Facultat d' informàtica de Barcelona

Capítol 2. Transmissió de dades

2.1 Medis i sistemes de transmissió

2.2 Adaptadors al canal

2.3 Sources of packet delay

Book: Data and Computer Communications, Tenth Edition by William Stallings, (c) Pearson Education - Prentice Hall, 2014

2.1 Medis de transmissió

2.1.1 Anàlisi freqüencial

2.1.2 Medis

2.1.1 Anàlisi freqüencial

Velocitats en transmissió de dades

- Transmissió

  Vt = bits/seg

  Vm = símbols/seg (Bauds)

  Vm= Vt si símbol=1 bit

- Propagació

  Vp = Km/seg

- Llargària d'un bit = Vp / Vt

Frequency, Spectrum and Bandwidth

Time Domain Concepts

- **analog signal**
  - *signal intensity varies smoothly with no breaks*
- **digital signal**
  - *signal intensity maintains a constant level and then abruptly changes to another level*
- **periodic signal**
  - *signal pattern repeats over time*
- **aperiodic signal**
  - *pattern not repeated over time*

Analog and Digital Signals

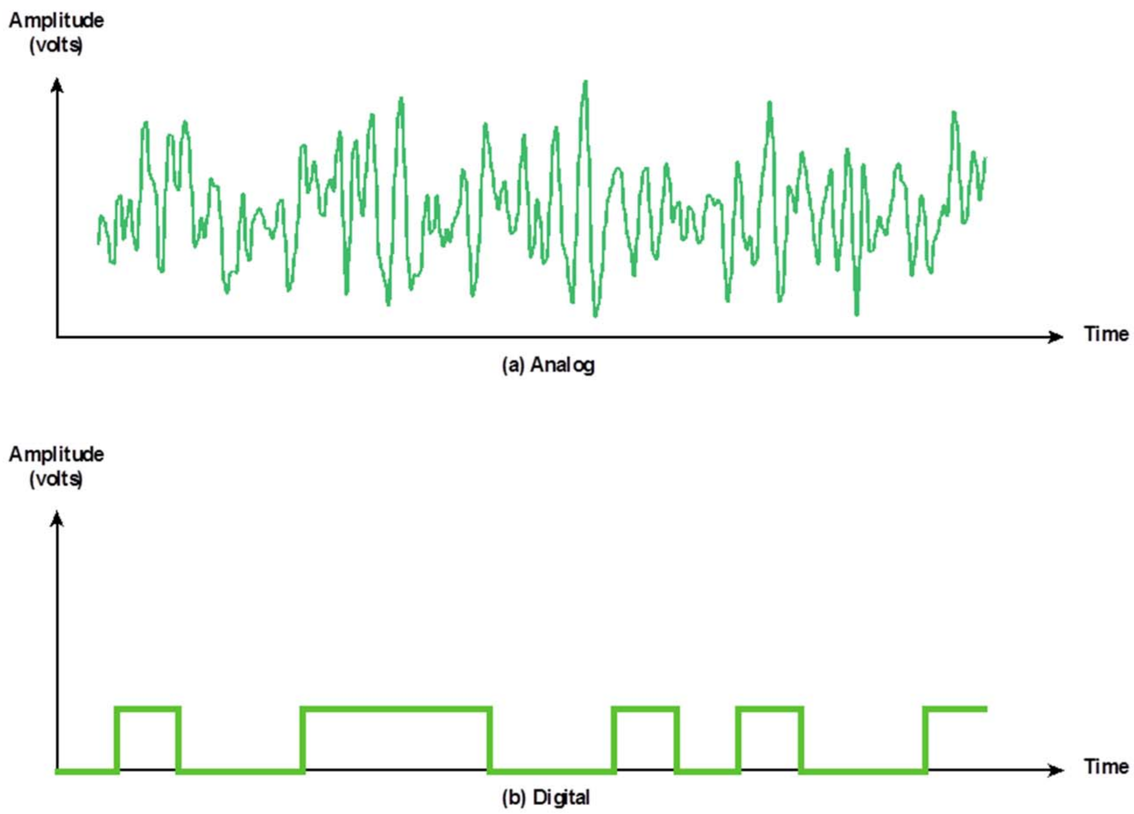
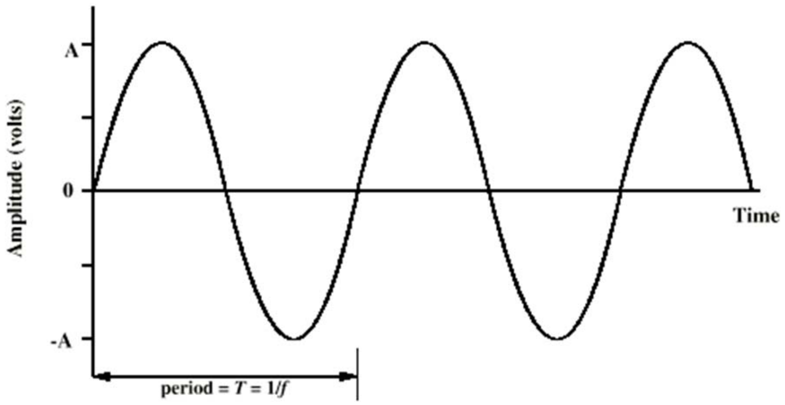
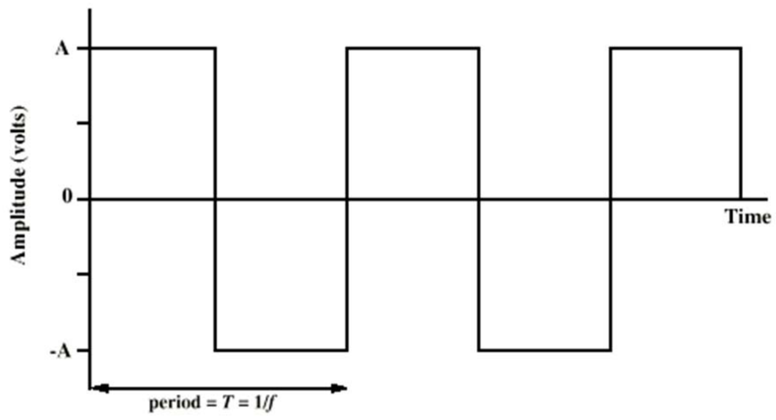


Figure 3.1 Analog and Digital Waveforms

Periodic Signals



(a) Sine wave



(b) Square wave

Sine Wave

(periodic continuous signal)

- **peak amplitude (A)**
  - maximum strength of signal
  - typically measured in volts
- **frequency (f)**
  - rate at which the signal repeats
  - Hertz (Hz) or cycles per second
  - period (T) is the amount of time for one repetition
  - $T = 1/f$
- **phase (ϕ)**
  - relative position in time within a single period of signal

Varying Sine Waves
$s(t) = A \sin(2\pi ft + \Phi)$

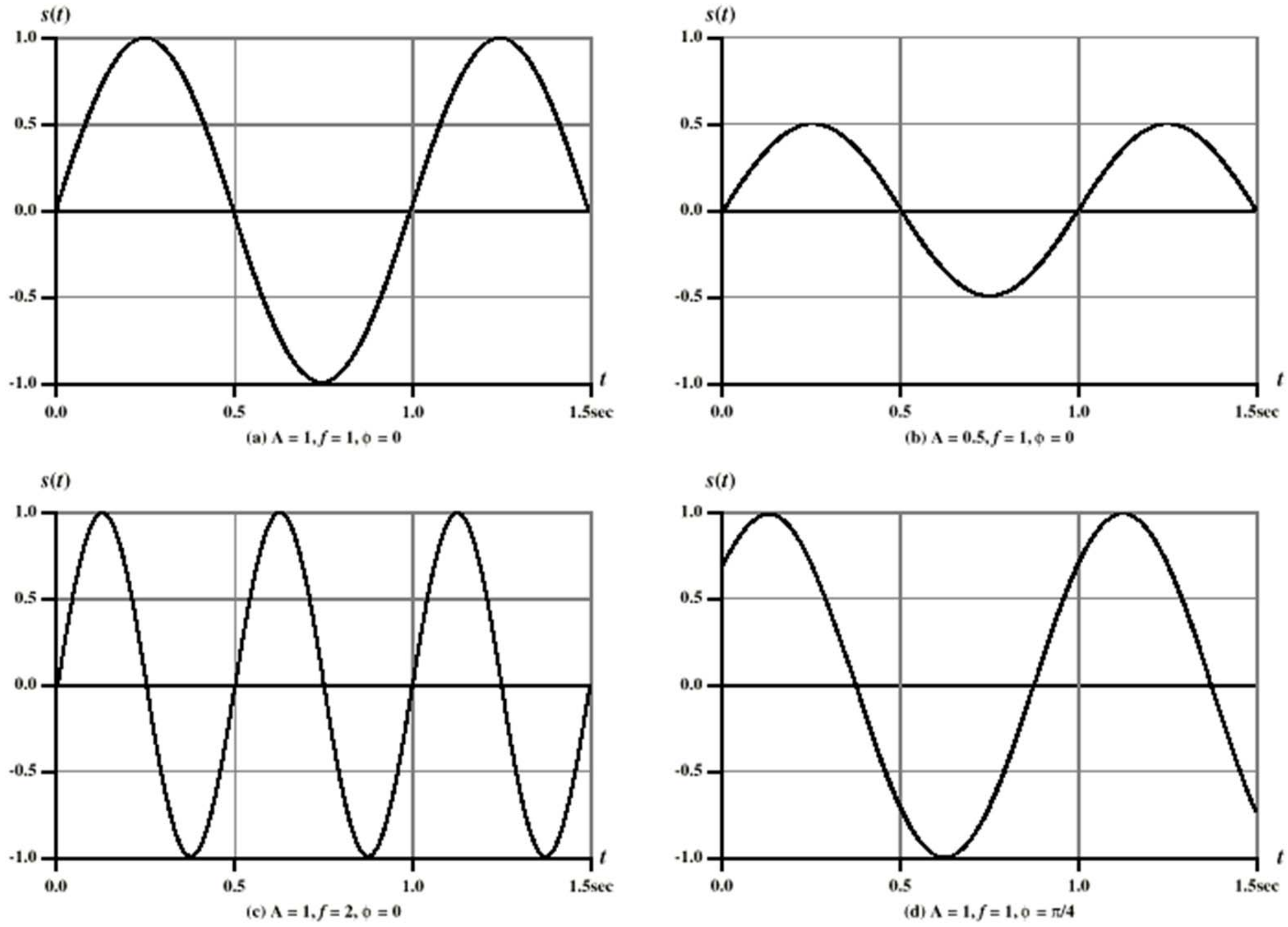


Figure 3.3

Frequency Domain Concepts

- signals are made up of many frequencies
- components are sine waves
- Fourier analysis can show that any signal is made up of components at various frequencies, in which each component is a sinusoid
- can plot frequency domain functions

Addition of Frequency Components (T=1/f)

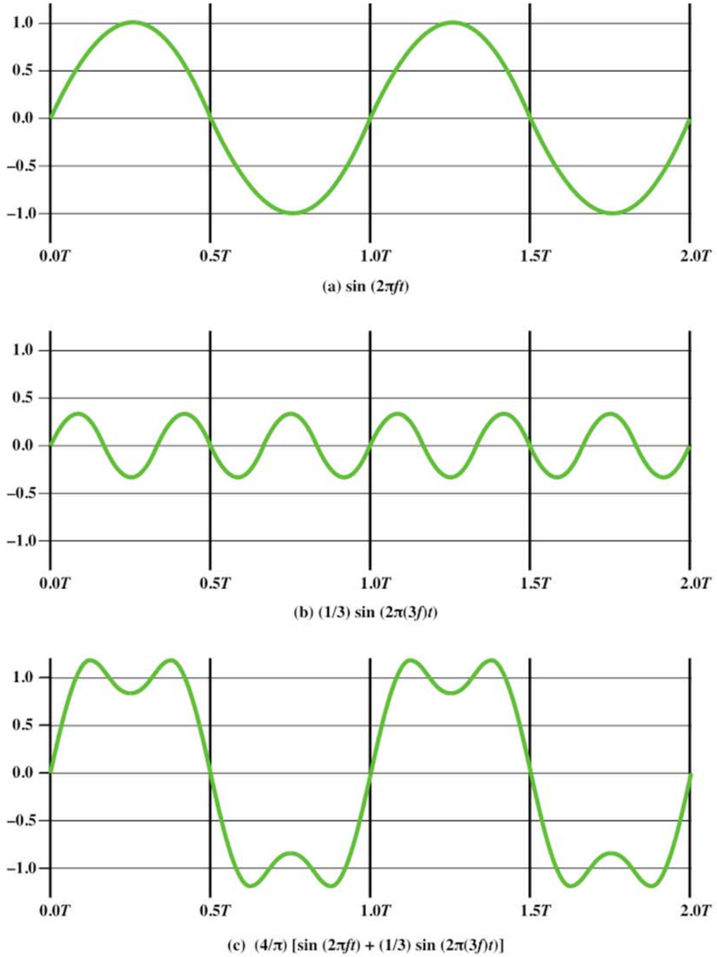


Figure 3.4 Addition of Frequency Components ($T = 1/f$)

