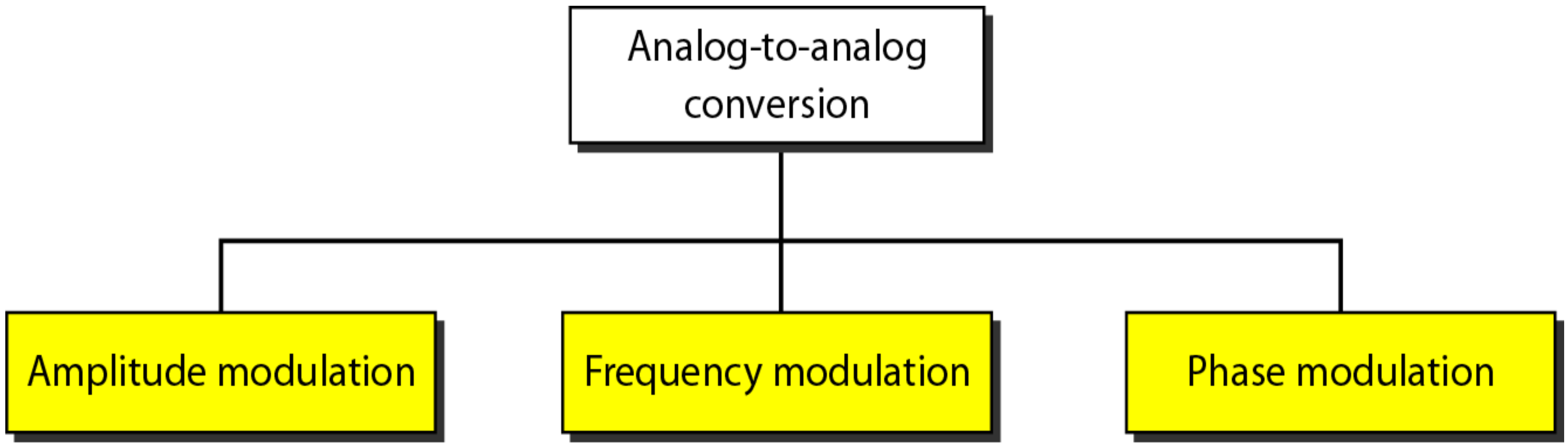


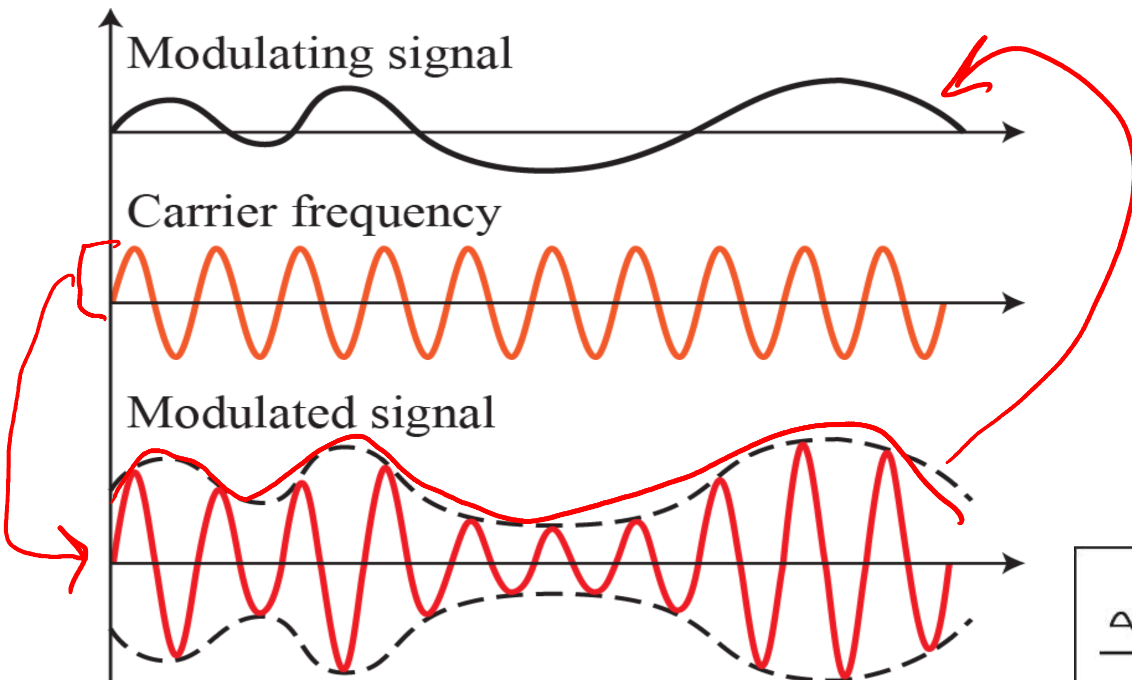
c. 4-QAM

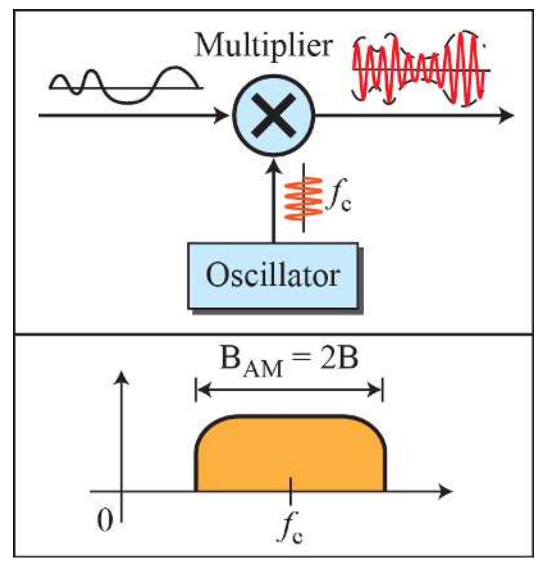


d. 16-QAM

- **Representation of Analog information by an Analog signal**
- **Amplitude Modulation (AM)**
- **Frequency Modulation (FM)**
- **Phase Modulation (PM)**

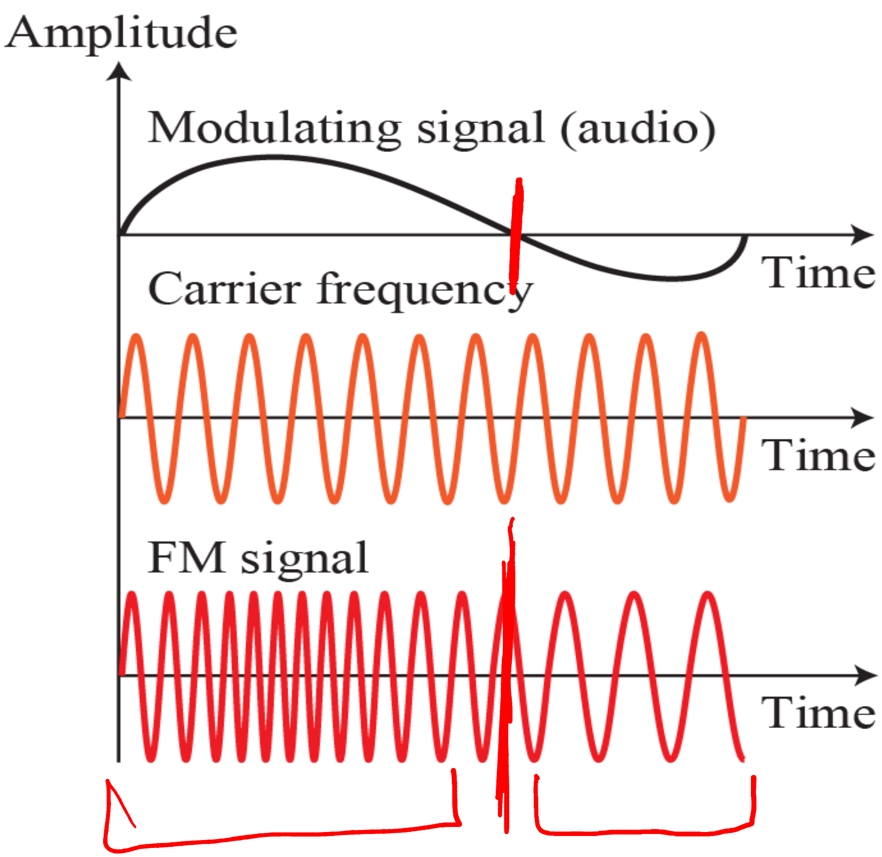

Analog-to-analog conversion
Amplitude modulation
Frequency modulation
Phase modulation


Modulating signal
Carrier frequency
Modulated signal


Multiplier
f_c
Oscillator
$B_{AM} = 2B$
0
f_c

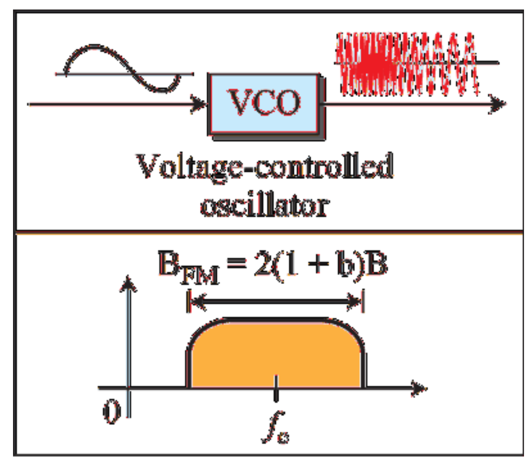
$B_{AM} = 2B$

f_c

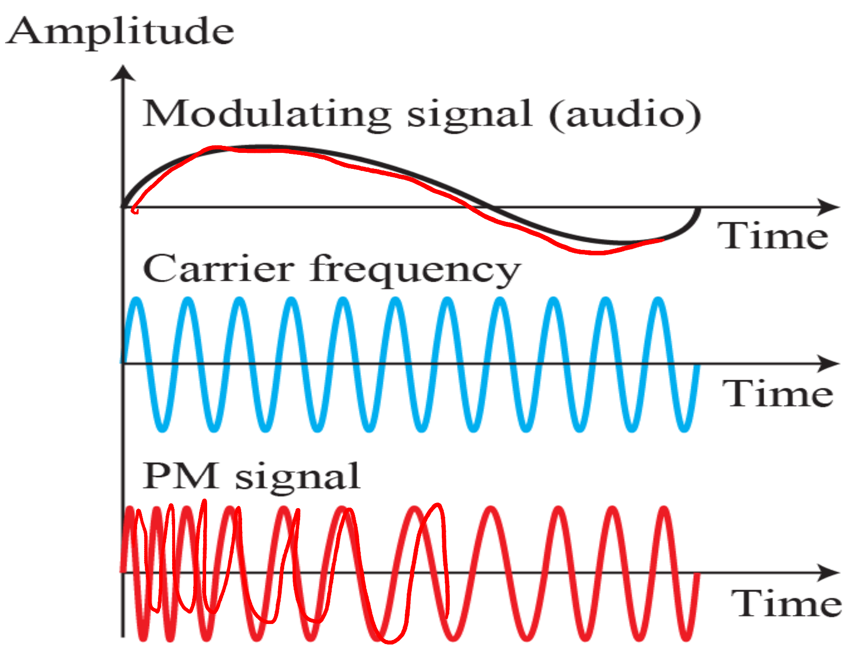


$$B_{FM} = 2(1+\beta)B$$

↳ Beta = 4



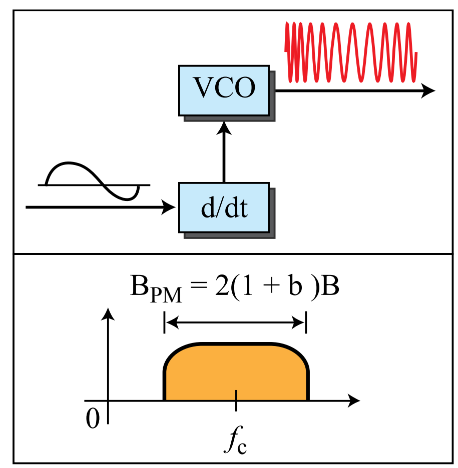
- **Representation of Analog information by an Analog signal**
- **Amplitude Modulation (AM)**
- **Frequency Modulation (FM)**
- **Phase Modulation (PM)**



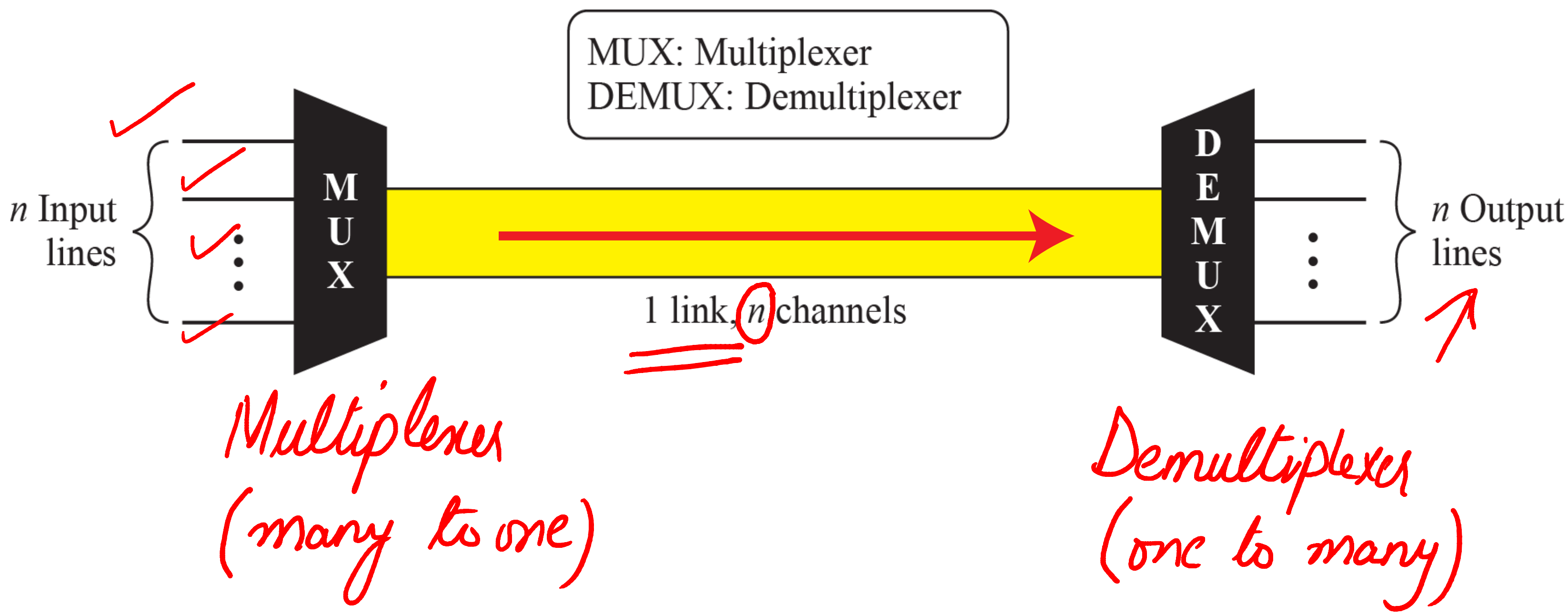
$$B_{PM} = 2(1+\beta)B$$

$\beta = 1$ narrowband

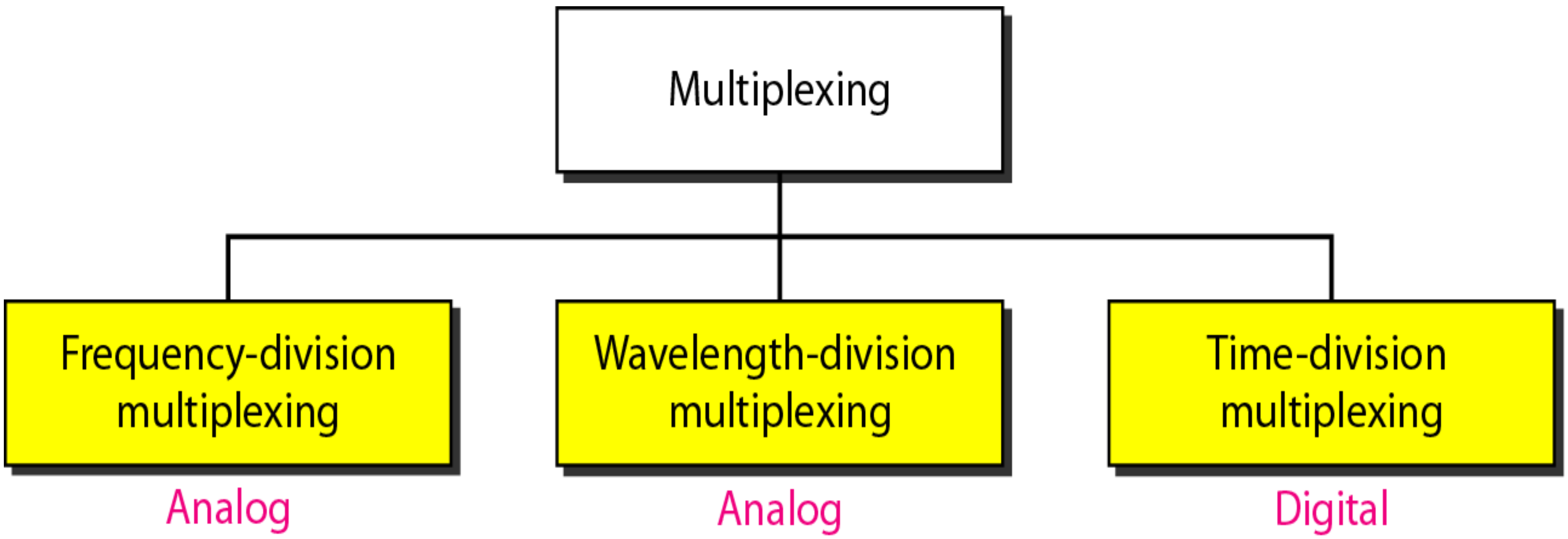
$\beta = 3$ wideband



- **Simultaneous transmission of multiple signals across a single data link**
- **As data & telecomm use increases, so does traffic**
  - ✓ **Add individual links each time a new channel is needed**
  - ✓ **Install higher-bandwidth links and use each to carry multiple signals**


MUX: Multiplexer
DEMUX: Demultiplexer
n Input lines
MUX
1 link, n channels
DEMUX
n Output lines
Multiplexer
(many to one)
Demultiplexer
(one to many)

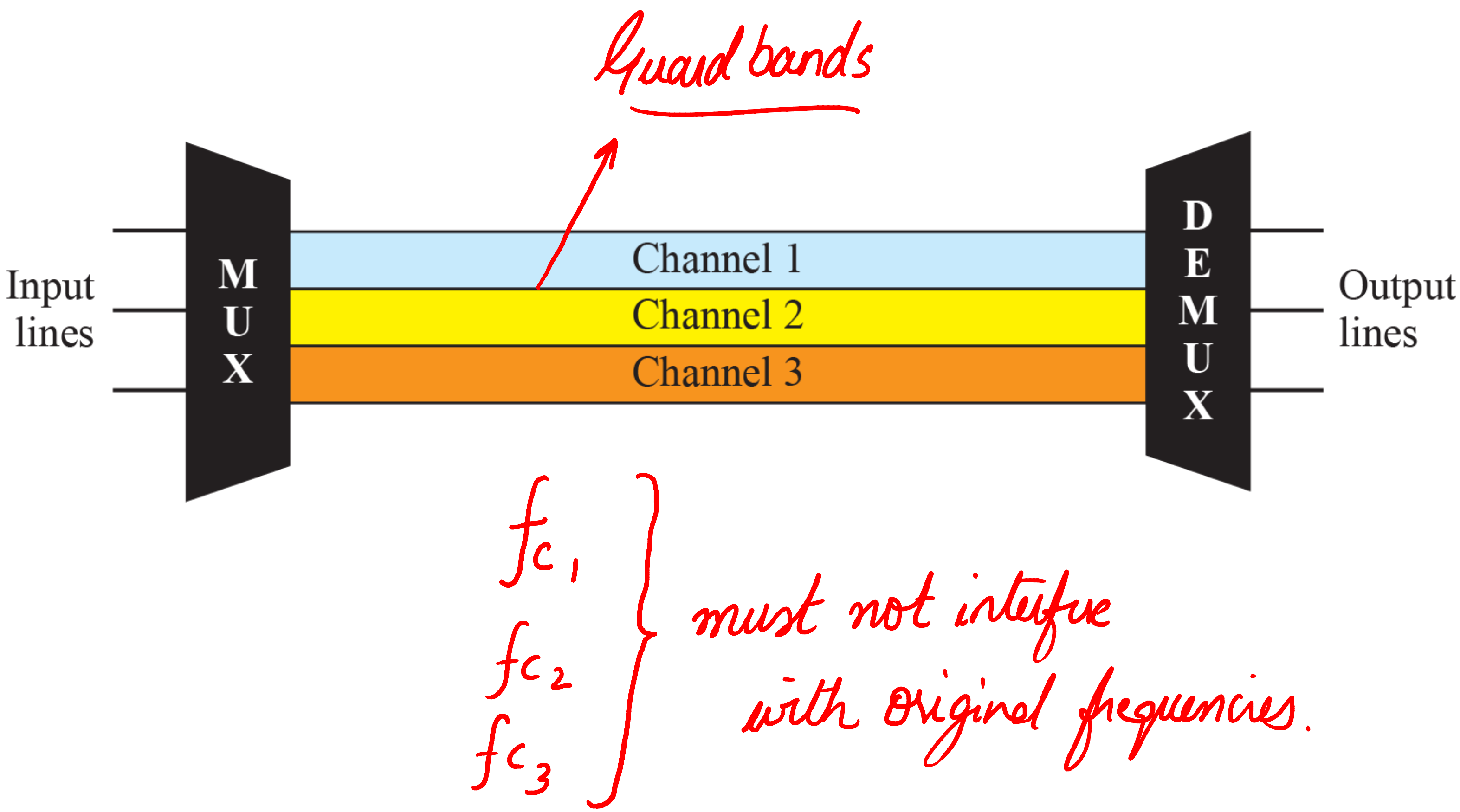
- **Simultaneous transmission of multiple signals across a single data link**


Multiplexing
Frequency-division multiplexing
Wavelength-division multiplexing
Time-division multiplexing
Analog
Analog
Digital

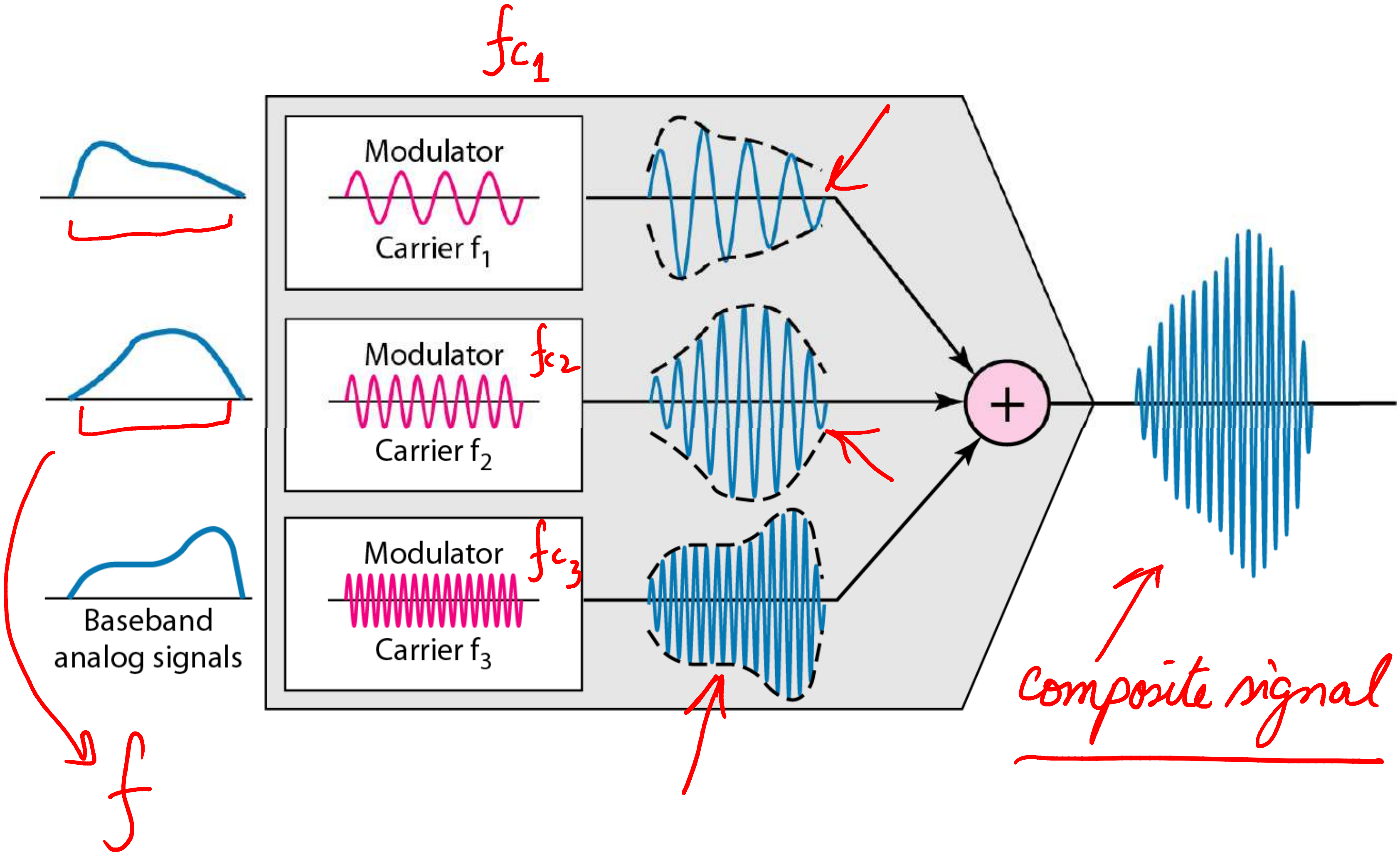
- **An analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted**

- **Signals generated by each sending device modulate different carrier frequencies**

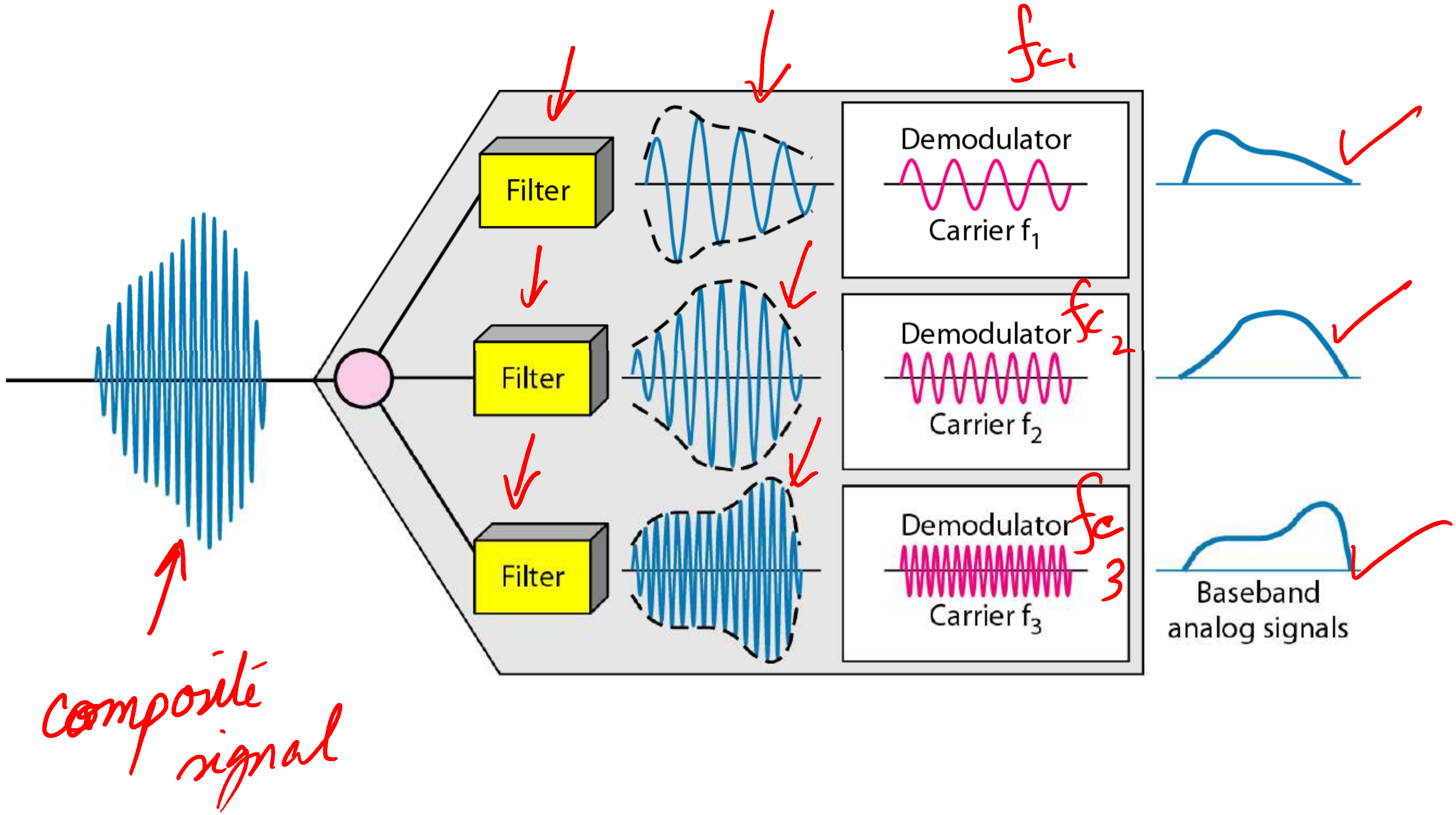
These modulated signals are then combined into a single composite signal that can be transported by the link


Guard bands
Input lines
MUX
Channel 1
Channel 2
Channel 3
DEMUX
Output lines
fc1
fc2
fc3
must not interfere with original frequencies.

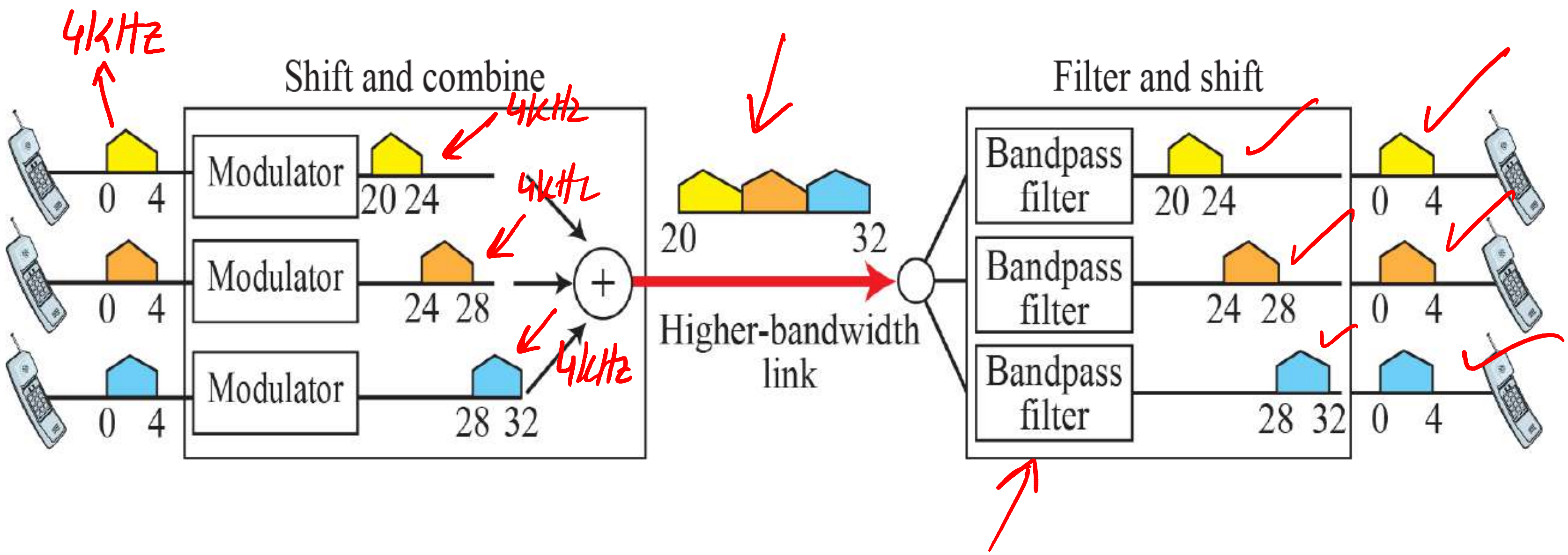
- **An analog technique that can be applied when the bandwidth of a link (in hertz) is greater than the combined bandwidths of the signals to be transmitted**



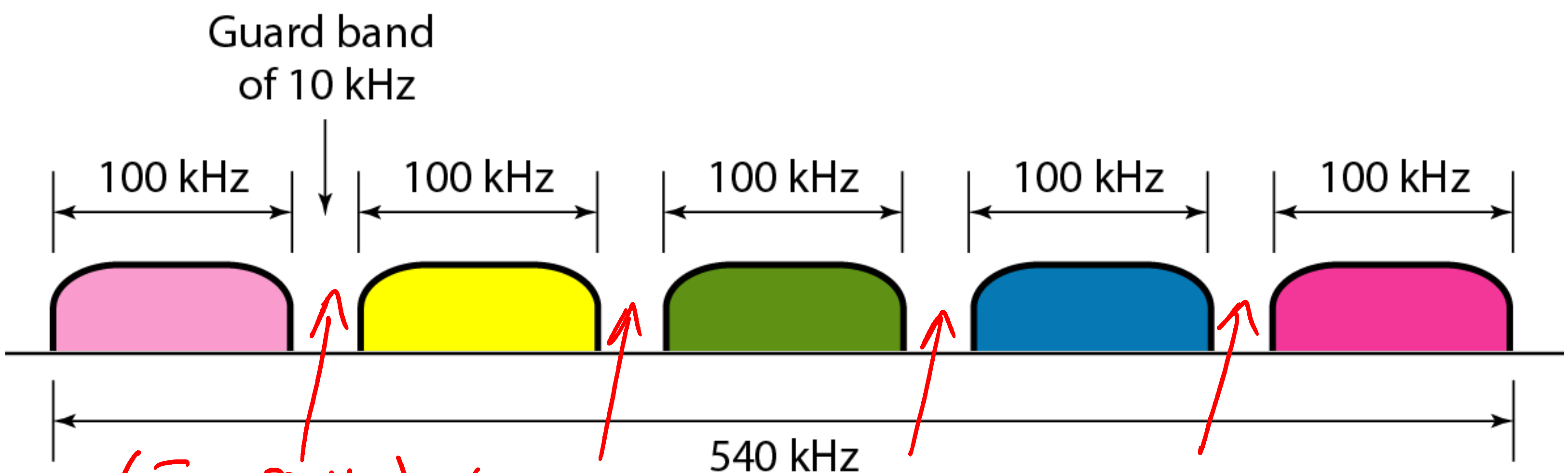
f_{c_1}
Modulator
Carrier f_1
Modulator
f_{c_2}
Carrier f_2
Modulator
f_{c_3}
Carrier f_3
Baseband analog signals
f
composite signal


Filter
Filter
Filter
Demodulator
Carrier f1
Demodulator
Carrier f2
Demodulator
Carrier f3
Baseband
analog signals
composite
signal
fc1
fc2
fc3

Assume that a voice channel occupies a bandwidth of 4 kHz. We need to combine three voice channels into a link with a bandwidth of 12 kHz, from 20 to 32 kHz. Show the configuration, using the frequency domain. Assume there are no guard bands.



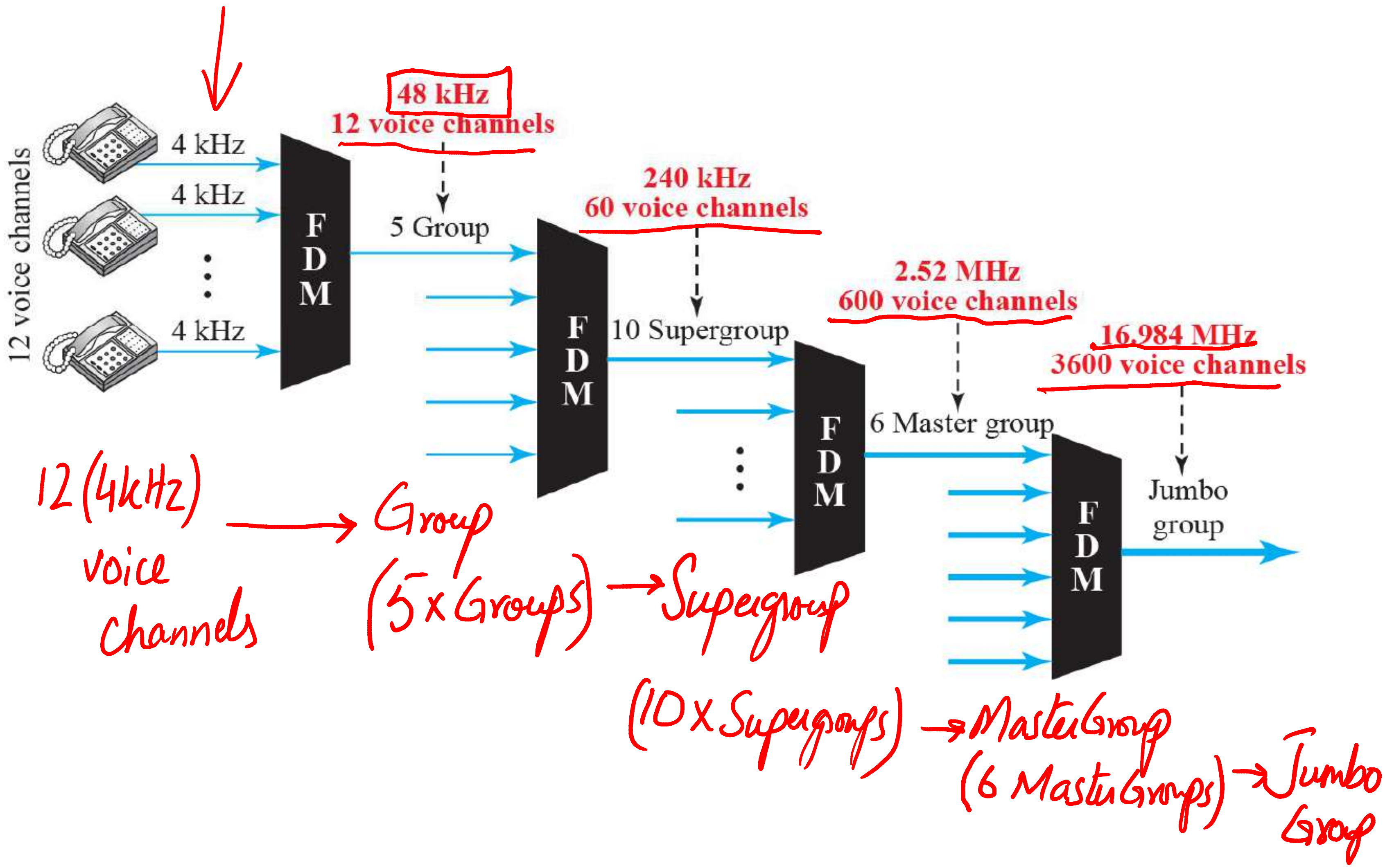
Five channels, each with a 100-kHz bandwidth, are to be multiplexed together. What is the minimum bandwidth of the link if there is a need for a guard band of 10 kHz between the channels to prevent interference?



$(5 \times 100\ Hz) + (4 \times 10\ kHz)$ = **540 KHZ**

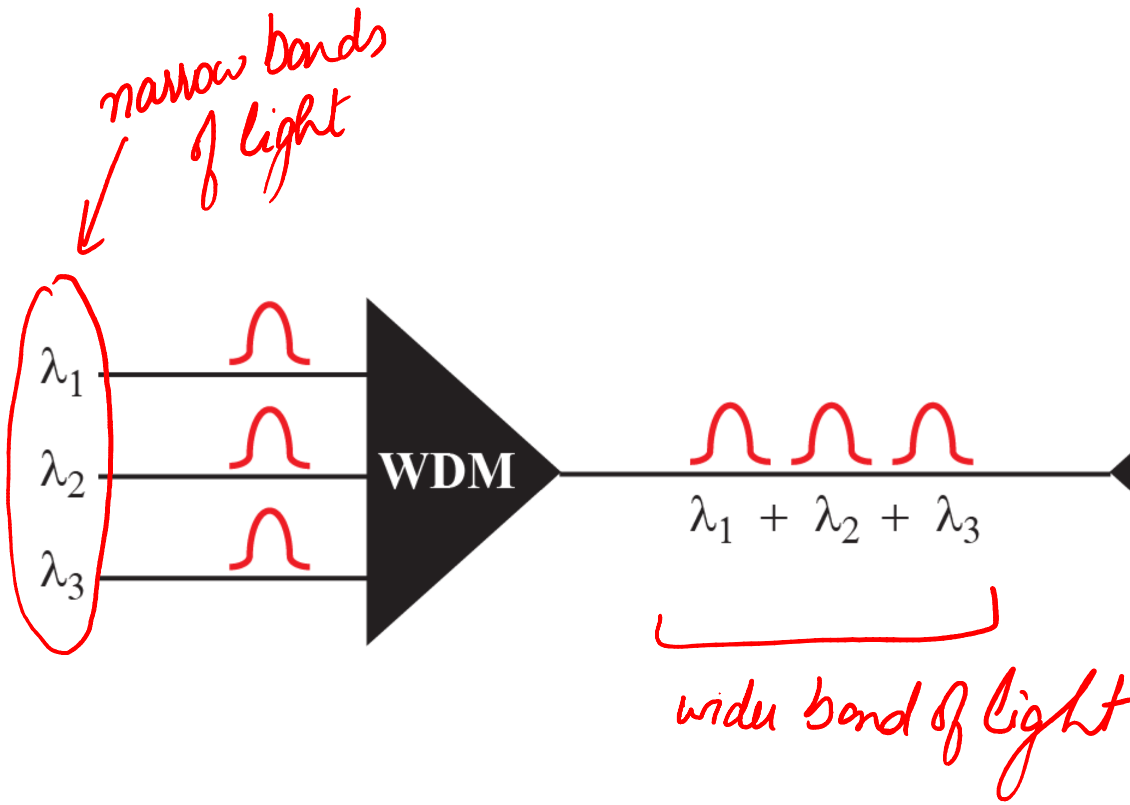
- **Telephone companies multiplex signals from lower-bandwidth lines on to higher-bandwidth lines**

- **For Analog, FDM is used**



12 voice channels
4 kHz
4 kHz
4 kHz
FDM
48 kHz
12 voice channels
5 Group
FDM
240 kHz
60 voice channels
10 Supergroup
FDM
2.52 MHz
600 voice channels
6 Master group
FDM
16.984 MHz
3600 voice channels
Jumbo group
12 (4kHz) voice channels → Group
(5 x Groups) → Supergroup
(10 x Supergroups) → MasterGroup
(6 MasterGroups) → Jumbo Group

- Designed to use the high-data-rate capability of fiber-optic cable
- Fiber data rate is higher than the data rate of metallic transmission cable
- Using a fiber-optic cable for a single line wastes the available bandwidth
- Multiplexing allows us to combine several lines into one

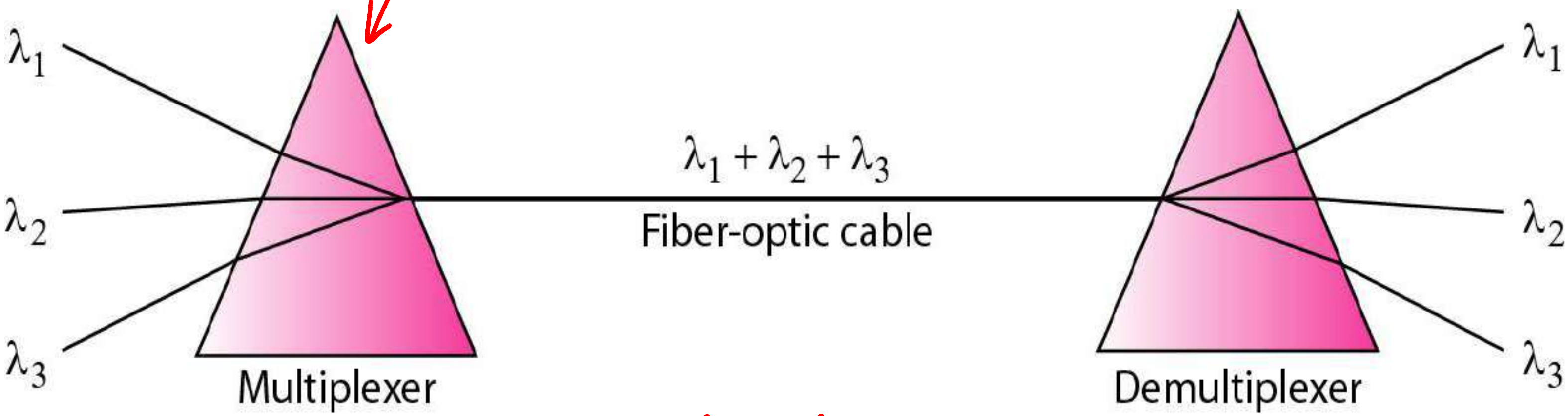


narrow bands of light
λ_1
λ_2
λ_3
WDM
$\lambda_1 + \lambda_2 + \lambda_3$
wide band of light
WDM
λ_1
λ_2
λ_3

SONET

Prism

Prism



DWDM → Efficient then WDM

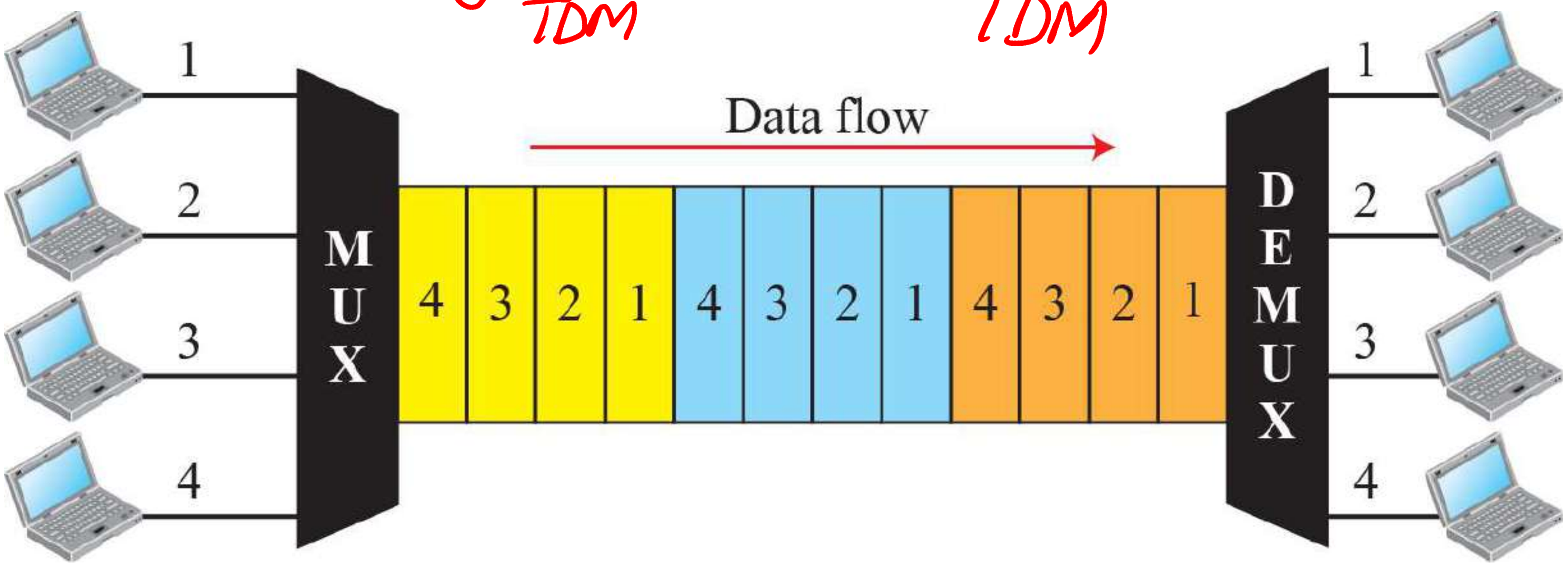
Dense

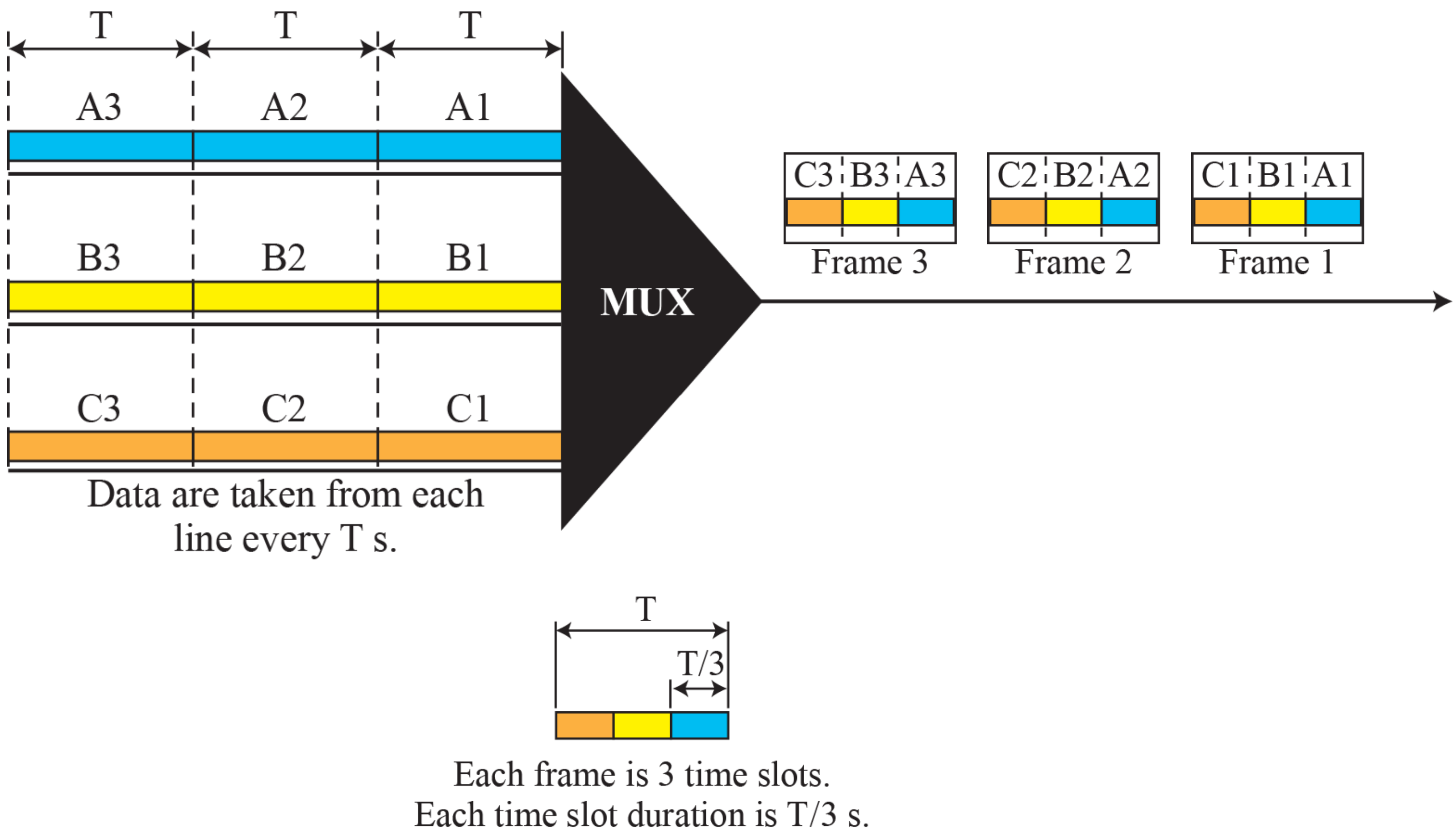
- **Digital process that allows several connections to share the high bandwidth of a link**

- **Time is shared i.e. each connection occupies a portion of time in the link**

Synchronous TDM

Statistical TDM



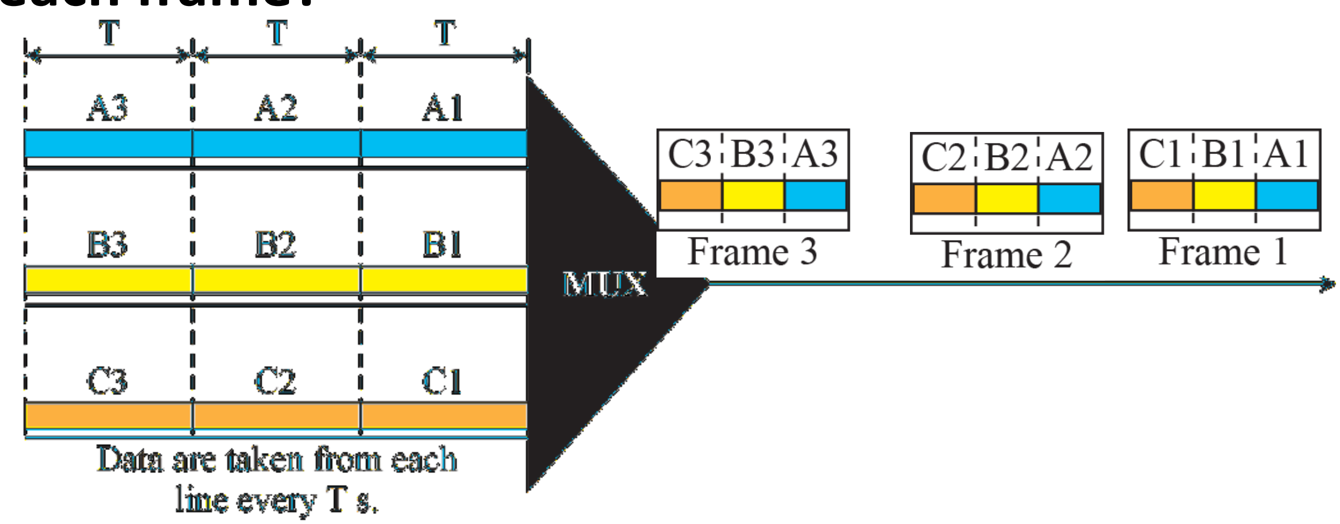

T
T
T
A3
A2
A1
B3
B2
B1
C3
C2
C1
MUX
C3 B3 A3
Frame 3
C2 B2 A2
Frame 2
C1 B1 A1
Frame 1
Data are taken from each line every T s.
T
T/3
Each frame is 3 time slots.
Each time slot duration is T/3 s.

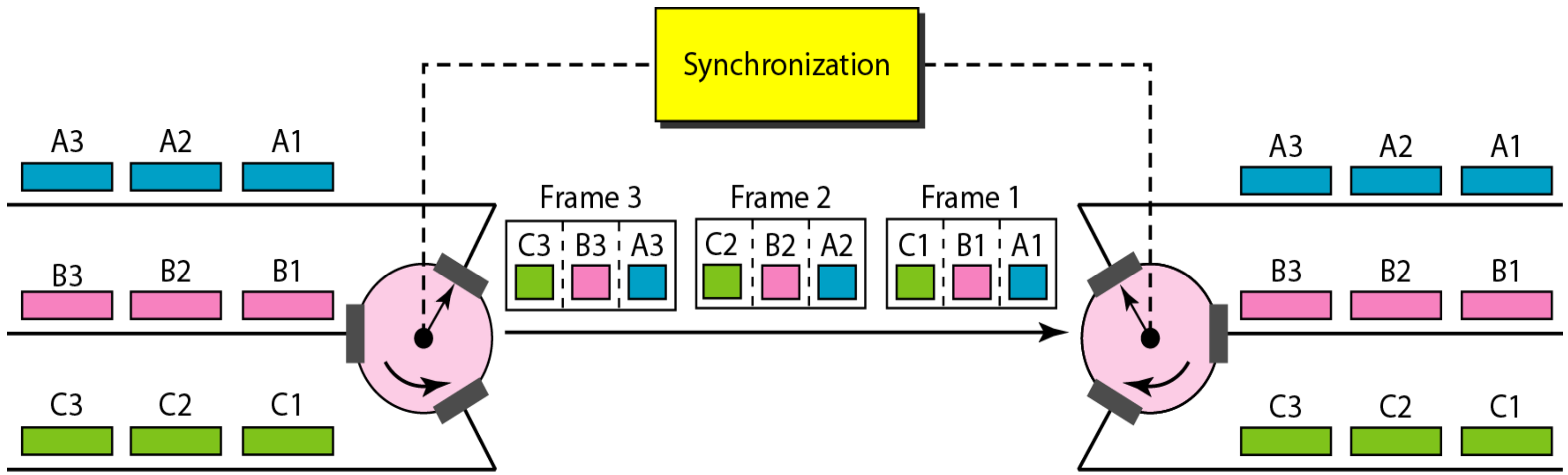
- Digital process that allows several connections to share the high bandwidth of a link

- Time is shared i.e. each connection occupies a portion of time in the link

In Figure the data rate for each input connection is 1 kbps. If 1 bit at a time is multiplexed (a unit is 1 bit), what is the duration of

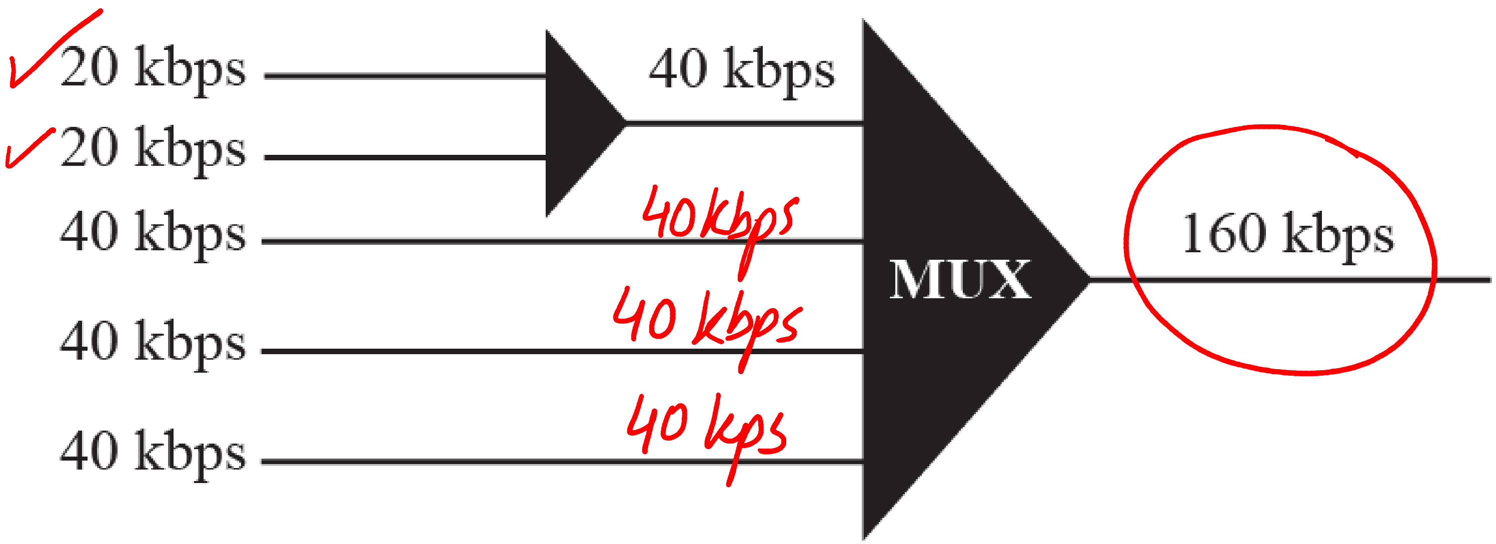
- each input slot,
- each output slot, and
- each frame?



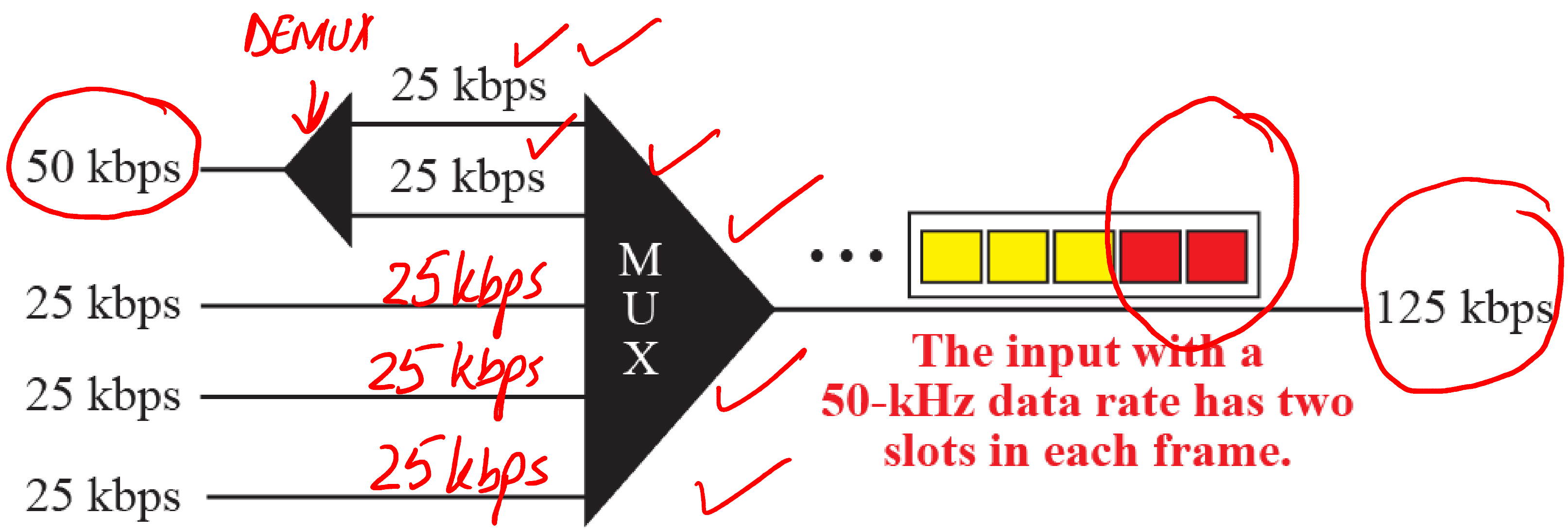

Synchronization
A3
A2
A1
B3
B2
B1
C3
C2
C1
Frame 3
C3
B3
A3
Frame 2
C2
B2
A2
Frame 1
C1
B1
A1
A3
A2
A1
B3
B2
B1
C3
C2
C1

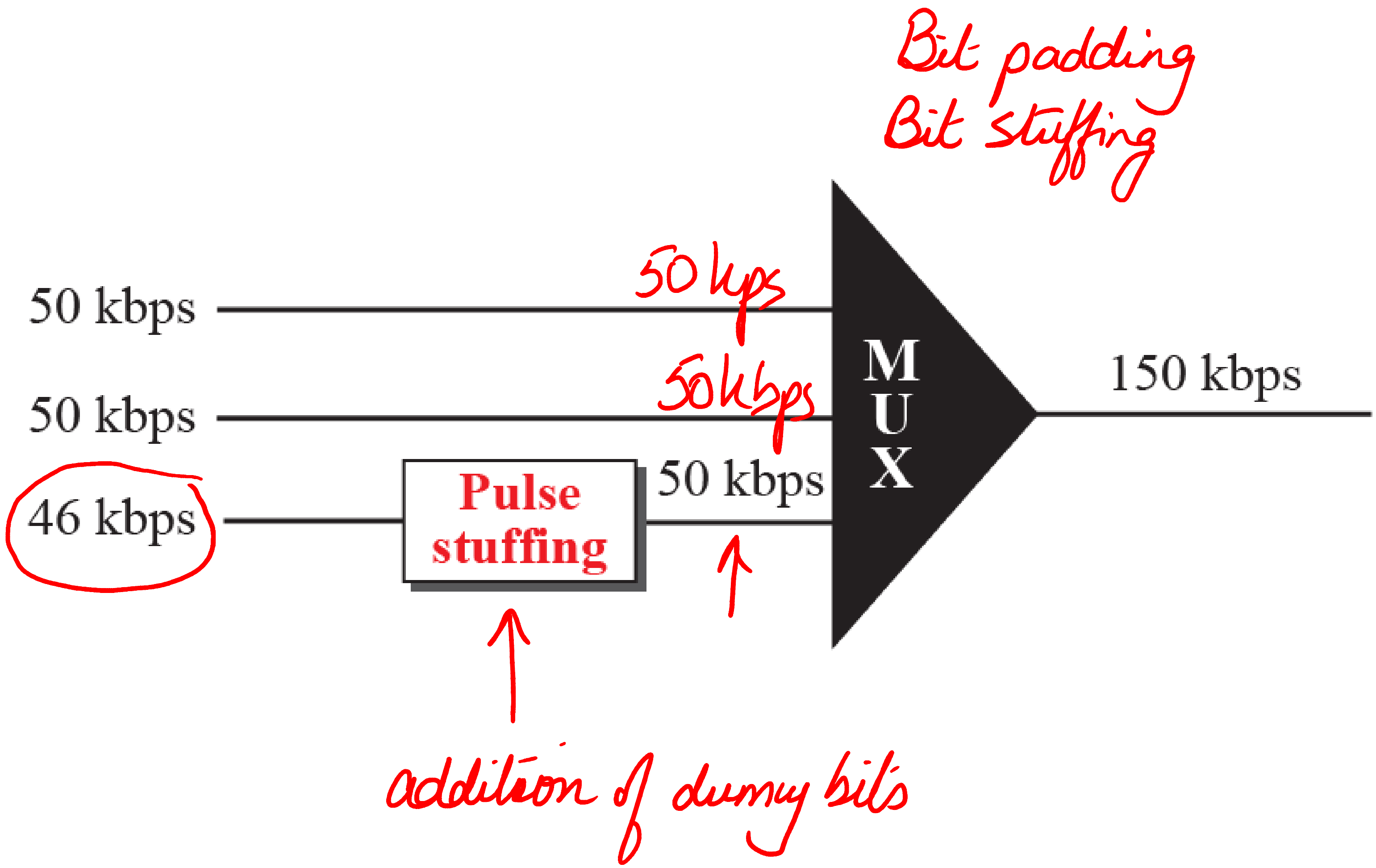
- **Digital process that allows several connections to share the high bandwidth of a link**

- **Time is shared i.e. each connection occupies a portion of time in the link**



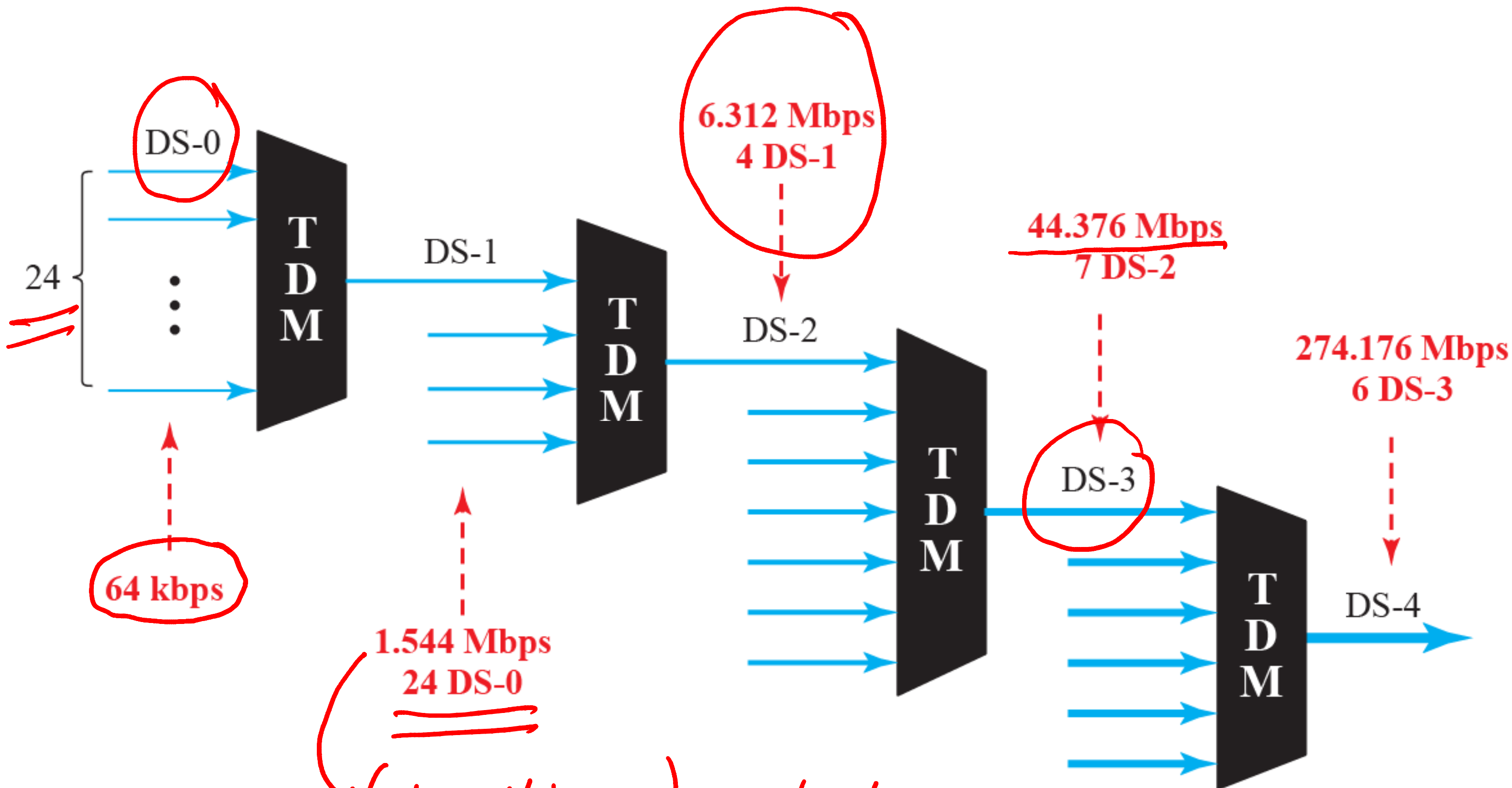
20 is a multiple of 40


DEMUX
25 kbps
25 kbps
50 kbps
25 kbps
25 kbps
25 kbps
25 kbps
25 kbps
25 kbps
M
U
X
125 kbps
The input with a
50-kHz data rate has two
slots in each frame.


Bit padding
Bit stuffing
50 kbps
50 kbps
50 kbps
50 kbps
46 kbps
Pulse stuffing
50 kbps
MUX
150 kbps
addition of dummy bits

- **Digital process that allows several connections to share the high bandwidth of a link**

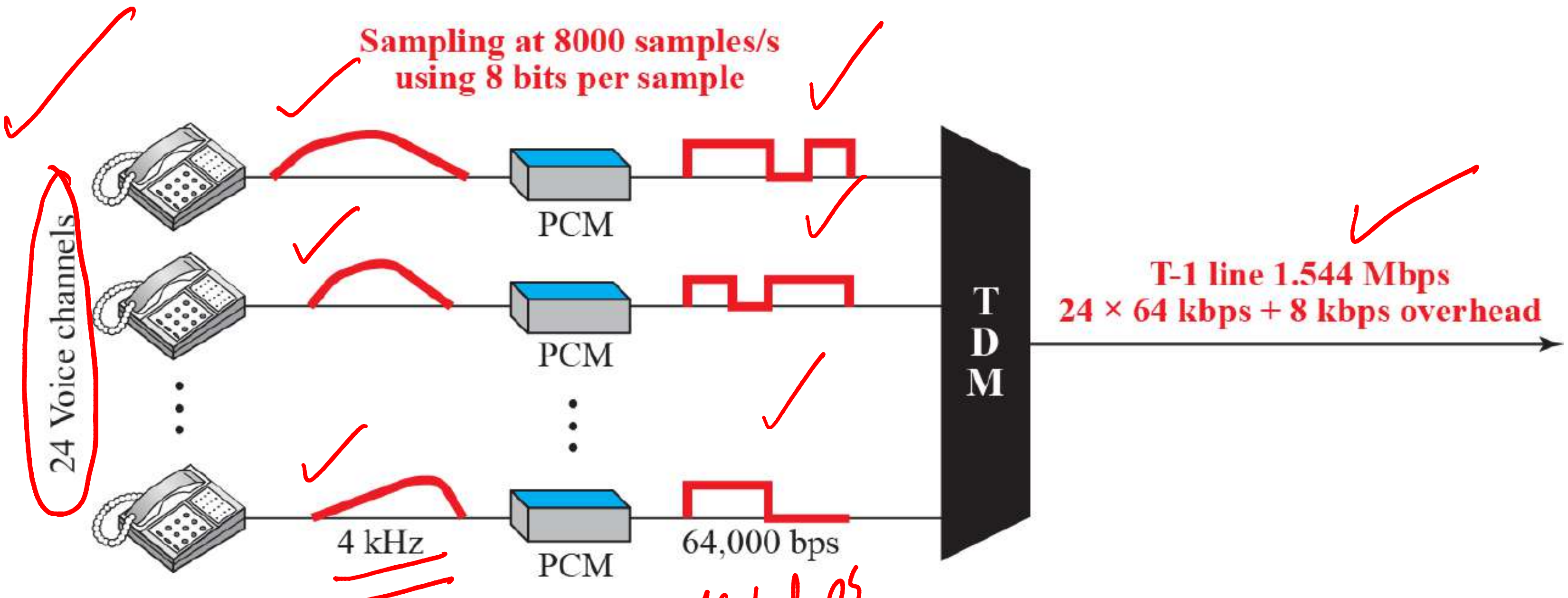
- **Time is shared i.e. each connection occupies a portion of time in the link**



(24 x 64kbps)+overhead
= 1.54Mbps

DS0

Service	Line	Rate (Mbps)	Voice Channels
DS-1	T-1	1.544	24
DS-2	T-2	6.312	96
DS-3	T-3	44.736	672
DS-4	T-4	274.176	4032

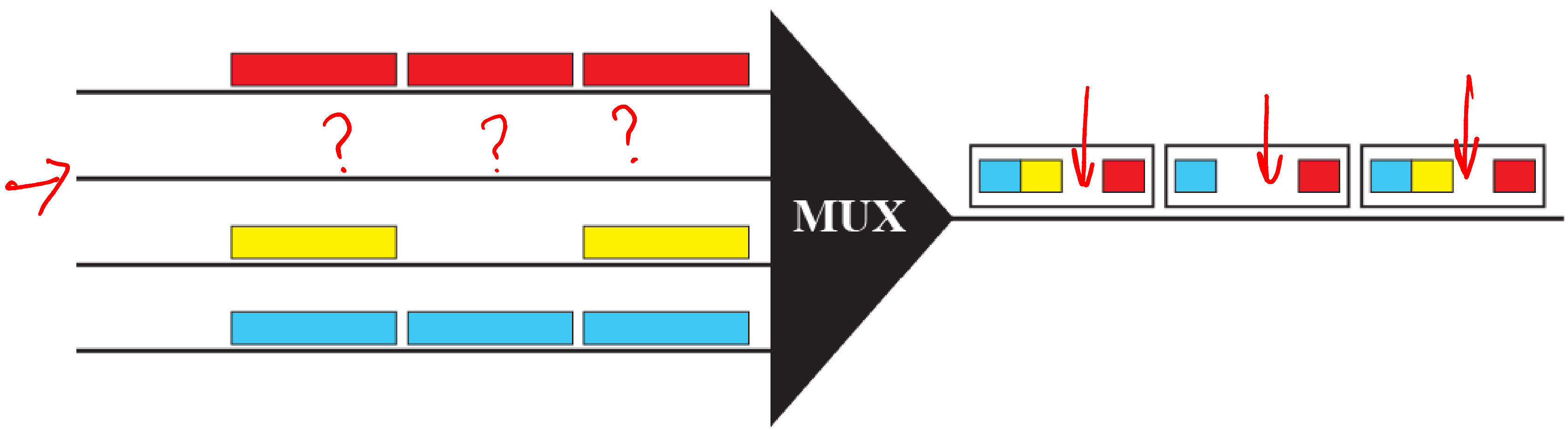


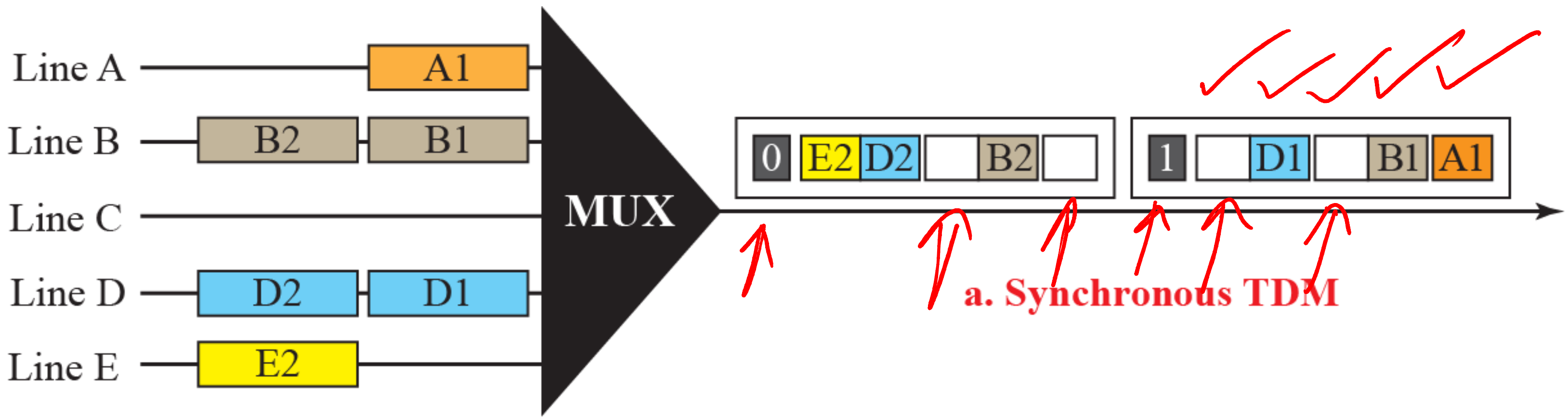
64kbps

4kHz $\xrightarrow{\text{8 bits/sample}}$ 64kbps

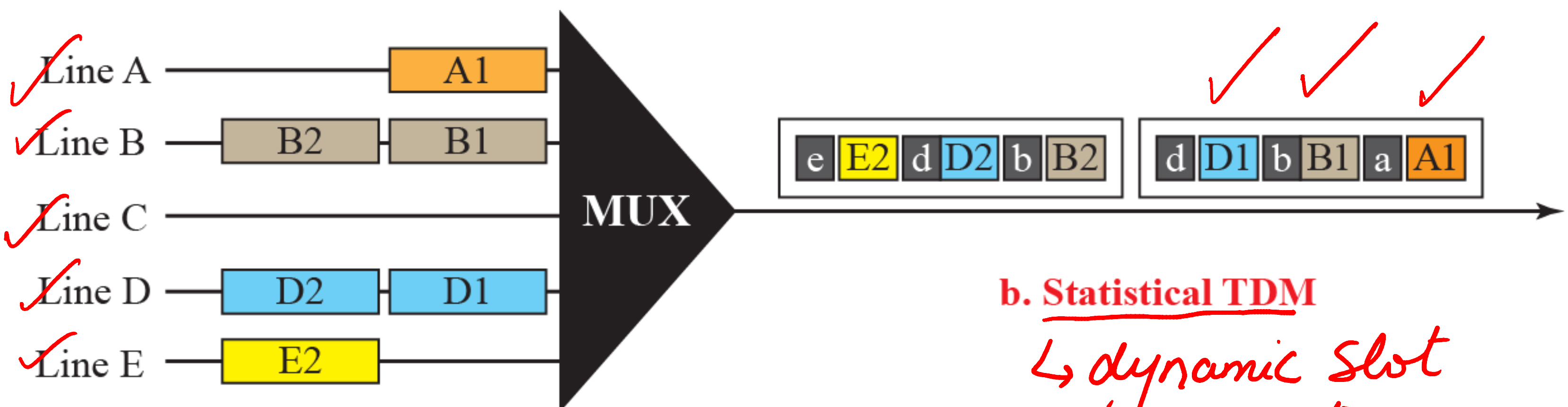
Line	*Rate (Mbps)*	*Voice Channels*
E-1	2.048	30
E-2	8.448	120
E-3	34.368	480
E-4	139.264	1920

- **Synchronous TDM**
- **Statistical TDM**


MUX
? ? ?



a. Synchronous TDM



b. Statistical TDM

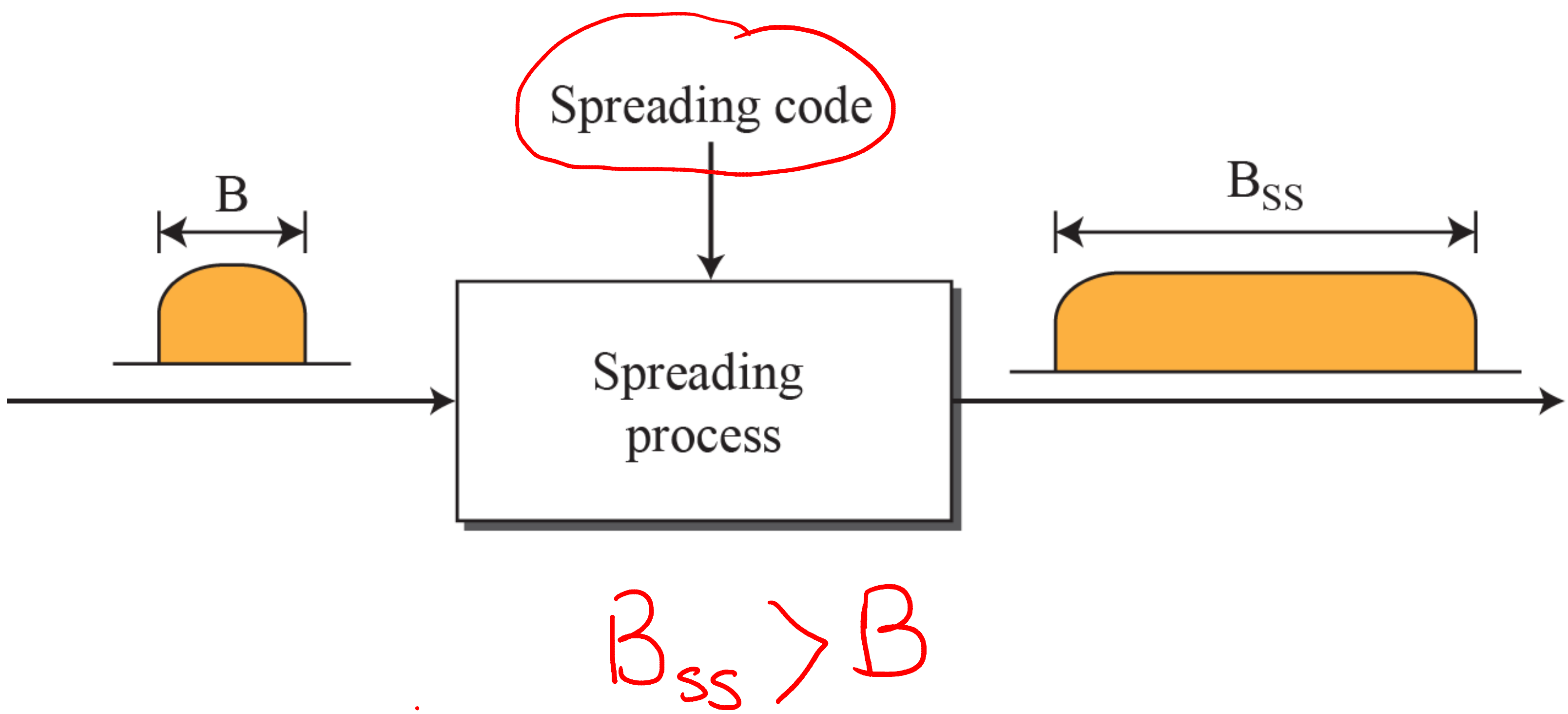
↳ dynamic slot allocation

- **In wireless applications, stations must be able to share the medium without interception by an eavesdropper and without being subject to jamming from a malicious intruder**

- **To achieve these goals, spread spectrum adds redundancy and spread original spectrum needed for each station**

- **Bandwidth allocated to each station needs to be larger than what is needed to allow Redundancy**

- **Spreading process should be independent of the original signal**


Spreading code
B
B_SS
Spreading process
Bss > B

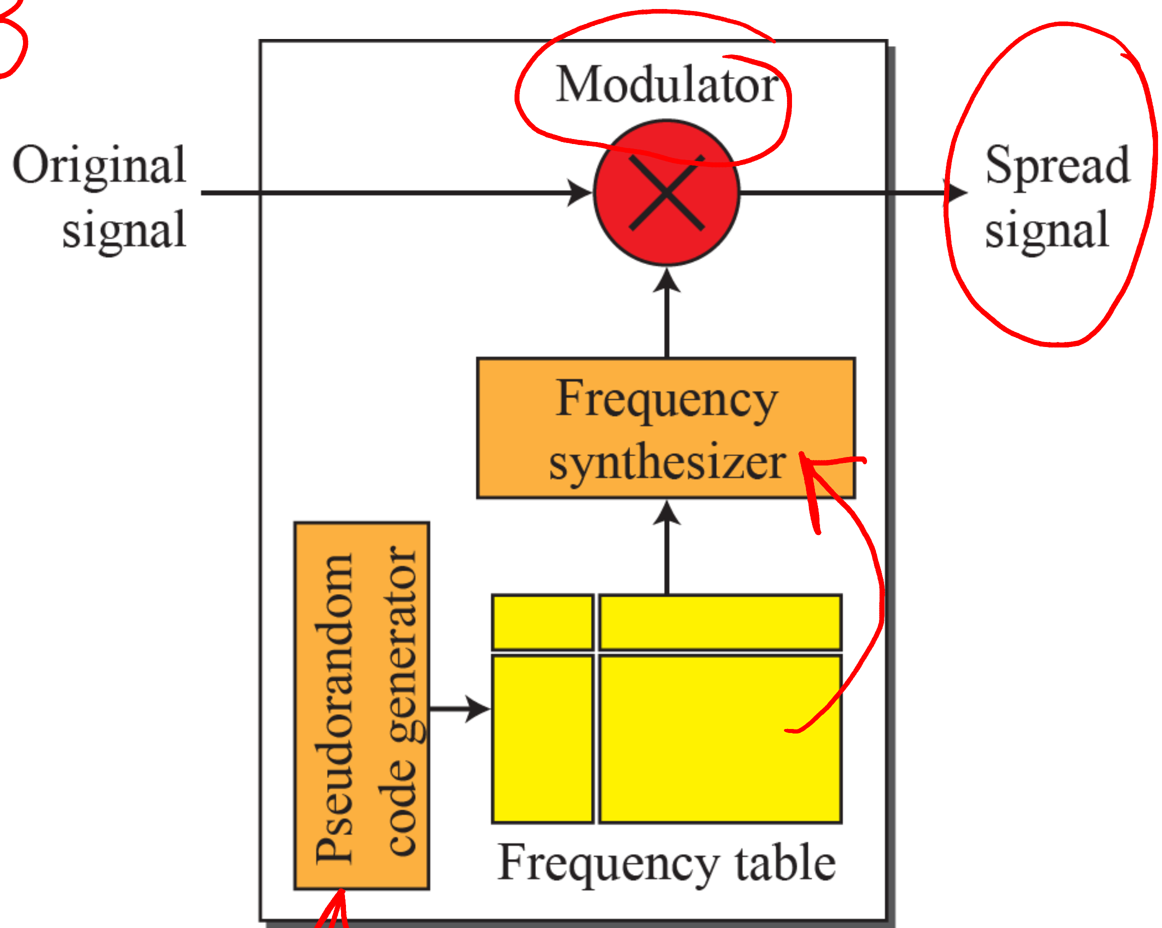
- **Frequency Hopping Spread Spectrum (FHSS)**

- **Direct Sequence Spread Spectrum (DSSS)**

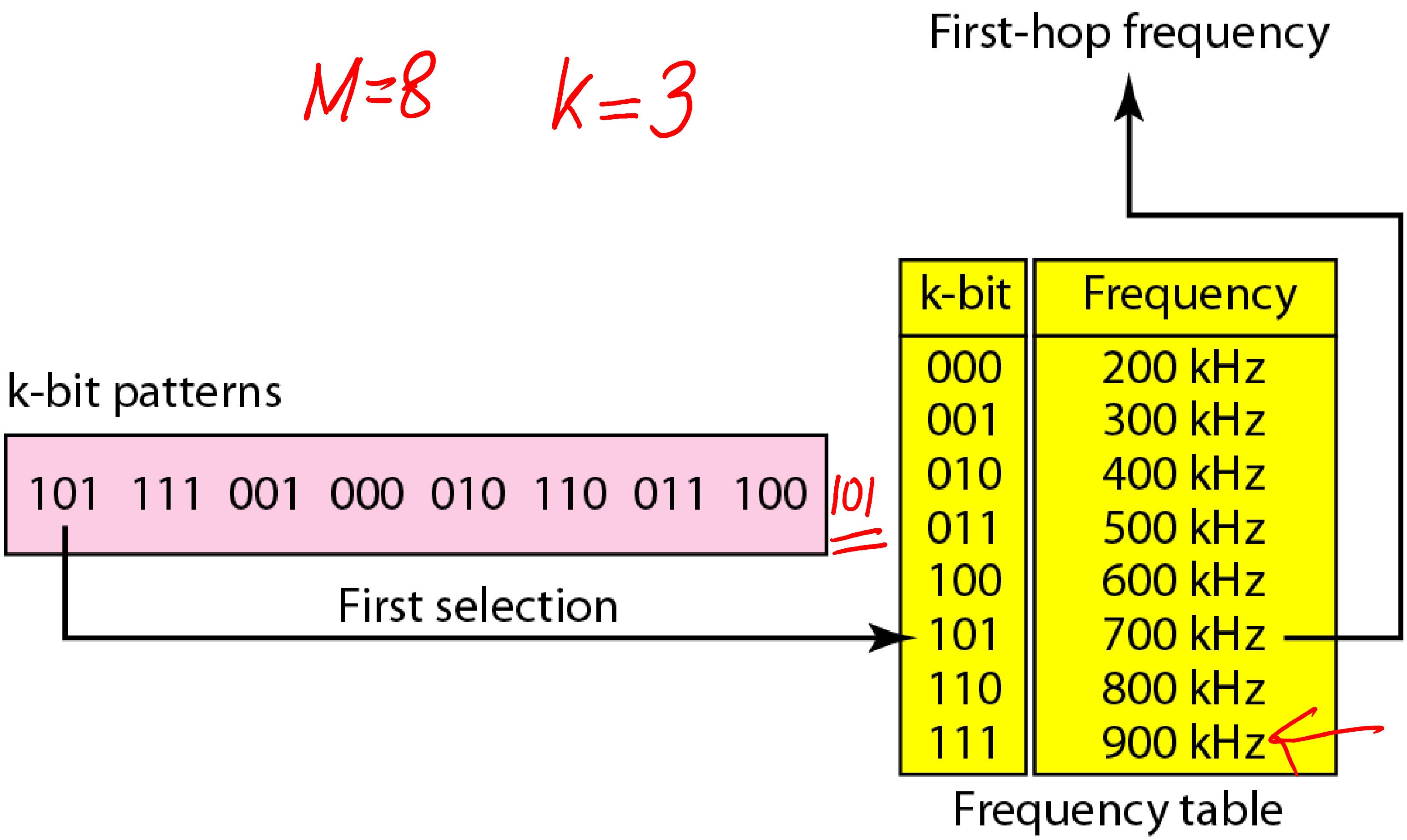
- ‘M’ different carrier frequencies that are modulated by the source signal

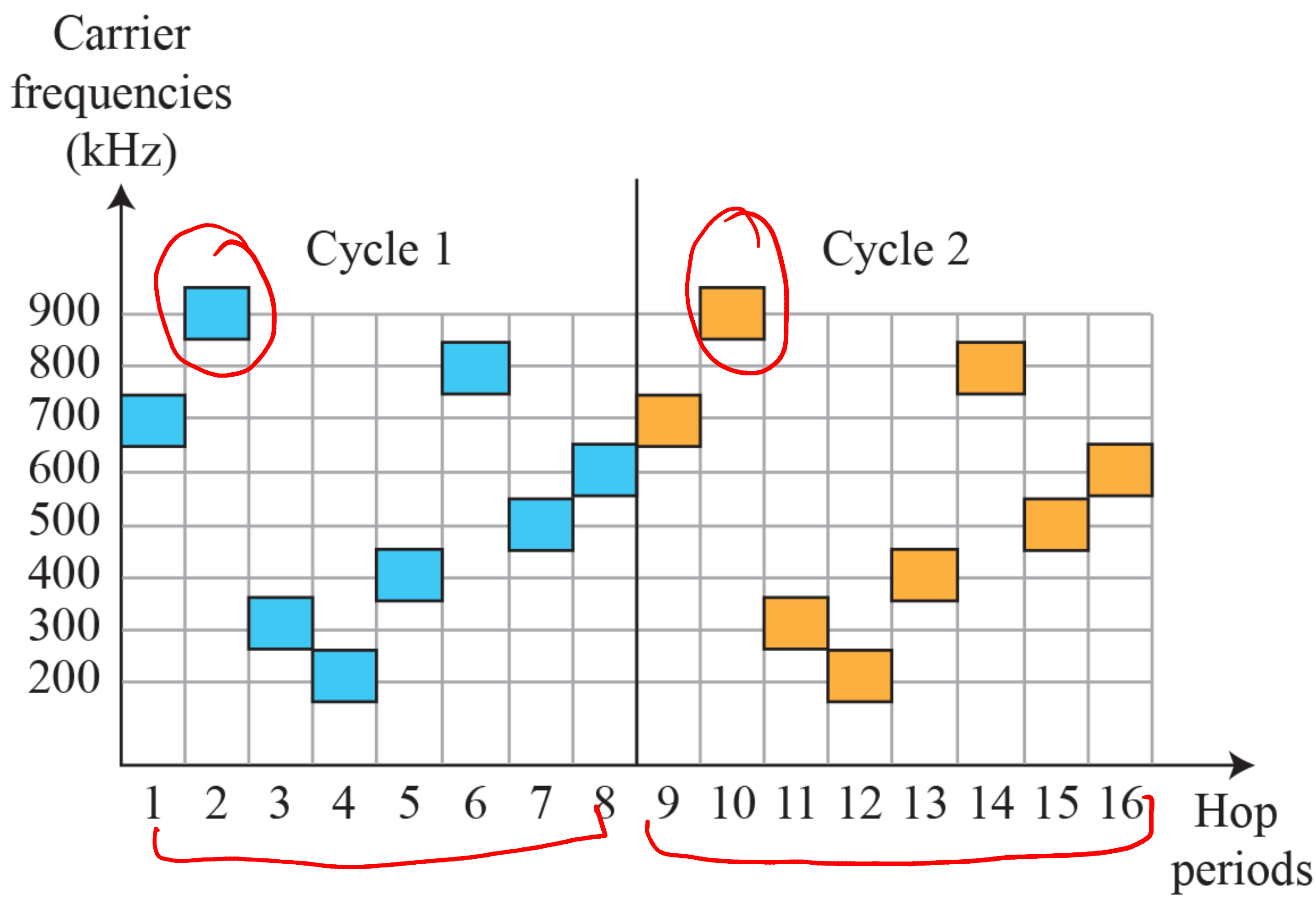
- At one moment, signal modulates one carrier frequency and at next moment, it modulates another

$B_{FHSS} \gg B$

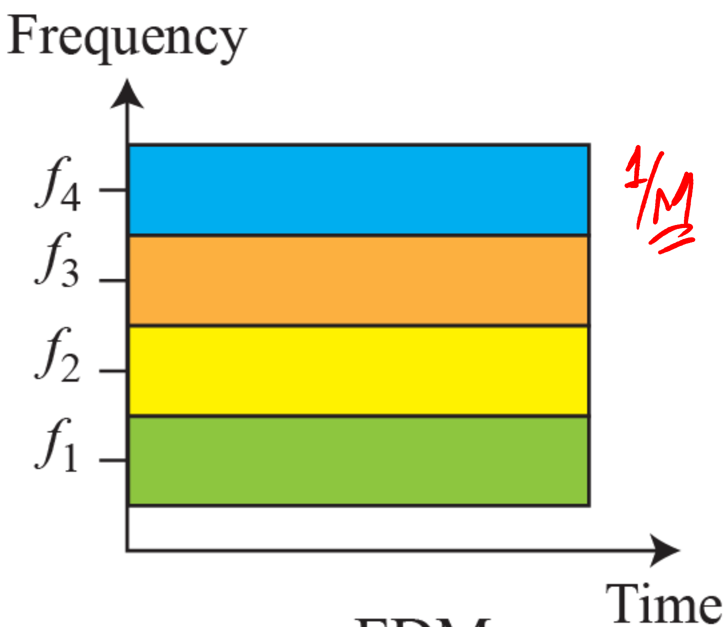


k-bit pattern (T_h)

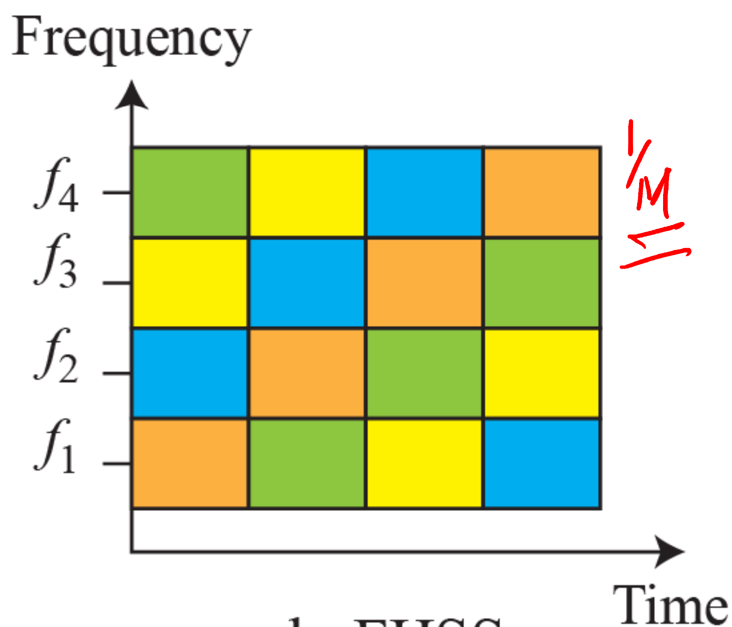

First-hop frequency
M=8
k=3
k-bit patterns
101 111 001 000 010 110 011 100
101
First selection
k-bit
Frequency
000
001
010
011
100
101
110
111
200 kHz
300 kHz
400 kHz
500 kHz
600 kHz
700 kHz
800 kHz
900 kHz
Frequency table



Carrier frequencies (kHz)
900
800
700
600
500
400
300
200
Cycle 1
Cycle 2
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Hop periods