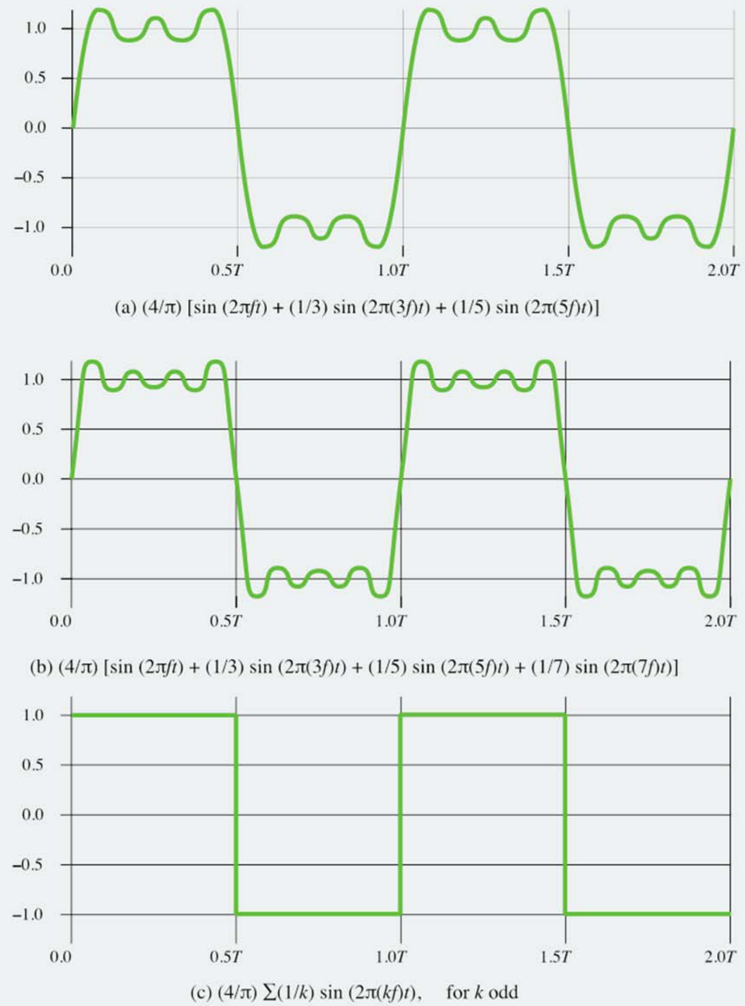
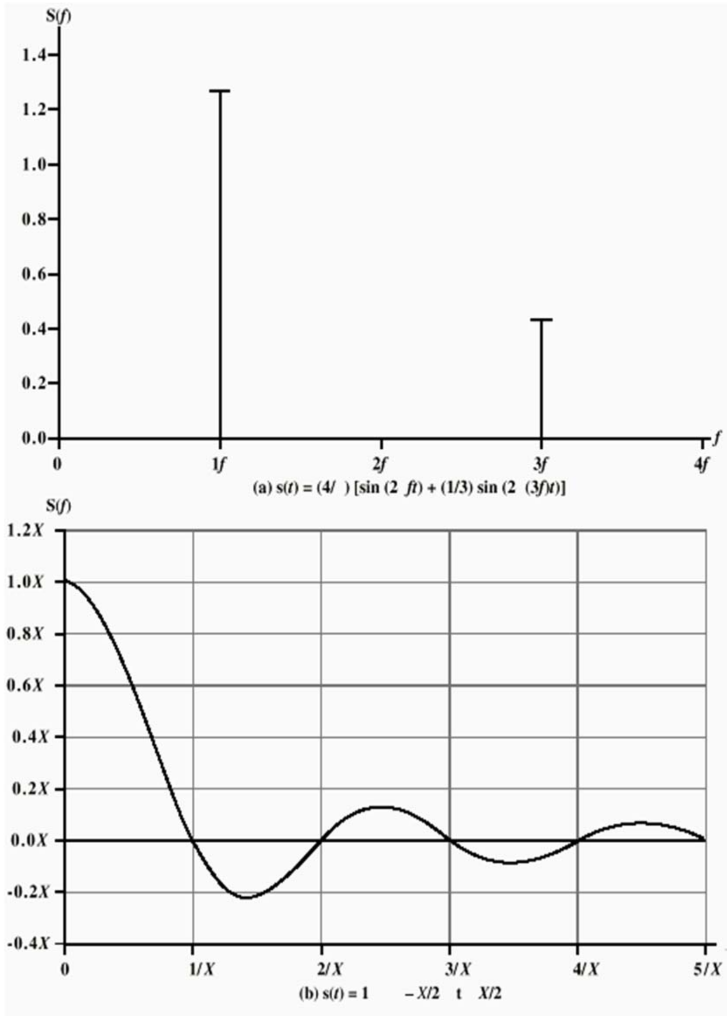


Figure 3.7 Frequency Components of Square Wave ($T = 1/f$)

Frequency Domain Representations

- frequency domain function
- frequency domain function of single square pulse



Spectrum & Bandwidth

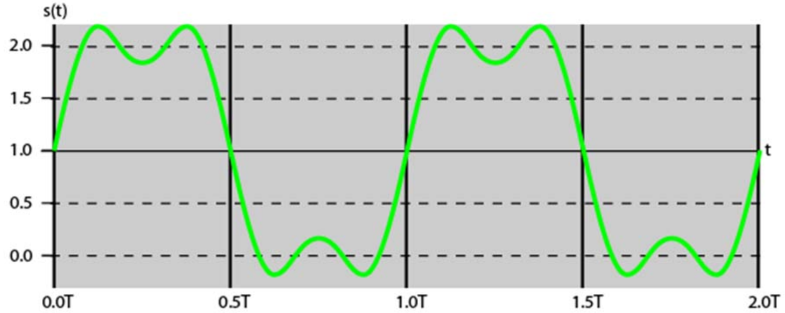
spectrum
- range of frequencies contained in signal

absolute bandwidth
- width of spectrum

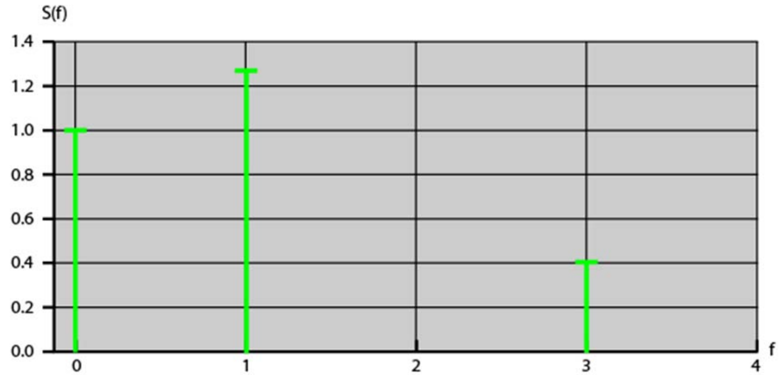
effective bandwidth
- often just bandwidth
- narrow band of frequencies containing most energy

dc component
- component of zero frequency

Signal with dc Component



(a) s(t) = 1 + (4/p) [sin (2pft) + (1/3) sin (2p(3f)t)]



(b) S(f)

Data Rate and Bandwidth

any transmission system has a limited band of frequencies

this limits the data rate that can be carried on the transmission medium

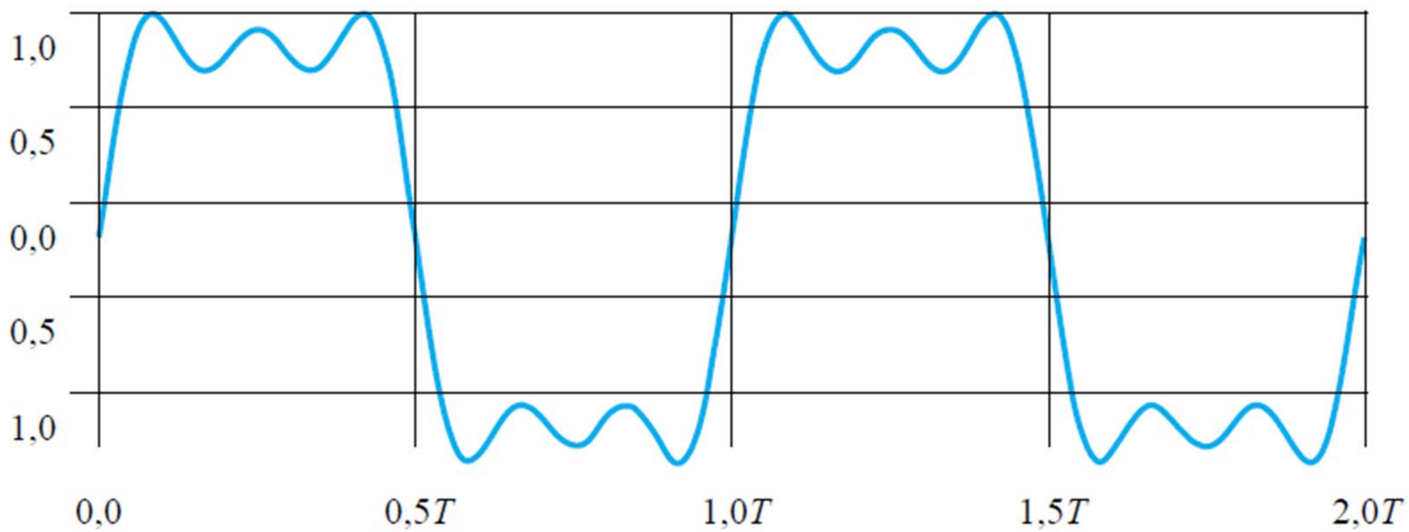
square waves have infinite components and hence an infinite bandwidth

most energy in first few components

limiting bandwidth creates distortions

There is a direct relationship between data rate and bandwidth.

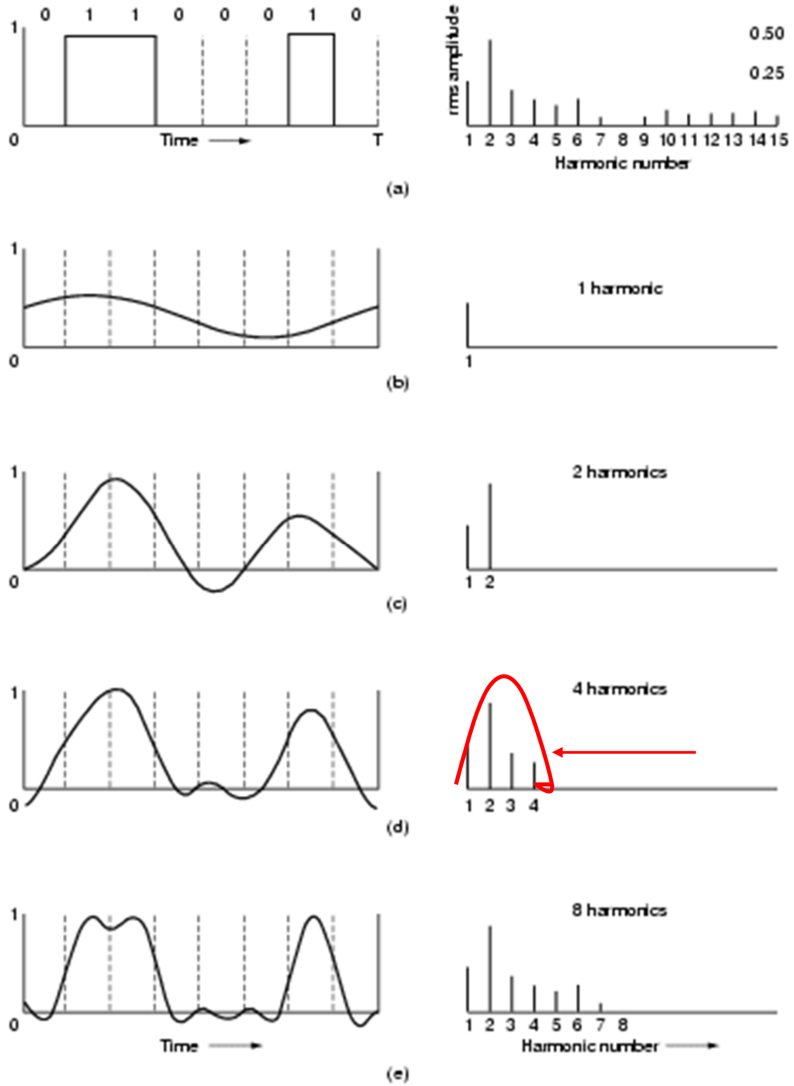
Data Rate and Bw

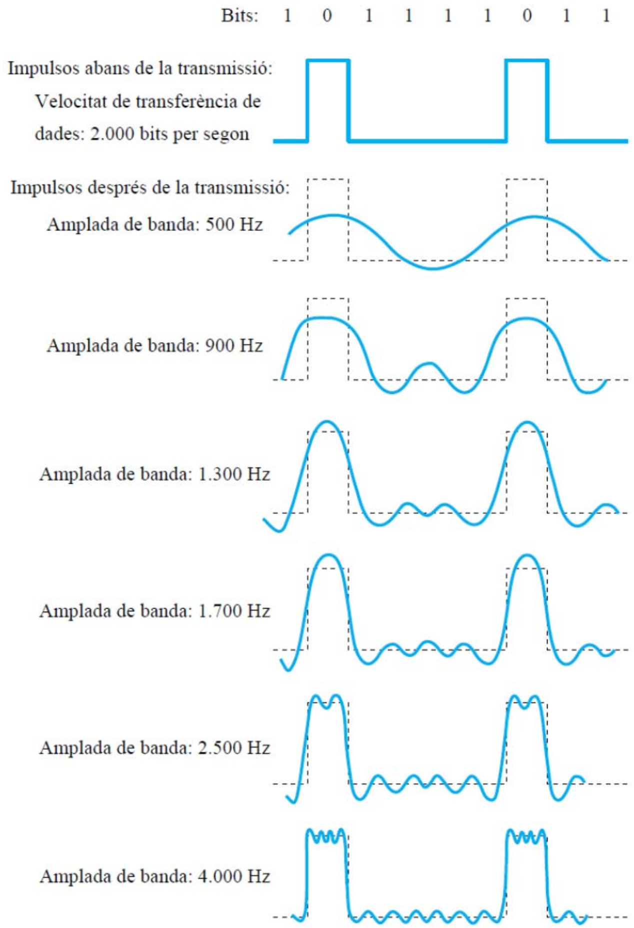


(a) $(4/\pi)\,[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$

Si f = 1 Mhz ; Bw = 4 Mhz (5f-1f)
T = 1/f = 1 microseg ; temps bit = 0,5 microseg
2 bits/hertz ; Vt. = 2x 1Mhz = 2 Mbps
Si f = 2 Mhz ; Bw = 8 Mhz ; T = 0,5 microseg
2 bits/hertz Vt = 4 Mbps

Example spectral analysis





Design Factors Determining Data Rate and Distance

bandwidth

- higher bandwidth gives higher data rate

transmission impairments

- impairments, such as attenuation, limit the distance

interference

- overlapping frequency bands can distort or wipe out a signal

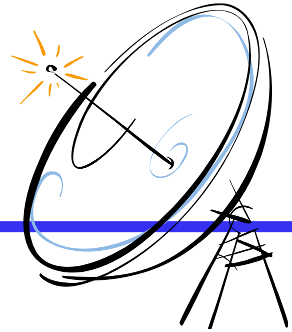
number of receivers

- more receivers introduces more attenuation

2.1.2 Medis de transmissió

1. Wireless
2. Parell trenat
3. Cable coaxial
4. Fibra òptica
5. Signal/Noise Rate

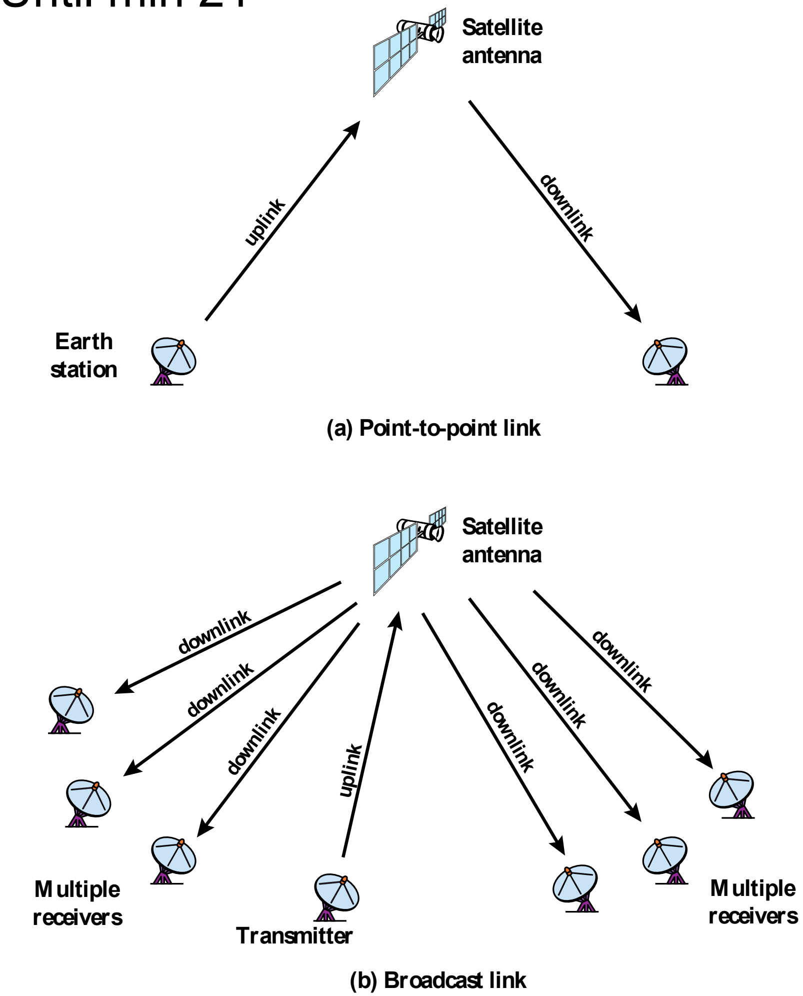
1. Wireless

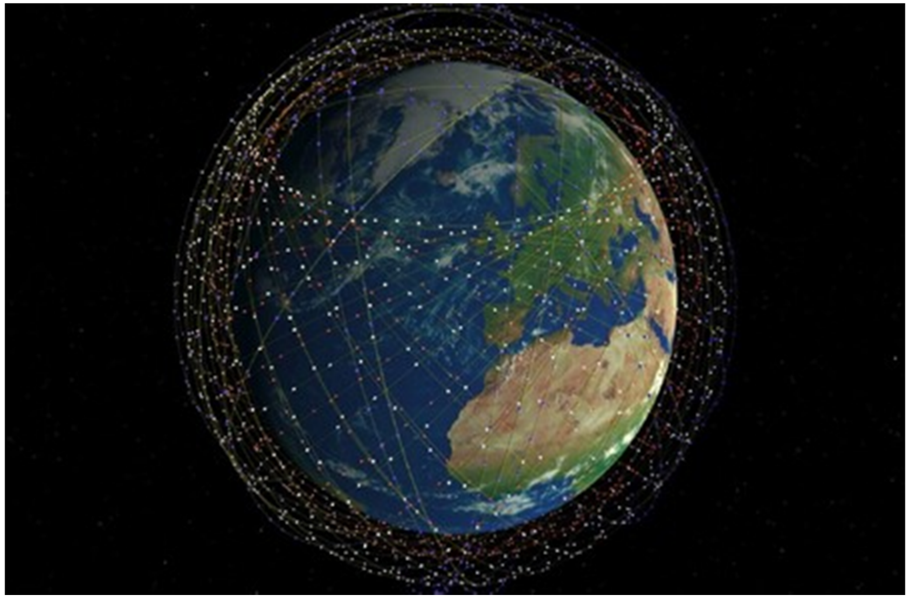


- Electrical conductor or system of conductors used to radiate or collect electromagnetic energy
- Radio frequency electrical energy from the transmitter is converted into electromagnetic energy by the antenna and radiated into the surrounding environment
- Reception occurs when the electromagnetic signal intersects the antenna
- In two way communication, the same antenna can be used for both transmission and reception

Configurations for satellite communication

https://www.youtube.com/watch?v=qs2QcycggWU&ab_channel=BranchEducation
Until min 21





Starlink (SpaceX)

2. Twisted Pair (Parell trenat)

—Separately insulated
—Twisted together
—Often "bundled" into cables
—Usually installed in building
during construction

(a) Twisted pair

Twisted pair is the least expensive and most widely used guided transmission medium.

- **consists of two insulated copper wires arranged in a regular spiral pattern**
- **a wire pair acts as a single communication link**
- **pairs are bundled together into a cable**
- **most commonly used in the telephone network and for communications within buildings**

Unshielded vs. Shielded Twisted Pair

Unshielded Twisted Pair (UTP)

- ordinary telephone wire
- cheapest
- easiest to install
- suffers from external electromagnetic interference

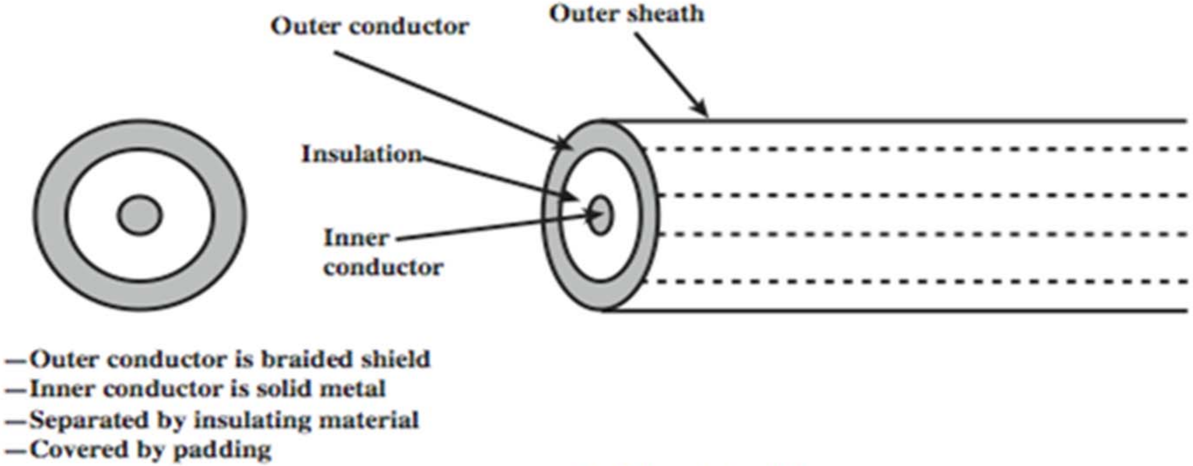
Shielded Twisted Pair (STP)

- has metal braid or sheathing that reduces interference
- provides better performance at higher data rates
- more expensive
- harder to handle (thick, heavy)

UTP Categories

	Category 3 Class C	Category 5 Class D	Category 5E	Category 6 Class E	Category 7 Class F
Bandwidth	16 MHz	100 MHz	100 MHz	200 MHz	600 MHz
Cable Type	UTP	UTP/FTP	UTP/FTP	UTP/FTP	SSTP
Link Cost (Cat 5 =1)	0.7	1	1.2	1.5	2.2

3. Coaxial Cable



(b) Coaxial cable

Coaxial cable can be used over longer distances and support more stations on a shared line than twisted pair.

- **consists of a hollow outer cylindrical conductor that surrounds a single inner wire conductor**
- **is a versatile transmission medium used in a wide variety of applications**
- **used for TV distribution, long distance telephone transmission and LANs**

4. Optical Fiber

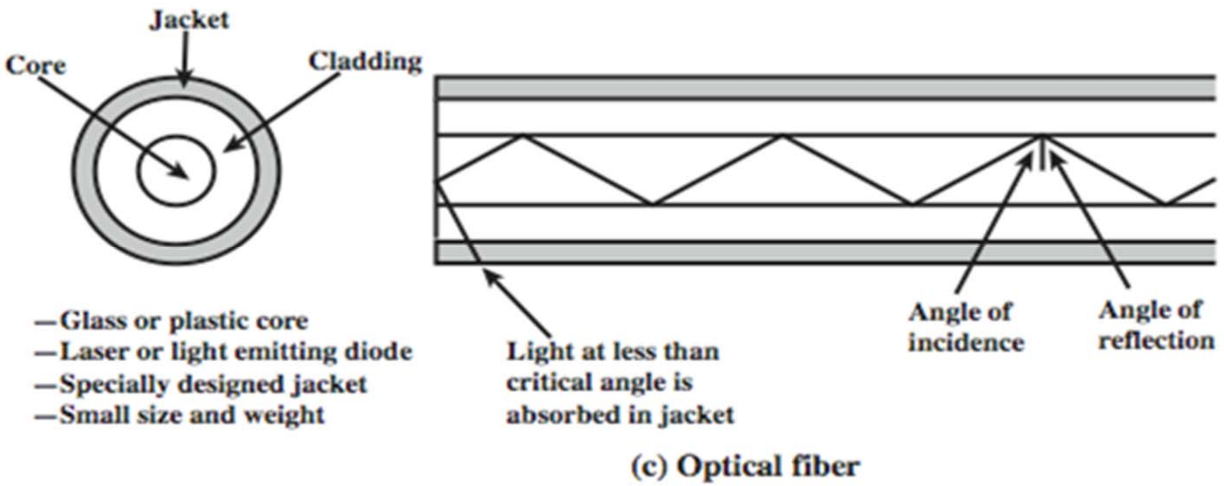
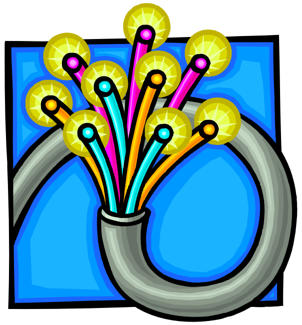


Figure 4.2

Optical fiber is a thin flexible medium capable of guiding an optical ray.