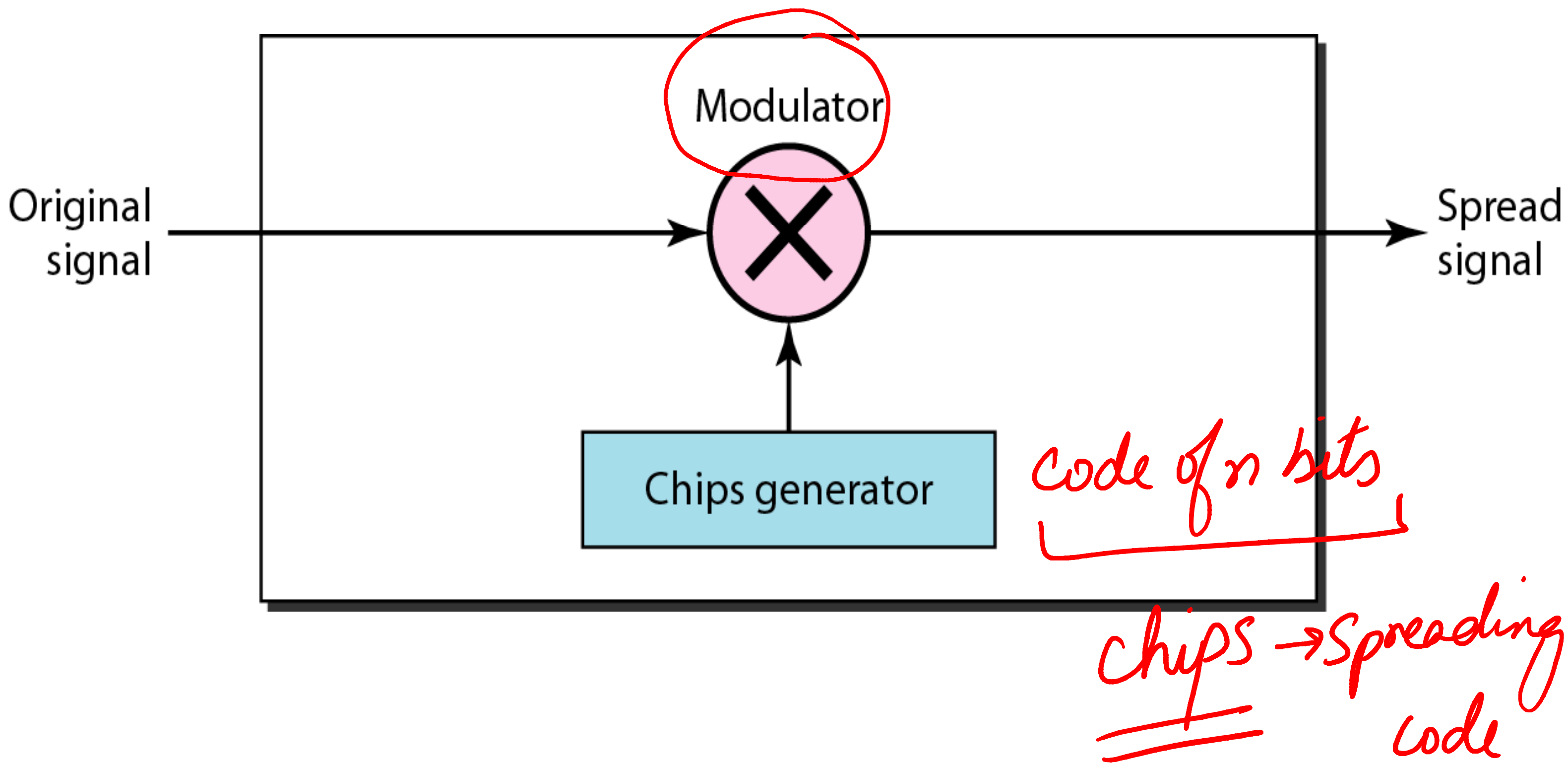


a. FDM



b. FHSS

- DSSS also expands the bandwidth of the original signal, but the process is different
- We replace each data bit with ‘n’ bits using a spreading code
- Each bit is assigned a code of ’n’ bits, called chips, where the chip rate is ‘n’ times that of the data bit



Original signal
Modulator
Spread signal
Chips generator
code of n bits
chips → spreading code

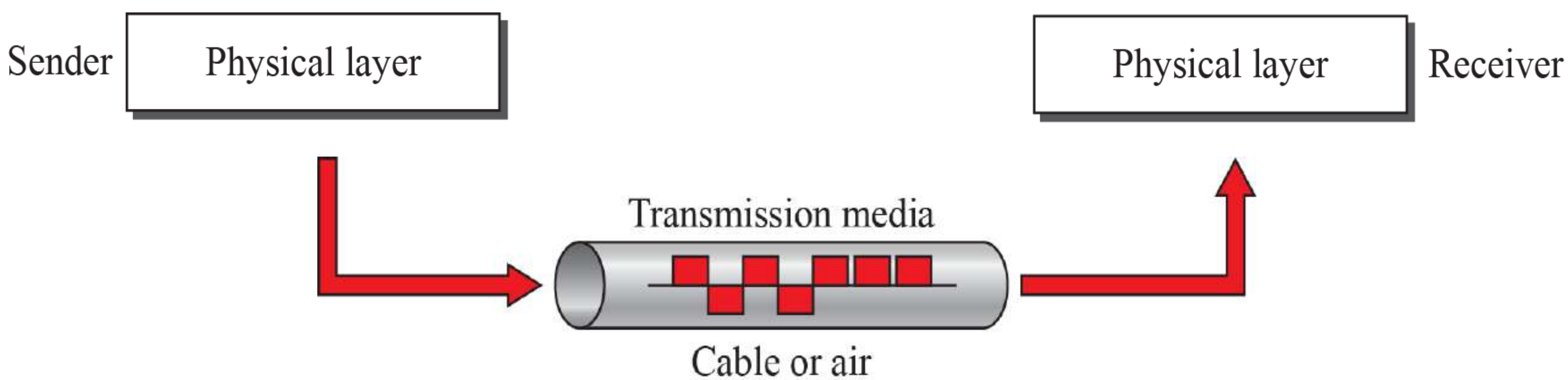
- **Located below the physical layer and are directly controlled by the physical layer**

- **Belong to layer zero**

- **Metallic Media i.e. Twisted pair and Coaxial Cable**

- **Optical Fiber Cable**

- **Free Space i.e. Air, Vaccum**


Sender
Physical layer
Physical layer
Receiver
Transmission media
Cable or air

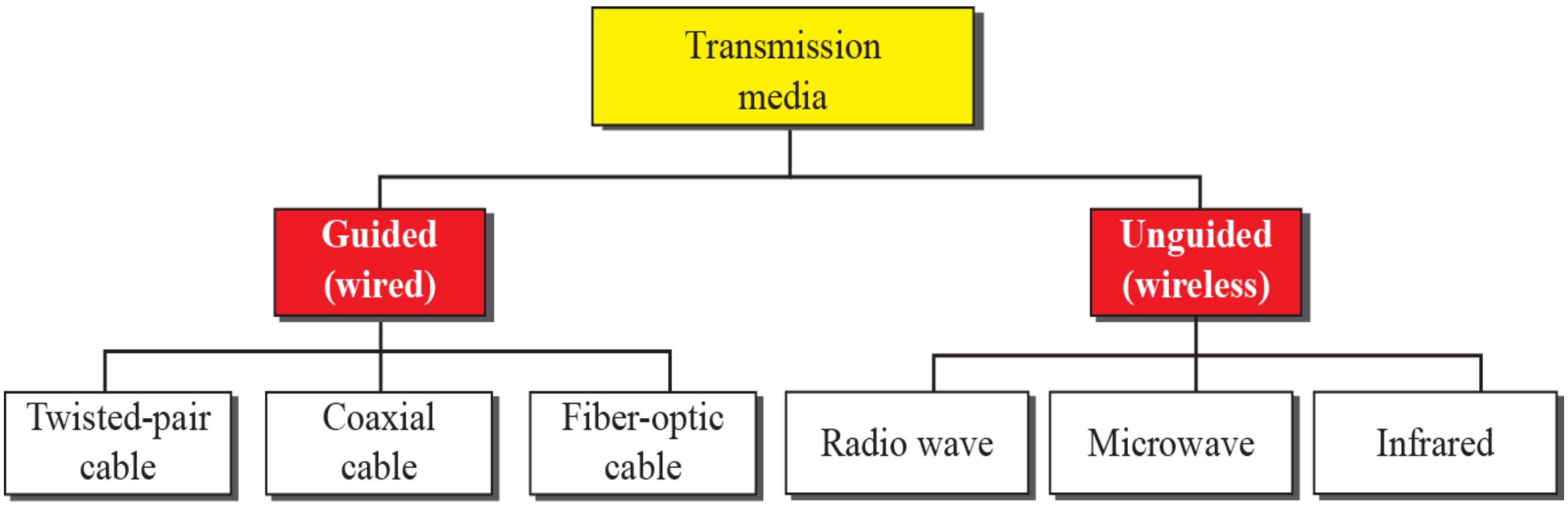
- **Located below the physical layer and are directly controlled by the physical layer**

- **Belong to layer zero**

- **Metallic Media i.e. Twisted pair and Coaxial Cable**

- **Optical Fiber Cable**

- **Free Space i.e. Air, Vaccum**


Transmission media
Guided (wired)
Unguided (wireless)
Twisted-pair cable
Coaxial cable
Fiber-optic cable
Radio wave
Microwave
Infrared

- Media that provides a conduit from one device to another

- Twisted-pair cable, coaxial cable, and fiber-optic cable

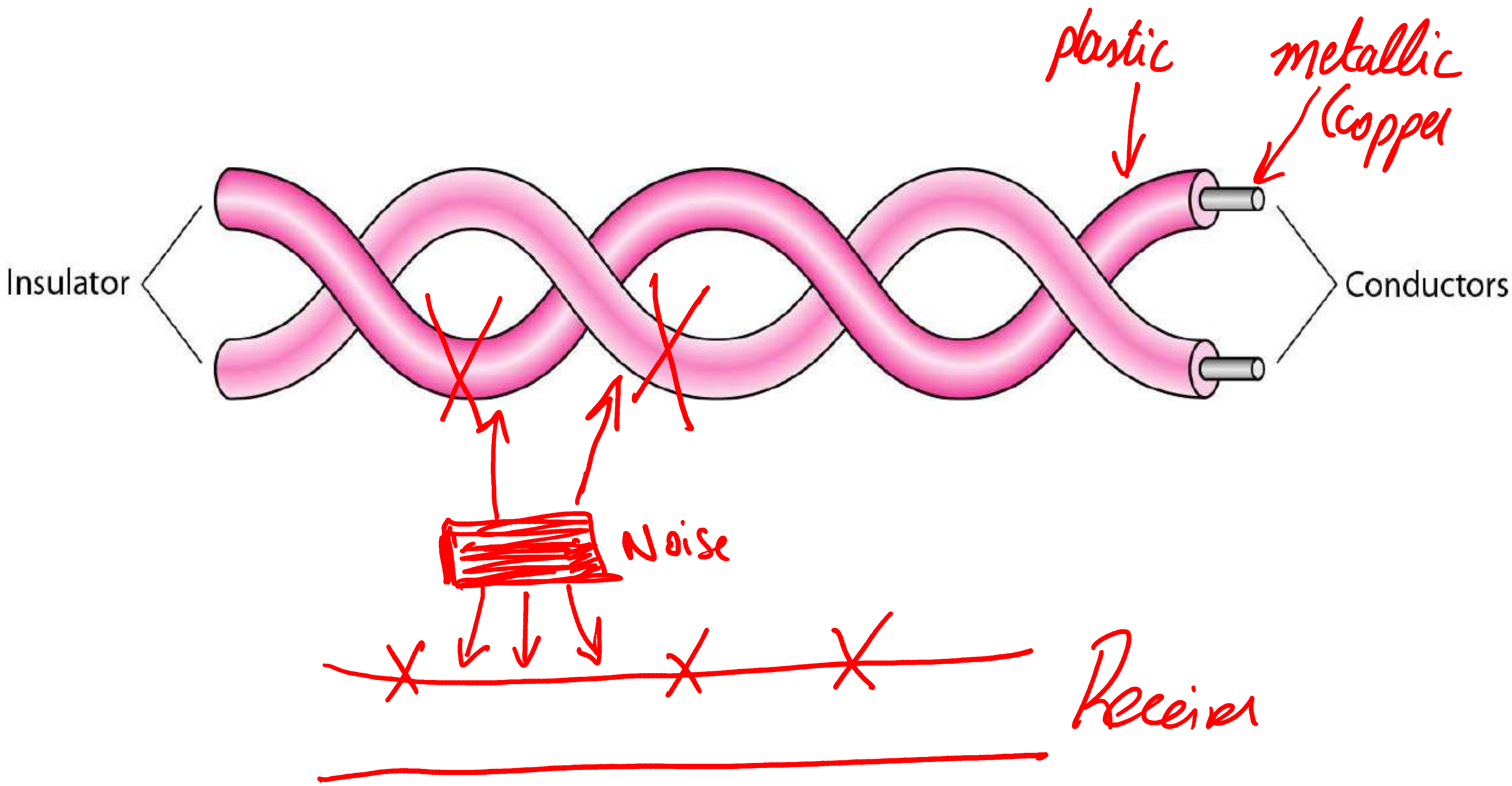
- Signal traveling along any of these media is directed and contained by the physical limits of the medium

- **Consists of 2 copper conductors, each with its own plastic insulation, twisted together**

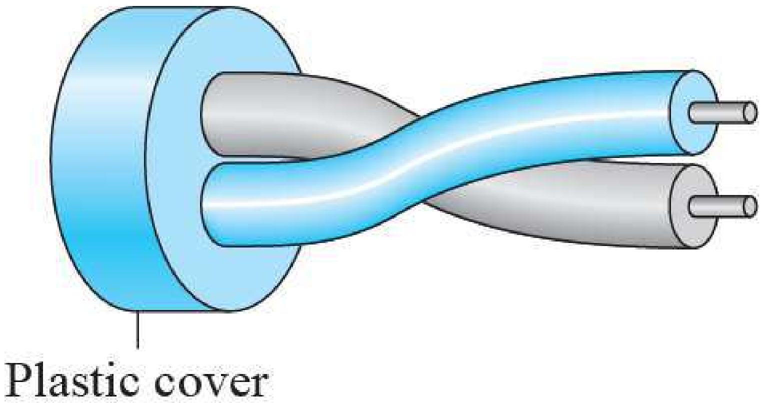
- **One wire carries signals and other is ground reference**

- **Receiver uses difference between the two**

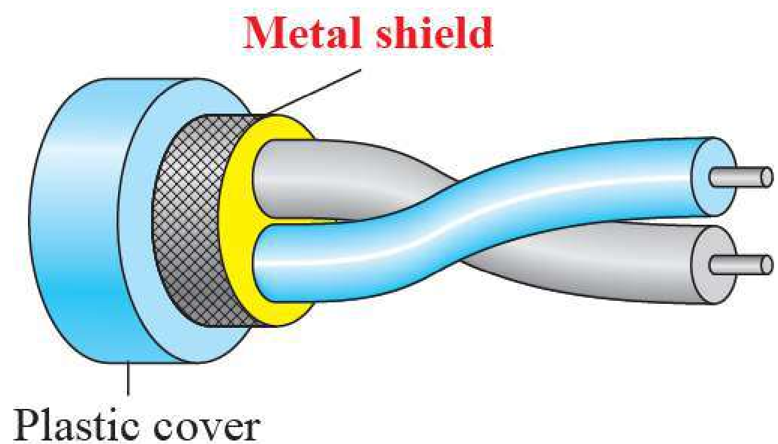
- **Interference (Noise) & Crosstalk**


plastic
metallic
(copper
Insulator
Conductors
Noise
Receiver

- **UTP**
- **STP**



a. UTP

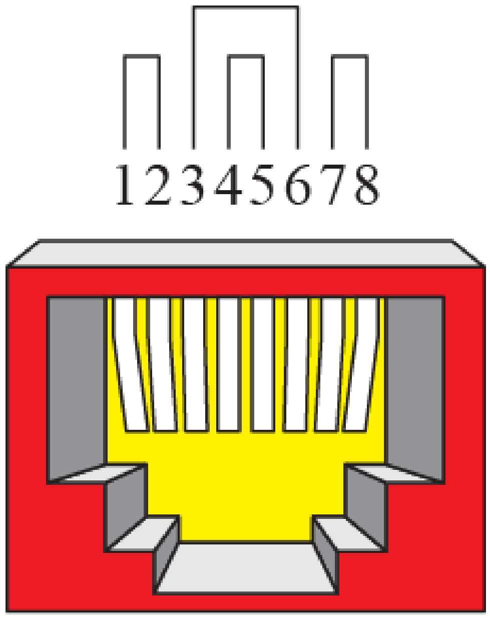


b. STP

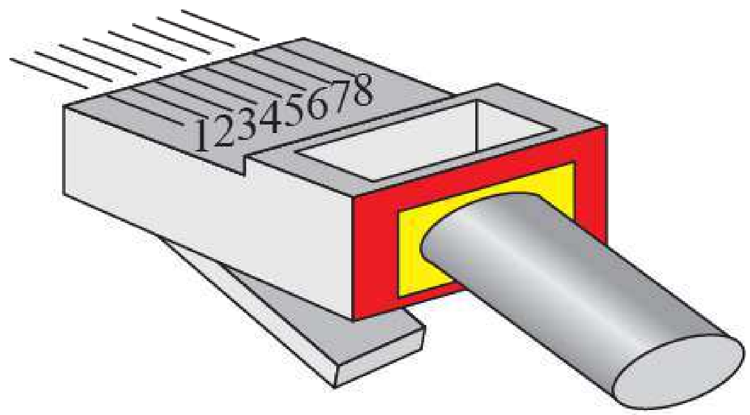
Category	Specification	Data Rate (Mbps)	Use
1	Unshielded twisted-pair used in telephone	< 0.1	Telephone
2	Unshielded twisted-pair originally used in T lines	2	T-1 lines
3	Improved CAT 2 used in LANs	10	LANs
4	Improved CAT 3 used in Token Ring networks	20	LANs
5	Cable wire is normally 24 AWG with a jacket and outside sheath	100	LANs
5E	An extension to category 5 that includes extra features to minimize the crosstalk and electromagnetic interference	125	LANs
6	A new category with matched components coming from the same manufacturer. The cable must be tested at a 200-Mbps data rate.	200	LANs
7	Sometimes called *SSTP (shielded screen twisted-pair)*. Each pair is individually wrapped in a helical metallic foil followed by a metallic foil shield in addition to the outside sheath. The shield decreases the effect of crosstalk and increases the data rate.	600	LANs

Registered Jack

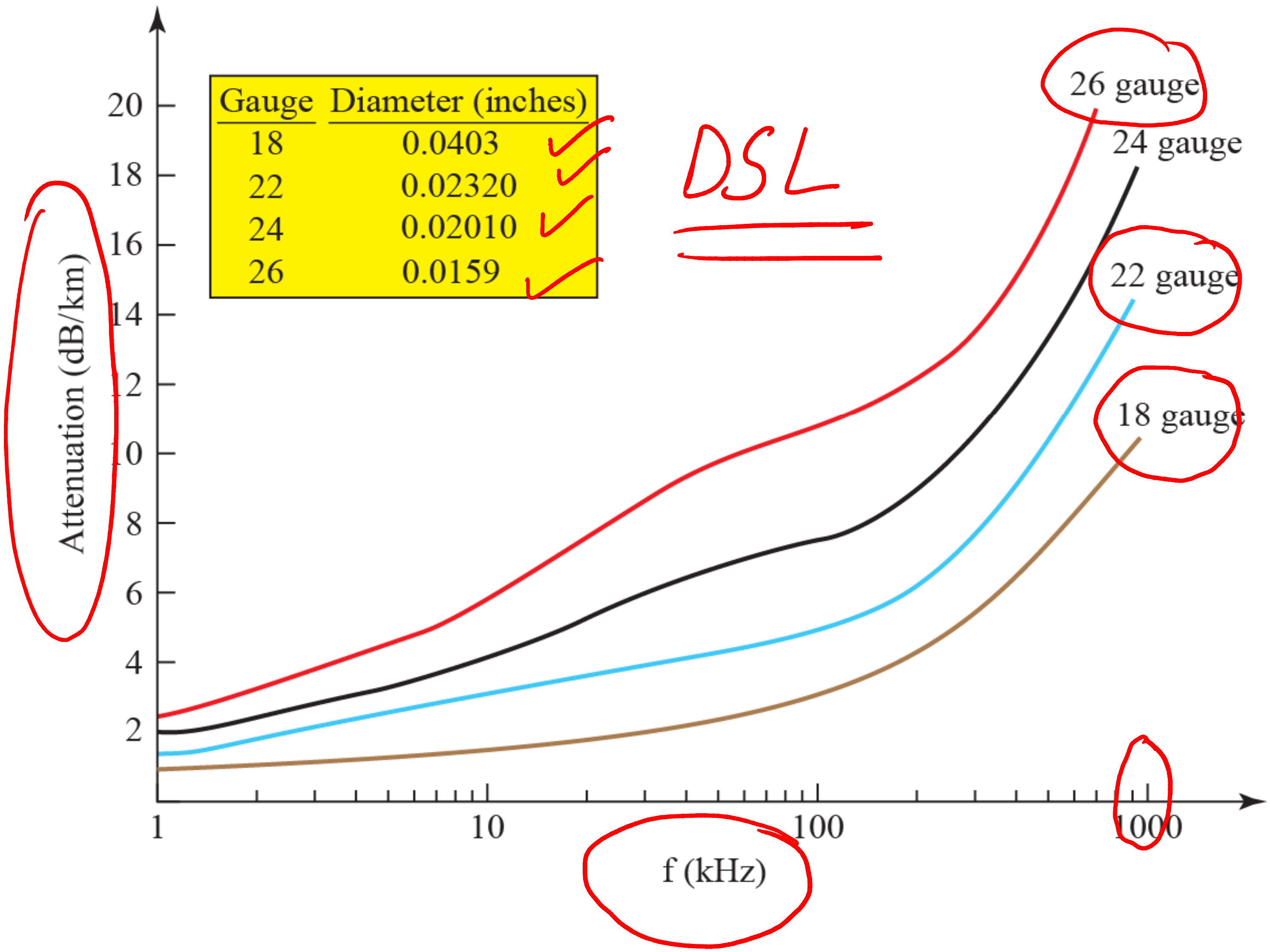
Keyed



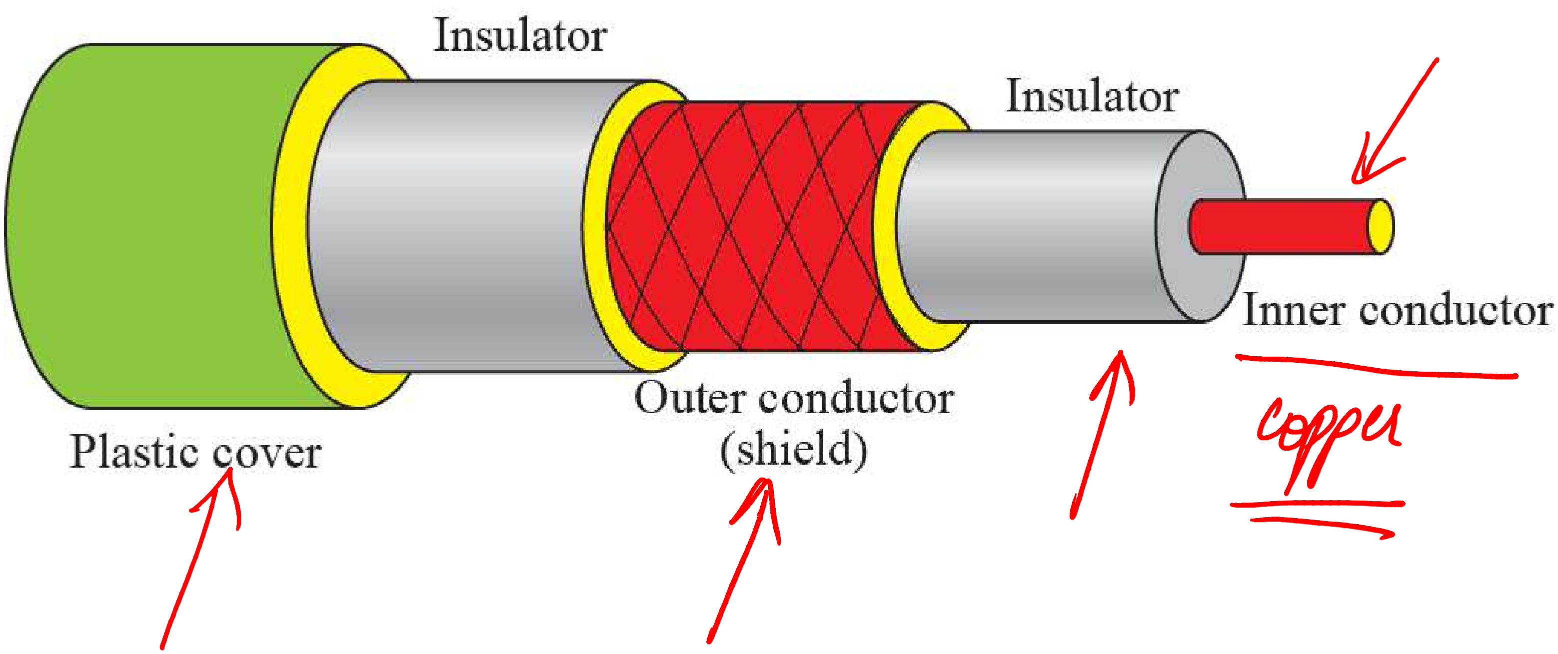
RJ-45 Female



RJ-45 Male


Gauge Diameter (inches)
18 0.0403
22 0.02320
24 0.02010
26 0.0159
DSL
26 gauge
24 gauge
22 gauge
18 gauge
Attenuation (dB/km)
20
18
16
14
12
10
8
6
4
2
1
10
100
1000
f (kHz)

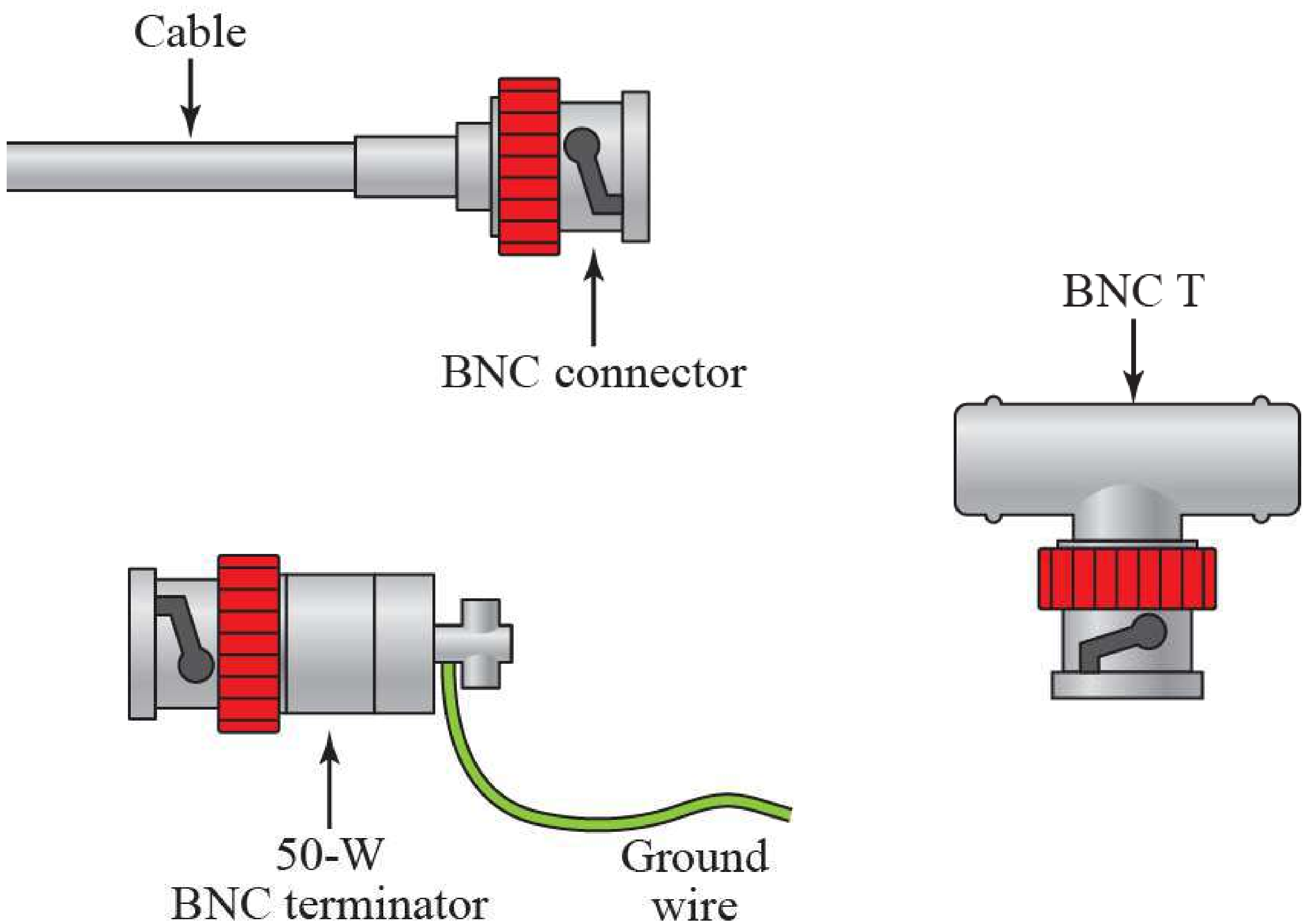
- **Carries signals of higher frequency ranges than those in twisted pair cable**

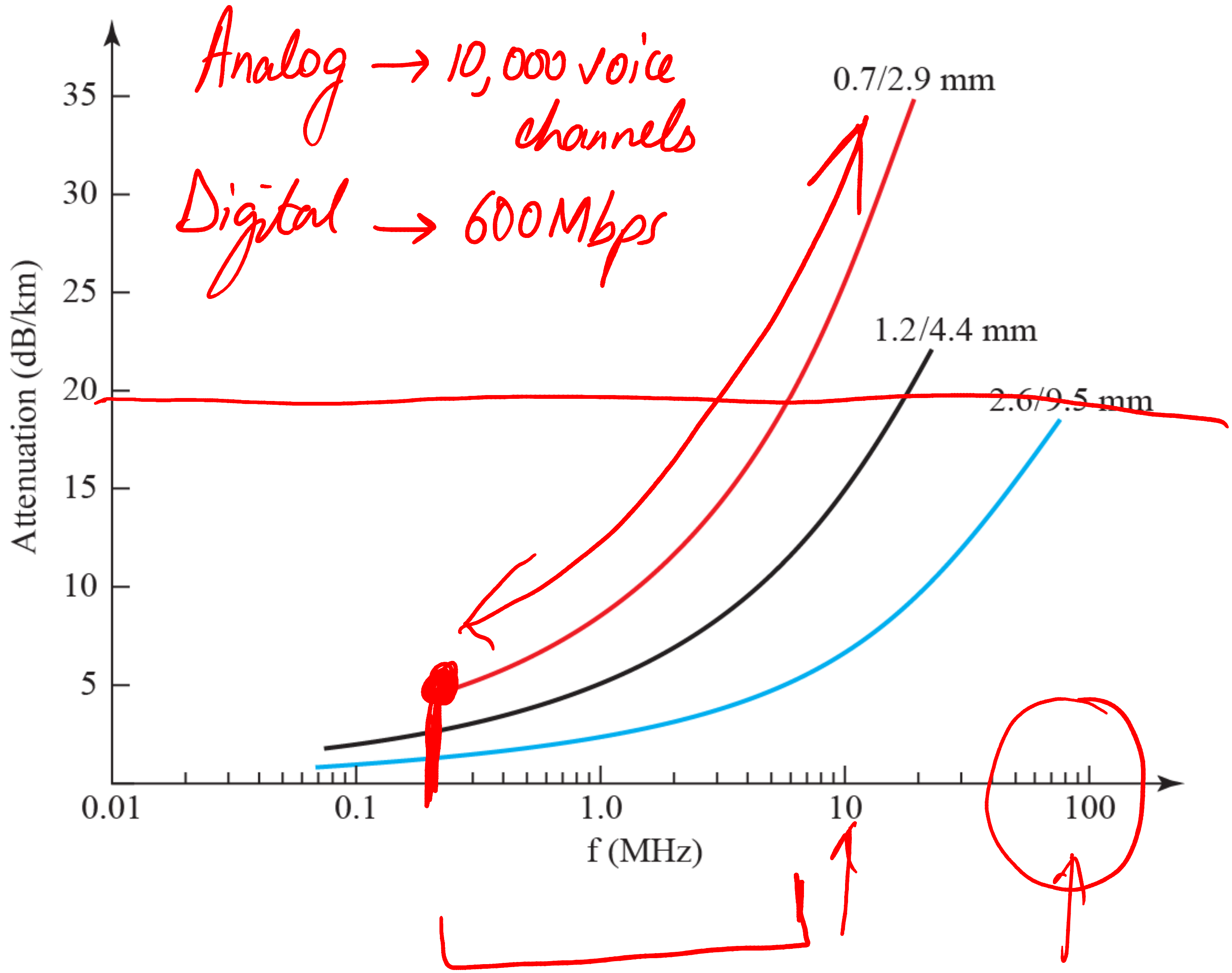

Insulator
Insulator
Inner conductor
copper
Outer conductor
(shield)
Plastic cover

ohms

Category	*Impedance*	*Use*
RG-59	75 Ω	Cable TV
RG-58	50 Ω	Thin Ethernet
RG-11	50 Ω	Thick Ethernet

- **Carries signals of higher frequency ranges than those in twisted pair cable**

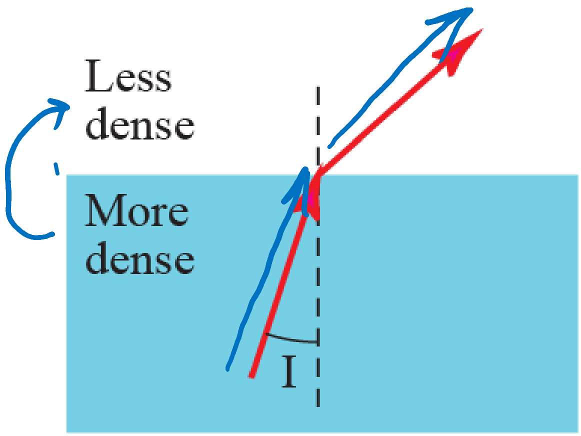

Cable
BNC connector
BNC T
50-W
BNC terminator
Ground
wire


Analog → 10,000 voice channels
Digital → 600 Mbps
0.7/2.9 mm
1.2/4.4 mm
2.6/9.5 mm
Attenuation (dB/km)
35
30
25
20
15
10
5
0.01
0.1
1.0
10
100
f (MHz)

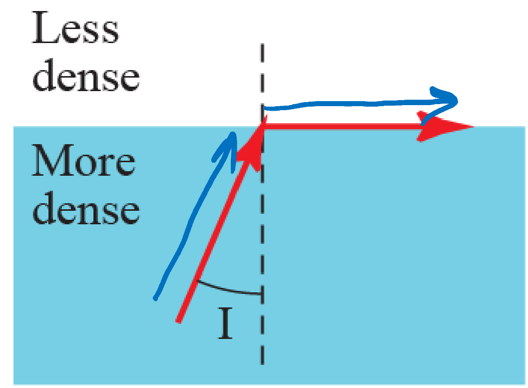
- **Made of glass or plastic and transmits signals in the form of light**

- **Light travels in a straight line as long as it is moving through a single uniform substance**

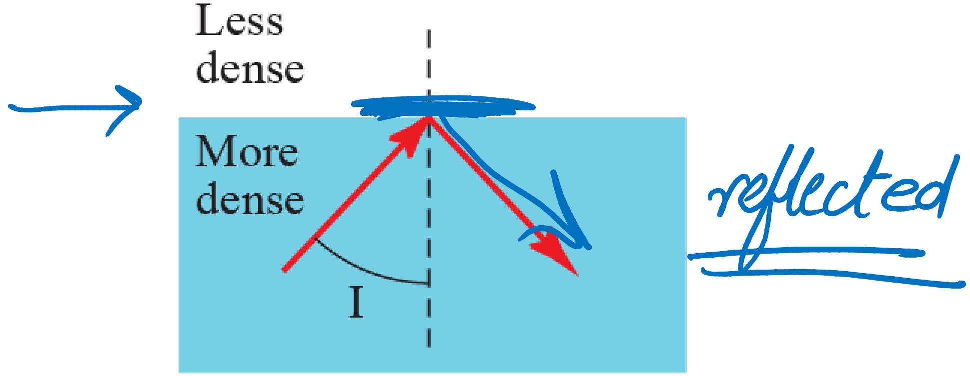
- **If a ray of light traveling through one substance suddenly enters another substance (of a different density), the ray changes direction**



I < critical angle,
refraction

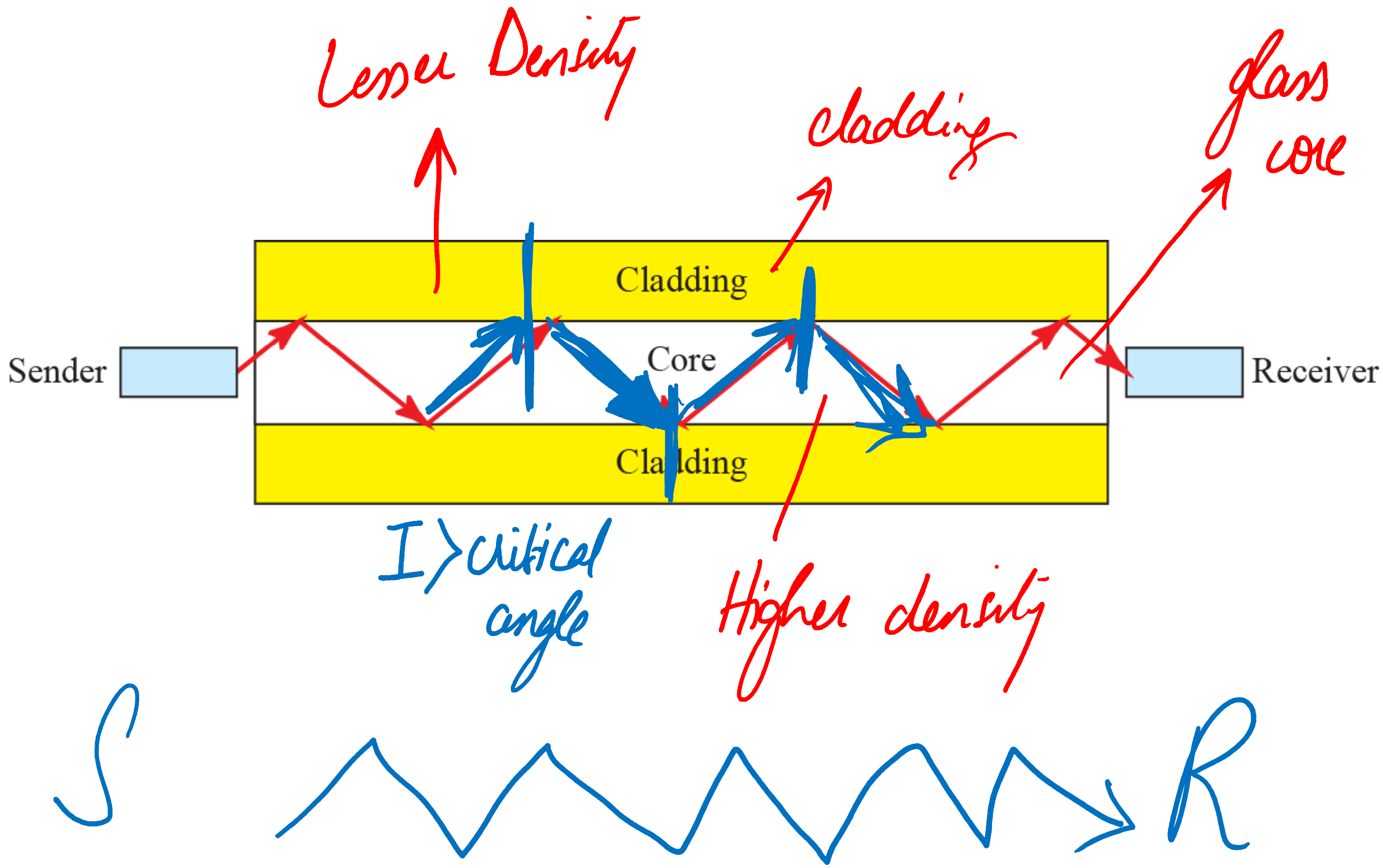


I = critical angle,
refraction

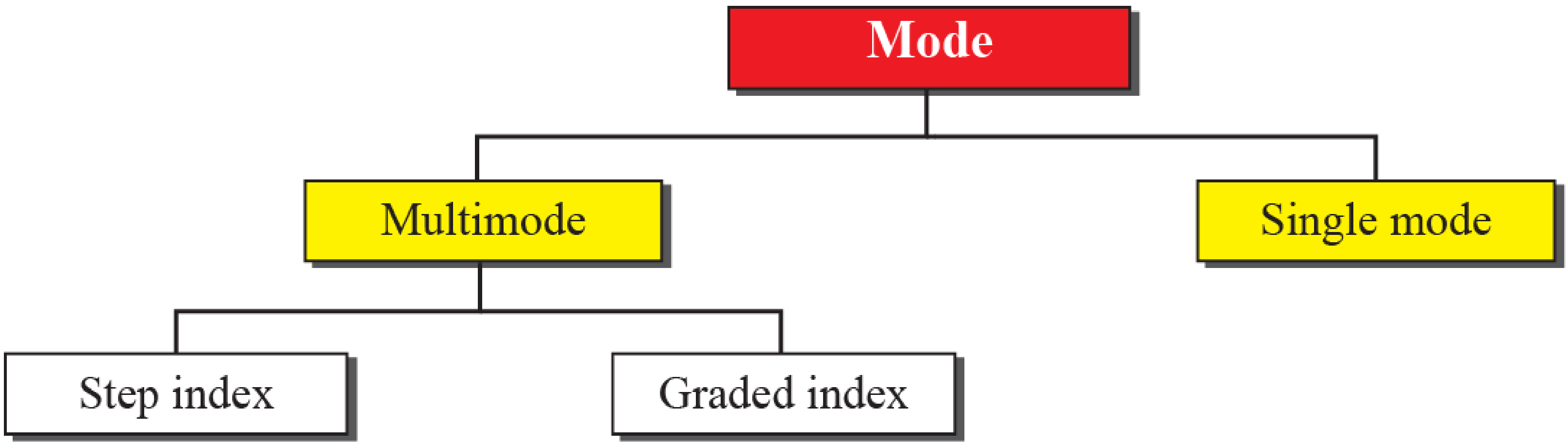


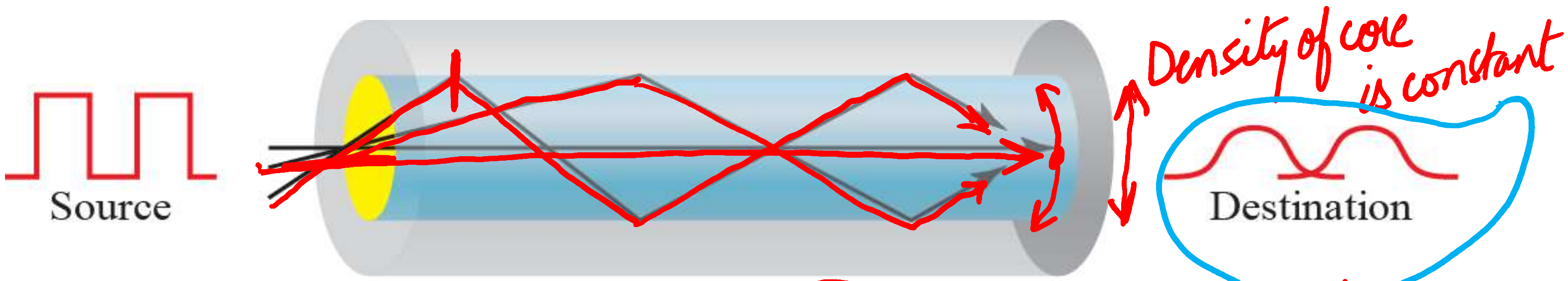
I > critical angle,
reflection

- **Made of glass or plastic and transmits signals in the form of light**

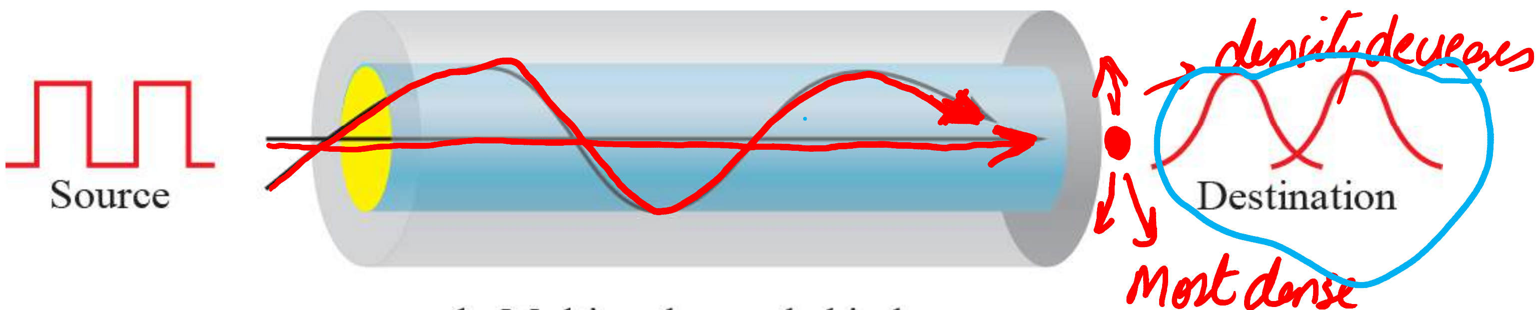

Lesser Density
cladding
glass core
Cladding
Core
Sender
Receiver
Cladding
I > critical angle
Higher density
S
R

- **Made of glass or plastic and transmits signals in the form of light**

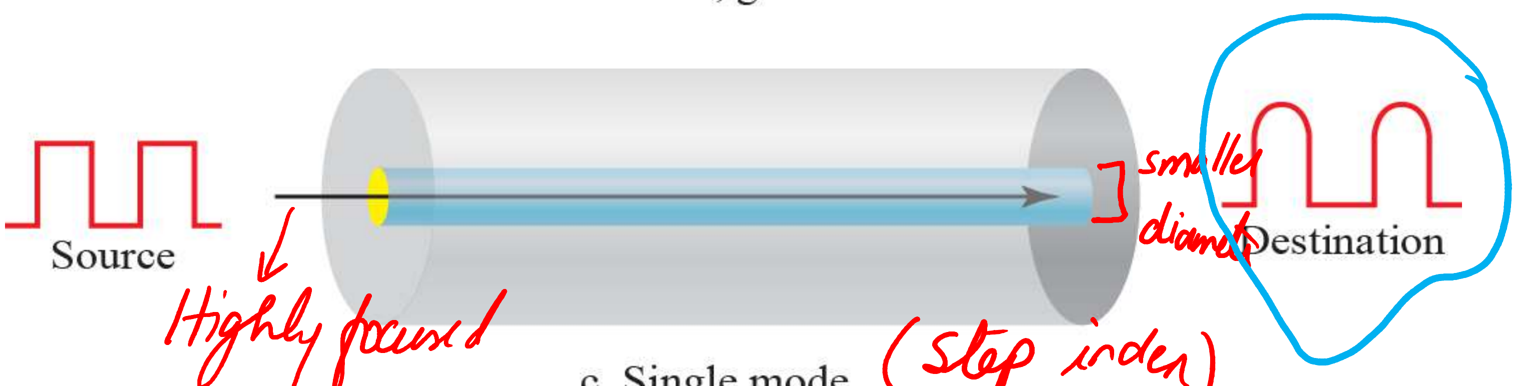

Mode
Multimode
Single mode
Step index
Graded index



a. Multimode, step index sudden → distortion



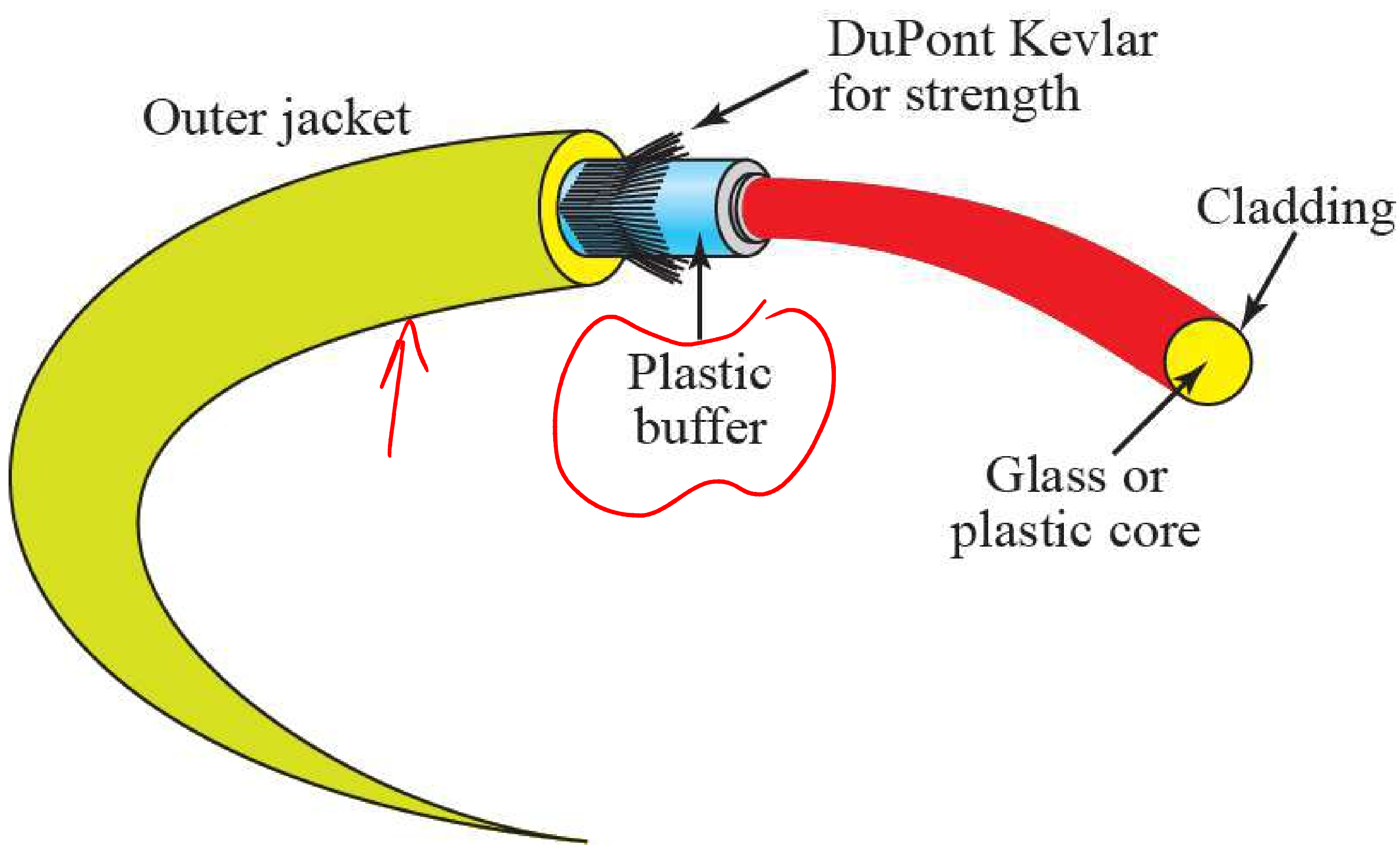
b. Multimode, graded index

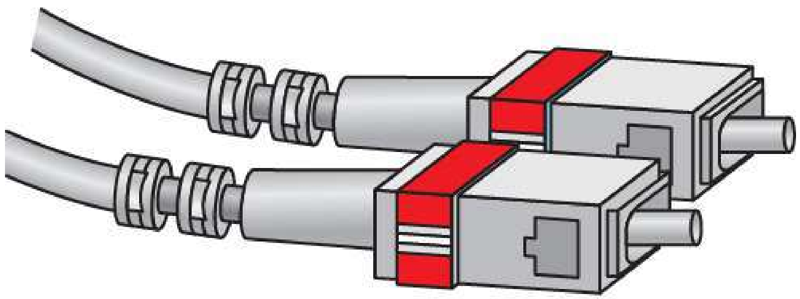


c. Single mode (step index)

- **Made of glass or plastic and transmits signals in the form of light**

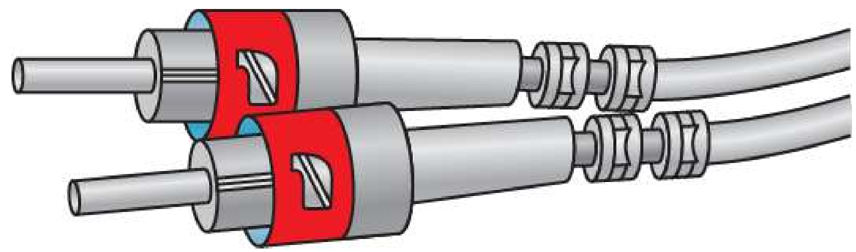
Type	*Core (μm)*	*Cladding (μm)*	*Mode*
50/125	50.0	125	Multimode, graded index
62.5/125	62.5	125	Multimode, graded index
100/125	100.0	125	Multimode, graded index
7/125	7.0	125	Single mode


DuPont Kevlar
for strength
Outer jacket
Cladding
Plastic
buffer
Glass or
plastic core



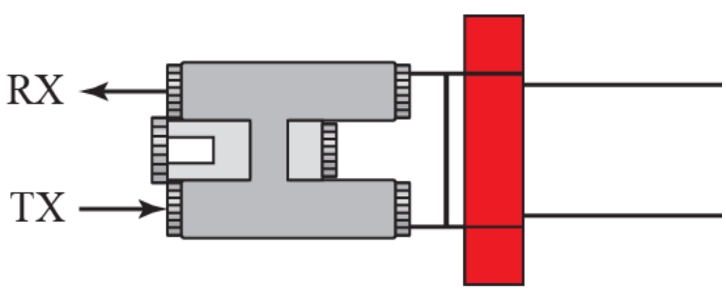
SC connector

Cable TV

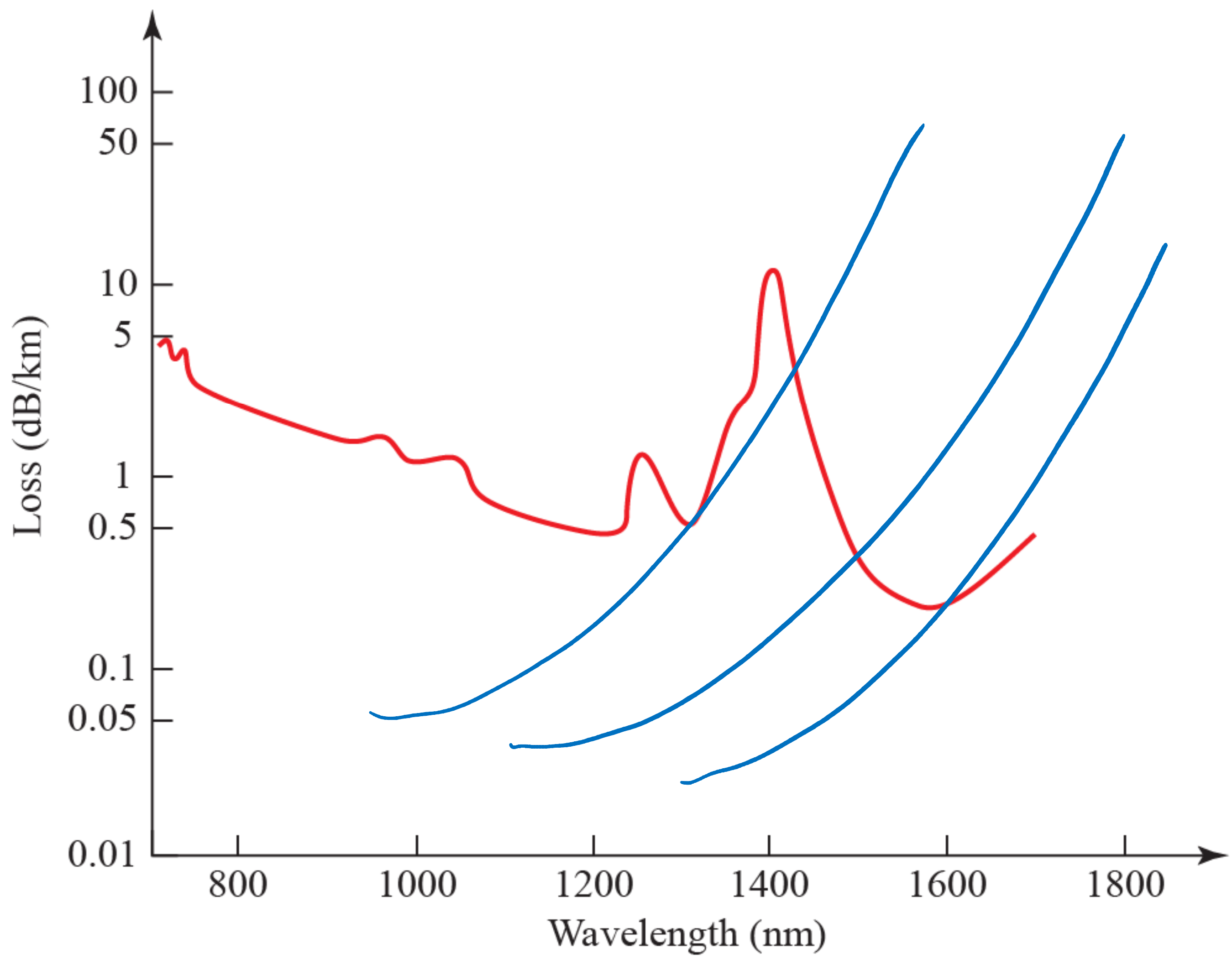


ST connector

Networking Routers



MT-RJ connector


100
50
10
5
1
0.5
0.1
0.05
0.01
Loss (dB/km)
800
1000
1200
1400
1600
1800
Wavelength (nm)

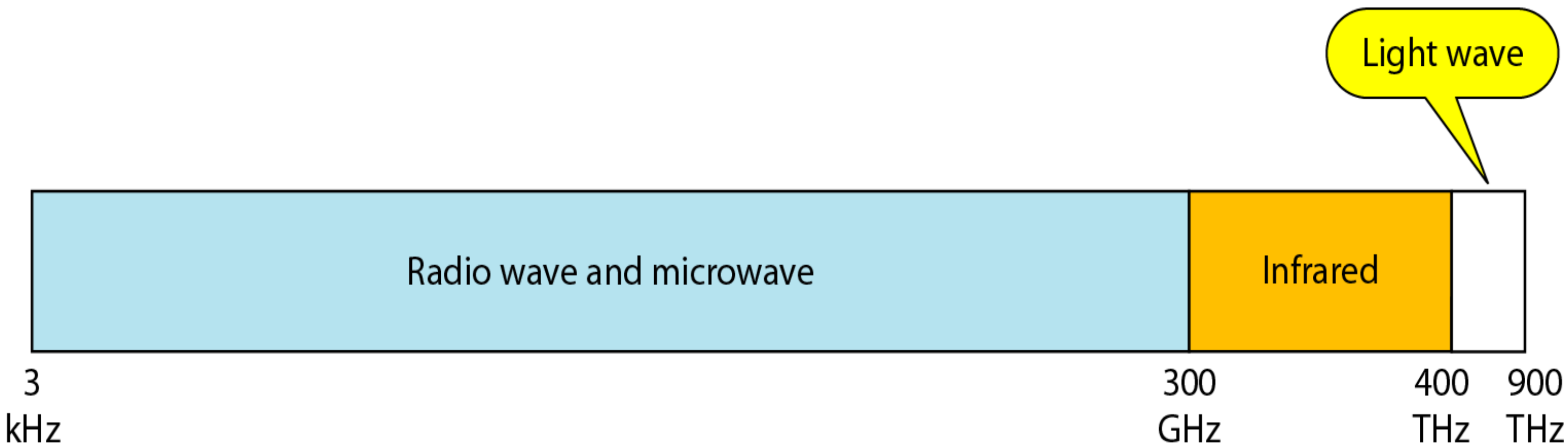
- Higher Bandwidth
- Less Attenuation
- Less EM Interference
- Light Weight
- Less corrosive than copper

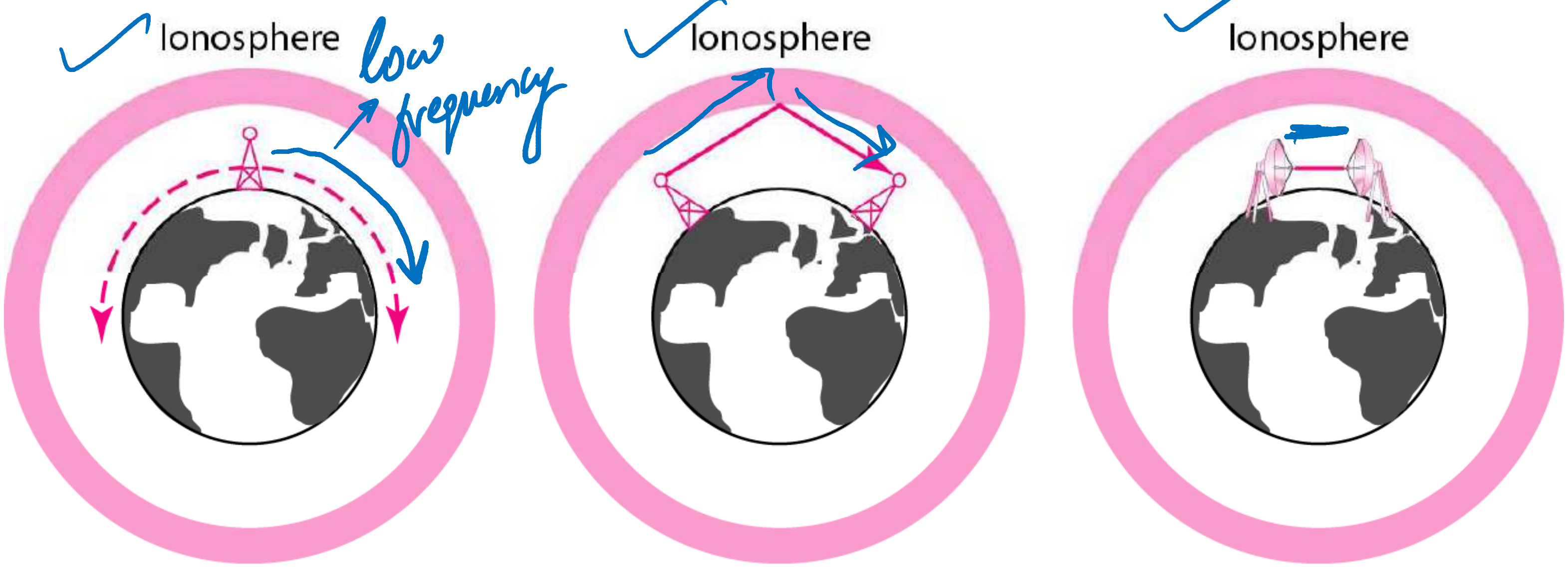
- Installation/Maintenance
- Unidirectional
- Cost

- **Unguided medium transport waves without using a physical conductor**

- **Often referred to wireless communication**

- **Signals are normally broadcast through free space and thus are available to anyone who has a device capable of receiving them**


Light wave
Radio wave and microwave
Infrared
3
kHz
300
GHz
400
THz
900
THz



Ground propagation
(below 2 MHz)

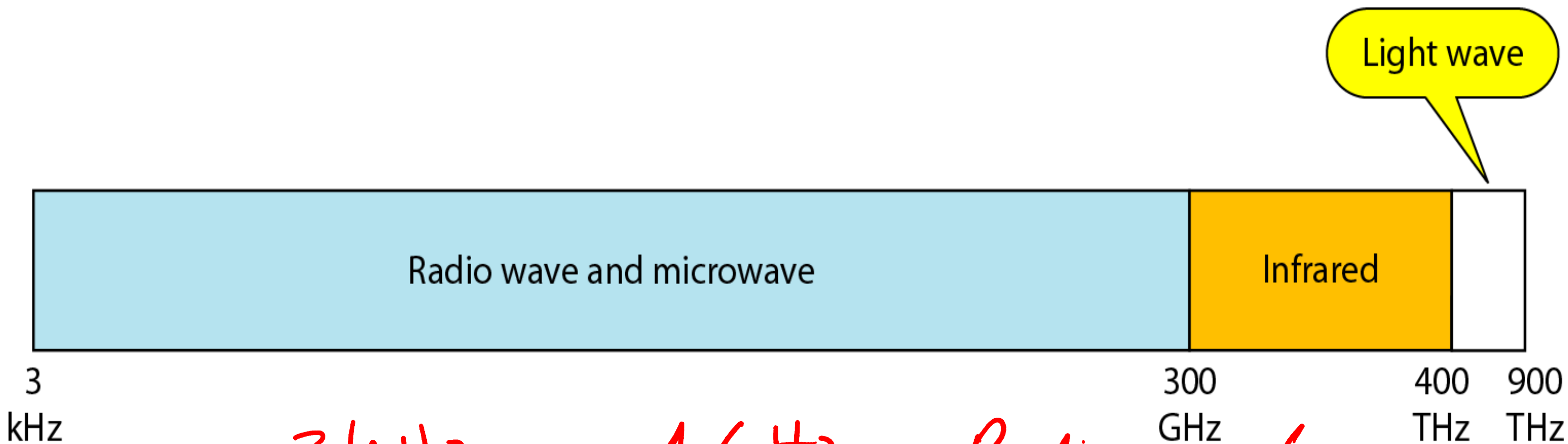
Sky propagation
(2–30 MHz)

Line-of-sight propagation
(above 30 MHz)

Band	*Range*	*Propagation*	*Application*
very low frequency (VLF)	3–30 kHz	Ground	Long-range radio navigation
low frequency (LF)	30–300 kHz	Ground	Radio beacons and navigational locators
middle frequency (MF)	300 kHz–3 MHz	Sky	AM radio
high frequency (HF)	3–30 MHz	Sky	Citizens band (CB), ship/aircraft
very high frequency (VHF)	30–300 MHz	Sky and line-of-sight	VHF TV, FM radio
ultrahigh frequency (UHF)	300 MHz–3 GHz	Line-of-sight	UHF TV, cellular phones, paging, satellite
superhigh frequency (SF)	3–30 GHz	Line-of-sight	Satellite
extremely high frequency (EHF)	30–300 GHz	Line-of-sight	Radar, satellite

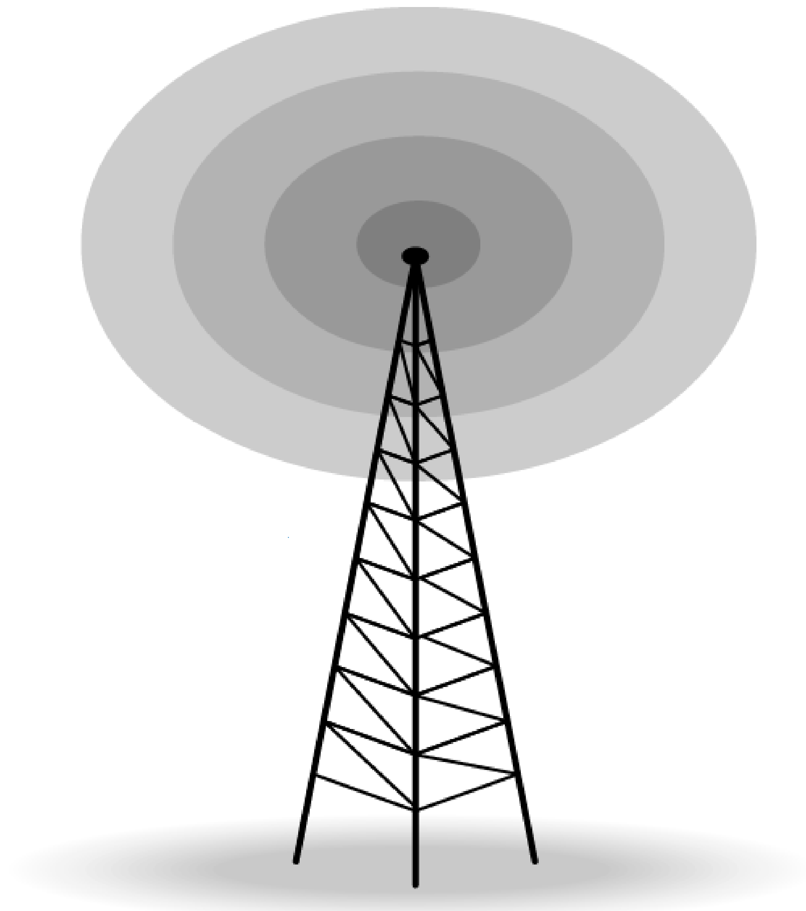
- **Electromagnetic waves ranging in frequencies between 3 kHz and 1 GHz are normally called radio waves**

- **Electromagnetic waves ranging in frequencies between 1 and 300 GHz are called microwaves**



3 kHz → 1 GHz → Radio waves (narrow)

Sub-bands 1 GHz → 3 GHz → Microwaves



AM

FM

Radio

TV

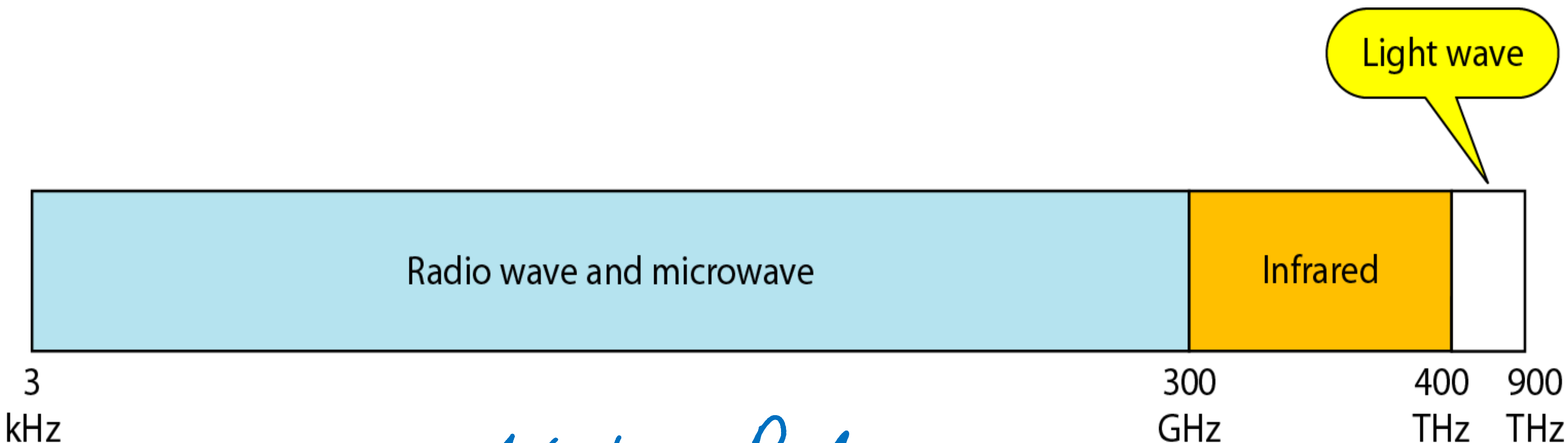
cordless phones

pagers

- **Electromagnetic waves having frequencies between 1 and 300 GHz are called microwaves**

- **Microwaves are unidirectional**

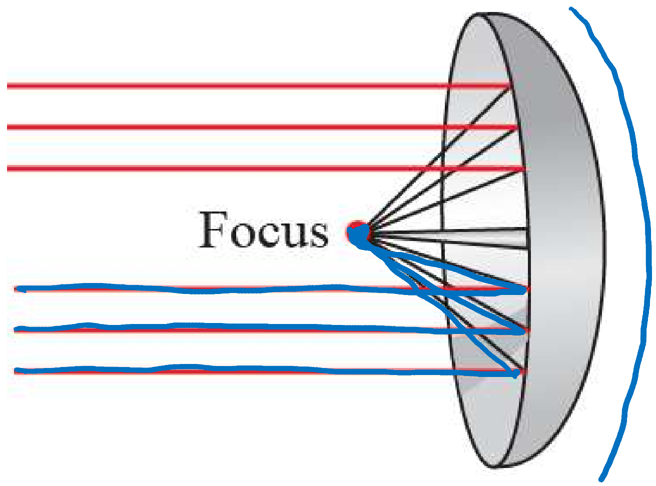
- **When an antenna transmits microwaves, they can be narrowly focused**



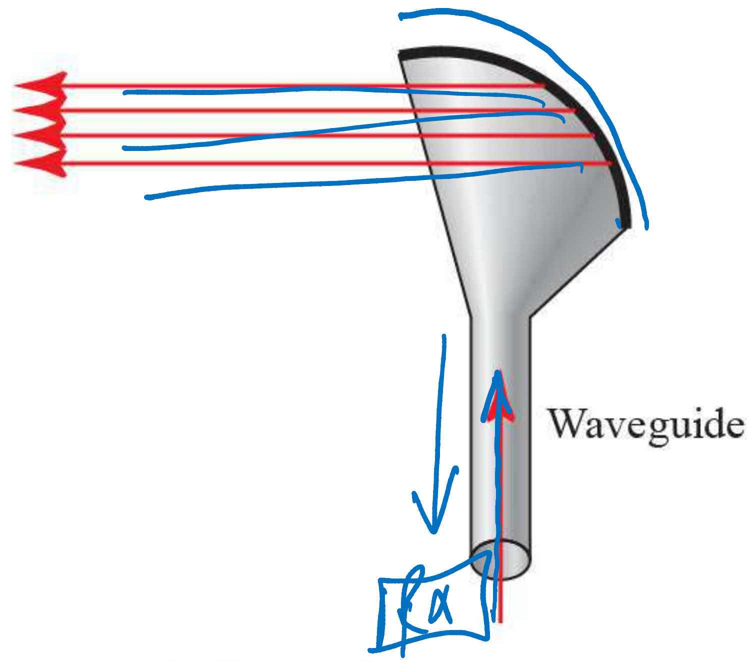
3kHz — 1GHz Radio waves

1GHz — 300GHz Microwaves (unidirectional) (line of sight)

299GHz → High data rates



a. Parabolic dish antenna



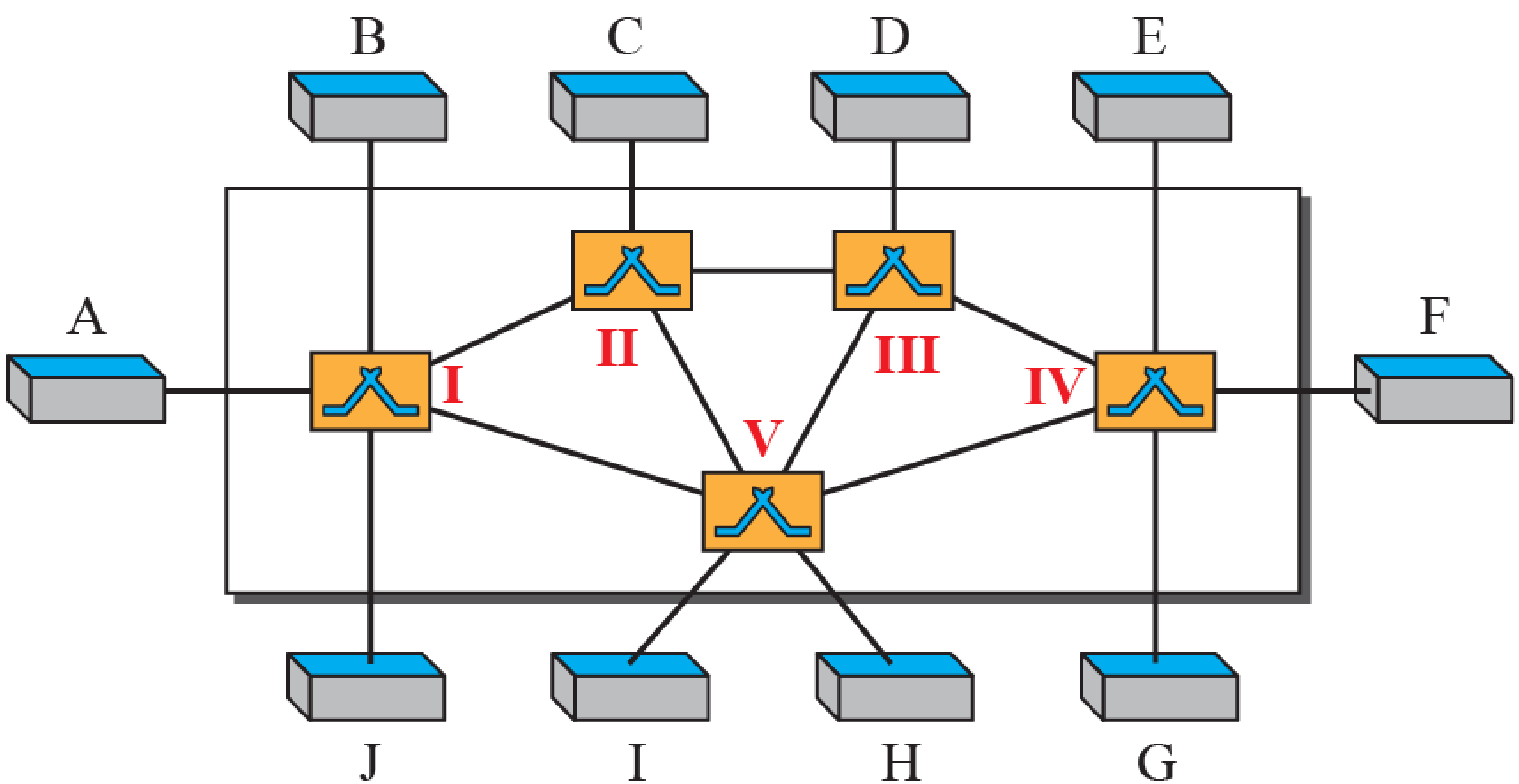
b. Horn antenna

- **Infrared waves, with frequencies from 300 GHz to 400 THz (wavelengths from 1 mm to 770 nm), can be used for short-range communication**

- **Infrared waves, having high frequencies, cannot penetrate walls**

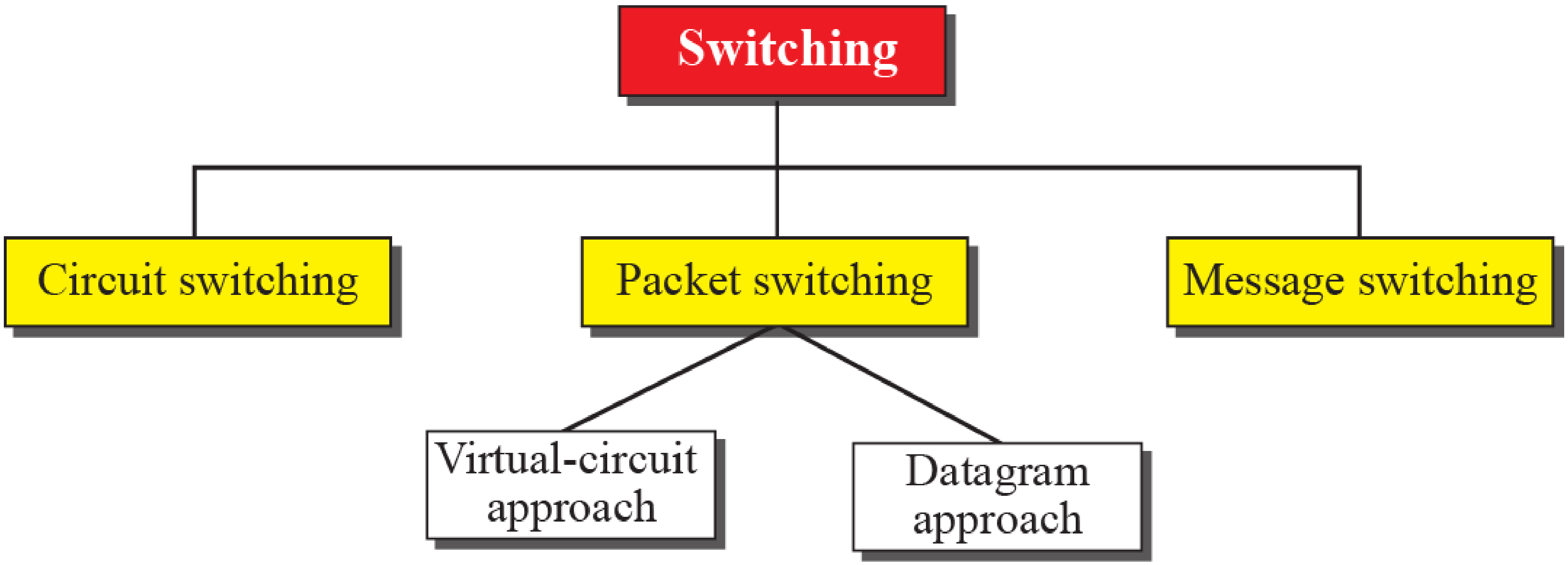
- **Prevents interference between one system and another**

- **A network is a set of connected devices**
- **Problem of how to connect multiple devices to make one-to-one communication possible**
- **The solution is Switching**
- **Switched network consists of a series of switches**



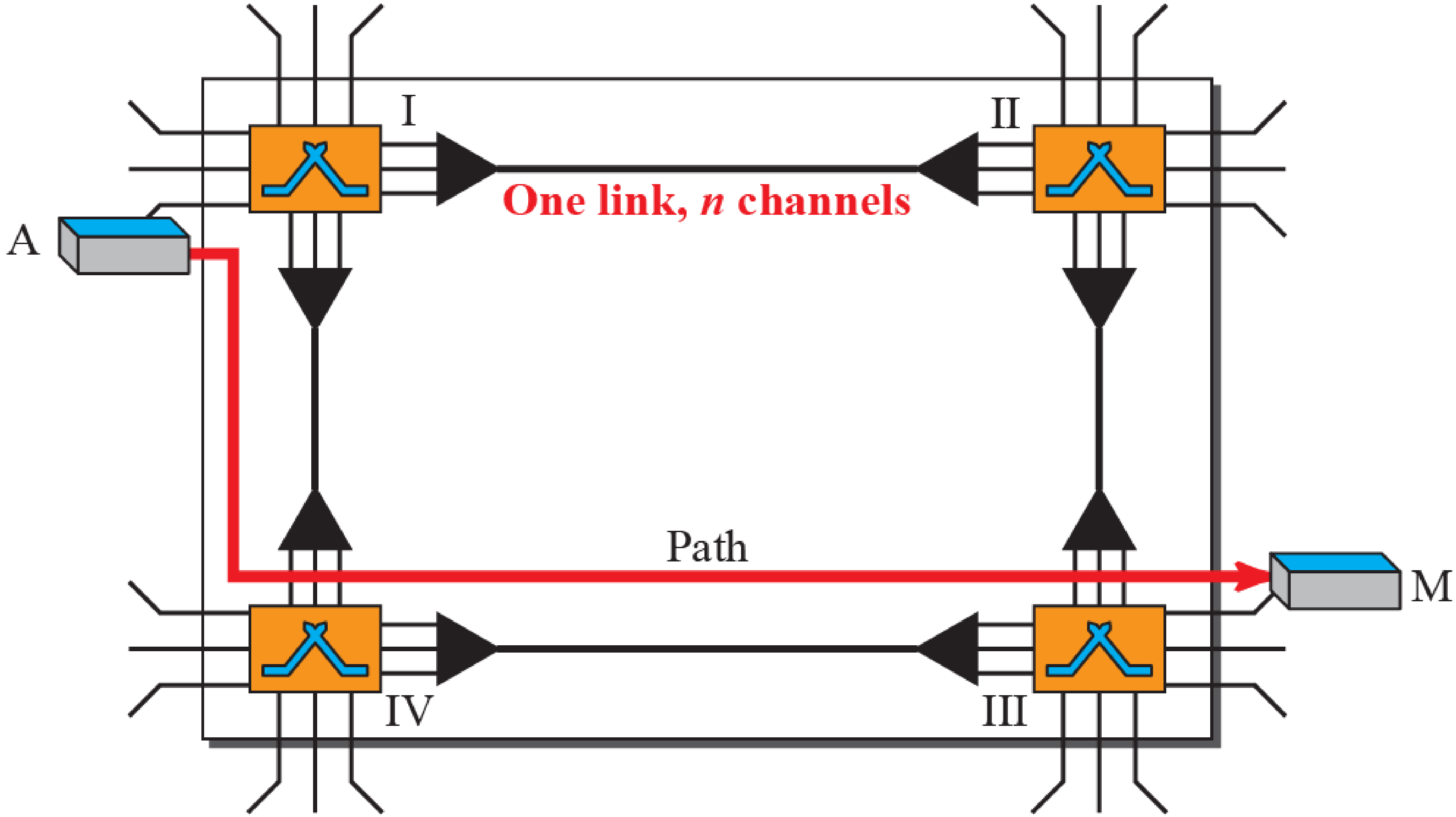
B
C
D
E
A
F
I
II
III
IV
V
J
I
H
G

- **Three Methods:**
  - ✓ **Circuit Switching**
  - ✓ **Packet Switching**
  - ✓ **Message switching**
- **The first two are commonly used today**
- **The third has been phased out in general communications**

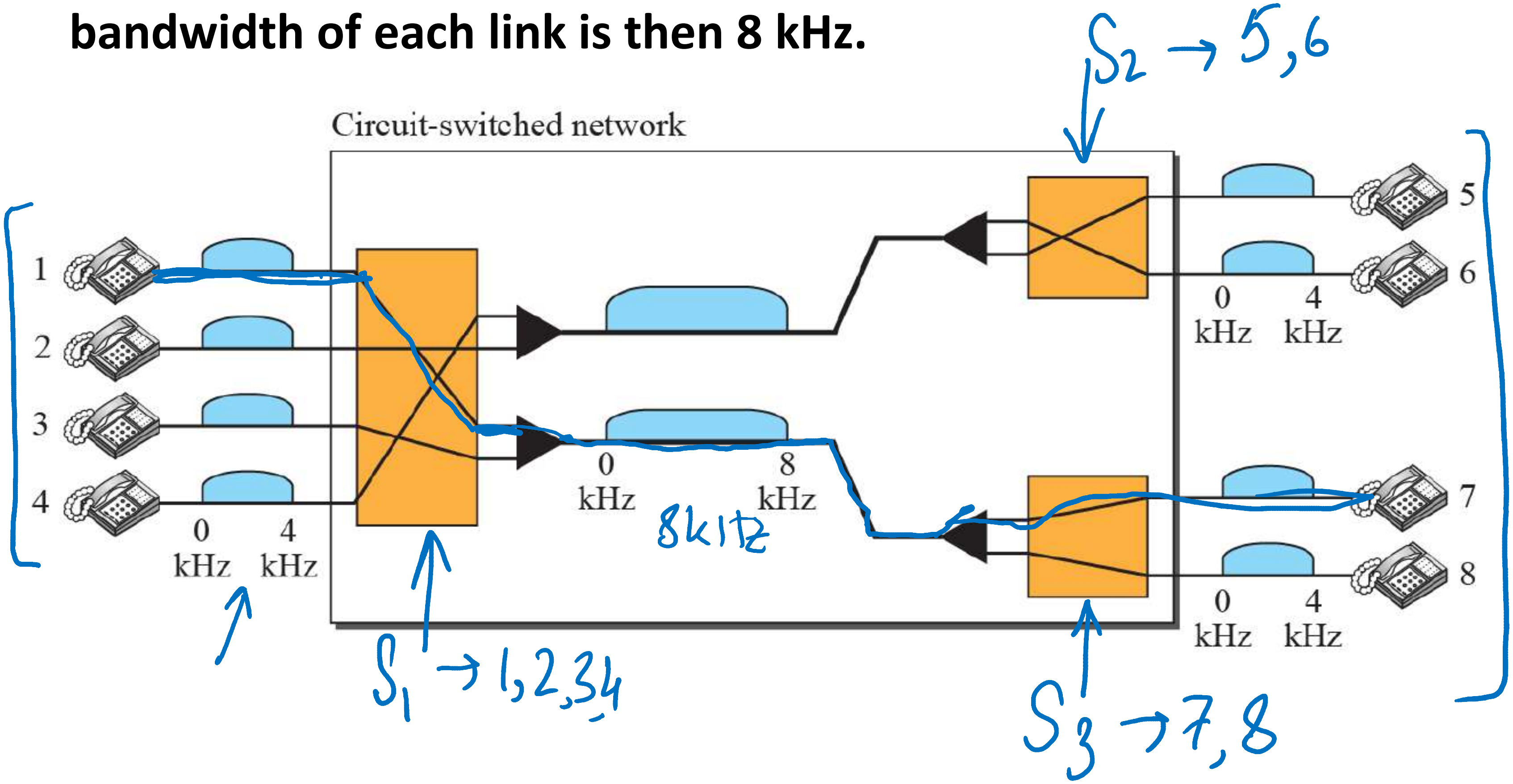

Switching
Circuit switching
Packet switching
Message switching
Virtual-circuit approach
Datagram approach

- **A set of switches connected by physical links**
- **A connection between two stations is a dedicated path made of one or more links**
- **Each connection uses only one dedicated channel on each link**
- **Each link is normally divided into n channels by using FDM or TDM**

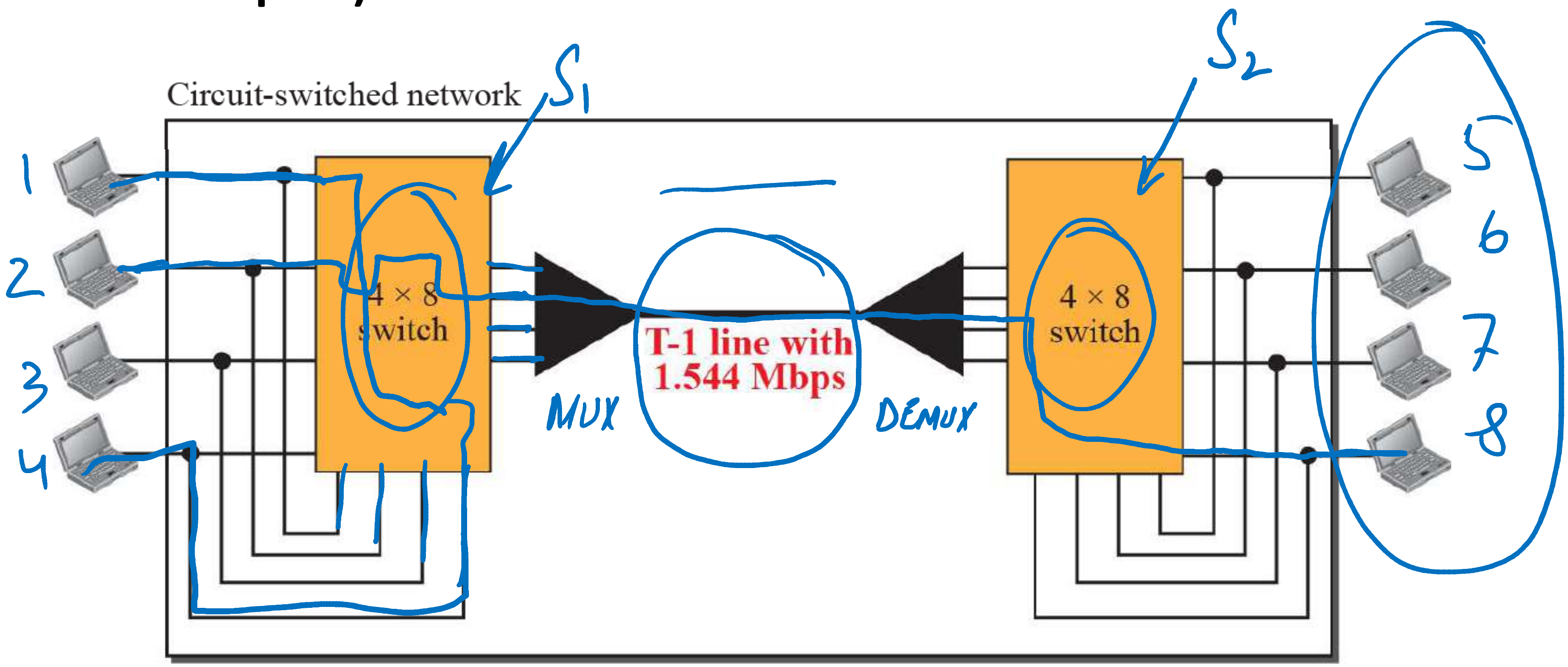
- **A set of switches connected by physical links**


I
II
III
IV
A
M
One link, *n* channels
Path

As a trivial example, let us use a circuit-switched network to connect eight telephones in a small area. Communication is through 4-kHz voice channels. We assume that each link uses FDM to connect a maximum of two voice channels. The bandwidth of each link is then 8 kHz.

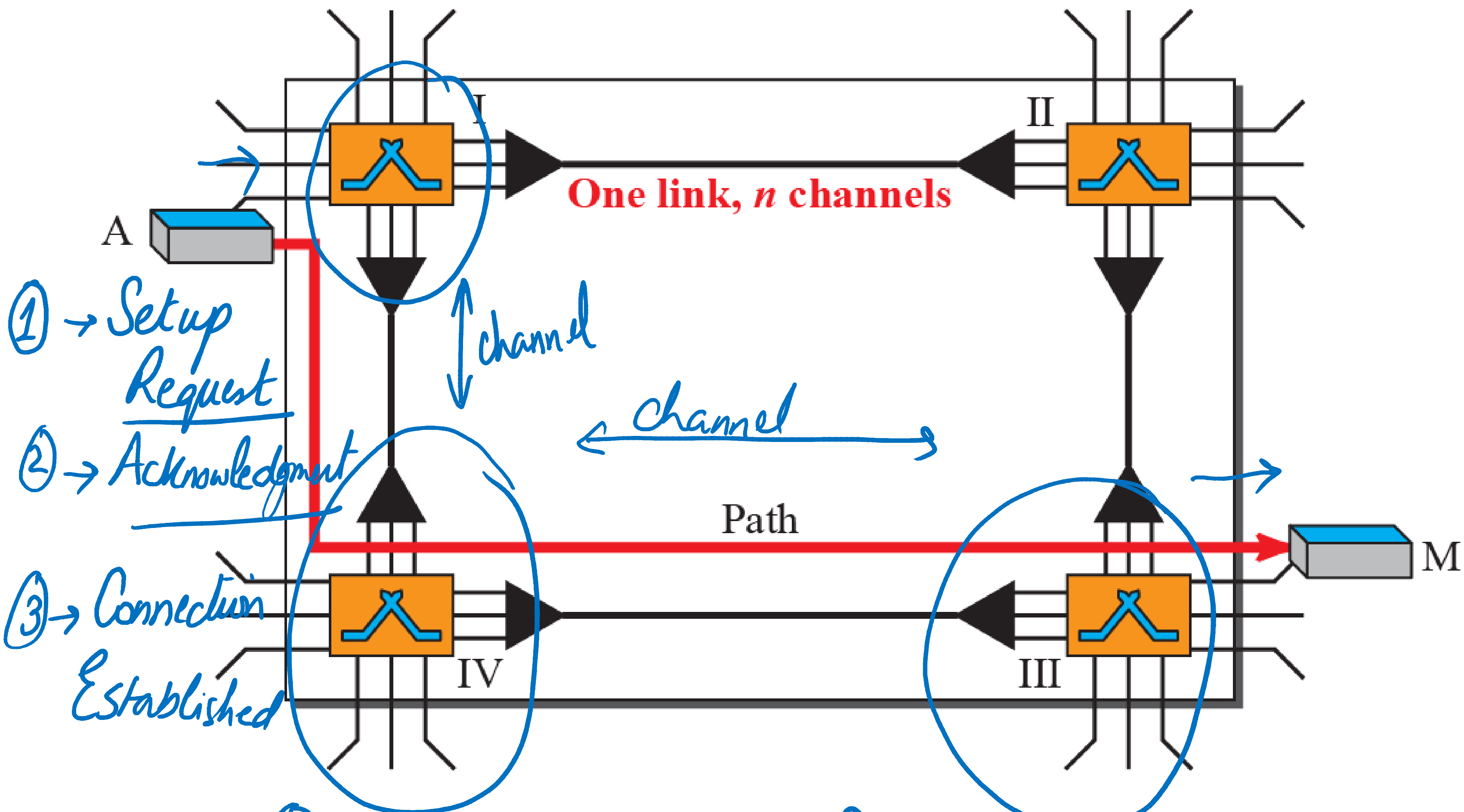


As another example, consider a circuit-switched network that connects computers in two remote offices of a private company. The offices are connected using a T-1 line leased from a communication service provider. There are two 4 × 8 (4 inputs and 8 outputs) switches in this network.



- **The actual communication in a circuit-switched network requires 3 phases:**
    - ✓ **Connection Setup**
    - ✓ **Data Transfer**
    - ✓ **Connection Teardown**

Dedicated Circuit → Link with channels



④ Data Transfer ⑤ Teardown phase.

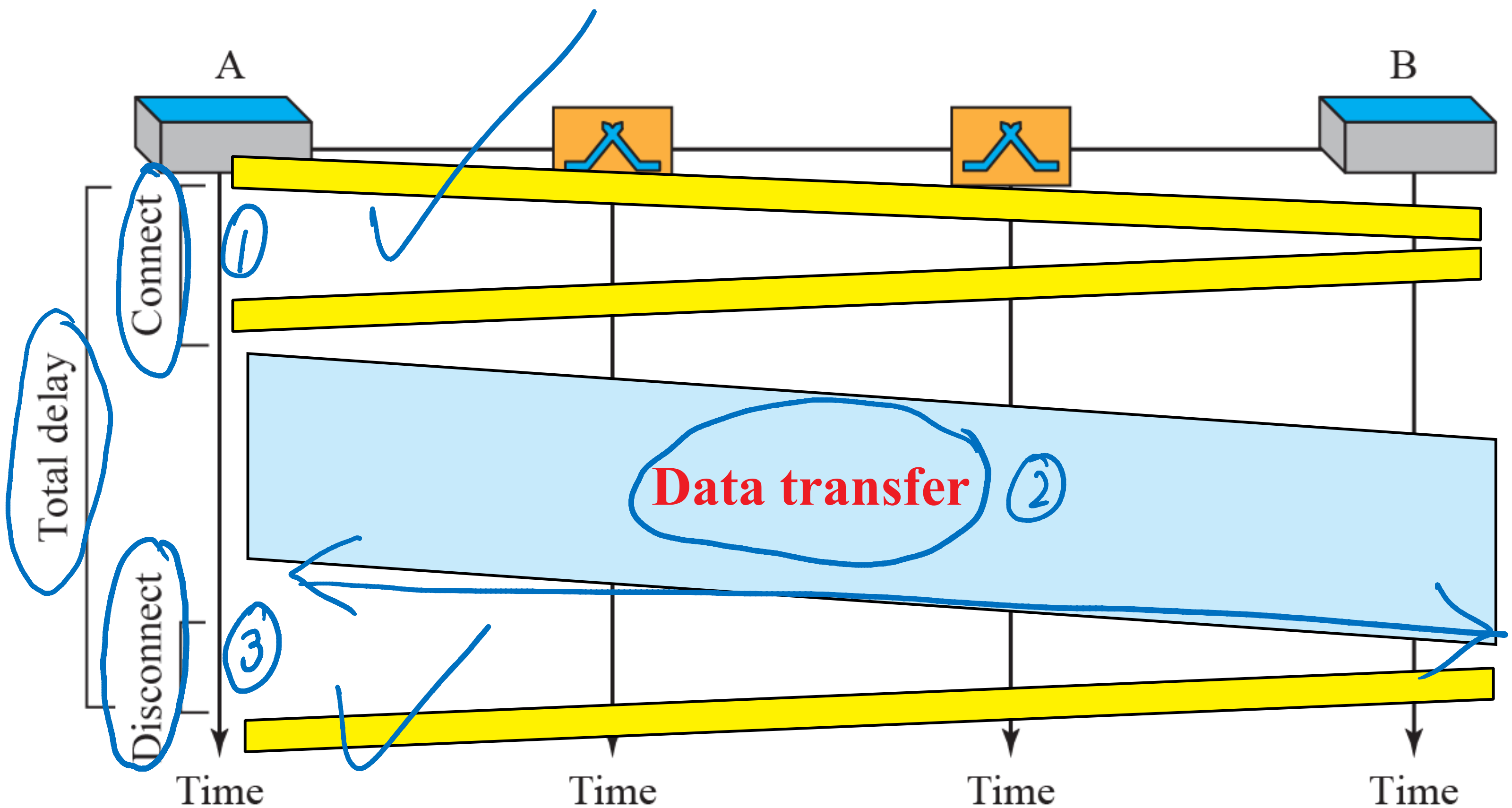
- **Not as efficient as packet switching because resources are allocated during the entire duration of the connection and these resources are unavailable to other connections**

- **In a telephone network, people normally terminate the communication when they have finished their conversation**

- **Data Network is an issue**

- **Circuit switched networks have low efficiency but minimal delay**

- **Data is not delayed at each switch; the resources are allocated for the duration of the connection**



A
B
Connect
Total delay
Disconnect
Data transfer
1
2
3
Time
Time
Time
Time

- If the message is going to pass through a packet-switched network, it needs to be divided into packets of fixed or variable size

- The size of the packet is determined by the network and the governing protocol

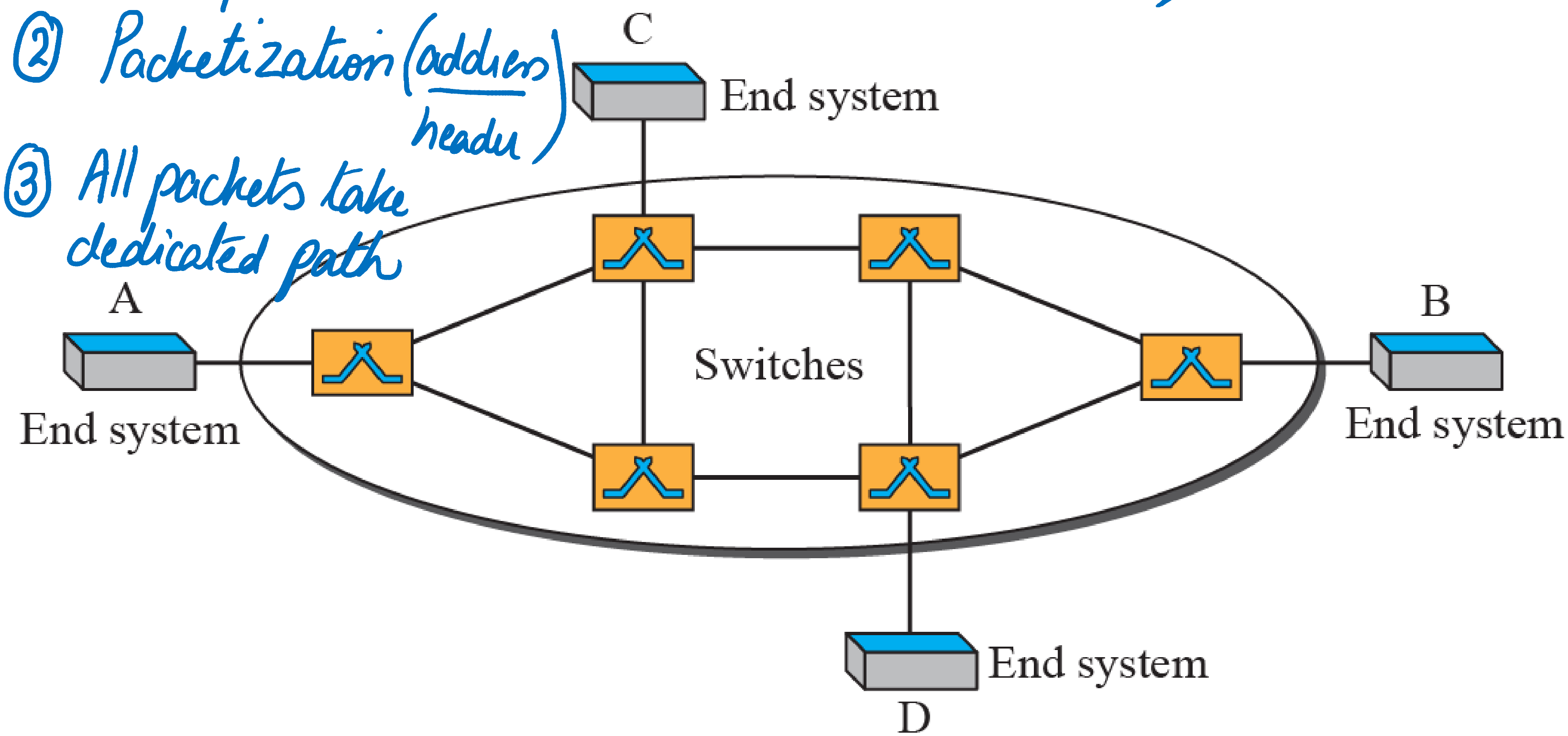
- Each packet is treated independently of all others.
- Even if a packet is part of a multi-packet transmission, the network treats it as though it existed alone
- Packets are referred to as datagrams

- **A virtual-circuit network is a cross between a circuit-switched network and a datagram network**

① Setup & Teardown process (resources reservation)

② Packetization (address header)

③ All packets take dedicated path



- **A virtual-circuit network is a cross between a circuit-switched network and a datagram network**

Physical → Circuit Switching (Set up, Transfer & Teardown)

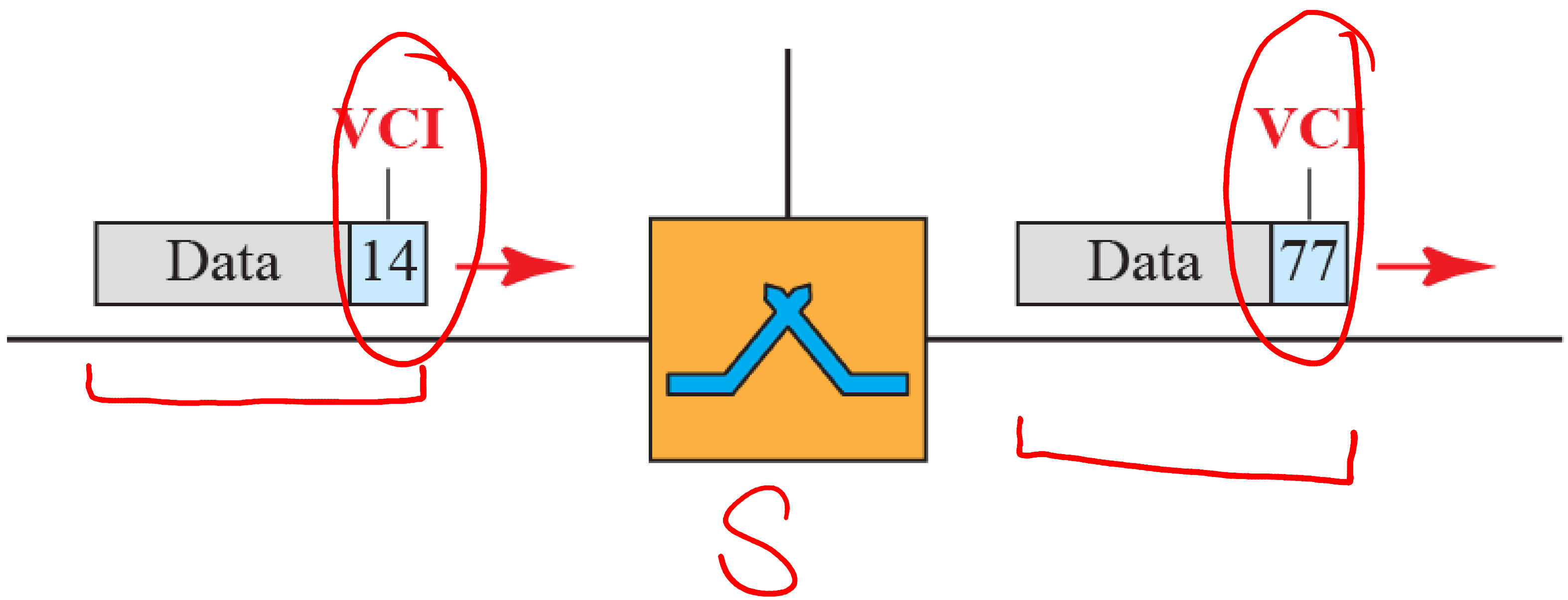
Data Link Layer → Virtual Circuit Approach (Set up, Transfer & Teardown

→ Packets (Frames)

Network Layer → Datagram Switching (Independent Datagrams or Packets)

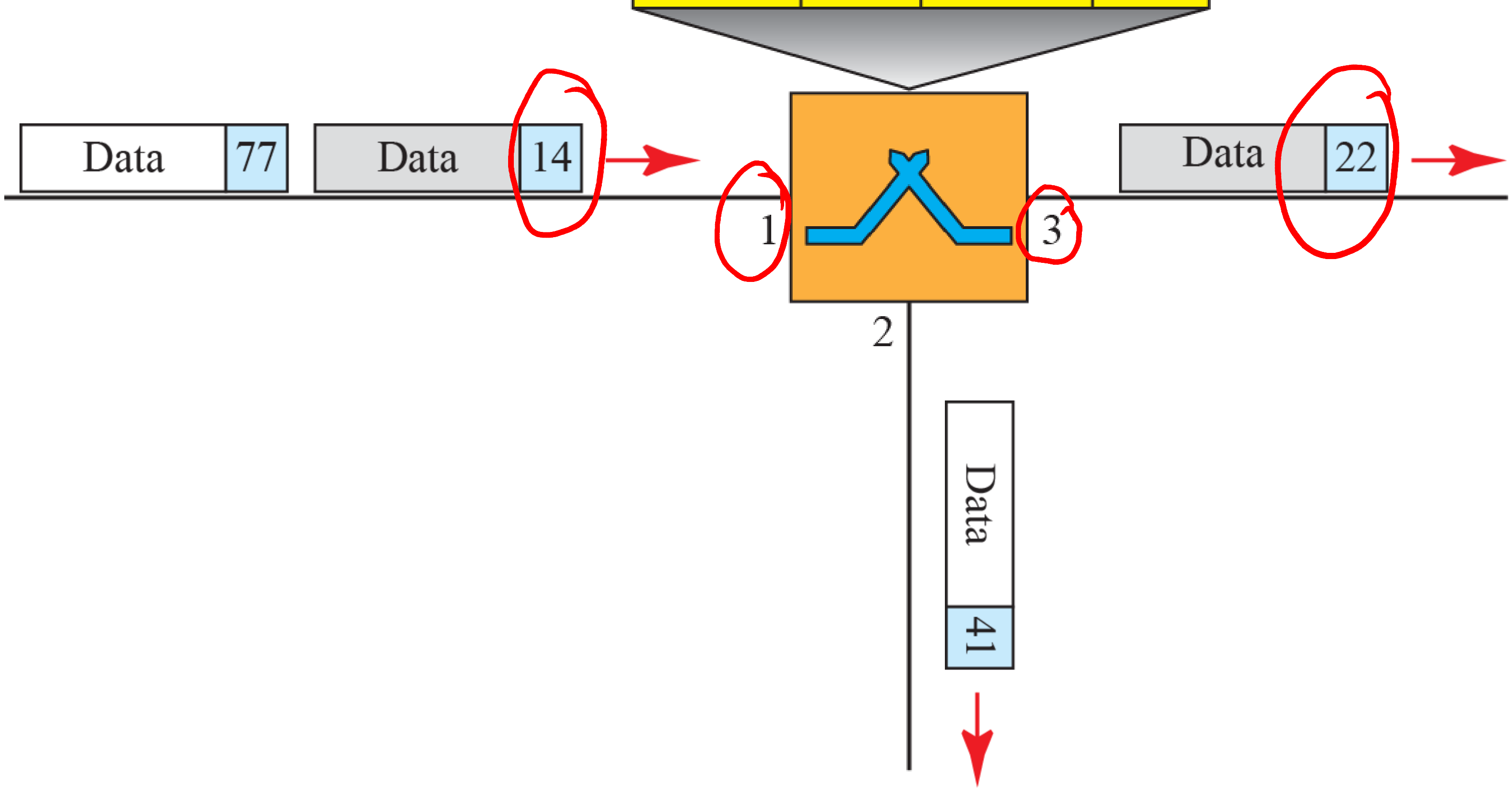
- **A virtual-circuit network is a cross between a circuit-switched network and a datagram network**

VCI (label) → local switch scope



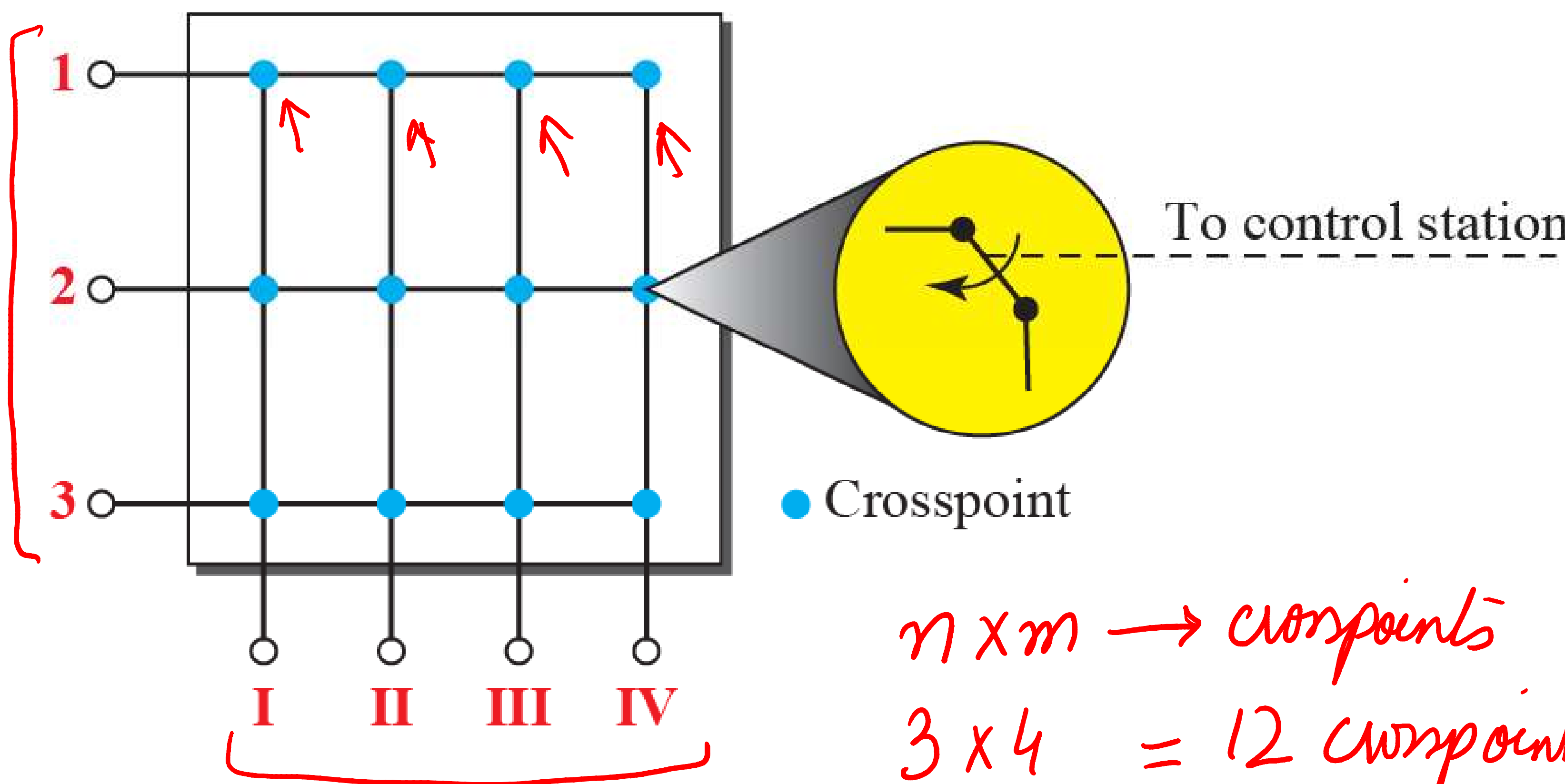
Data Transfer Phase

Incoming		Outgoing	
Port	VCI	Port	VCI
1	14	3	22
1	77	2	41



- **Circuit switching today can use either of two technologies:**
  - ✓ **The Space-Division switch**
  - ✓ **The Time-Division switch**

n inputs m outputs $(n=3;\ m=4)$

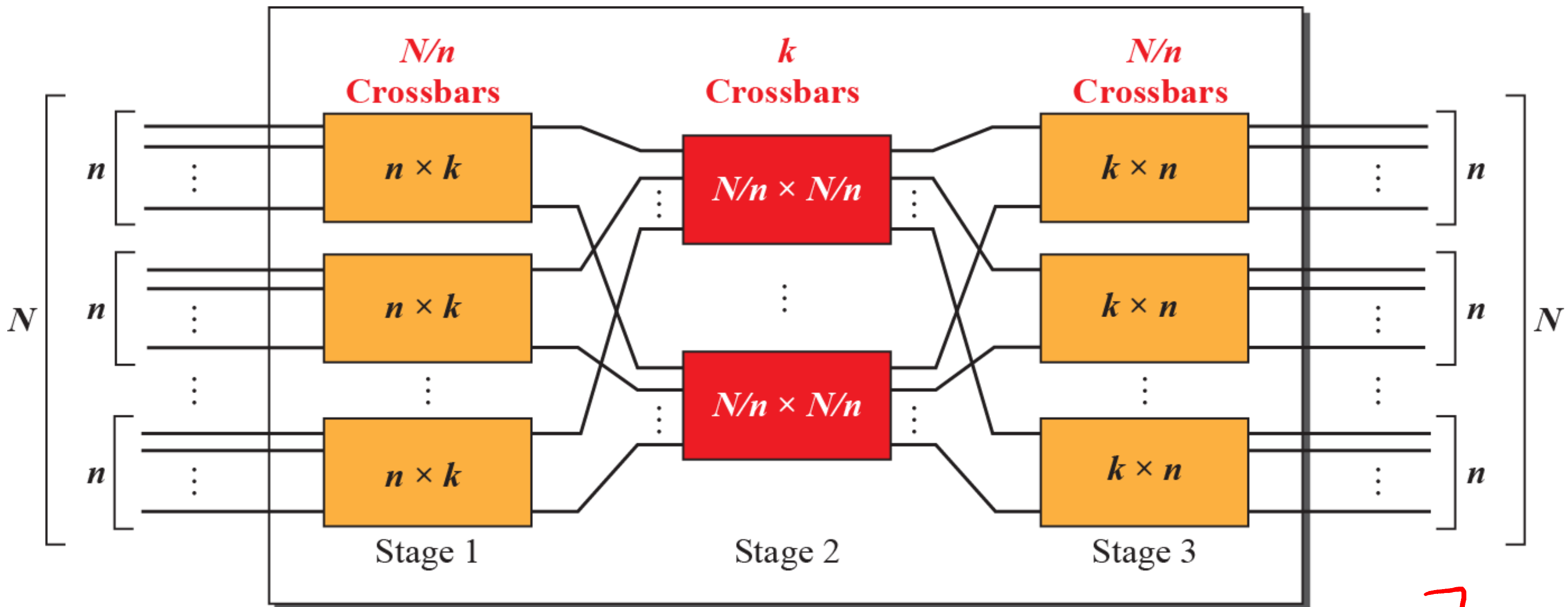


$n \times m \rightarrow$ crosspoints

$3 \times 4 = 12$ crosspoints

$\boxed{25\% \text{ of crosspoints}}$

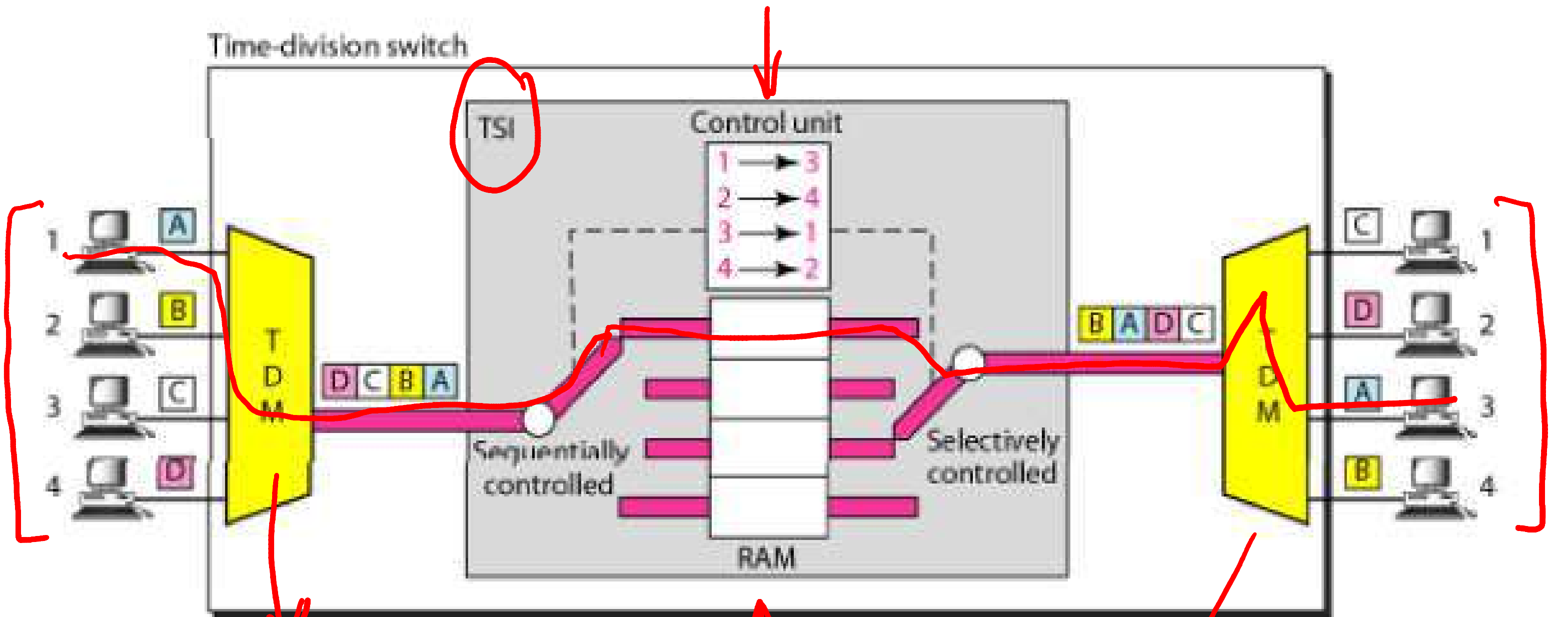
$N \times N$ crosspoints



No. of crosspoints $\Rightarrow 2kN + k\left(\frac{N}{n}\right)^2$ → lesser

" " " $\Rightarrow N^2$

- **Uses TDM inside a switch**
- **Most popular technology is Time-Slot Interchange (TSI)**



MUX

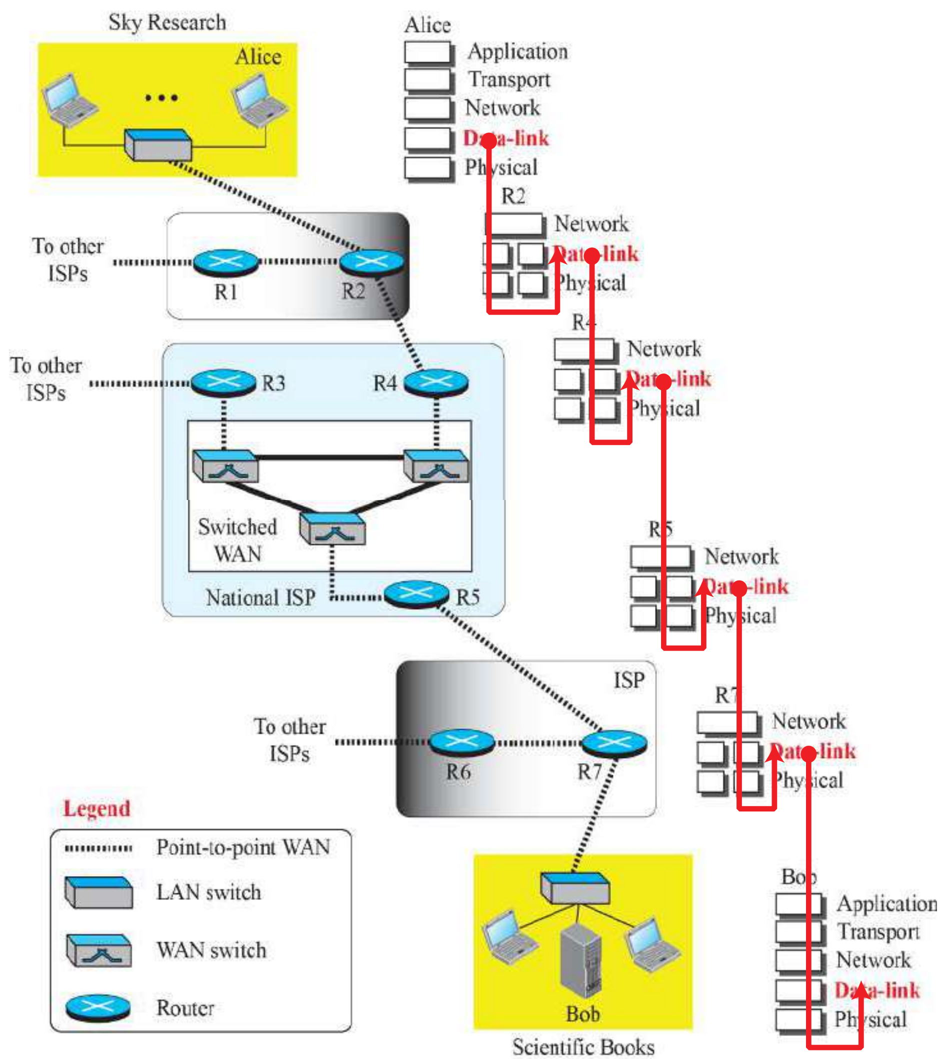
memory locations
↕
time slots

DEMUX

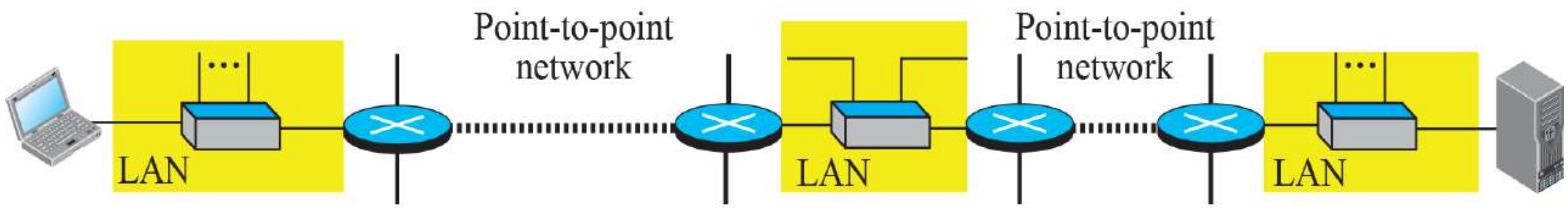
1 → 3
2 → 4
3 → 1
4 — 2

Data-Link Layer

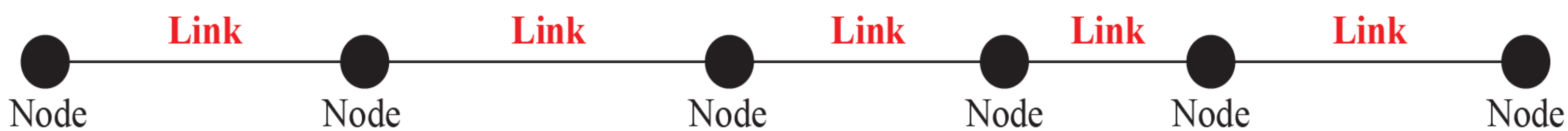
- The Internet is a combination of networks glued together by connecting devices (routers or switches)
- If a packet is to travel from a host to another host, it needs to pass through these networks
- Data Link layer controls node-to-node communication


Sky Research
Alice
To other ISPs
R1
R2
To other ISPs
R3
R4
Switched WAN
National ISP
R5
ISP
To other ISPs
R6
R7
Bob
Scientific Books
Legend
Point-to-point WAN
LAN switch
WAN switch
Router
Alice
Application
Transport
Network
Data-link
Physical
R2
Network
Data-link
Physical
R4
Network
Data-link
Physical
R5
Network
Data-link
Physical
R7
Network
Data-link
Physical
Bob
Application
Transport
Network
Data-link
Physical

- Communication at the data-link layer is node-to-node
- A data unit from one point in the Internet needs to pass through many networks (LANs and WANs) to reach another point
- We refer to the two end hosts and the routers as nodes and the networks in between as links

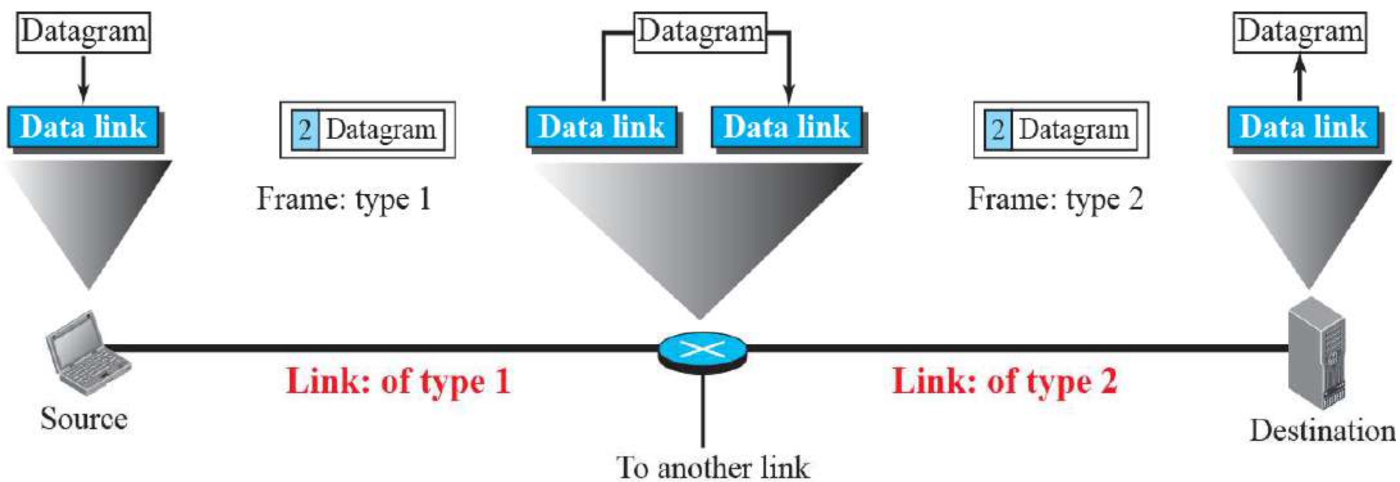


a. A small part of the Internet



b. Nodes and links

- **Located between the physical and the network layers**
- **Provides services to Network Layer and receives services from Physical layer**
- **Framing**
- **Flow Control**
- **Error Control**
- **Congestion Control**


Datagram
Data link
2 Datagram
Frame: type 1
Datagram
Data link
Data link
2 Datagram
Frame: type 2
Datagram
Data link
Source
Link: of type 1
To another link
Link: of type 2
Destination

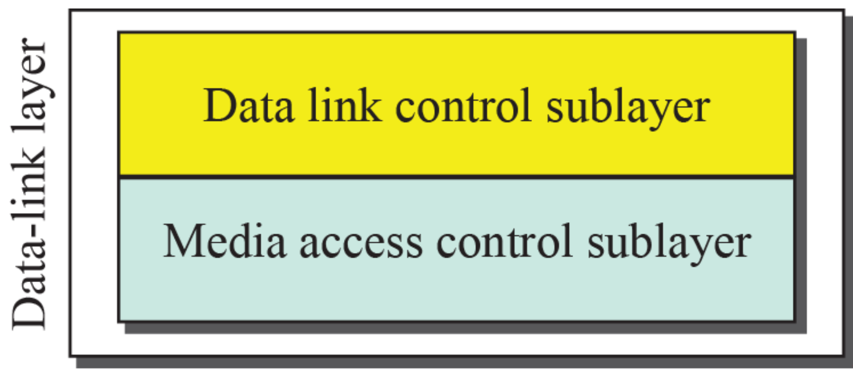
- **Data-Link layer provides services to Network Layer and receives services from Physical layer**

  - ✓ **Framing**
  - ✓ **Flow Control**
  - ✓ **Error Control**
  - ✓ **Congestion Control**

- **Two nodes are physically connected by a transmission medium such as cable or air**
- **Data-link layer controls how the medium is used**
  - ✓ **Data-link layer can use whole capacity**
  - ✓ **Data-link layer can use only part of the capacity**

- **We can have the following two types of links:**
    - ✓ **Point-to-point link or a**
    - ✓ **Broadcast link**

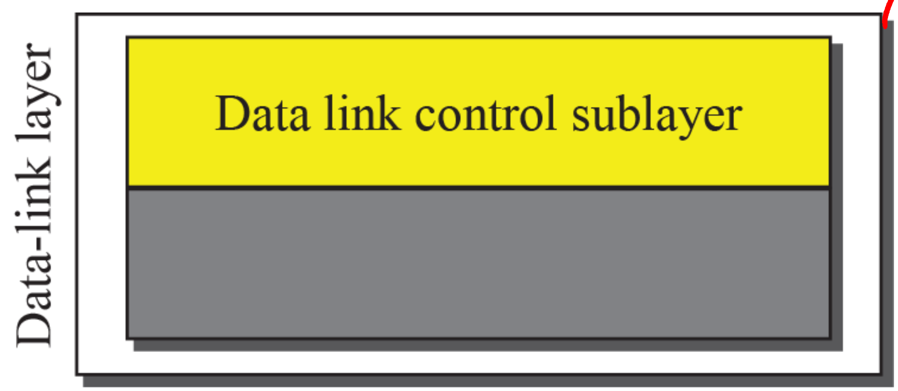
- We can divide the data-link layer into two sublayers:
  - Data Link Control (DLC)
  - Media Access Control (MAC)



a. Data-link layer of a broadcast link

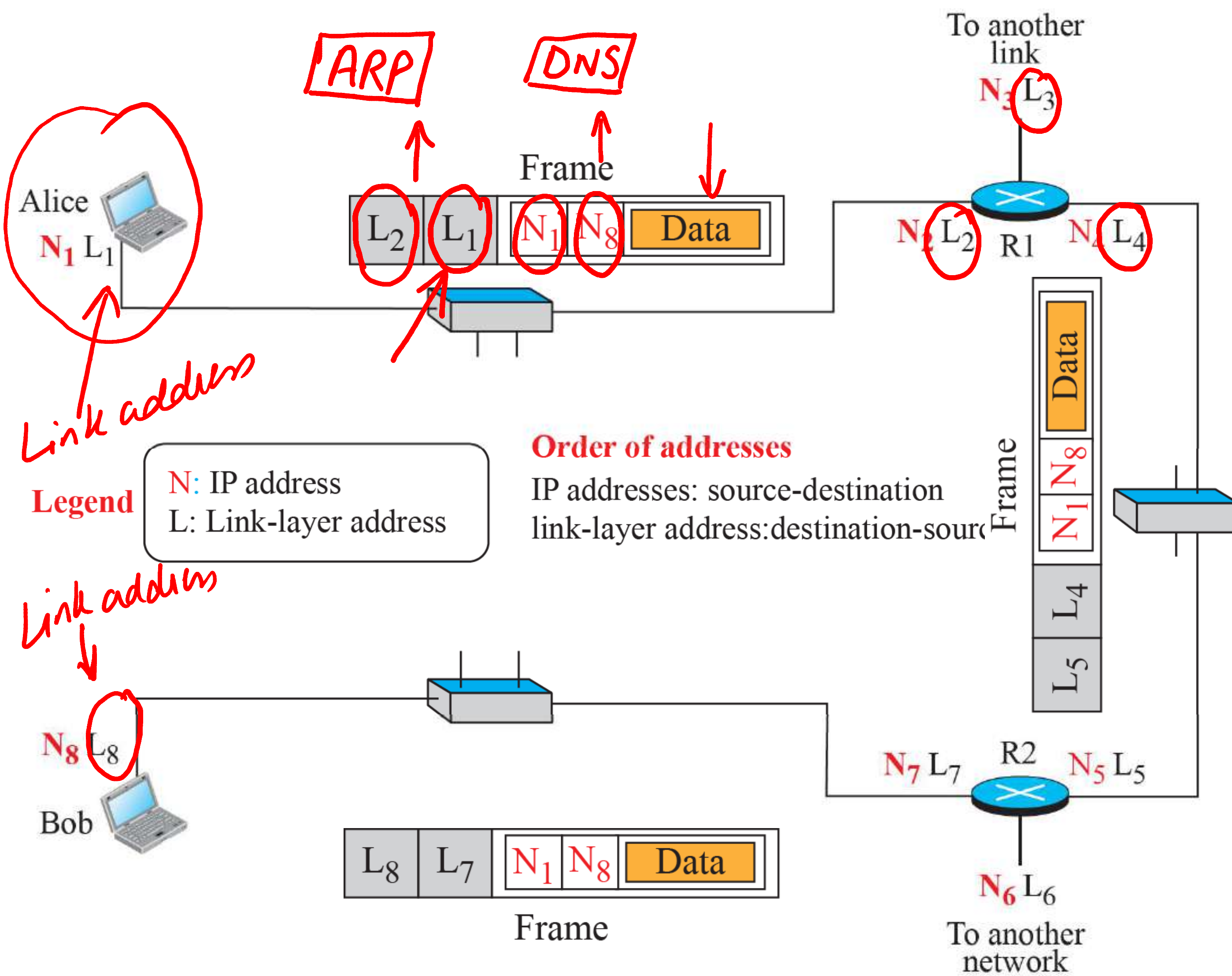
*DLC → - Broadcast links
- Point-to-point Links

*MAC → - Broadcast Link only



b. Data-link layer of a point-to-point link

- IP addresses are the identifiers at the network layer
- In Internet we cannot make a packet reach its destination using only IP addresses
- Source and destination IP addresses define the two ends but cannot define which links the packet will take



Router → n interfaces
↳ n link addresses.

- **Some link-layer protocols define three types of addresses:**
- **Unicast**
- **Multicast**
- **Broadcast**

The unicast link-layer addresses in the most common LAN, Ethernet, are 48 bits (six bytes) that are presented as 12 hexadecimal digits separated by colons; for example, the following is a link-layer address of a computer. The second digit needs to be an odd number.

48 bits

↳ 6 Bytes

A3:34:45:11:92:F1

12 Hex digits separated by colons

The multicast link-layer addresses in the most common LAN, Ethernet, are 48 bits (six bytes) that are presented as 12 hexadecimal digits separated by colons. The second digit, however, needs to be an even number in hexadecimal. The following shows a
multicast address:

*DLC → – Broadcast Links
– Point-to-point Links

*MAC → – Broadcast Link only

A2:34:45:11:92:F1

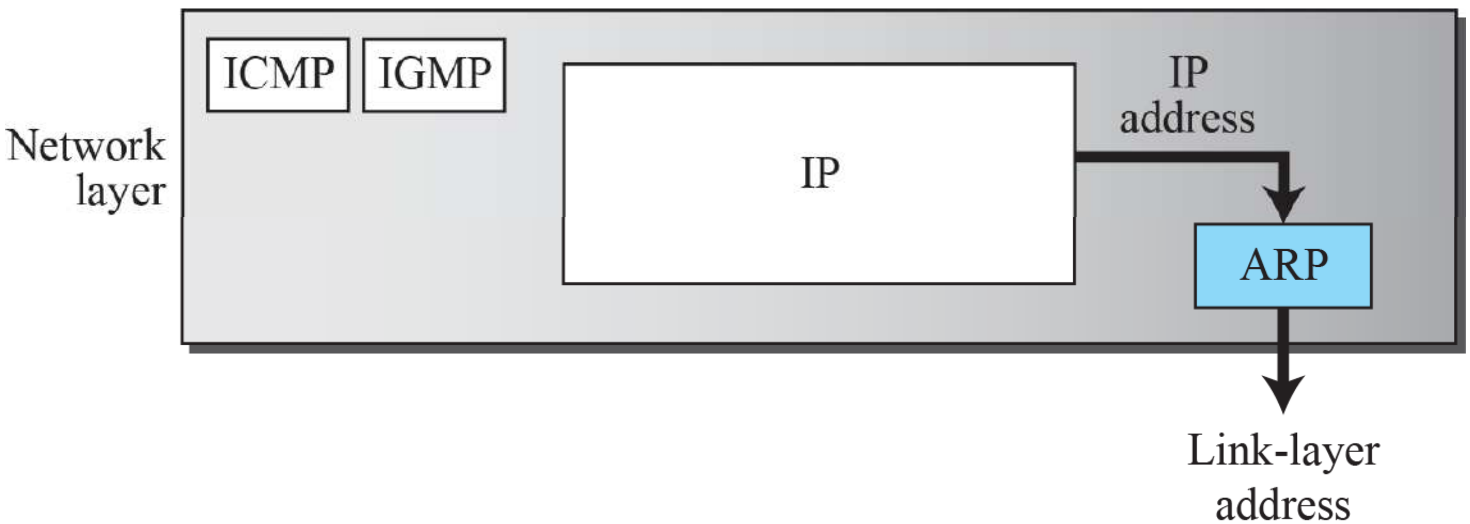
The broadcast link-layer addresses in the most common LAN, Ethernet, are 48 bits, all 1s, that are presented as 12 hexadecimal digits separated by colons. The following shows a broadcast address:

FF:FF:FF:FF:FF:FF

- **Anytime a node has an IP packet to send to another node in a link, it has the IP address of the receiving node**

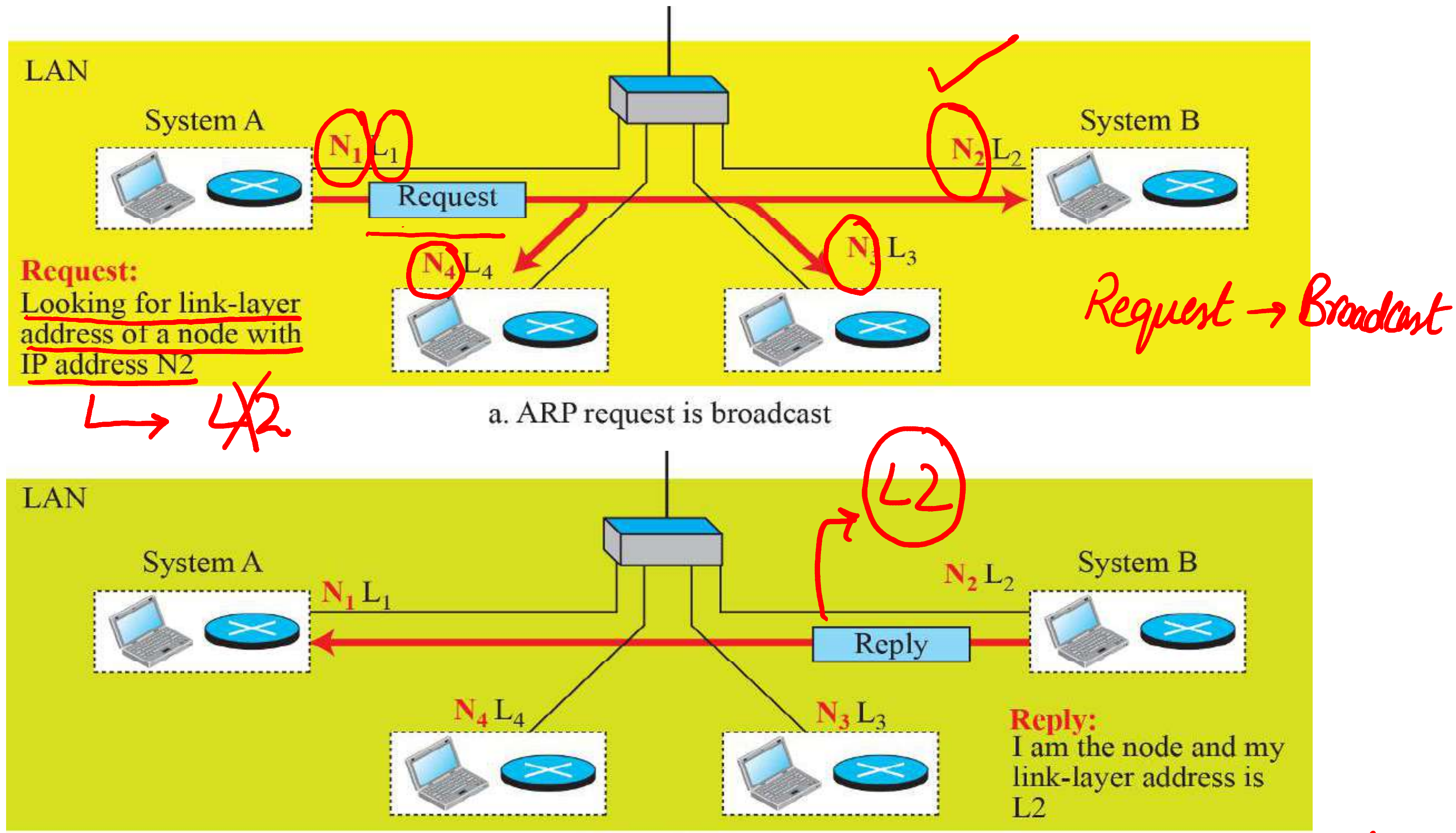
- **IP address of the next node is not helpful in moving a frame through a link; we need the link-layer address of the next node**

- **We need Address Resolution Protocol (ARP)**


Network layer
ICMP
IGMP
IP
IP address
ARP
Link-layer address

- **Anytime a node has an IP packet to send to another node in a link, it has the IP address of the receiving node**

- **IP address of the next node is not helpful in moving a frame through a link; we need the link-layer address of the next node**



a. ARP request is broadcast

b. ARP reply is unicast

Reply → unicast

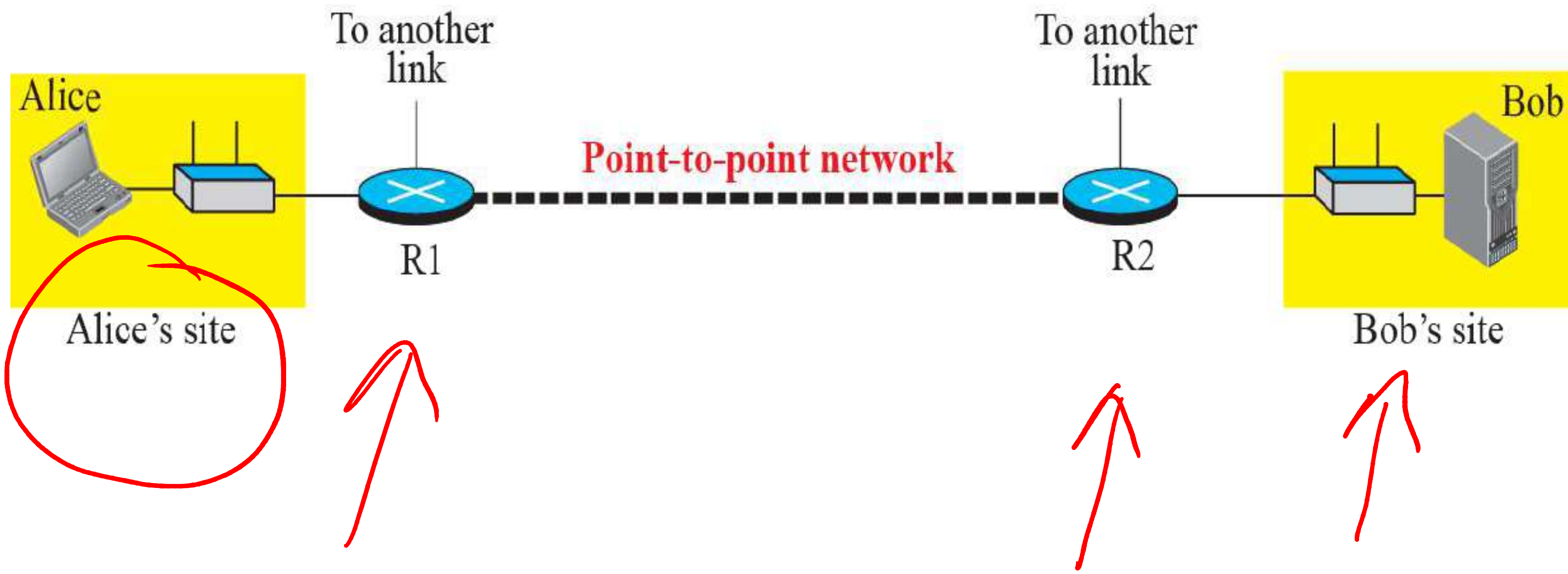
- **Anytime a node has an IP packet to send to another node in a link, it has the IP address of the receiving node**

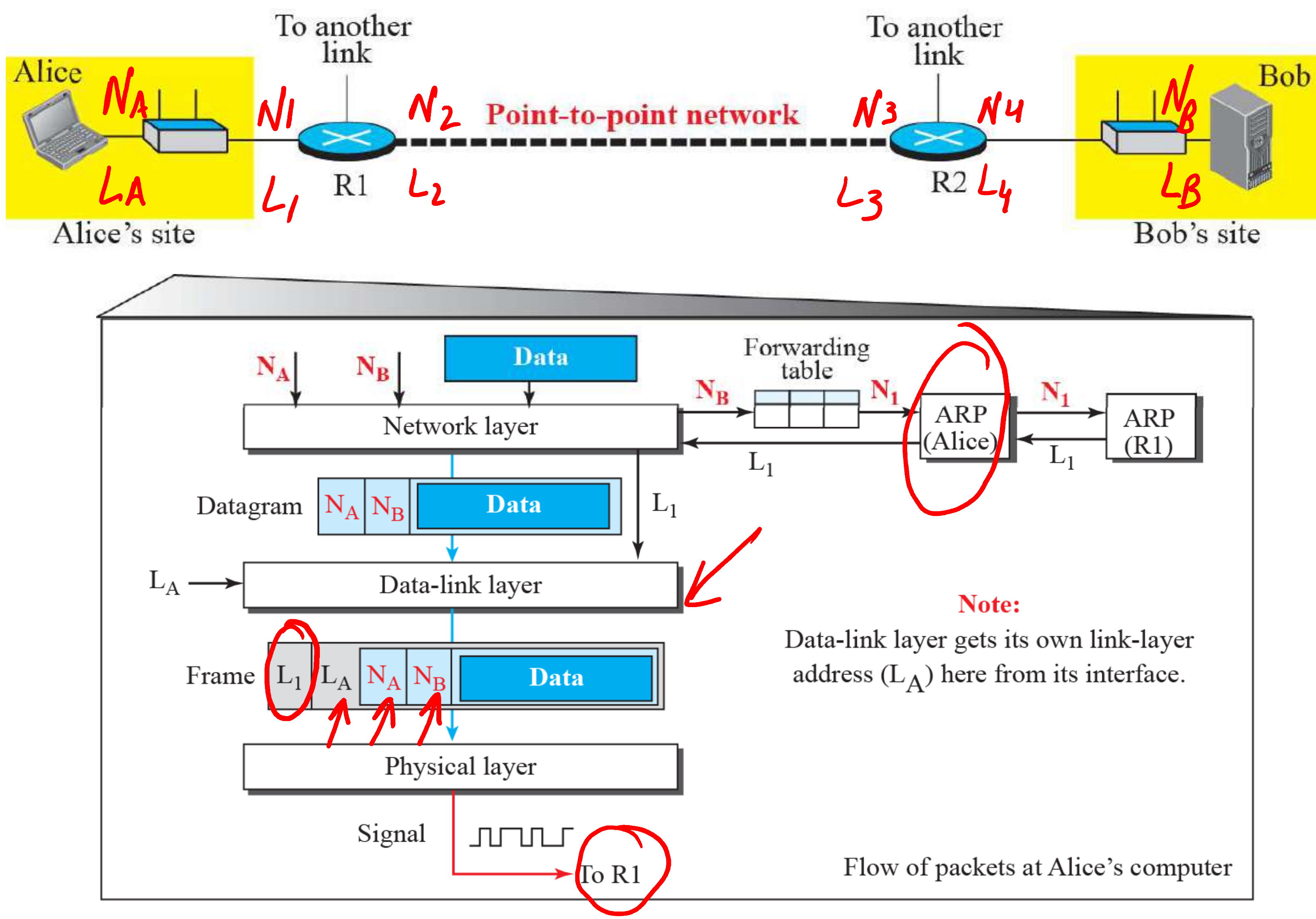
- **IP address of the next node is not helpful in moving a frame through a link; we need the link-layer address of the next node**

Hardware: LAN or WAN protocol

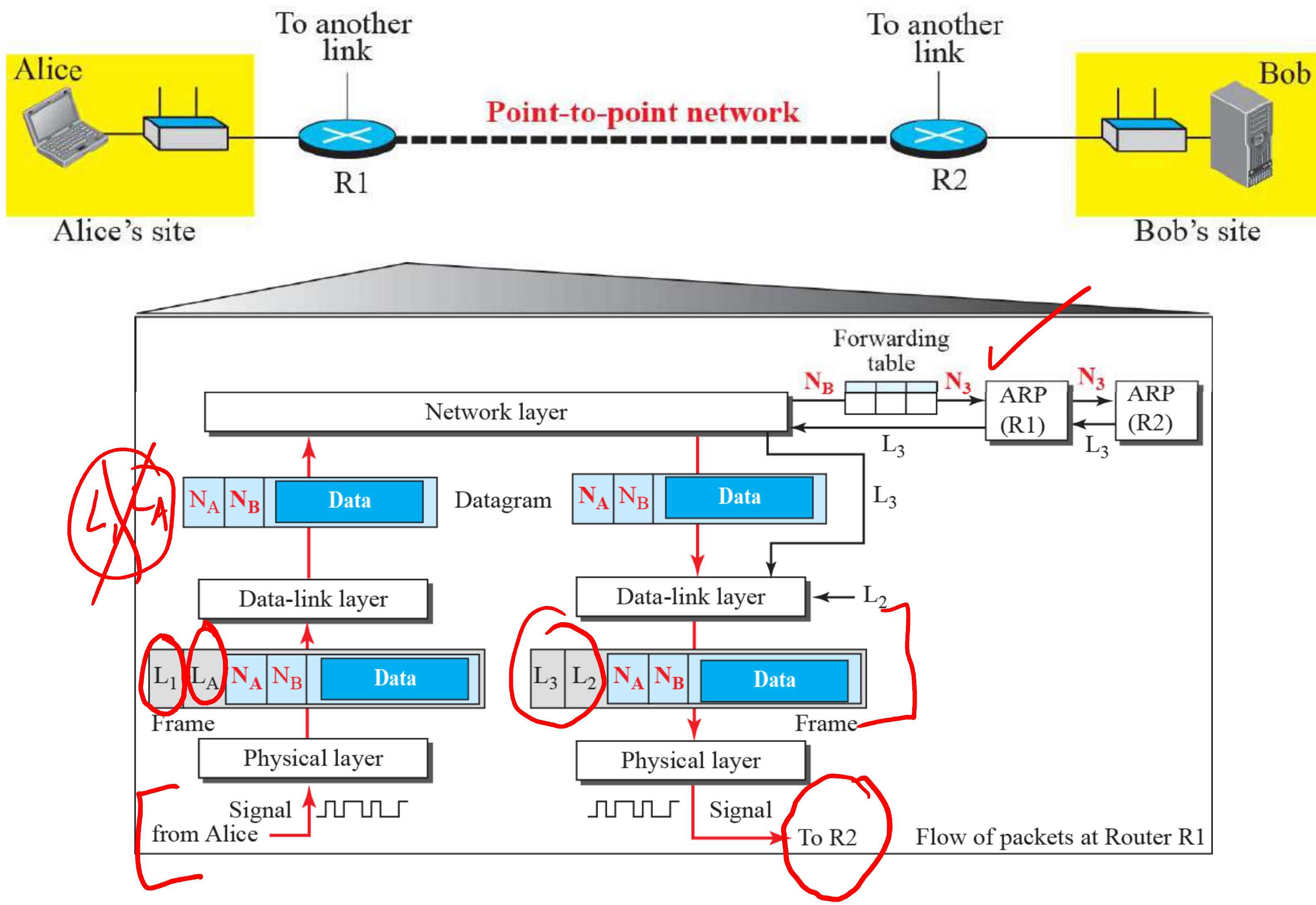
Protocol: Network-layer protocol

0	8	16	31
Hardware Type		Protocol Type	$(0800)_{16}$
Hardware length	Protocol length	Operation **Request:1, Reply:2**	
Source hardware address			
Source protocol address			
Destination hardware address (Empty in request)		empty	
Destination protocol address			

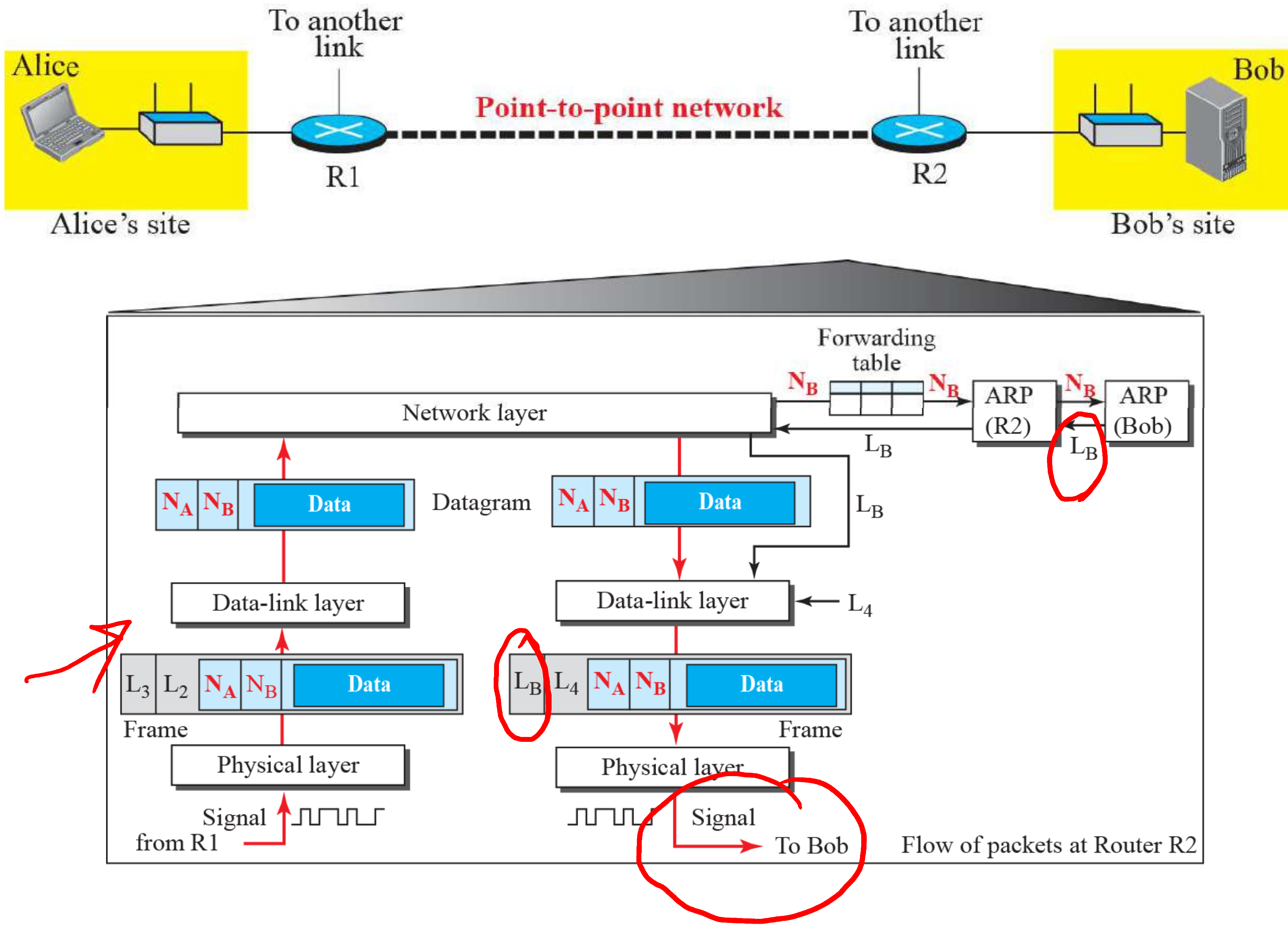

To another link
To another link
Alice
Bob
Point-to-point network
R1
R2
Alice's site
Bob's site



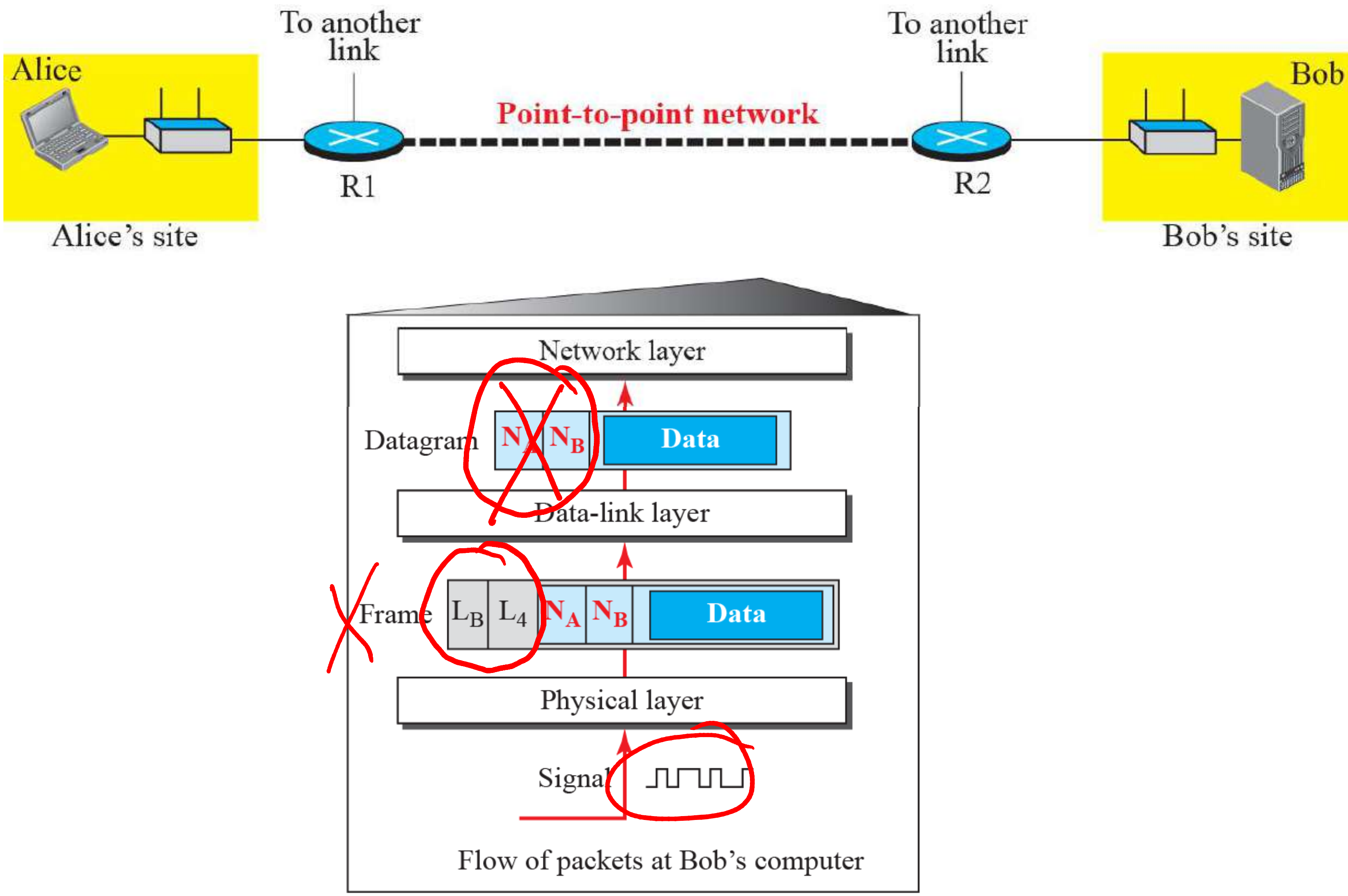
To another link
To another link
Alice
NA
N1
N2
Point-to-point network
N3
N4
NB
Bob
LA
L1
R1
L2
L3
R2
L4
LB
Alice's site
Bob's site
NA
NB
Data
Forwarding table
NB
N1
N1
ARP (Alice)
ARP (R1)
Network layer
L1
L1
Datagram
NA
NB
Data
L1
LA
Data-link layer
Note:
Data-link layer gets its own link-layer address (LA) here from its interface.
Frame
L1
LA
NA
NB
Data
Physical layer
Signal
To R1
Flow of packets at Alice's computer



To another link
To another link
Alice
Bob
Point-to-point network
R1
R2
Alice's site
Bob's site
Forwarding table
Network layer
ARP (R1)
ARP (R2)
N_B
N_3
N_3
L_3
L_3
L_3
L_2
N_A N_B Data
Datagram
N_A N_B Data
Data-link layer
Data-link layer
L_1 L_A N_A N_B Data
L_3 L_2 N_A N_B Data
Frame
Frame
Physical layer
Physical layer
Signal from Alice
Signal
To R2
Flow of packets at Router R1



To another link
To another link
Alice
Bob
Point-to-point network
R1
R2
Alice's site
Bob's site
Forwarding table
N_B
N_B
N_B
ARP (R2)
ARP (Bob)
L_B
L_B
L_B
Network layer
N_A N_B Data
Datagram
N_A N_B Data
Data-link layer
Data-link layer
L_4
L_3 L_2 N_A N_B Data
L_B L_4 N_A N_B Data
Frame
Frame
Physical layer
Physical layer
Signal from R1
Signal
To Bob
Flow of packets at Router R2


To another link
To another link
Alice
Bob
Point-to-point network
R1
R2
Alice's site
Bob's site
Network layer
Datagram
N_A N_B Data
Data-link layer
Frame
L_B L_4 N_A N_B Data
Physical layer
Signal
Flow of packets at Bob's computer

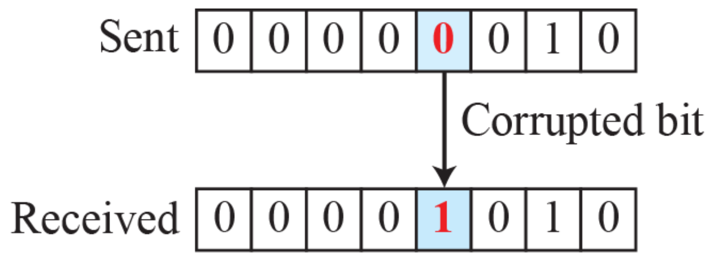
Types of Errors

- **Data transmission suffers unpredictable changes because of interference**
- **The interference can change the shape of the signal**
  - ✓ **<u>Single-bit error</u> means that only 1 bit of a given data unit (such as a byte, character, or packet) is changed from 1 to 0 or from 0 to 1**

- ✓ <u>Burst Error </u>**means that 2 or more bits in the data unit have changed from 1 to 0 or from 0 to 1**

- ✓ <u>Single-bit error</u> means that only 1 bit of a given data unit (such as a byte, character, or packet) is changed from 1 to 0 or from 0 to 1

- ✓ <u>Burst Error</u> means that 2 or more bits in the data unit have changed from 1 to 0 or from 0 to 1



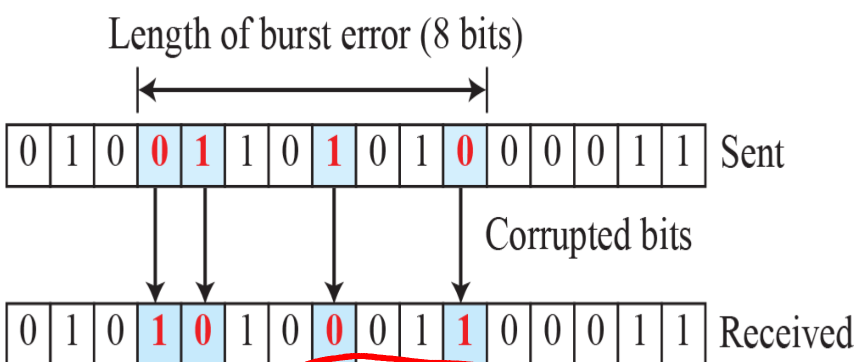
a. Single-bit error

No. of impacted bits

Data Rate

Duration of Noise

Duration of Noise > Duration of bit



b. Burst error → More common

1kbps $\frac{1}{100}$ sec

↳ 10 bits

1Mbps $\frac{1}{100}$ sec

↳ 10,000 bits

- **Central concept in detecting or correcting errors is Redundancy**

- **To be able to detect or correct errors, we send some extra bits with our data**

- **The presence of these redundant bits allows the receiver to detect or correct corrupted bits**

- Correction is more difficult than the detection
- In error detection, we are only looking to see if any error has occurred (Yes or No)
- We are not interested in the number of corrupted bits in Detection
- Single-bit error is same as a Burst error

- **In Error Correction, we need to know:**
  - ✓ **The exact number of bits that are corrupted and,**
  - ✓ **Their location in the message**

- **Redundancy is achieved through various coding schemes**
- **Sender adds redundant bits through a process that creates a relationship between redundant bits and the actual data bits**
- **The receiver checks the relationships between the two sets of bits to detect errors**

- **The ratio of redundant bits to data bits and the robustness of the process are important factors in any coding scheme**

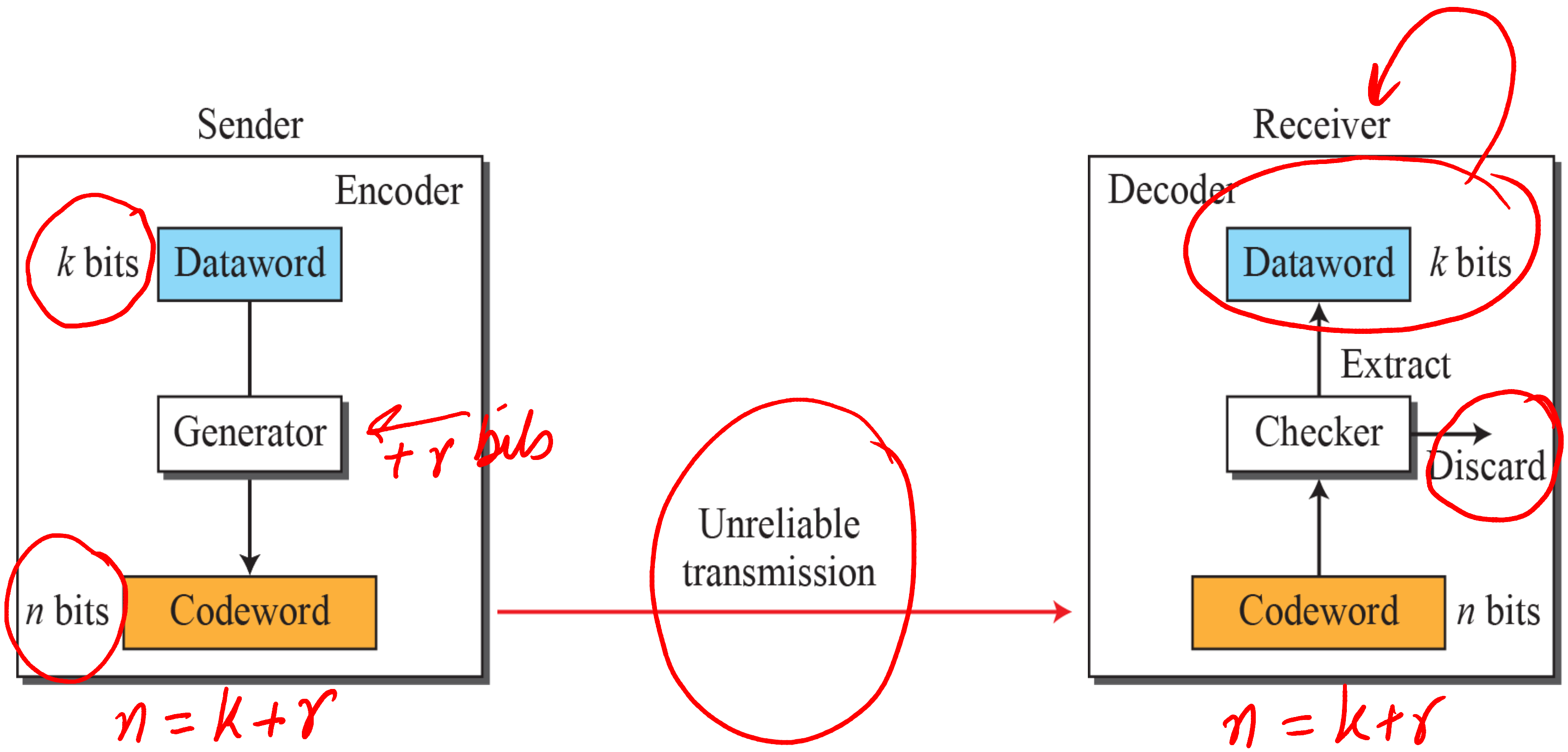
- **Coding schemes can be divided into 2 broad categories:**
  - ✓ **Block Coding**
  - ✓ **Convolution Coding**

- We divide our message into blocks, each of ‘k’ bits, called datawords

- We add ‘r’ redundant bits to each block to make the length ‘n = k + r’

- The resulting ‘n-bit’ blocks are called codewords

- **If the following two conditions are met, the receiver can detect a change in the original codeword:**
  - ✓ **The receiver has (or can find) a list of valid codewords**
  - ✓ **The original codeword has changed to an invalid one**



Checker → received word is matching a valid code word

- We divide our message into blocks, each of ‘k’ bits, called datawords

- We add ‘r’ redundant bits to each block to make the length ‘n = k + r’

- The resulting ‘n-bit’ blocks are called codewords

Let us assume that k = 2 and n = 3. Table below shows the list of datawords and codewords. Later, we will see how to derive a cod word from a dataword.

$2^n = 2^3 = 8$

$2^2 = 4$

$n = k + r$ — codeword, dataword, red bits

Datawords	Codewords	Datawords	Codewords
1). 00	000	3). 10	101
2). 01	011	4). 11	110

① 011 → valid codeword   01 → extracted

② 111 → Corrupted codeword   111 → discarded

01 → 011

③ 000 → Right 2 bits are corrupted → Receiver accept as valid → 00

- **Hamming Distance between two words of the same size is the number of differences between the corresponding bits**
- **Hamming Distance between two words x and y is *d*(x,y)**
- **Hamming distance between received codeword and sent codeword is number of bits corrupted**

Let us find the Hamming distance between two pairs of words.

1. **d(000, 011)** → $d(x,y) = d(000, 011) = 2$
2. **d(10101, 11110)**

→ $d(10101, 11110) = 3$

$d(x,y) \neq 0$ → corrupted (error)

XOR $\oplus$ $000 \oplus 011$ → Count no. of 1's in result → 2

- **Minimum Hamming Distance is smallest hamming distance between all possible pairs of codewords**

- **d_{min}= s+1**
  where,
  s → no. of detectable errors
  d_{min} → minimum hamming distance

A code scheme has a Hamming distance d_{min} = 4. This code guarantees the detection of up to how many errors?

$$d_{min} = 4$$

$$d_{min} = S + 1$$

$$S = d_{min} - 1$$

$$= 4 - 1$$

$$\boxed{S = 3} \rightarrow$$

Block code guarantees error detection for upto 3 bits in a codeword

- **Subset of Block Codes in which the exclusive OR of two valid codewords creates another valid codeword**

The code below is a linear block code because the result of XORing any codeword with any other codeword is a valid codeword. For example, the XORing of the second and third codewords creates the fourth one.

Datawords	*Codewords*	*Datawords*	*Codewords*
00	000	10	101
01	011	11	110

2 2 2

$011 \oplus 101 = 110 \rightarrow$ Linear block code

The numbers of 1s in the nonzero codewords are 2, 2, and 2. So the minimum Hamming distance is $d_{min} = 2$.

$d_{min} = 2$

- Most common error-detecting code

- Linear block code ($n=k+1$)

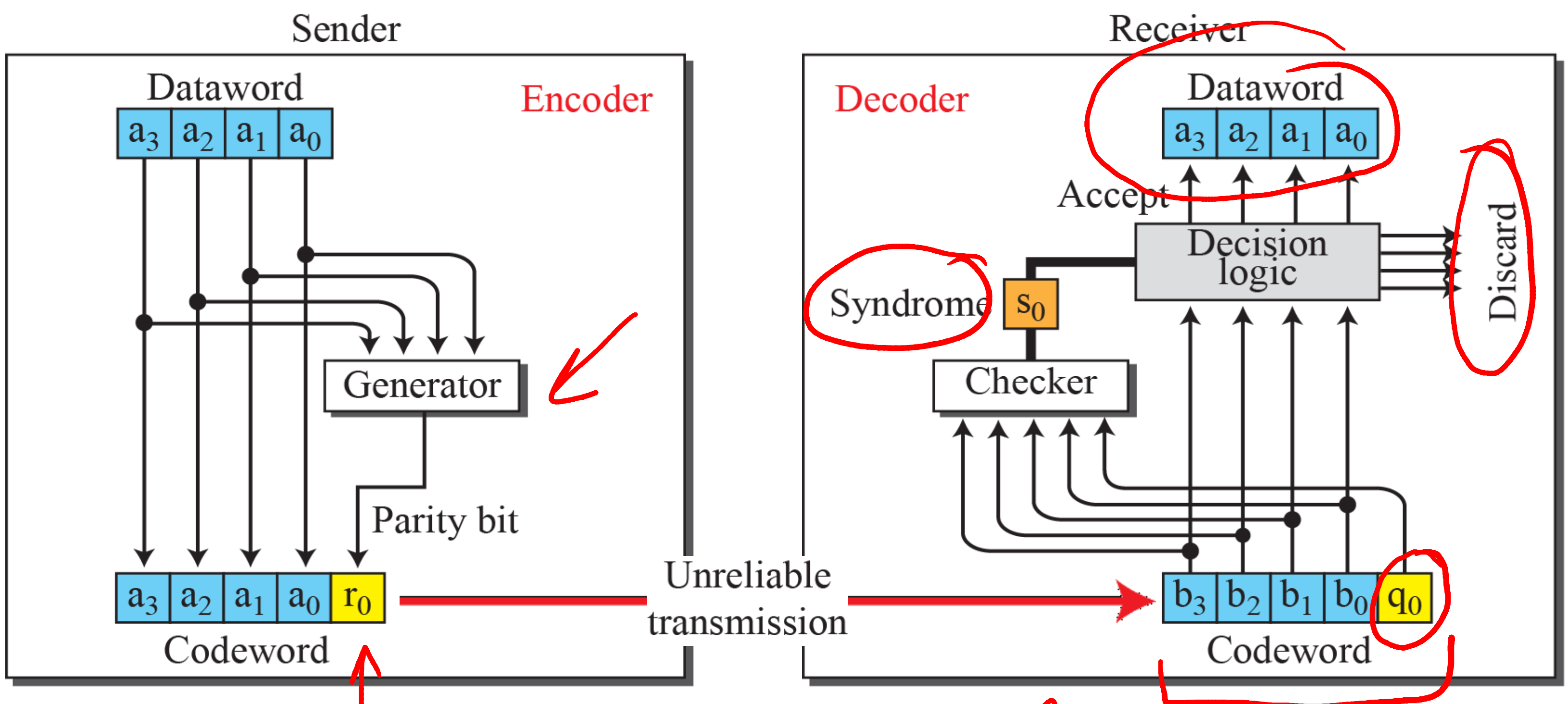
- The extra parity bit is selected to make total number of 1s in codeword even

$2^4 = 16$ $2^5 = 32$ $k = 4, n = 5$

Datawords	**Codewords**	*Datawords*	**Codewords**
0000	**00000**	1000	**10001**
0001	**00011**	1001	**10010**
0010	**00101**	1010	**10100**
0011	**00110**	1011	**10111**
0100	**01001**	1100	**11000**
0101	**01010**	1101	**11011**
0110	**01100**	1110	**11101**
0111	**01111**	1111	**11110**

$n > k \rightarrow$ no. of codewords > no. of datawords

$2^n - 2^k \rightarrow$ (codewords) $\rightarrow$ invalid



$r_0 \rightarrow$ Total 1's is even

Syndrome $\rightarrow S_0$

$\hookrightarrow 0$ (no. of 1s is even)

$S_0 = 1$ (no. of 1s is odd.

- **Special linear block codes with one extra property**
- **If a codeword is cyclically shifted (rotated), the result is another codeword**
- **If 1011000 is a codeword and we cyclically left-shift, then 0110001 is also a codeword**

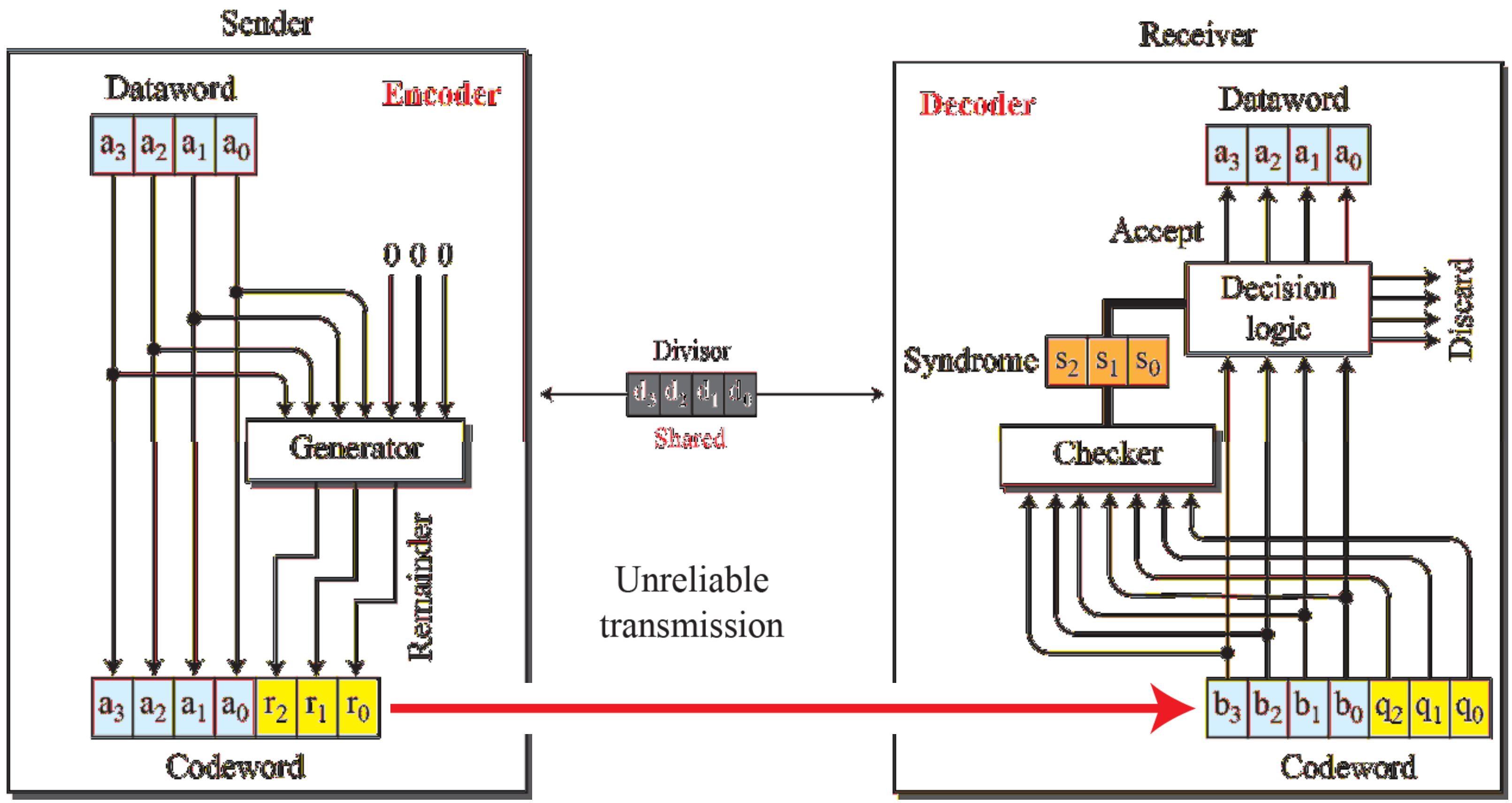
- **Subset of Cyclic Codes**

- **Cyclic redundancy check (CRC) is used in networks such as LANs and WANs**

Dataword	Codeword	Dataword	Codeword
0000	0000000	1000	1000101
0001	0001011	1001	1001110
0010	0010110	1010	1010011
0011	0011101	1011	1011000
0100	0100111	1100	1100010
0101	0101100	1101	1101001
0110	0110001	1110	1110100
0111	0111010	1111	1111111

- **Subset of Cyclic Codes**

- **Cyclic redundancy check (CRC) is used in networks such as LANs and WANs**


Sender
Dataword
Encoder
a_3 a_2 a_1 a_0
0 0 0
Generator
Remainder
a_3 a_2 a_1 a_0 r_2 r_1 r_0
Codeword
Divisor
d_3 d_2 d_1 d_0
Shared
Unreliable
transmission
Receiver
Decoder
Dataword
a_3 a_2 a_1 a_0
Accept
Decision
logic
Discard
Syndrome
s_2 s_1 s_0
Checker
b_3 b_2 b_1 b_0 q_2 q_1 q_0
Codeword

Dataword = $d(x)$, Codeword = $c(x)$, Generator = $g(x)$, Syndrome = $S(x)$, Error $= e(x)$

$S(x) \neq 0 \longrightarrow$ Data is corrupted $\longrightarrow$ Discard

$S(x) = 0 \longrightarrow$ No bit is corrupted

$\longrightarrow$ Corruption $\longrightarrow$ decoder has not detected it

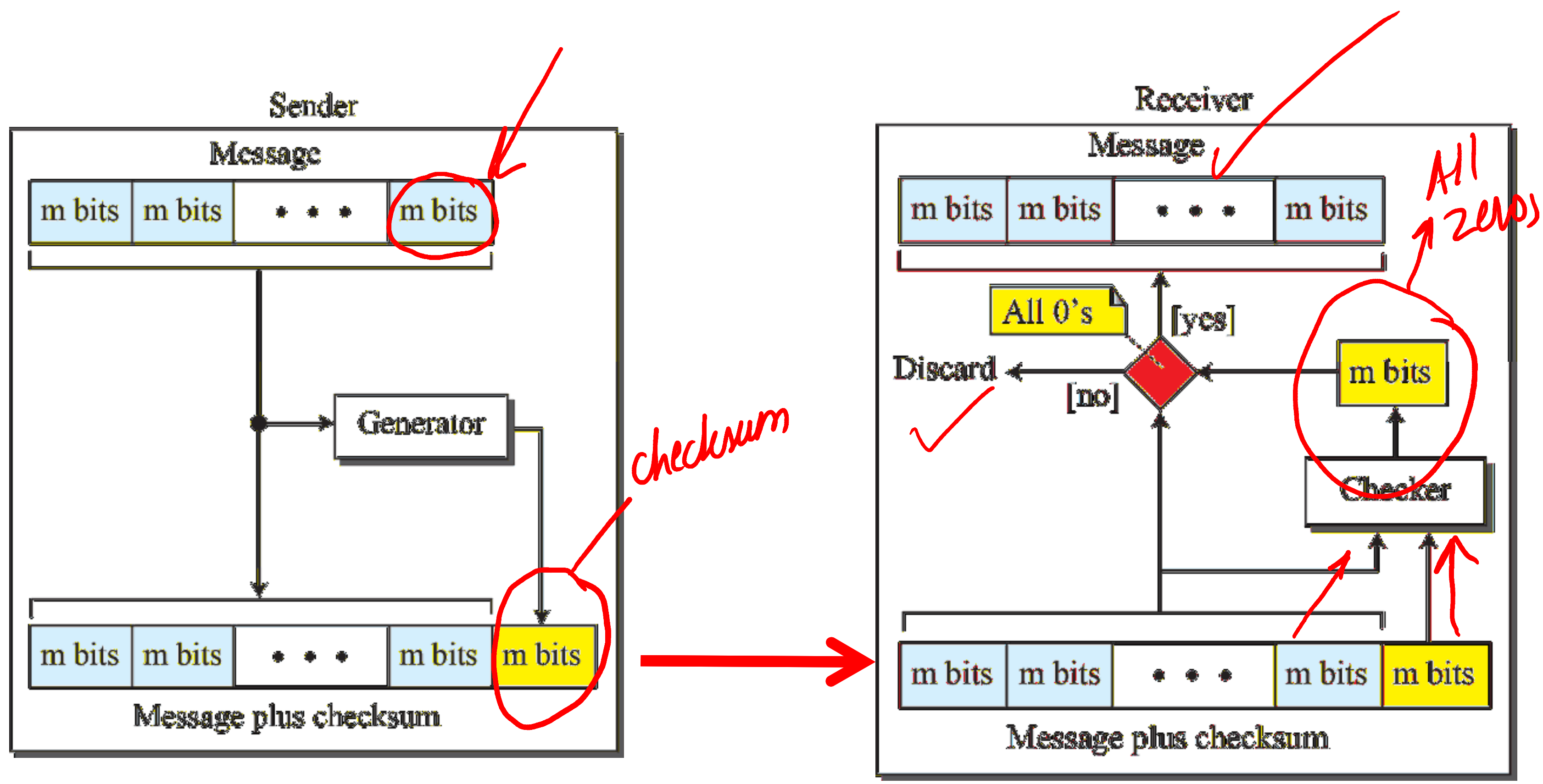
Received codeword $= c(x) + e(x)$

$$S(x)\ \frac{\text{R. Codeword}}{g(x)} = \frac{c(x)}{g(x)} + \frac{e(x)}{g(x)}$$

$$S(x) = 0 + \frac{e(x)}{g(x)} \longrightarrow \text{Not Caught}$$

- Good performance in detection:
  - Single-bit errors
  - Double errors
  - Odd number of errors
  - Burst errors
- Easy Implementation
- Fast Implementation

- **Error-detection technique that can be applied to a message of any length**
- **Checksum mostly used at the network and transport layer rather than the data-link layer**


Sender
Message
m bits
m bits
m bits
Generator
m bits
m bits
m bits
m bits
Message plus checksum
checksum
Receiver
Message
m bits
m bits
m bits
All 0's
[yes]
Discard
[no]
m bits
Checker
All zeros
m bits
m bits
m bits
m bits
Message plus checksum

- **The idea of the traditional checksum is simple. We show this using a simple example**

Suppose the message is a list of five 4-bit numbers that we want to send to a destination. In addition to sending these numbers, we send the sum of the numbers.
Set of numbers is (7, 11, 12, 0, 6)

$7+11+12+0+6 = \underline{\underline{36}}$

$(7, 11, 12, 0, 6, 36)$

4-bit word (each < 15)

36

In the previous example, the decimal number 36 in binary is $(100100)_2$. To change it to a 4-bit number we add the extra leftmost bit to the right four bits as shown below

$$(10)_2 + (0100)_2 = (0110)_2$$

$\longrightarrow (6)_{10}$

one's compliment

arithmetic

(7, 11, 12, 0, 6, 36)

(7, 11, 12, 0, 6, 6)

- **Retransmission of corrupted and lost packets is not useful for real-time multimedia transmission**

- **We need to correct the error or reproduce the packet immediately**

- **Several techniques developed and are commonly called Forward Error Correction techniques**

- For error detection, we definitely need more distance
- It can be shown that to correct 't' errors, we need to have:

$$d_{min} = 2t + 1$$

- If we want to correct 10 bits in a packet, we need to make the minimum hamming distance 21 bits
- A lot of redundant bits need to be sent with the data

If we want to correct 10 bits in a packet, we need to make the minimum hamming distance 21 bits

$$d_{min} = 2t + 1$$

$$d_{min} = 2(10) + 1$$

$$d_{min} = 21$$

no. of bits (red) that you will send with dataword

BCH

99 bits → 255 bits

↳ 156

(23)

Another recommendation is to use the property of the exclusive OR operation as shown below.

$$R = P_1 \oplus P_2 \oplus \ldots \oplus P_i \oplus \ldots \oplus P_N$$

This means:

$$P_i = P_1 \oplus P_2 \oplus \ldots \oplus R \oplus \ldots \oplus P_N$$

Another recommendation is to use the property of the exclusive OR operation as shown below.

$$R = P_1 \oplus P_2 \oplus \ldots \oplus P_i \oplus \ldots \oplus P_N$$

Data $\rightarrow P_1 \longrightarrow P_N$

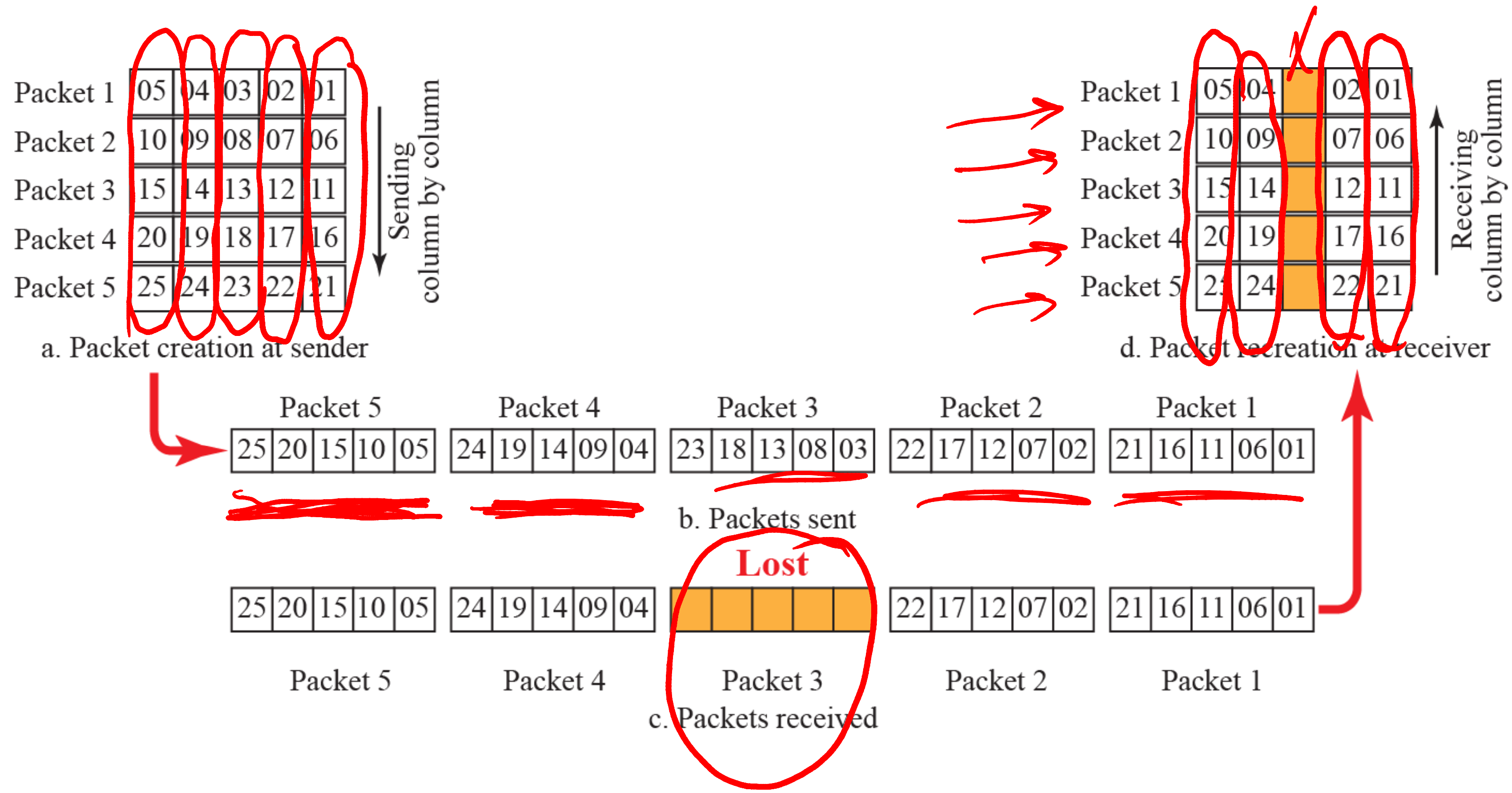
$$\underbrace{P_i = P_1 \oplus P_2 \oplus \cdots \oplus R \oplus \ldots \oplus P_N}_{N \text{ chunks}}$$

↳ N+1 chunks are send.