- **various glasses and plastics can be used to make optical fibers**
- **has a cylindrical shape with three sections – core, cladding, jacket**
- **widely used in long distance telecommunications**
- **performance, price and advantages have made it popular to use**

Optical Fiber - Benefits



- greater capacity
  - data rates of hundreds of Gbps
- smaller size and lighter weight
  - considerably thinner than coaxial or twisted pair cable
  - reduces structural support requirements
- lower attenuation
- electromagnetic isolation
  - not vulnerable to interference, impulse noise, or crosstalk
  - high degree of security from eavesdropping
- greater repeater spacing
  - lower cost and fewer sources of error

Optical Fiber Transmission Modes

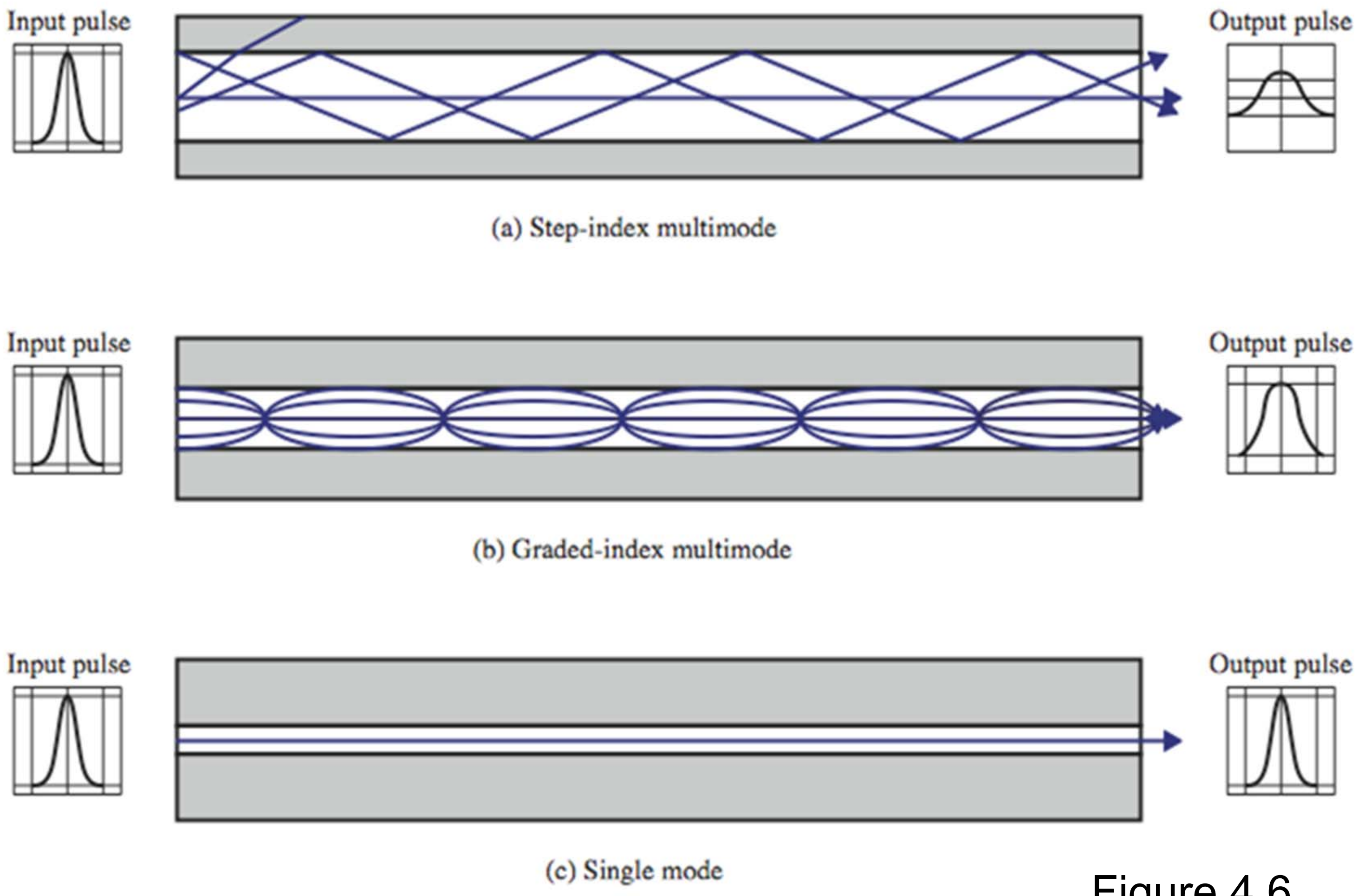


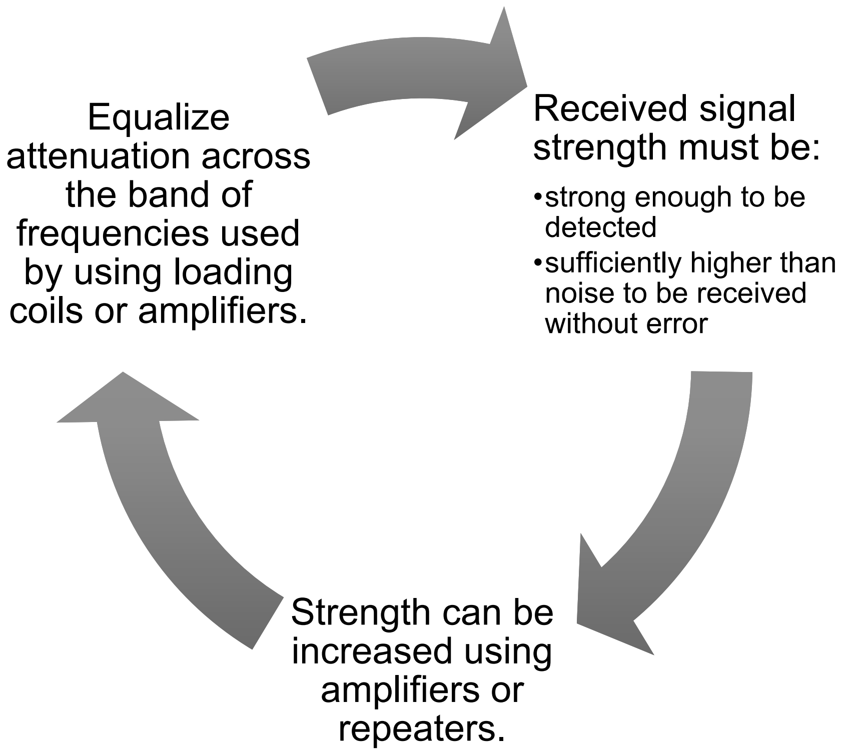
Figure 4.6

Frequency Utilization for Fiber Applications

Wavelength (in vacuum) range (nm)	Frequency Range (THz)	Band Label	Fiber Type	Application
820 to 900	366 to 333		Multimode	LAN
1280 to 1350	234 to 222	S	Single mode	Various
1528 to 1561	196 to 192	C	Single mode	WDM
1561 to 1620	192 to 185	L	Single mode	WDM

Table 4.3

Attenuation



- **signal strength falls off with distance over any transmission medium**
- **varies with frequency**

Attenuation in Guided Media

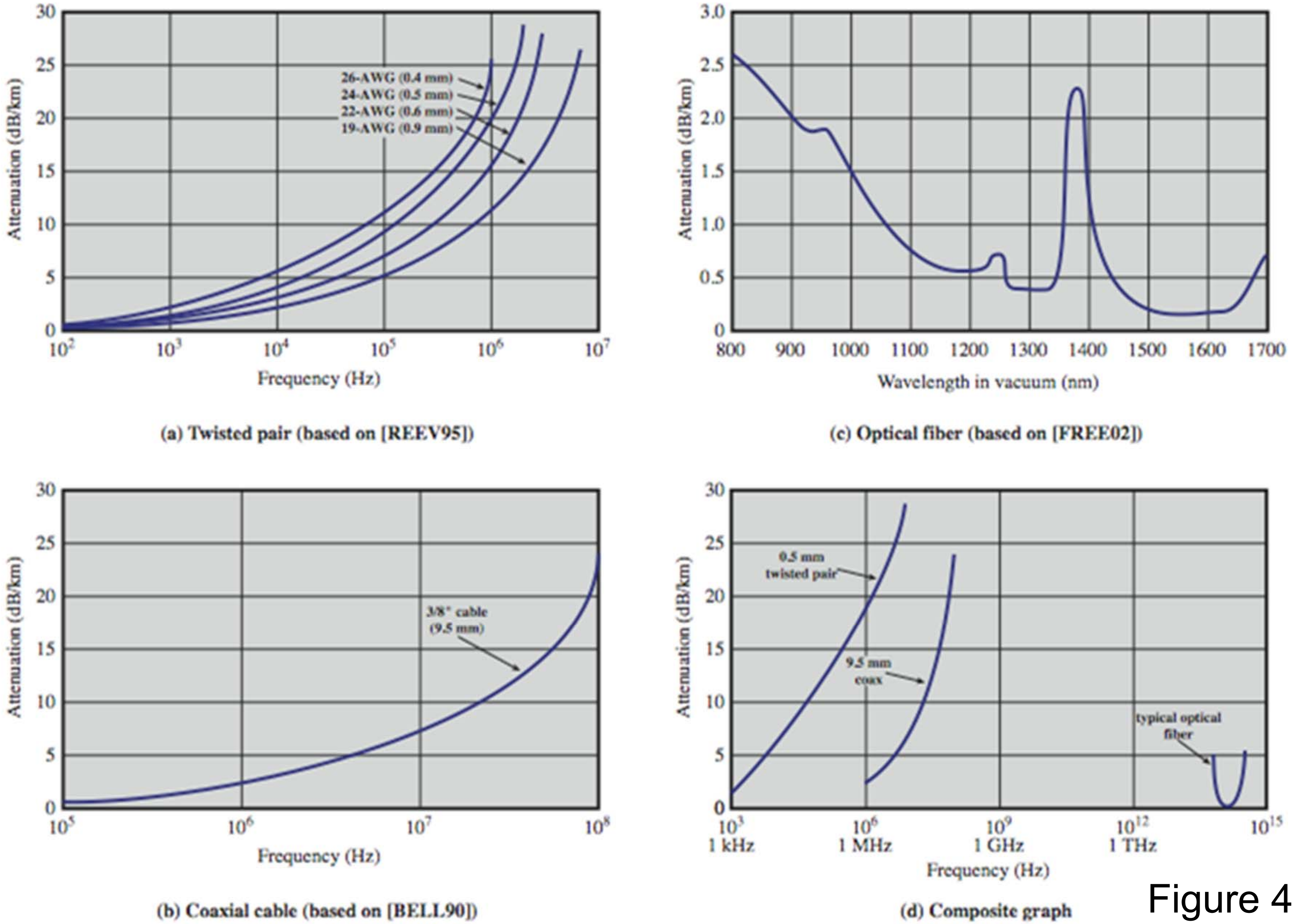


Figure 4.3

Attenuation Distortion

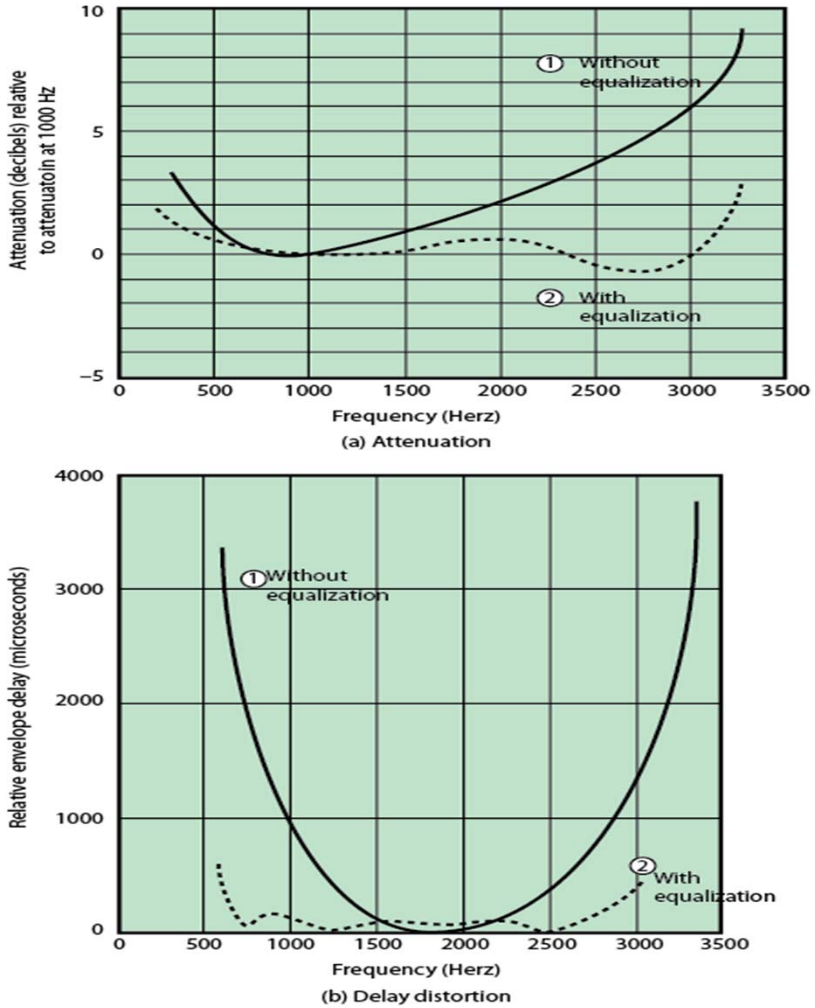


Figure 3.14

Delay Distortion

- occurs because propagation velocity of a signal through a guided medium varies with frequency
- various frequency components arrive at different times resulting in phase shifts between the frequencies
- particularly critical for digital data since parts of one bit spill over into others causing intersymbol interference

5. Signal/Noise rate. Categories of Noise

Impulse Noise:

- caused by external electromagnetic interferences
- noncontinuous, consisting of irregular pulses or spikes
- short duration and high amplitude
- minor annoyance for analog signals but a major source of error in digital data

Crosstalk:

- a signal from one line is picked up by another
- can occur by electrical coupling between nearby twisted pairs or when microwave antennas pick up unwanted signals

Signal/Noise S/N es mesura en dB. dB= 10 log S/N

Nyquist Bandwidth

- Difference between symbol/s and b/s

In the case of a channel that is noise free:

- if rate of signal transmission is *2B* then can carry signal with frequencies no greater than *B*
  - given bandwidth B, highest signal rate is 2B
- for binary signals, *2B* bps needs bandwidth *B* Hz
- can increase rate by using *M* signal levels
- Nyquist Formula: $C\ (b/s) = 2B\ (symbol/s)\ \log_2 M$
- data rate can be increased by increasing signals
  - however this increases burden on receiver
  - noise & other impairments limit the value of *M*

Shannon Capacity Formula

- considering the relation of data rate, noise and error rate:
  - faster data rate shortens each bit so bursts of noise corrupts more bits
  - given noise level, higher rates mean higher errors
- Shannon developed formula relating these to signal to noise ratio (in decibels)
- $SNR_{db}=10 \log_{10}$ (signal/noise)
- capacity $C = B \log_2(1+SNR)$
  - theoretical maximum capacity
  - get much lower rates in practice

2.2 Adaptadors al canal

1. Codificació
2. Modulació
3. Multiplexació
4. Commutació

Signal Adaptation Techniques

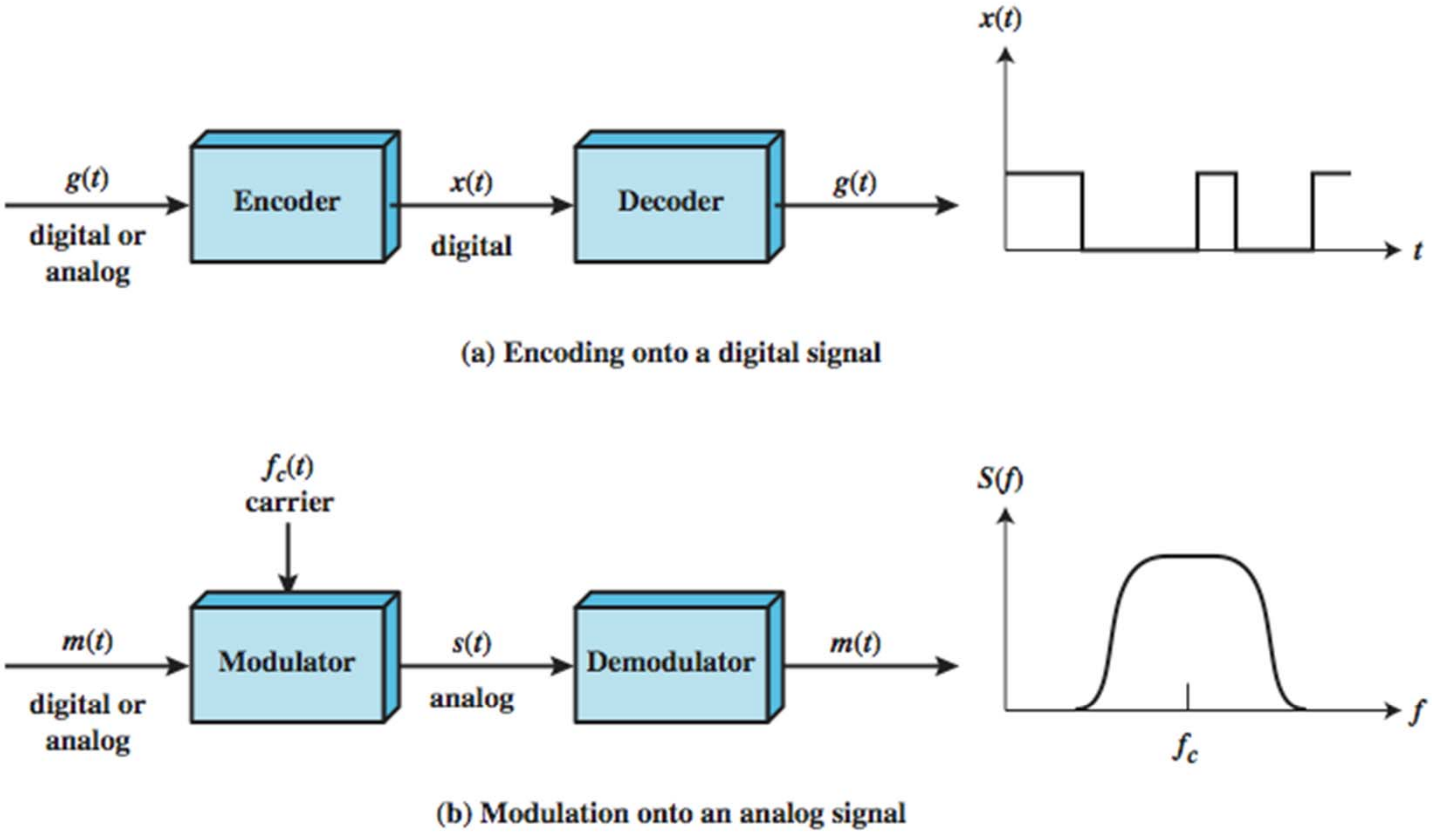


Figure 5.1 Encoding and Modulation Techniques

1. Encoding

- signal spectrum
- clocking
- error detection
- signal interference and noise immunity
- cost and complexity