$N = 4$ → 25% extra data XOR (one out of 4 chunks)

- **Another way to achieve FEC in multimedia is to allow some small chunks to be missing at the receiver**

- **We cannot afford to let all the chunks belonging to the same packet be missing; however, we can afford to let one chunk be missing in each packet**

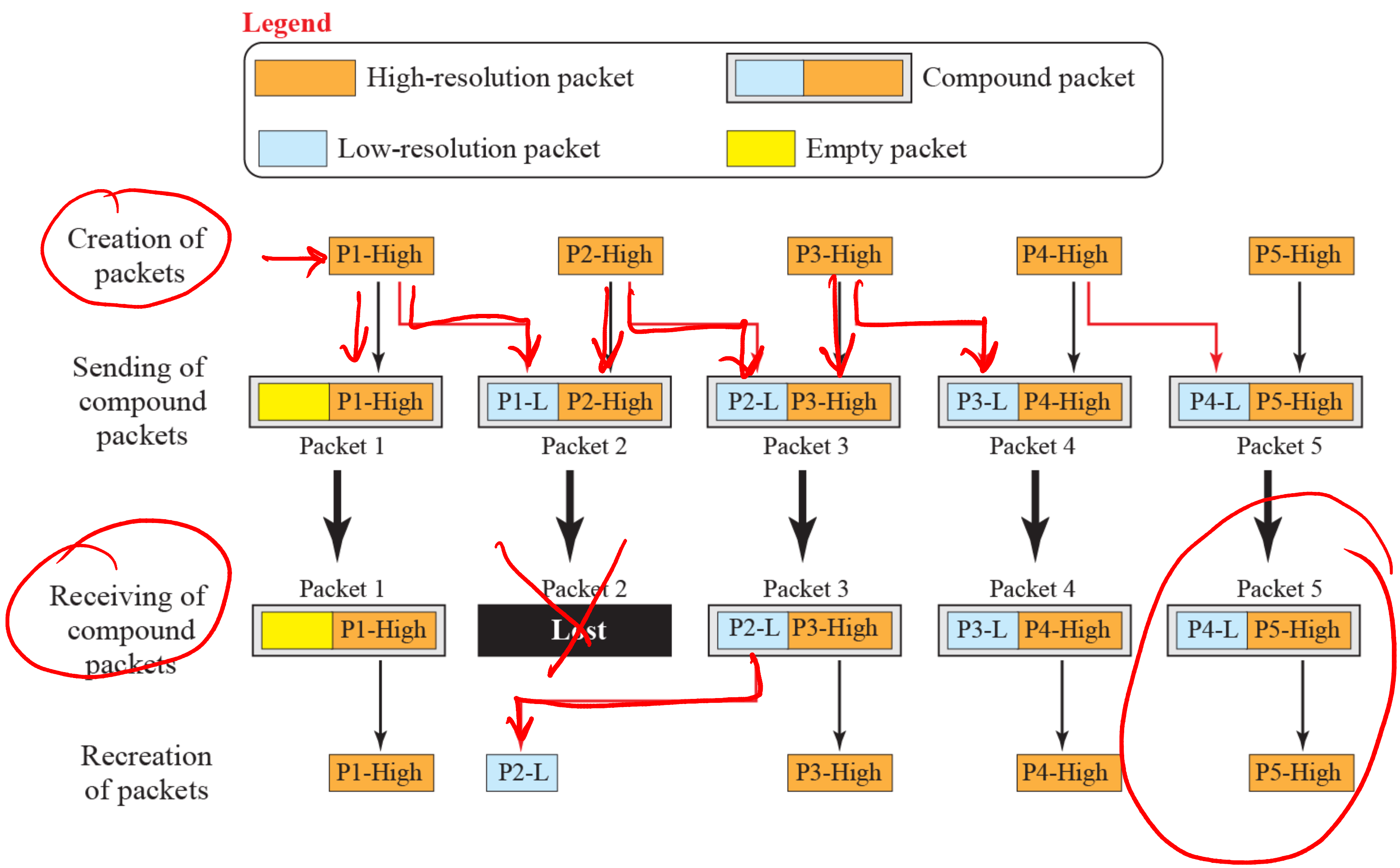


Packet 1
Packet 2
Packet 3
Packet 4
Packet 5
05 04 03 02 01
10 09 08 07 06
15 14 13 12 11
20 19 18 17 16
25 24 23 22 21
Sending column by column
a. Packet creation at sender
Packet 5 25 20 15 10 05
Packet 4 24 19 14 09 04
Packet 3 23 18 13 08 03
Packet 2 22 17 12 07 02
Packet 1 21 16 11 06 01
b. Packets sent
Lost
c. Packets received
Receiving column by column
d. Packet recreation at receiver

- Hamming distance and interleaving can be combined
- We can first create n-bit packets that can correct t-bit errors
- Then we interleave m rows and send the bits column by column
- Possible to correct burst errors up to m × t bits of errors

- **Creation of a duplicate of each packet with a low-resolution redundancy and combine the redundant version with the next packet**

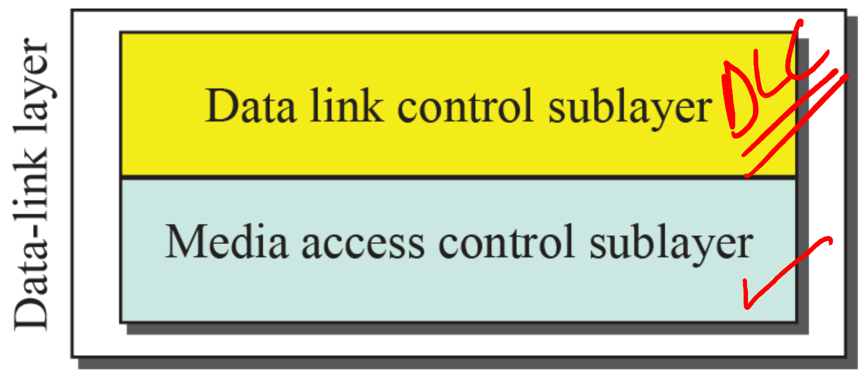
- **For example, we can create four low-resolution packets out of five high-resolution packets and send them**


Legend
High-resolution packet
Compound packet
Low-resolution packet
Empty packet
Creation of packets
P1-High
P2-High
P3-High
P4-High
P5-High
Sending of compound packets
P1-High
Packet 1
P1-L
P2-High
Packet 2
P2-L
P3-High
Packet 3
P3-L
P4-High
Packet 4
P4-L
P5-High
Packet 5
Receiving of compound packets
Packet 1
P1-High
Packet 2
Lost
Packet 3
P2-L
P3-High
Packet 4
P3-L
P4-High
Packet 5
P4-L
P5-High
Recreation of packets
P1-High
P2-L
P3-High
P4-High
P5-High

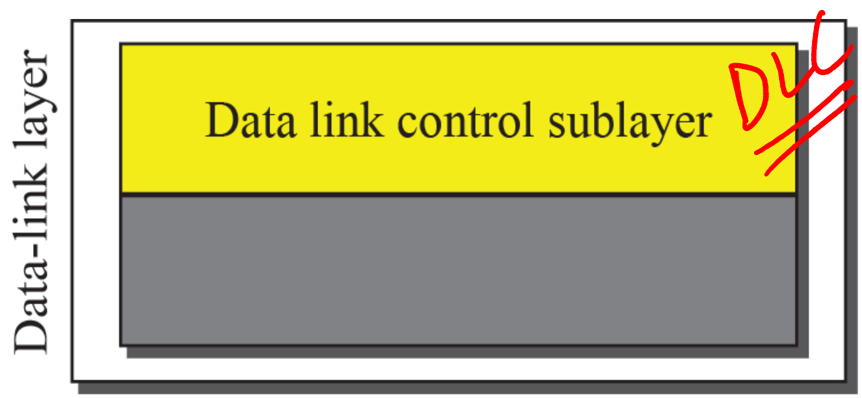
Data Link Control (DLC) Services

- The data link control (DLC) deals with procedures for communication between two adjacent nodes no matter whether the link is dedicated or broadcast

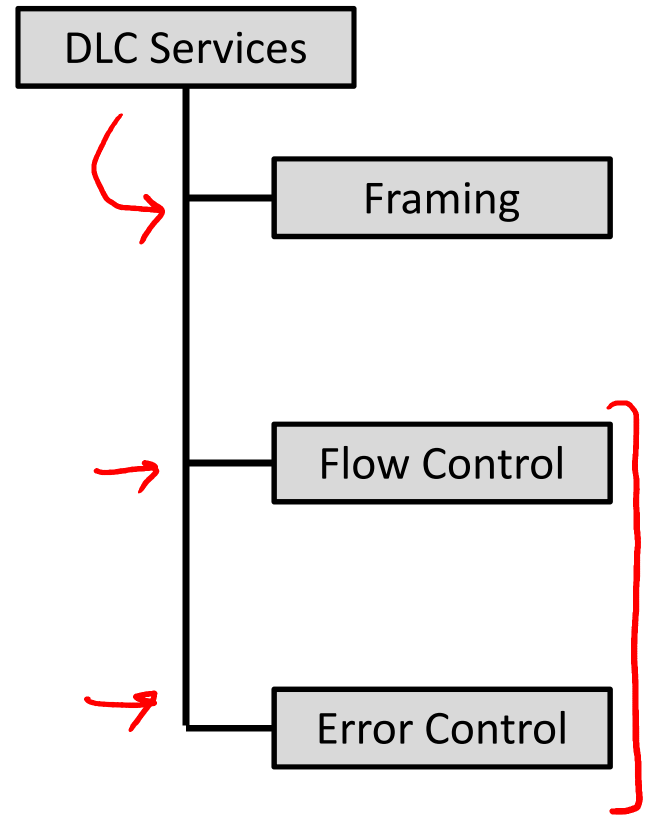
- Data link control functions include framing, flow control and error control



a. Data-link layer of a broadcast link



b. Data-link layer of a point-to-point link



- **Data-Link layer needs to pack bits into frames, so that each frame is distinguishable from another**

- **Our postal system practices a type of framing**

- **Framing separates a message by adding a sender address and a destination address**

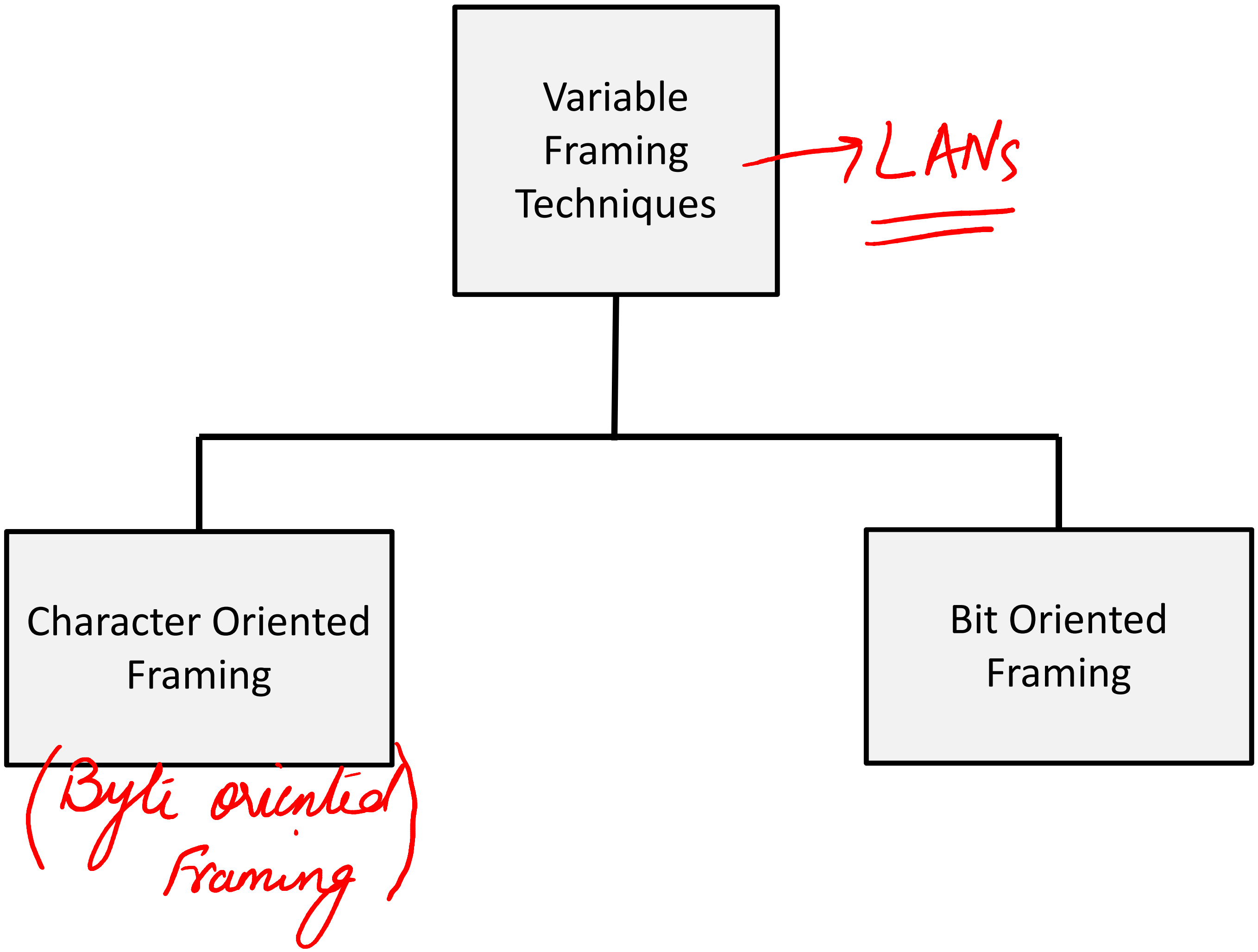
- **The destination address defines where the packet is to go; the sender address helps the recipient acknowledge the receipt**

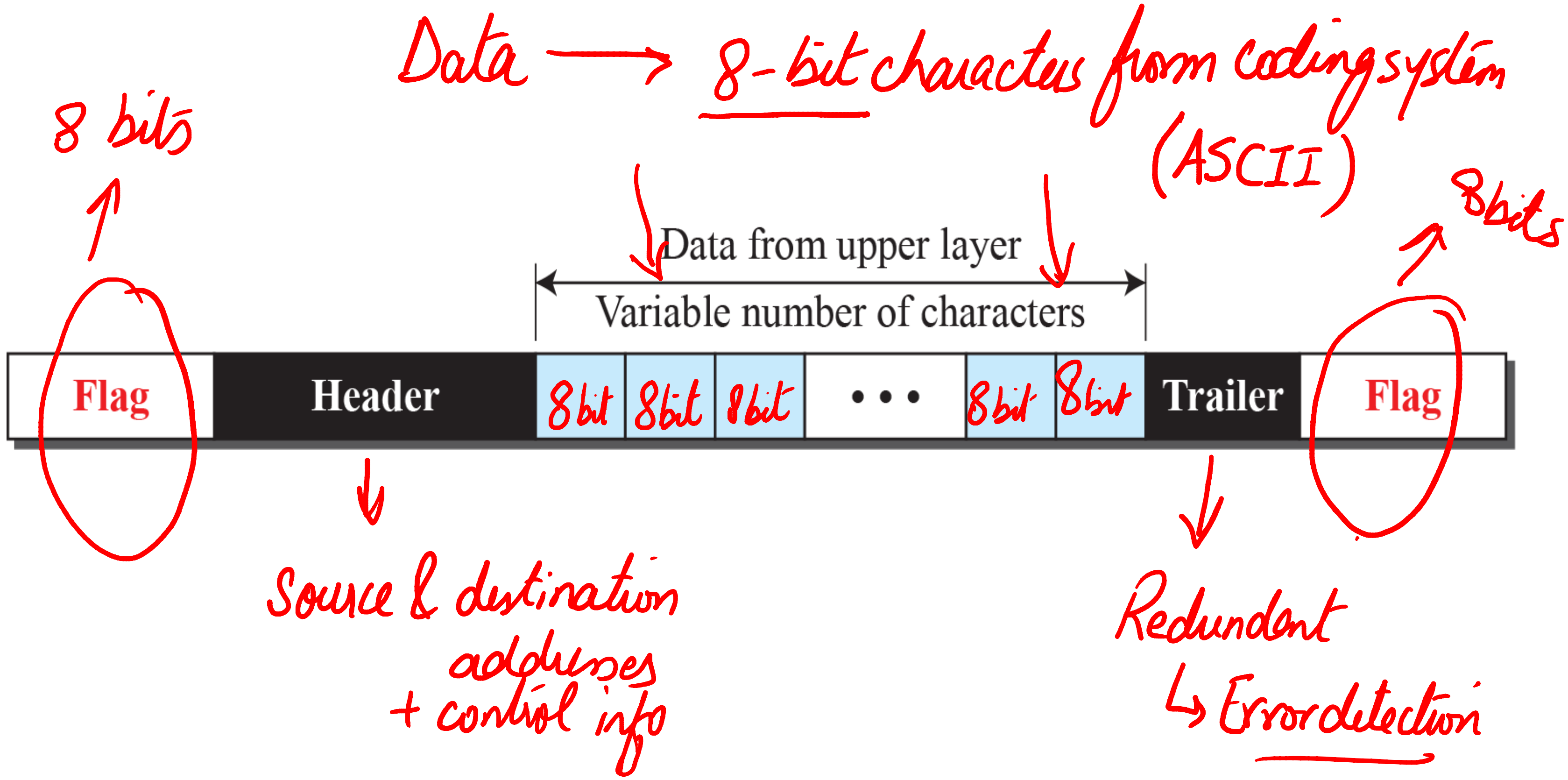
- **Why not one BIG Frame?**

- **Frames can be of:**

  - ✓ **Fixed Size**
    - ➢ **Size acts as a boundary/delimiter**

  - ✓ **Variable Size**
    - ➢ **How to define Beginning and End of a Frame?**


Variable Framing Techniques
LANs
Character Oriented Framing
(Byte oriented Framing)
Bit Oriented Framing


Data → 8-bit characters from coding system (ASCII)
8 bits
8bits
Data from upper layer
Variable number of characters
Flag
Header
8 bit
8 bit
8 bit
• • •
8 bit
8 bit
Trailer
Flag
Source & destination addresses + control info
Redundant
↳ Error detection

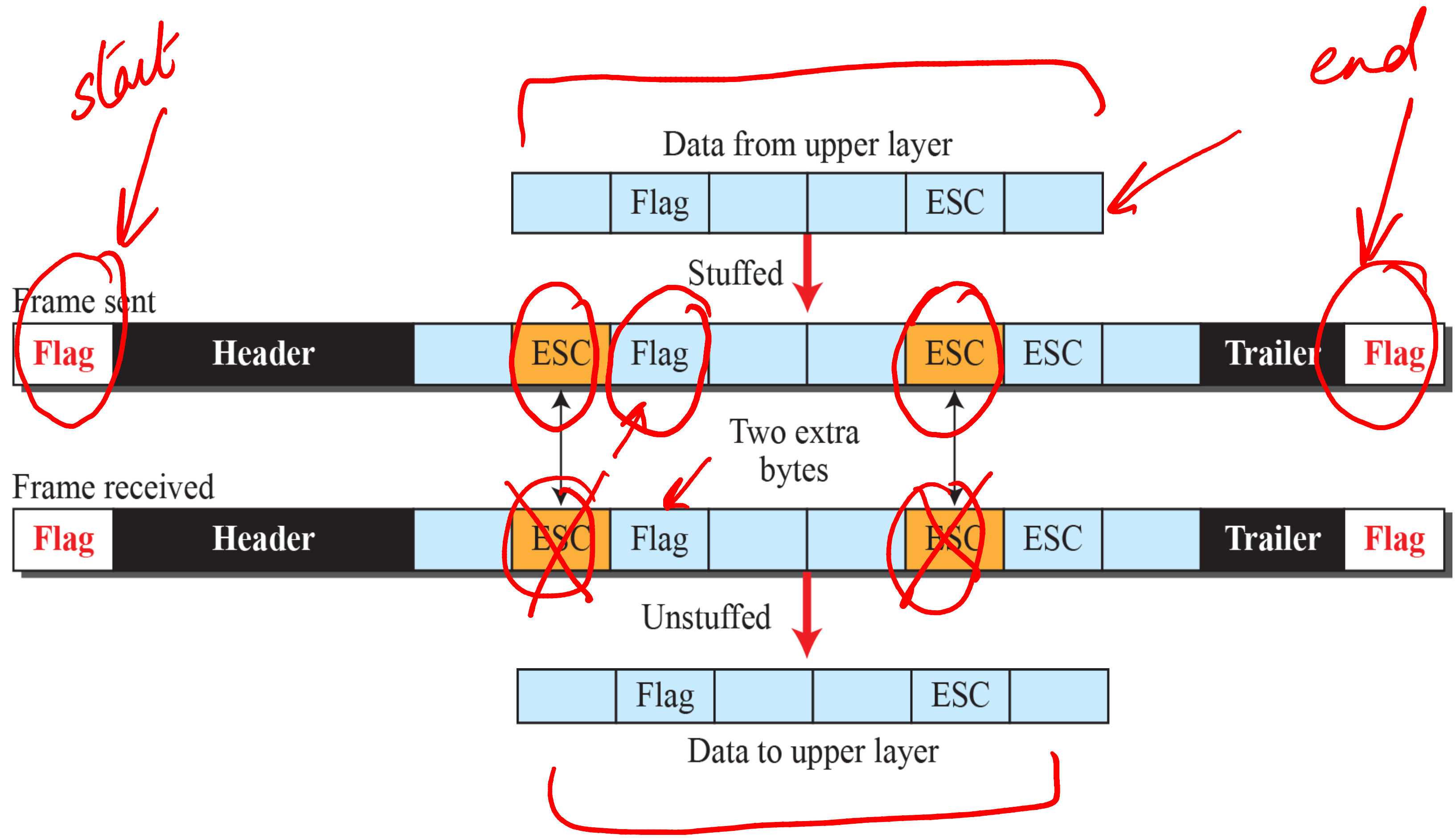
- **Data to be carried are 8-bit characters**

- **Connection-oriented Framing used text characters as flags**

- **Nowadays any character used for flag can also be a part of the data**

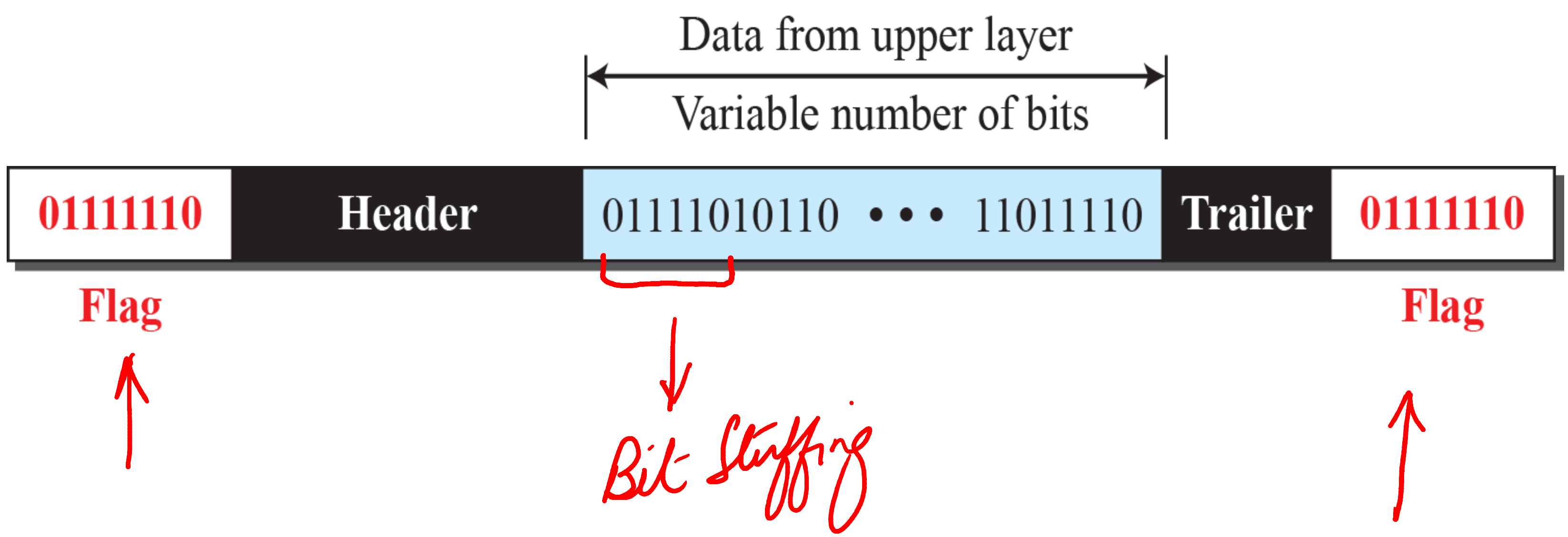
- **In order to avoid confusing the receiver, we use Byte Stuffing**

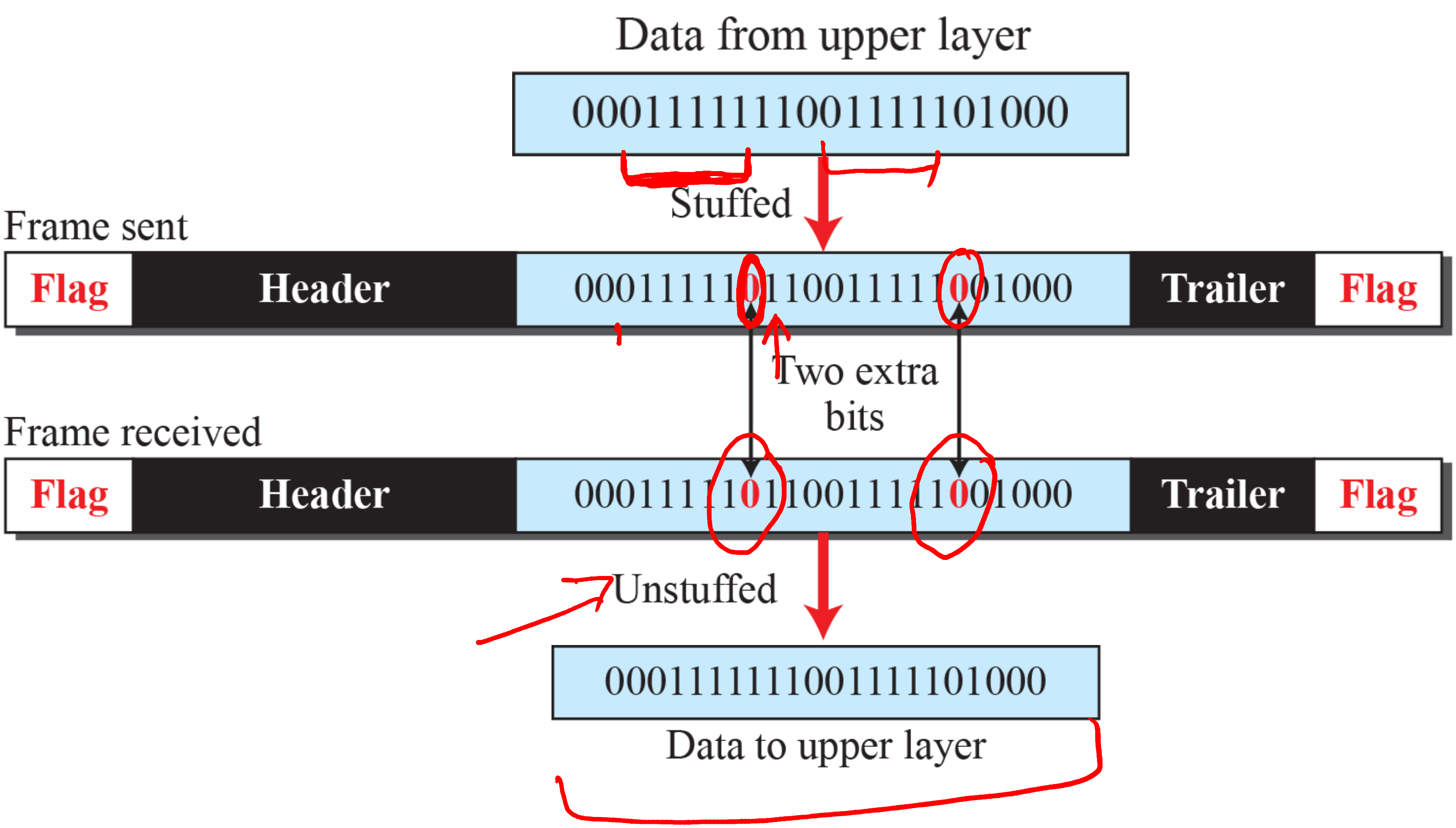
- **Several Issues:**
  - ✓ **One or more escape characters followed by a byte with same pattern as a flag?**
  - ✓ **Unicode (16/32 bit) vs. 8-bit characters**
- **Data is stuffed with a pre-defined Escape Character (byte) when there is a character with same pattern as a flag**



start
end
Data from upper layer
Flag
ESC
Stuffed
Frame sent
Flag
Header
ESC
Flag
ESC
ESC
Trailer
Flag
Two extra
bytes
Frame received
Flag
Header
ESC
Flag
ESC
ESC
Trailer
Flag
Unstuffed
Flag
ESC
Data to upper layer

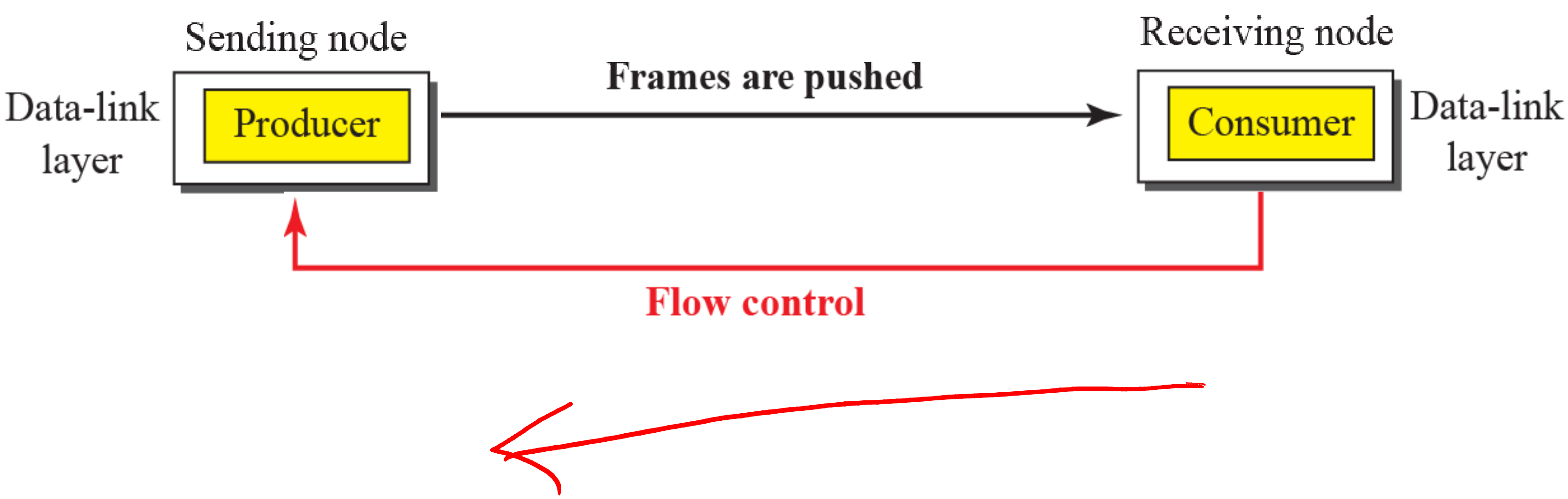
- Data section of frame is a sequence of bits
- We need a delimiter to separate one frame from the other
- A special 8-bit pattern (01111110) to define beginning and end of a frame
- Same issue as Connection-oriented Framing


Data from upper layer
Variable number of bits
01111110
Header
01111010110 • • • 11011110
Trailer
01111110
Flag
Flag
Bit Stuffing


Data from upper layer
0001111111001111101000
Stuffed
Frame sent
Flag
Header
000111110110011111001000
Trailer
Flag
Two extra bits
Frame received
Flag
Header
000111110110011111001000
Trailer
Flag
Unstuffed
0001111111001111101000
Data to upper layer

- **One of the responsibilities of the data-link control sublayer is flow and error control at the data-link layer**

- **Balance between production and consumption rates**
- **If frames are produced faster than they are consumed at the receiving data link layer, the frames will be discarded**
- **Use of buffers; one at sending end and other at receiving end**



Sending node
Frames are pushed
Receiving node
Data-link layer
Producer
Consumer
Data-link layer
Flow control

- **Consumers need to communicate with the producers on two occasions:**
  - ✓ **When the buffer is full; &**
  - ✓ **When there are vacancies**

✓ **If the two parties use a buffer with only one slot, the communication can be easier**

- Error Control at Data Link layer uses CRC in one of the two ways:

  - ✓ If a frame is corrupted, it is silently discarded and if it is good, it is delivered to network layer

  - ✓ If frame is corrupted, it is silently discarded and if it is good, an acknowledgement is sent to sender

- A DLC protocol can be either connectionless or connection-oriented

- Connectionless: No relationship between the frames

- Connection-Oriented: Frames are numbered and sent in order

- Traditionally four protocols have been defined for the data-link layer to deal with flow and error control:
  - ✓ Simple Protocol
  - ✓ Stop-and-Wait Protocol
  - ✓ Go-Back-N Protocol
  - ✓ Selective-Repeat Protocol
- Last two protocols have almost disappeared completely

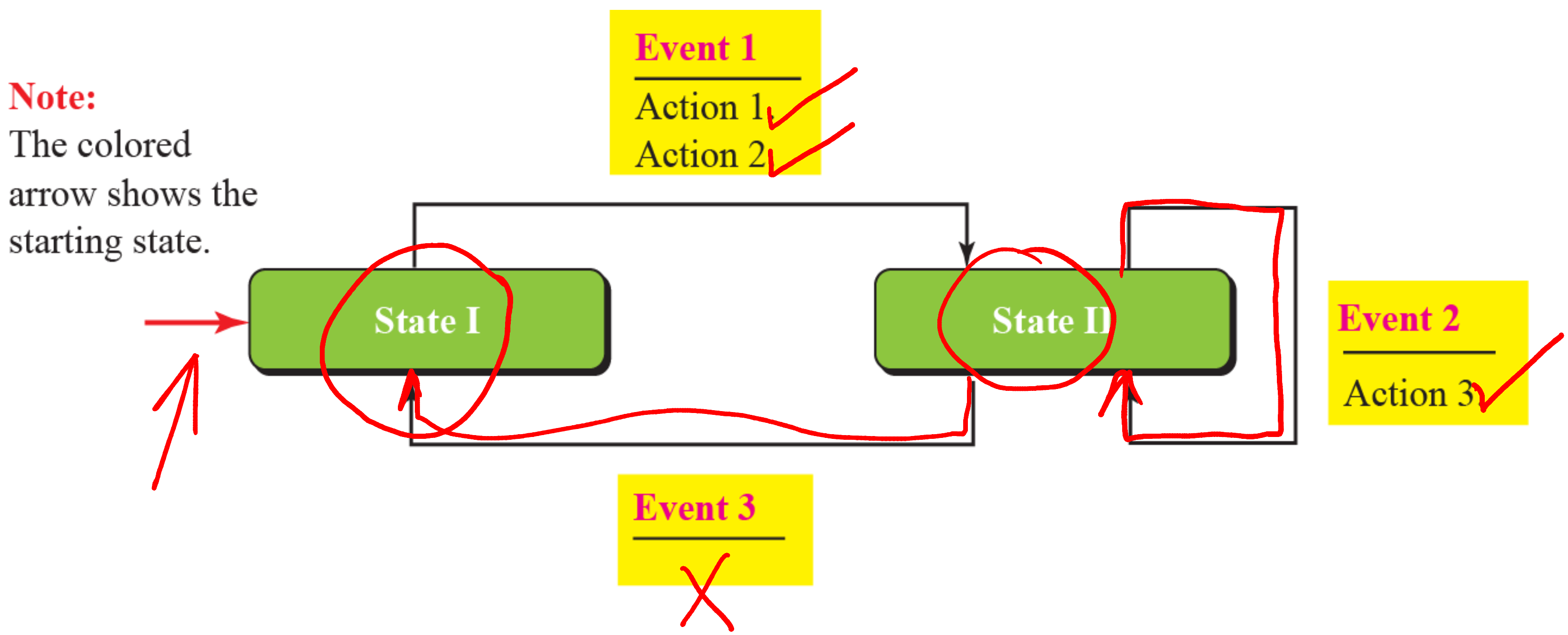
- A machine with a finite number of states

- Machines stays in one of the states until an event occurs

- Each event is associated with 2 reactions:

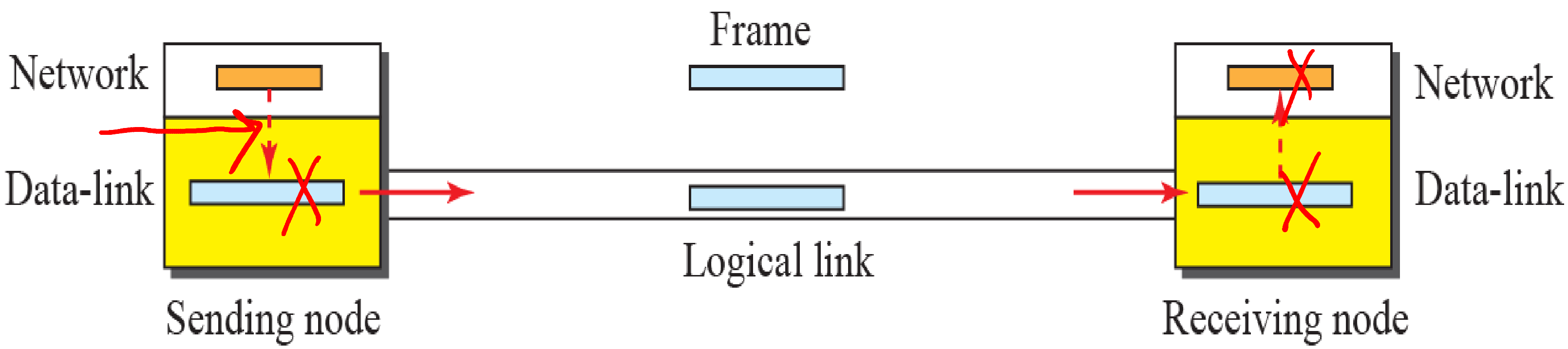
  - ✓ List of actions to be performed

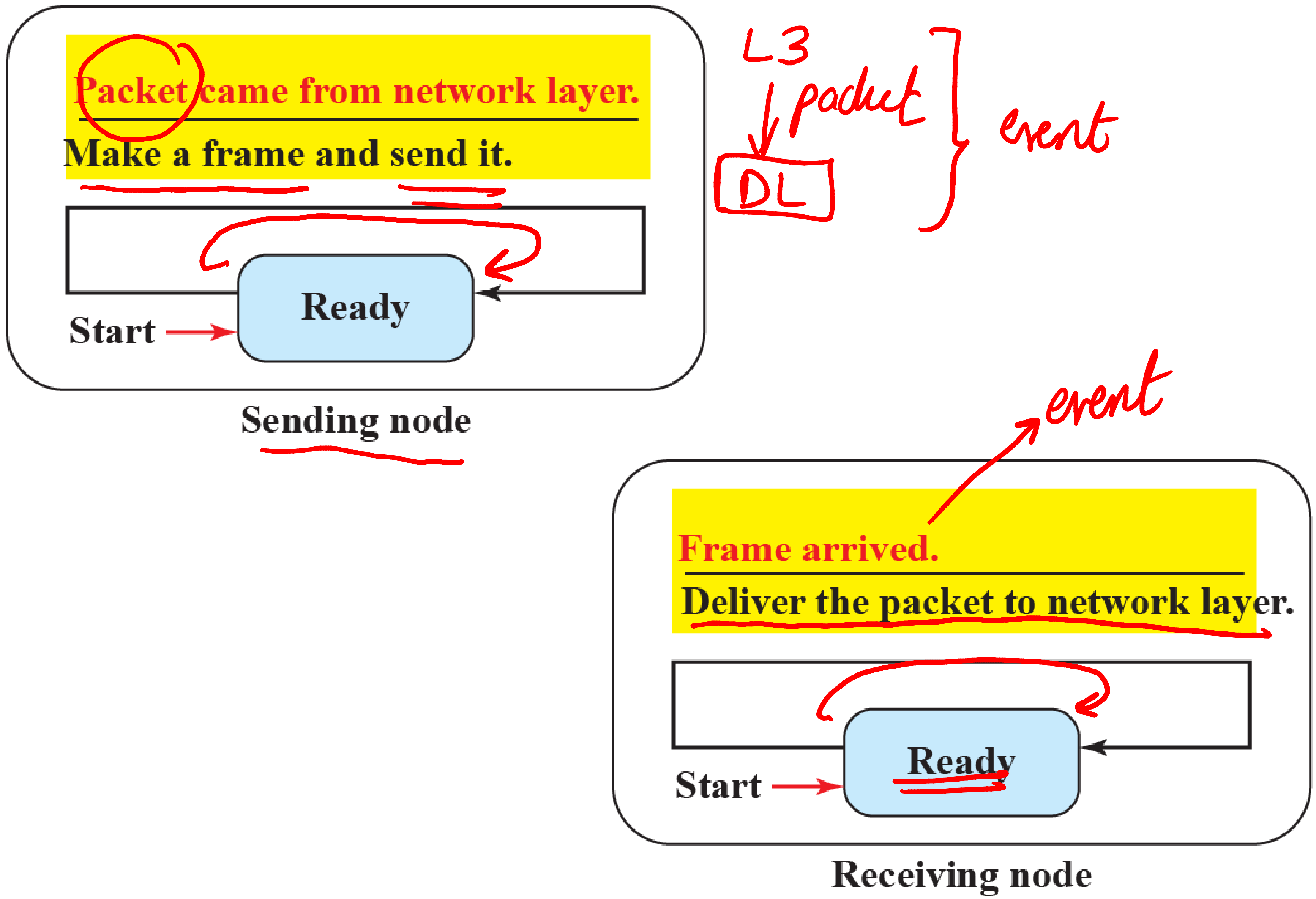
  - ✓ Determining the next state


Note:
The colored
arrow shows the
starting state.
Event 1
Action 1
Action 2
State I
State II
Event 2
Action 3
Event 3

- **Traditionally four protocols have been defined for the data-link layer to deal with flow and error control:**
  - ✓ **Simple Protocol**
  - ✓ **Stop-and-Wait Protocol**
  - ✓ **Go-Back-N Protocol**
  - ✓ **Selective-Repeat Protocol**

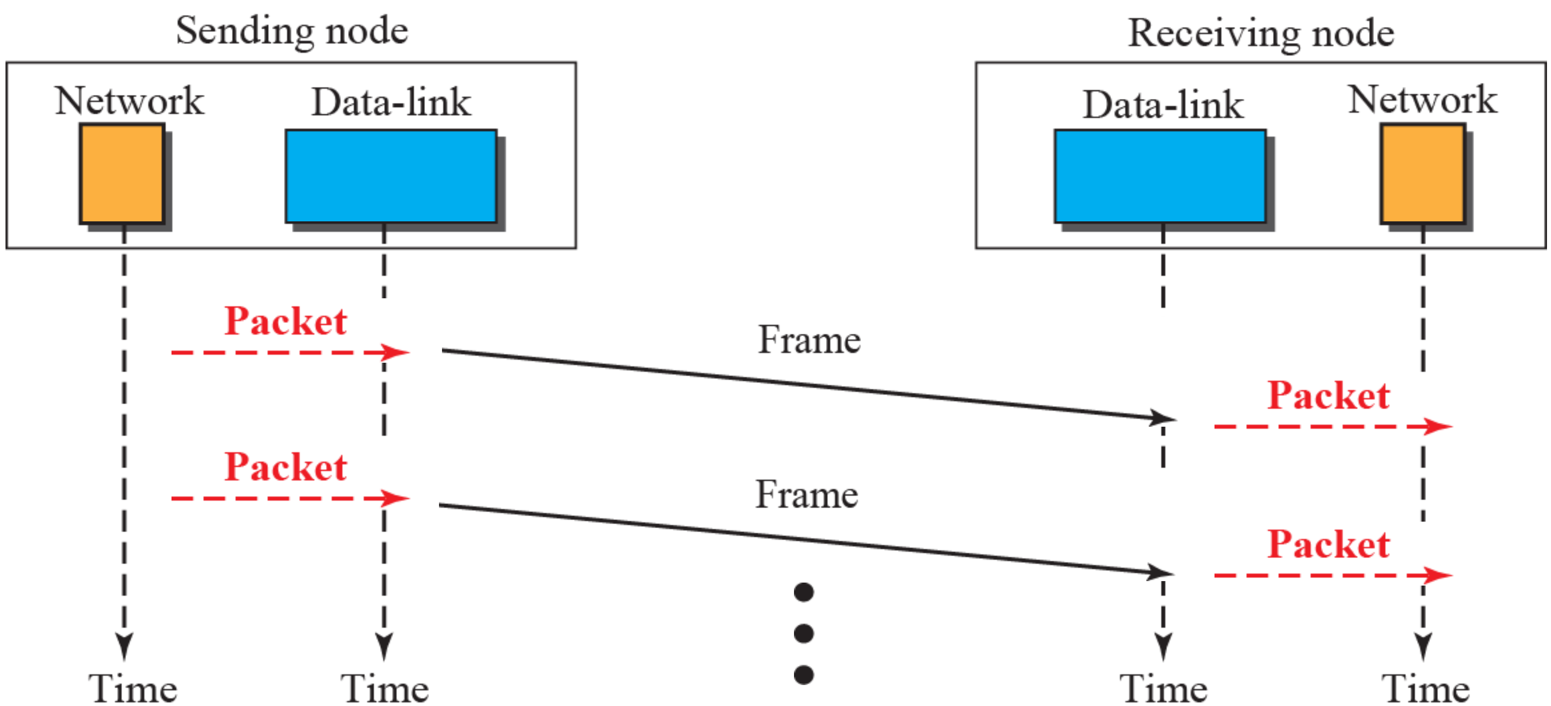
- **Simple protocol has neither flow nor error control**
- **Assumption: The receiver can immediately handle any frame it receives**
- **The receiver can never be overwhelmed with incoming frames**


Frame
Network
Data-link
Sending node
Logical link
Network
Data-link
Receiving node



Packet came from network layer.
Make a frame and send it.
Ready
Start
Sending node
L3
packet
DL
event
event
Frame arrived.
Deliver the packet to network layer.
Ready
Start
Receiving node

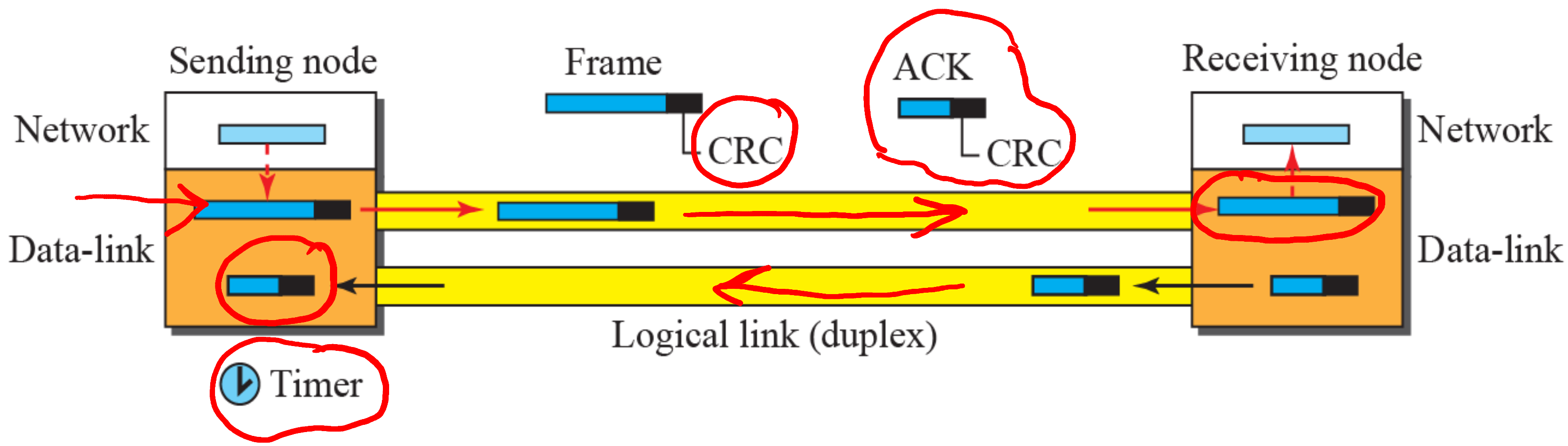
Here is an example of communication using this protocol. It is very simple. The sender sends frames one after another without even thinking about the receiver.



- **Stop-and-Wait protocol uses both flow and error control**

- **The sender sends one frame at a time and waits for an acknowledgment before sending the next one**

- **To detect corrupted frames, we add a CRC code**



Sending node
Frame
ACK
Receiving node
Network
CRC
CRC
Network
Data-link
Data-link
Logical link (duplex)
Timer

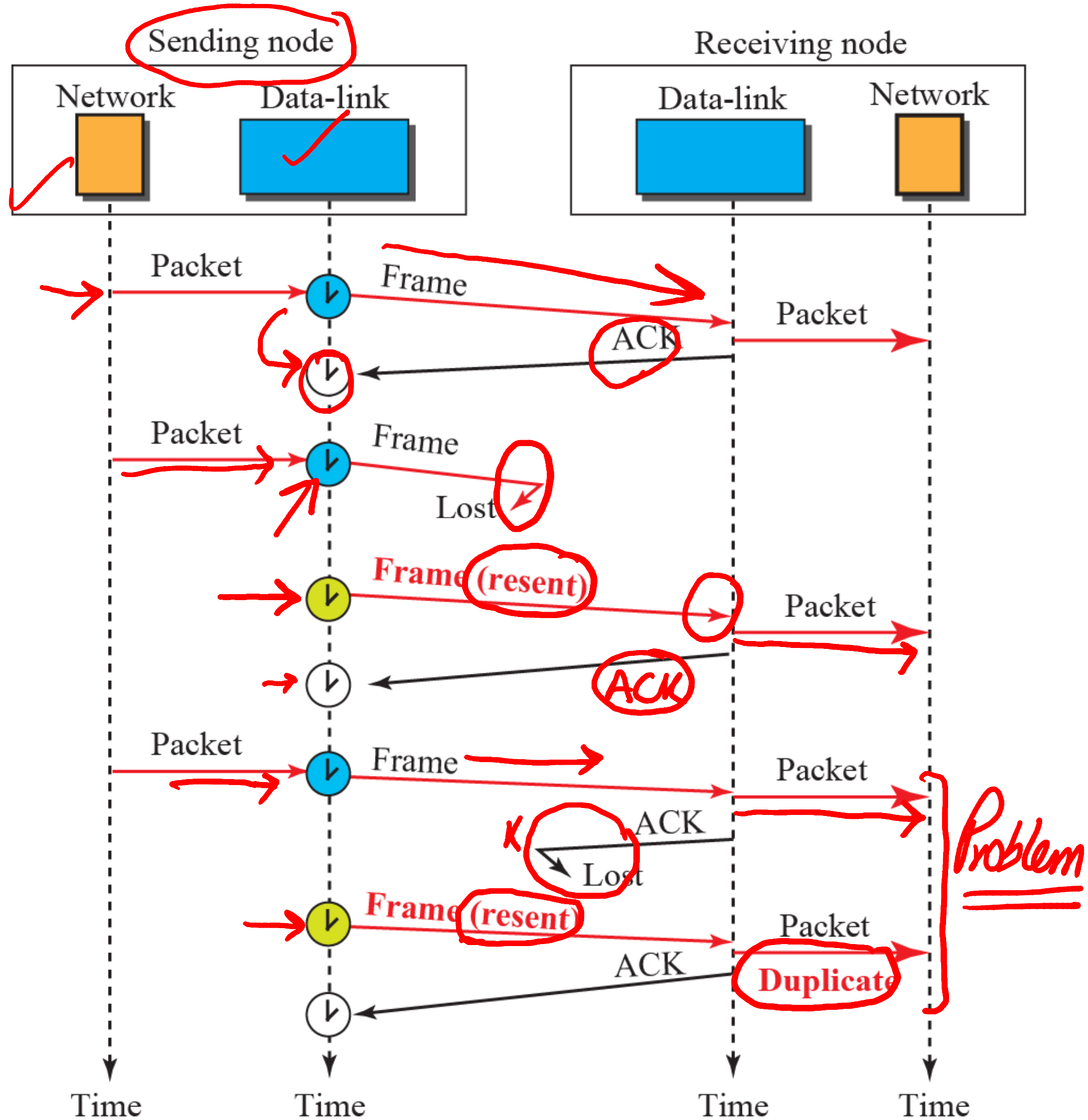
- Stop-and-Wait protocol uses both flow and error control

- The sender sends one frame at a time and waits for an acknowledgment before sending the next one

- To detect corrupted frames, we add a CRC code

Legend

- Start the timer.
- Stop the timer.
- Restart a time-out timer.



Notes:

A lost frame means either lost or corrupted.

A lost ACK means either lost or corrupted.

Legend

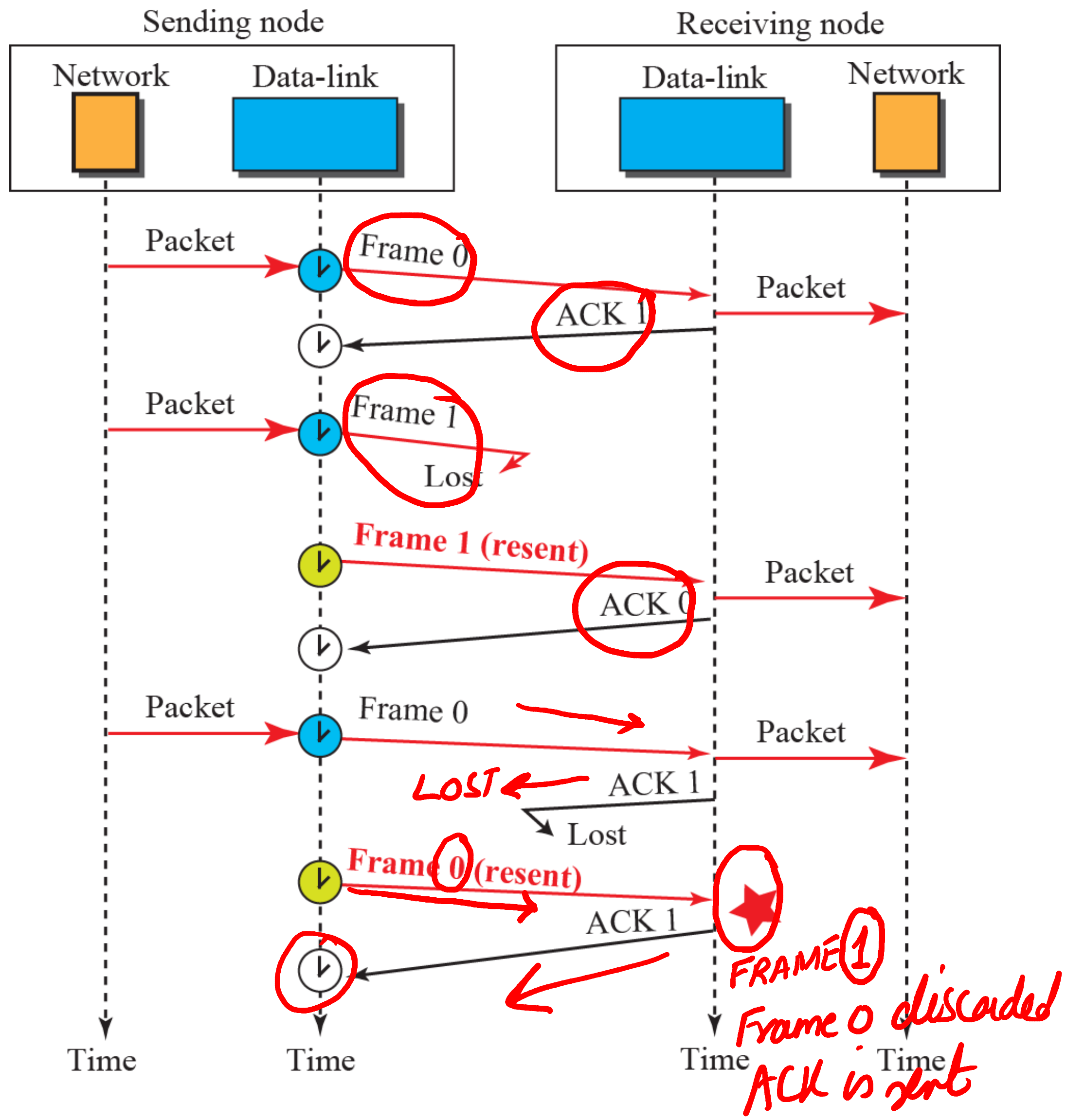
- Start the timer.
- Stop the timer.
- Restart a time-out timer.

Notes:

A lost frame means either lost or corrupted.

A lost ACK means either lost or corrupted.

★ Frame 0 is discarded because the receiver expects frame 1.



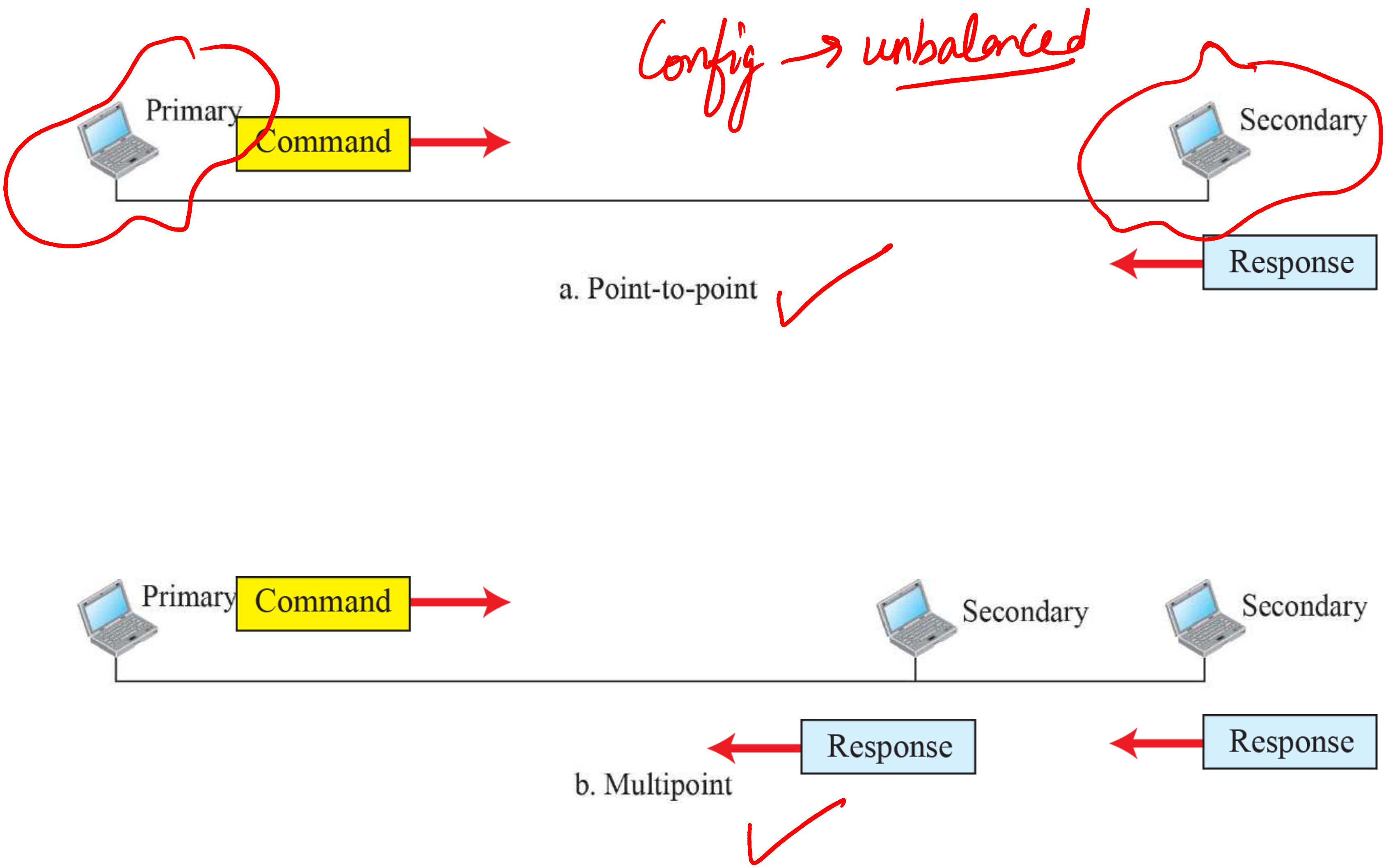
- Both Simple and Stop-and-wait protocols are designed for unidirectional communication

- Data flows in one direction and ACK travels in the other

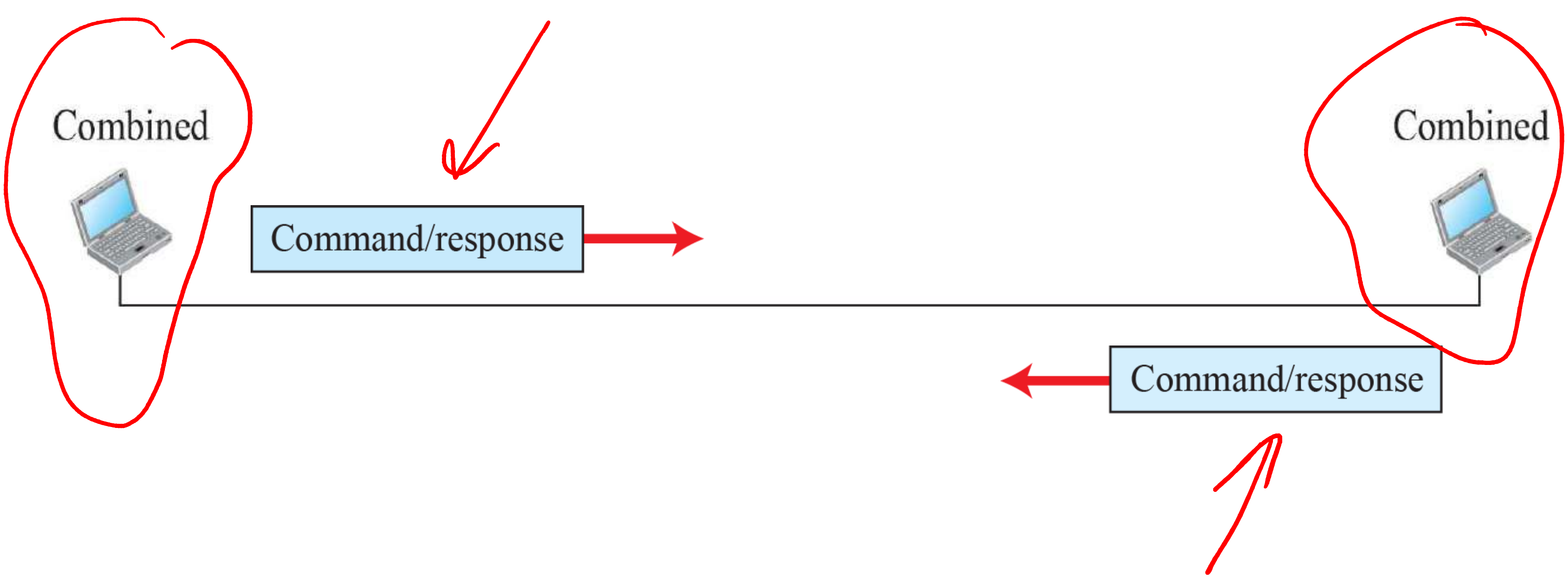
- To make the system efficient, the data in one direction is piggybacked with the acknowledgment in the other direction

- Bit -oriented protocol for communication over point-to-point and multipoint links
- It implements Stop-and-Wait protocol
- Most of the concepts defined in this protocol is the basis for other protocols such as PPP, Ethernet, or wireless LANs

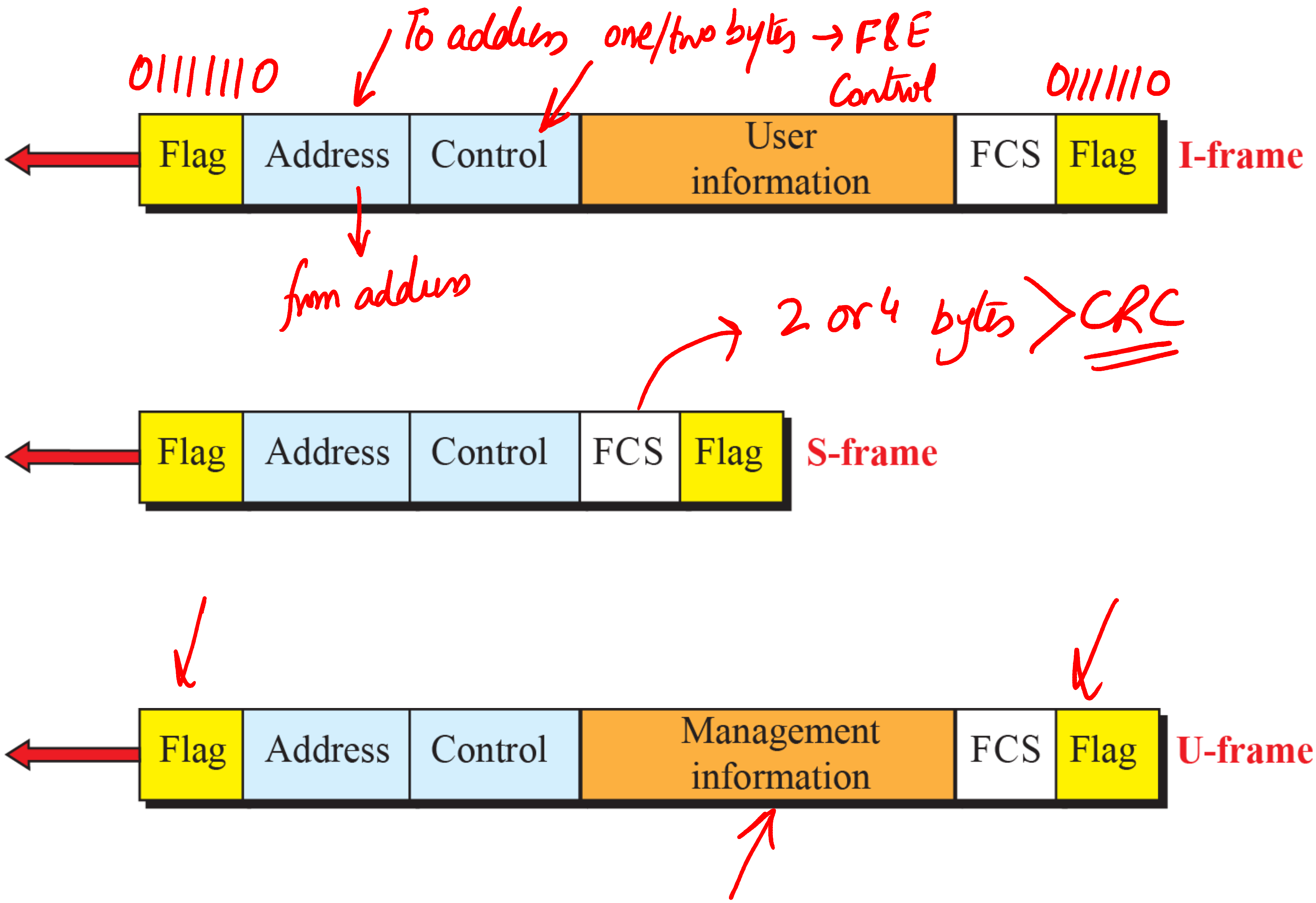
- HDLC provides two common transfer modes that can be used in different configurations:
  - ✓ Normal Response Mode (NRM) &
  - ✓ Asynchronous Balanced Mode (ABM)


Config → unbalanced
Primary
Command
Secondary
Response
a. Point-to-point
Primary
Command
Secondary
Secondary
Response
Response
b. Multipoint

ABM



- **HDLC defines three types of frames:**
  - ✓ **information frames (I-frames)**
  - ✓ **Supervisory frames (S-frames)**
  - ✓ **Unnumbered frames (U-frames)**



01111110
To address
one/two bytes → F&E Control
01111110
Flag
Address
Control
User information
FCS
Flag
I-frame
from address
2 or 4 bytes > CRC
Flag
Address
Control
FCS
Flag
S-frame
Flag
Address
Control
Management information
FCS
Flag
U-frame

- **Most common protocol for point-to-point access**

- **Millions of Internet users who need to connect their home computers to the server of an Internet service provider use PPP**

- **To control and manage the transfer of data, there is a need for a PPP at the data-link layer**

The designers of PPP have included several services to make it suitable for a point-to-point protocol, but have ignored some traditional services to make it simple

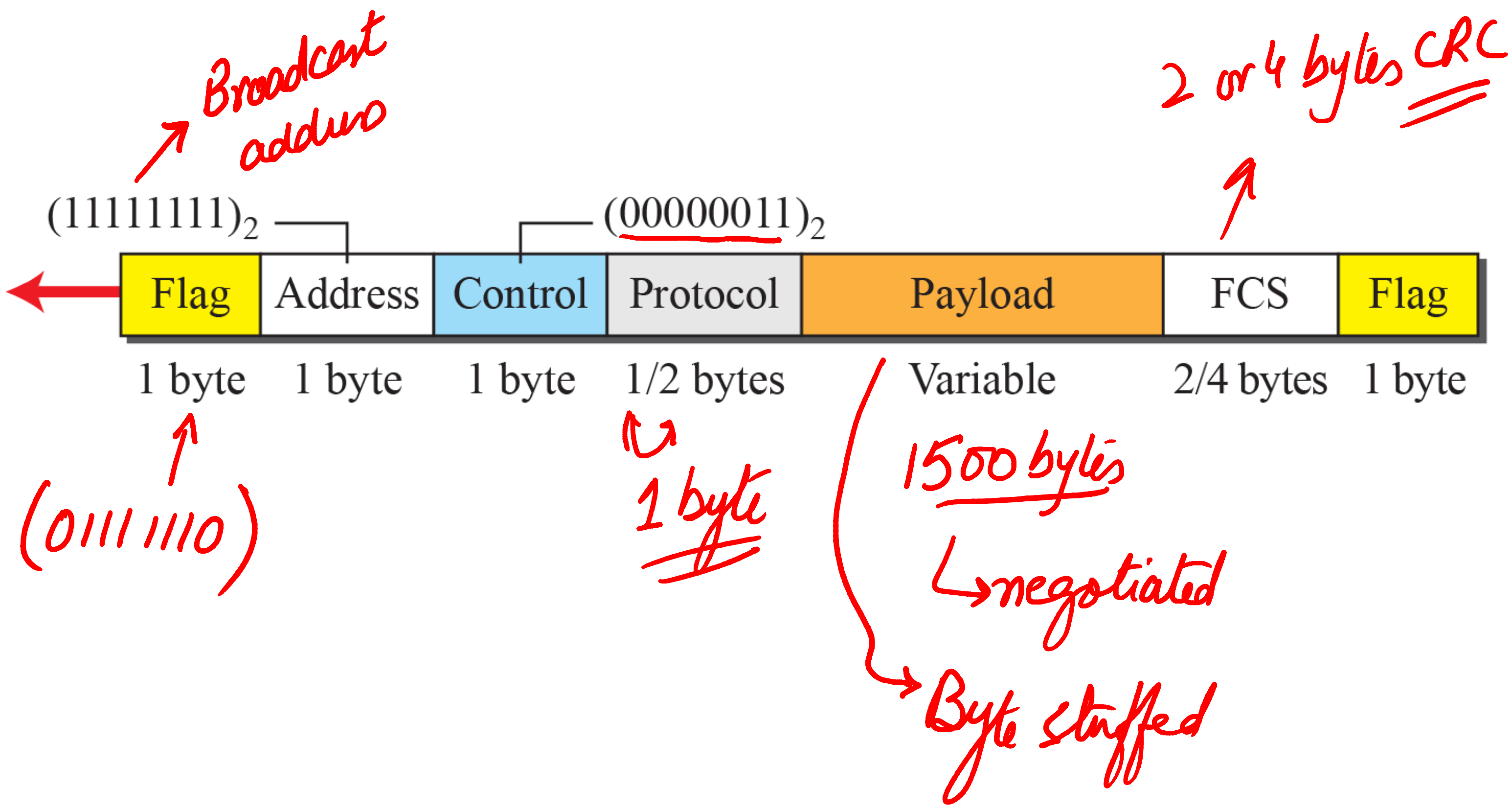
Services Included	Services Not Included
Framing	Flow Control
Link Establishment and Data Exchange	Error Correction (PPP has CRC detection only)
Authentication	No Sequence Numbering
Multilink PPP Address configuration	Absence of sophisticated Addressing Mechanism
Network Address configuration	

- **Most common protocol for point-to-point access**

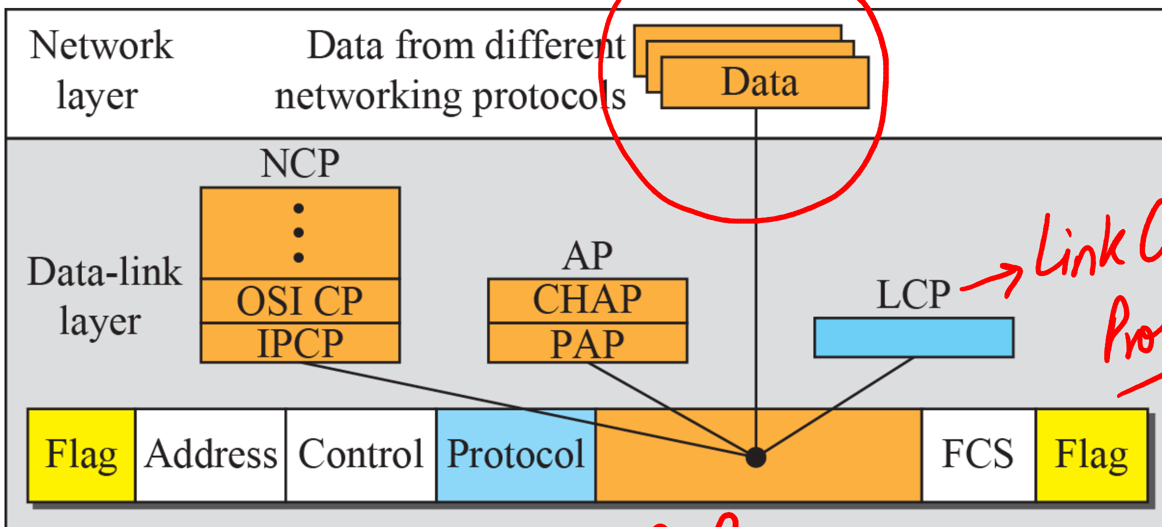
- **Millions of Internet users who need to connect their home computers to the server of an Internet service provider use PPP**

- **To control and manage the transfer of data, there is a need for a PPP at the data-link layer**

PPP uses a character-oriented (or byte-oriented) frame



- Although PPP is a link-layer protocol, it uses another set of protocols to establish the link, authenticate and carry the network-layer data
- Three sets of protocols are:
  - Link Control Protocol (LCP)
  - Two Authentication Protocols (APs)
  - Several Network Control Protocols (NCPs)



Link Control Protocol

↓ establishing maintaining configuring terminating links

Legend

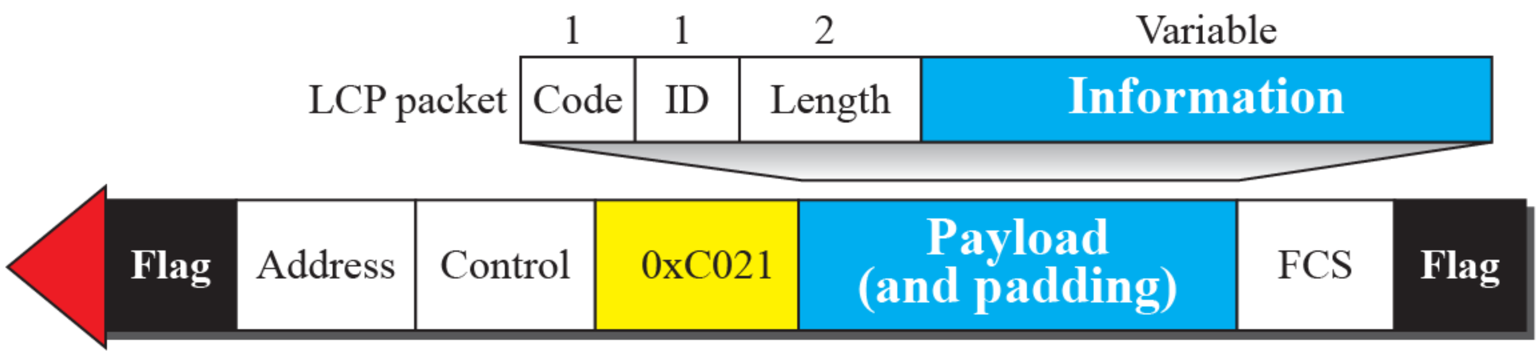
LCP : Link control protocol
AP : Authentication protocol
NCP: Network control protocol

AP → PAP
→ CHAP

NCP → IPCP

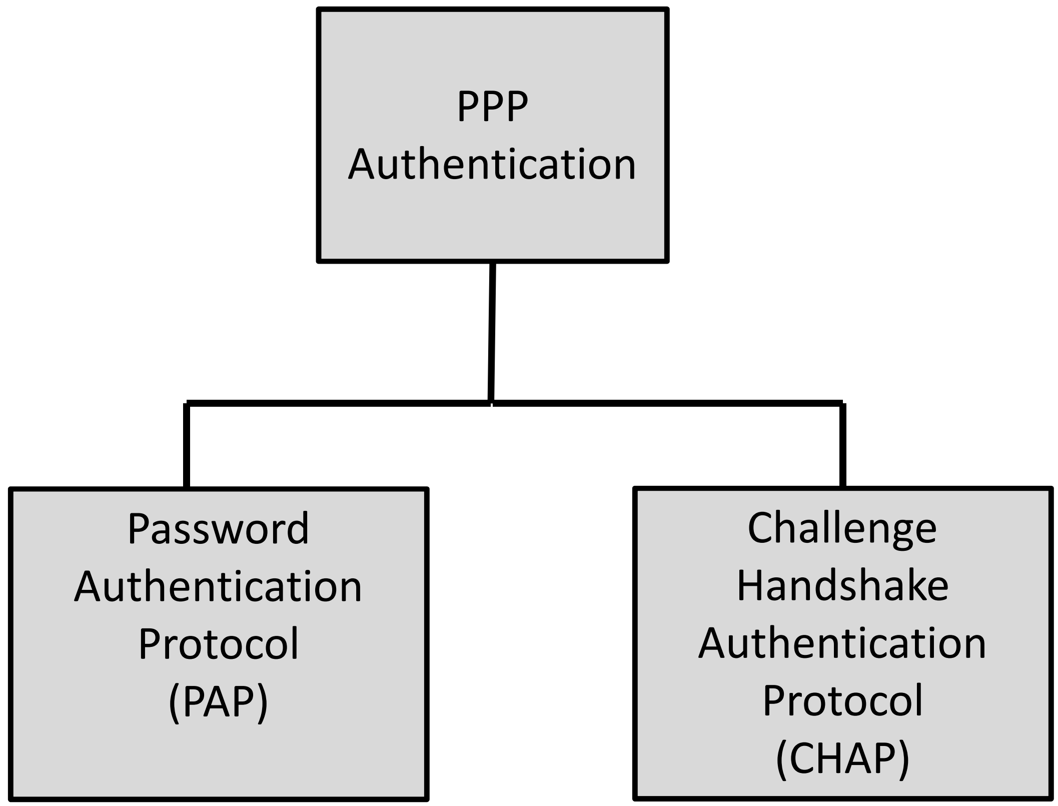
Protocol values:

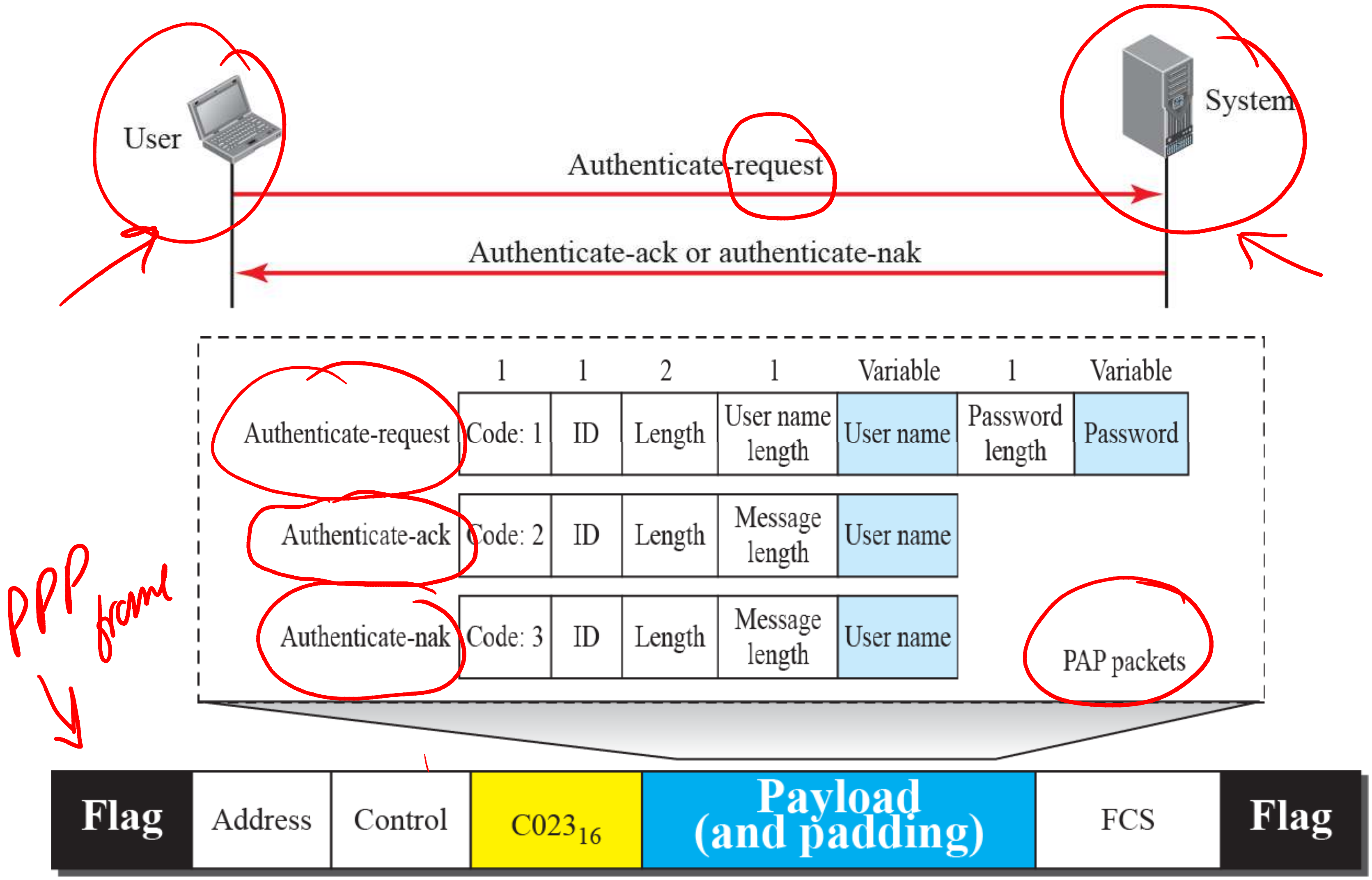
LCP : 0xC021
AP : 0xC023 and 0xC223
NCP: 0x8021 and ....
Data: 0x0021 and ....

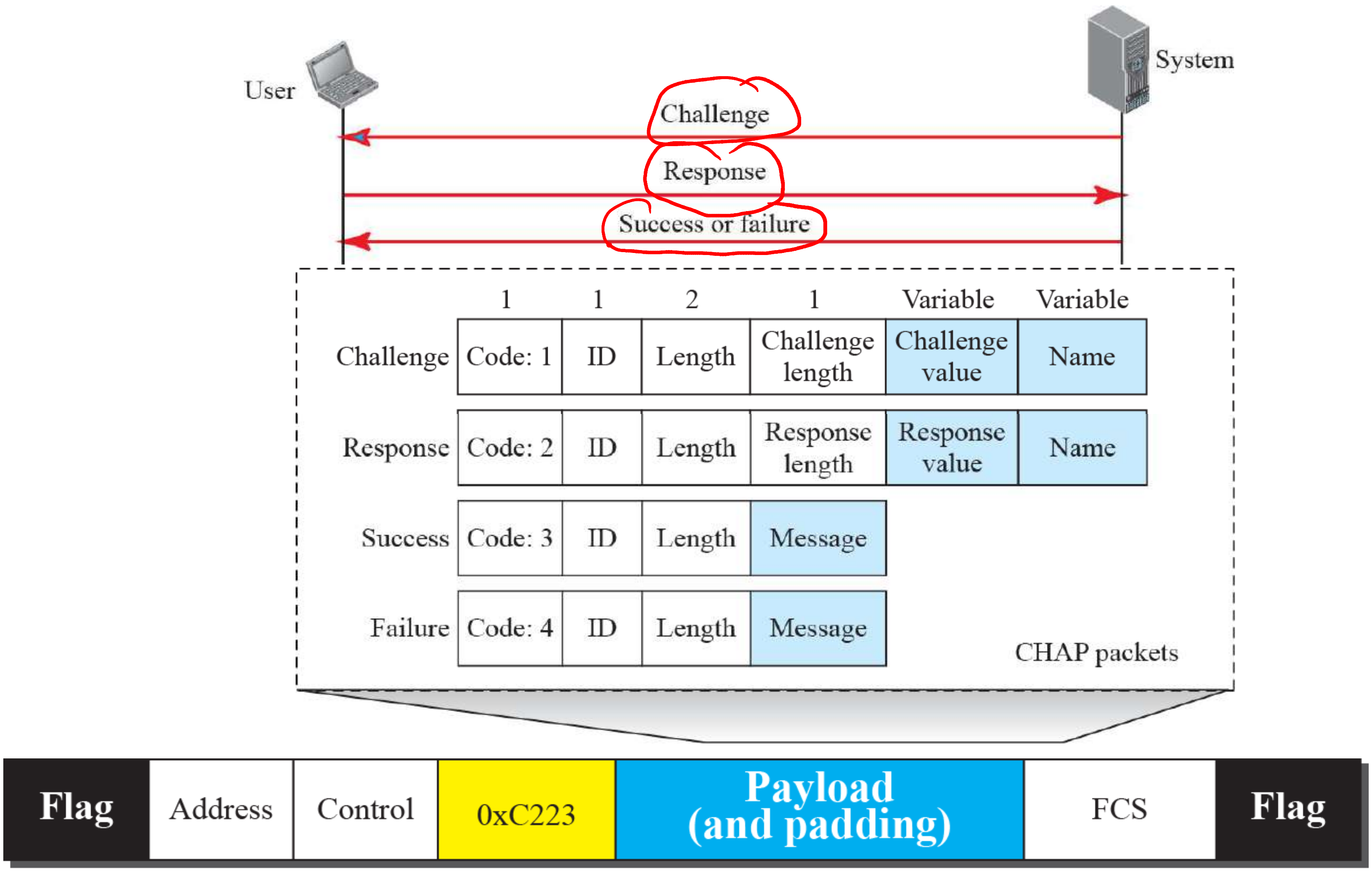

1
1
2
Variable
LCP packet
Code
ID
Length
Information
Flag
Address
Control
0xC021
Payload
(and padding)
FCS
Flag

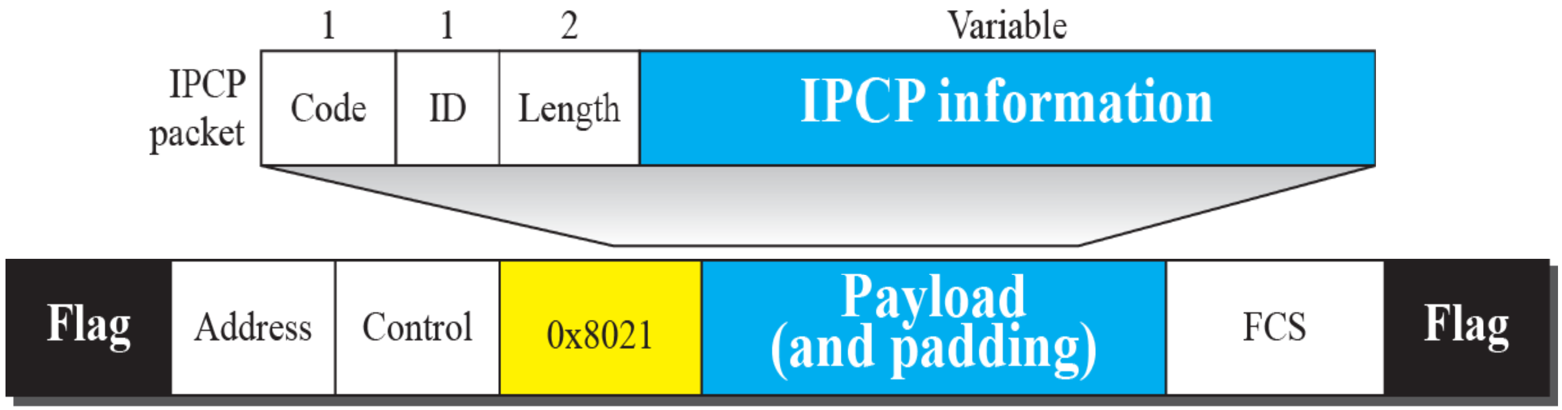
Code	Packet Type	Description
0x01	Configure-request	Contains the list of proposed options and their values
0x02	Configure-ack	Accepts all options proposed
0x03	Configure-nak	Announces that some options are not acceptable
0x04	Configure-reject	Announces that some options are not recognized
0x05	Terminate-request	Request to shut down the line
0x06	Terminate-ack	Accept the shutdown request
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

- **Although PPP is a link-layer protocol, it uses another set of protocols to establish the link, authenticate and carry the network-layer data**
- **Three sets of protocols are:**
  - **Link Control Protocol (LCP)**
  - **Two Authentication Protocols (APs)**
  - **Several Network Control Protocols (NCPs)**

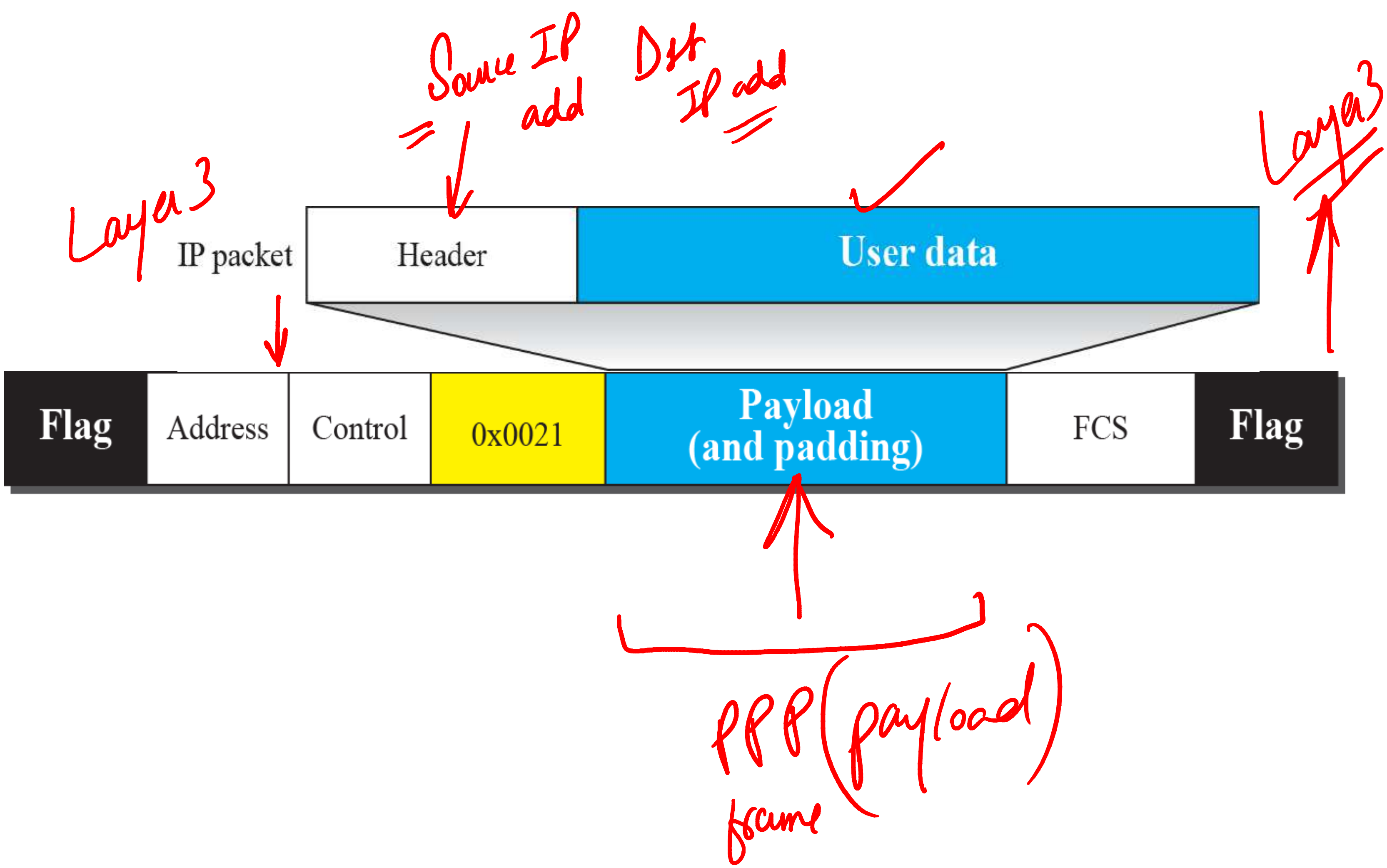

PPP
Authentication
Password
Authentication
Protocol
(PAP)
Challenge
Handshake
Authentication
Protocol
(CHAP)


User
System
Authenticate-request
Authenticate-ack or authenticate-nak
1
1
2
1
Variable
1
Variable
Authenticate-request
Code: 1
ID
Length
User name length
User name
Password length
Password
Authenticate-ack
Code: 2
ID
Length
Message length
User name
Authenticate-nak
Code: 3
ID
Length
Message length
User name
PAP packets
PPP frame
Flag
Address
Control
$C023_{16}$
Payload (and padding)
FCS
Flag


User
System
Challenge
Response
Success or failure
1
1
2
1
Variable
Variable
Challenge
Code: 1
ID
Length
Challenge length
Challenge value
Name
Response
Code: 2
ID
Length
Response length
Response value
Name
Success
Code: 3
ID
Length
Message
Failure
Code: 4
ID
Length
Message
CHAP packets
Flag
Address
Control
0xC223
Payload (and padding)
FCS
Flag


1
1
2
Variable
IPCP
packet
Code
ID
Length
IPCP information
Flag
Address
Control
0x8021
Payload
(and padding)
FCS
Flag

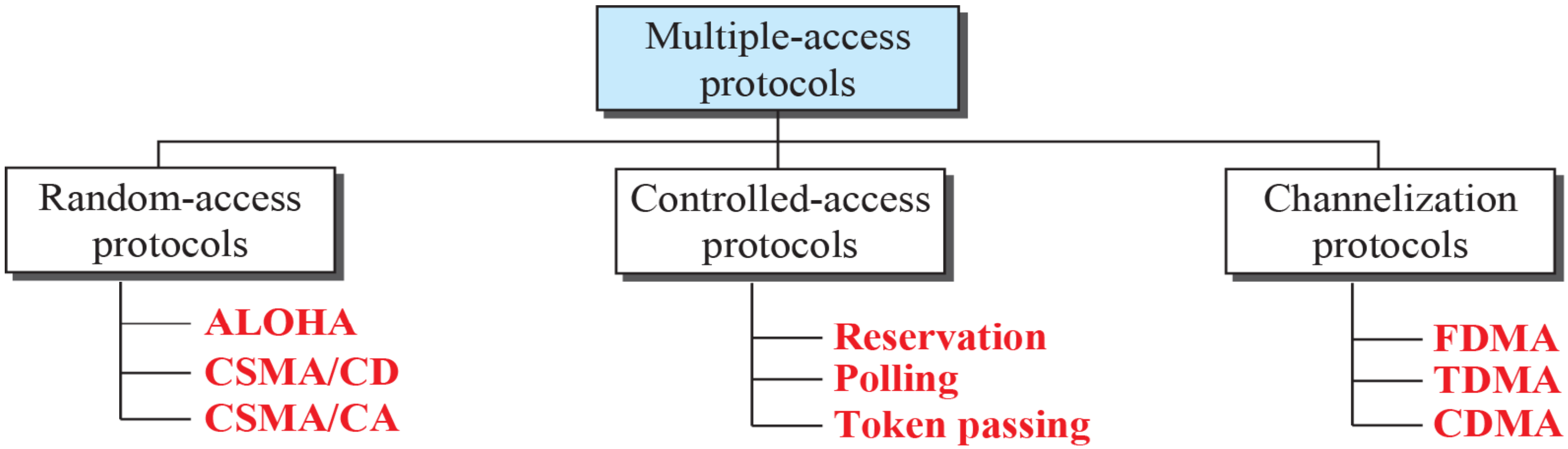
Code	*IPCP Packet*
0x01	Configure-request ✓
0x02	Configure-ack ✓
0x03	Configure-nak ✓
0x04	Configure-reject ✓
0x05	Terminate-request ✓
0x06	Terminate-ack ✓
0x07	Code-reject ✓



Source IP add
Dst IP add
Layer3
IP packet
Header
User data
Layer3
Flag
Address
Control
0x0021
Payload
(and padding)
FCS
Flag
PPP (payload)
frame

Media Access Control (MAC) Sub-Layer

- When nodes use a multipoint or broadcast link, we need a multiple-access protocol to coordinate access to the link
- Many protocols have been devised to handle access to a shared link
- All of these protocols belong to Media Access Control (MAC) sub-layer


Multiple-access protocols
Random-access protocols
ALOHA
CSMA/CD
CSMA/CA
Controlled-access protocols
Reservation
Polling
Token passing
Channelization protocols
FDMA
TDMA
CDMA

- In random-access or contention no station is superior to the other and none is assigned control over the other
- Station that has data to send uses a procedure defined by the protocol to make a decision on whether or not to send
- This decision depends on the state of the medium (idle or busy)

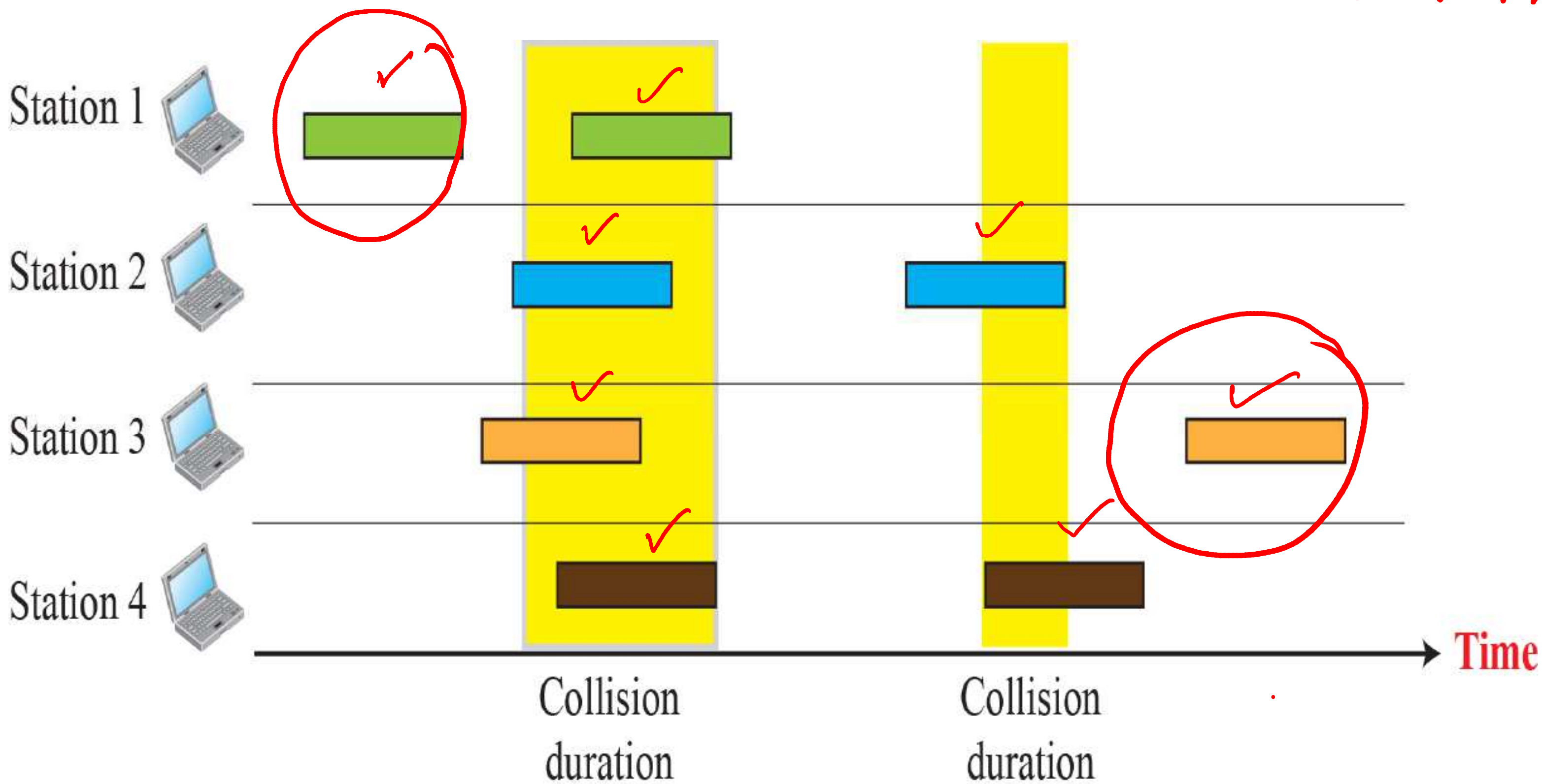
- **ALOHA, the earliest random access method, was developed in early 1970s**

- **Designed for a radio (wireless) LAN, but it can be used on any shared medium**

- **Potential collisions in this arrangement as the medium is shared between the stations**

- **When a station sends data, another station may attempt to do so at the same time**
- **The data from the two stations collide and become garbled**

Pure ALOHA → Slotted ALOHA



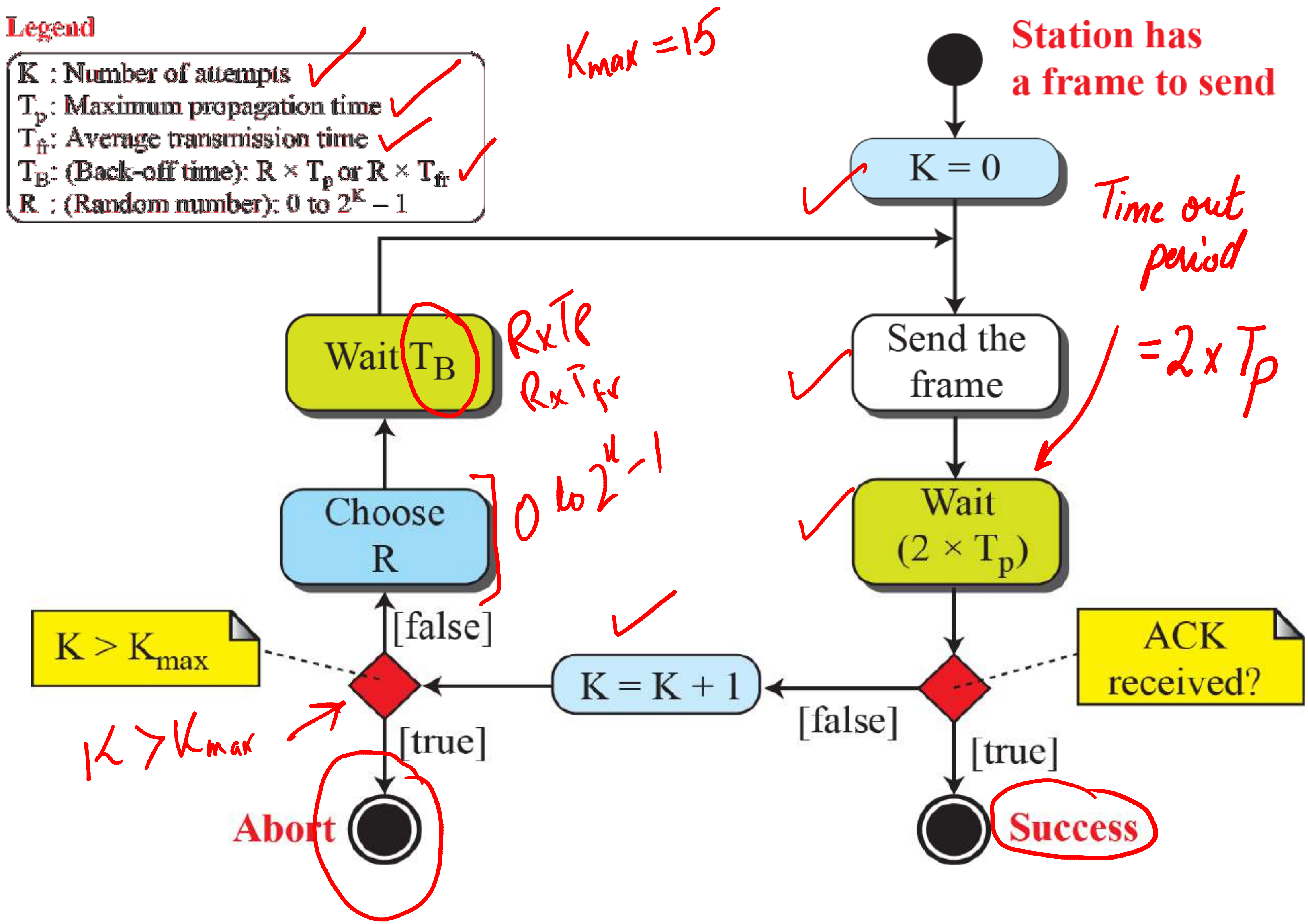
ACK → Sending waits from Rec station

T_B → Back off Time → Random wait

- **ALOHA, the earliest random access method, was developed in early 1970s**

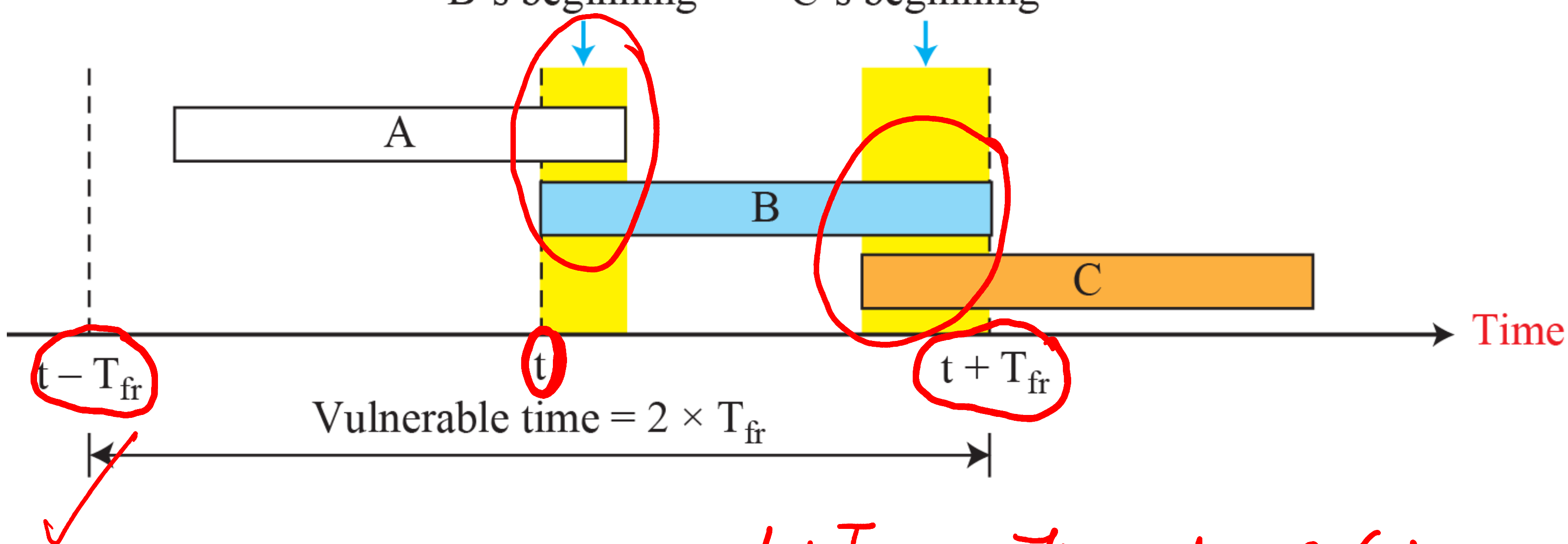
- **Designed for a radio (wireless) LAN, but it can be used on any shared medium**

- **Potential collisions in this arrangement as the medium is shared between the stations**



Legend
K : Number of attempts
T_p : Maximum propagation time
T_{fr}: Average transmission time
T_B: (Back-off time): $R \times T_p$ or $R \times T_{fr}$
R : (Random number): 0 to $2^K - 1$
$K_{max} = 15$
Station has a frame to send
K = 0
Time out period
$= 2 \times T_p$
Send the frame
Wait $(2 \times T_p)$
ACK received?
[false]
[true]
Success
K = K + 1
Wait T_B
$R \times T_p$
$R \times T_{fr}$
Choose R
0 to $2^K - 1$
[false]
$K > K_{max}$
[true]
$K > K_{max}$
Abort

$\boxed{V_T = 2 \times T_{fr}}$

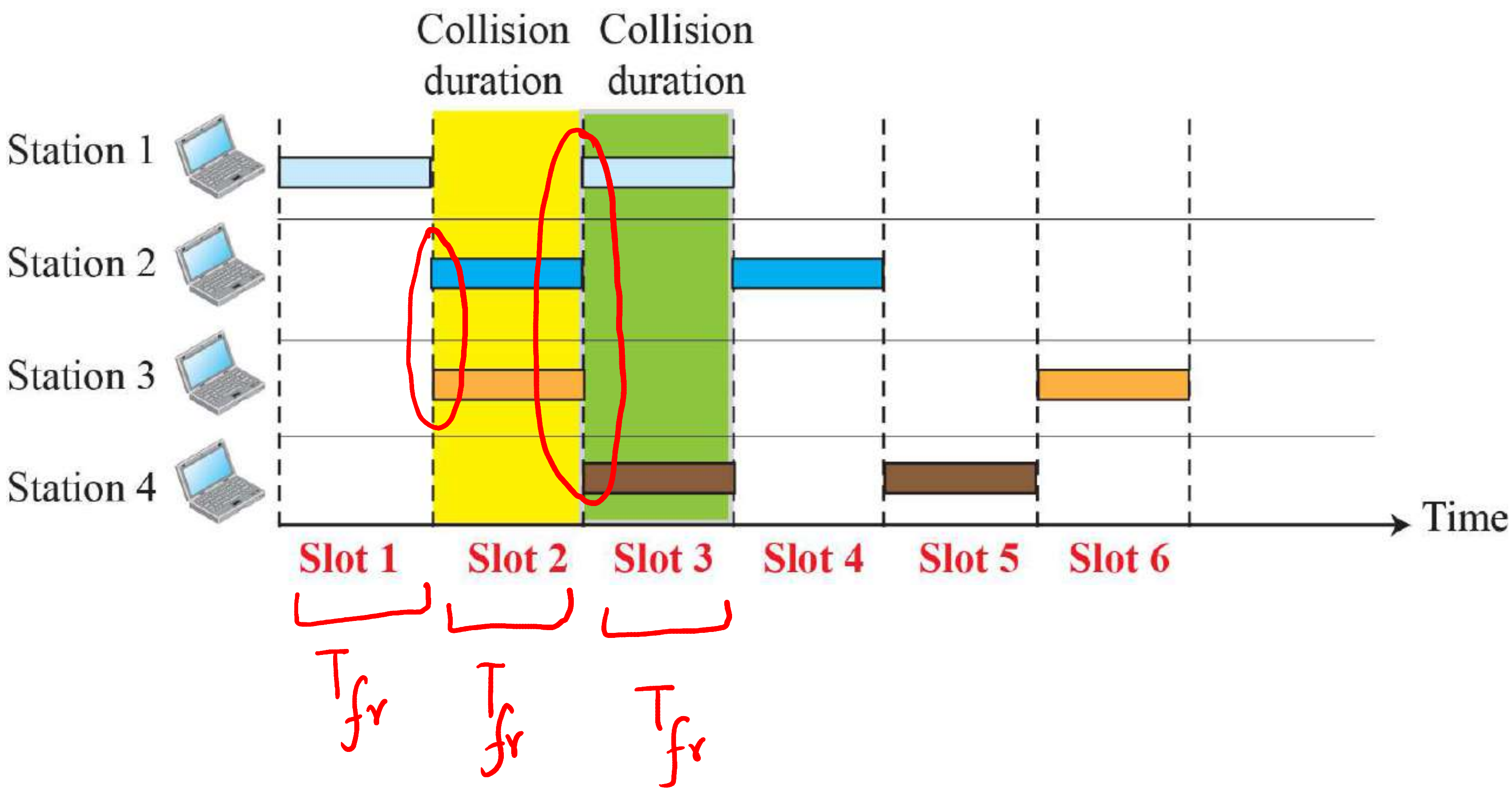


$t + T_{fr}$ → Time when B (t) is going to finish/vacate the medium

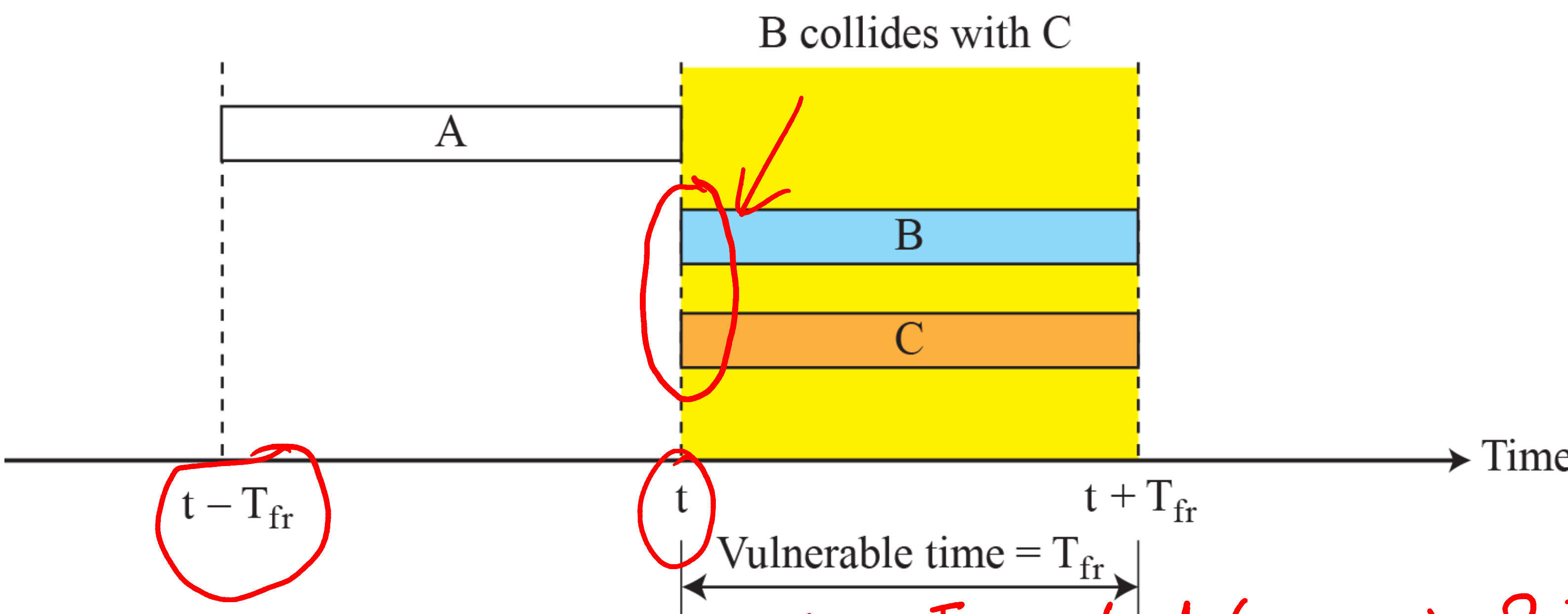
- **We divide time into slots of T_{fr} sec and force the station to send only at the beginning of the slot**

- **Invented to improve the efficiency of pure ALOHA**

- **If a station misses the time slot, it must wait until beginning of next time slot reducing vulnerable time to T_{fr} (vs. 2 x T_{fr} for pure ALOHA)**



Collision duration
Collision duration
Station 1
Station 2
Station 3
Station 4
Time
Slot 1
Slot 2
Slot 3
Slot 4
Slot 5
Slot 6
T_{fr}
T_{fr}
T_{fr}



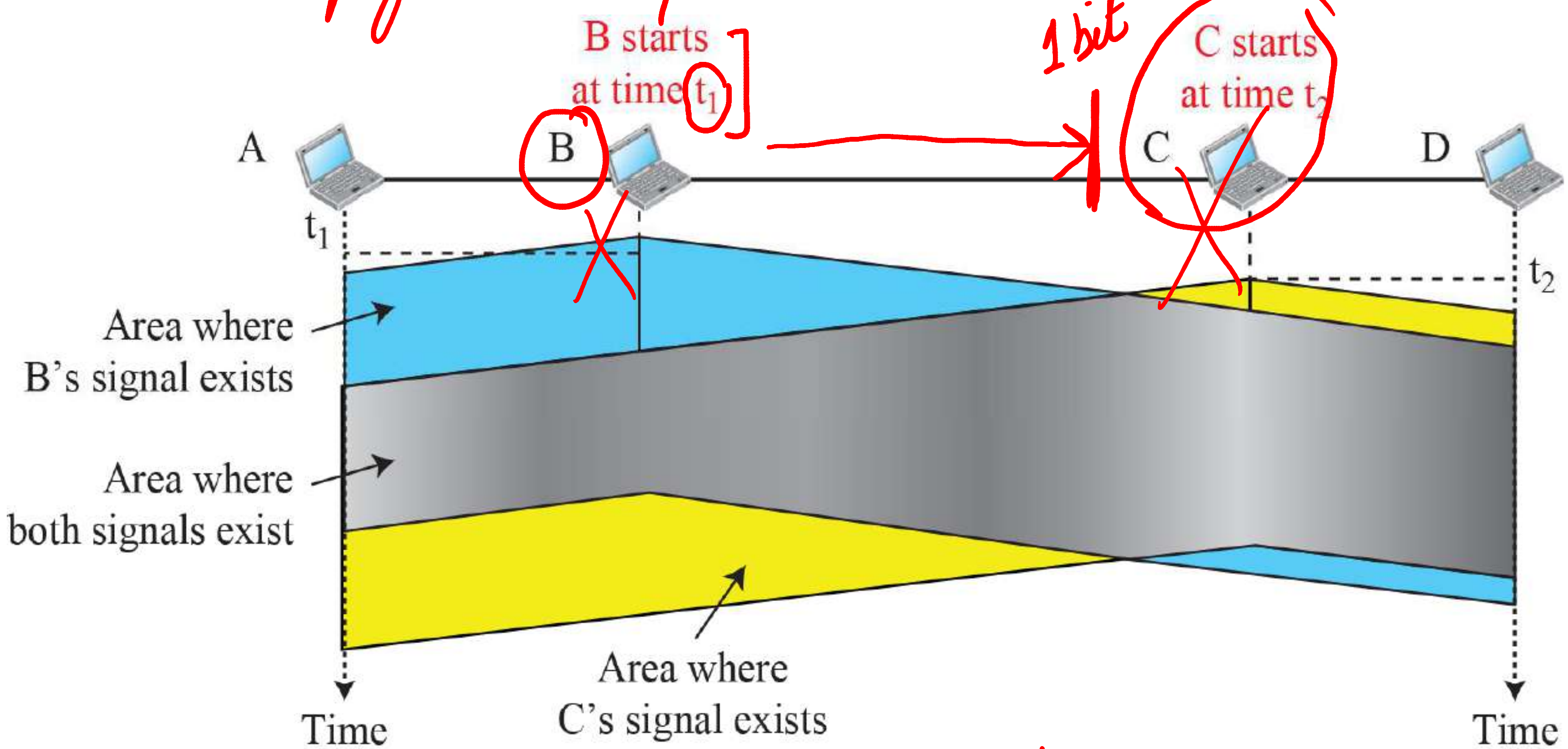
$V_T = T_{fr}$ $(V_T\,(\text{pure ALOHA}) = 2 \times T_{fr})$

- To minimize the chance of collision and, therefore, increase the performance, CSMA was developed

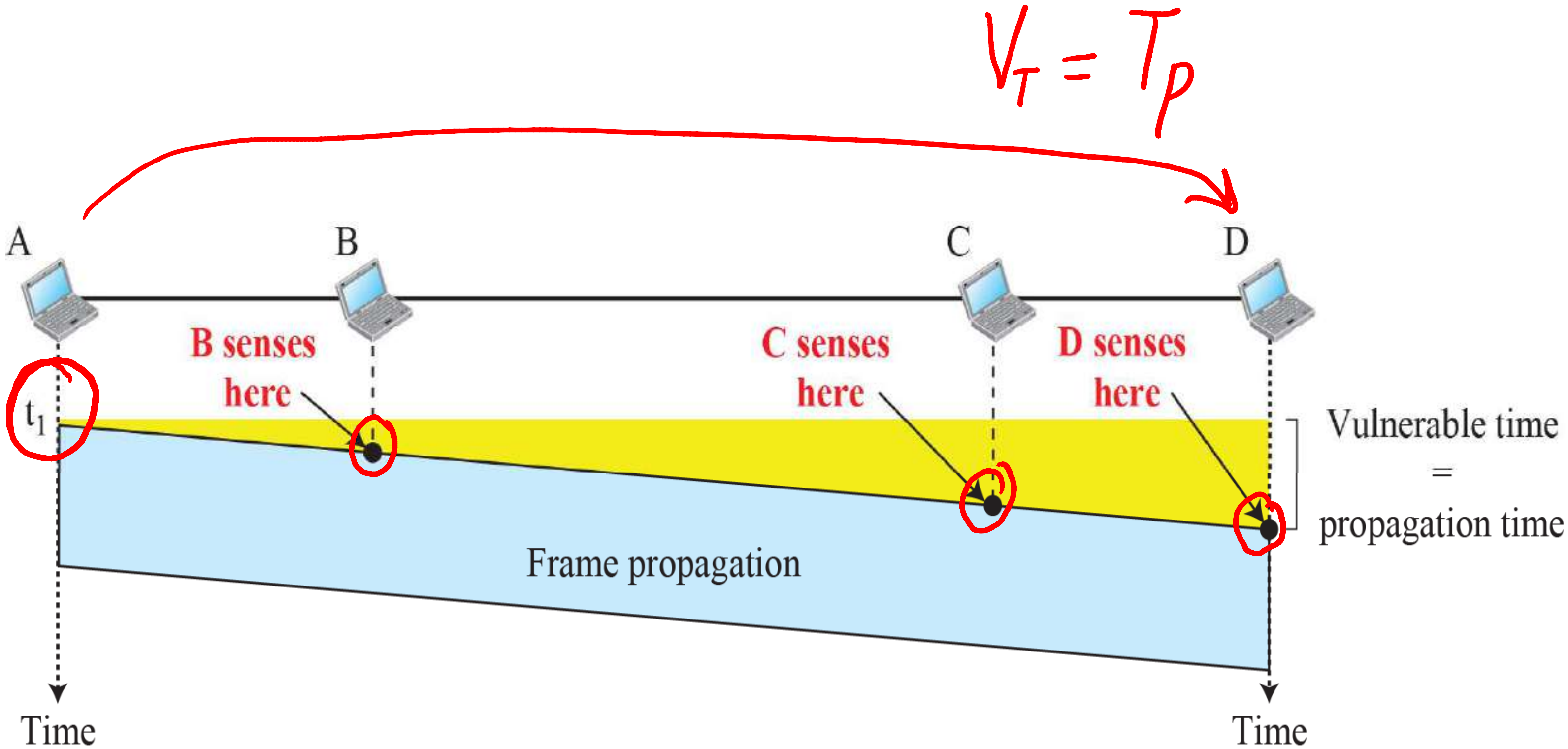
- The chance of collision is reduced as the station is required to sense/listen to the medium before sending data

- ‘sense before transmit’ or ‘listen before talk’

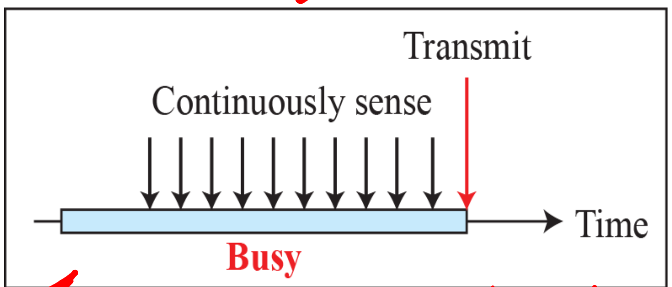
Propagation Delay → Collisions



$t_2 > t_1$



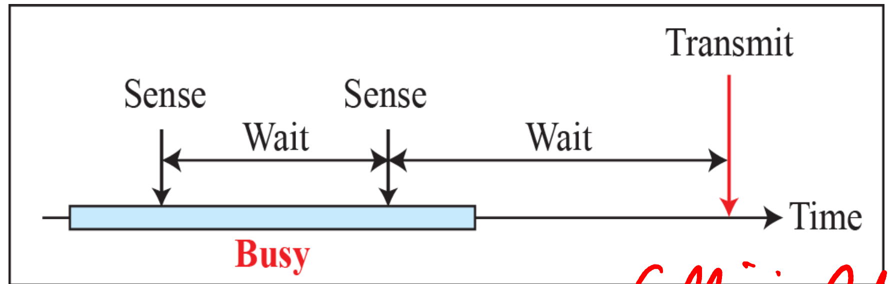
$V_T = T_P$
A
B
C
D
B senses here
C senses here
D senses here
t_1
Vulnerable time = propagation time
Frame propagation
Time
Time



a. 1-persistent

(ETHERNET)

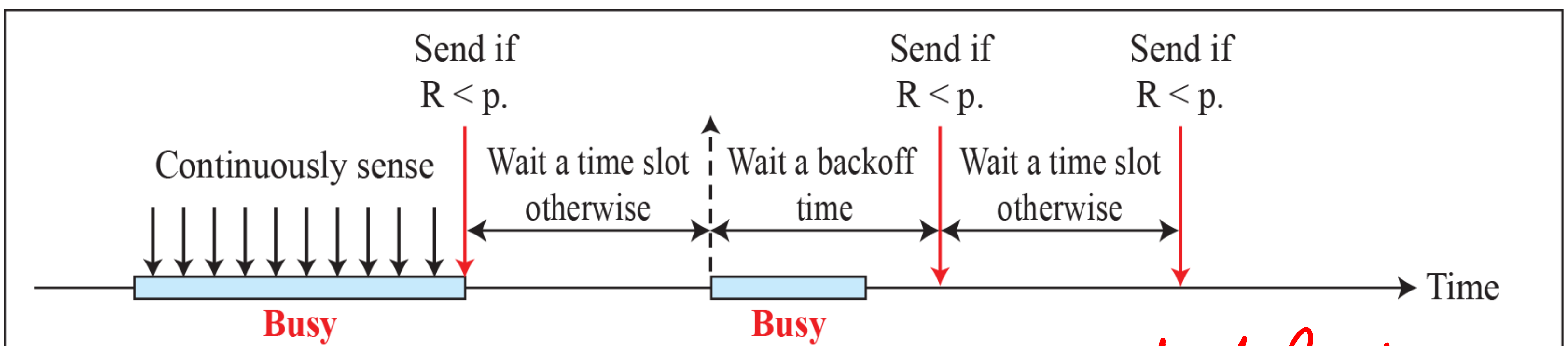
Highest Collision Rate



b. Nonpersistent

Collision Rate ↓

Efficiency ↓



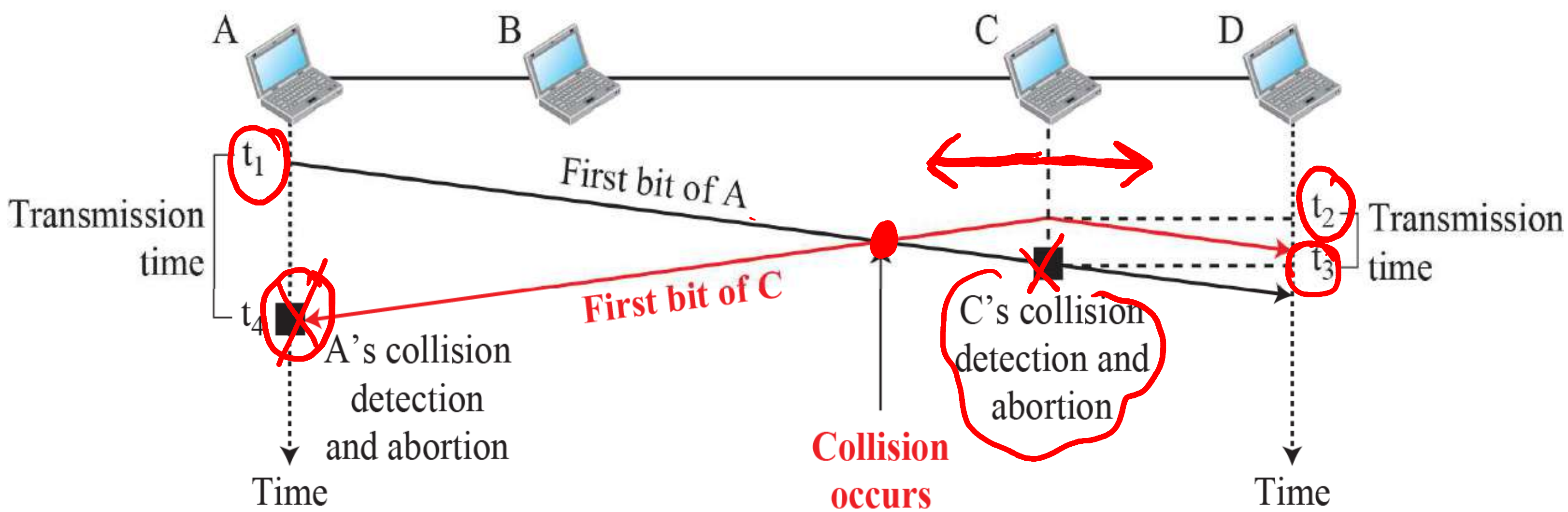
c. *p*-persistent

* Back off Procedure *

- **CSMA method does not specify the procedure following a collision**

- **CSMA/CD augments the algorithm to handle the collision**

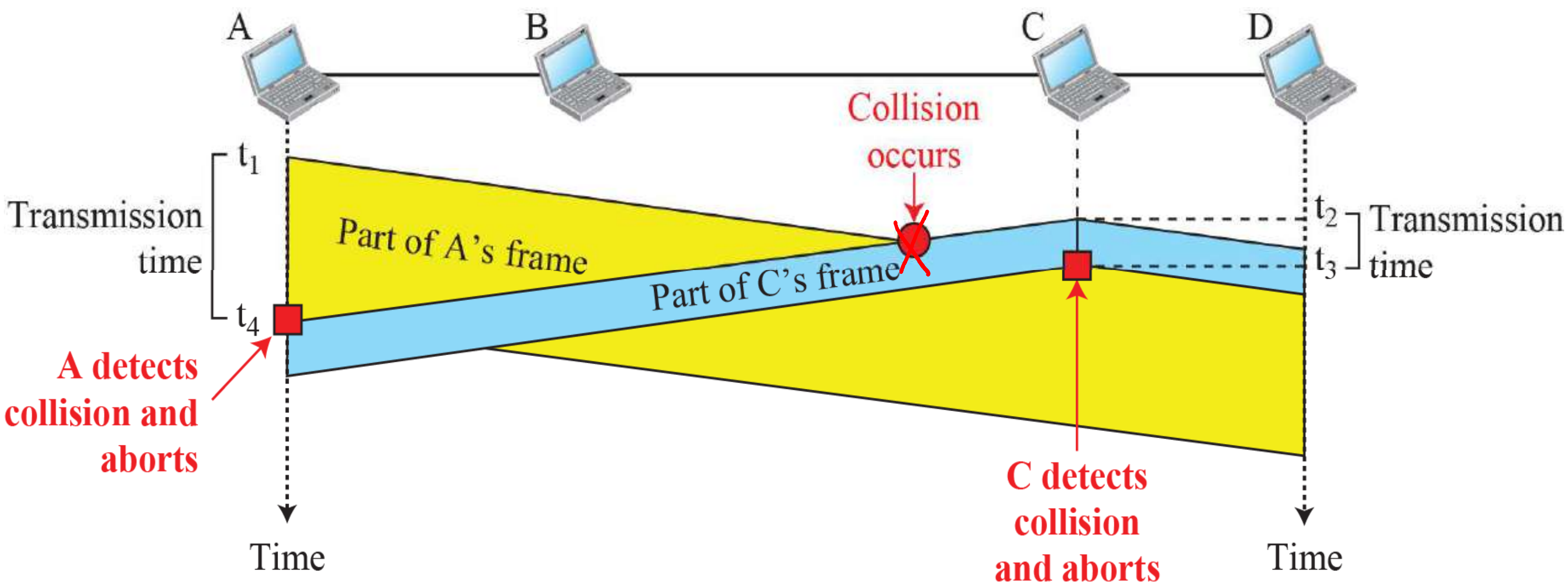
- **The station monitors the medium after it sends a frame to see if the transmission was successful. If there is a collision, the frame is sent again**



$A \rightarrow t_4 - t_1$

$C \rightarrow t_3 - t_2$

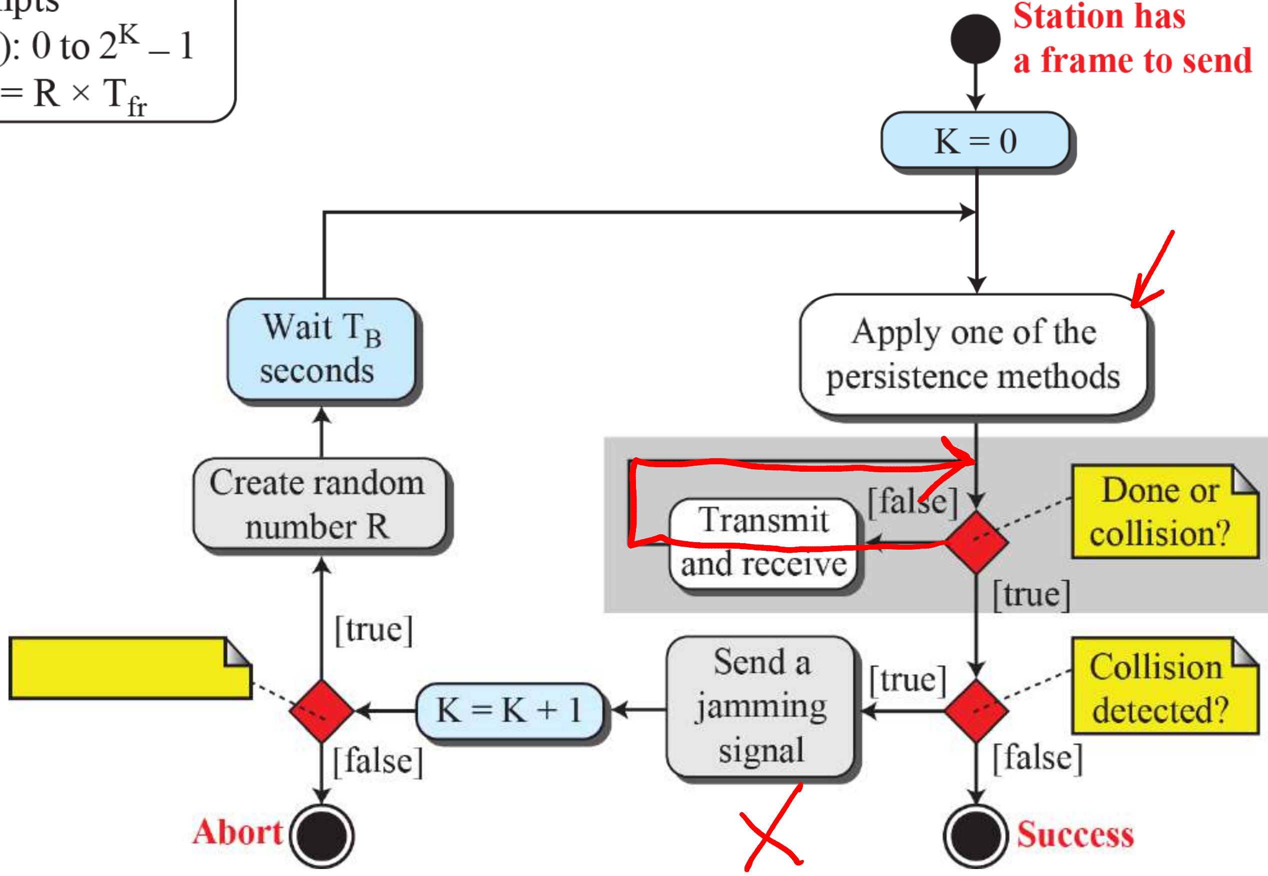
$\rightarrow$ Duration of two transmissions



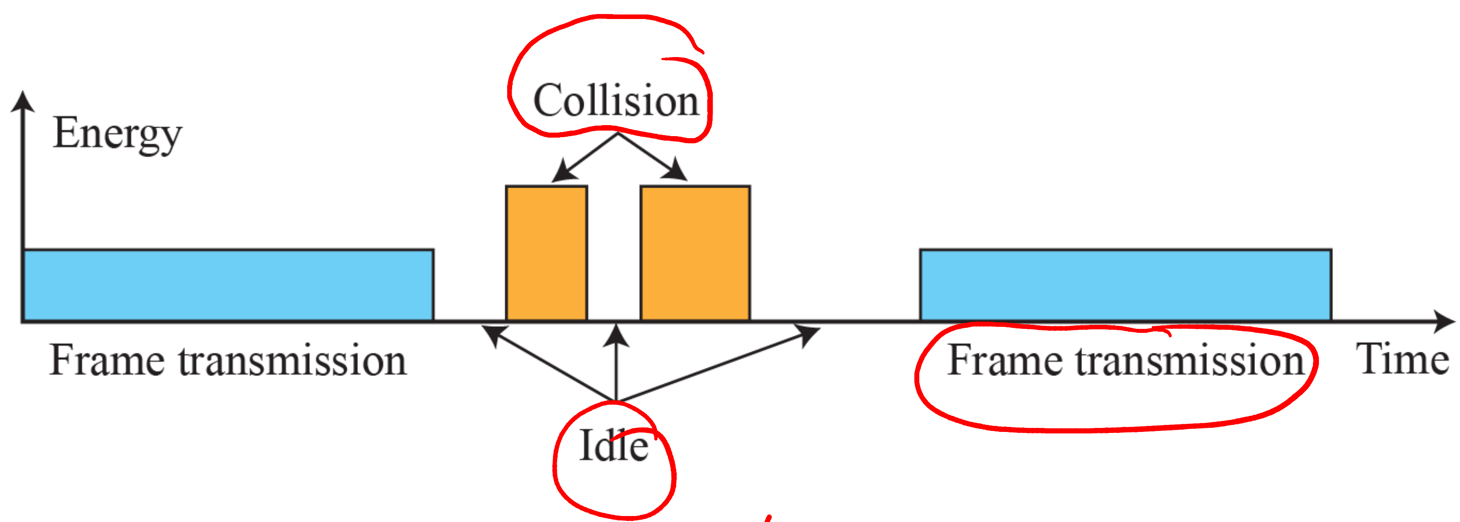
A
B
C
D
Collision occurs
t_1
Transmission time
t_4
Part of A's frame
Part of C's frame
t_2
t_3
Transmission time
A detects collision and aborts
C detects collision and aborts
Time
Time

Legend

T_{fr}: Frame average transmission time
K : Number of attempts
R : (random number): 0 to $2^K - 1$
T_B: (Back-off time) = $R \times T_{fr}$



$\text{Throughput}_{CSMA/CD} > \text{Throughput}_{ALOHA}$



10Mbps Ethernet Standard

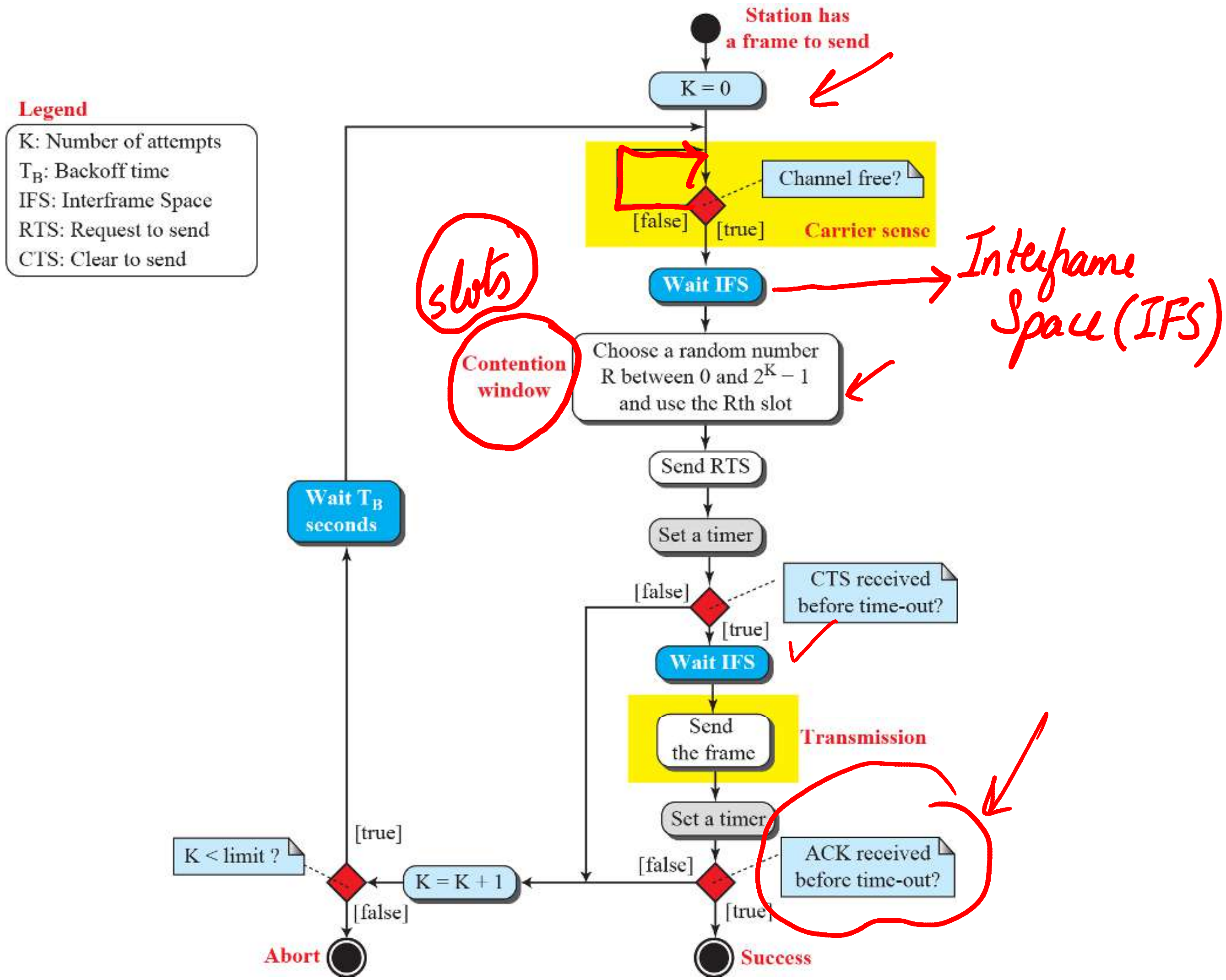
- **CSMA/CA was invented for Wireless Networks**

- **Collisions are avoided through the use of three strategies:**

  - ✓ **The Interfame Space**

  - ✓ **The Contention Window**

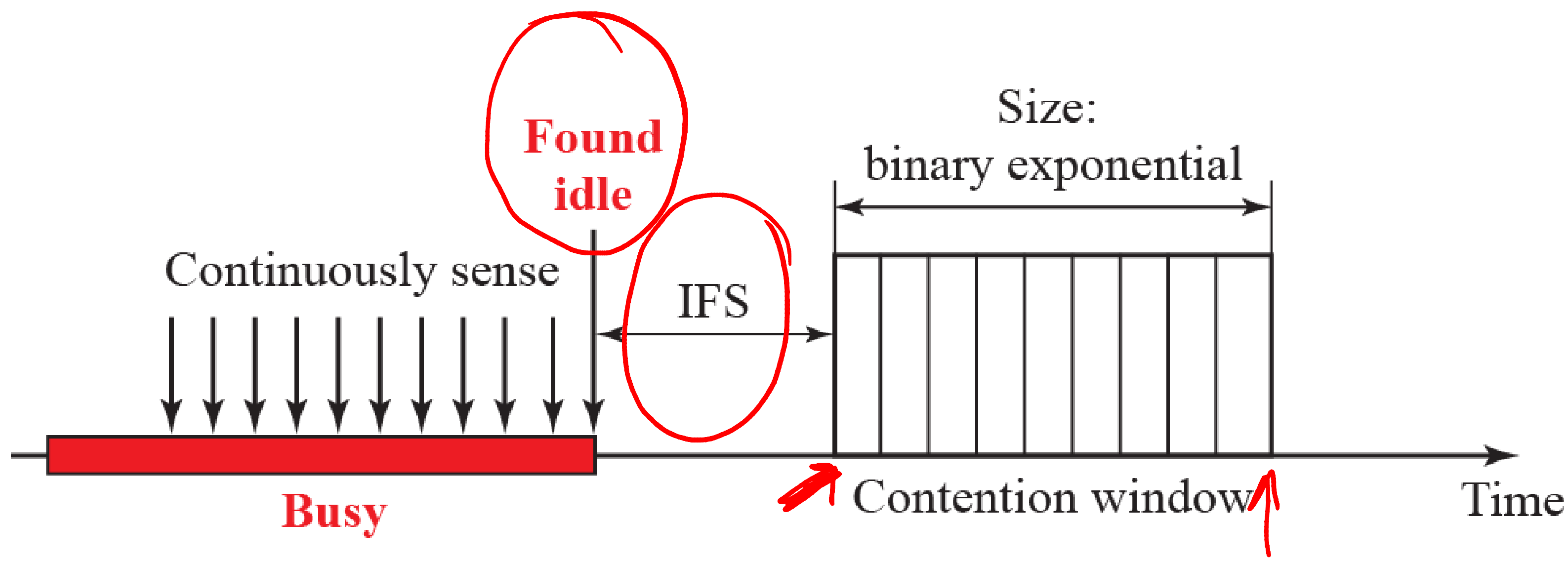
  - ✓ **Acknowledgements**



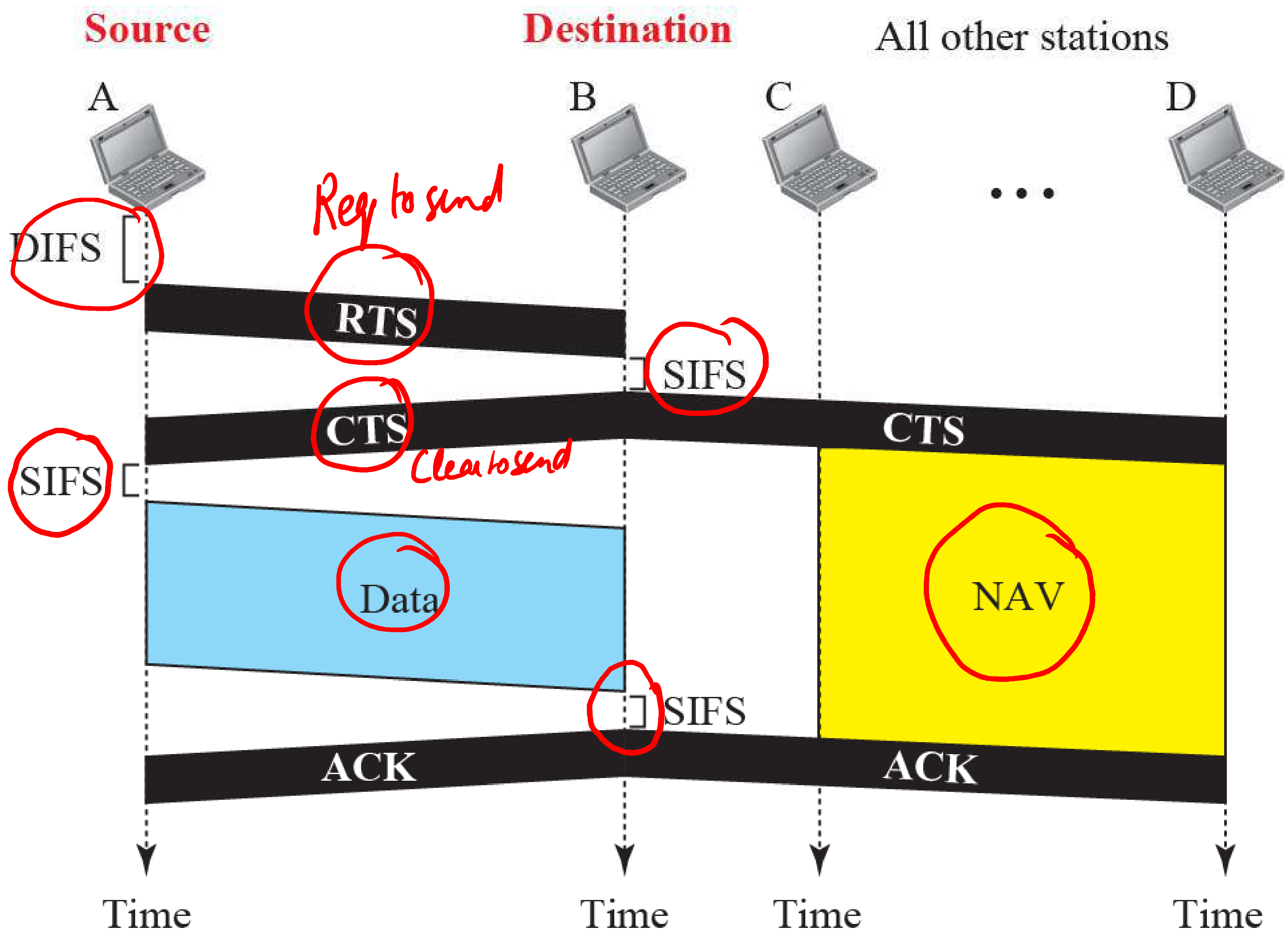
Legend
K: Number of attempts
T_B: Backoff time
IFS: Interframe Space
RTS: Request to send
CTS: Clear to send
Station has a frame to send
K = 0
Channel free?
[false]
[true]
Carrier sense
Wait IFS
Interframe Space (IFS)
slots
Contention window
Choose a random number R between 0 and $2^K - 1$ and use the Rth slot
Send RTS
Set a timer
CTS received before time-out?
[false]
[true]
Wait IFS
Send the frame
Transmission
Set a timer
ACK received before time-out?
[false]
[true]
Success
Wait T_B seconds
K < limit ?
[true]
[false]
K = K + 1
Abort

- **CSMA/CA was invented for Wireless Networks**
- **Collisions are avoided through the use of three strategies:**
  - ✓ **The Interfame Space**
  - ✓ **The Contention Window**
  - ✓ **Acknowledgements**

- **Interframe Space (IFS): Collisions are avoided by deferring transmission even if the channel is idle**
- **Contention Window: Amount of time divided into slots. Station chooses a random number of slots as its wait time (one slot first time and double each time system cannot detect an idle channel)**


Found
idle
Size:
binary exponential
Continuously sense
IFS
Busy
Contention window
Time

- **Acknowledgement: Positive acknowledgement and time-out timer can help guarantee that the receiver has received the frame**


Source
Destination
All other stations
A
B
C
D
Req to send
DIFS
RTS
SIFS
CTS
CTS
Clear to send
SIFS
Data
NAV
SIFS
ACK
ACK
Time
Time
Time
Time

- **The stations consult one another to find which station has the right to send**
- **A station cannot send unless authorized by other stations**
- **We discuss three controlled-access methods:**
  - ✓ **Reservation**
  - ✓ **Polling**
  - ✓ **Token Passing**

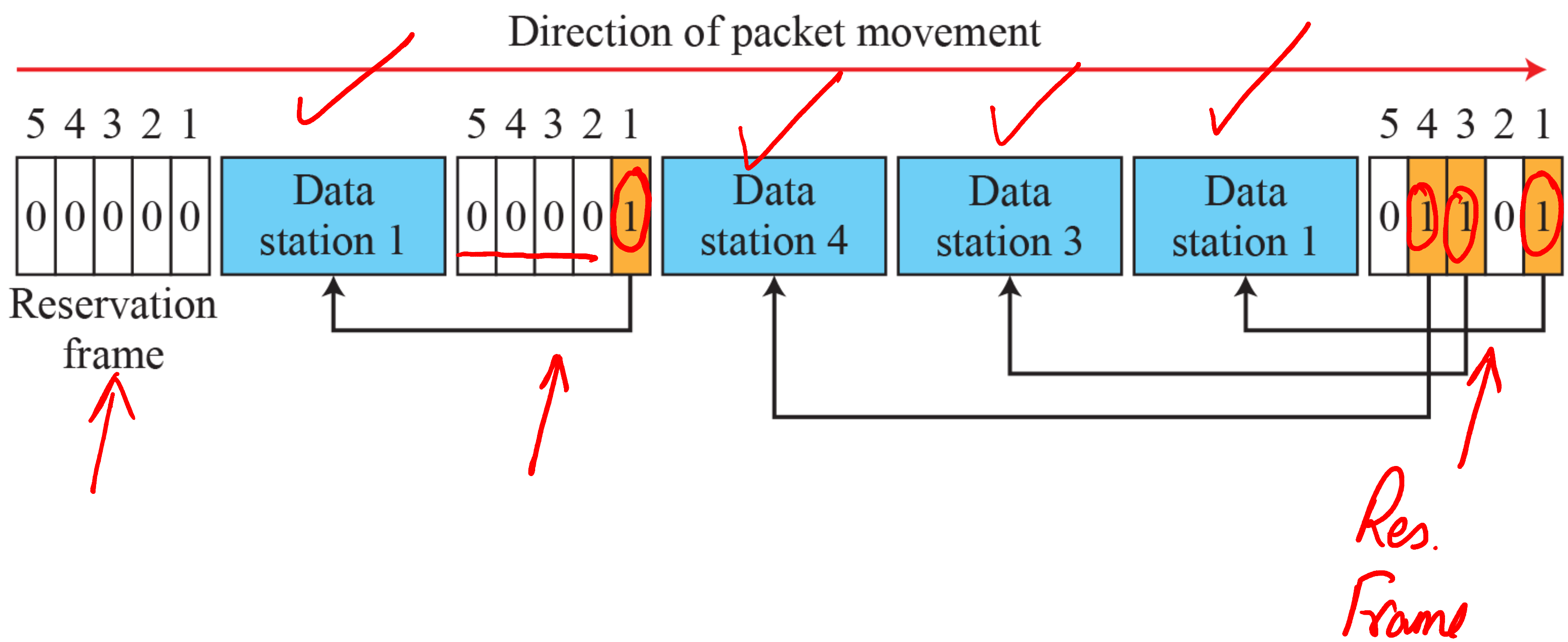
- **In the reservation method, a station needs to make a reservation before sending data**

- **Time is divided into intervals**

- **In each interval, a reservation frame precedes the data frames sent in that interval**

N stations

N → minislots (reservation)

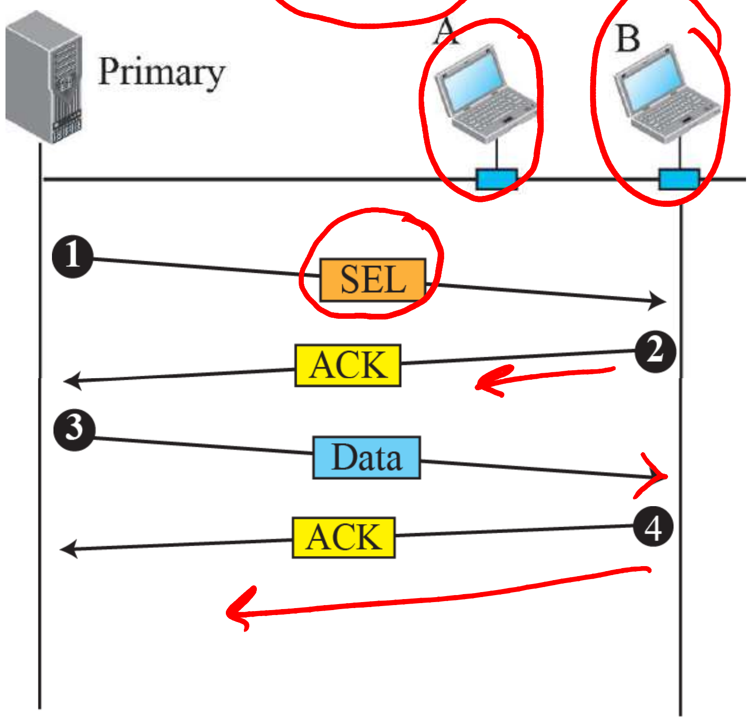


- **Polling works with topologies in which one device is designated as a primary station and the other devices are secondary stations**
- **All data exchanges must be made through primary device even when the ultimate destination is a secondary device**

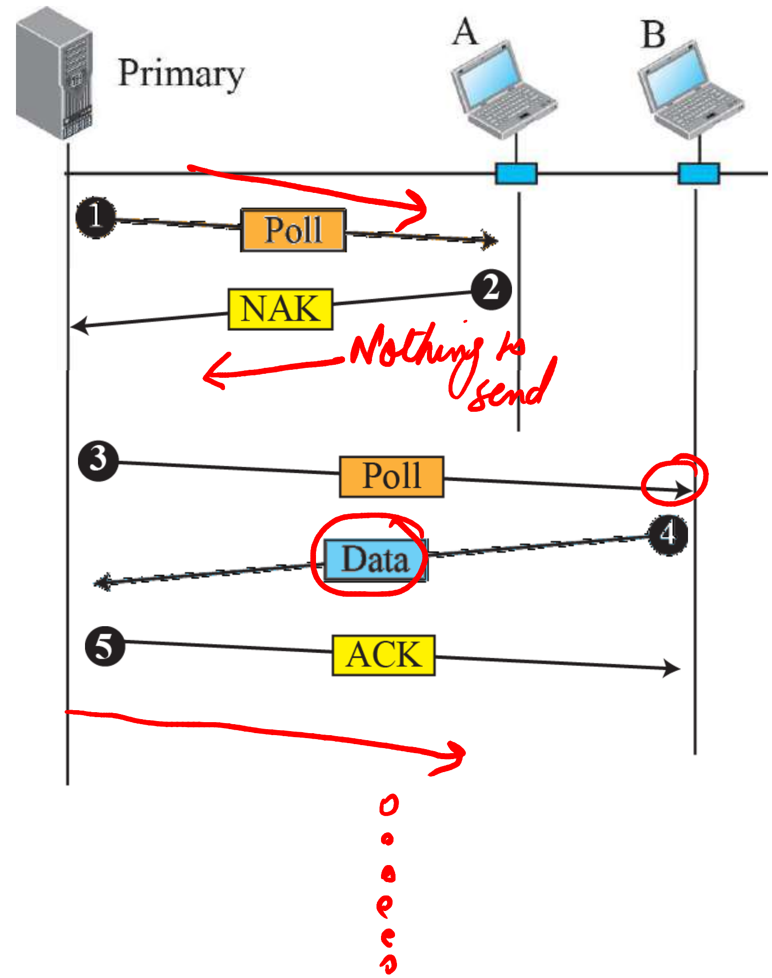
- **The primary device controls the link; the secondary devices follow its instructions**

Select & Poll

Select



Poll



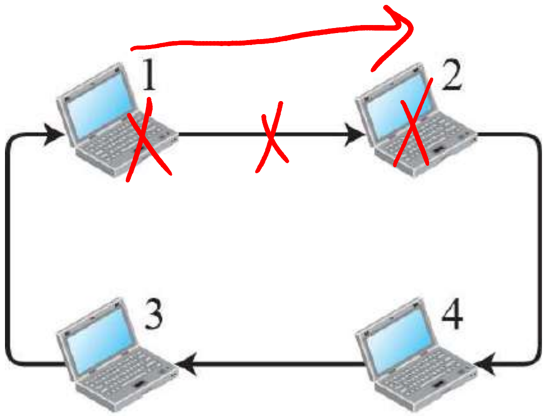
- **Three controlled-access methods:**
  - ✓ **Reservation**
  - ✓ **Polling**
  - ✓ **Token Passing**

- **In the token-passing method, the stations in a network are organized in a logical ring**
- **For each station, there is a predecessor and a successor**
- **The predecessor is the station which is logically before the station in the ring; the successor is the station which is after the station in the ring**

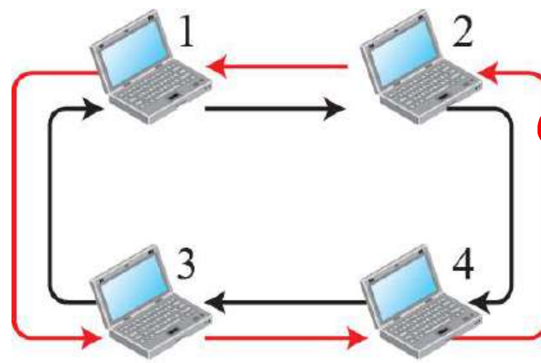
- **Special packet called TOKEN circulates through the ring**

- **Possession of TOKEN gives the station the right to send the data**

- **TOKEN Management is required to manage possession time, Token monitoring, priority assignment etc.**



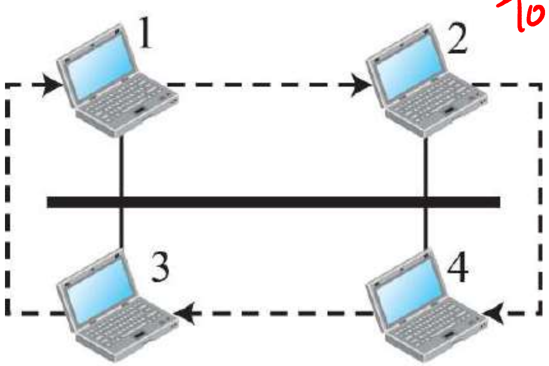
a. Physical ring



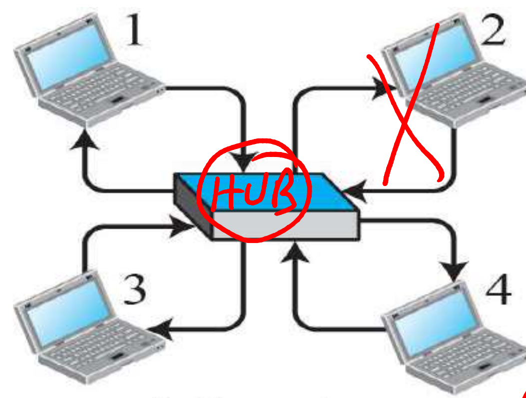
FDDI
CDDI

b. Dual ring

Token Bus
LAN



c. Bus ring Token Bus



Token Ring
LAN
(IBM)

d. Star ring

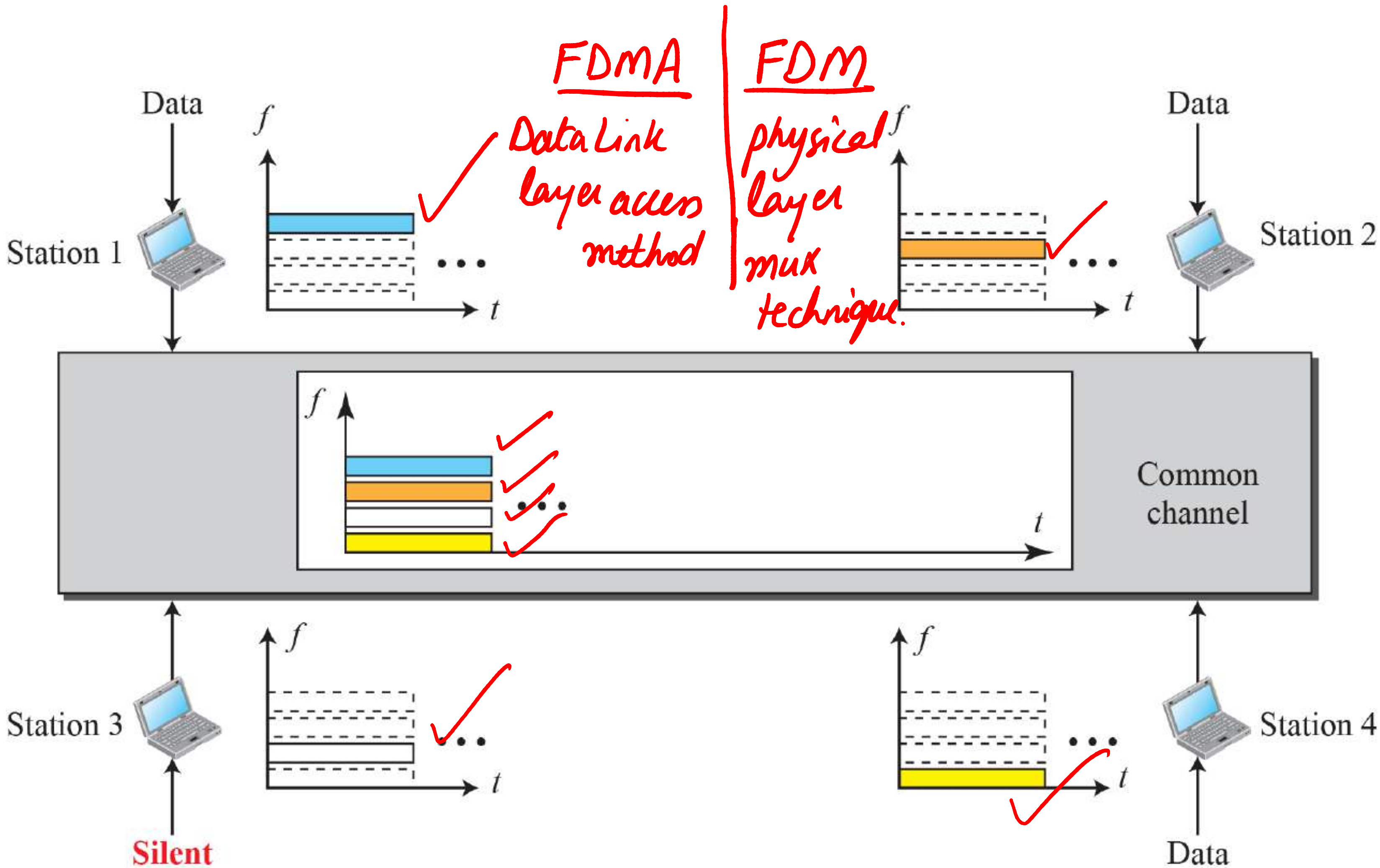
- **The available bandwidth of a link is shared in time, frequency, or through code, among different stations**

- **We discuss three protocols:**
  - ✓ **Frequency Division Multiple Access (FDMA)**
  - ✓ **Time Division multiple Access (TDMA)**
  - ✓ **Code Division Multiple Access (CDMA)**

- In FDMA, the available bandwidth is divided into frequency bands

- Each station is allocated a band to send its data i.e. each band is reserved for a specific station, and it belongs to the station all the time

- Each station also uses a bandpass filter to confine the transmitter frequencies



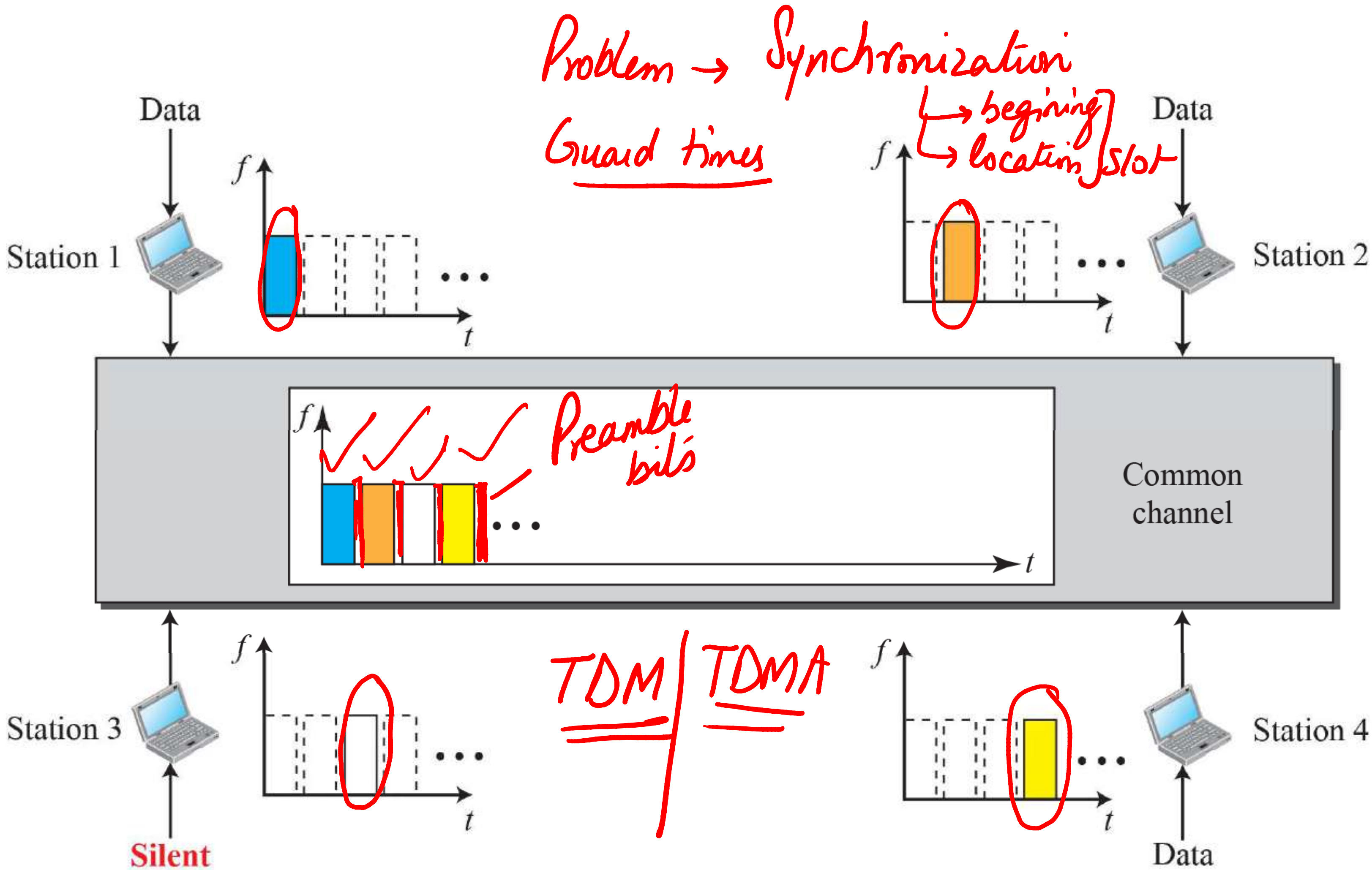
FDMA
Data Link layer access method
FDM
physical layer mux technique.
Data
Station 1
Data
Station 2
Common channel
Station 3
Silent
Station 4
Data
f
t

- **Three protocols:**
  - ✓ **Frequency Division Multiple Access (FDMA)**
  - ✓ **Time Division Multiple Access (TDMA)**
  - ✓ **Code Division Multiple Access (CDMA)**

- Stations share the bandwidth of the channel in time

- Each station is allocated a time slot during which it can send data

- Each station transmits its data in its assigned time slot

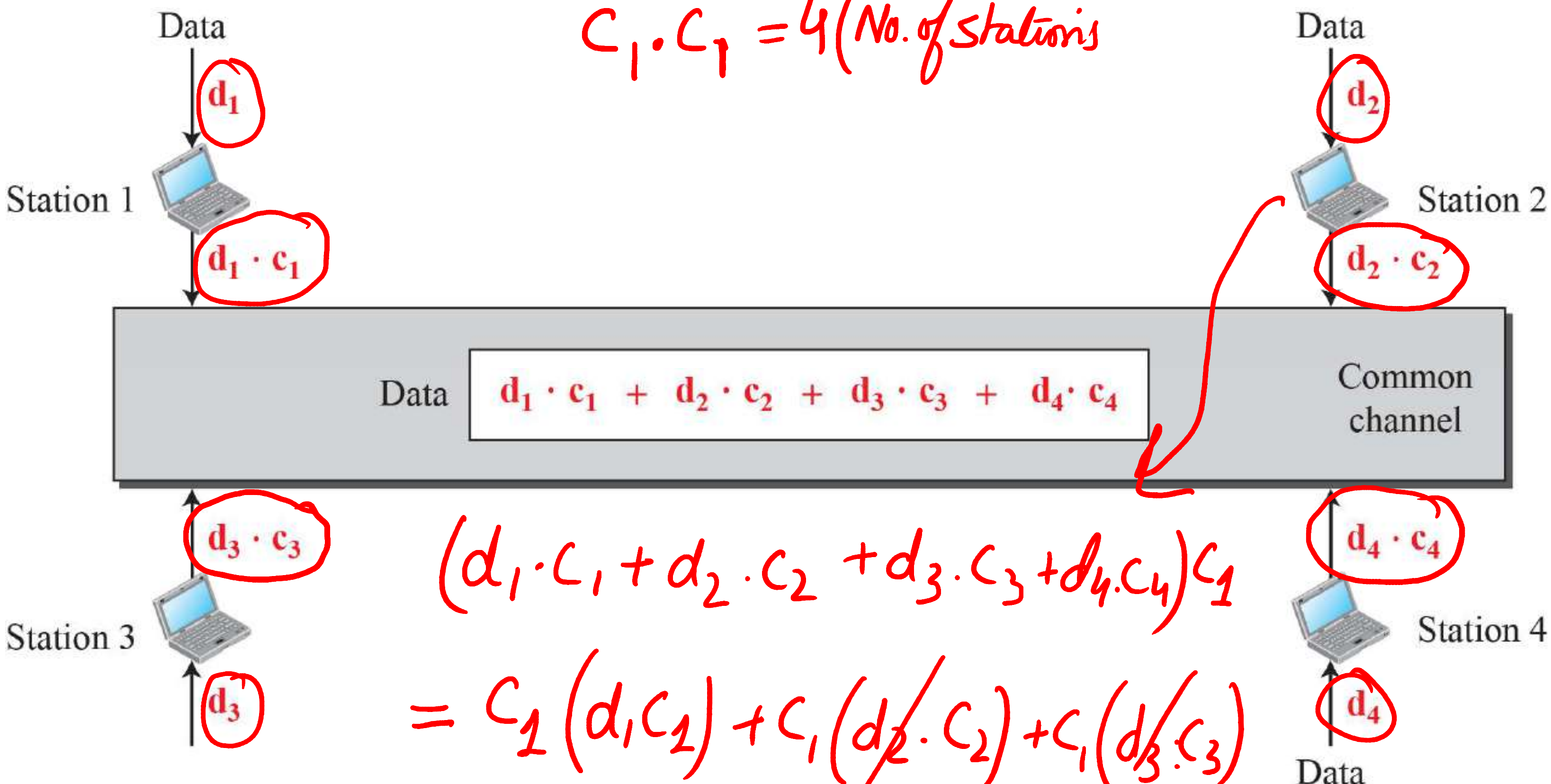

Problem → Synchronization
→ begining
→ location slot
Guard times
Data
Station 1
Data
Station 2
Preamble bits
Common channel
TDM
TDMA
Station 3
Silent
Station 4
Data

- **Three protocols:**
  - ✓ **Frequency Division Multiple Access (FDMA)**
  - ✓ **Time Division Multiple Access (TDMA)**
  - ✓ **Code Division Multiple Access (CDMA)**

- **CDMA differs from FDMA in that only one channel occupies the entire bandwidth of the link**
- **CDMA differs from TDMA in that all stations can send data simultaneously; there is no timesharing**

$c_1 \cdot c_2 = 0 \ (c_2 \cdot c_3 | c_3 \cdot c_4)$

$c_1 \cdot c_1 = 4$ (No. of stations

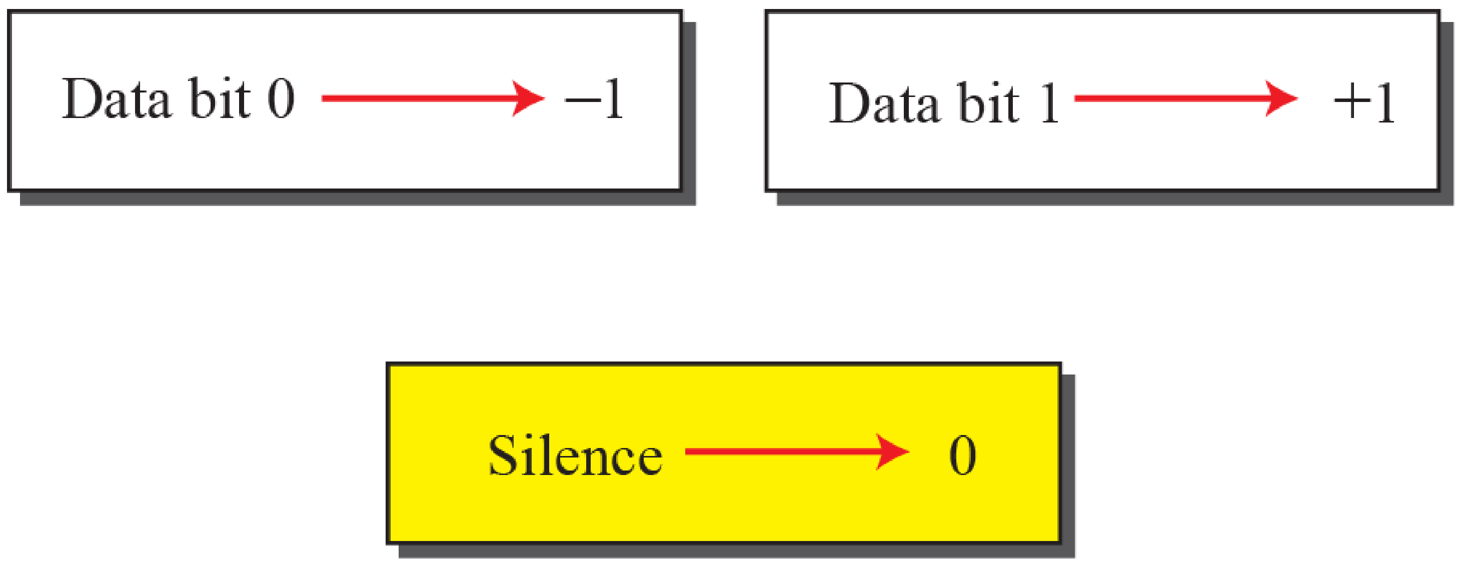


$(d_1 \cdot c_1 + d_2 \cdot c_2 + d_3 \cdot c_3 + d_4 \cdot c_4)\, c_1$

$= c_1(d_1 c_1) + c_1(\cancel{d_2} \cdot c_2) + c_1(\cancel{d_3} \cdot c_3) + c_1(\cancel{d_4} \cdot c_4)$

$= 4d_1$

$\boxed{B \rightarrow \text{divides by } 4 \rightarrow \frac{4d_1}{\cancel{4}} = d_1}$


Data bit 0 → −1
Data bit 1 → +1
Silence → 0

Ethernet Protocol

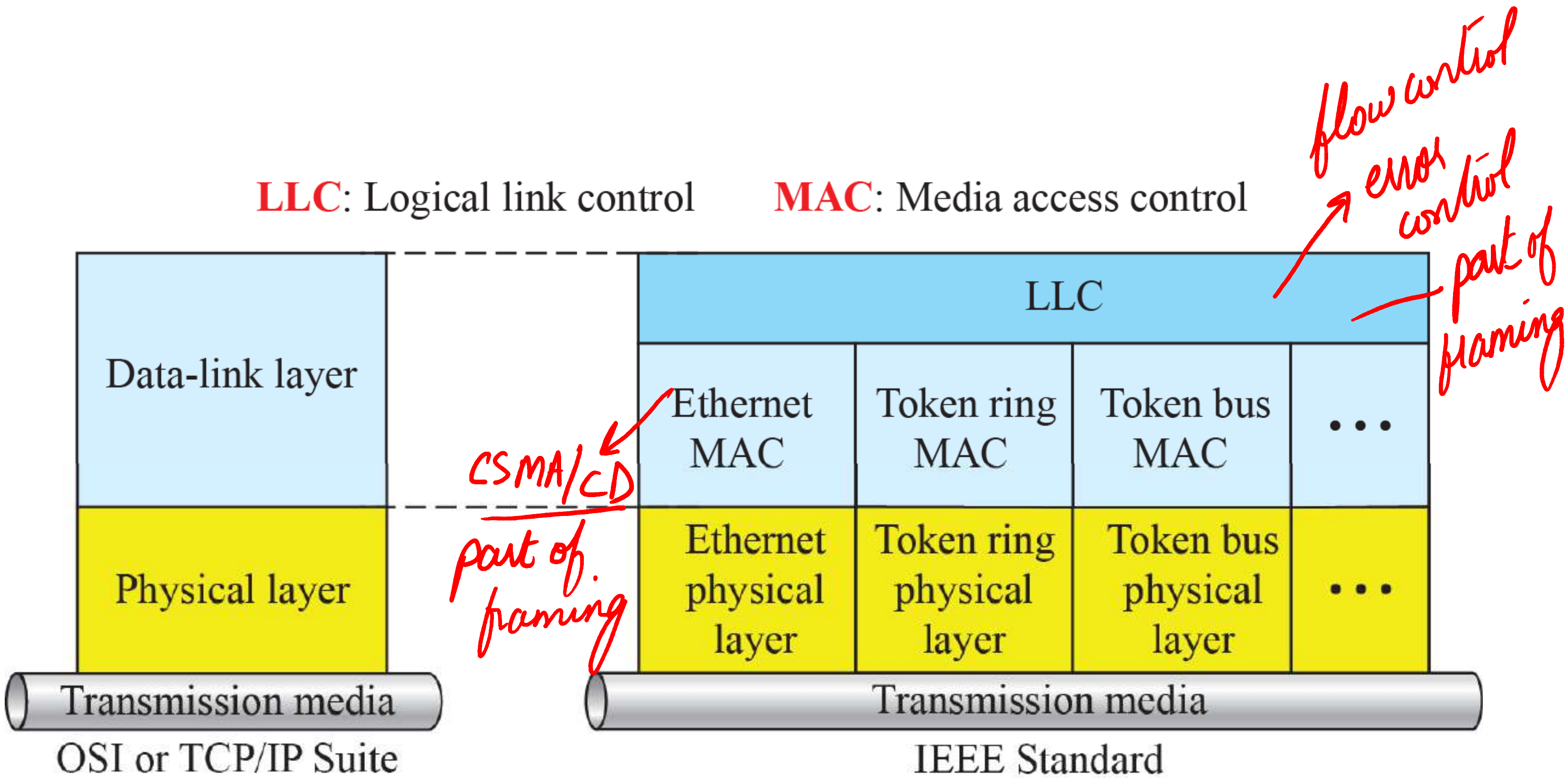
- **Data-link layer and the physical layer are the territory of the local and wide area networks**

- **We can have wired or wireless networks**

- **In 1985, the Computer Society of the IEEE started a project, called Project 802, to set standards to enable inter-communication among equipment from a variety of manufacturers**

- **Project 802 did not seek to replace any part of the OSI model or TCP/IP protocol suite**

- **A way of specifying functions of the physical layer and the data-link layer of major LAN protocols**

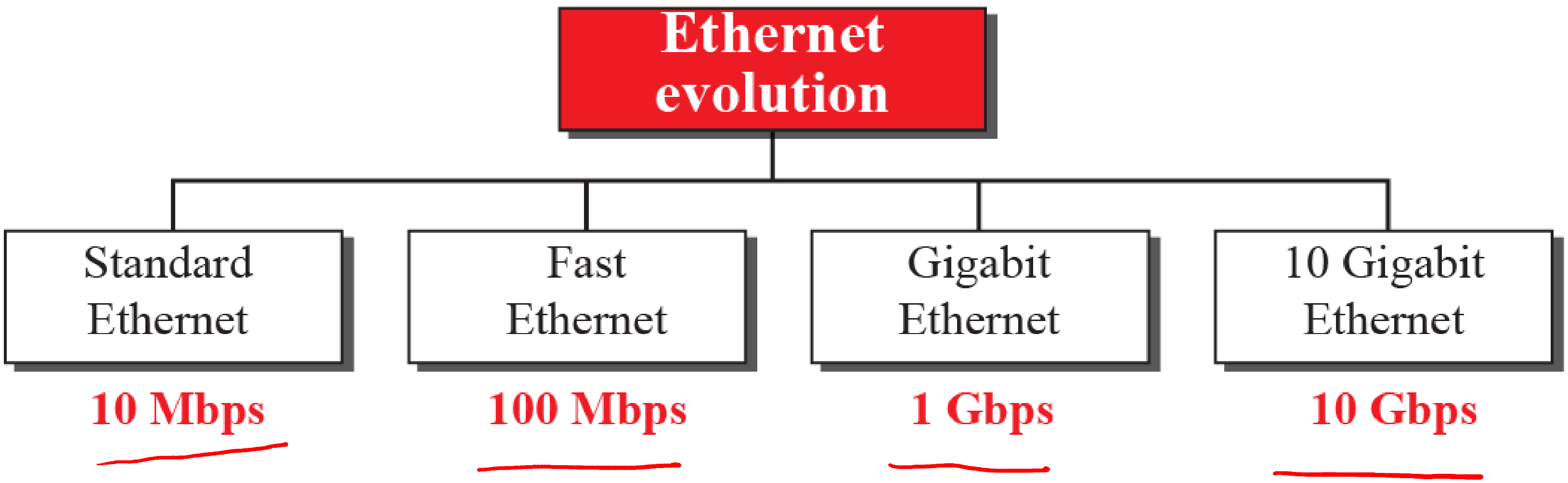


LLC: Logical link control
MAC: Media access control
Data-link layer
Physical layer
Transmission media
OSI or TCP/IP Suite
LLC
Ethernet MAC
Token ring MAC
Token bus MAC
• • •
Ethernet physical layer
Token ring physical layer
Token bus physical layer
• • •
Transmission media
IEEE Standard
flow control
error control
part of framing
CSMA/CD
part of framing

- **The Ethernet LAN was developed in the 1970s**

- **Since then, it has gone through four generations:**

  - ✓ **Standard Ethernet (10 Mbps)**
  - ✓ **Fast Ethernet (100 Mbps)**
  - ✓ **Gigabit Ethernet (1 Gbps)**
  - ✓ **10 Gigabit Ethernet (10 Gbps)**


Ethernet evolution
Standard Ethernet
10 Mbps
Fast Ethernet
100 Mbps
Gigabit Ethernet
1 Gbps
10 Gigabit Ethernet
10 Gbps

- The original Ethernet technology with the data rate of 10 Mbps is called Standard Ethernet

- Most implementations have moved to later evolutions

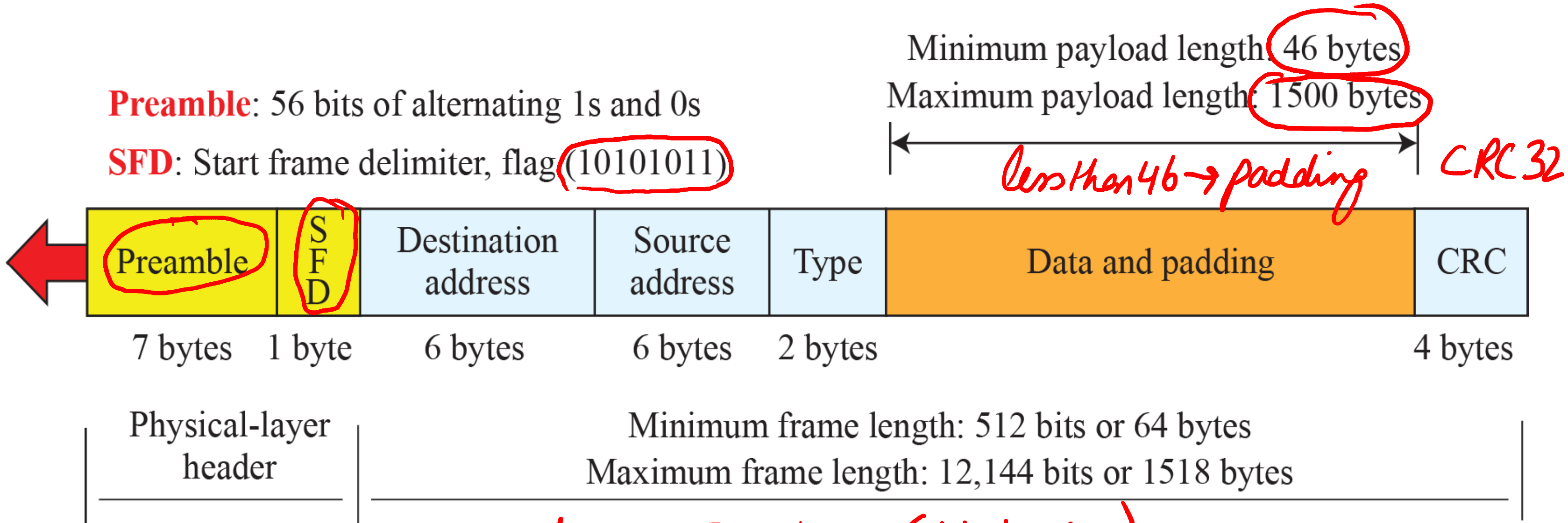
- Still some features of the Standard Ethernet that have not changed during the evolution

- Each frame is independent of other
- No connection establishment or tear down process
- The sender may overwhelm receiver with frames and frames are dropped
- If frame drops, sender will not know about it unless we are using TCP (Transport)

- Ethernet is unreliable like IP and UDP
- If a frame is corrupted, receiver silently drops it
- Left to high level protocols to find out abut it

- **The original Ethernet technology with the data rate of 10 Mbps is called Standard Ethernet** max = 1518 bytes   18 bytes of header

max length = 1518 − 18 = 1500 Bytes



min = 512 bits (64 bytes)

18 bytes of header

min length = 64 − 18 = 46 Bytes

- **Each station on Ethernet has its own network interface card (NIC)**
- **The NIC fits inside the station and provides the station with a link-layer/physical address**
- **The Ethernet address is 6 bytes (48 bits), normally written in hexadecimal notation, with a colon between the bytes**

- **For example, the following shows an Ethernet MAC address:**

  4A:30:10:21:10:1A

How the address 47:20:1B:2E:08:EE is sent out online.

The address is sent left to right, byte by byte; for each byte, it is sent right to left, bit by bit, as shown below:

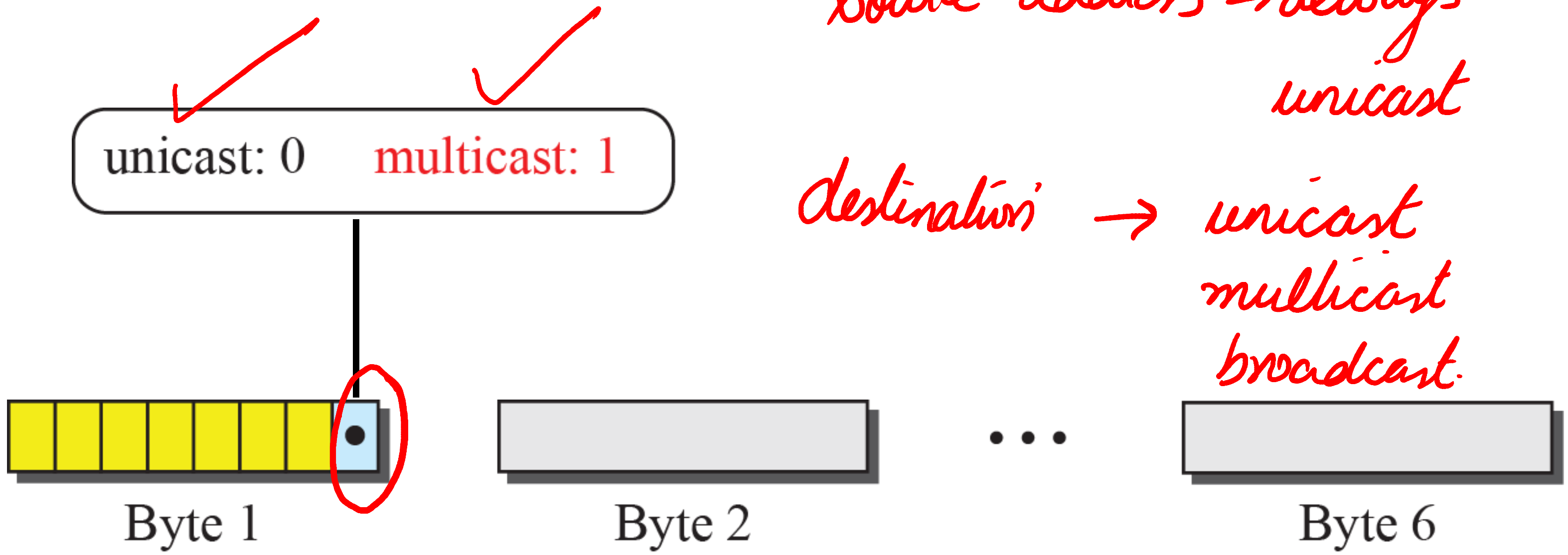
Hexadecimal	47	20	1B	2E	08	EE
Binarys	01000111	00100000	00011011	00101110	00001000	11101110
Transmitted ←	11100010	00000100	11011000	01110100	00010000	01110111

LS MS

→ unicast

→ multicast

→ broadcast



Source address → always unicast

destination → unicast
multicast
broadcast

Define the type of the following destination addresses:

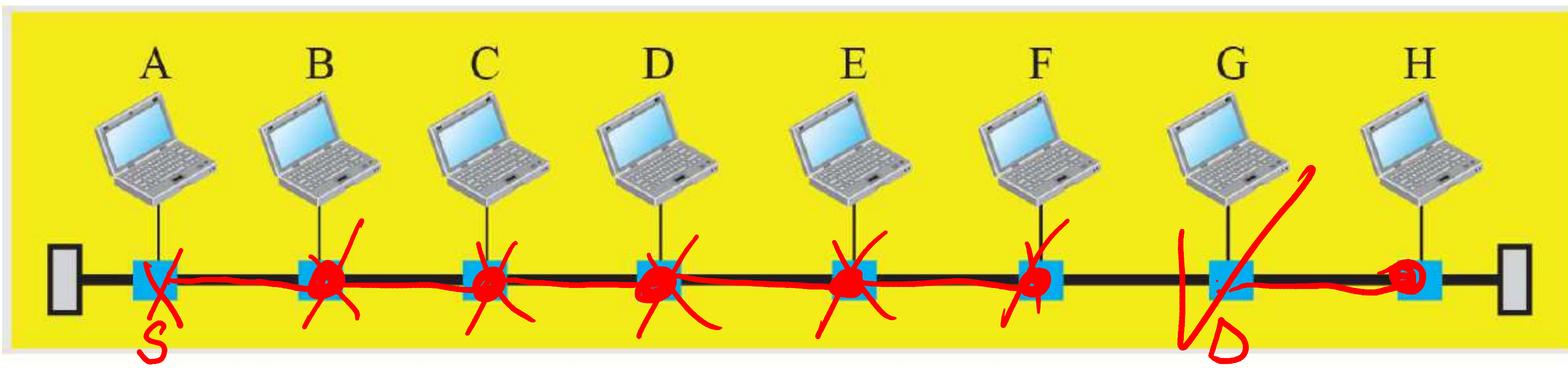
a. **4A:30:10:21:10:1A** ✓ 4A A → 1010 (0 → LS)

b. **47:20:1B:2E:08:EE** ✓ 47 7 → 0111 (1 → LS)

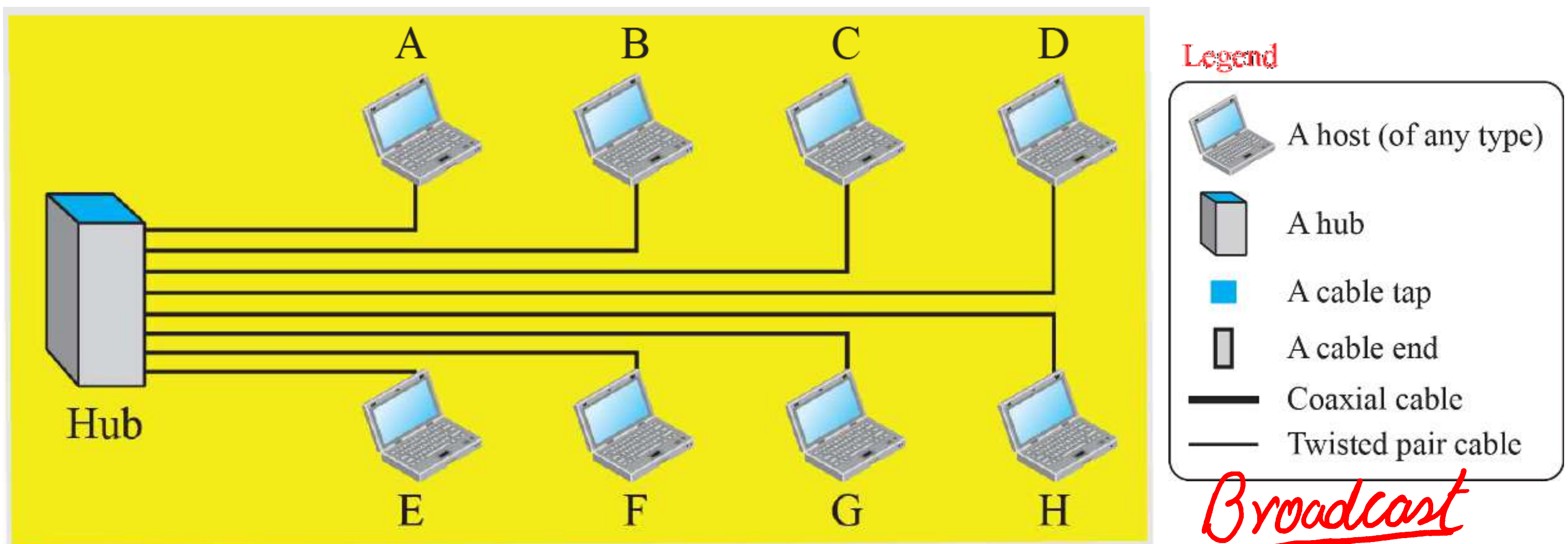
c. **FF:FF:FF:FF:FF:FF**

To find the type of the address, we need to look at the second hexadecimal digit from the left. If it is even, the address is unicast. If it is odd, the address is multicast. If all digits are Fs, the address is broadcast. Therefore, we have the following:

- **a.** **This is a unicast address because A in binary is 1010 (even).**
- **b.** **This is a multicast address because 7 in binary is 0111 (odd).**
- **c.** **This is a broadcast address because all digits are Fs in hexadecimal.**



a. A LAN with a bus topology using a coaxial cable



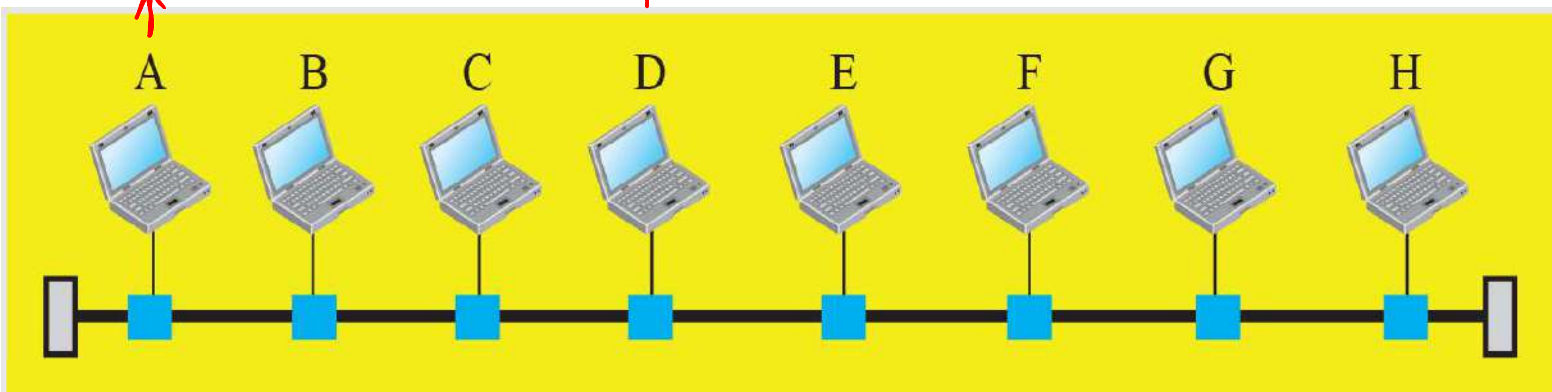
Broadcast

b. A LAN with a star topology using a hub

- Since the network that uses the standard Ethernet protocol is a broadcast network, we need to use an access method to control access to the sharing medium

- The standard Ethernet chose CSMA/CD with 1-Persistent Method

Source Destination



a. A LAN with a bus topology using a coaxial cable

① Station A → sensed medium for full duration of frame – no collision

$\boxed{CS}$MA/CD
↓
measuring energy on medium (100 μs)

② Station A → senses a collision
↳ Backoff (48-bit Jam signal)

- **The ratio of the time used by a station to send data to the time the medium is occupied by this station**

- **The practical efficiency of standard Ethernet has been measured to be:**

Efficiency = 1/(1+ 6.4 x a)

where a = number of frames that can fit on a medium

In the Standard Ethernet with the transmission rate of 10 Mbps, we assume that the length of the medium is 2500 m and the size of the frame is 512 bits. The propagation speed of a signal in a cable is normally 2 × 10^{8} m/s.

$$\text{Propagation Delay} = \frac{2500\ m}{2 \times 10^{8}\ m/s} = 12.5\ \mu sec$$

$$\text{Transmission Delay} = \frac{512}{10^{7}} = 51.2\ \mu sec$$

IDEAL

$a = 0$

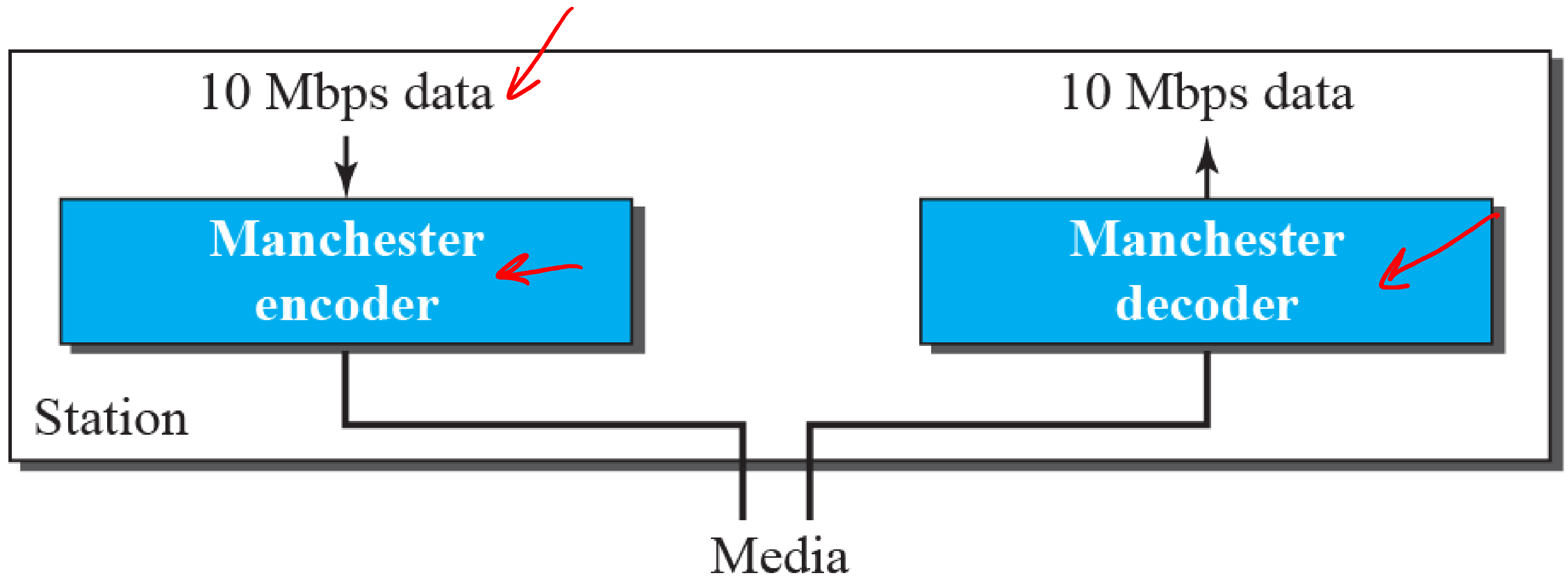
$\boxed{\mathcal{E} = 1}$

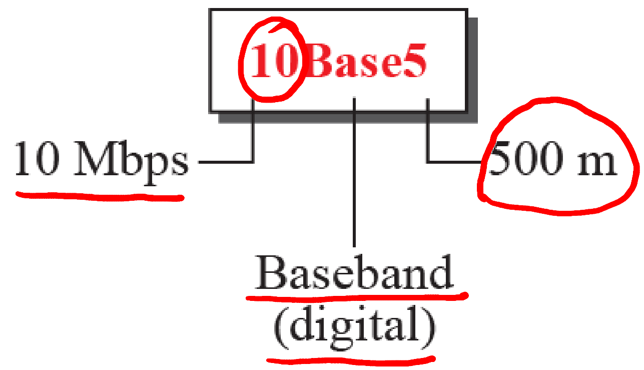
$$a = \frac{\text{Prop. Delay}}{\text{Trans Delay}} = \frac{12.5}{51.2} = 0.24 \rightarrow$$ 0.24 of a frame occupies medium

$$\mathcal{E} = \frac{1}{(1 + 6.4 \times a)} = 39\ \% \rightarrow$$ moduate only 61% of time