Encoding Schemes

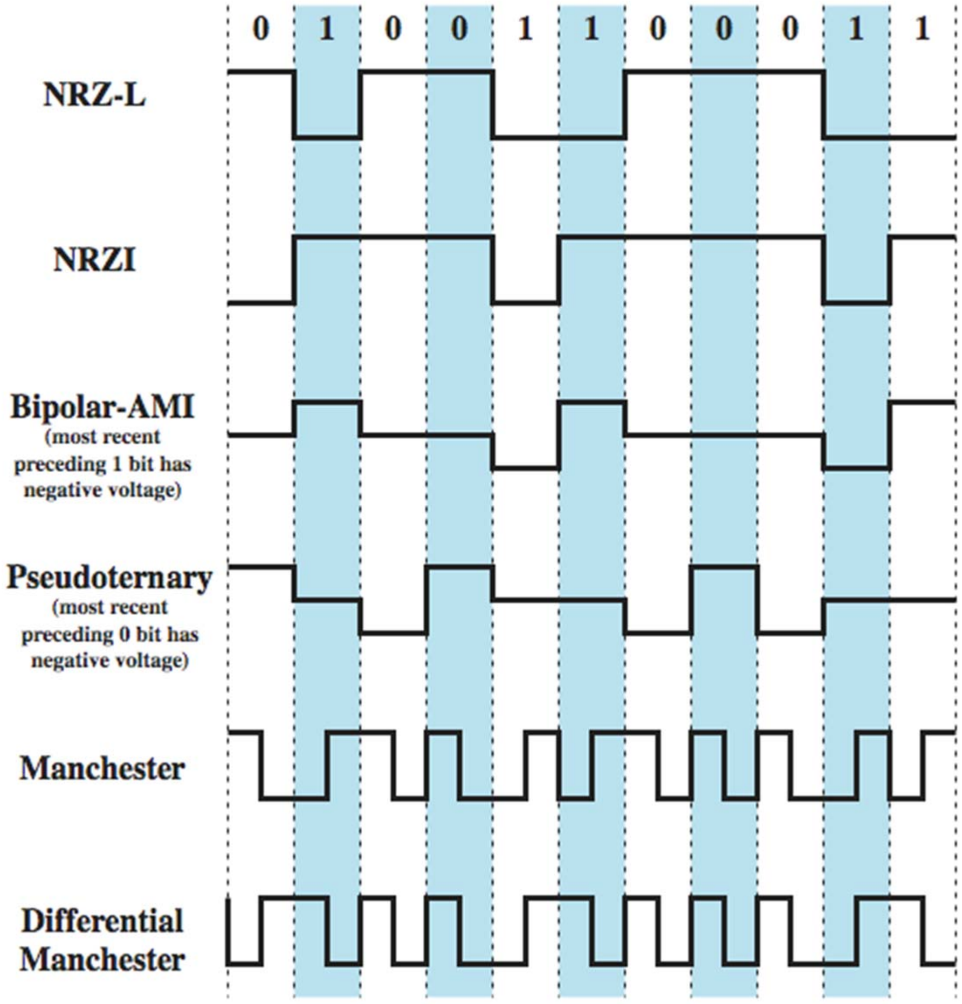


Figure 5.2

Modulation Rate

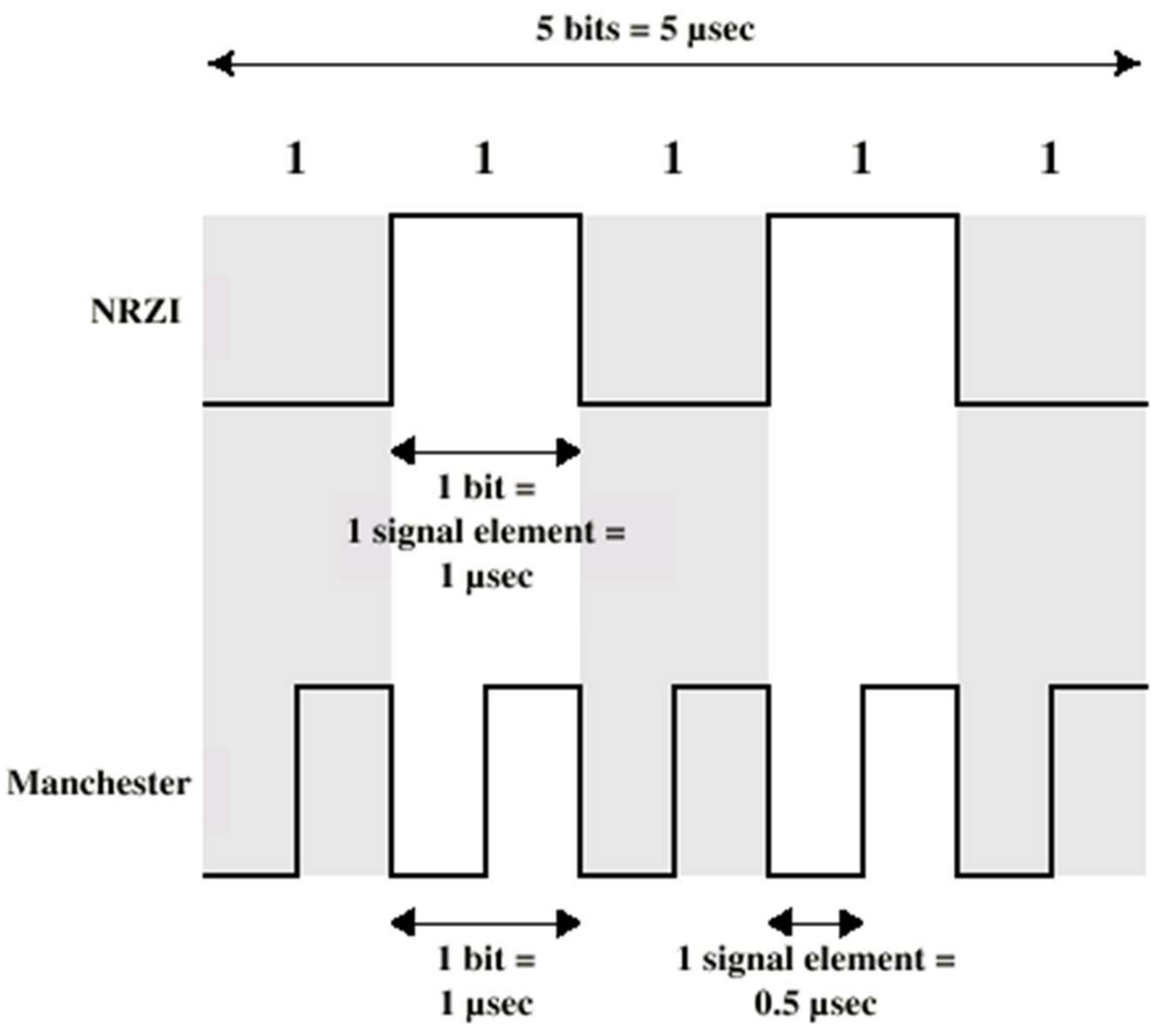


Figure 5.5

2.Modulation Techniques

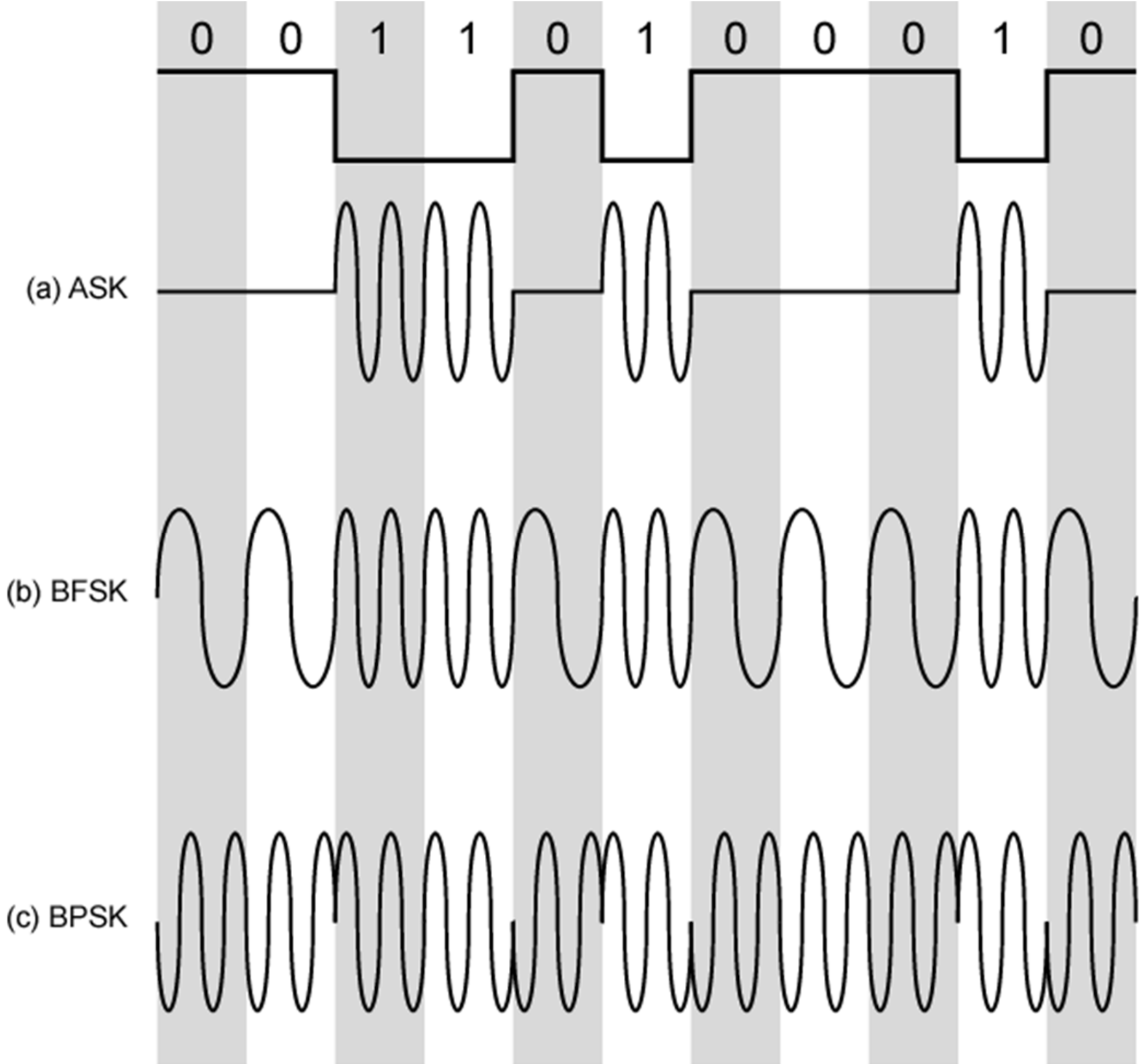
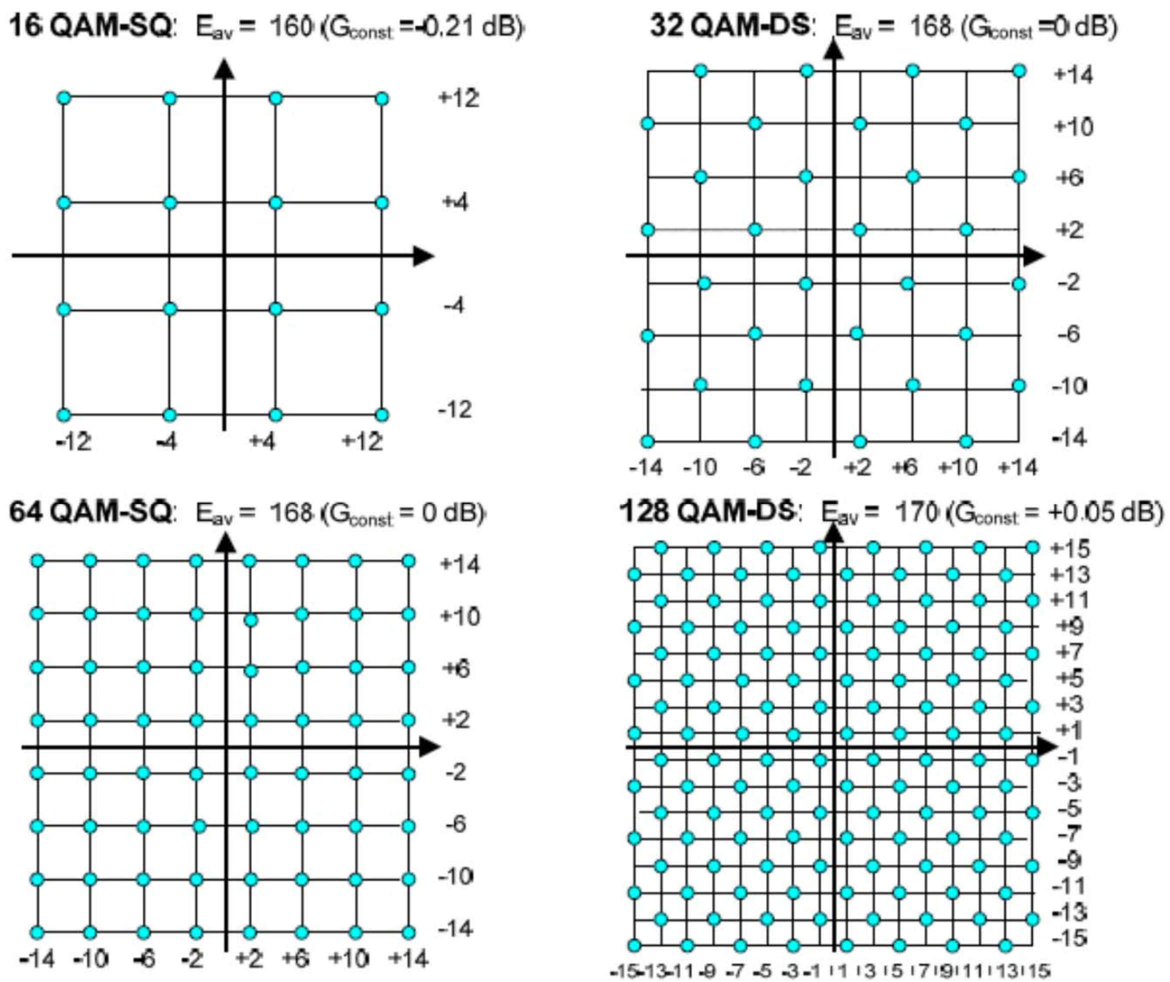


Figure 5.7

Quadrature Amplitude Modulation

- QAM used on asymmetric digital subscriber line (ADSL) and some wireless
- combination of ASK and PSK
- send two different signals simultaneously on same carrier frequency
  - use two copies of carrier, one shifted 90°
  - each carrier is ASK modulated
  - two independent signals over same medium
  - demodulate and combine for original binary output

QAM examples



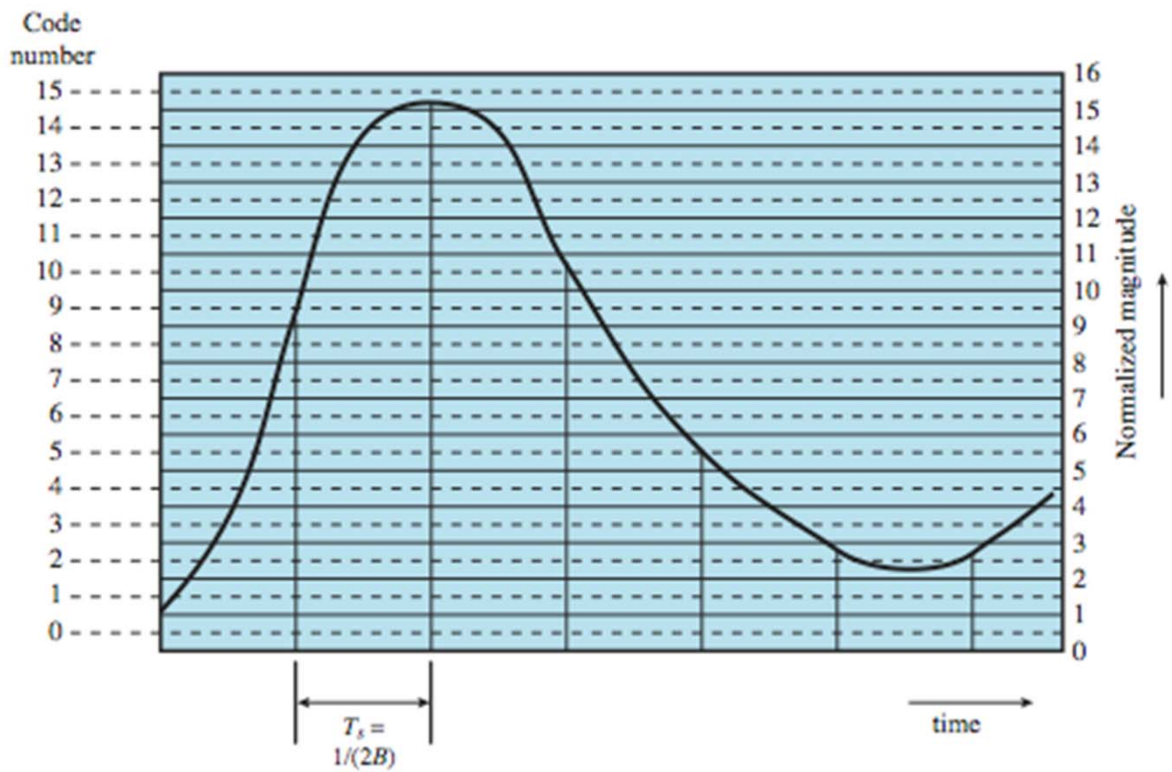
https://www.youtube.com/watch?v=qs2QcycggWU&ab_channel=BranchEducation

 Min 22:12 to the end

Pulse Code Modulation (PCM)

- sampling theorem:
  - “If a signal is sampled at regular intervals at a rate higher than twice the highest signal frequency, the samples contain all information in original signal”
  - eg. 4000Hz voice data, requires 8000 sample per sec
- strictly have analog samples
  - Pulse Amplitude Modulation (PAM)
- so assign each a digital value

PCM Example

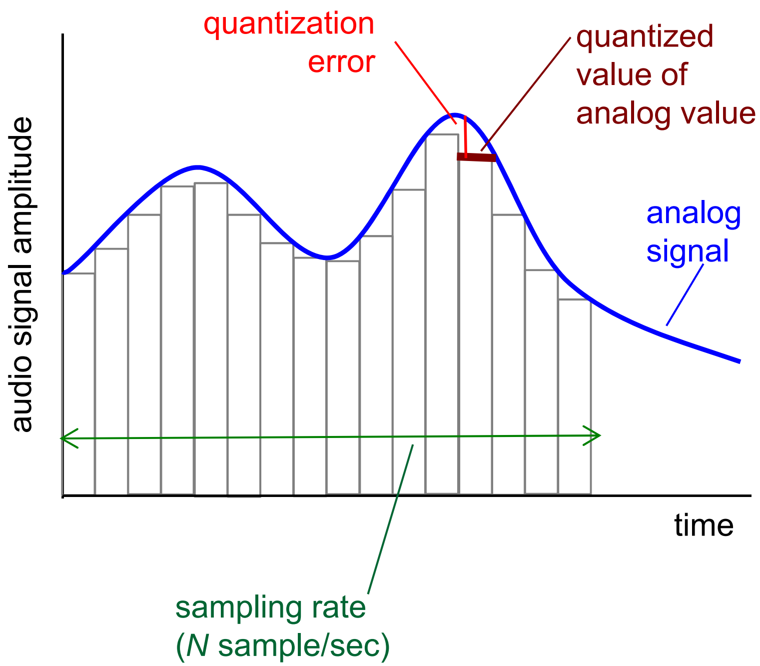


PAM value	1.1	9.2	15.2	10.8	5.6	2.8	2.7
quantized code number	1	9	15	10	5	2	2
PCM code	0001	1001	1111	1010	0101	0010	0010

Figure 5.17

Multimedia: audio

- analog audio signal sampled at constant rate
  - telephone: 8,000 samples/sec
  - CD music: 44,100 samples/sec
- each sample quantized, i.e., rounded
  - e.g., 2^8=256 possible quantized values
  - each quantized value represented by bits, e.g., 8 bits for 256 values