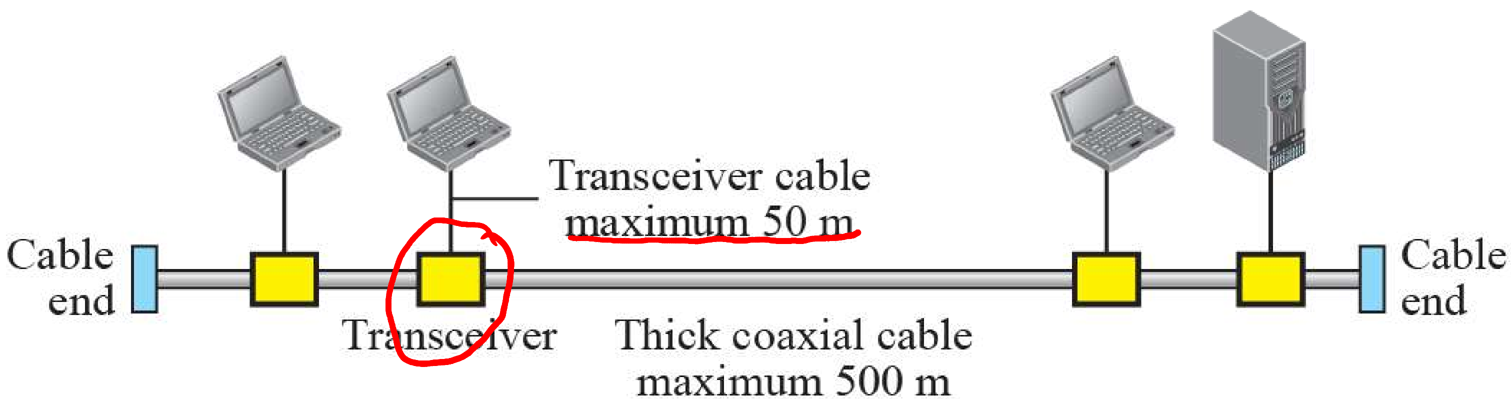
- **The Standard Ethernet defined several implementations, but only four of them became popular during the 1980s**

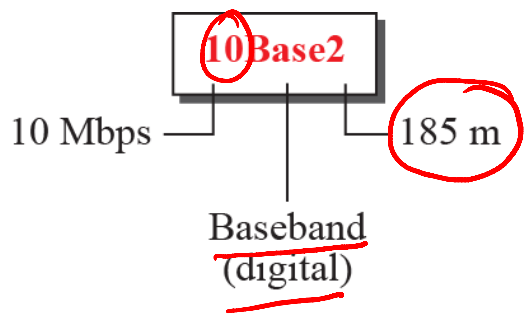
Implementation	*Medium*	*Medium Length*	*Encoding*
10Base5	Thick coax	500 m	Manchester
10Base2	Thin coax	185 m	Manchester
10Base-T	2 UTP	100 m	Manchester
10Base-F	2 Fiber	2000	Manchester


10 Mbps data
10 Mbps data
Manchester encoder
Manchester decoder
Station
Media

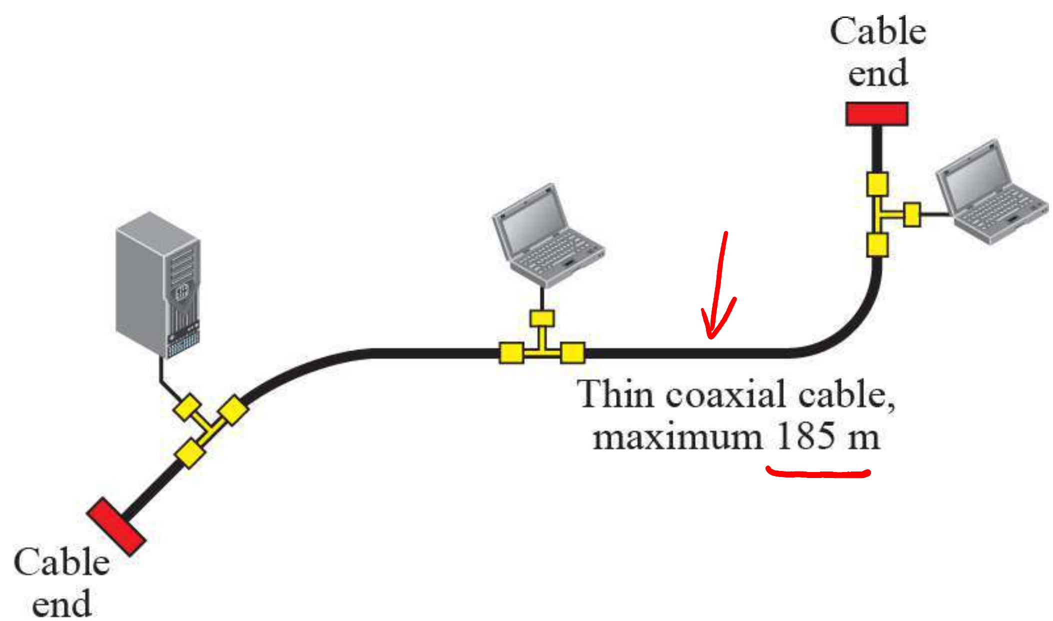


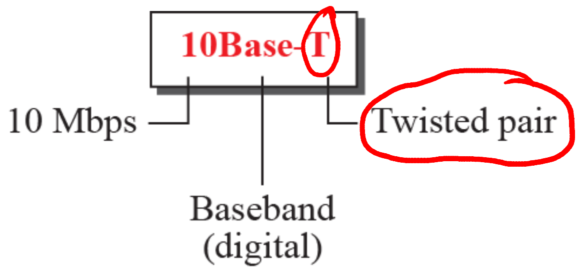
- Thick Ethernet
- Thicknet
- Repeaters



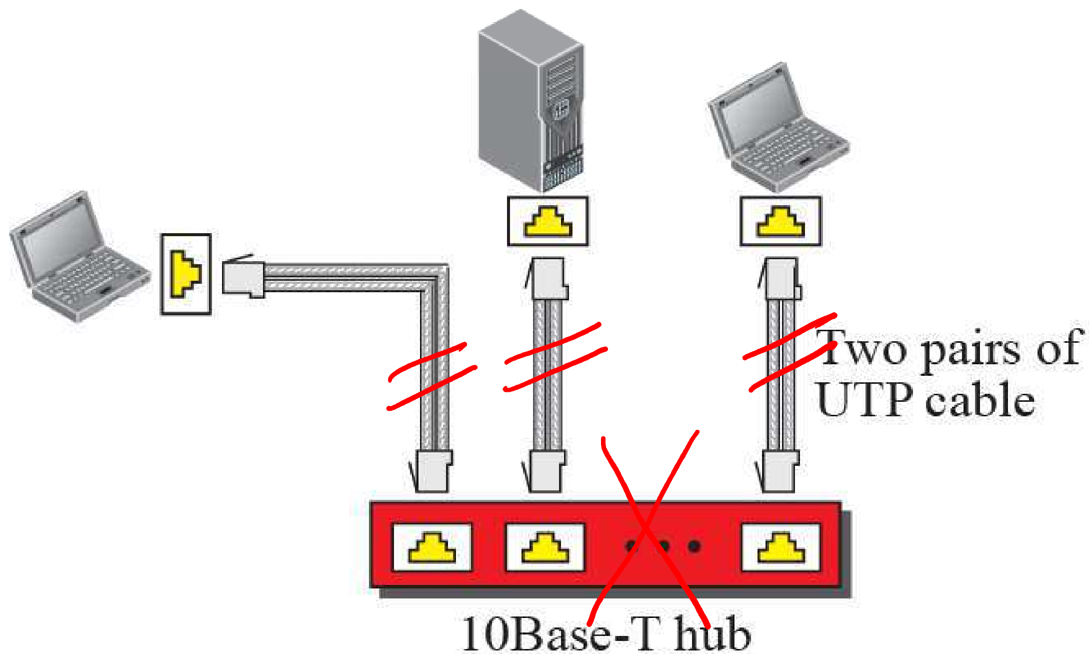


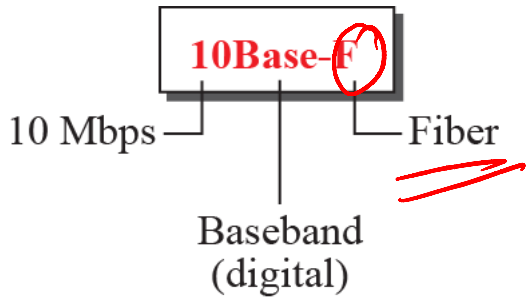
→ Thin Ethernet



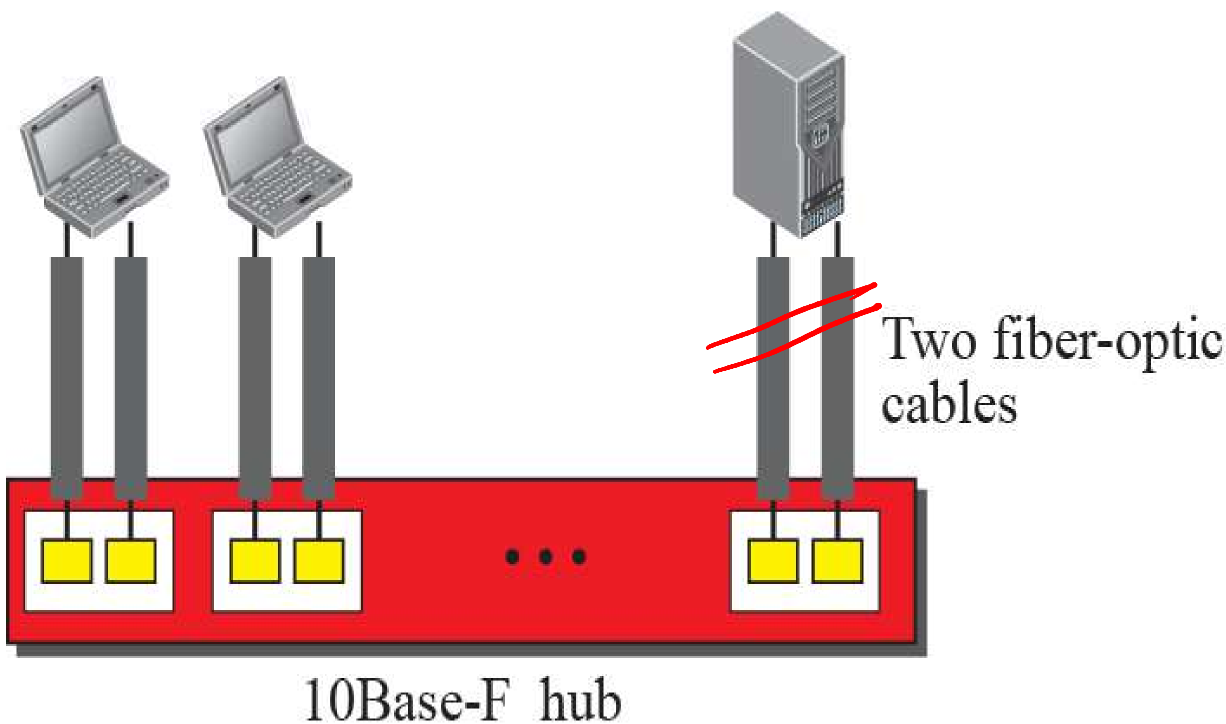


- Twisted Pair
Ethernet



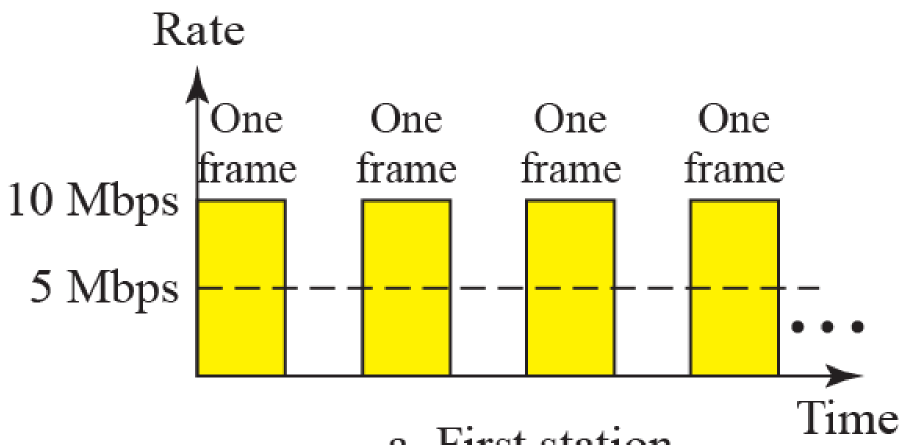


10Base-F
10 Mbps
Baseband
(digital)
Fiber



Two fiber-optic
cables
10Base-F hub

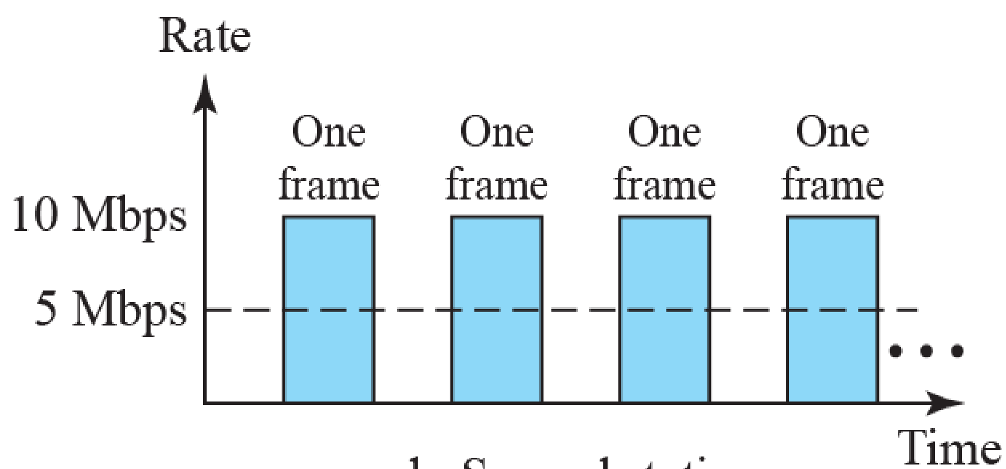
- **The changes that occurred to the 10-Mbps Standard Ethernet opened the road to the evolution of the Ethernet to become compatible with other high-data-rate LANs**
  - ✓ **Bridged Ethernet**
  - ✓ **Switched Ethernet**
  - ✓ **Full-Duplex Ethernet**



a. First station

10 Mbps → One station

Two station ⇒ 5 Mbps



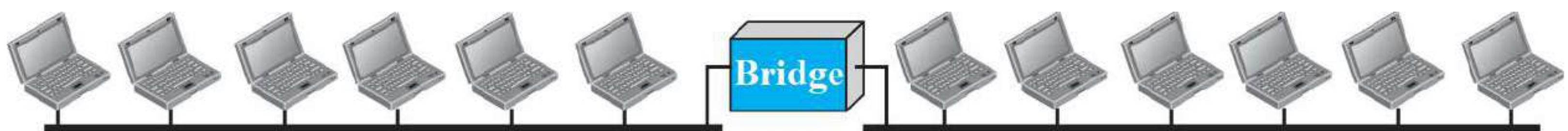
b. Second station

12

a. Without bridging

$10 Mbps / 12$

6 6



$10 Mbps / 6$ $10 Mbps / 6$

b. With bridging

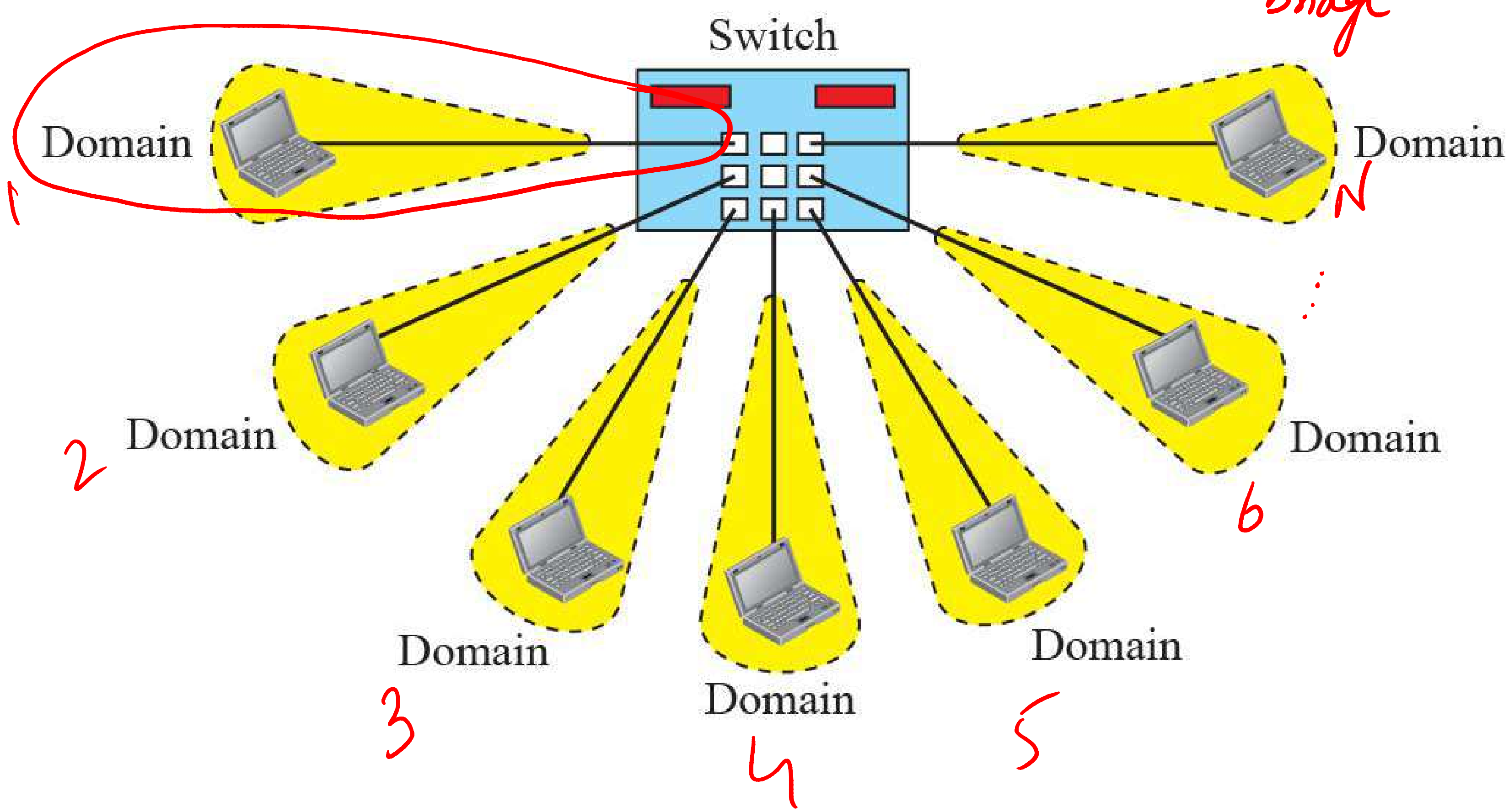
4 port bridge → $10/4$ Mbps → 3 times more than unbridged

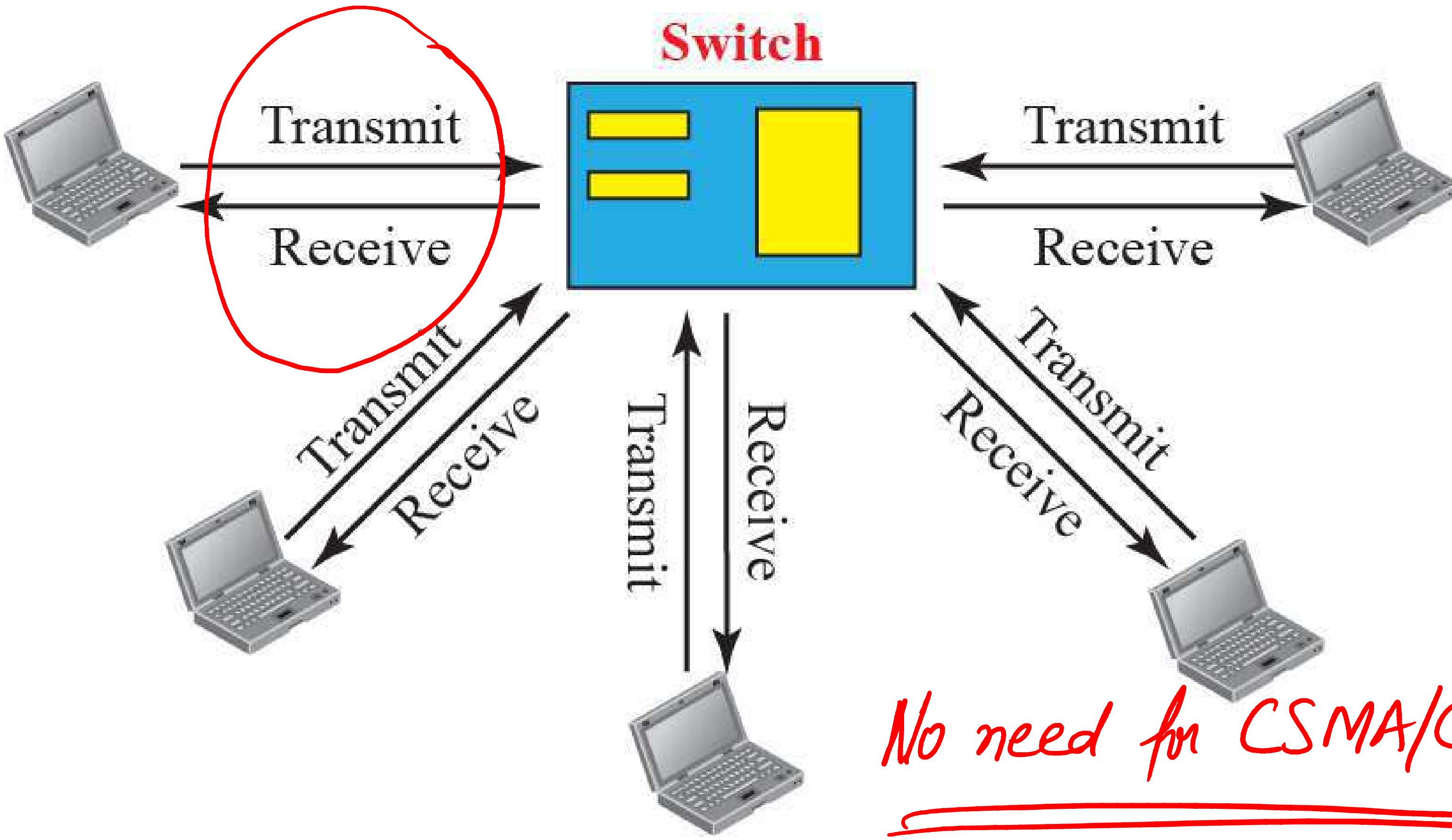
* Collision Domains

- **The changes that occurred to the 10-Mbps Standard Ethernet opened the road to the evolution of the Ethernet to become compatible with other high-data-rate LANs**

  - ✓ **Bridged Ethernet**
  - ✓ **Switched Ethernet**
  - ✓ **Full-Duplex Ethernet**

Layer 2 Switch → N-port bridge





No need for CSMA/CD

- **In the 1990s, Ethernet made a big jump by increasing the transmission rate to 100 Mbps, and the new generation was called the Fast Ethernet**

- **To make it compatible with the Standard Ethernet, the MAC sublayer was left unchanged**

- **But the features of the Standard Ethernet that depend on the transmission rate, had to be changed**

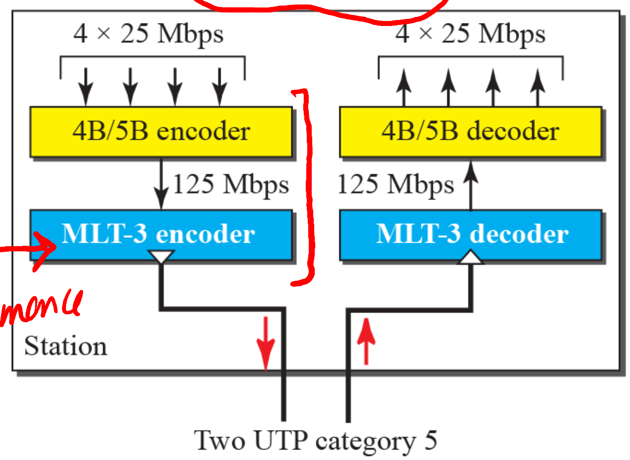
- **Goals of Fast Ethernet:**

  - ✓ **Upgrade data rate to 100Mbps**
  - ✓ **Make it compatible with Standard Ethernet**
  - ✓ **Keep same 48-bit address**
  - ✓ **Keep same frame format**

- **To be able to handle a 100 Mbps data rate, several changes need to be made at the physical layer**

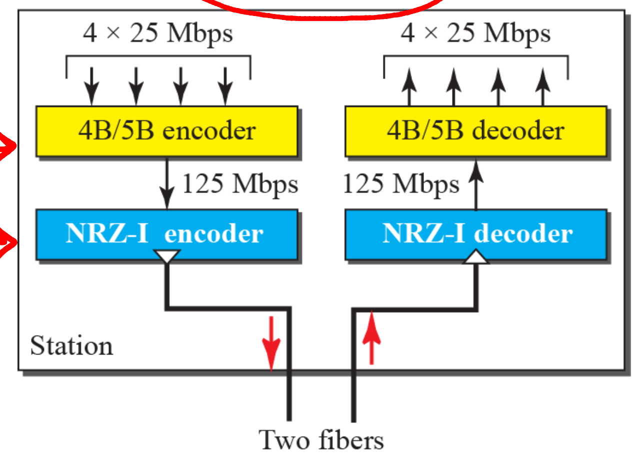
100Base-TX

UTP/STP

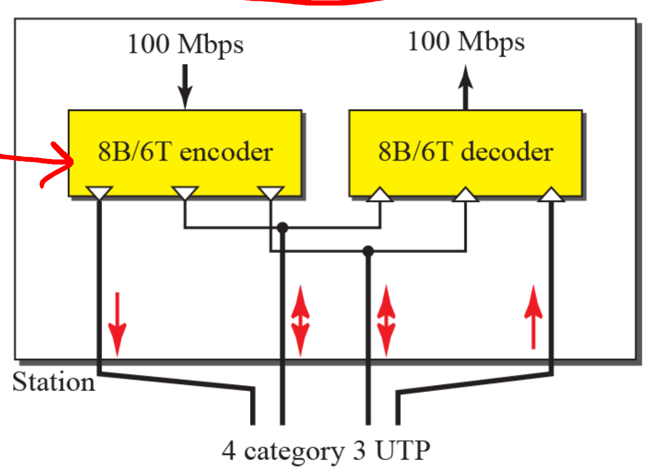


BW performance

100Base-FX



100Base-T4



Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
100Base-TX	STP	100 m	2	4B5B + MLT-3
100Base-FX	Fiber	185 m	2	4B5B + NRZ-I
100Base-T4	UTP	100 m	4	Two 8B/6T

- **Need for an even higher data rate resulted in the design of IEEE Standard 802.3z Gigabit Ethernet Protocol (1000 Mbps)**

- **The goals of the Gigabit Ethernet were:**
  - ✓ **Upgrade the data rate to 1 Gbps**
  - ✓ **Make it compatible with standard or Fast Ethernet**
  - ✓ **Use same 48 bit address**
  - ✓ **Use the same frame format**
  - ✓ **Keep same minimum and maximum frame lengths**

- **A main consideration in the evolution of Ethernet was to keep the MAC sublayer untouched**

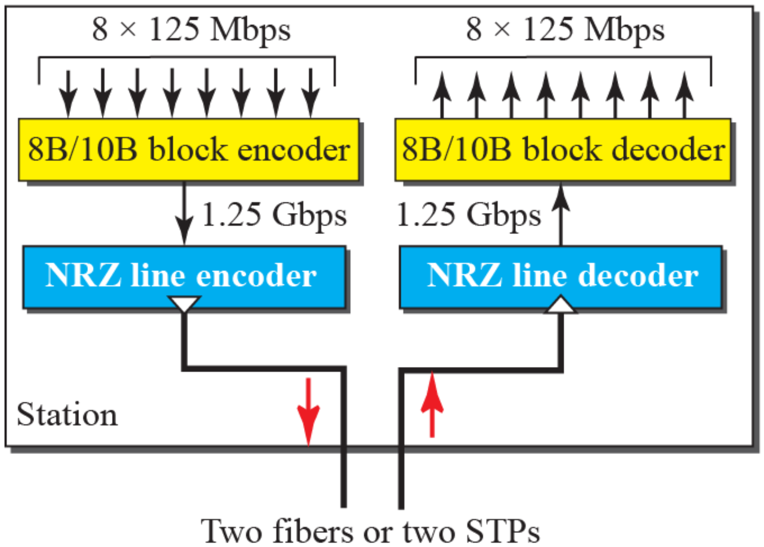
- **To achieve a data rate of 1 Gbps, this was no longer possible**

- **Gigabit Ethernet has two distinctive approaches for medium access:**
  - ✓ **Half-duplex**
  - ✓ **Full-duplex**

- **The physical layer in Gigabit Ethernet is more complicated than that in Standard or Fast Ethernet**

- **We briefly discuss some features of this layer:**

1000Base-SX, 1000Base-LX, and 1000Base-CX

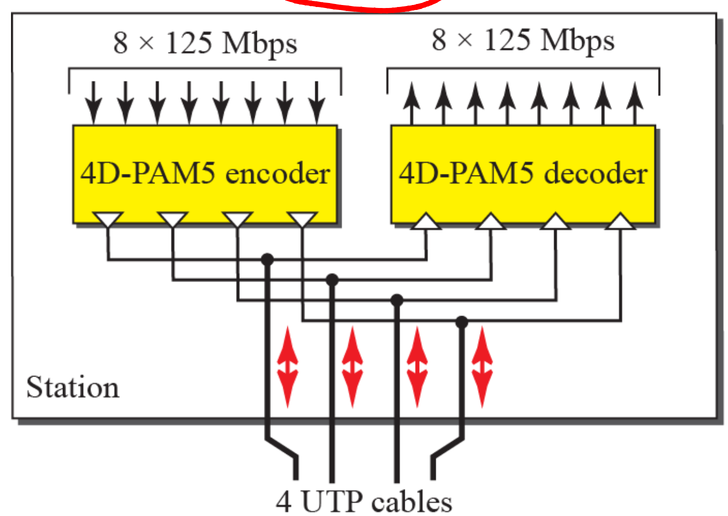


Fiber → 1000 Base SX
1000 Base LX

STP → 1000 Base CX

UTP → 1000 Base T

1000Base-T



Implementation	*Medium*	*Medium Length*	*Wires*	*Encoding*
1000Base-SX	Fiber S-W	550 m	2	8B/10B + NRZ
1000Base-LX	Fiber L-W	5000 m	2	8B/10B + NRZ
1000Base-CX	STP	25 m	2	8B/10B + NRZ
1000Base-T4	UTP	100 m	4	4D-PAM5

- **The idea is to extend the technology, the data rate, and the coverage distance so that the Ethernet can be used in LANs and MANs (metropolitan area network)**

- **The IEEE committee created 10 Gigabit Ethernet and called it Standard 802.3ae**

- 10 Gigabit Ethernet operates only in full-duplex mode, which means there is no need for contention; CSMA/CD is not used in 10 Gigabit Ethernet

- Four implementations are most common:

Implementation	*Medium*	*Medium Length*	*Number of wires*	*Encoding*
10GBase-SR	Fiber 850 nm	300 m	2	64B66B
10GBase-LR	Fiber 1310 nm	10 Km	2	64B66B
10GBase-EW	Fiber 1350 nm	40 Km	2	SONET
10GBase-X4	Fiber 1310 nm	300 m to 10 Km	2	8B10B

Other Wired Networks

- Access Networks
  - ✓ Networks that connect a small LAN to an ISP
- Wide Area Networks
  - ✓ Wired networks used to transfer data over long distances

- **The telephone network had its beginnings in the late 1800s**

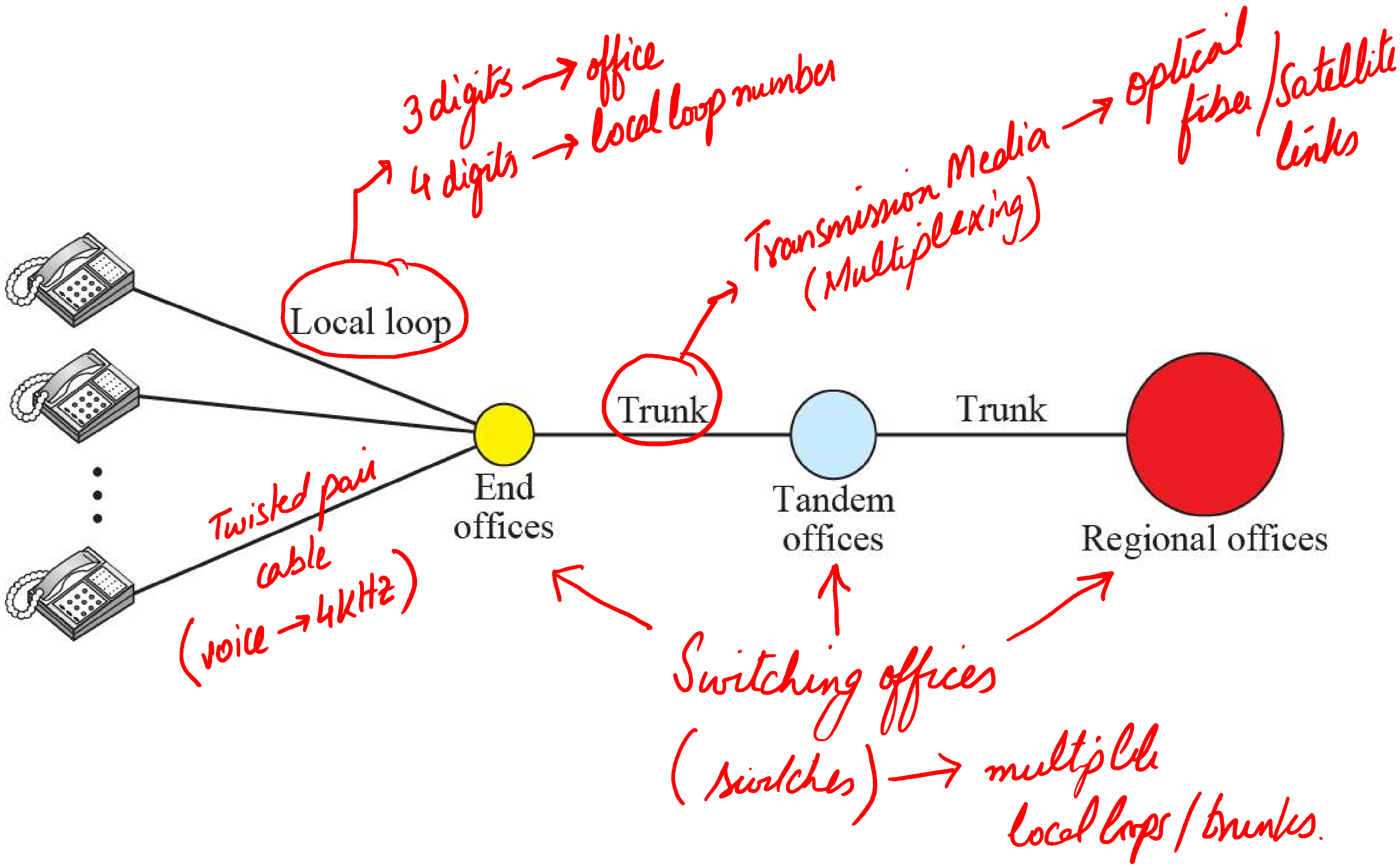
- **Plain Old Telephone System (POTS) was originally an analog system using analog signals to transmit voice**

- **With the advent of the computer era, the network, in the 1980s, began to carry data in addition to voice**

- **During the last decade, the telephone network has undergone many technical changes and the network is now Digital as well as Analog**

- **The telephone network is made of three major components:**
  - ✓ **Local Loops**
  - ✓ **Trunks**
  - ✓ **Switching offices**

- **The telephone network has several levels of switching offices:**
  - ✓ **End offices**
  - ✓ **Tandem offices**
  - ✓ **Regional offices**


3 digits → office
4 digits → local loop number
Local loop
Transmission Media → optical fiber / satellite links
(Multiplexing)
Trunk
Trunk
End offices
Tandem offices
Regional offices
Twisted pair cable
(voice → 4kHz)
Switching offices
(switches) → multiple local loops / trunks.

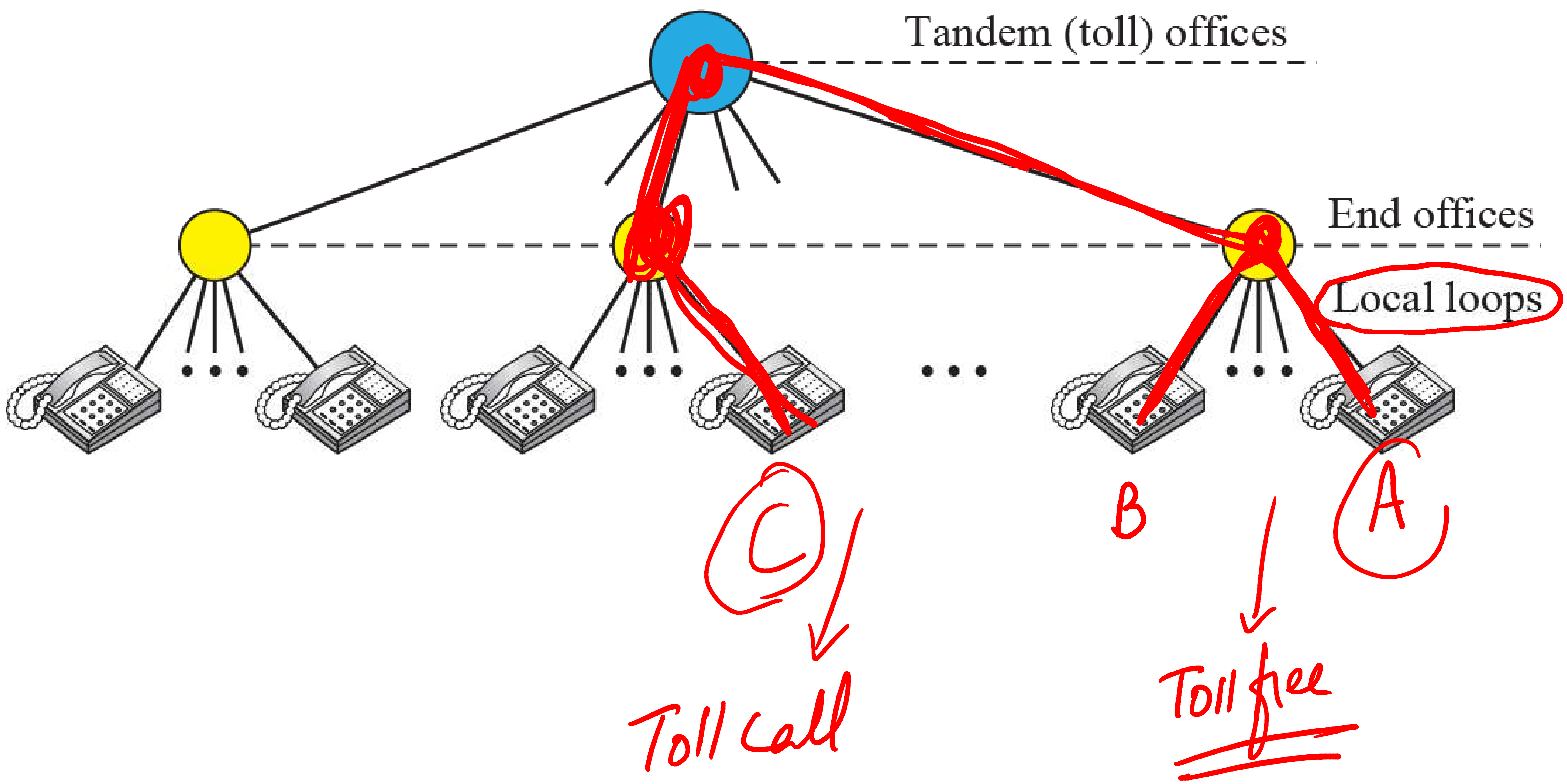
- **A LATA can be a small or large metropolitan area**

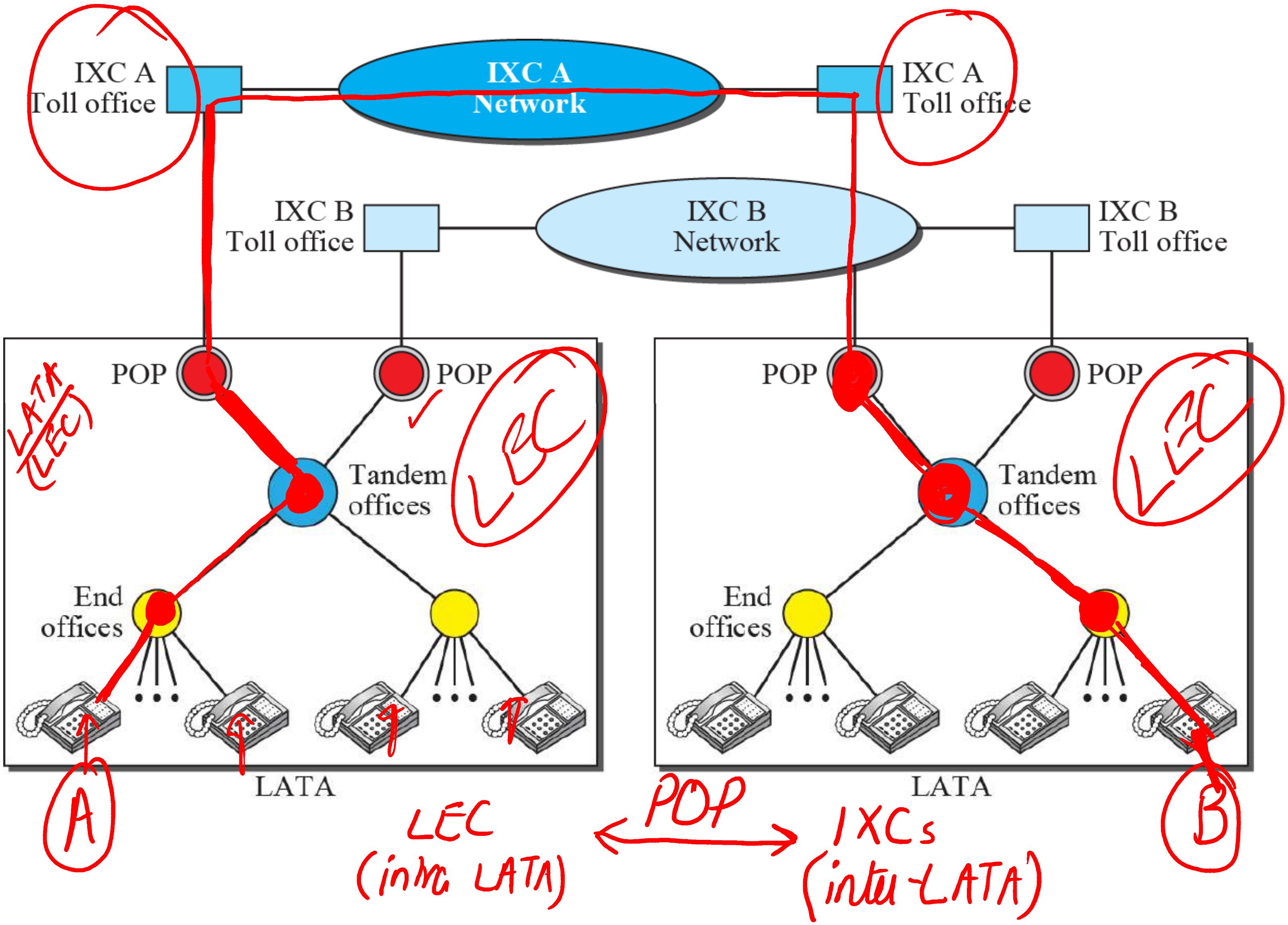
- **A small state may have a single LATA; a large state may have several LATAs**

- **A LATA boundary may overlap with state boundary; part of a LATA can be in one state, part in another state**

- **Services offered by Telephone companies inside a LATA are called Intra-LATA services and between LATAs are called Inter-LATA services**

- **Carrier that handles Intra-LATA are called a Local Exchange Carrier (LEC) and the ones that handle Inter-LATA are called Interexchange Carriers (IXCs)**


Tandem (toll) offices
End offices
Local loops
C
B
A
Toll call
Toll free

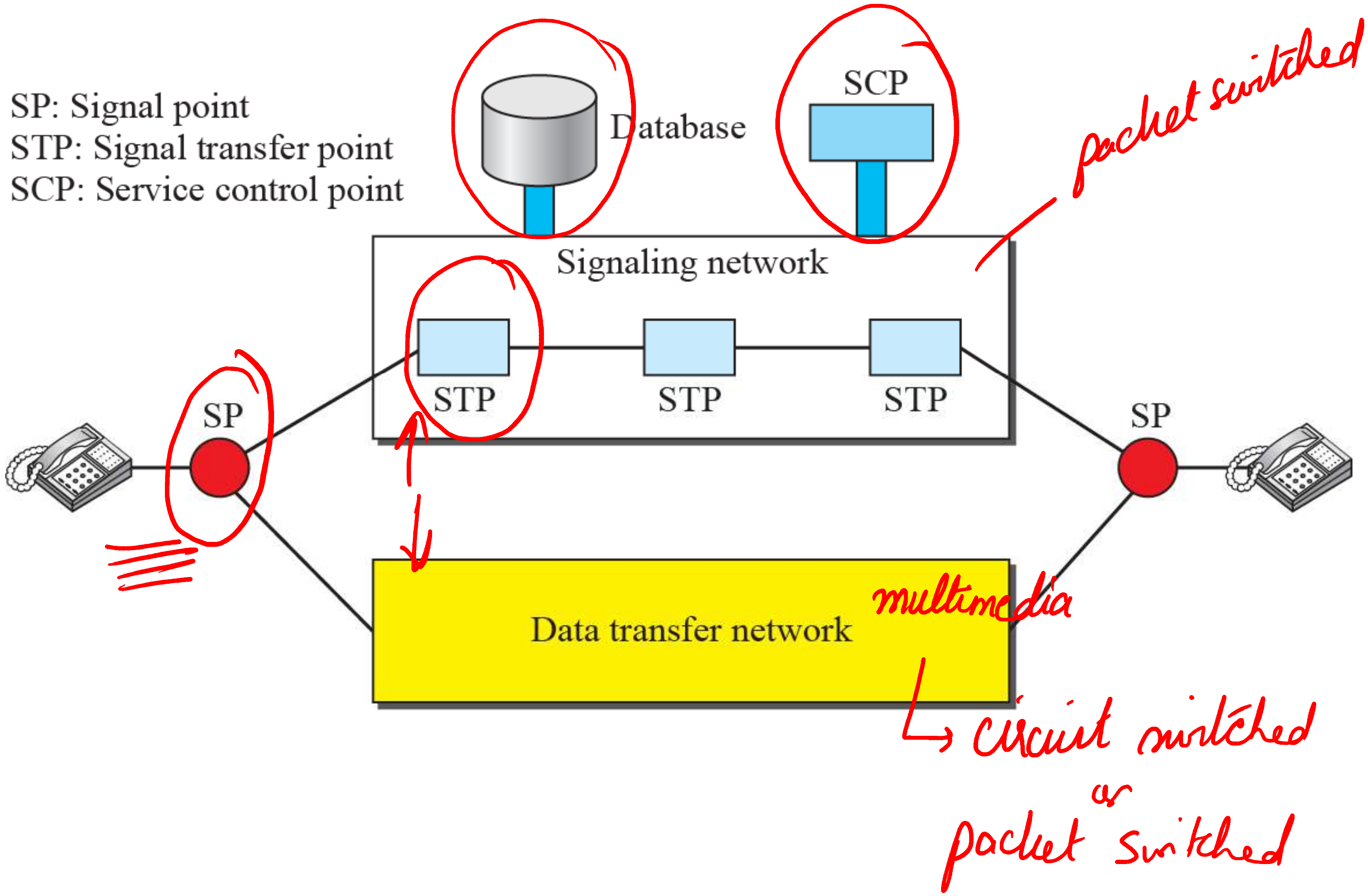


IXC A
Toll office
IXC A
Network
IXC A
Toll office
IXC B
Toll office
IXC B
Network
IXC B
Toll office
POP
POP
POP
POP
Tandem
offices
Tandem
offices
End
offices
End
offices
LATA
LATA
LATA (LEC)
LEC
LEC
A
B
LEC
(intra LATA)
POP
IXCs
(inter-LATA)

- The telephone network in the beginning, used a circuit-switched network with dedicated links to transfer voice communication
- The operator connected the two parties by using a wire with two plugs inserted into the corresponding two jacks
- Later, the signaling system became automatic

- **Rotary telephones were invented that sent a digital signal defining each digit in a multi-digit telephone number**

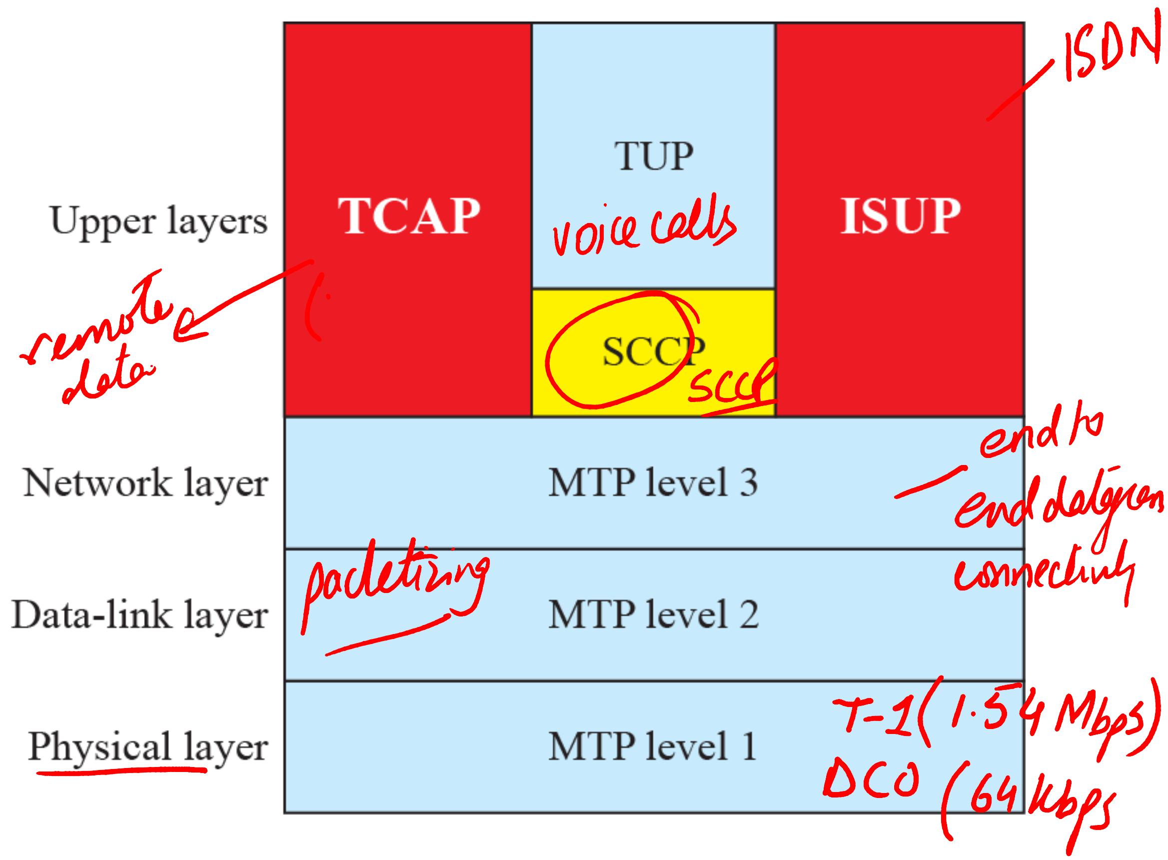
- **As telephone networks evolved into a complex network, the functionality of the signaling system increased**



SP: Signal point
STP: Signal transfer point
SCP: Service control point
Database
SCP
Signaling network
STP
STP
STP
SP
SP
Data transfer network
packet switched
multimedia
circuit switched
or
packet switched

Signalling System 7

MTP: Message transfer part
SCCP: Signaling connection control point
TCAP: Transaction capabilities application port
TUP: Telephone user port
ISUP: ISDN user port

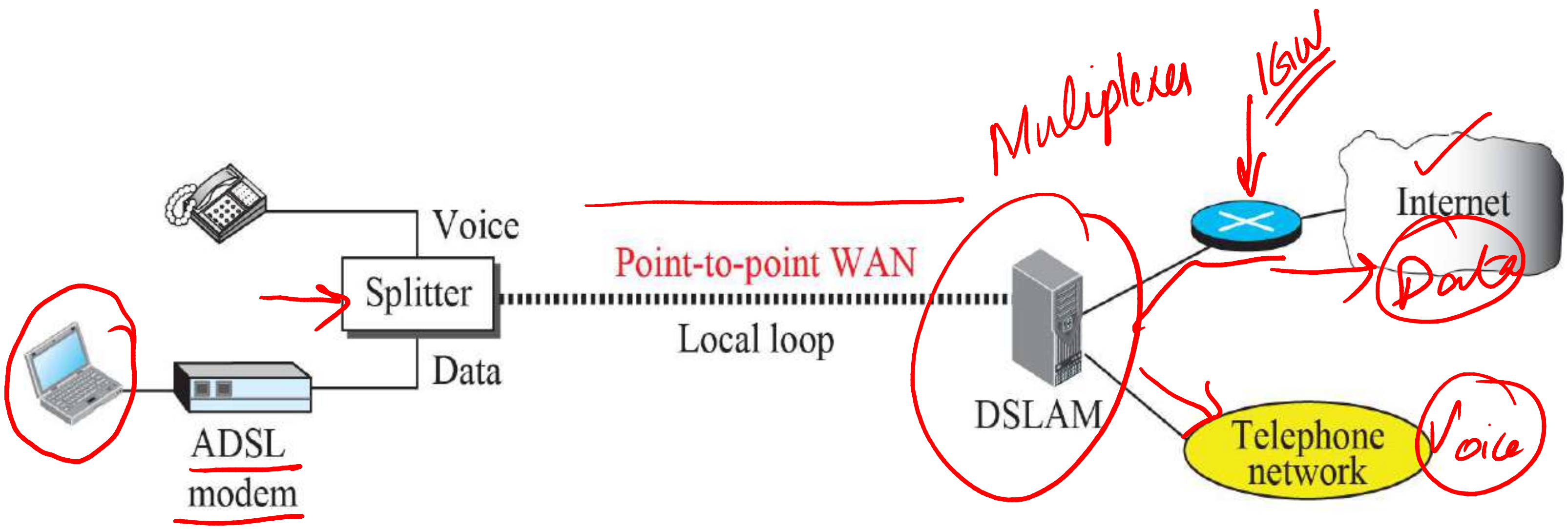


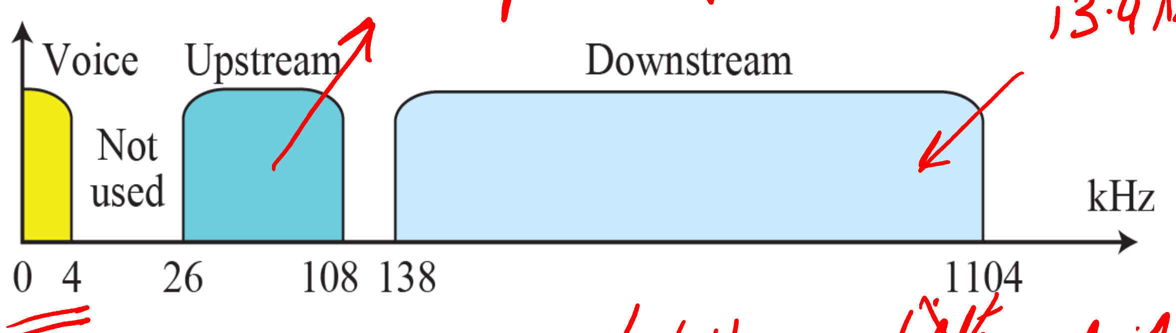
- **Telephone companies provide two types of services:**
  - ✓ **Analog Services**
    - ➢ **Analog Switched Services**
    - ➢ **Analog Leased Services**
  - ✓ **Digital Services**
    - ➢ **Switched /56 Service**
    - ➢ **Digital Data Service**

- After traditional dial-up modems reached their peak data rate, telephone companies developed another technology, DSL, to provide higher-speed access to the Internet

- DSL supports high-speed digital communication over the existing telephone

- **DSL technology is a set of technologies, each differing in the first letter (ADSL, VDSL, HDSL, and SDSL)**





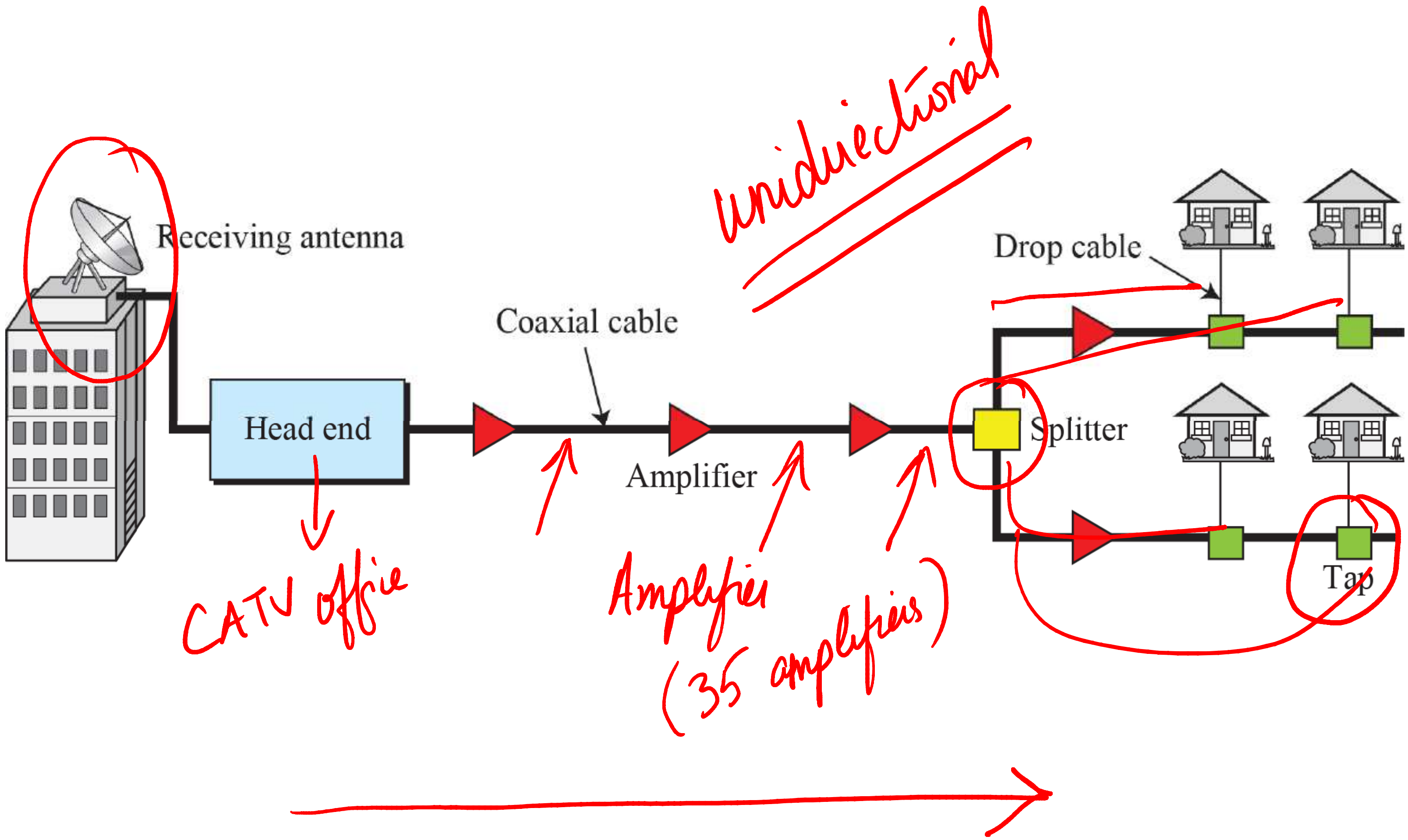
1.104 MHz

4kHz (voice) ← ~~filter~~ 1.1 MHz

- **The Cable TV networks were initially created to provide remote subscribers access to TV programs**
- **Cable networks enabled access to remote broadcasting stations via microwave connections**
- **Cable TV also found a good ISP market by using some of the channels originally designed for video**

- Cable TV started to distribute broadcast video signals to locations with poor or no reception in the late 1940s

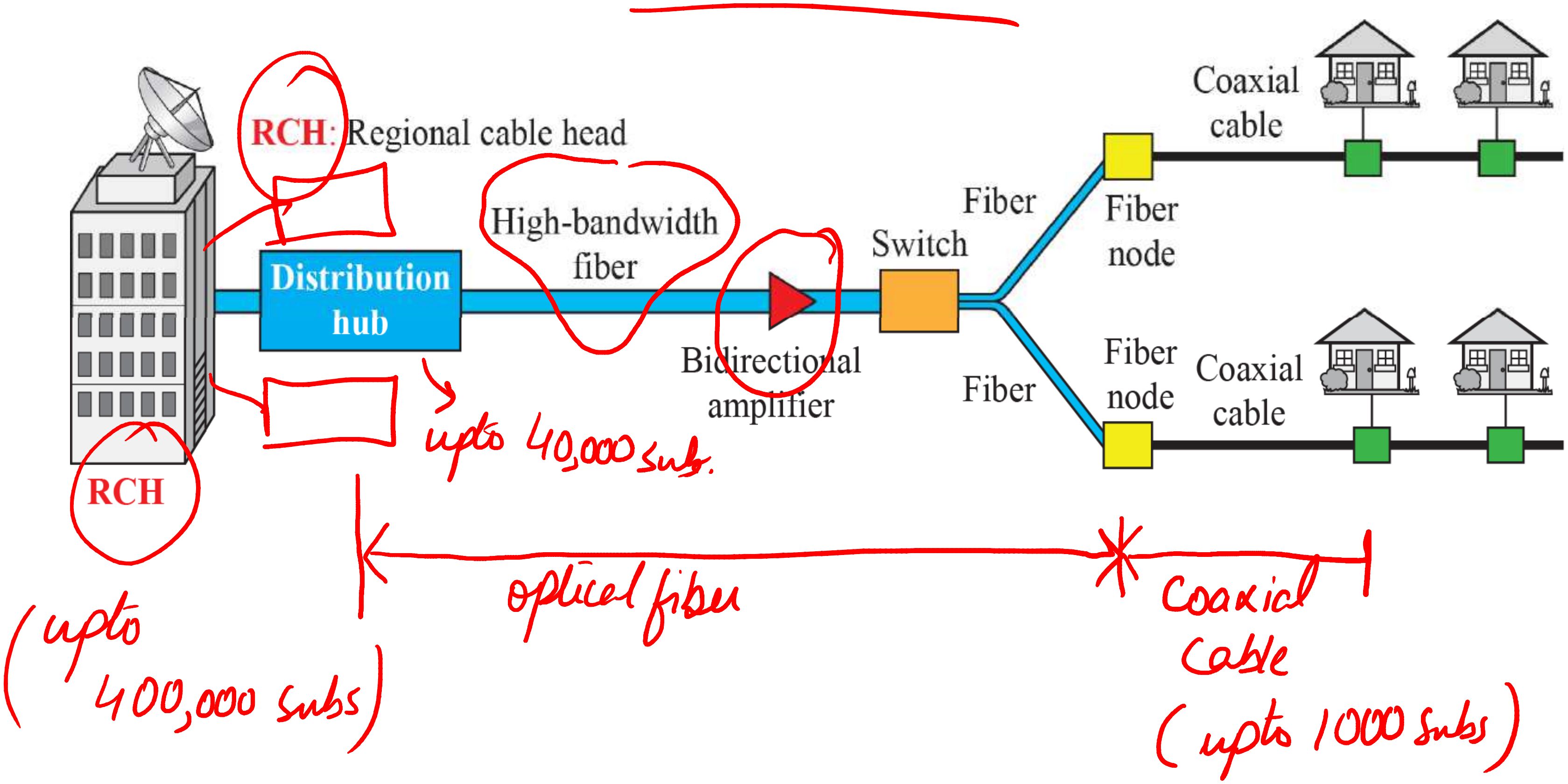
- It was called community antenna television (CATV) because an antenna at the top of a tall hill or building received the signals from the TV stations


Receiving antenna
Head end
Coaxial cable
Amplifier
Splitter
Drop cable
Tap
unidirectional
CATV office
Amplifier
(35 amplifiers)

- **Second generation of cable network is called a Hybrid Fiber-Coaxial (HFC) network**

- **The network uses a combination of fiber-optic and coaxial cable**

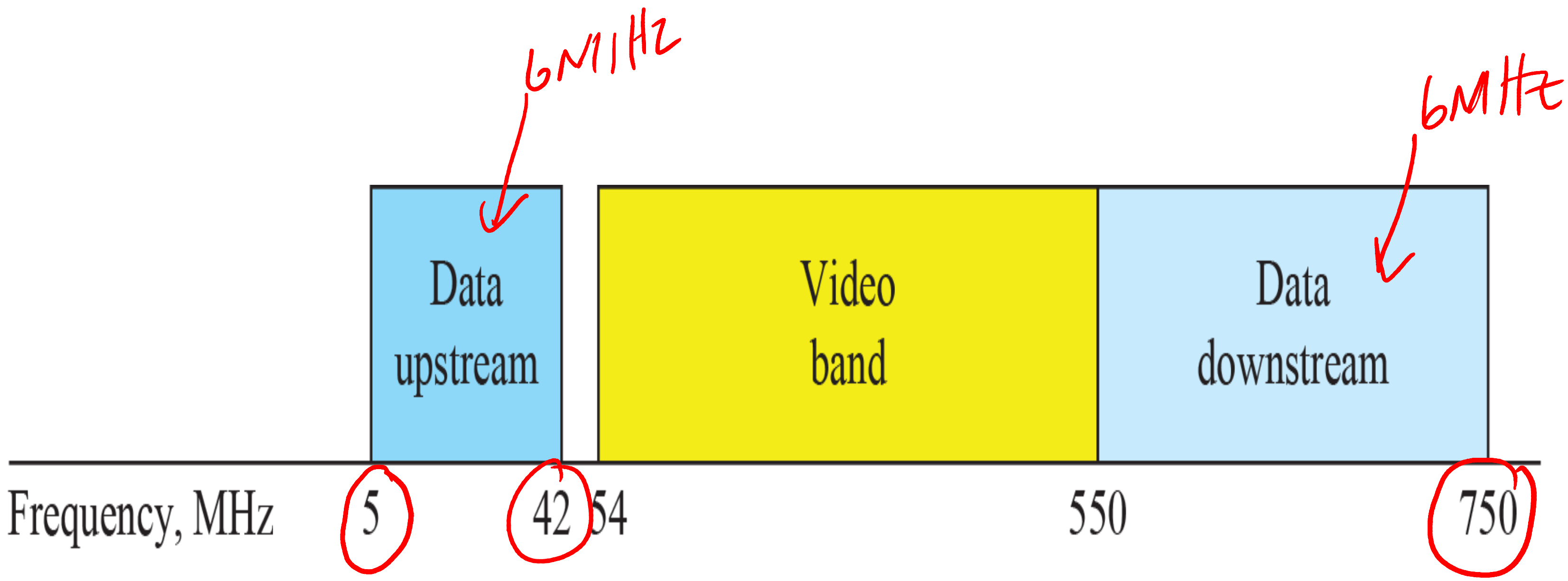
Bidirectional



- **Cable companies are now competing with telephone companies for the residential customer who wants high-speed data transfer**

- **DSL technology provides high-data-rate connections for residential subscribers over the local loop BUT UTP is susceptible to Interfence**

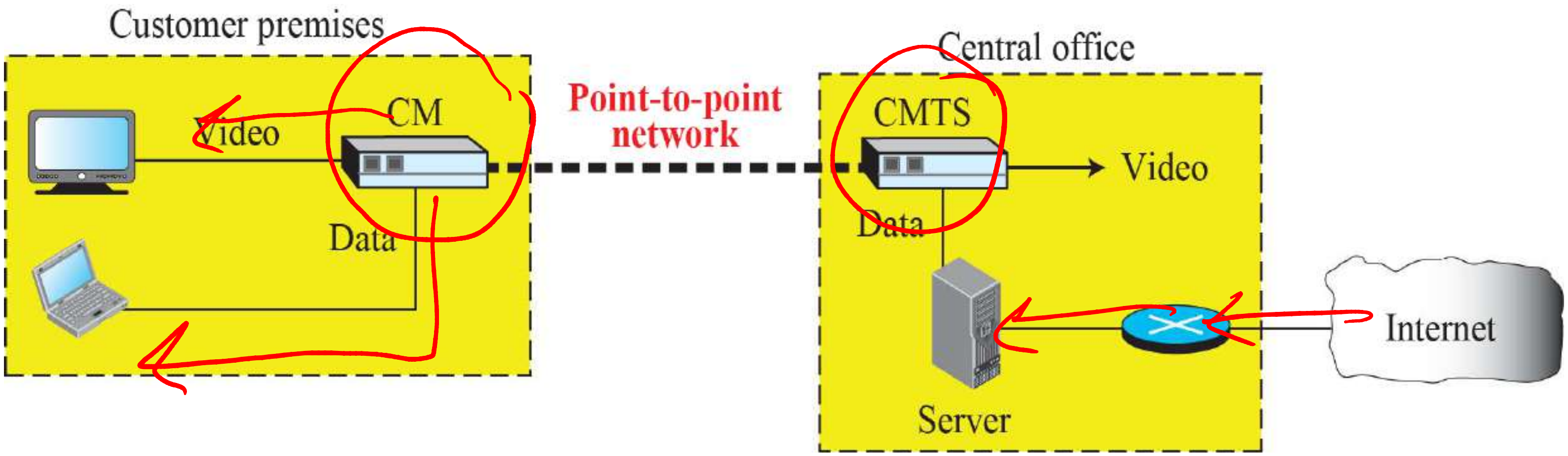
- **This imposes an upper limit on the data rate. A solution is the use of the cable TV network**



Video → 54MHz — 550MHz = 496 MHz

Each TV channel = 6MHz

80 TV channels (80 x 6MHz = 480MHz)



CM → Cable Modem (Subscriber premise)
CMTS → cable company.

Synchronous Optical Network (SONET

- A wide area network (WAN) that is used as a transport network to carry loads from other WANs

- ITU–T standard called Synchronous Digital Hierarchy (SDH)

- Architecture of a SONET system consists of signals, devices, and connections

- **Signals**
  - ✓ Synchronous Transport Signals (STS)
  - ✓ Optical Carriers (OCs)
  - ✓ Synchronous Transport Module (STM)

- **SONET Devcies**
  - ✓ STS Mux/Demux
  - ✓ Regenerators
  - ✓ Add-Drop Multiplexer and Terminals

- **Connections**
  - ✓ Section
  - ✓ Line
  - ✓ Path

ANSI SONET

SDH

3 STS 1

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**

DS3

44.73

Europe

USA

Europe

- **Signals**
  - ✓ Synchronous Transport Signals (STS)
  - ✓ Optical Carriers (OCs)
  - ✓ Synchronous Transport Module (STM)
- **SONET Devcies**
  - ✓ STS Mux/Demux
  - ✓ Regenerators
  - ✓ Add-Drop Multiplexer and Terminals
- **Connections**
  - ✓ Section
  - ✓ Line
  - ✓ Path

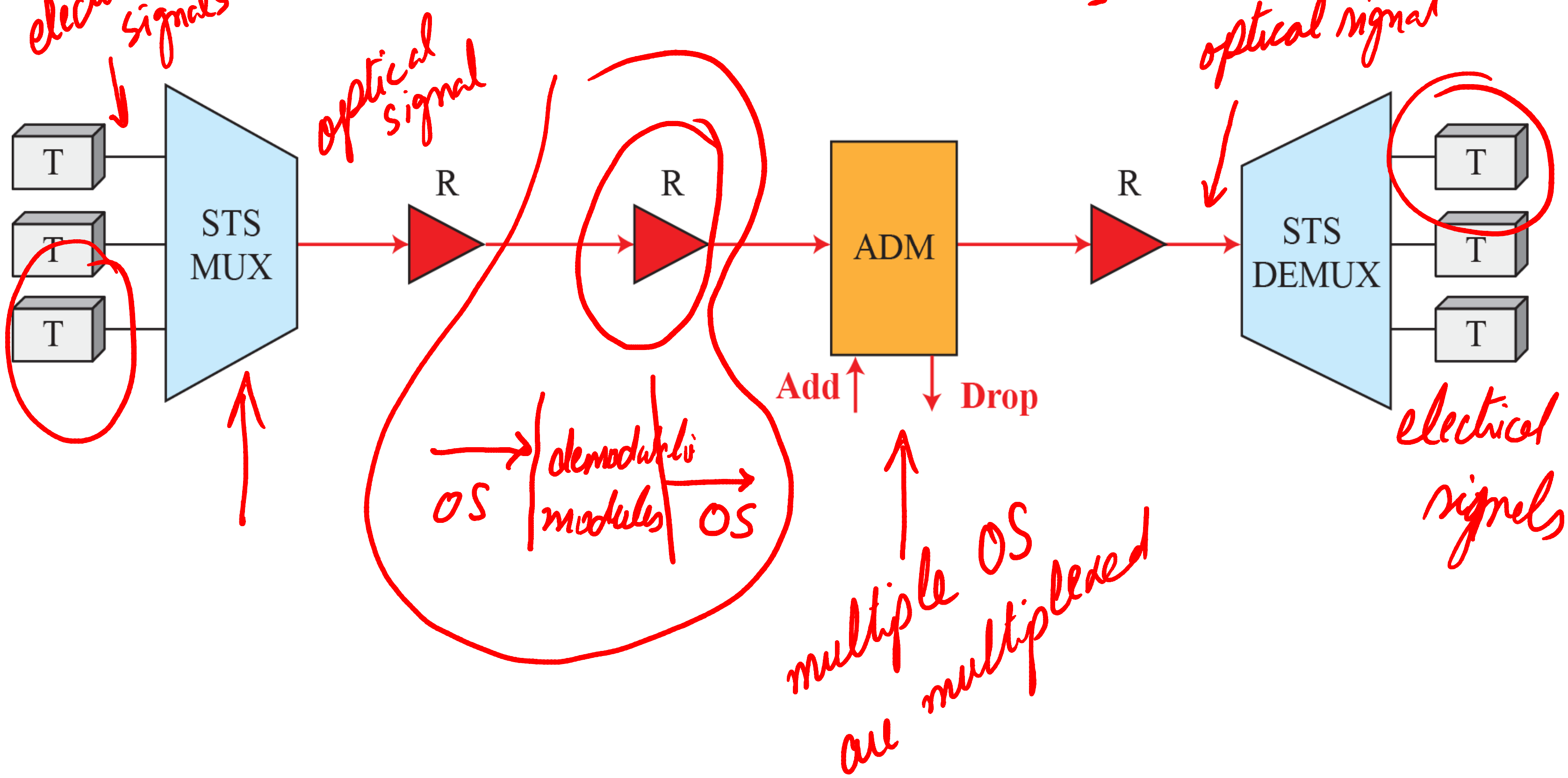
ADM: Add/drop multiplexer

STS MUX: Synchronous transport signal multiplexer

STS DEMUX: Synchronous transport signal demultiplexer

R: Regenerator

T: Terminal



ADM: Add/drop multiplexer

STS MUX: Synchronous transport signal multiplexer

STS DEMUX: Synchronous transport signal demultiplexer

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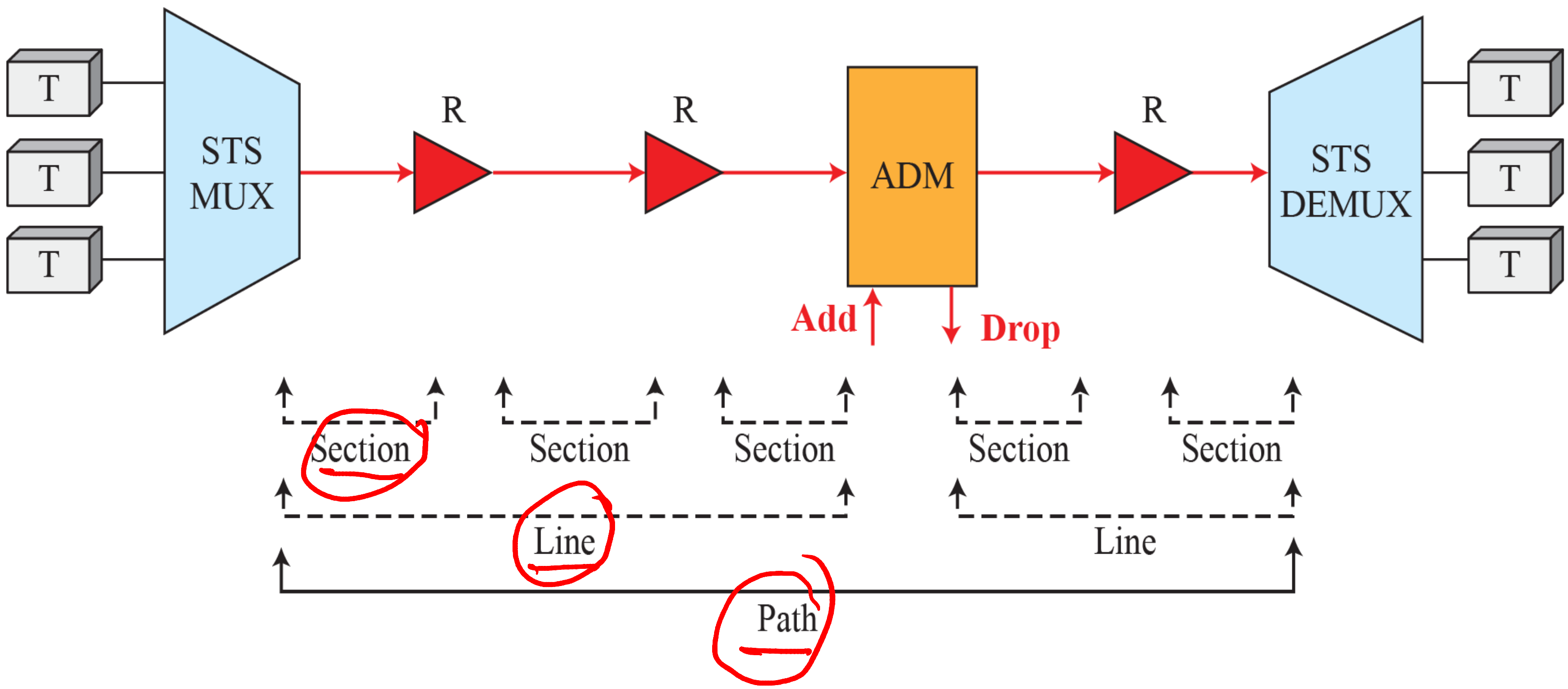
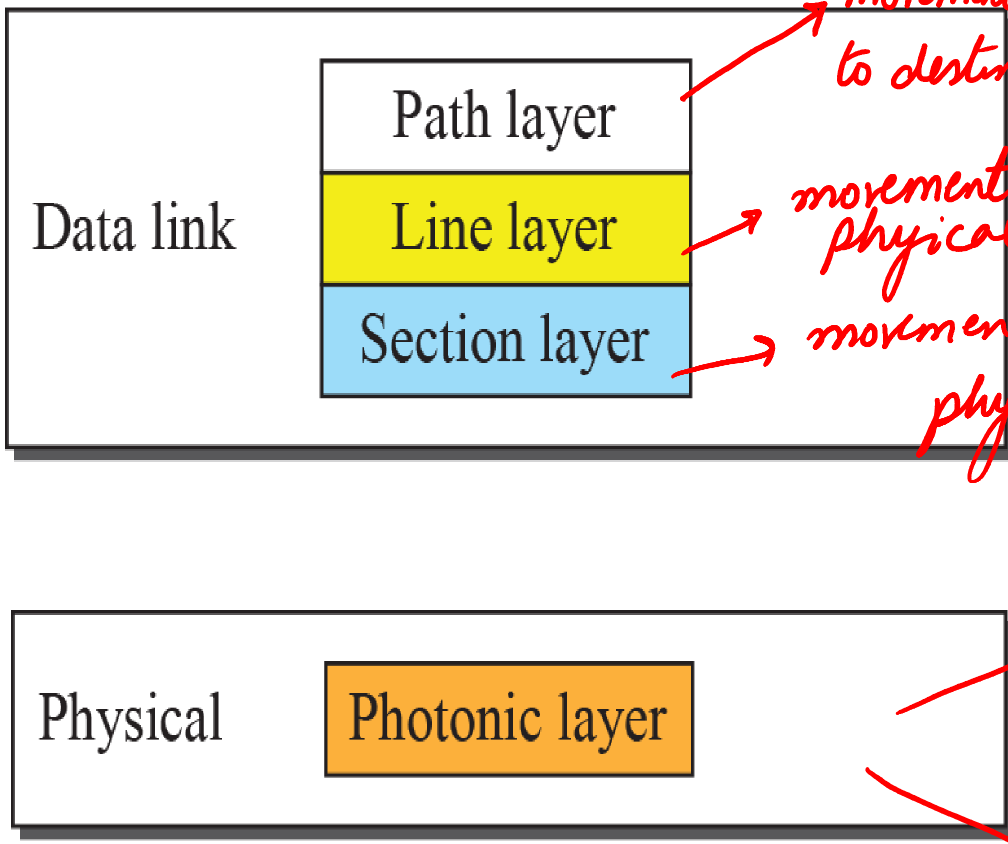


- **The SONET standard includes four functional layers:**
  - ✓ **The Path Layer**
  - ✓ **The Line Layer**
  - ✓ **The Section Layer**
  - ✓ **The Photonic Layer**
- **The layers correspond to both the physical and the data-link layers**



movement from source to destination optical devices

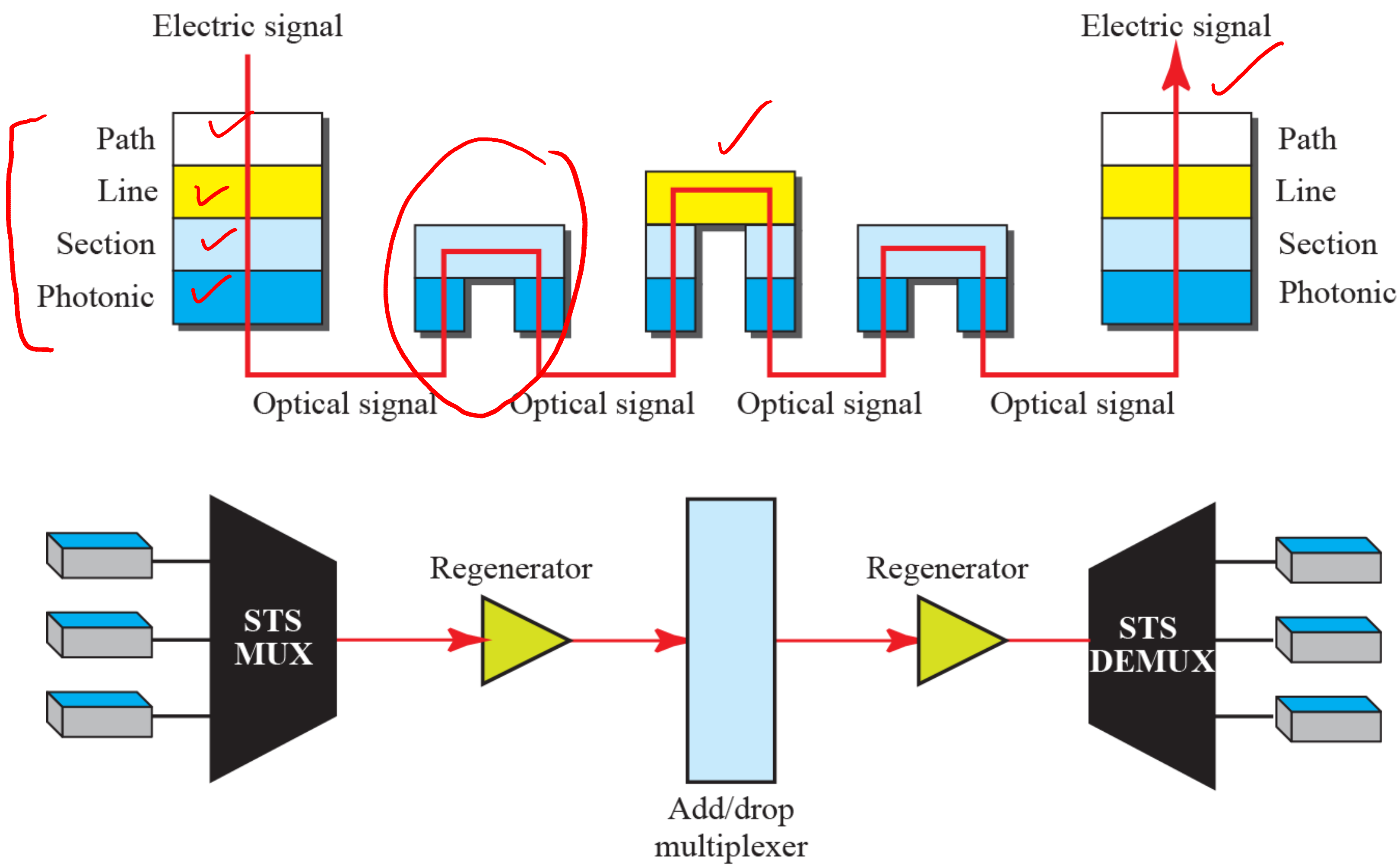
movement across a physical line

movement across a physical section

physical specification

NRZ

(presence of light → 1
absence of light → 0)

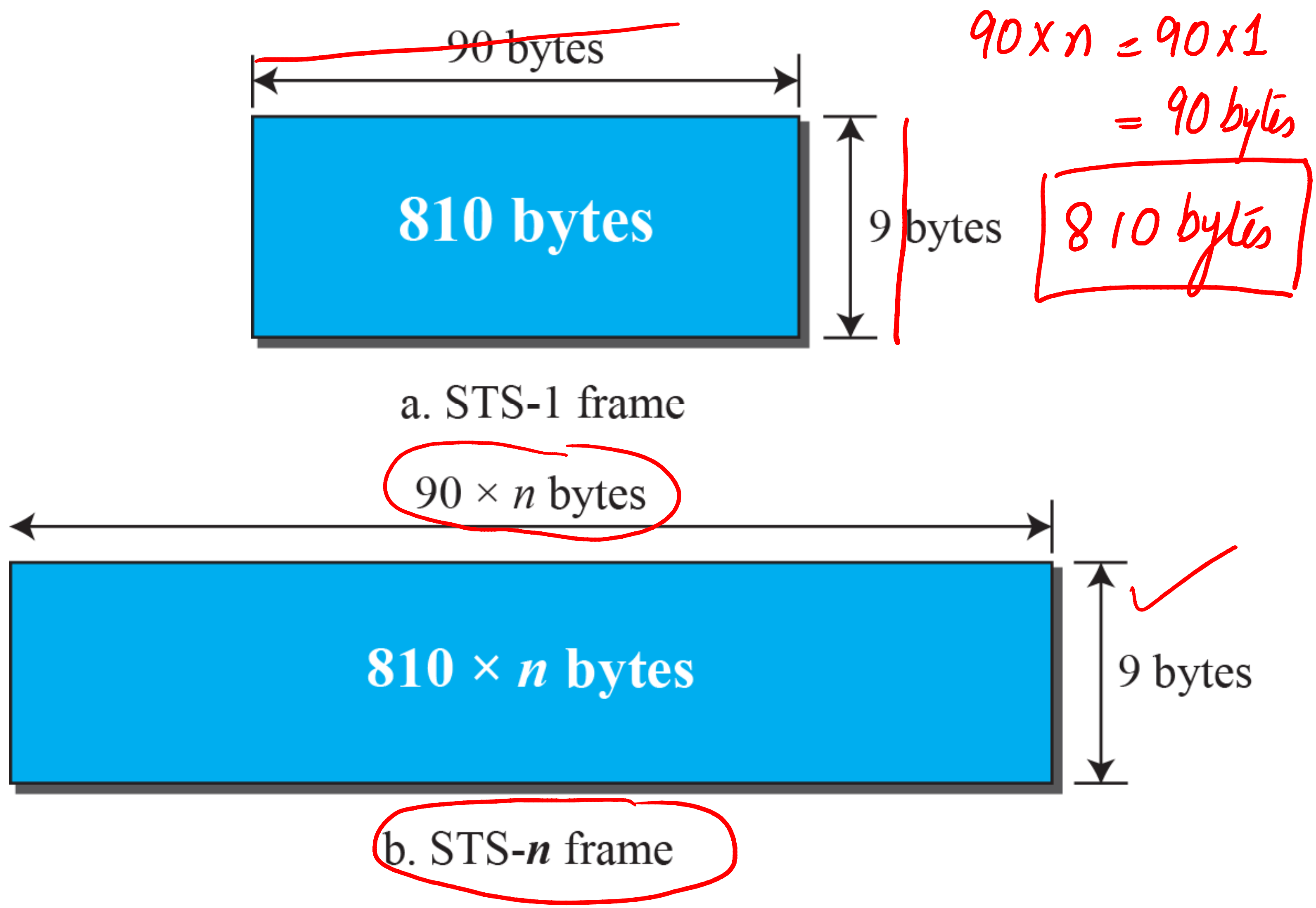


Electric signal
Electric signal
Path
Line
Section
Photonic
Path
Line
Section
Photonic
Optical signal
Optical signal
Optical signal
Optical signal
Regenerator
Regenerator
STS MUX
STS DEMUX
Add/drop multiplexer

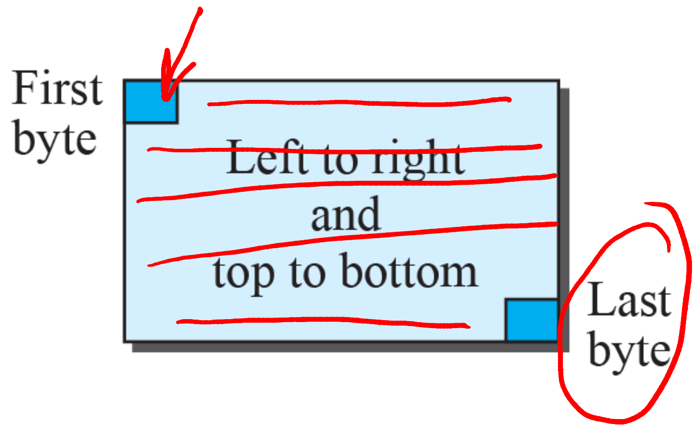
- Each synchronous transport signal STS-n is composed of 8000 frames

- Each frame is a two-dimensional matrix of bytes with 9 rows by 90×n columns

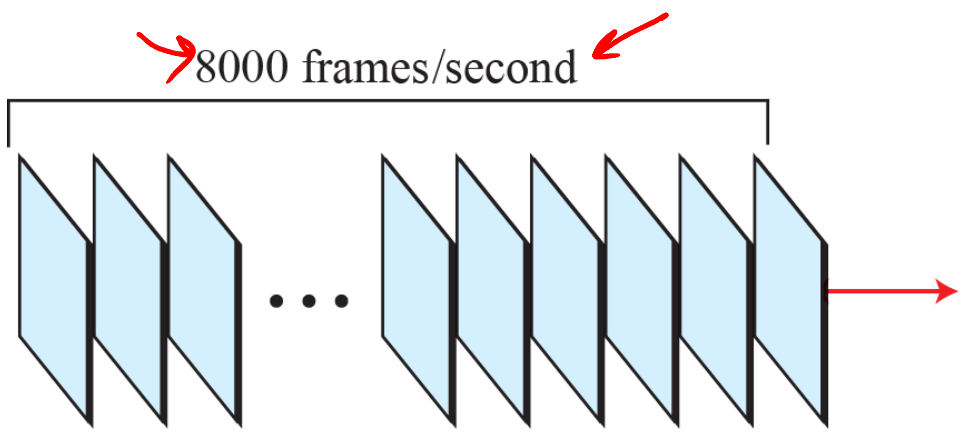
- STS-1 frame is 9 rows by 90 columns (810 bytes), and an STS-3 is 9 rows by 270 columns (2430 bytes)



~~90 bytes~~
810 bytes
9 bytes
$90 \times n = 90 \times 1$
$= 90$ bytes
$\boxed{810 \text{ bytes}}$
a. STS-1 frame
90 × n bytes
810 × n bytes
9 bytes
b. STS-n frame



a. Byte transmission



b. Frame transmission

Find the data rate of an STS-1 signal

8000 frames per second

9 bytes x (1x 90) bytes

Data Rate $= 8000 \times 9(1 \times 90)$

$= \underline{\underline{51.84 \text{ Mbps}}}$

Find the data rate of an STS-3 signal

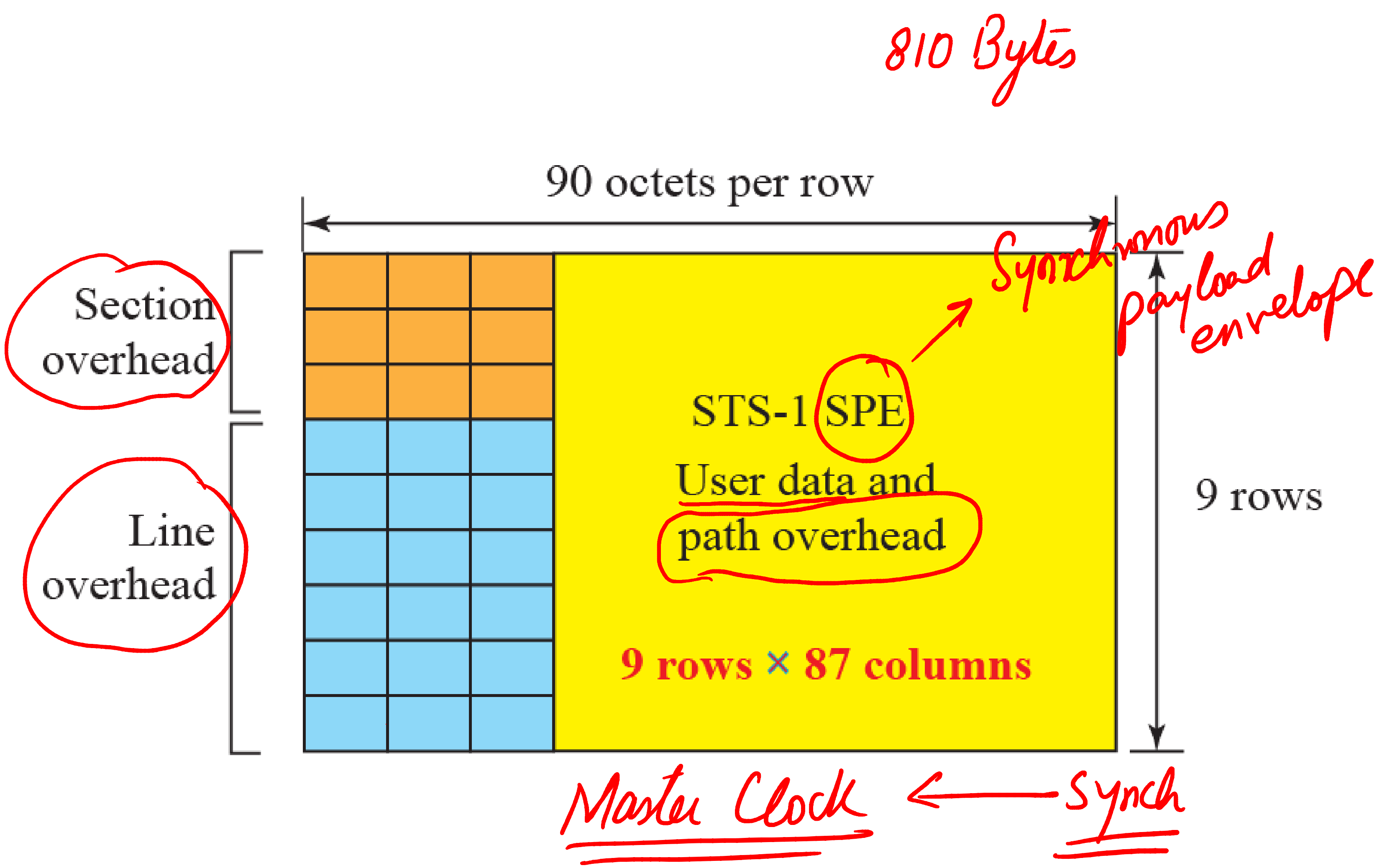
$n=3$

$$\text{Data Rate} = 8000 \times 9 (3 \times 90)$$

$$= 155.52 \text{ Mbps}$$

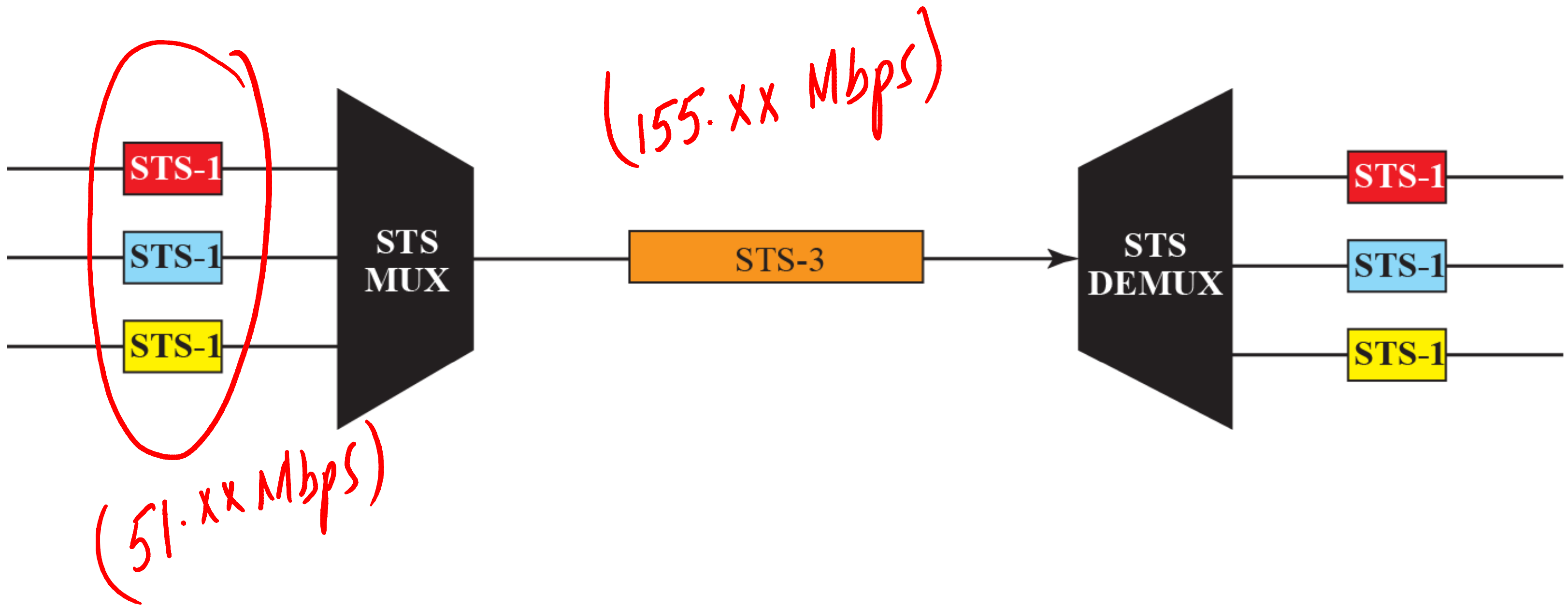
STS-1 Data Rate $\times$ 3

= STS-3 Data Rate.