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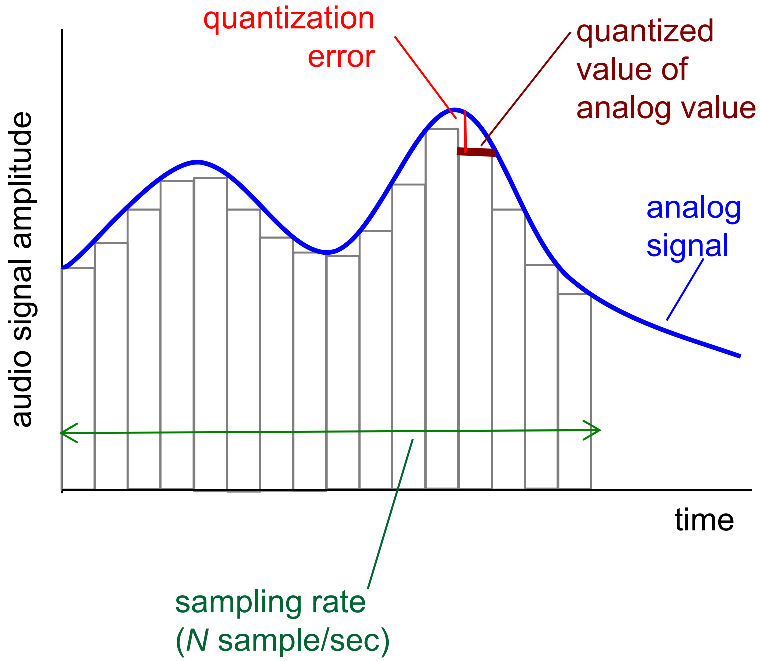
Multimedia: audio

- example: 8,000 samples/sec, 256 quantized values: 64,000 bps
- receiver converts bits back to analog signal:
  - some quality reduction



<u>example rates</u>

- CD: 1.411 Mbps
- MP3: 96, 128, 160 kbps
- Internet telephony: 5.3 kbps and up

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3. Multiplexing

- multiple links on 1 physical line
- common on long-haul, high capacity, links
- have FDM, TDM, STDM alternatives

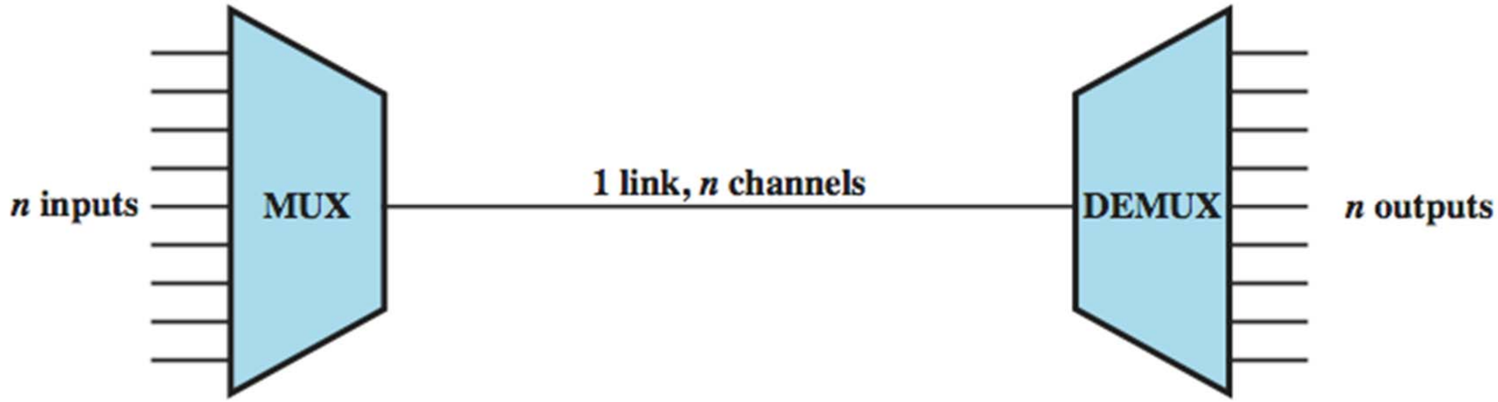
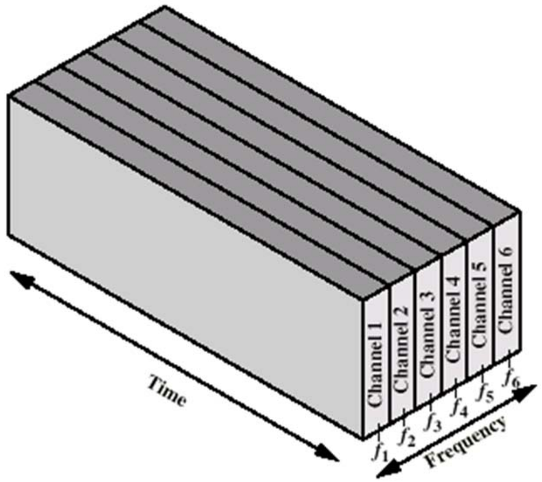


Figure 8.1

Frequency Division Multiplexing

- FDM
- Useful bandwidth of medium exceeds required bandwidth of channel
- Each signal is modulated to a different carrier frequency
- Carrier frequencies separated so signals do not overlap (guard bands)
- e.g. broadcast radio
- Channel allocated even if no data

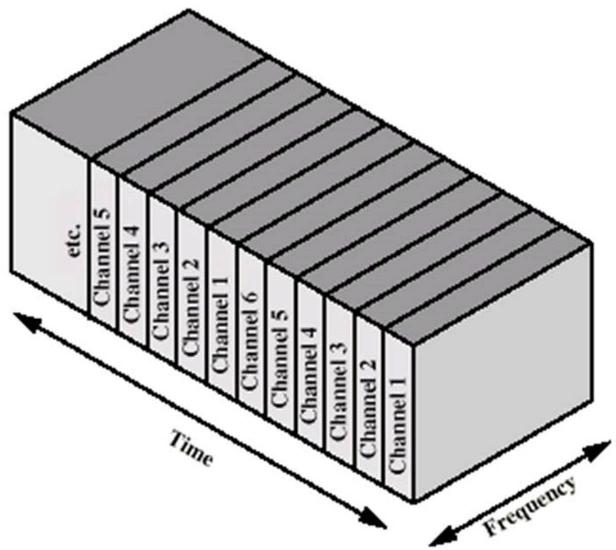


Wavelength Division Multiplexing

- Multiple beams of light at different frequency
- Carried by optical fiber
- A form of FDM
- Each color of light (wavelength) carries separate data channel
- Commercial systems of 400 Gbps now available

Time Division Multiplexing

- Data rate of medium exceeds data rate of digital signal to be transmitted
- Multiple digital signals interleaved in time
- May be at bit level of blocks
- Time slots preassigned to sources and fixed
- Time slots allocated even if no data
- Time slots do not have to be evenly distributed amongst sources

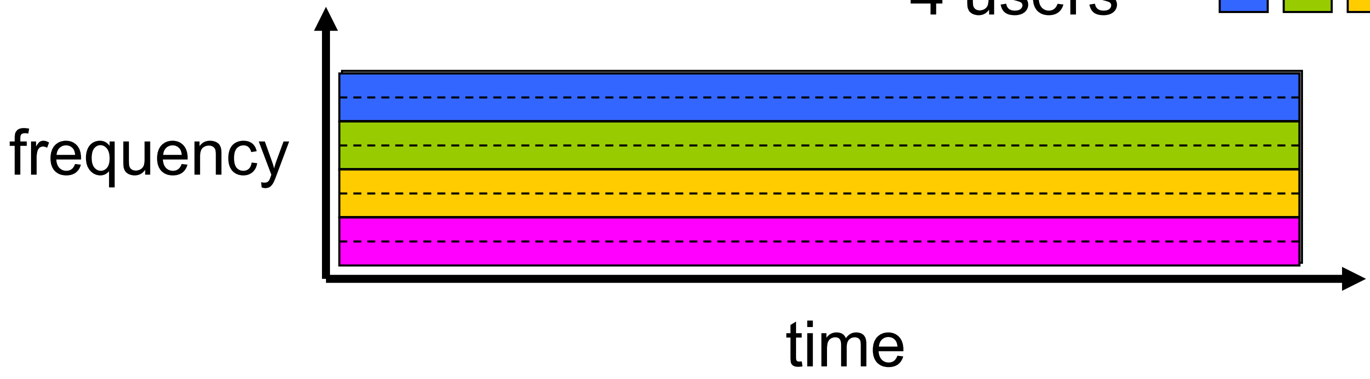


FDM versus TDM

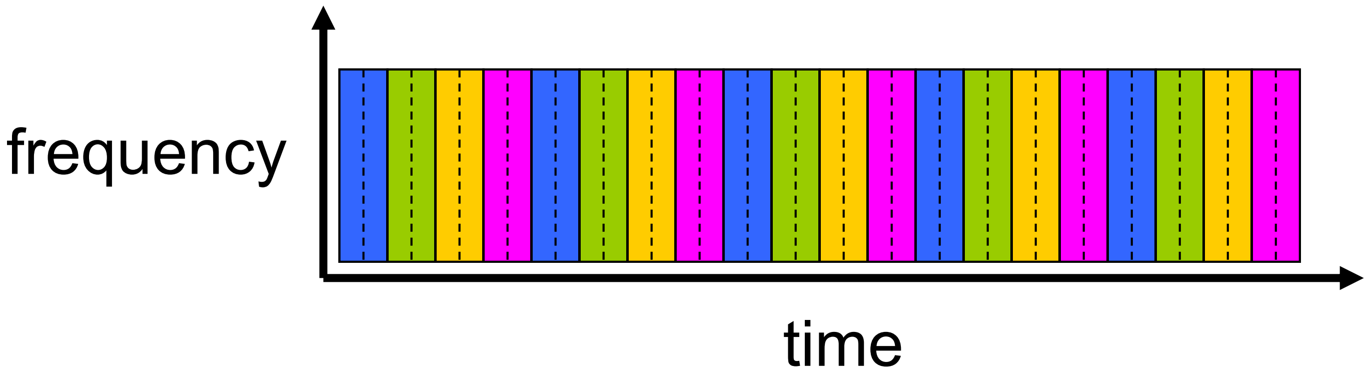
Example:

4 users

FDM



TDM



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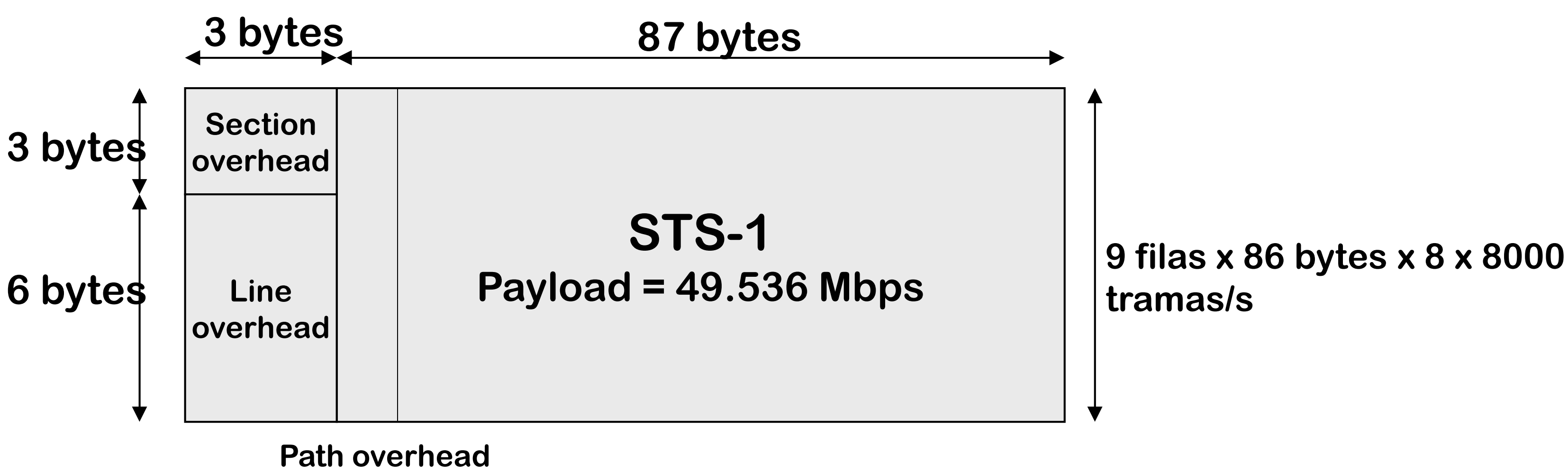
Multiplexació digital
Xarxes SDH

SONET/SDH

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

SONET

- SONET transmite datos en tramas:
  - La trama OC-1 es un conjunto bidimensional de 90 columnas por 9 filas de octetos (bytes).
    - *Las primeras 3 columnas (27 bytes) son el overhead de transporte*
    - *La velocidad es 8000 tramas por segundo (cada 125 microsegundos):*
    - *90 x 9 x 8 x 8000=90 x 9 x 64 kbps = 51.84 Mbps*
  - La trama de OC-n son n tramas de OC-1