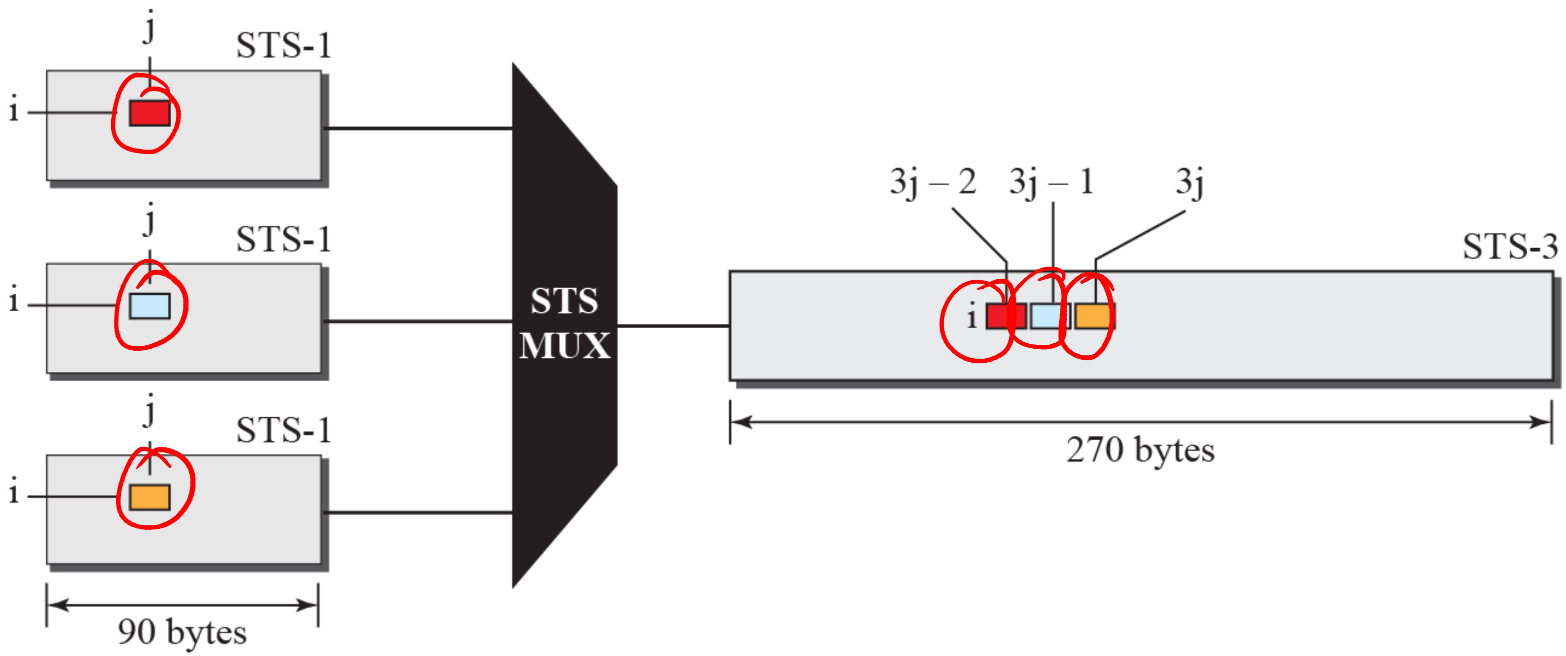

810 Bytes
90 octets per row
Section overhead
Line overhead
STS-1 SPE
Synchronous payload envelope
User data and path overhead
9 rows × 87 columns
9 rows
Master Clock
Synch

- In SONET, frames of lower rate can be synchronously time-division multiplexed into a higher-rate frame

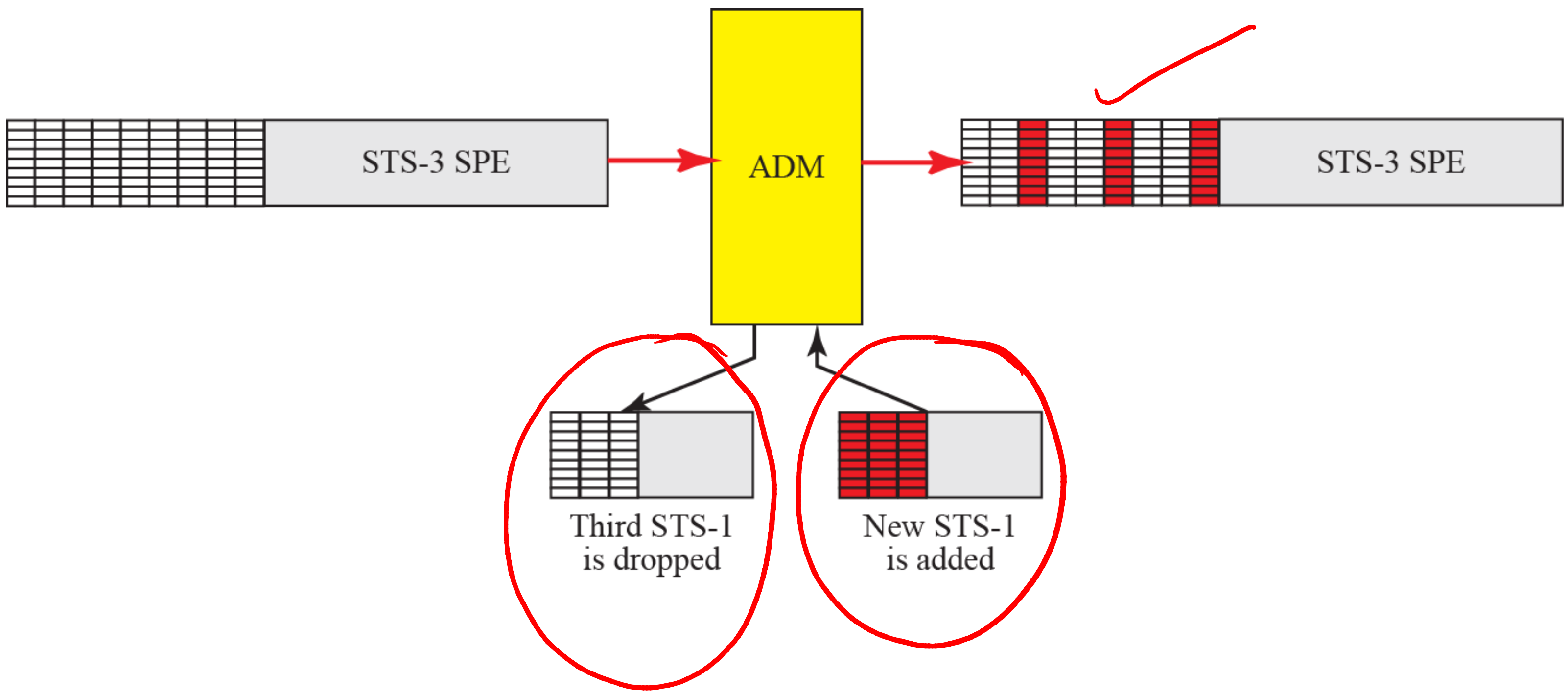
- For example, three STS-1 signals (channels) can be combined into one STS-3 signal (channel), four STS-3s can be multiplexed into one STS-12, and so on



(155.xx Mbps)
STS-1
STS-1
STS-1
STS MUX
STS-3
STS DEMUX
STS-1
STS-1
STS-1
(51.xx Mbps)



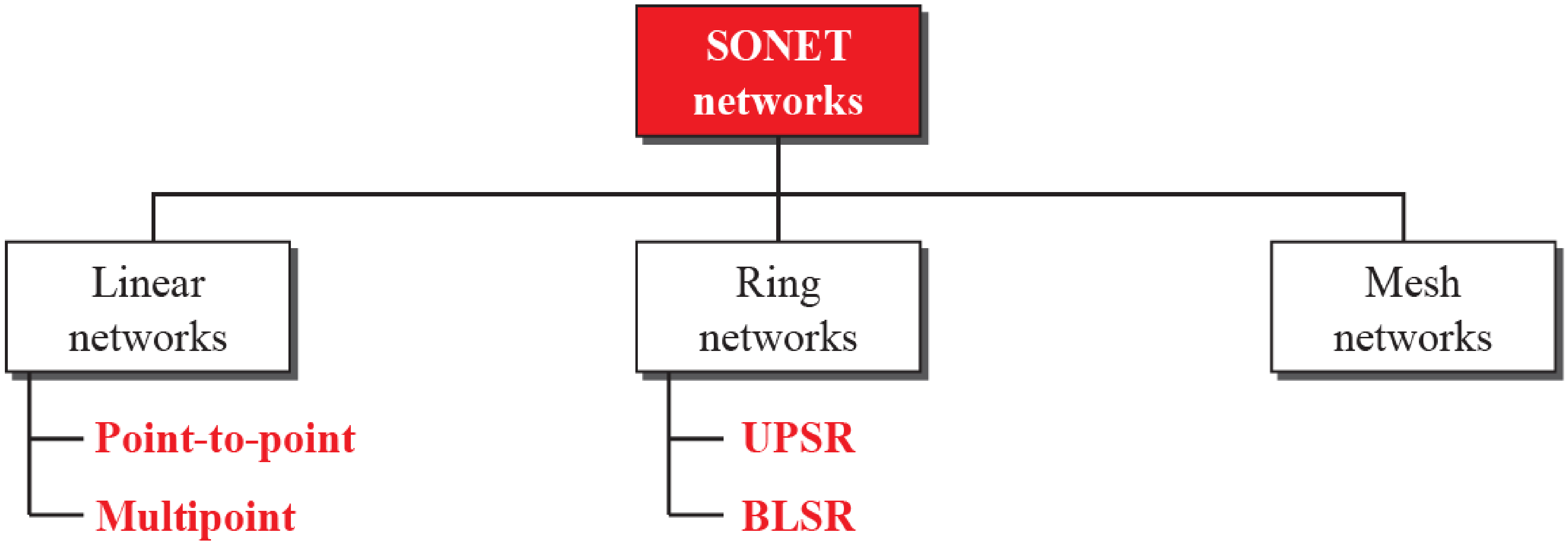
j
STS-1
i
j
STS-1
i
j
STS-1
i
90 bytes
STS
MUX
3j – 2
3j – 1
3j
STS-3
i
270 bytes

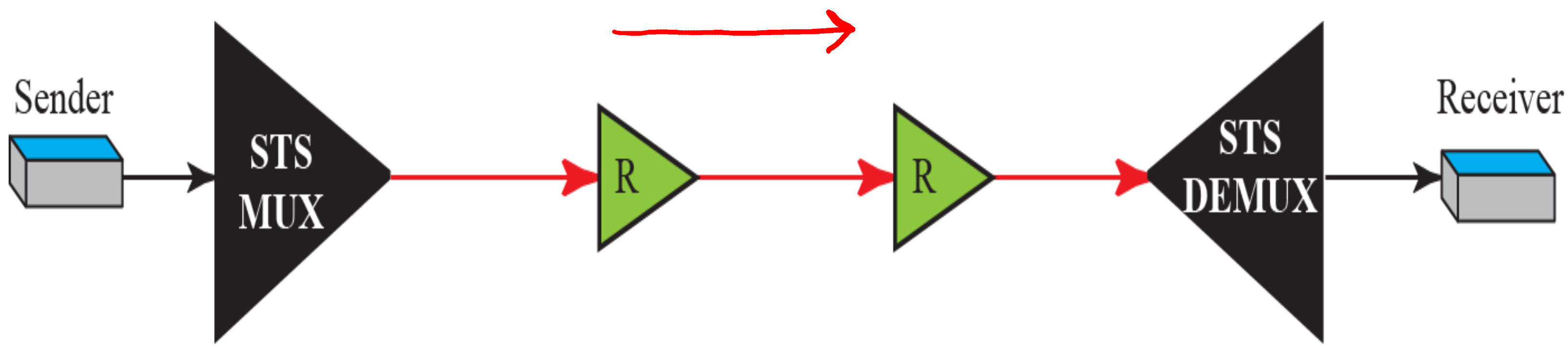

STS-3 SPE
ADM
STS-3 SPE
Third STS-1
is dropped
New STS-1
is added

- **SONET network can be used as a high-speed backbone carrying loads from other networks such as ATM or IP**

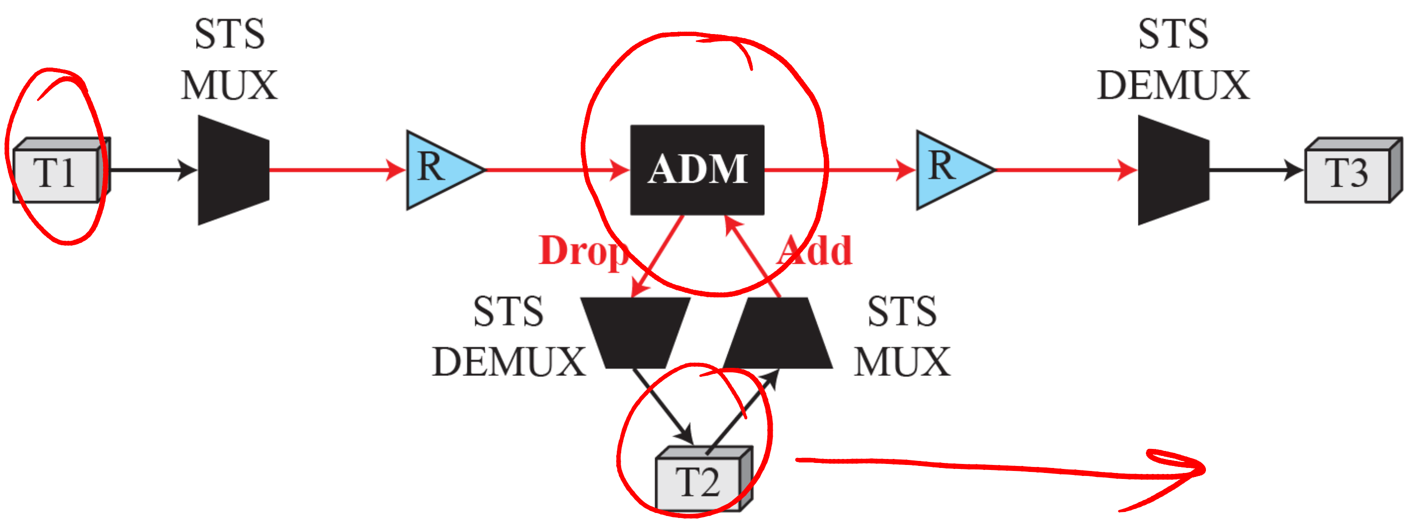
- **We can roughly divide SONET networks into three categories:**

  - ✓ **Linear Networks**
  - ✓ **Ring Networks**
  - ✓ **Mesh networks**


SONET networks
Linear networks
Ring networks
Mesh networks
Point-to-point
Multipoint
UPSR
BLSR

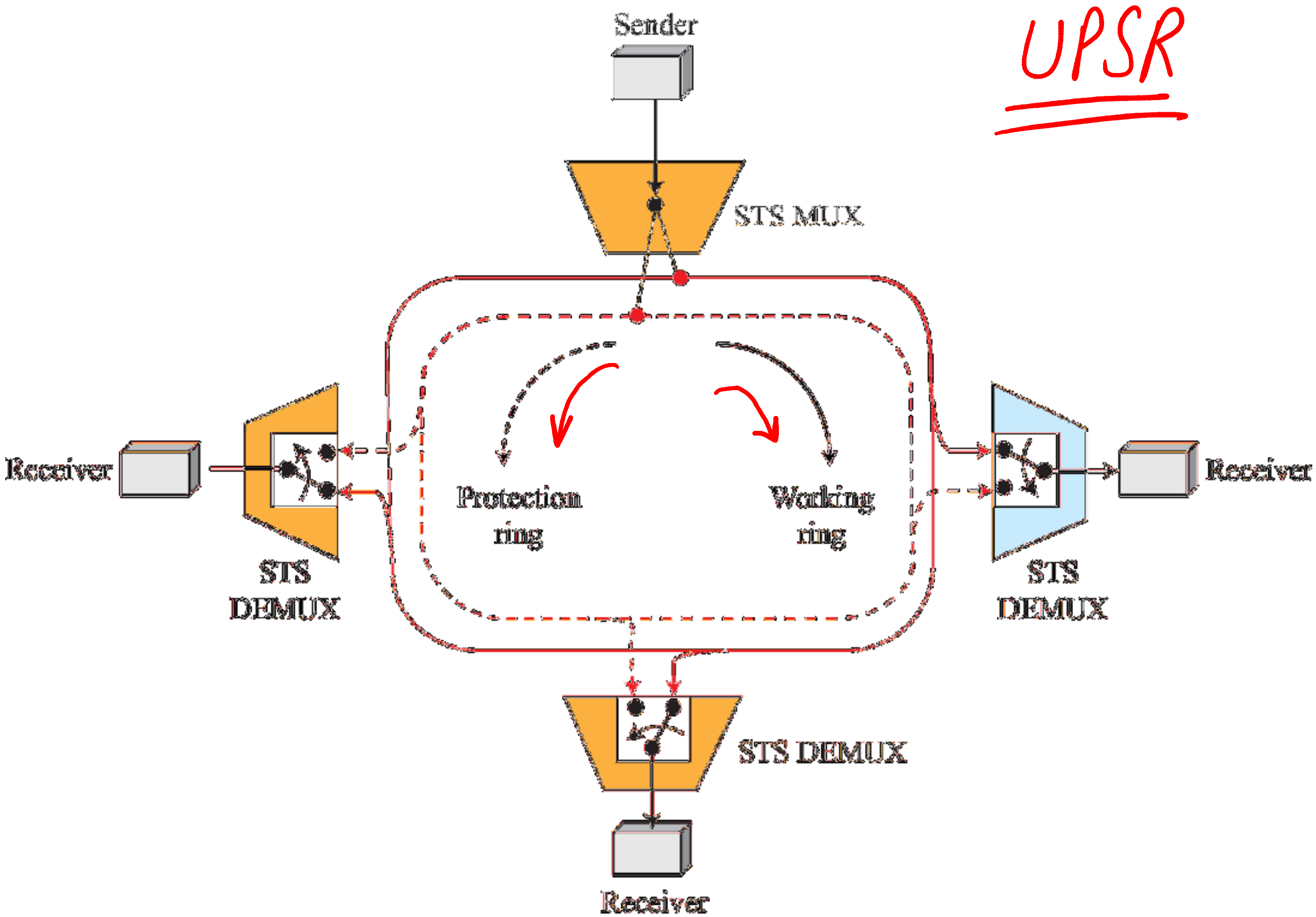


Sender
STS
MUX
R
R
STS
DEMUX
Receiver

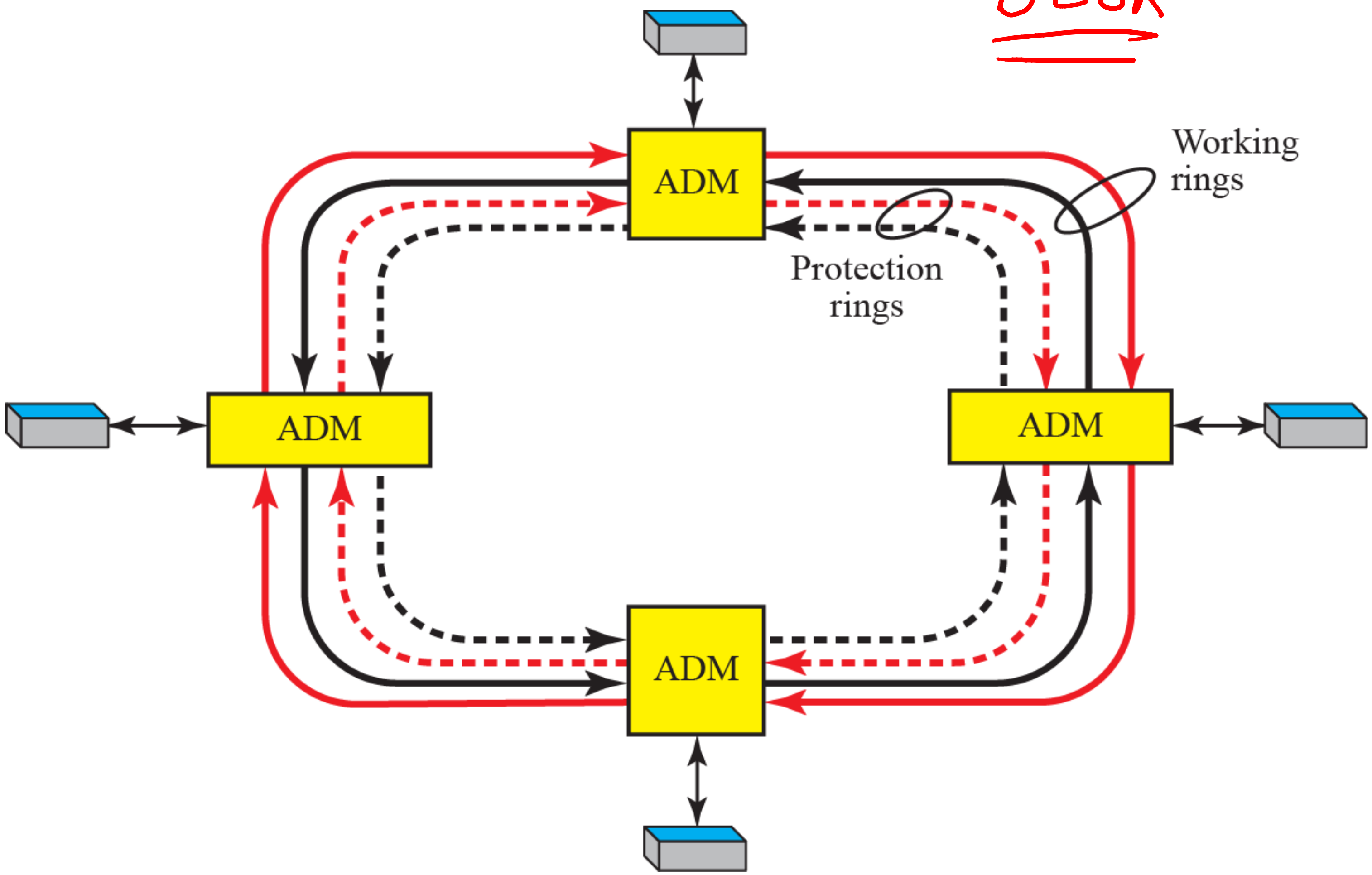


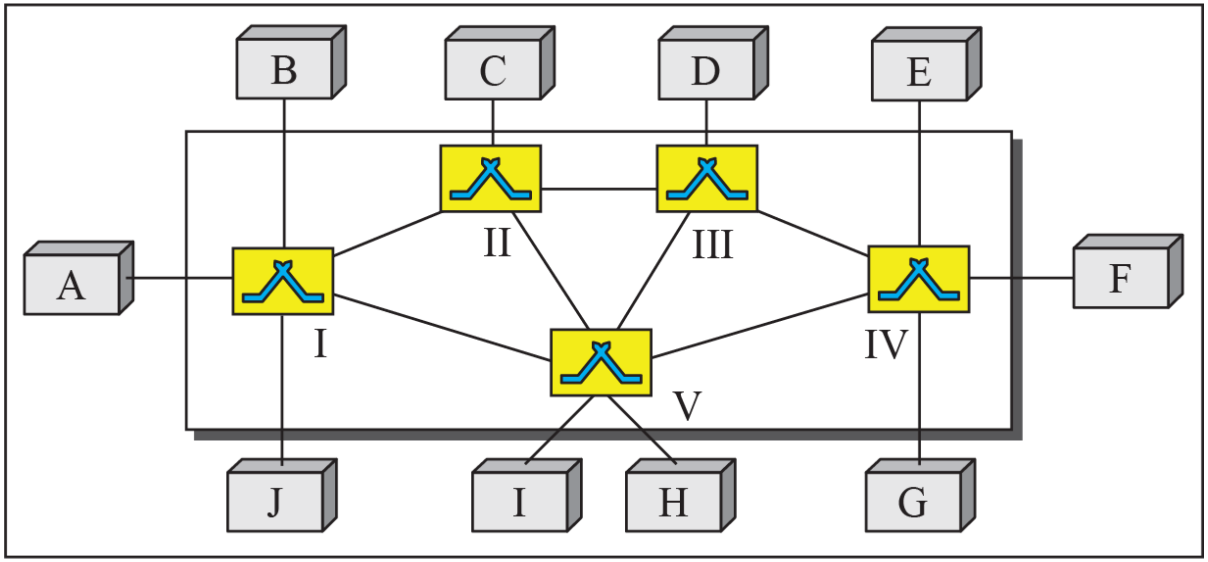
T1
STS
MUX
R
ADM
R
STS
DEMUX
T3
Drop
Add
STS
DEMUX
STS
MUX
T2

UPSR


Sender
STS MUX
Receiver
STS DEMUX
Protection ring
Working ring
Receiver
STS DEMUX
STS DEMUX
Receiver

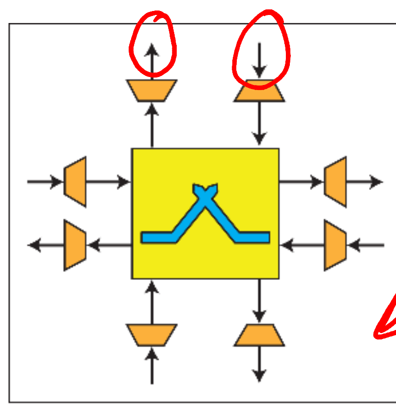
BLSR





a. SONET mesh network

Scalability

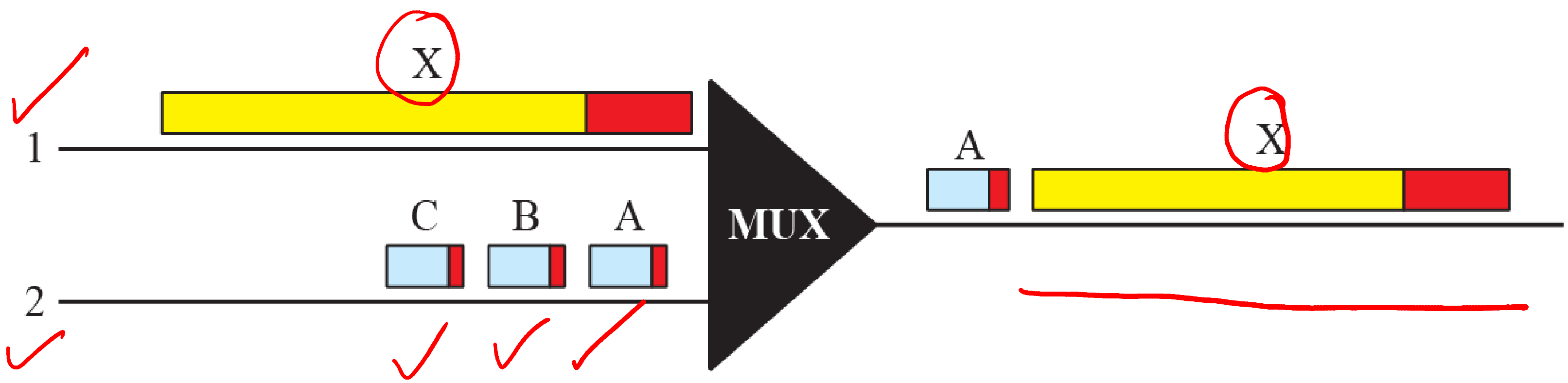


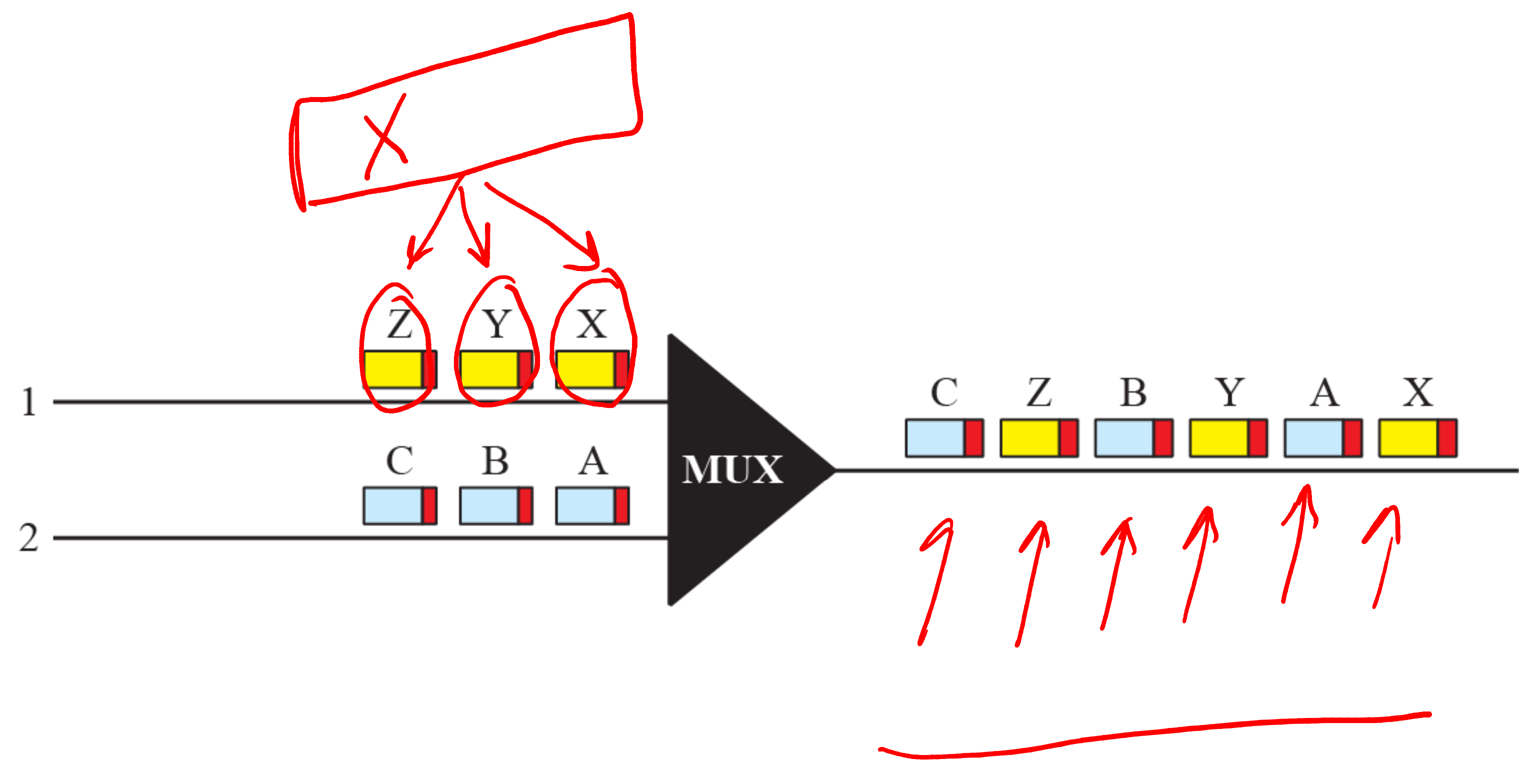
b. Cross-connect switch

- **Asynchronous Transfer Mode (ATM) is a switched wide area network based on the cell relay protocol designed by the ATM forum**

- **The combination of ATM and SONET will allow high-speed interconnection of networks**

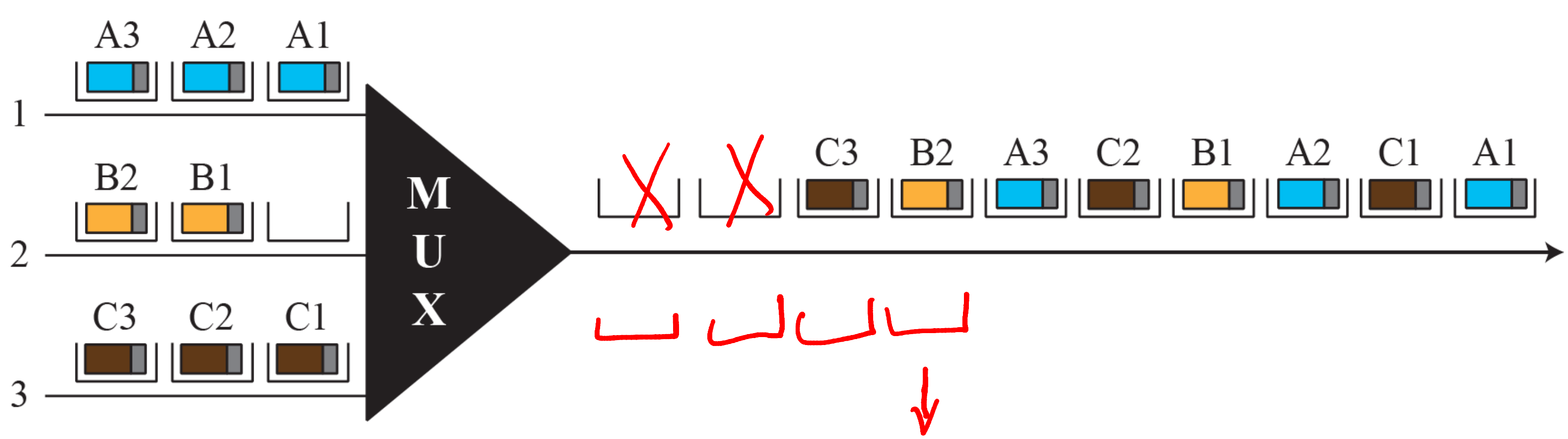
- **Some of the problems associated with existing systems are:**
  - ✓ **Frame Networks**
  - ✓ **Mixed Network Traffic**
- **Solution**
  - ✓ **Cell Networks**
  - ✓ **Asynchronous TDM**


X
1
C
B
A
2
MUX
A
X



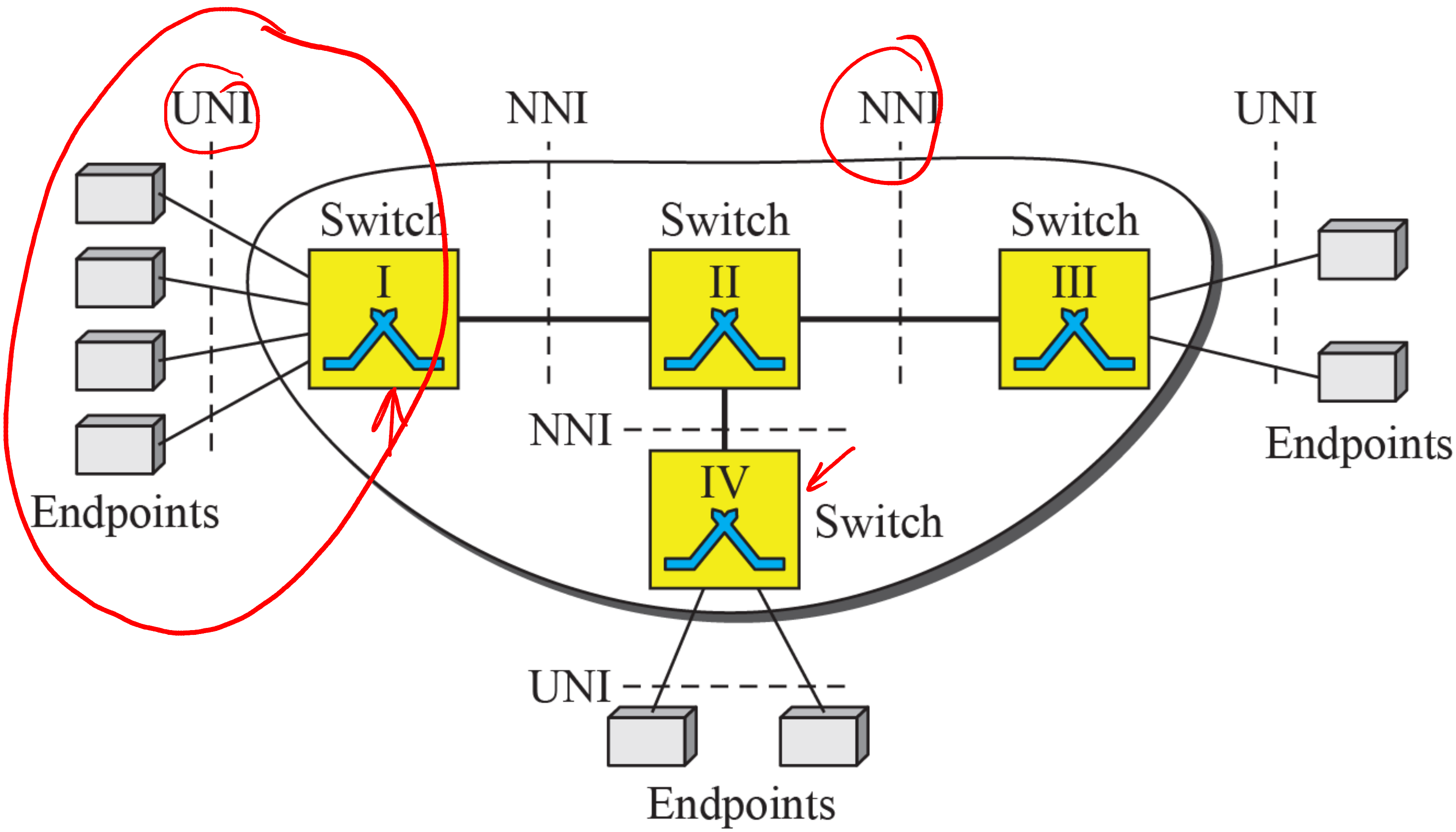
X
Z
Y
X
1
C
B
A
2
MUX
C
Z
B
Y
A
X

Asynchronous TDM

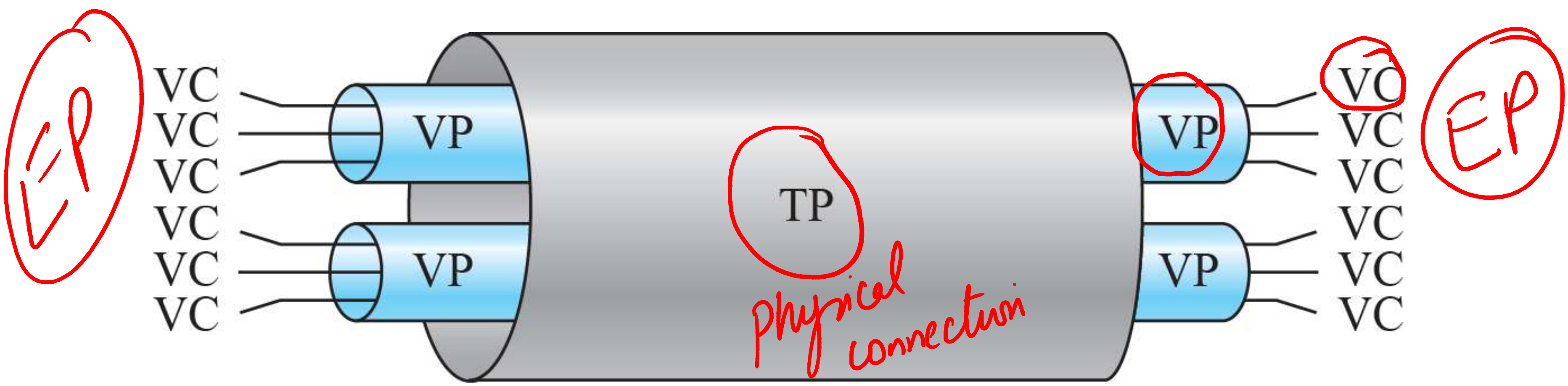


= cell size

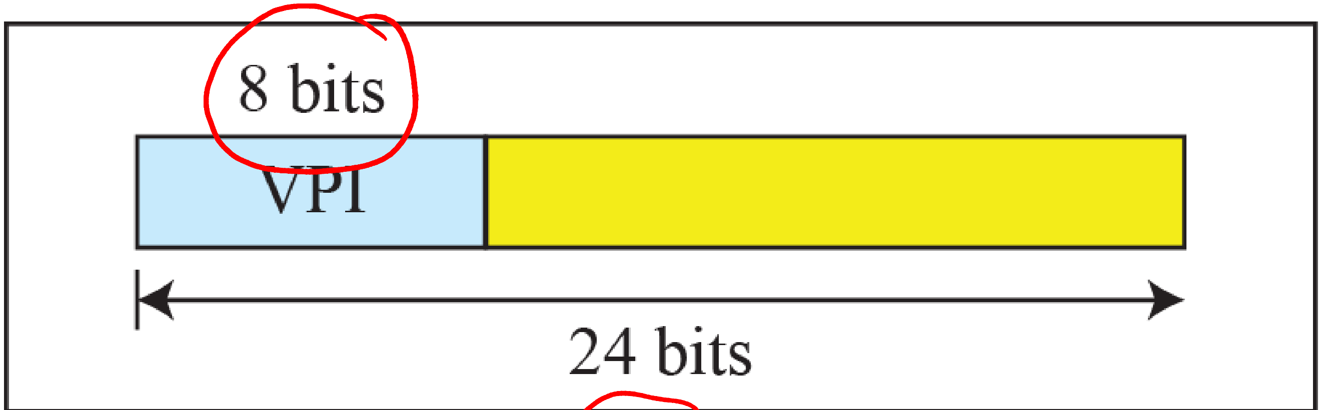
- ATM is a cell-switched network
- The user access devices, called the endpoints, are connected through a user-to-network interface (UNI) to the switches inside the network
- The switches are connected through network-to-network interfaces (NNIs)



UNI
NNI
NNI
UNI
Switch
I
Switch
II
Switch
III
NNI
IV
Switch
Endpoints
Endpoints
UNI
Endpoints

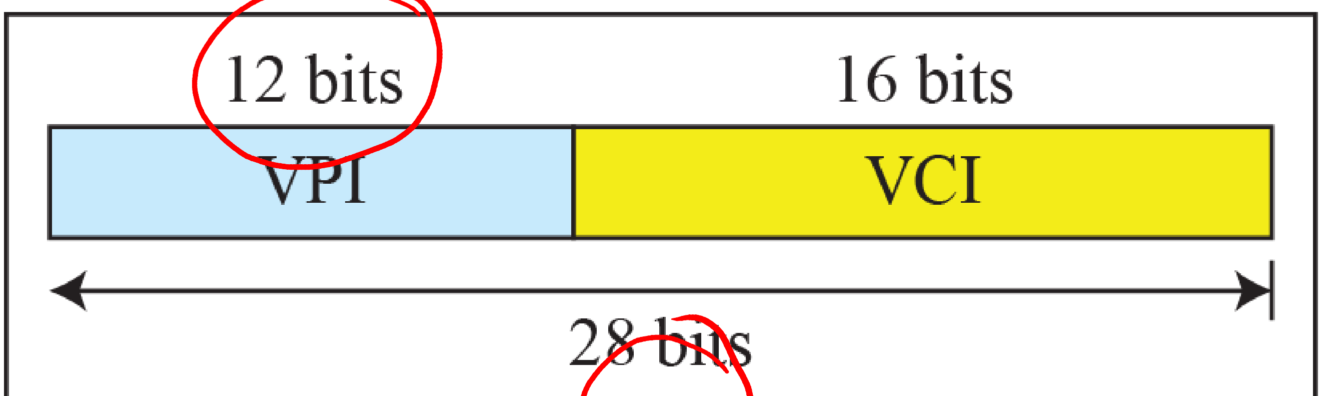


EP
VC
VC
VC
VC
VC
VC
VP
VP
TP
physical connection
VP
VP
VC
VC
VC
VC
VC
VC
EP



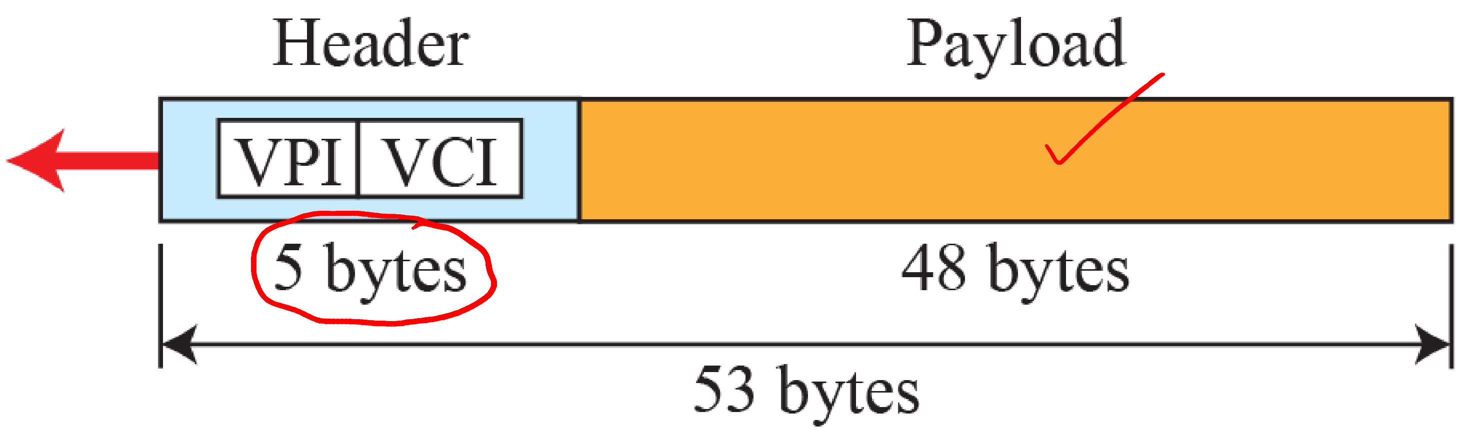
24 bits

a. VPI and VCI in a UNI

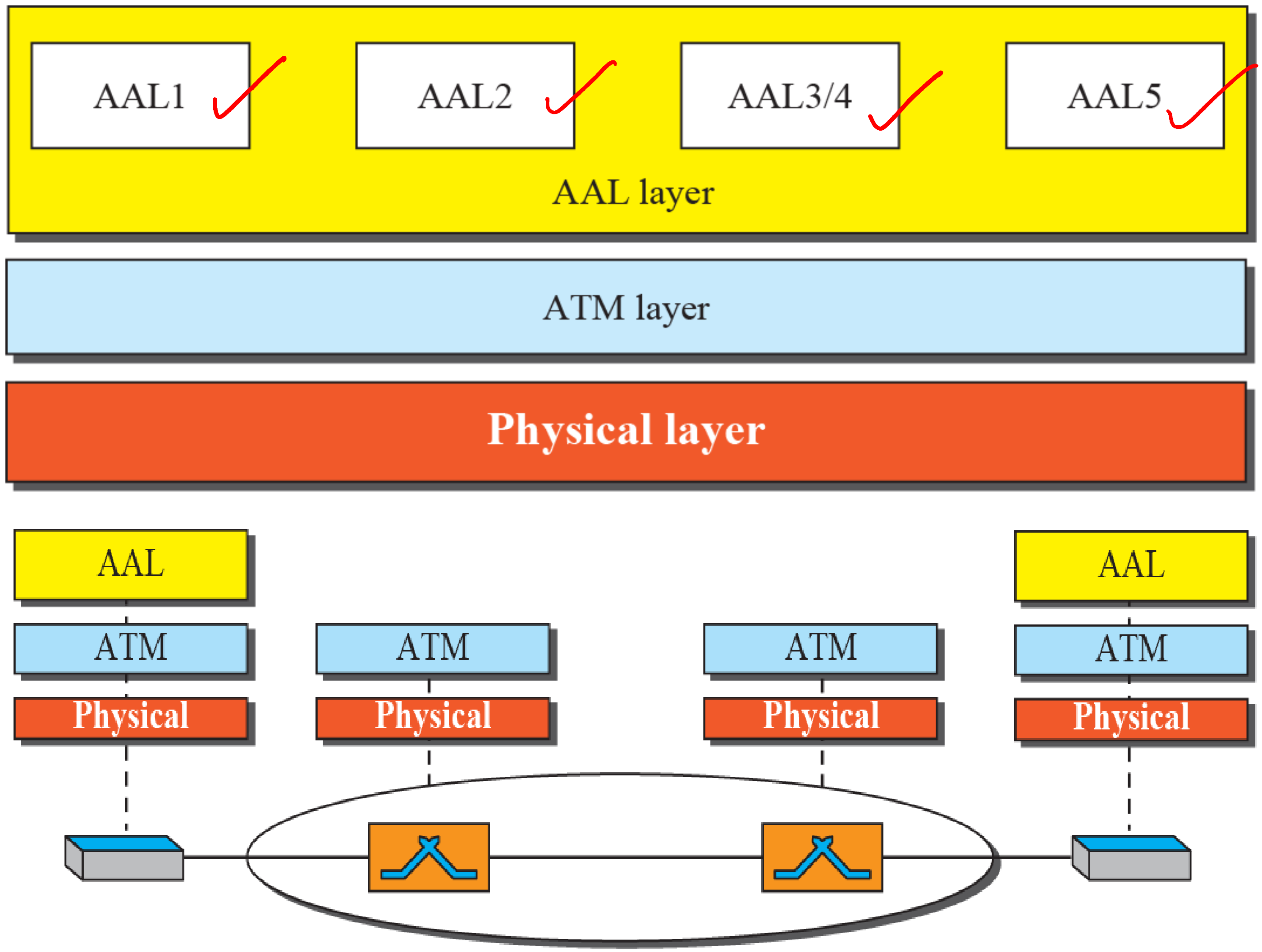


28 bits

b. VPI and VCI in an NNI



ATM cell ⇒ 53 Bytes


AAL1
AAL2
AAL3/4
AAL5
AAL layer
ATM layer
Physical layer
AAL
ATM
Physical
ATM
Physical
ATM
Physical
AAL
ATM
Physical

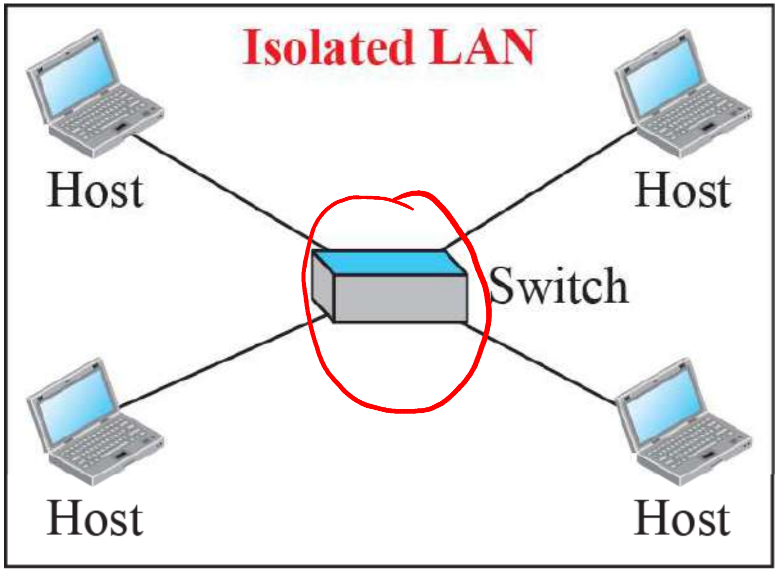
Introduction

- Wireless communication is one of the fastest-growing technologies

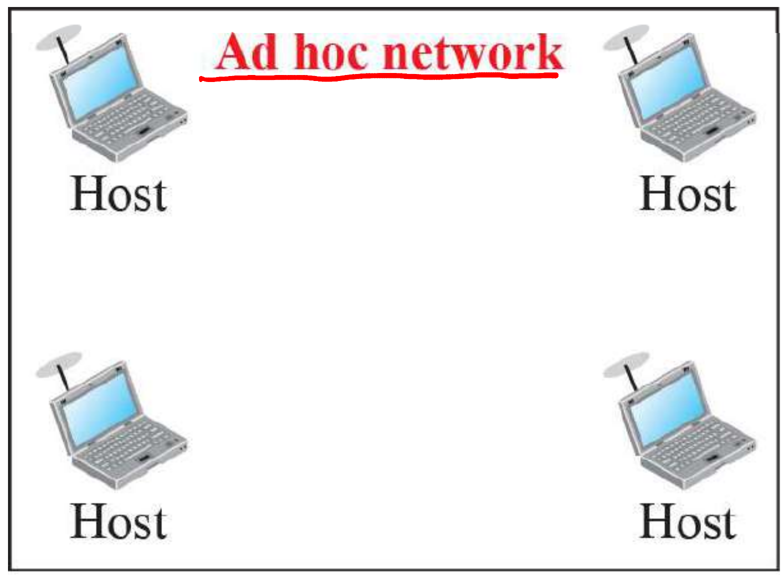
- The demand for connecting devices without the use of cables is increasing everywhere

- Wireless LANs can be found on college campuses, in office buildings, and in many public areas

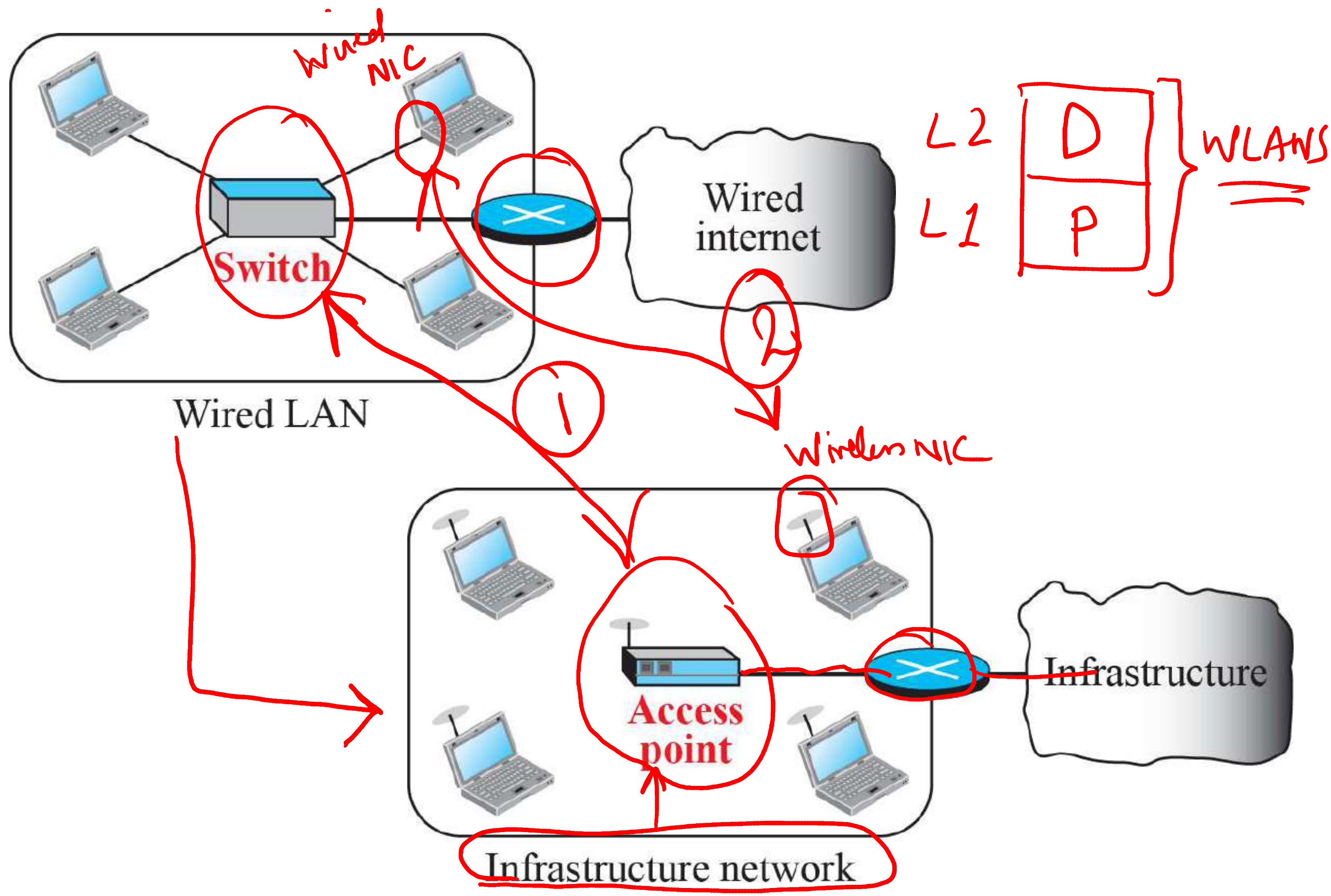
- **Architecture comparison of wired and wireless LANs**
  - ✓ **Medium**
  - ✓ **Hosts**
  - ✓ **Isolated LANs**
  - ✓ **Connection to other Networks**
  - ✓ **Moving between Environments**



Wired



Wireless



Wired NIC
Switch
Wired internet
L2
L1
D
P
WLANS
Wired LAN
1
2
Wireless NIC
Access point
Infrastructure
Infrastructure network

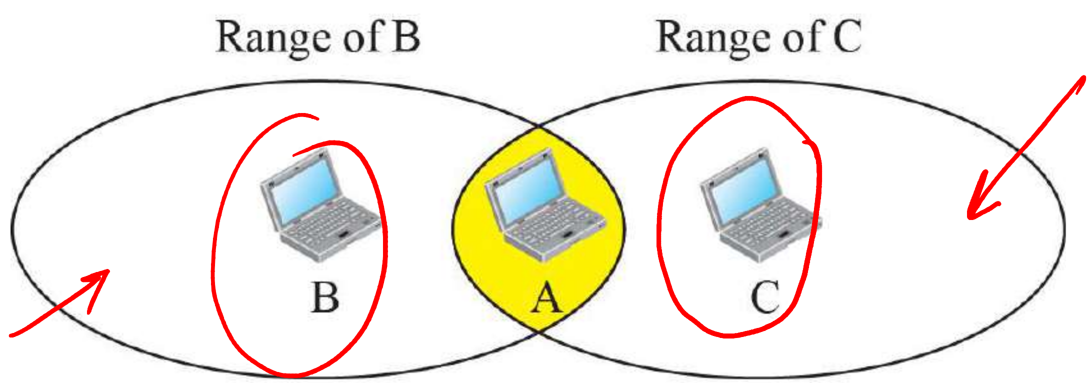
- **Several characteristics of wireless LANs either do not apply to wired LANs or the existence of these is negligible and can be ignored**

  - ✓ **Attenuation**
  - ✓ **Interference**
  - ✓ **Multipath Propagation**
  - ✓ **Error**

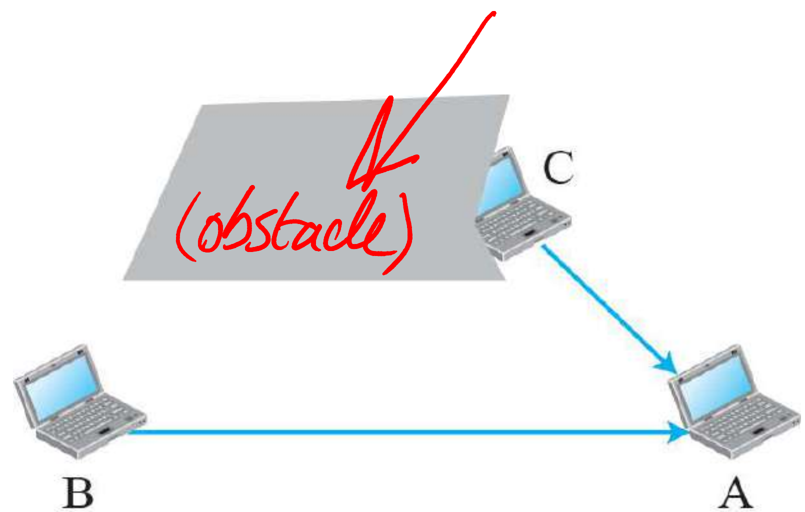
- **Most important issue in a wireless LAN is how a wireless host can get access to the shared medium (air)**
- **CSMA/CD does not work in wireless LANs for three reasons:**
  1. **Wireless hosts don’t have power to send and receive at the same time**

2. The hidden station problem prevents collision detection

3. The distance between stations can be large



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



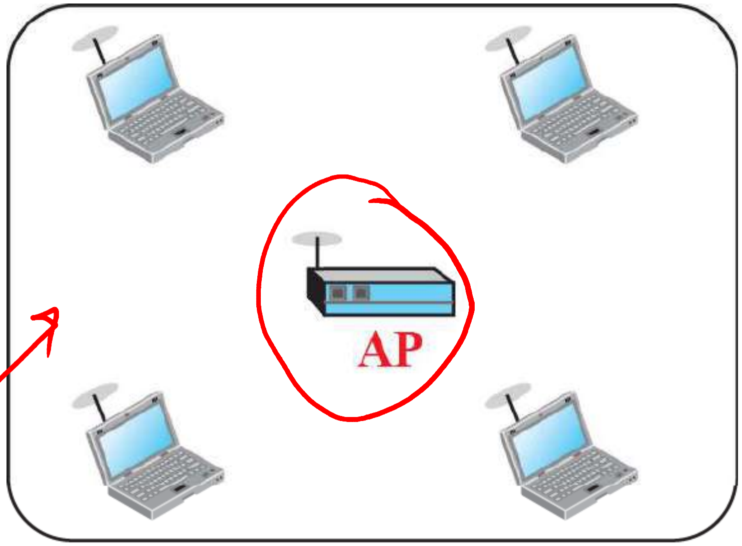
b. Stations B and C are hidden from each other.

- IEEE has defined the specifications for a wireless LAN, called IEEE 802.11, which covers the physical and data-link layers

- It is sometimes called Wireless Ethernet

- The term WiFi (short for wireless fidelity) as a synonym for wireless LAN (certified by WiFi alliance)

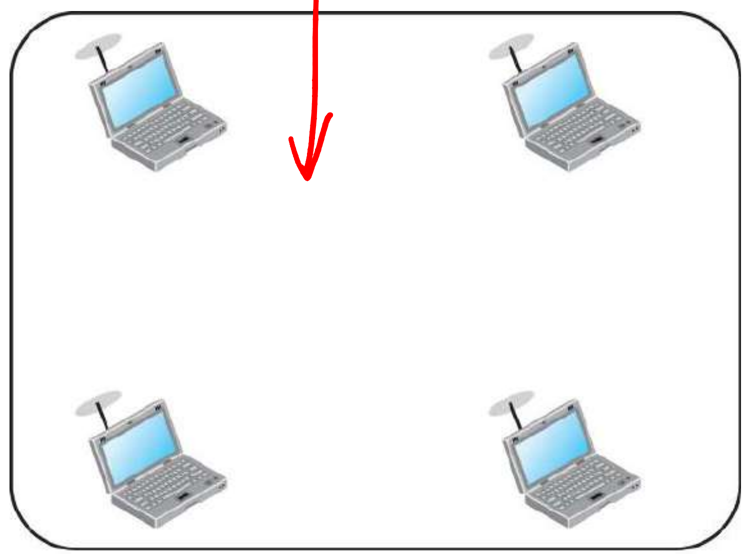
- **The standard defines two kinds of services:**
  - ✓ **The basic service set (BSS); and**
  - ✓ **The Extended service set (ESS)**



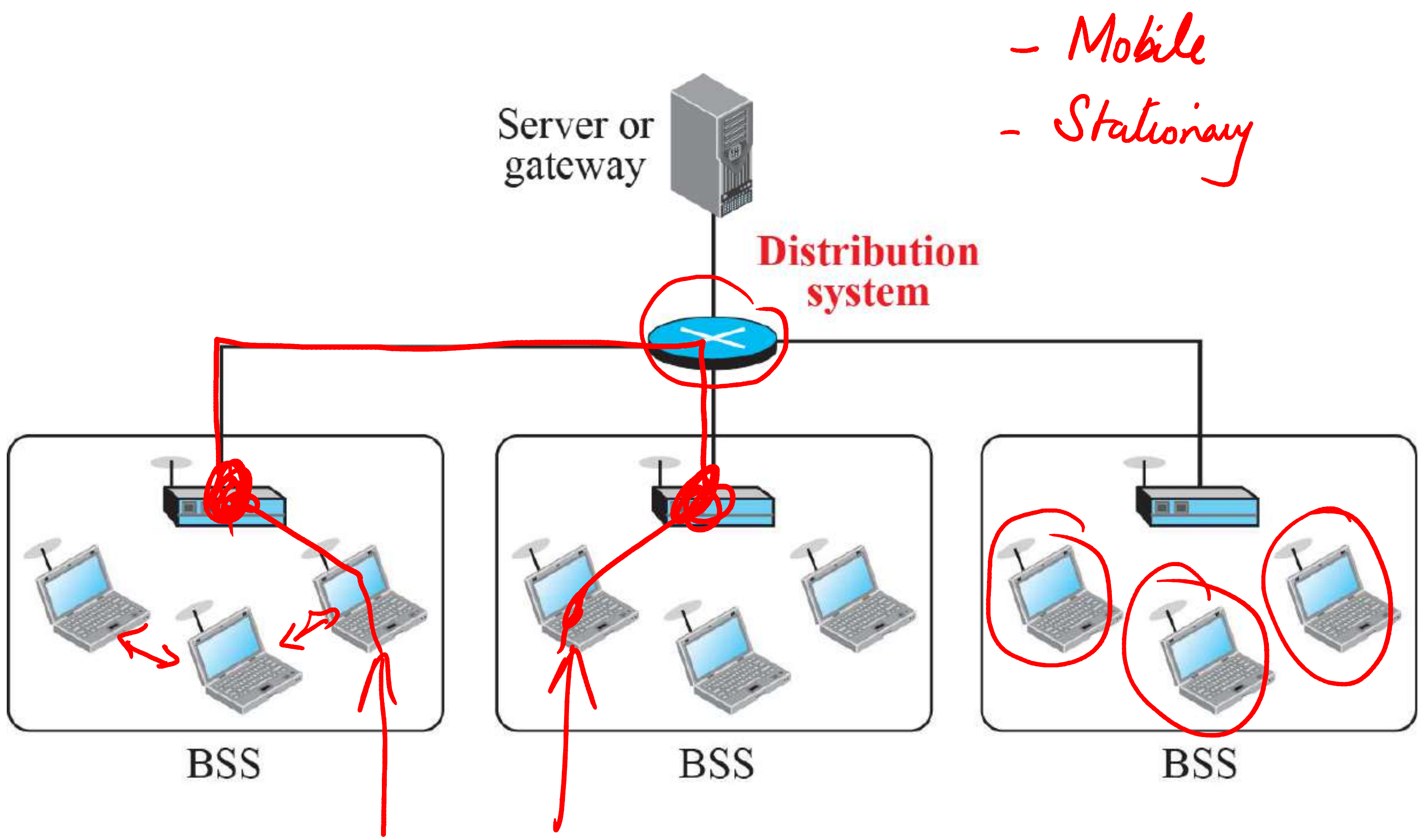
Infrastructure BSS

Without AP → ad hoc network

With AP → Infrastructure BSS



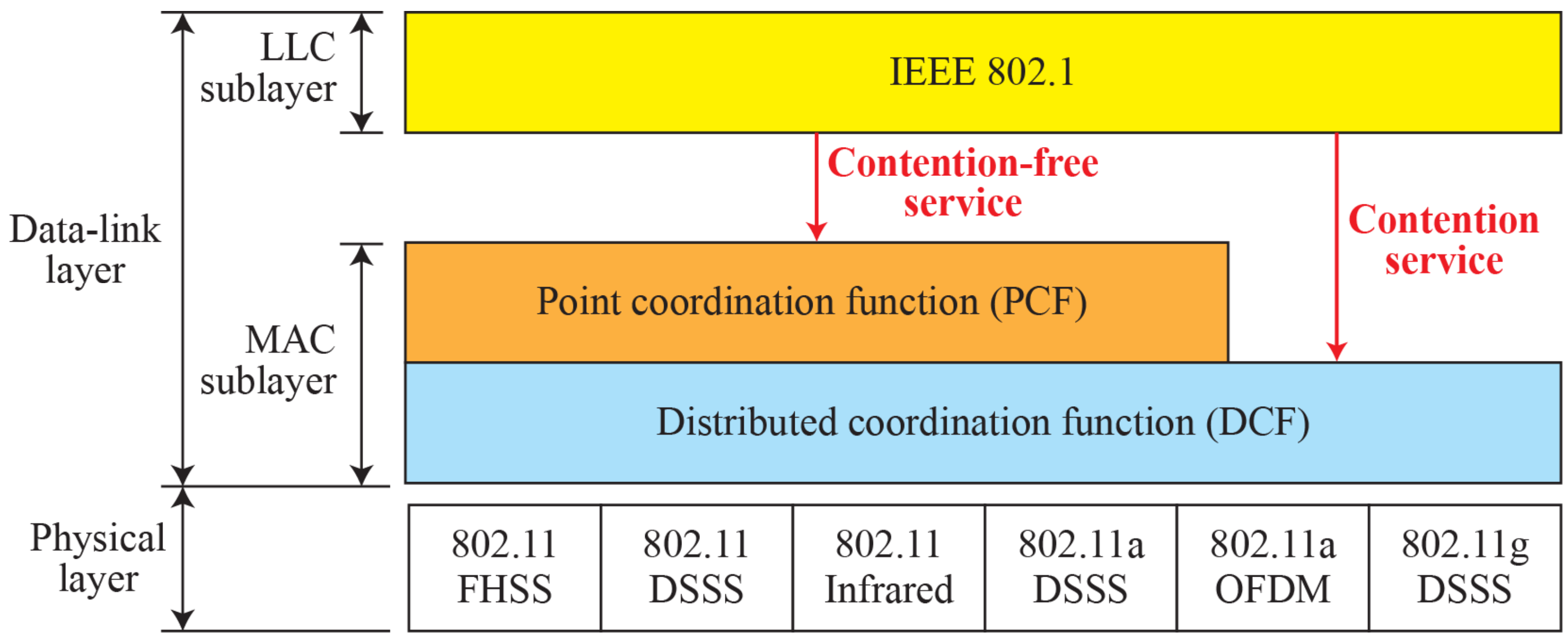
Ad hoc BSS

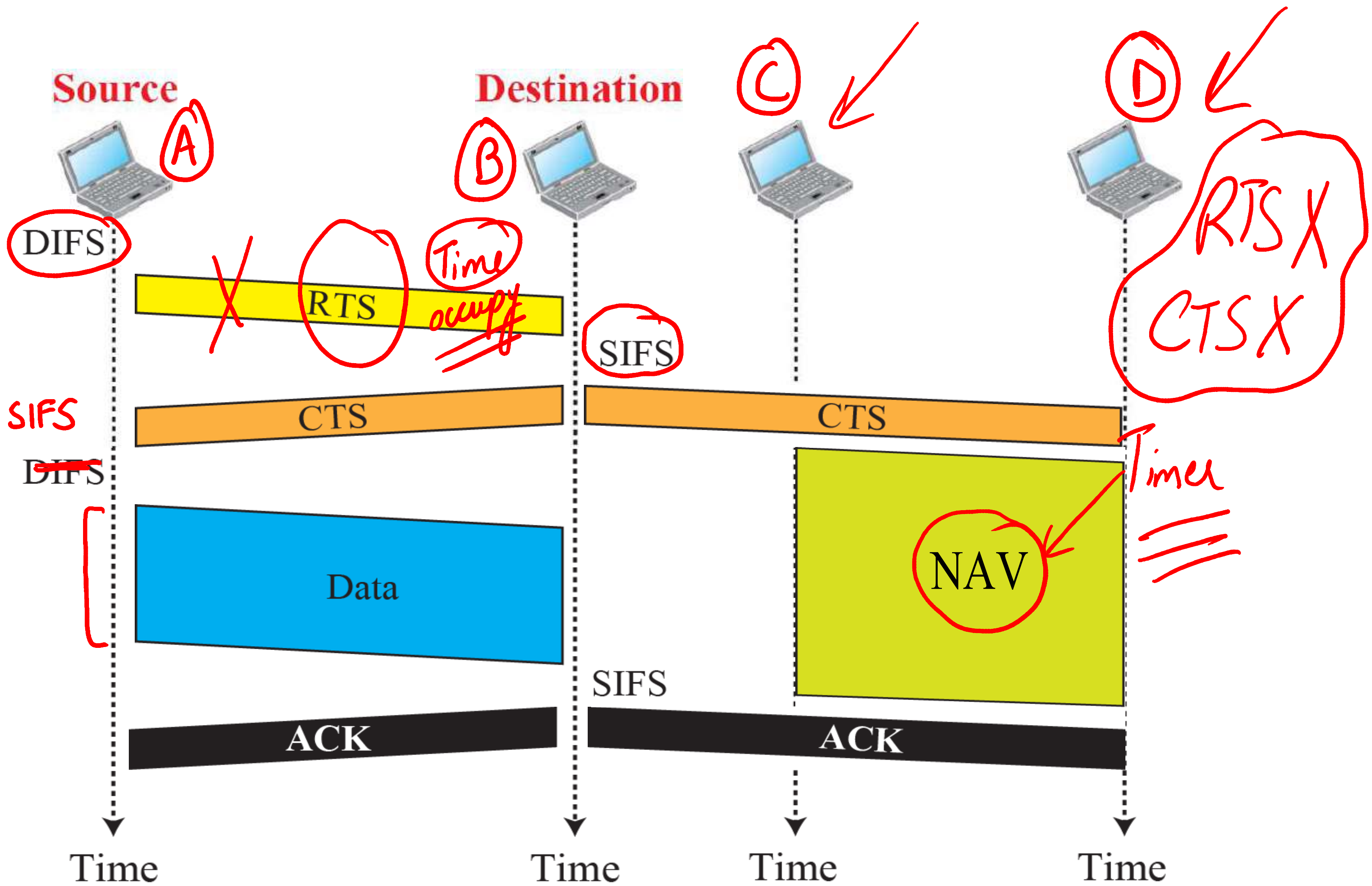


Server or gateway
Distribution system
BSS
BSS
BSS
- Mobile
- Stationary

- **No-Transition Mobility**
- **BSS-Transition Mobility**
- **ESS-Transition Mobility**

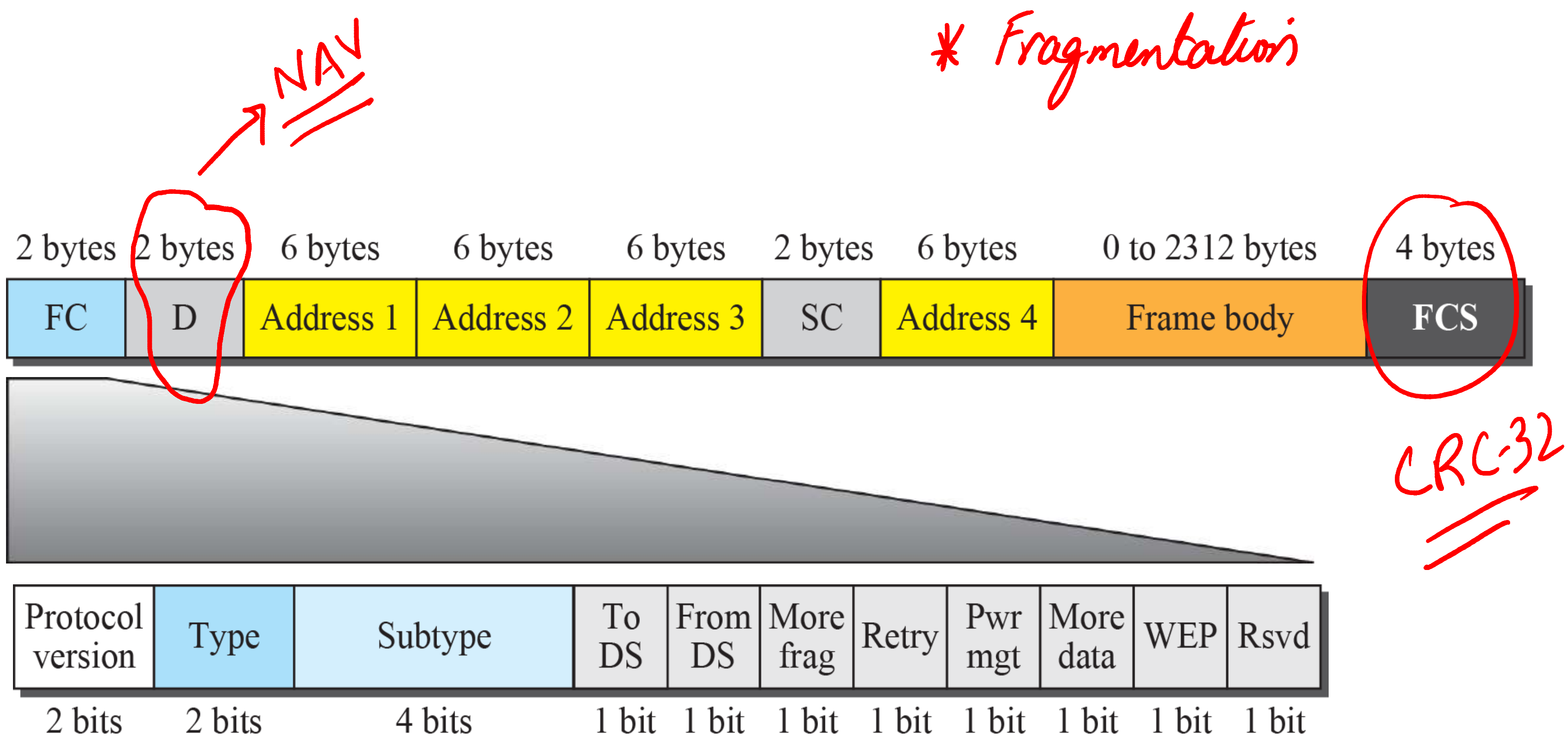
- IEEE 802.11 defines two MAC sub-layers:
  - ✓ The Distributed Coordination Function (DCF) ; and
  - ✓ The Point Coordination Function (PCF)


LLC
sublayer
Data-link
layer
MAC
sublayer
Physical
layer
IEEE 802.1
Contention-free
service
Contention
service
Point coordination function (PCF)
Distributed coordination function (DCF)
802.11
FHSS
802.11
DSSS
802.11
Infrared
802.11a
DSSS
802.11a
OFDM
802.11g
DSSS



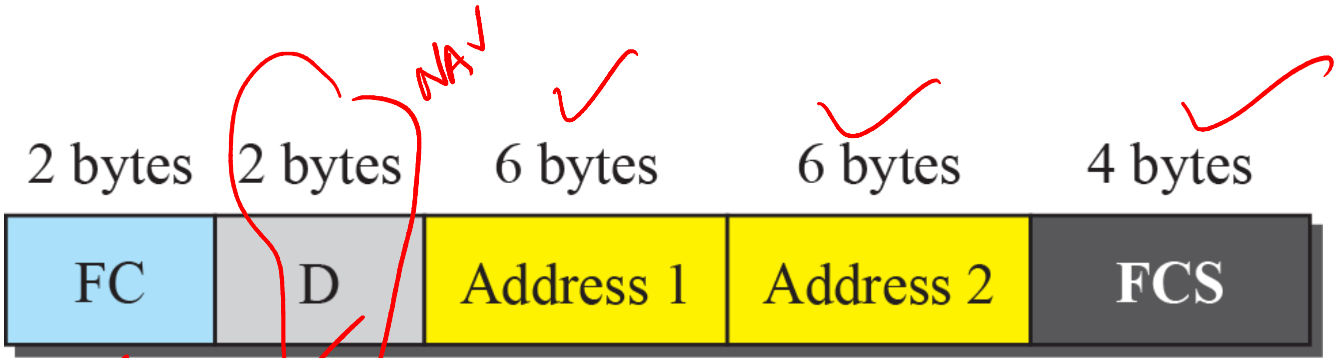
Source
Destination
A
B
C
D
DIFS
RTS
Time
occupy
SIFS
CTS
SIFS
~~DIFS~~
Data
NAV
Timer
RTS X
CTS X
SIFS
ACK
ACK
Time
Time
Time
Time

- IEEE 802.11 defines two MAC sub-layers:
  - ✓ The Distributed Coordination Function (DCF) ; and
  - ✓ The Point Coordination Function (PCF)

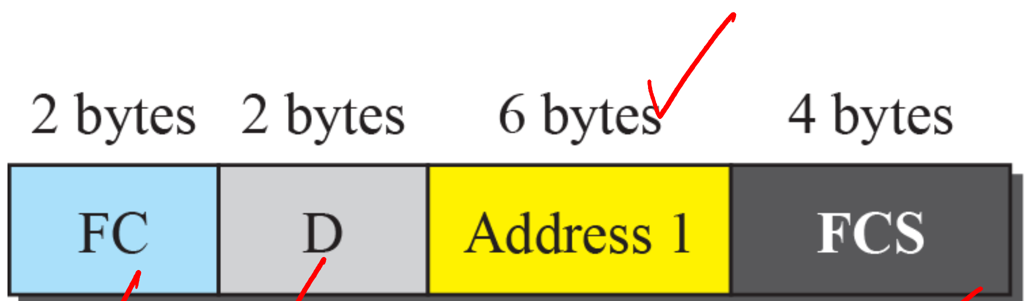

NAV
* Fragmentation
2 bytes
2 bytes
6 bytes
6 bytes
6 bytes
2 bytes
6 bytes
0 to 2312 bytes
4 bytes
FC
D
Address 1
Address 2
Address 3
SC
Address 4
Frame body
FCS
CRC-32
Protocol version
Type
Subtype
To DS
From DS
More frag
Retry
Pwr mgt
More data
WEP
Rsvd
2 bits
2 bits
4 bits
1 bit
1 bit
1 bit
1 bit
1 bit
1 bit
1 bit
1 bit

Field	*Explanation*
Version	Current version is 0
Type	Type of information: management (00), control (01), or data (10)
Subtype	Subtype of each type (see Table 6.2)
To DS	Defined later
From DS	Defined later
More flag	When set to 1, means more fragments
Retry	When set to 1, means retransmitted frame
Pwr mgt	When set to 1, means station is in power management mode
More data	When set to 1, means station has more data to send
WEP	Wired equivalent privacy (encryption implemented)
Rsvd	Reserved

- **Management Frames**
- **Control Frames**
- **Data Frames**



RTS



CTS or ACK

Subtype	*Meaning*
1011	Request to send (RTS)
1100	Clear to send (CTS)
1101	Acknowledgment (ACK)

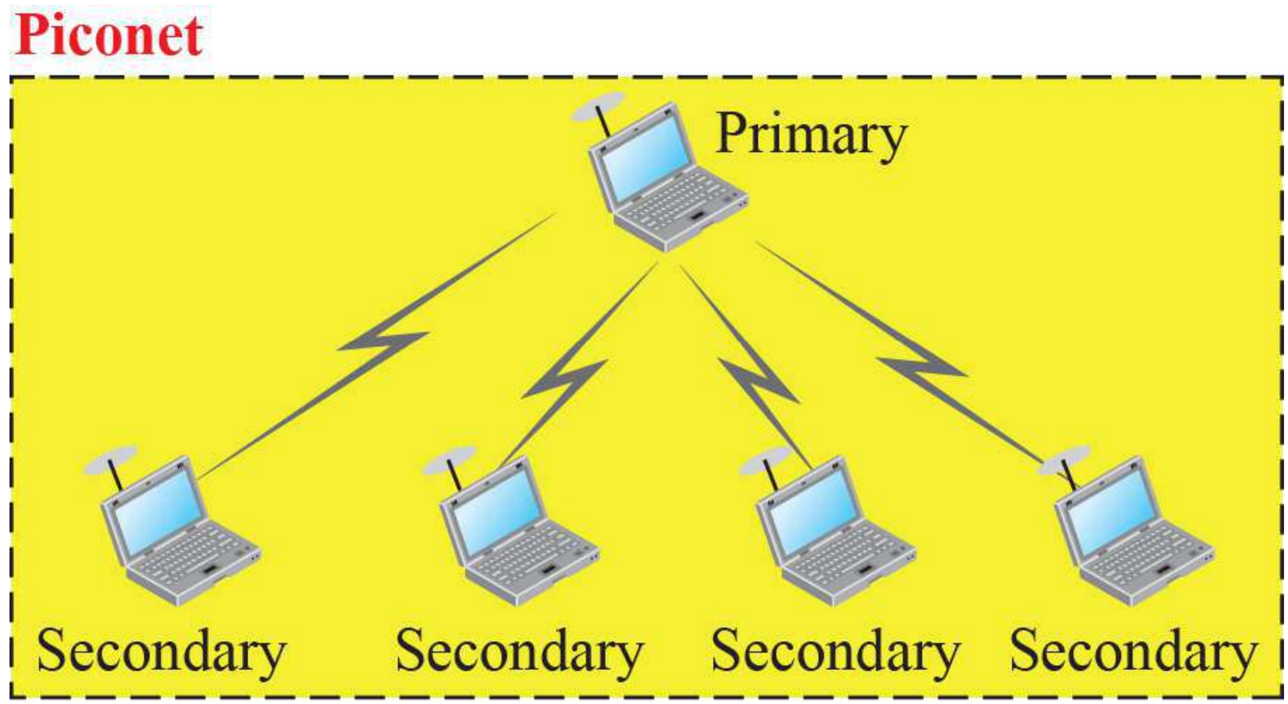
- All physical implementations, except the infrared, operate in the industrial, scientific, and medical (ISM) band, which defines 3 unlicensed bands in 3 ranges:

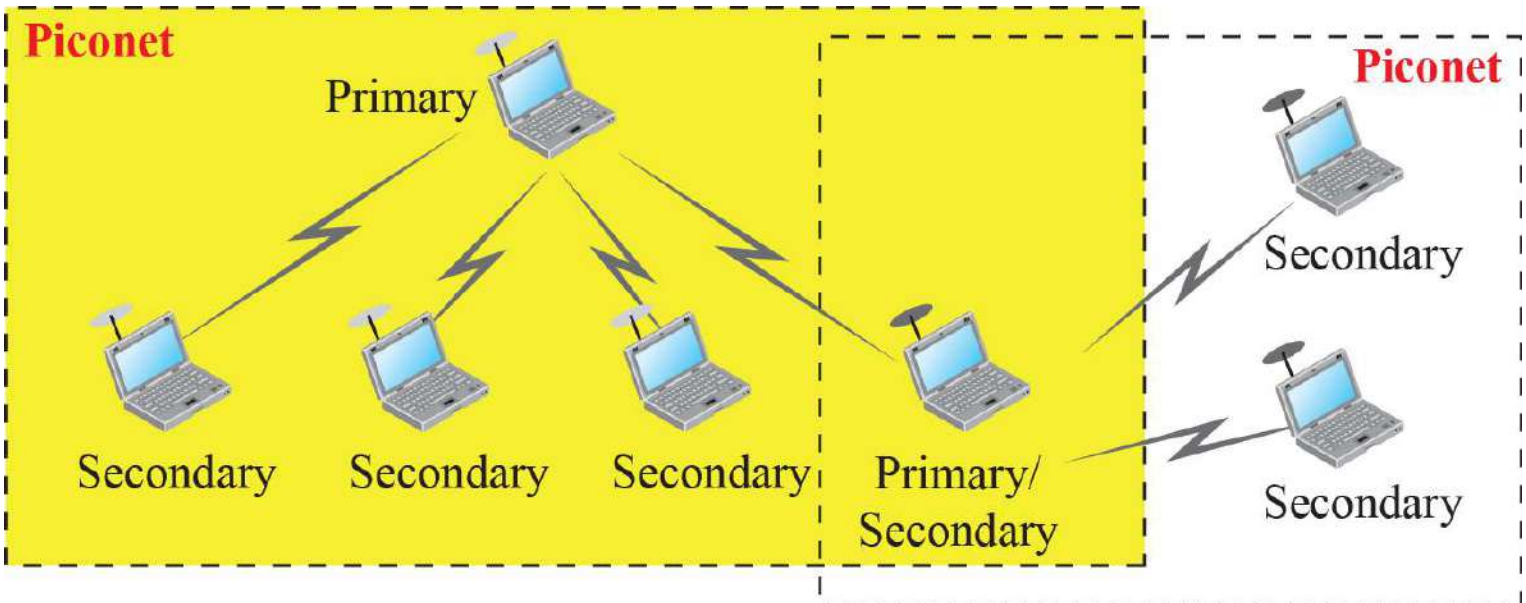
  - ✓ 902–928 MHz
  - ✓ 2.400–4.835 GHz
  - ✓ 5.725–5.850 GHz

IEEE	Technique	Band	Modulation	Rate (Mbps)
802.11	FHSS	2.400–4.835 GHz	FSK	1 and 2
	DSSS	2.400–4.835 GHz	PSK	1 and 2
	None	Infrared	PPM	1 and 2
802.11a	OFDM	5.725–5.850 GHz	PSK or QAM	6 to 54
802.11b	DSSS	2.400–4.835 GHz	PSK	5.5 and 11
802.11g	OFDM	2.400–4.835 GHz	Different	22 and 54
802.11n	OFDM	5.725–5.850 GHz	Different	600

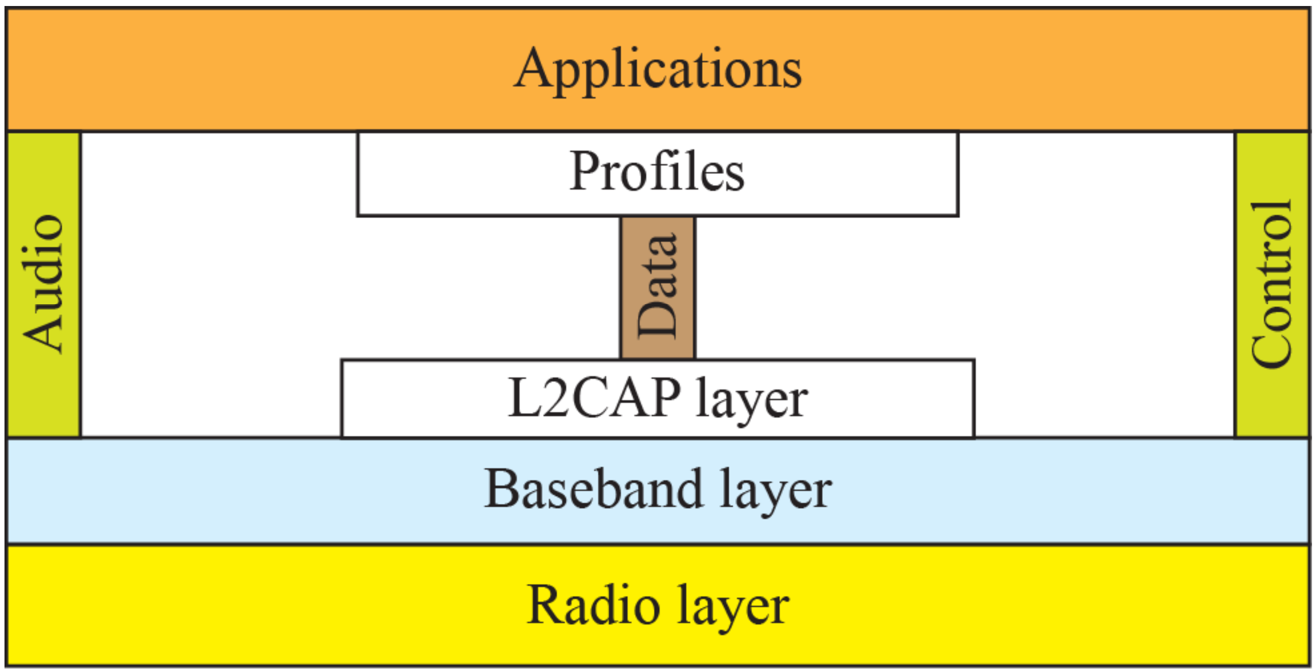
- **Bluetooth is a wireless LAN technology designed to connect devices of different functions when they are at a short distance from each other**
- **A Bluetooth LAN is an ad hoc network**
- **The devices, sometimes called gadgets, find each other and make a network called a Piconet**

- **Bluetooth defines two types of networks:**
  - ✓ **Piconet**
  - ✓ **Scatternet**

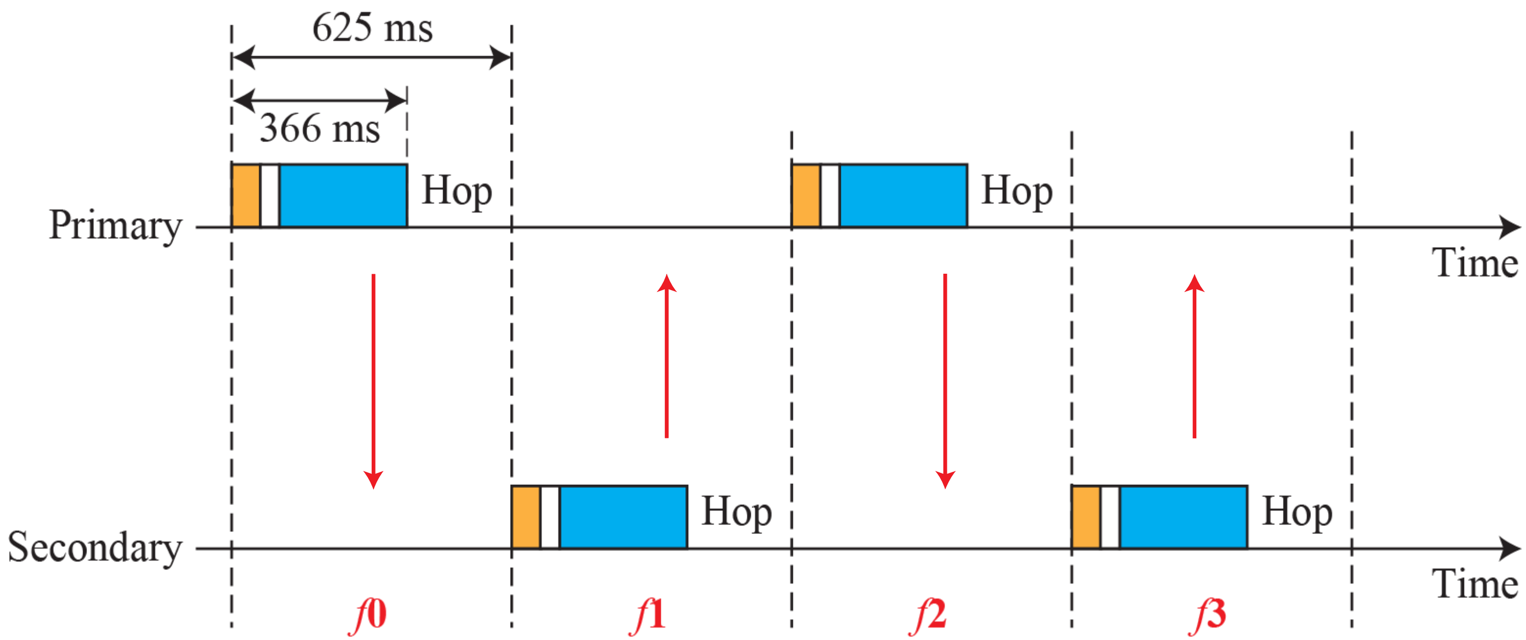

Piconet
Primary
Secondary
Secondary
Secondary
Secondary


Piconet
Primary
Piconet
Secondary
Secondary
Secondary
Secondary
Primary/
Secondary
Secondary

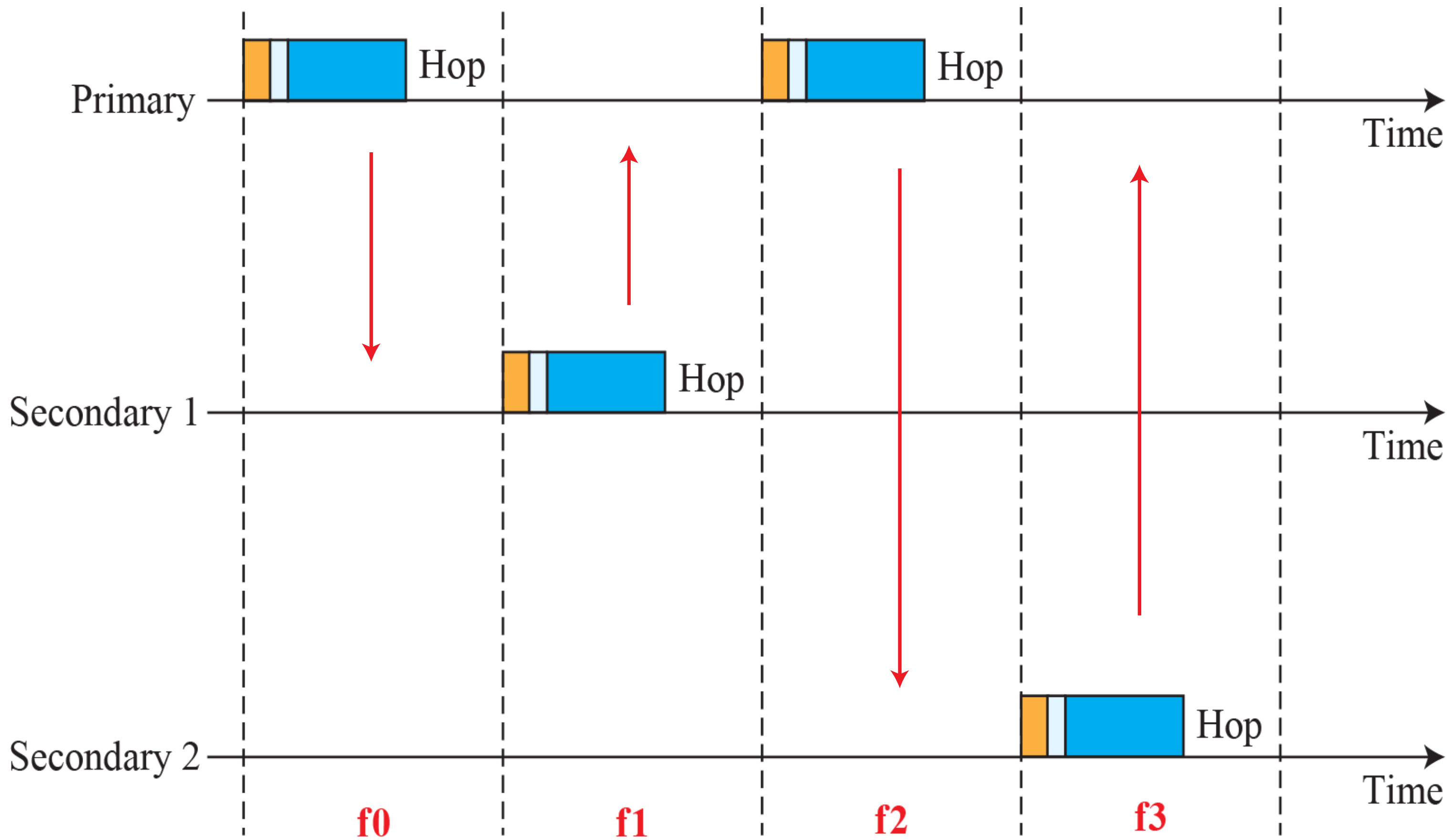
- **Bluetooth uses several layers that do not exactly match those of the Internet model we have defined in this book**

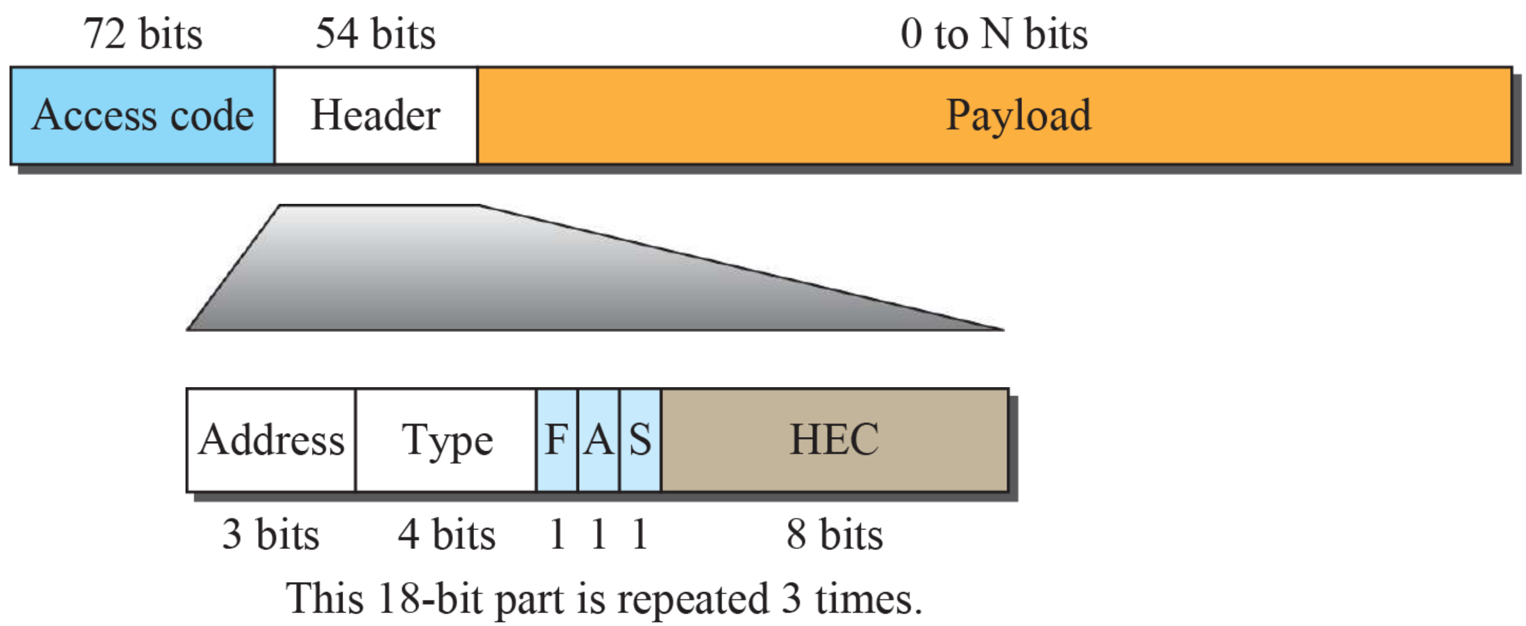

Applications
Profiles
Audio
Data
Control
L2CAP layer
Baseband layer
Radio layer


2 bytes
2 bytes
0 to 65,535 bytes
Length
Channel ID
Data and control



625 ms
366 ms
Hop
Hop
Primary
Time
Hop
Hop
Secondary
Time
f0
f1
f2
f3


Primary
Hop
Hop
Time
Secondary 1
Hop
Time
Secondary 2
Hop
Time
f0
f1
f2
f3



N = 240 for 1-slot frame

N = 1490 for 3-slot frame

N = 2740 for 5-slot frame

Bluetooth

- Bluetooth is a wireless LAN technology designed to connect devices of different functions when they are at a short distance from each other

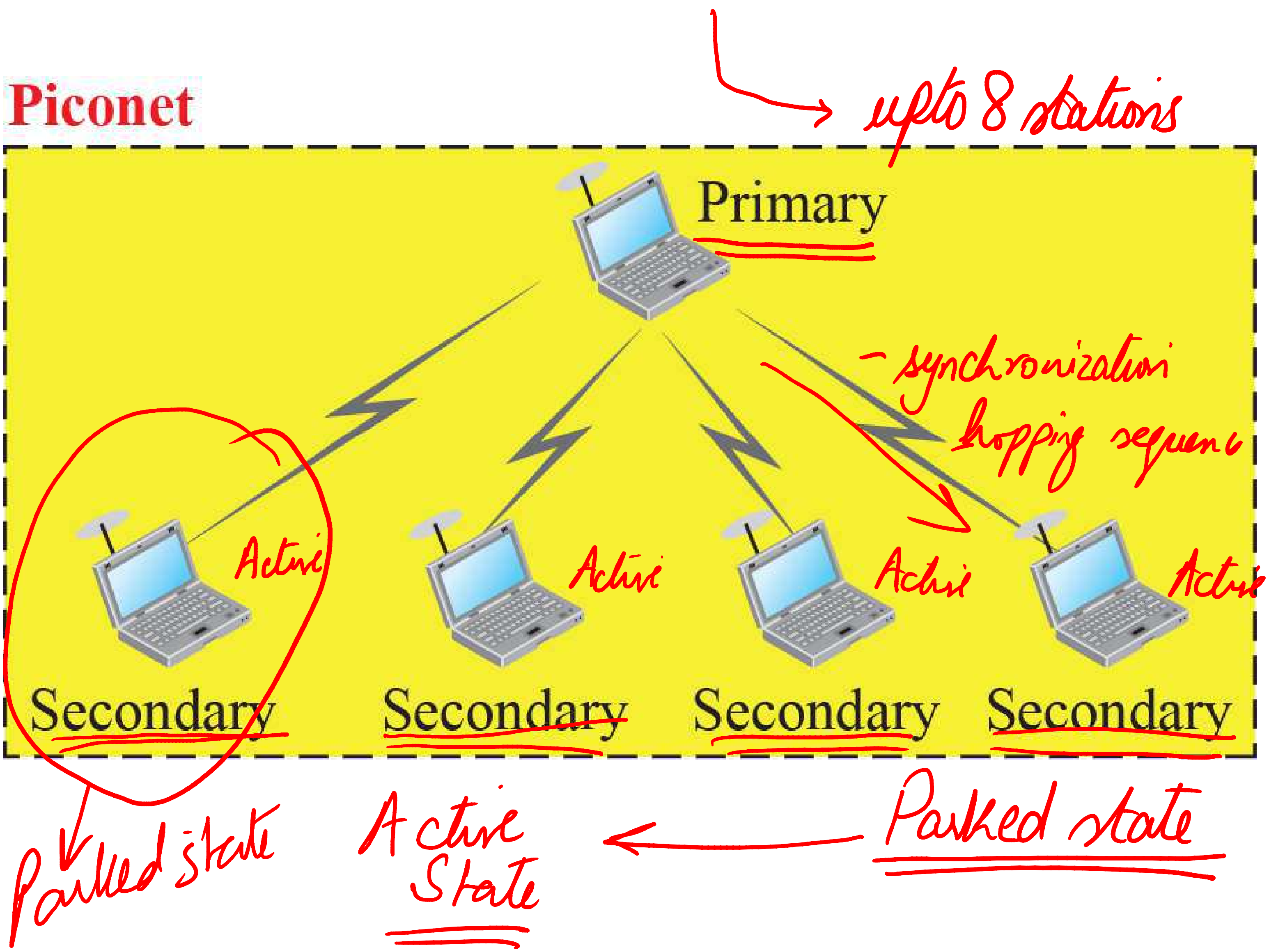
- A Bluetooth LAN is an ad hoc network

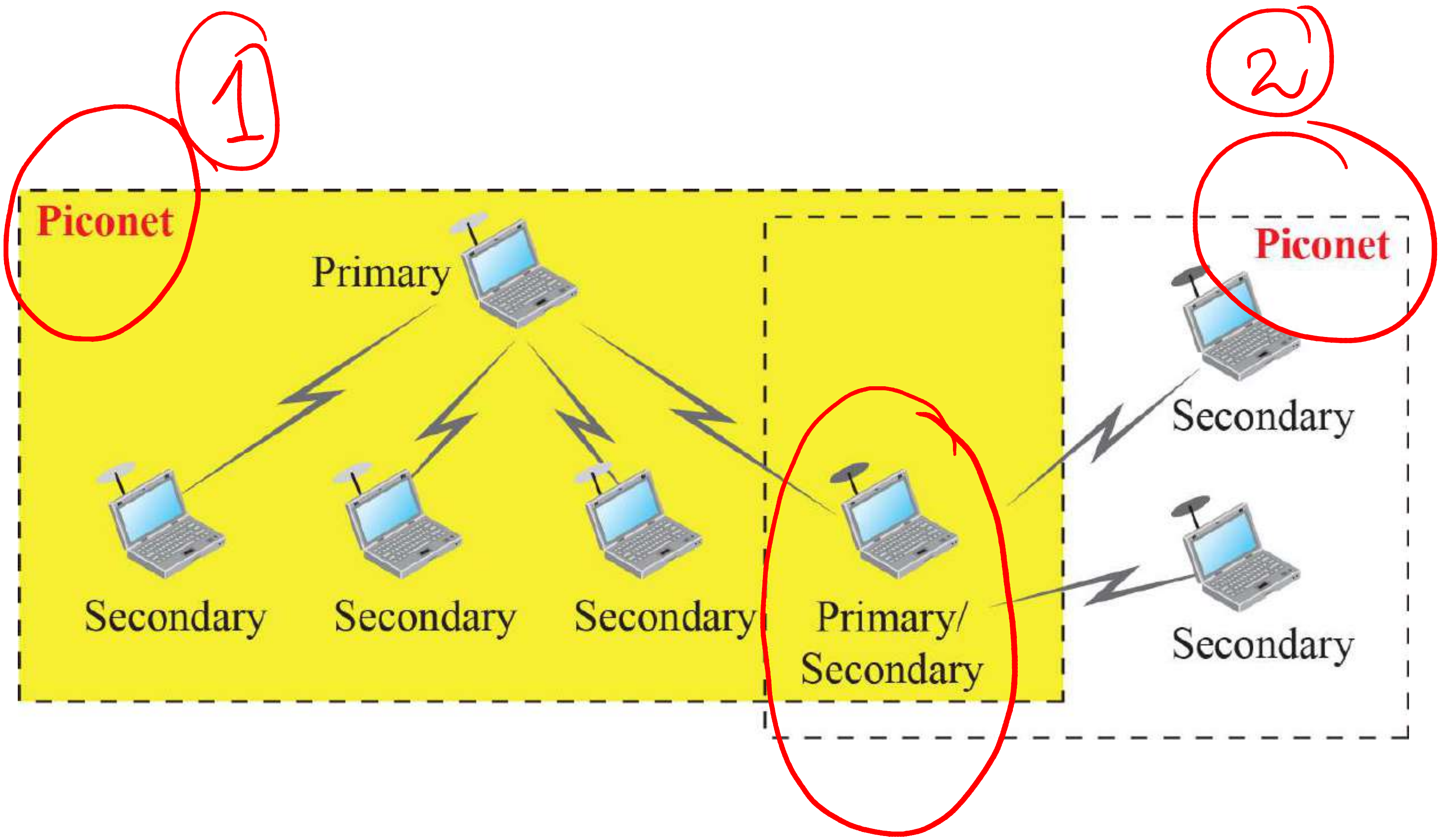
- The devices, sometimes called gadgets, find each other and make a network called a Piconet

- **Bluetooth technology is the implementation of a protocol defined by the IEEE 802.15 standard**

- **The standard defines a wireless Personal-Area Network (PAN) operable in an area the size of a room or a hall**

- **Bluetooth defines two types of networks:**
  - ✓ **Piconet**
  - ✓ **Scatternet**

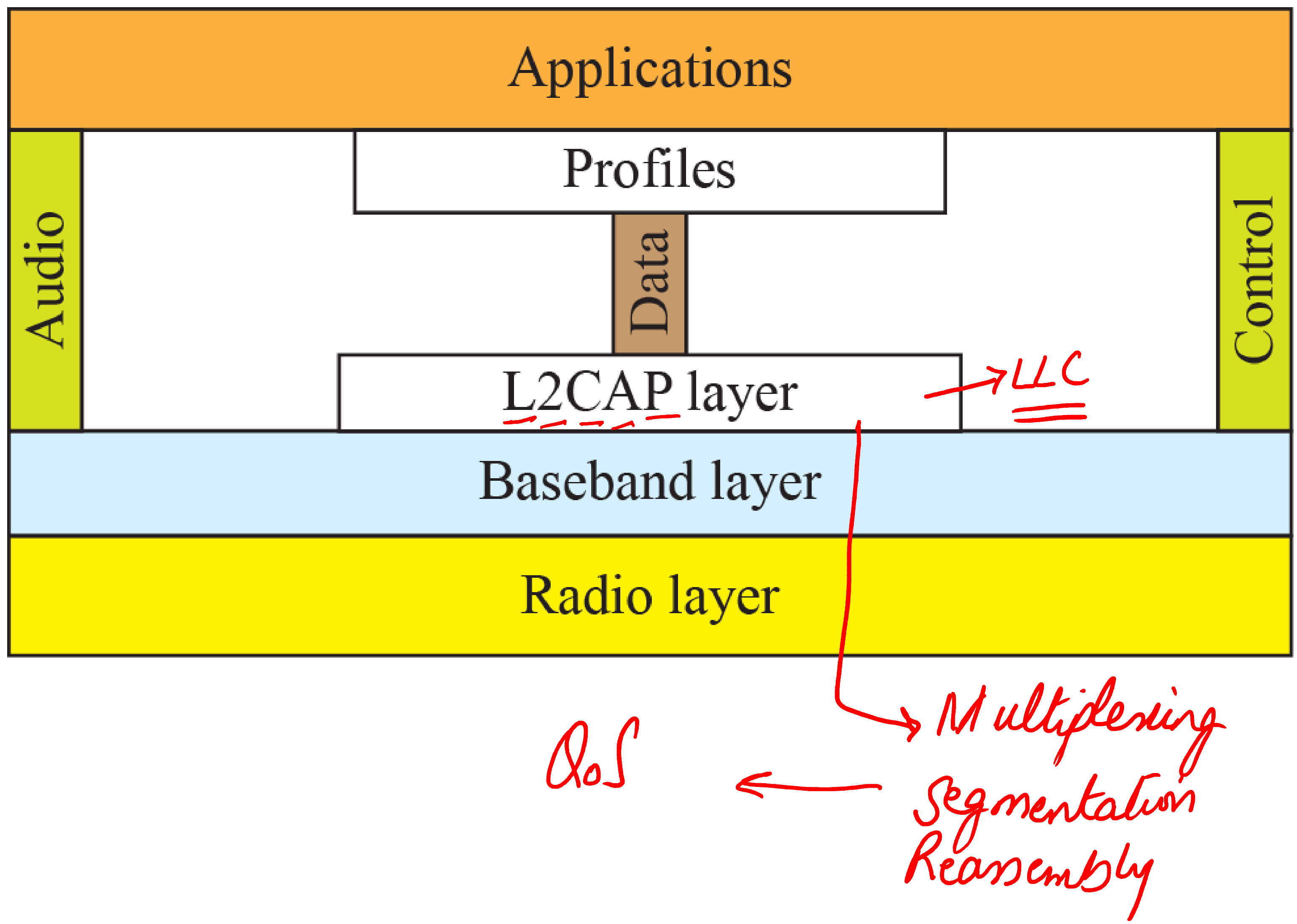

Piconet
Primary
Secondary
Secondary
Secondary
Secondary
upto 8 stations
- synchronization
hopping sequence
Active
Active
Active
Active
Parked state
Active State
Parked state

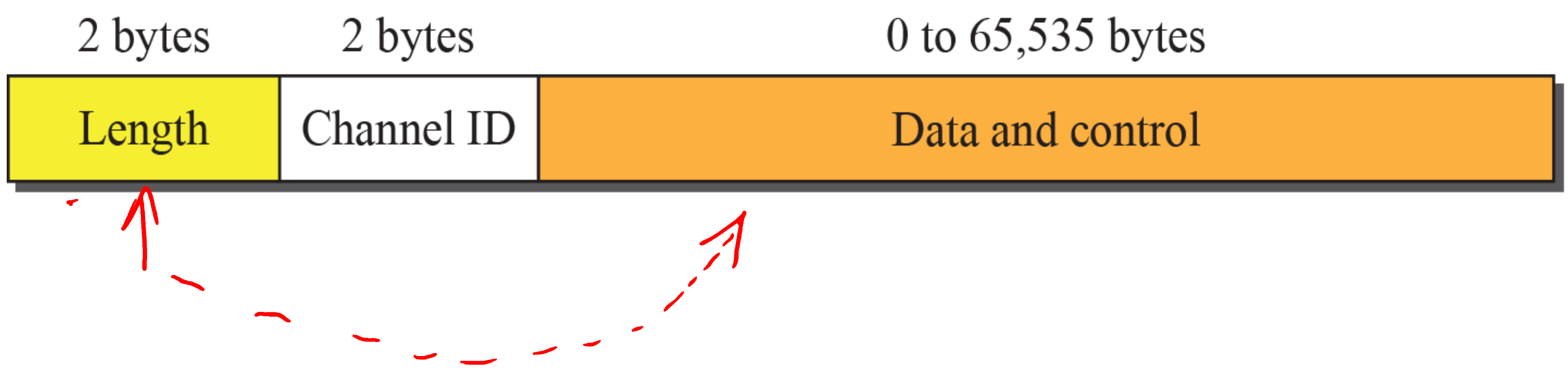


1
2
Piconet
Primary
Secondary
Secondary
Secondary
Primary/
Secondary
Piconet
Secondary
Secondary

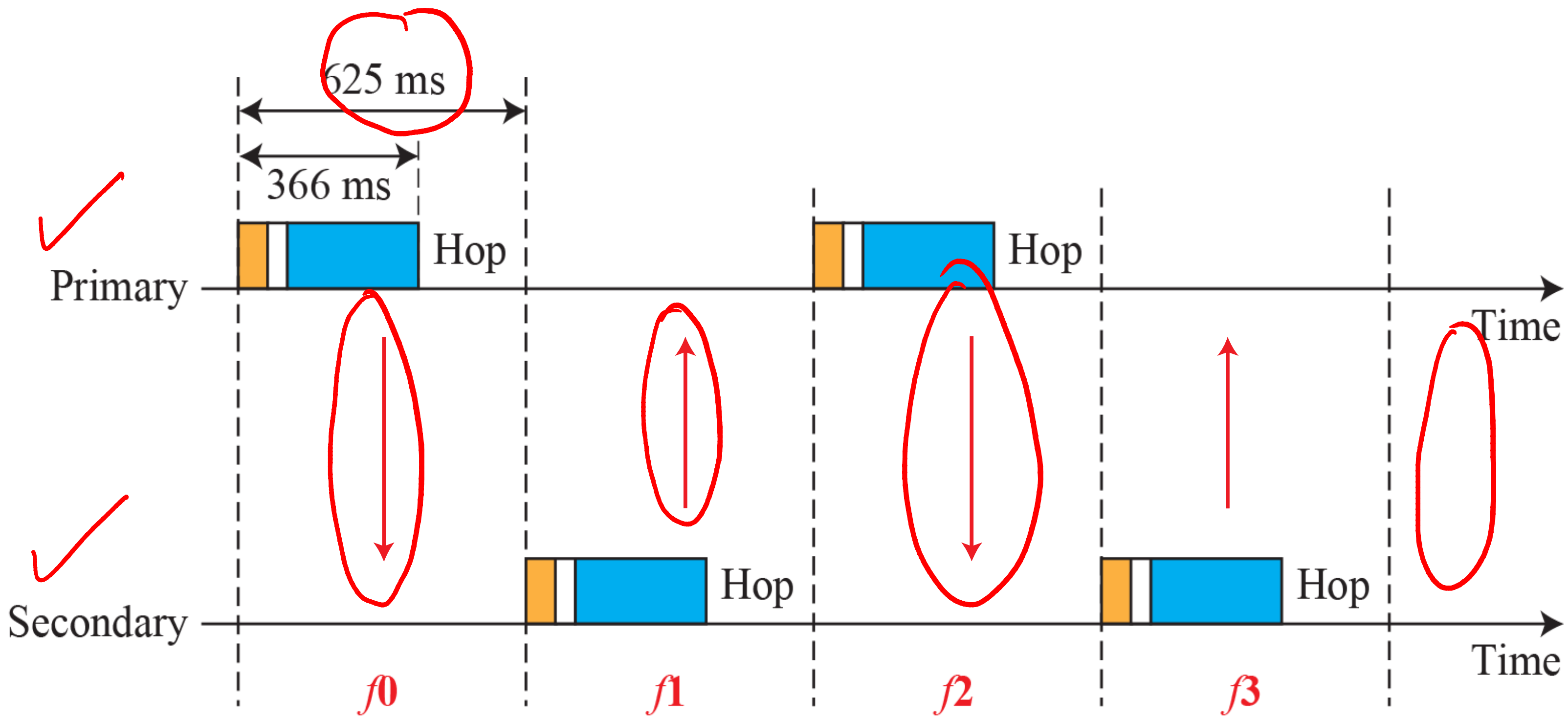
- **A Bluetooth device has a built-in short-range radio transmitter**
- **The current data rate is 1 Mbps with a 2.4-GHz bandwidth**
- **This means that there is a possibility of interference between the IEEE 802.11b wireless LANs and Bluetooth LANs**

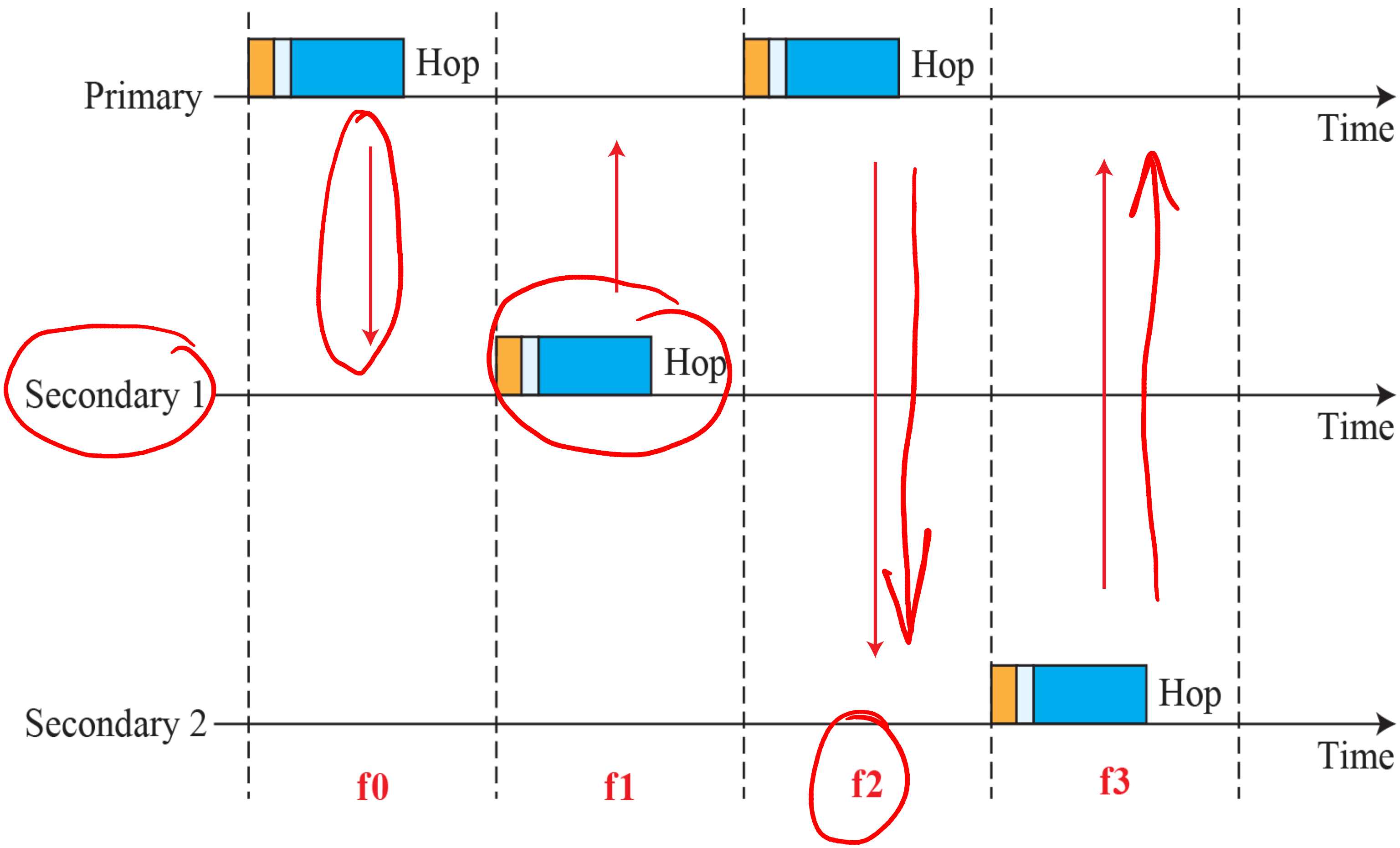
- **Bluetooth uses several layers that do not exactly match those of the Internet model we have defined already**


Applications
Profiles
Audio
Data
Control
L2CAP layer
LLC
Baseband layer
Radio layer
QoS
Multiplexing
Segmentation
Reassembly


2 bytes
2 bytes
0 to 65,535 bytes
Length
Channel ID
Data and control

TDD-TDMA





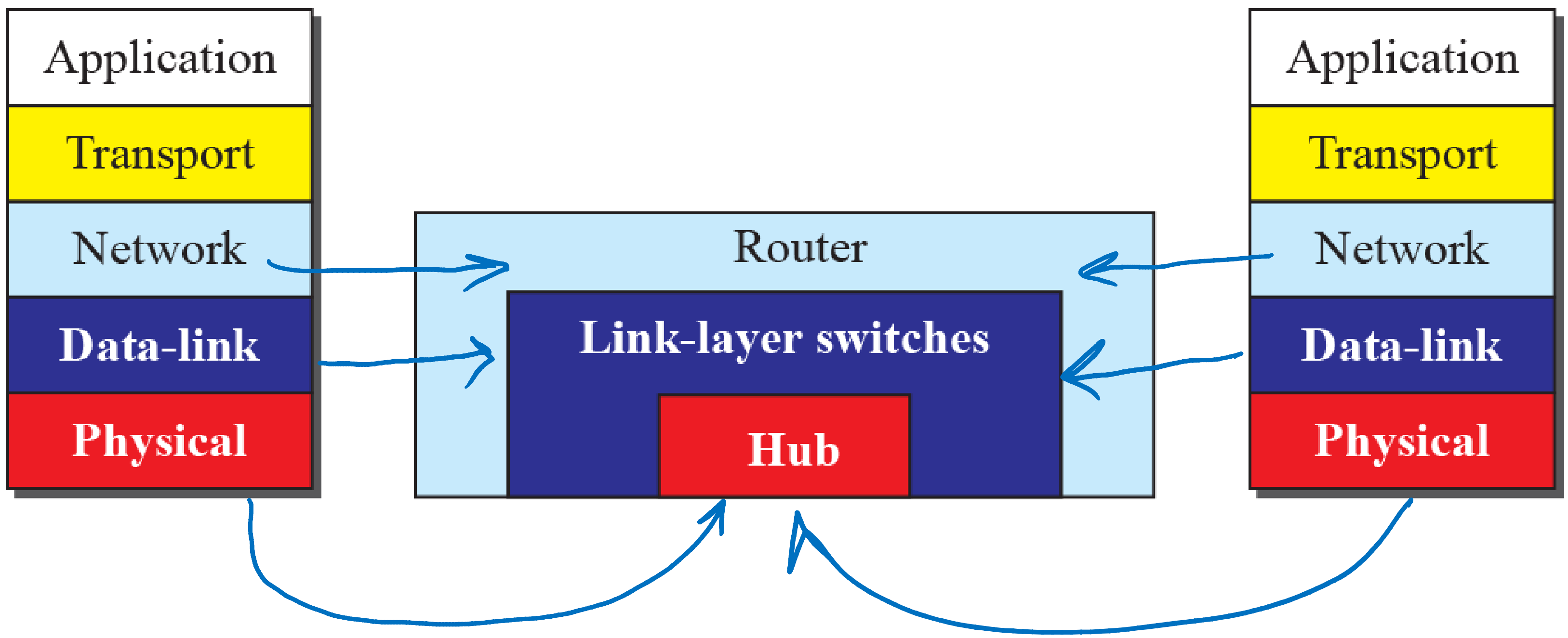
Primary
Hop
Hop
Time
Secondary 1
Hop
Time
Secondary 2
Hop
Time
f0
f1
f2
f3

Connecting Devices

- Hosts and networks do not normally operate in isolation
- Connecting devices connect hosts together to make a network or connect networks together to make an internet
- Connecting devices can operate in different layers of the Internet model

- **Three kinds of connecting devices:**

  - ✓ **Hubs**
  - ✓ **Link-layer switches**
  - ✓ **Routers**


Application
Transport
Network
Data-link
Physical
Router
Link-layer switches
Hub
Application
Transport
Network
Data-link
Physical

- Hub is a device that operates only in the physical layer

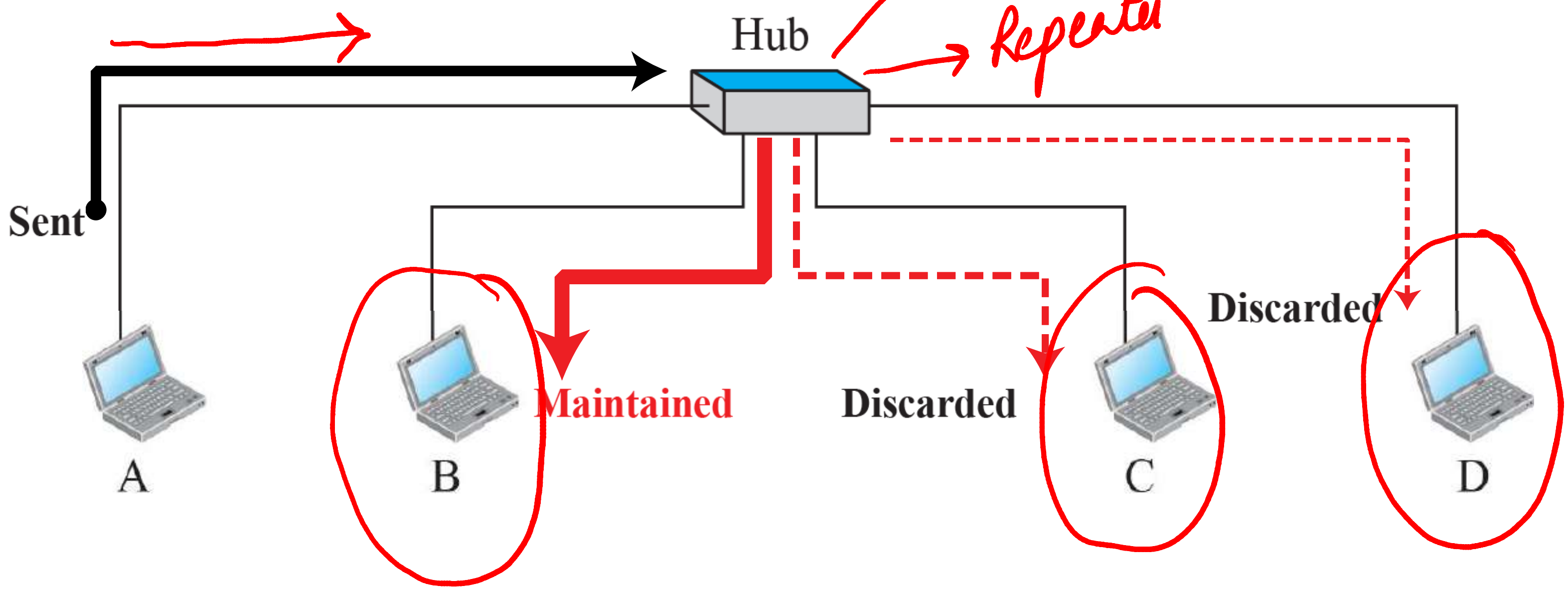
- Signals that carry information within a network can travel a fixed distance before attenuation impacts the data

- A hub (repeater) receives a signal and, before it becomes too weak or corrupted, regenerates it

- **Hub is a device that operates only in the physical layer**

Connecting Device

Repeater



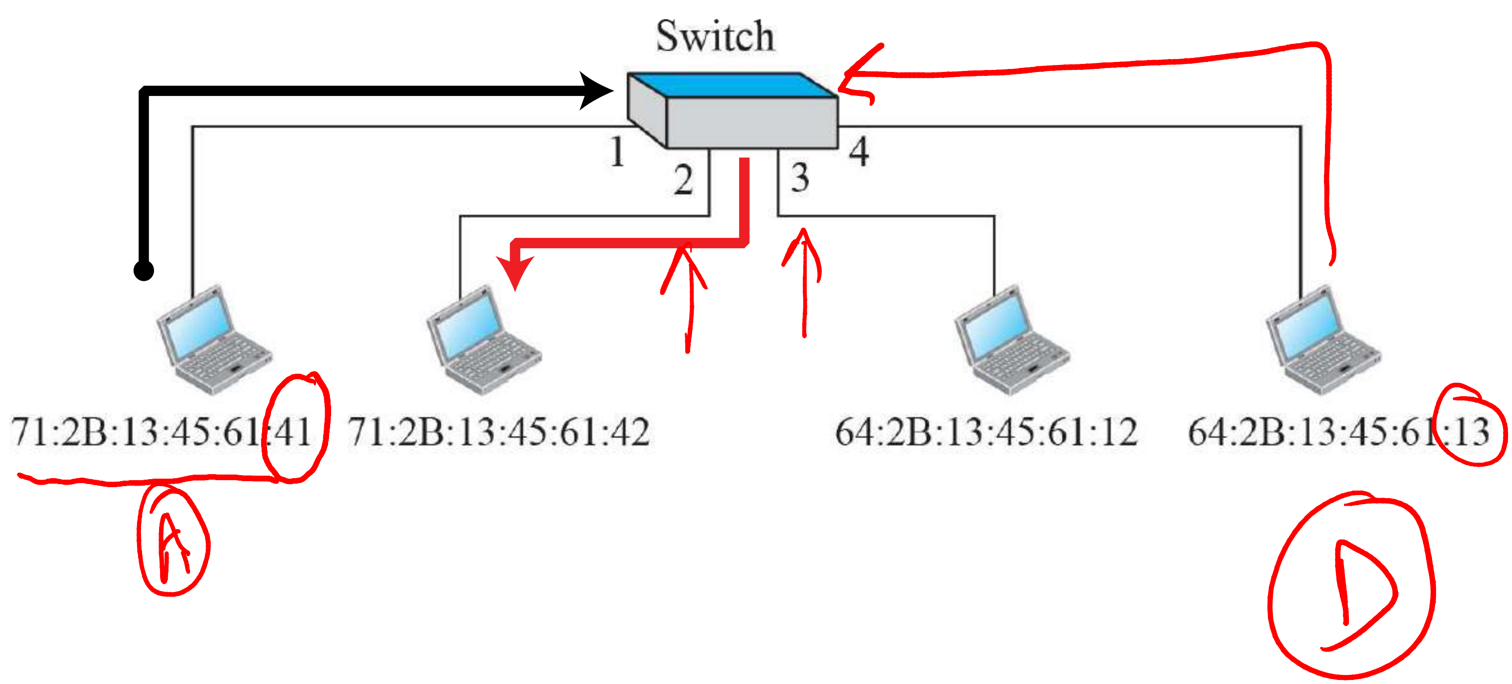
Filtering

- **A link-layer switch (or switch) operates in both the physical and the data-link layers**
- **As a physical-layer device, it regenerates the signal it receives**
- **As a link-layer device, the link-layer switch can check the MAC addresses (source and destination) contained in the frame**

- **Switch has the ‘Filtering’ capability**
- **Unlike hub, a switch can check the destination address of a frame and decide on outgoing port**
- **Switch eliminates collisions and does not require carrier sensing**
- **Switches connect heterogeneous devices**

Switching table

Address	Port
71:2B:13:45:61:41	1
71:2B:13:45:61:42	2
64:2B:13:45:61:12	3
64:2B:13:45:61:13	4



- **A link-layer switch (or switch) operates in both the physical and the data-link layers**

Address	Port

a. Original

Address	Port
71:2B:13:45:61:41	1

b. After A sends a frame to D

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4

c. After D sends a frame to B

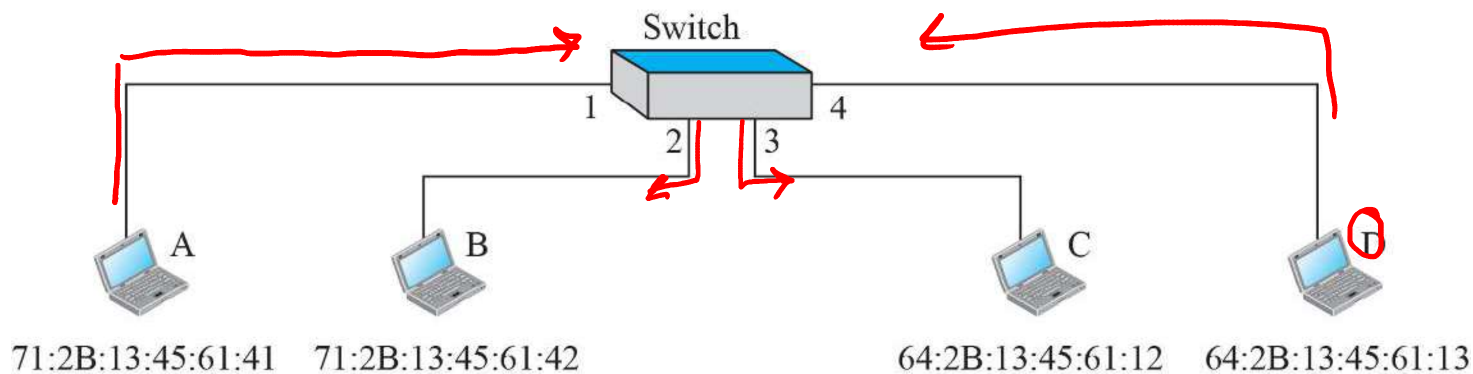
Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4
71:2B:13:45:61:42	2

d. After B sends a frame to A

Address	Port
71:2B:13:45:61:41	1
64:2B:13:45:61:13	4
71:2B:13:45:61:42	2
64:2B:13:45:61:12	3

e. After C sends a frame to D

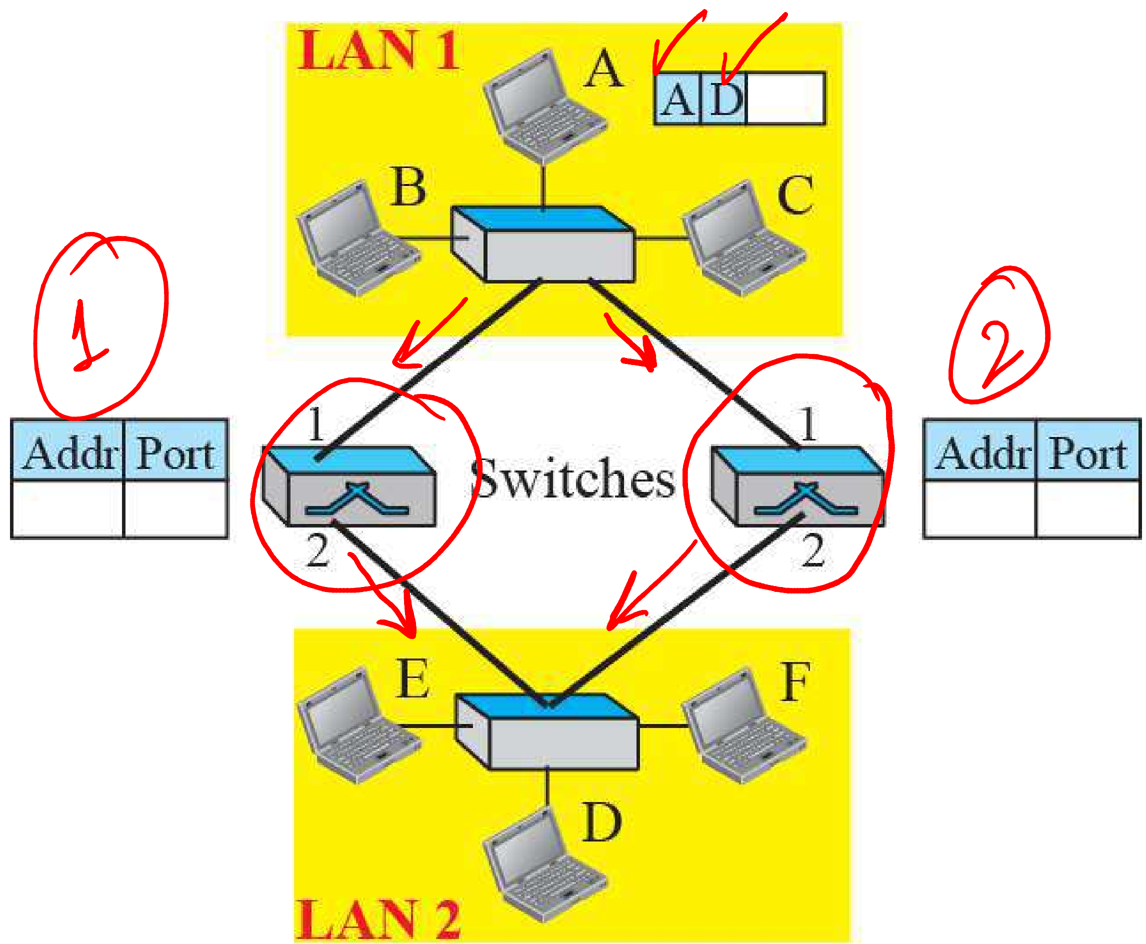
Gradual building of Table



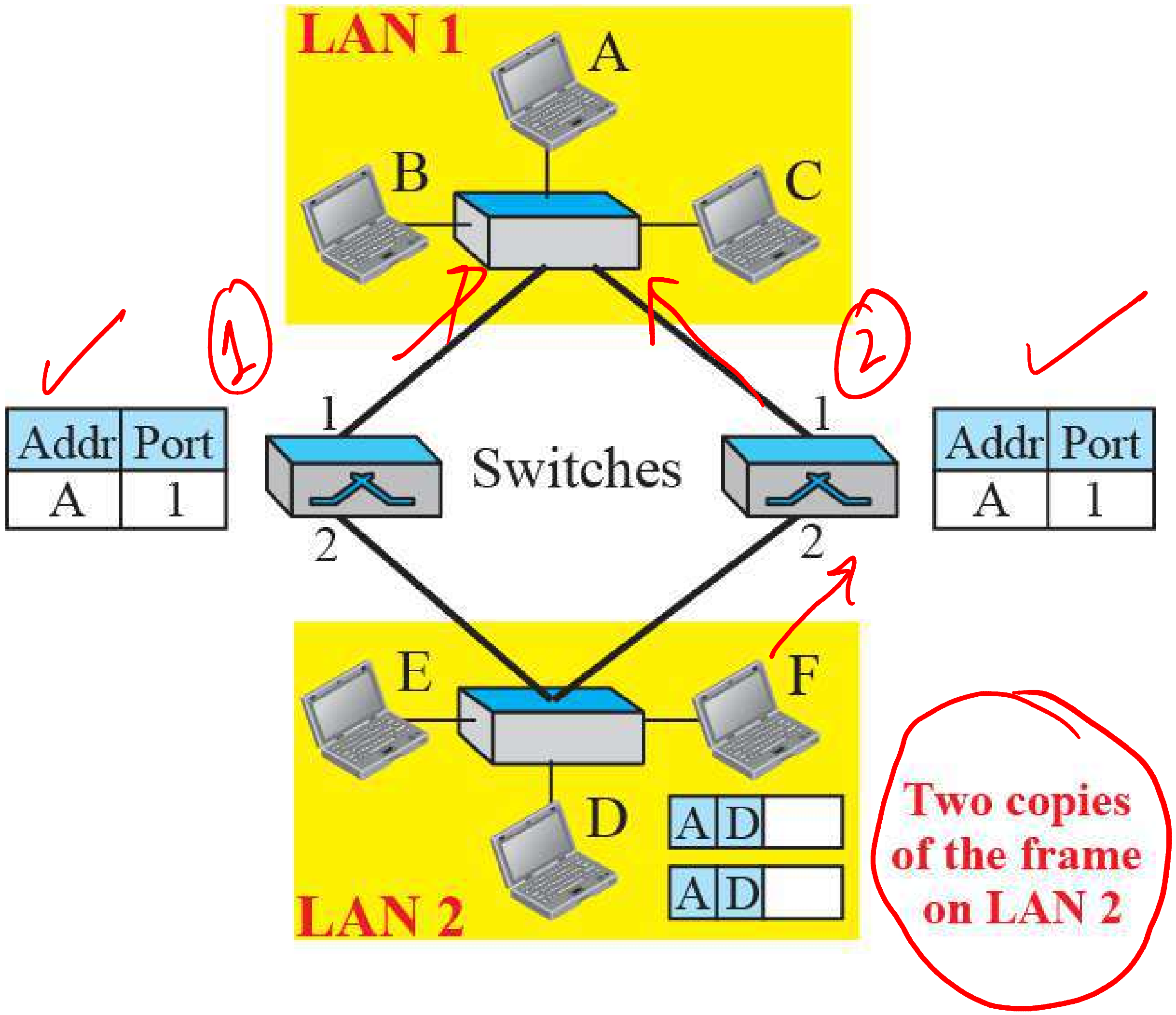
- **Redundant switches create Loops in the system**

- **Created when two or more broadcasting LANs are connected by more than one switch**

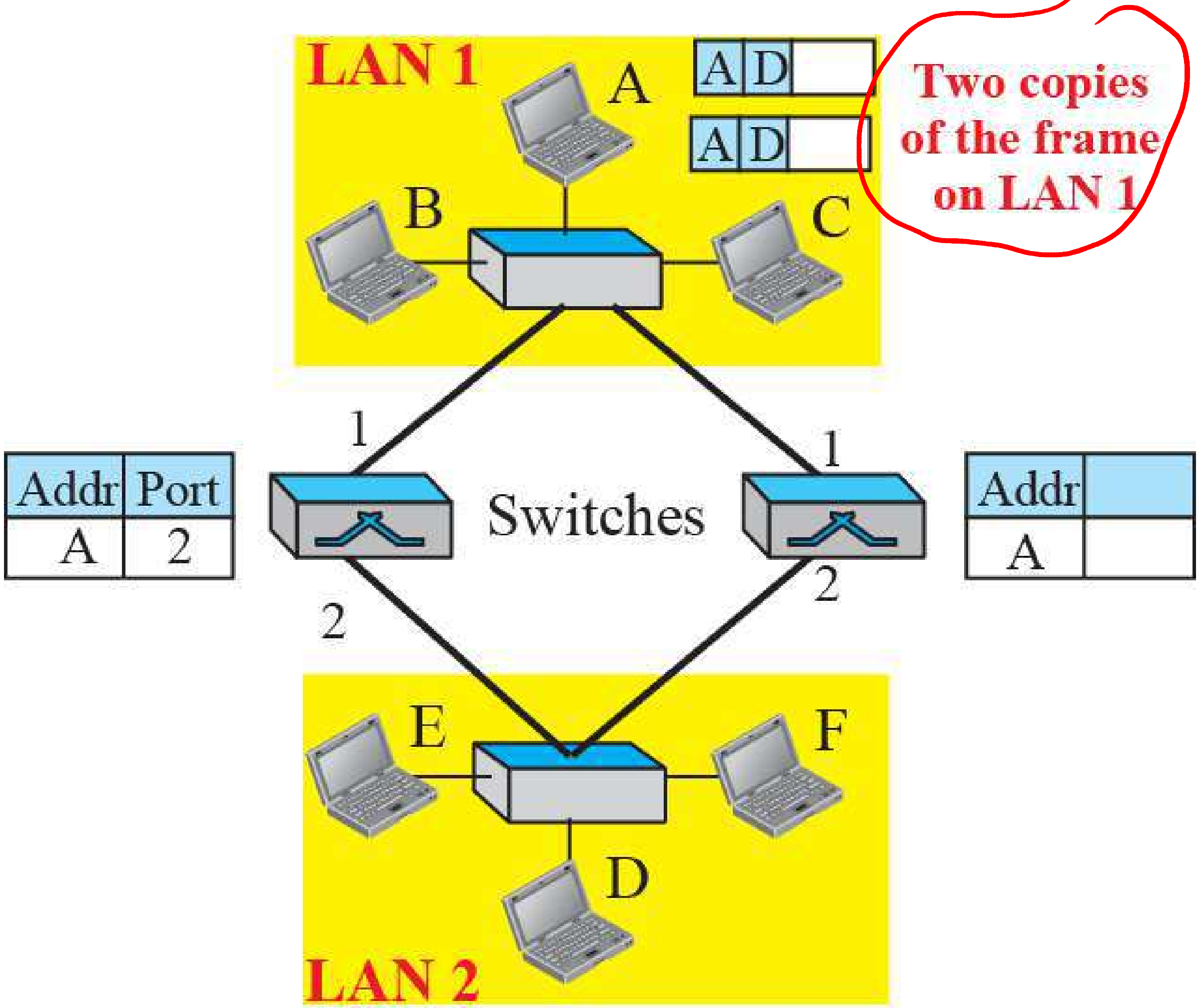
a. Station A sends a frame to station D



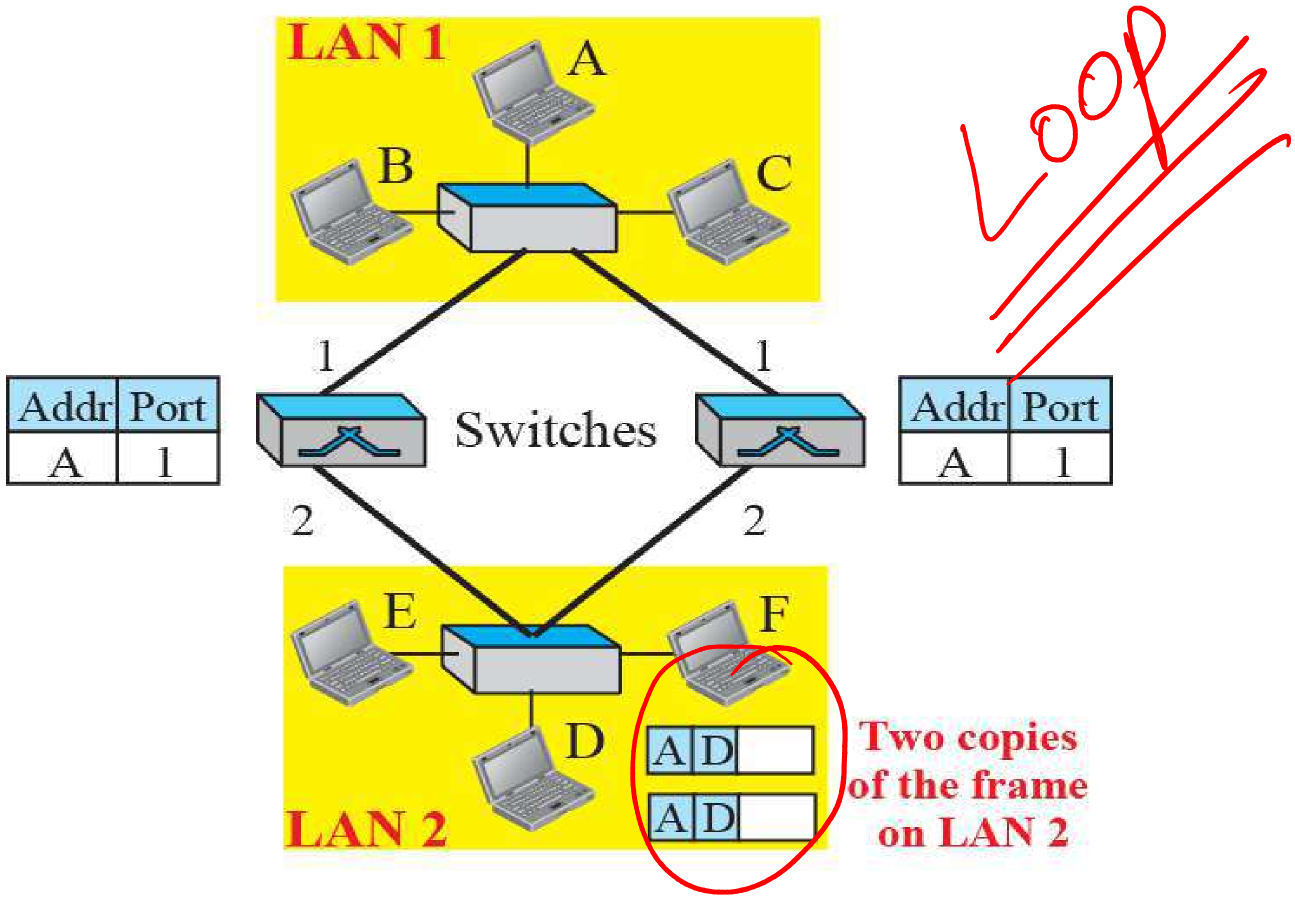
b. Both switches forward the frame



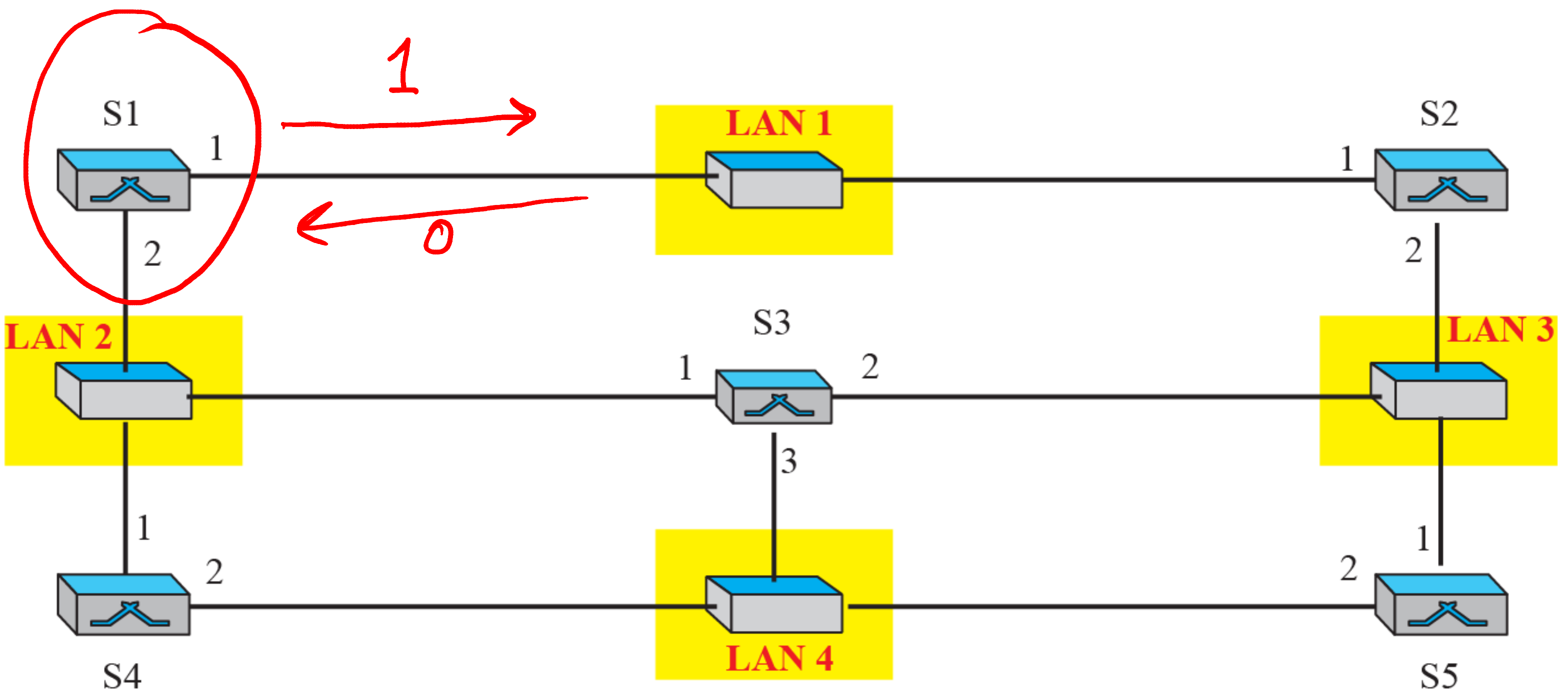
c. Both switches forward the frame



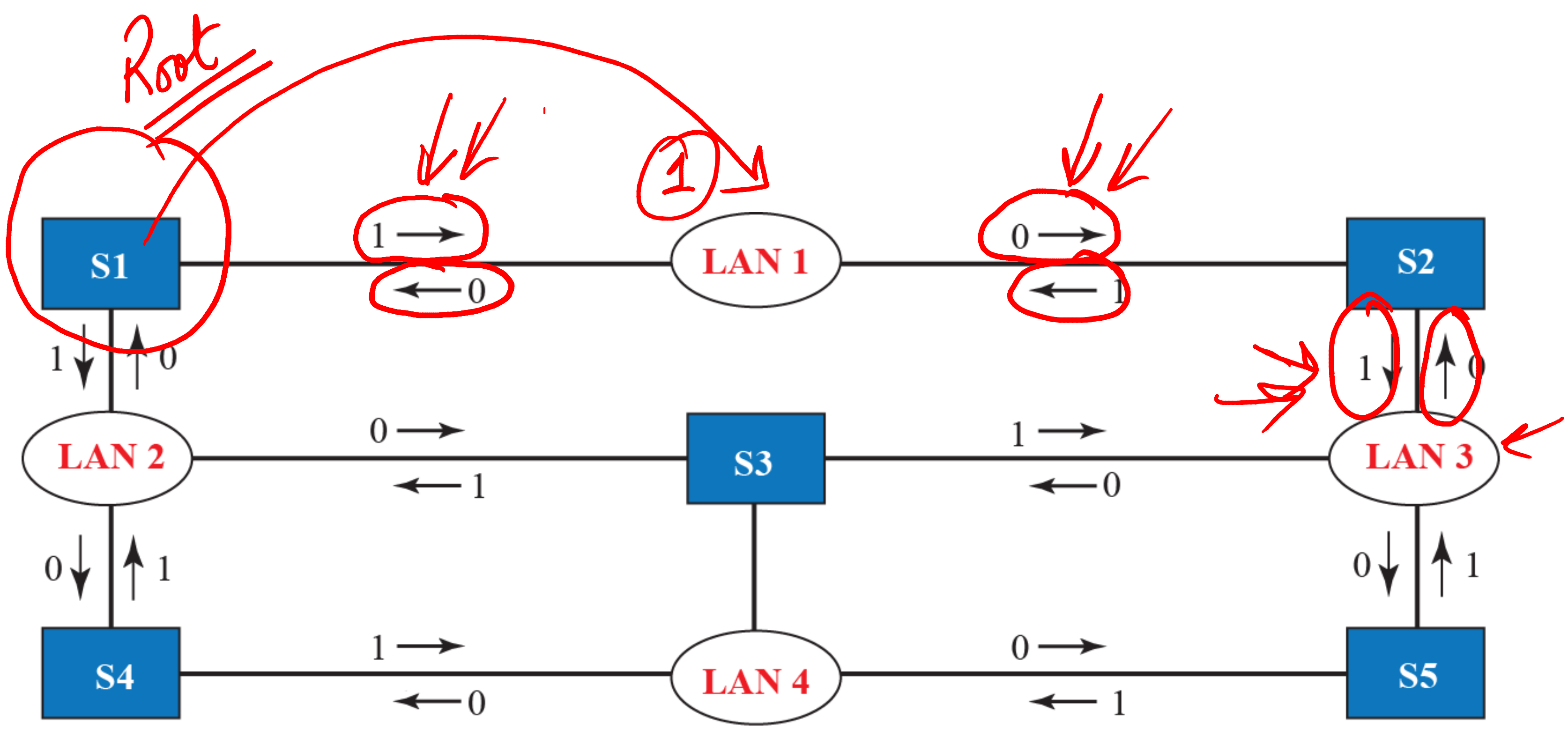
d. Both switches forward the frame



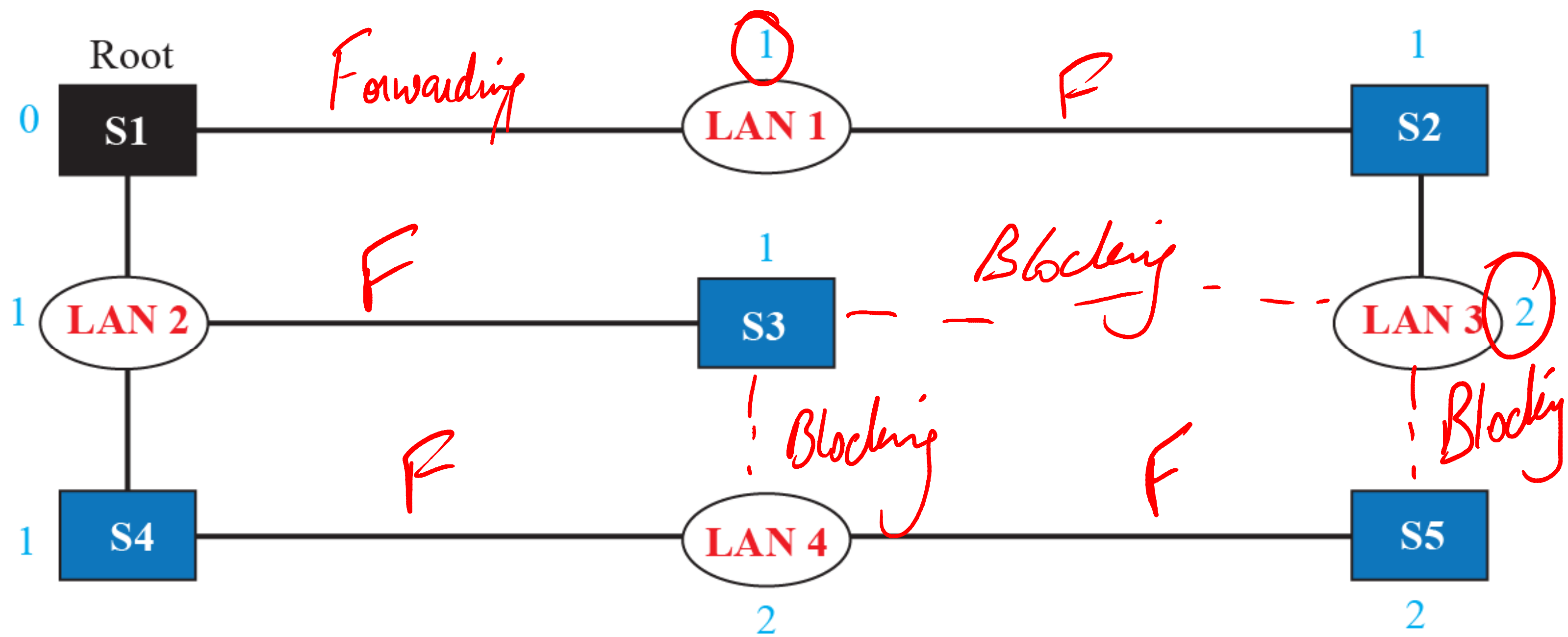
- **In graph theory, Spanning Tree is a graph in which there is no loop**
- **In a switched LAN, this means creating a topology in which each LAN can be reached from any other LAN through one path only (no loop)**
- **To find the spanning tree, we assign a cost (metric) to each LAN link**



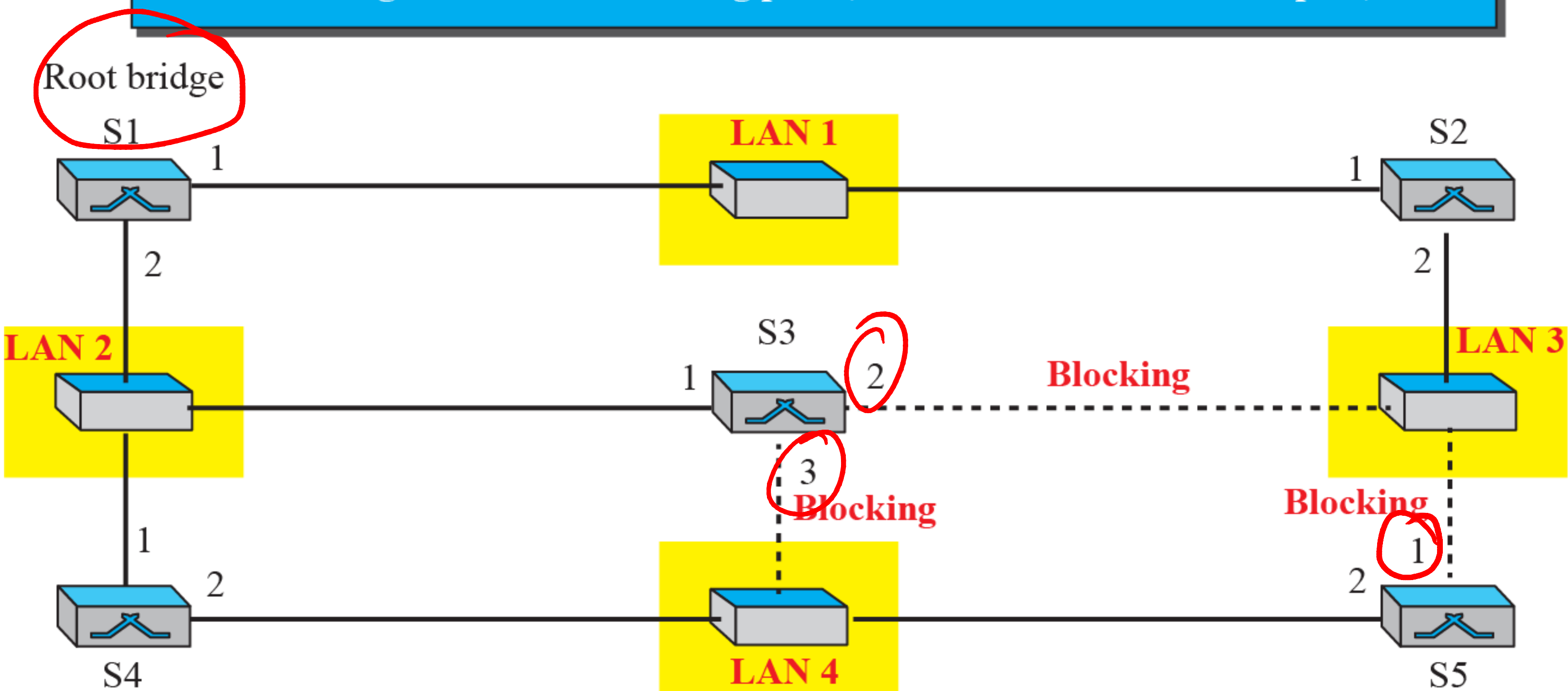
a. Actual system



b. Graph representation with cost assigned to each arc


Root
0
S1
Forwarding
1
LAN 1
F
1
S2
F
1
LAN 2
1
S3
Blocking
LAN 3
2
Blocking
Blocking
1
S4
F
LAN 4
F
S5
2
2

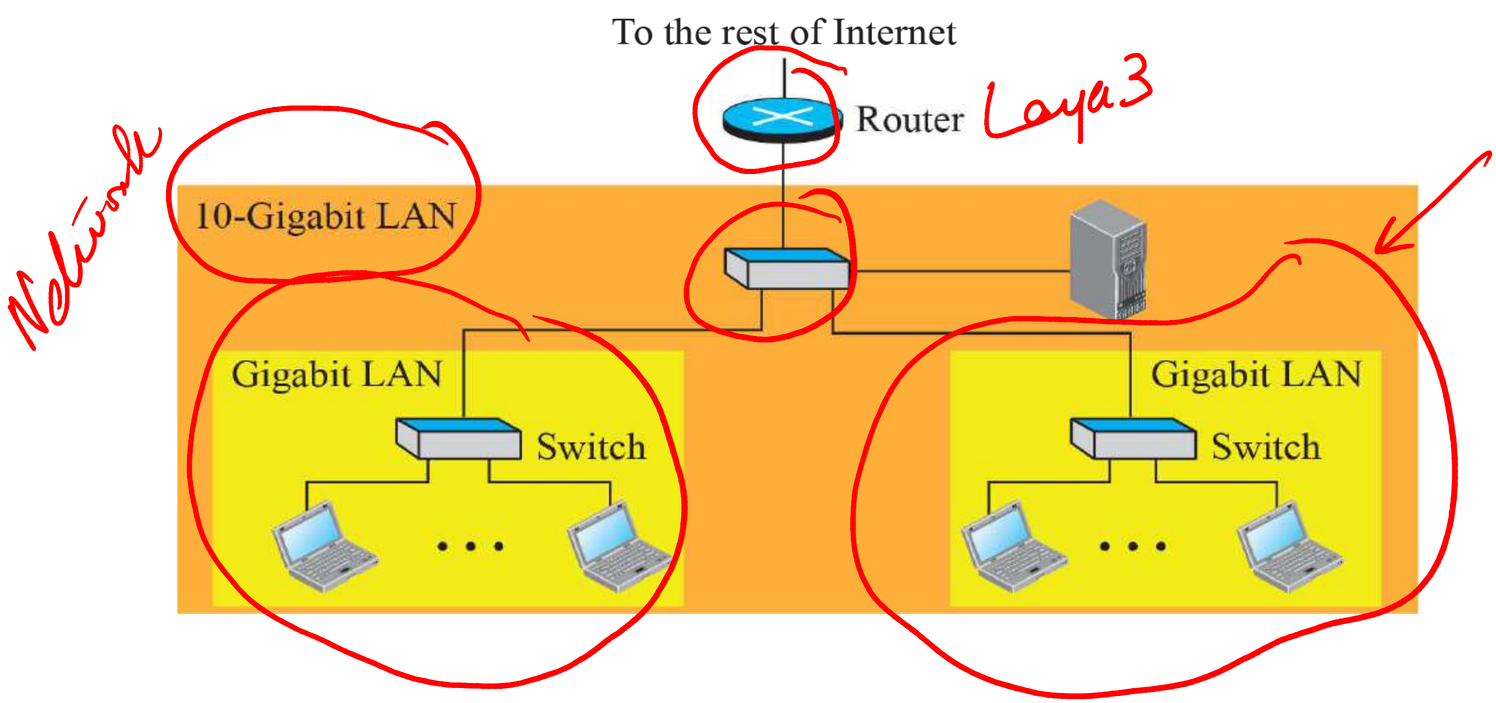
Ports 2 and 3 of bridge S3 are blocking ports (no frame is sent out of these ports). Port 1 of bridge S5 is also a blocking port (no frame is sent out of this port).



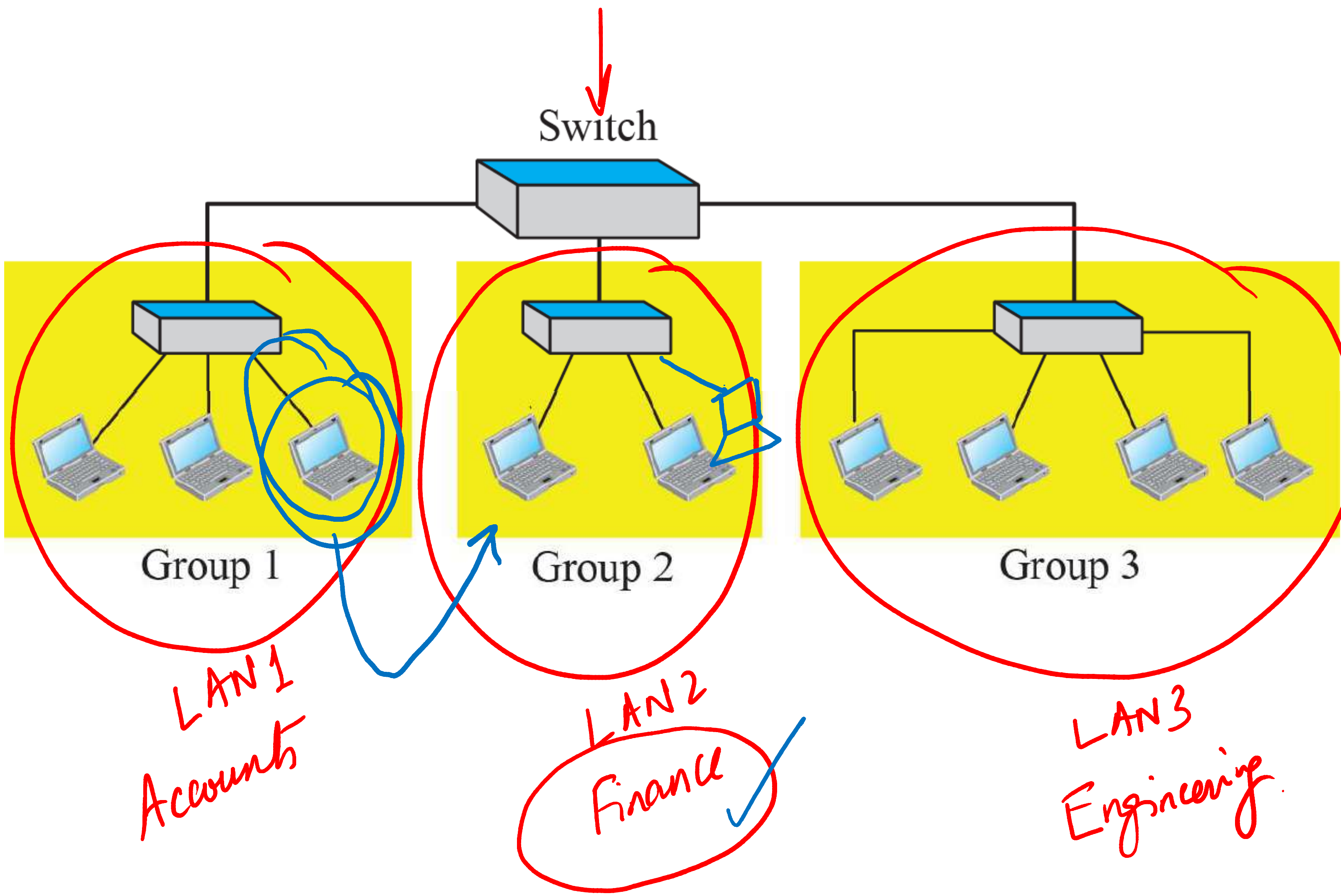
- **We compare routers to two-layer switch and a hub**
- **A router is a three-layer device; it operates in the physical, data-link, and network layers**

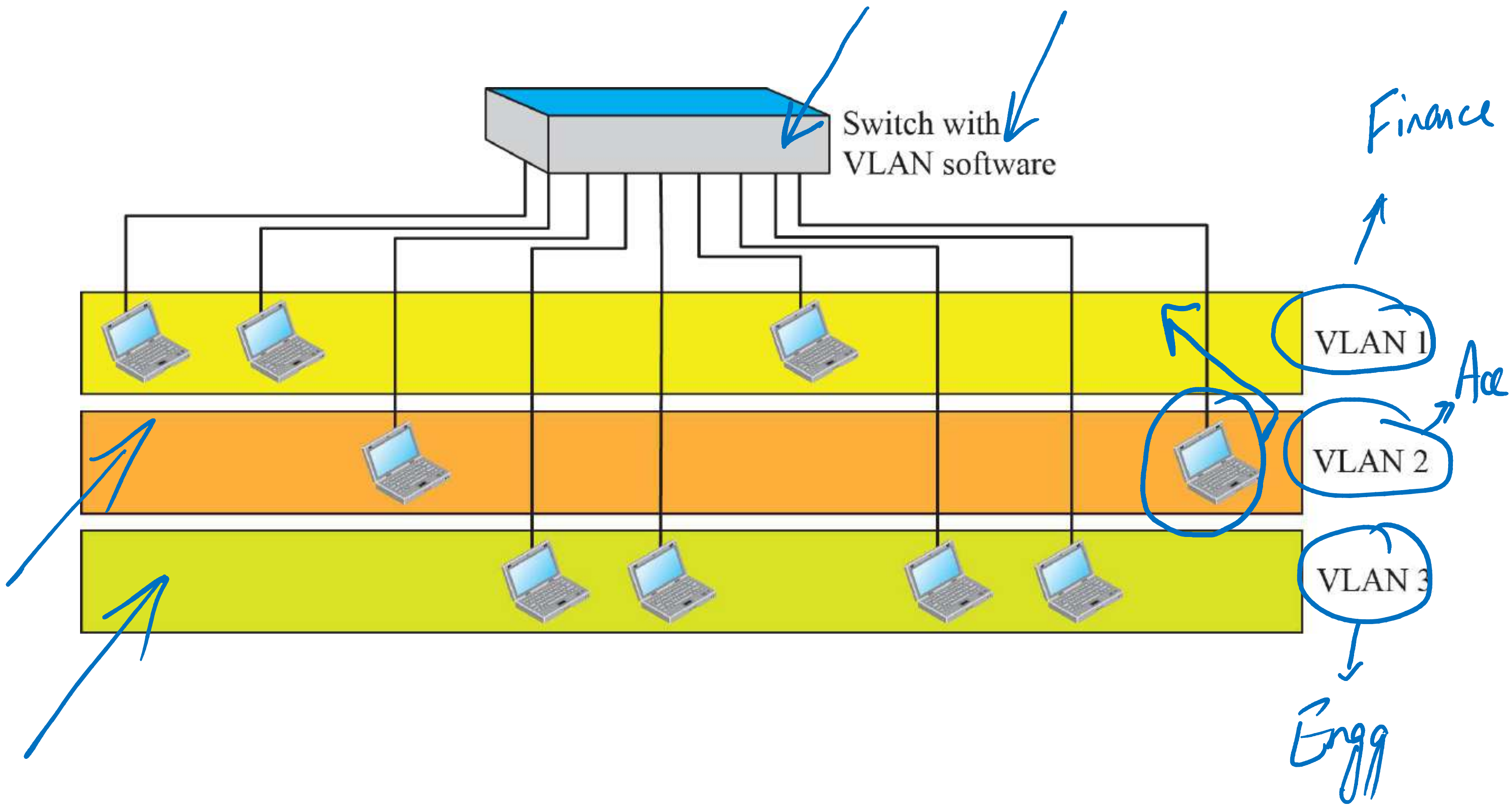
Three differences between a router and a repeater or a switch:

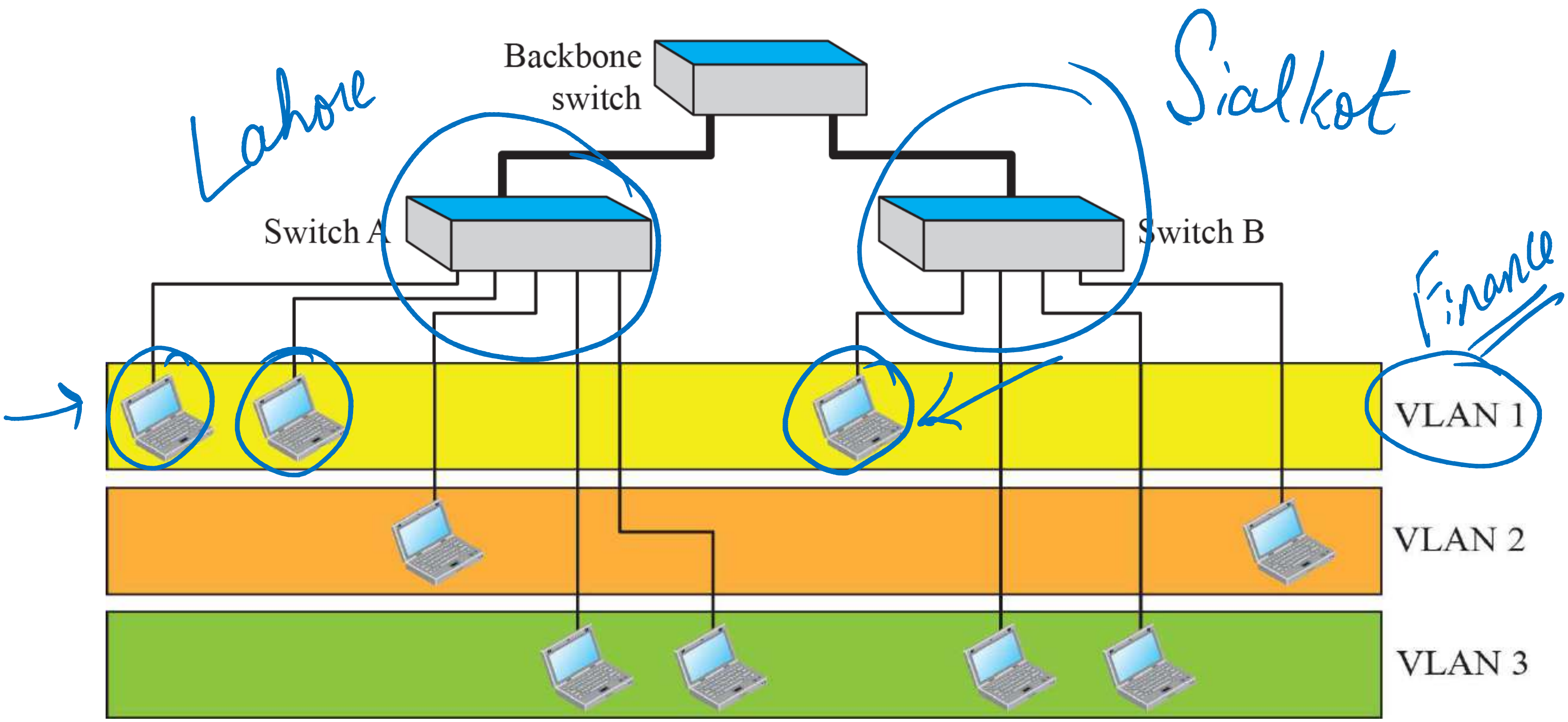
1. A router has a physical and logical (IP) address for each of its interfaces.
2. A router acts only on those packets in which the link-layer destination address matches the address of the interface at which the packet arrives.
3. A router changes the link-layer address of the packet (both source and destination) when it forwards the packet.



- A VLAN is a LAN configured by software, not by physical wiring
- A station is considered part of a LAN if it physically belongs to that LAN i.e. The criterion of membership is geographic
- Provides a virtual connection between two stations belonging to two different physical LANs


Switch
Group 1
Group 2
Group 3
LAN 1
Accounts
LAN 2
Finance
LAN 3
Engineering


Switch with
VLAN software
VLAN 1
VLAN 2
VLAN 3
Finance
Acc
Engg


Backbone switch
Switch A
Switch B
Lahore
Sialkot
Finance
VLAN 1
VLAN 2
VLAN 3

- **What characteristic can be used to group stations in a VLAN?**

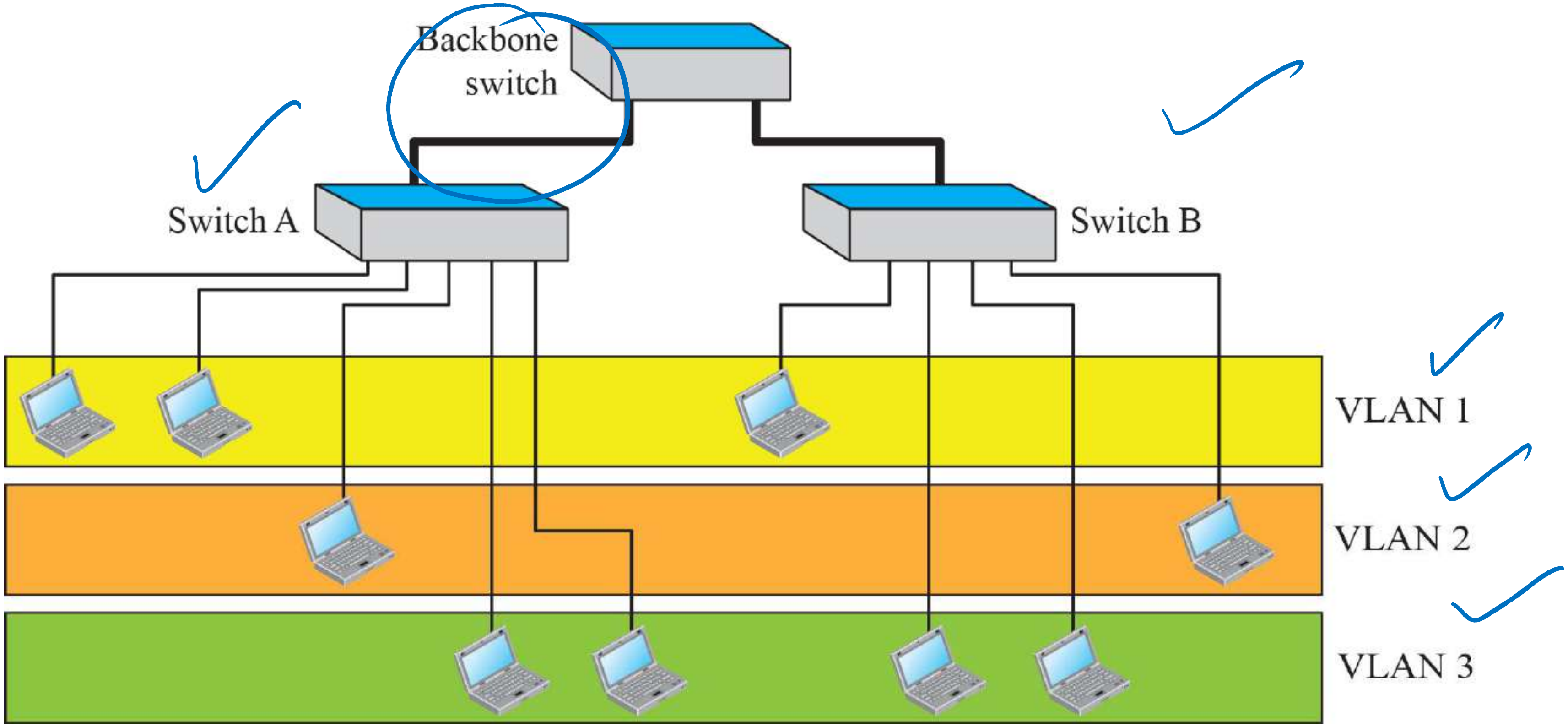
- **Vendors use different characteristics such as interface numbers, port numbers, MAC addresses, IP addresses, IP multicast addresses, or a combination of two or more of these**

- **How are the stations grouped into different VLANs?**

- **Stations are configured in one of three ways:**

  - ✓ **Manually**
  - ✓ **Semi-Automatically**
  - ✓ **Automatically**

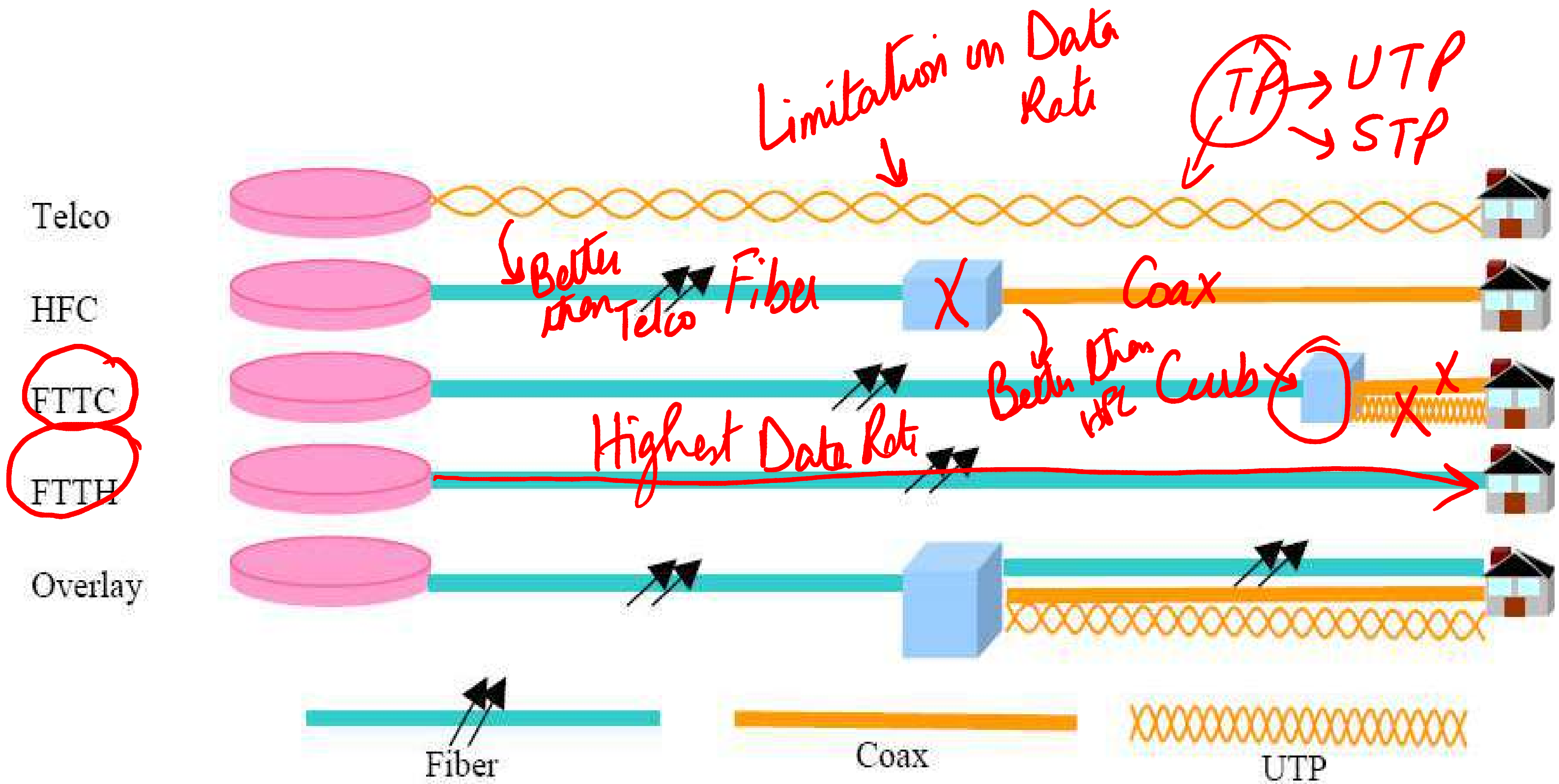
- **In a multi-switched backbone, each switch must know:**
  - ✓ **Which station belongs to which VLAN; and**
  - ✓ **The membership of stations connected to other switches**



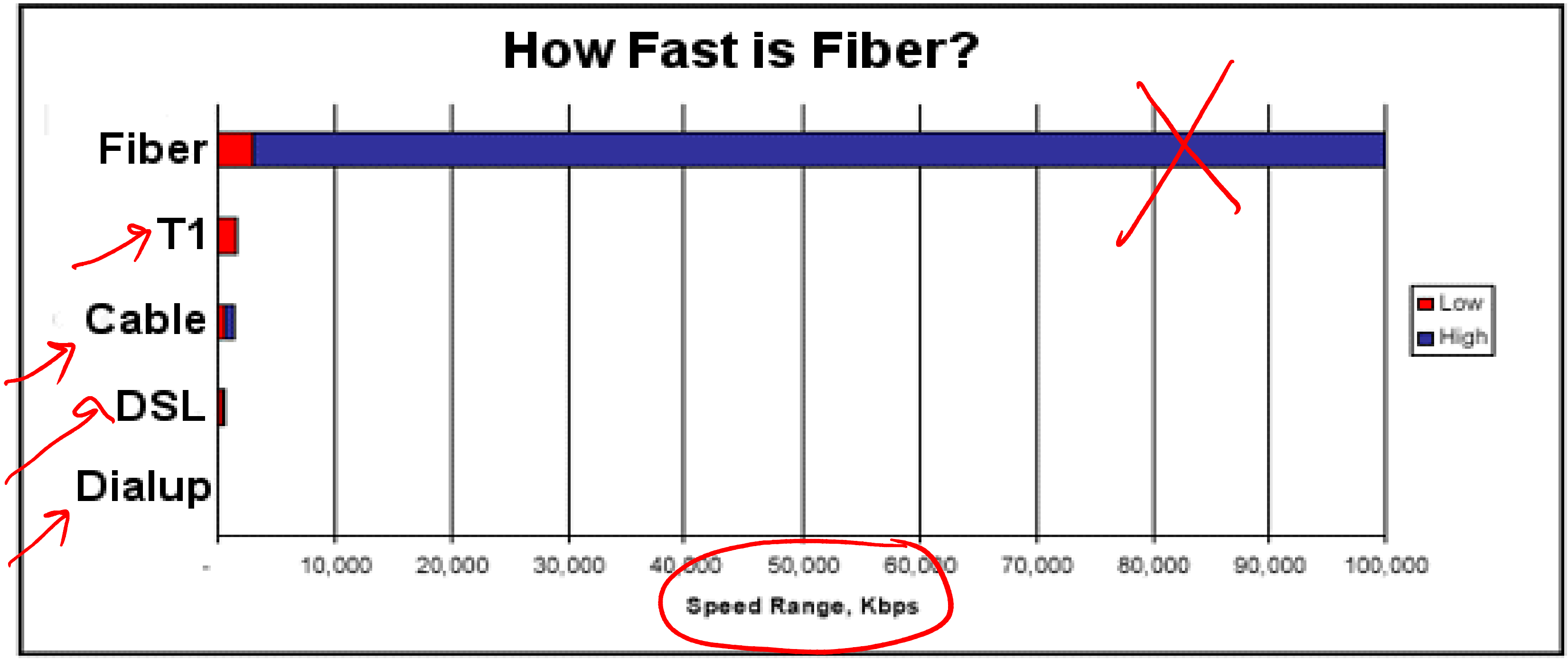
Switch A must know the membership status of stations connected to switch B, and switch B must know the same about switch A. Three methods have been devised for this purpose: table maintenance, frame tagging, and time-division multiplexing.

- **Cost and Time Reduction**
- **Creating virtual Workgroups**
- **Security**

- **Telco**
- **HFC**
- **FTTx**



Telco
HFC
FTTC
FTTH
Overlay
Fiber
Coax
UTP
Limitation on Data Rate
TP
UTP
STP
Better than Telco
Fiber
Coax
Better than HFC
Curb
Highest Data Rate

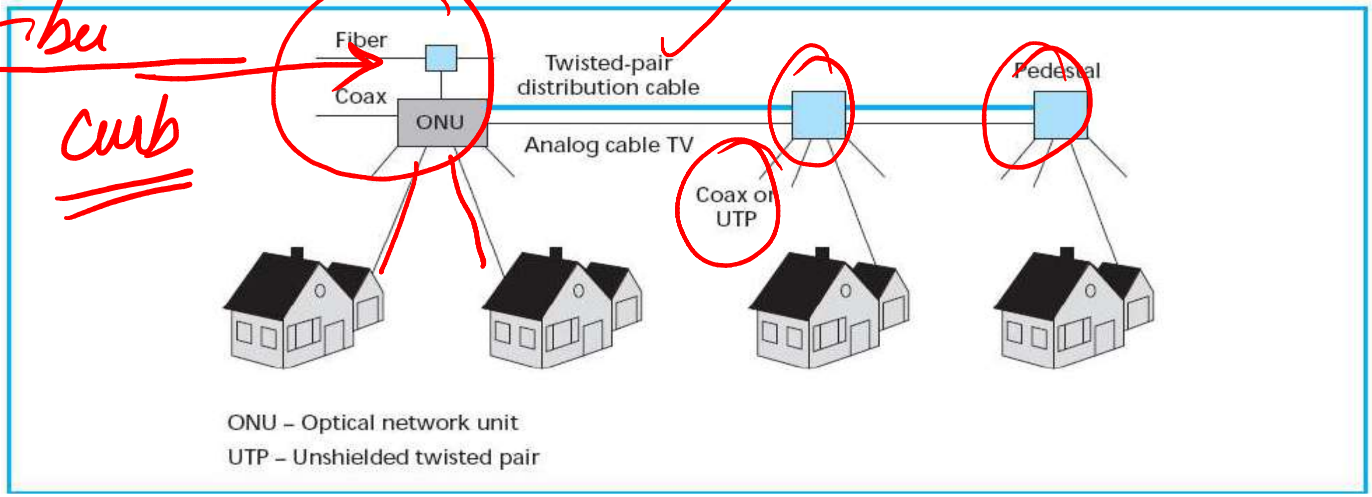

How Fast is Fiber?
Fiber
T1
Cable
DSL
Dialup
Low
High
-
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
Speed Range, Kbps

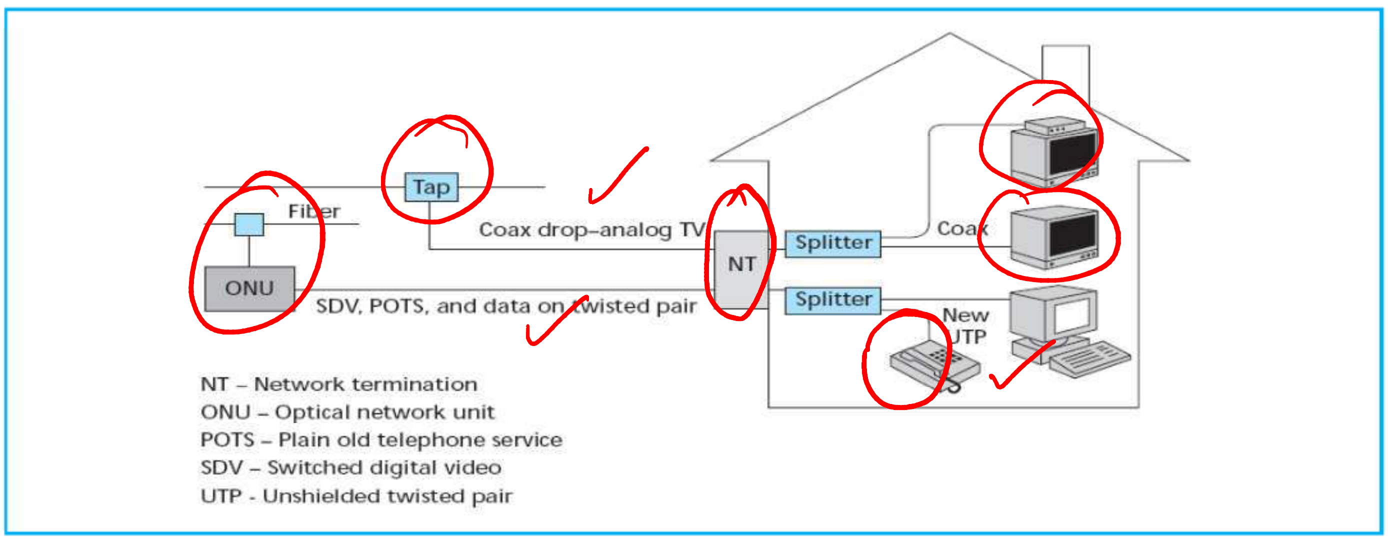
- An access network in which fiber is used for part, but not the entire link from the provider to the end-user
- An optical to electrical (O/E) conversion takes place somewhere near the end-user
- The terminal network segment of a FTTC network is usually twisted pair or coaxial cable

- **The final optical receiver in a FTTC network typically serves several customers**

CO Fiber

Curb





- **Need: High-speed data, reliable voice and high-quality video**

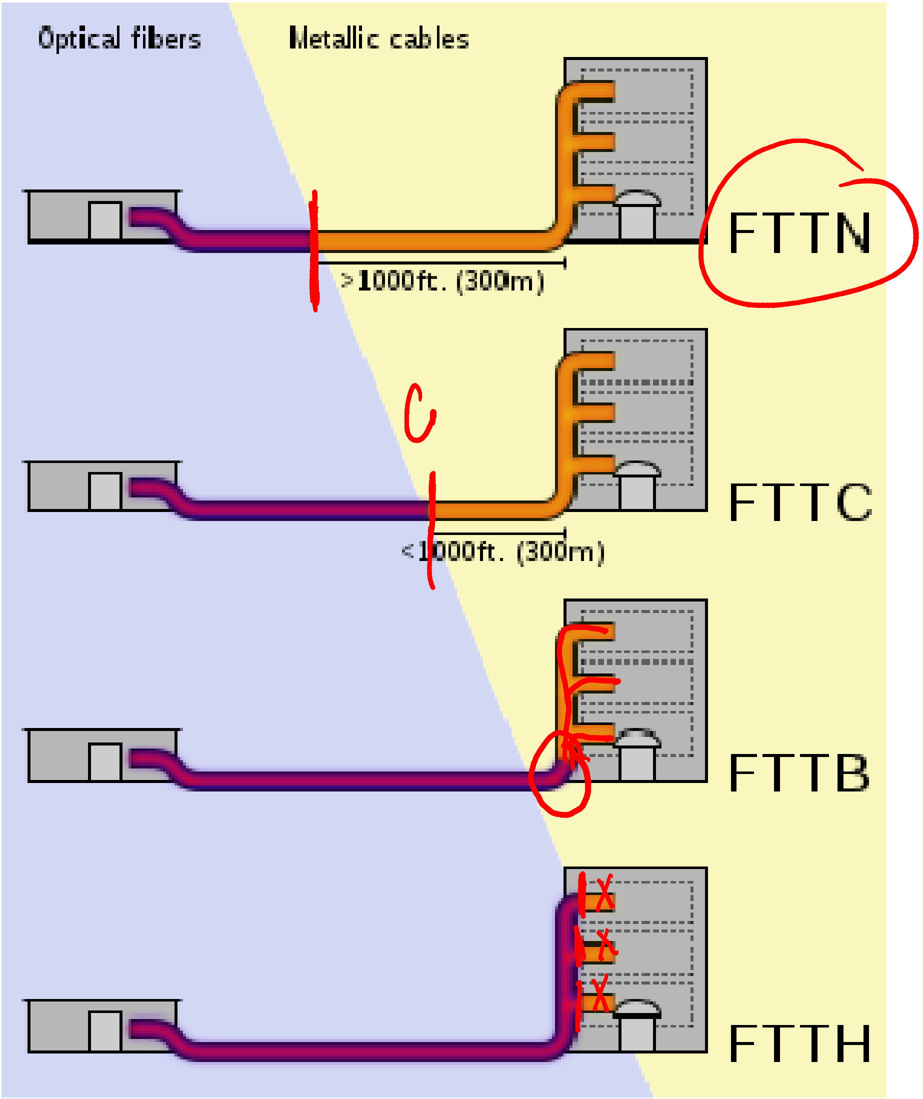
- **Problems:**
  - ✓ **How to get high speed lines out to each customer?**
  - ✓ **How to future-proof the architecture?**

- **Solution: <u>FTTH</u>**

- Fiber-to-the-home (FTTH) is the installation of optical fiber from a telephone switch directly into the subscriber's home

- It is one of the latest access technologies

- FTTH is also referred to as Fiber-to-the-Building (FTTB)



Optical fibers
Metallic cables
FTTN
>1000ft. (300m)
C
FTTC
<1000ft. (300m)
FTTB
FTTH