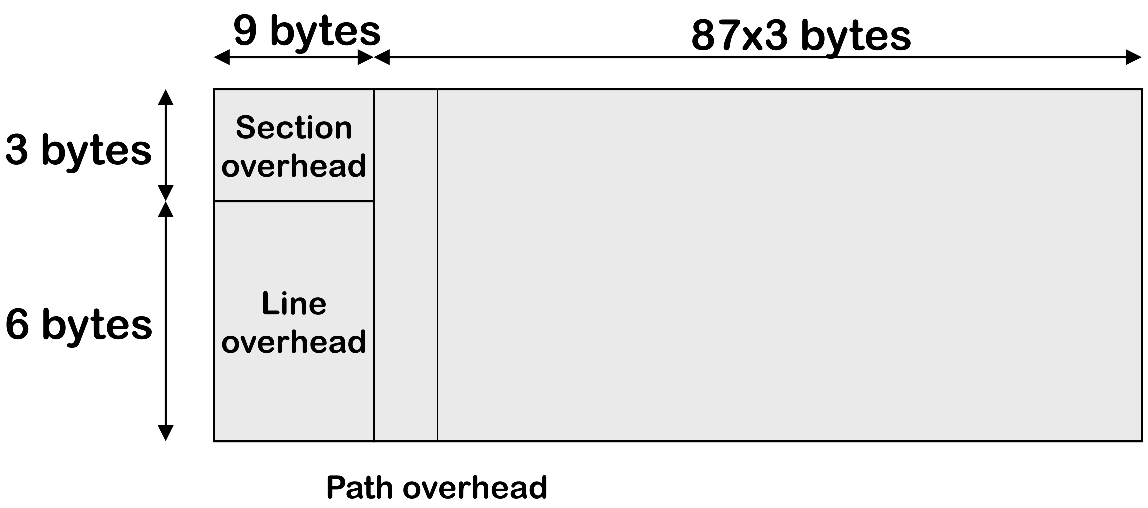


SDH

- SDH: Synchronous Digital Hierarchy
- SDH es una tecnología de transmisión (G.707-G.709)
  - la forma en que los datos están codificados
  - velocidades
  - esquemas de multiplexación
  - técnicas de codificación
  - medios de transmisión

SDH

- 3 tramas Sonet forman una SDH
- 3 x 51.84 Mbps = 155.52 Mbps



Cada 125 μs

SONET/SDH Signal Hierarchy

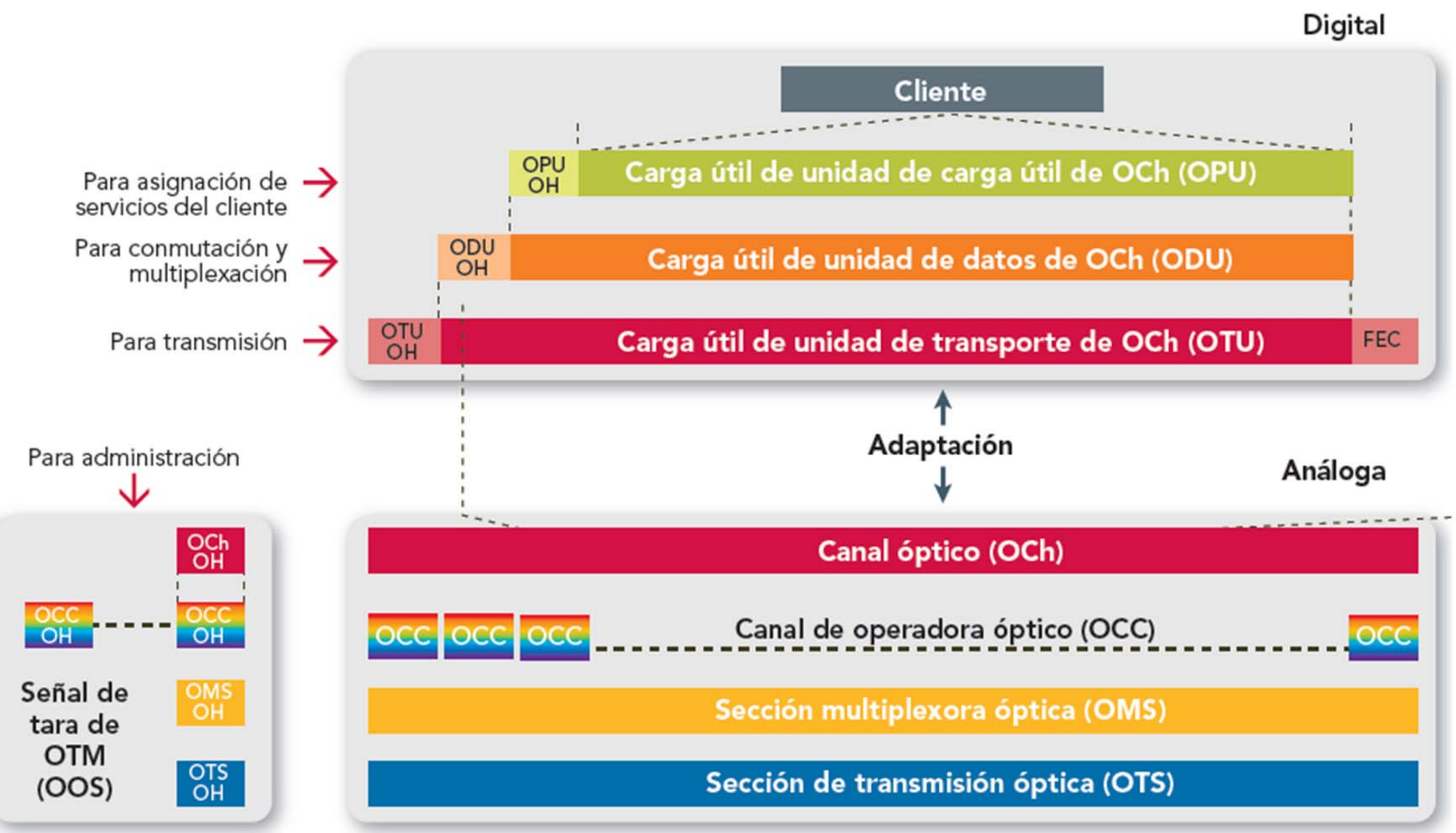
SONET Designation	ITU-T Designation	Data Rate	Payload Rate (Mbps)
STS-1/OC-1		51.84 Mbps	50.112 Mbps
STS-3/OC-3	STM-1	155.52 Mbps	150.336 Mbps
STS-12/OC-12	STM-4	622.08 Mbps	601.344 Mbps
STS-48/OC-48	STM-16	2.48832 Gbps	2.405376 Gbps
STS-192/OC-192	STM-64	9.95328 Gbps	9.621504 Gbps
STS-768	STM-256	39.81312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

Table 8.4

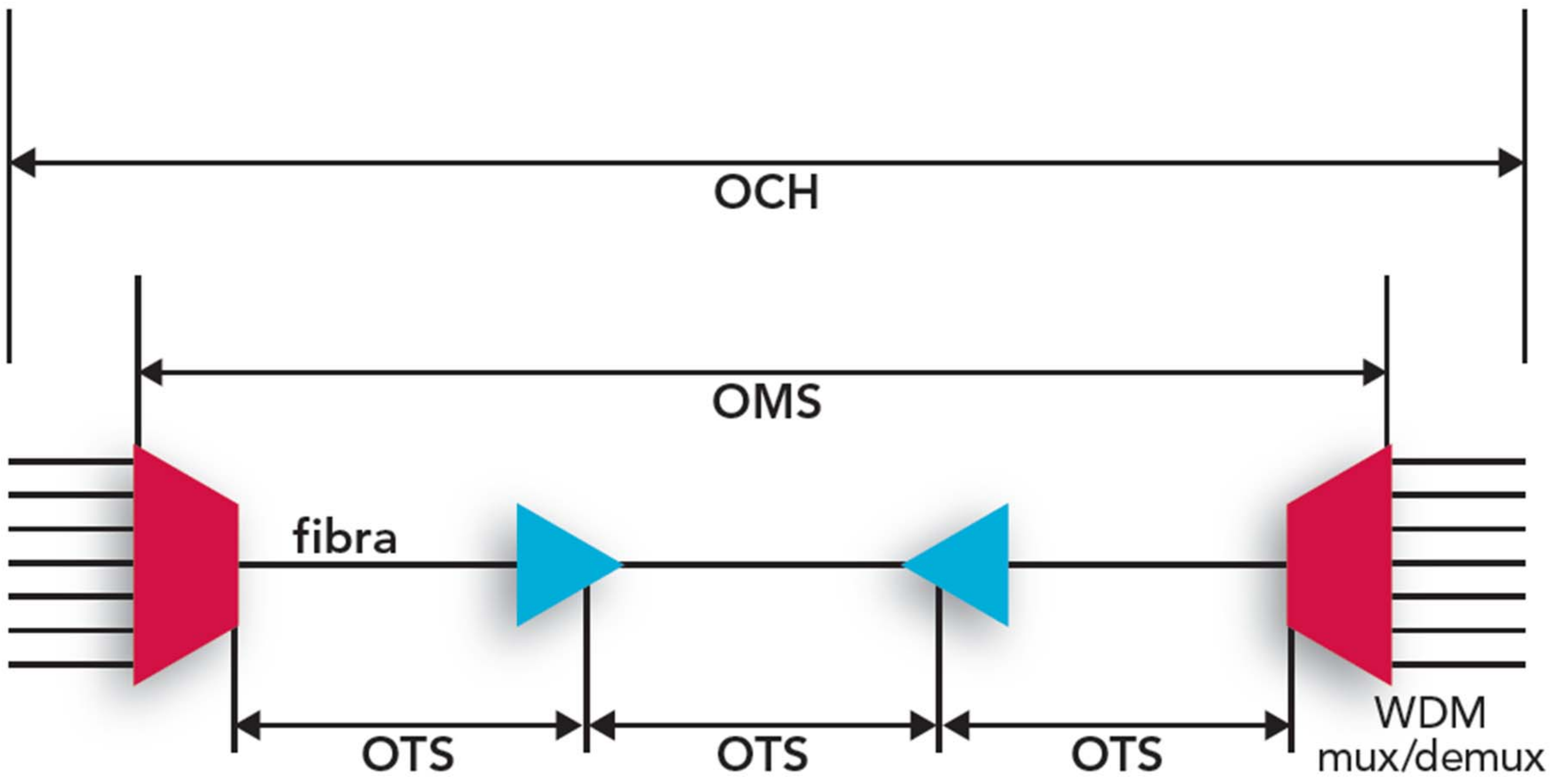
Facultat d' informàtica de Barcelona

Multiplexació òptica
Xarxes OTN

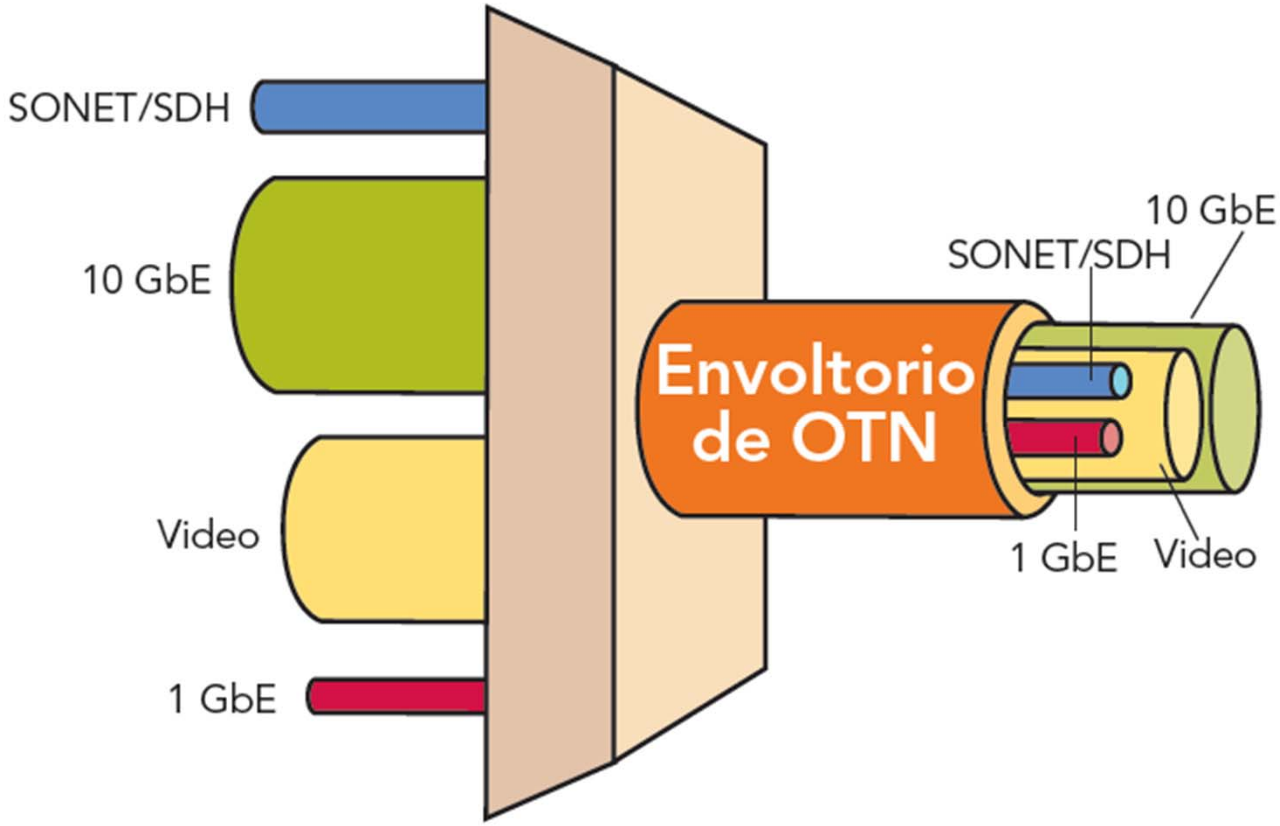
Mòdul de transport òptic (OTM)



Estructura de la linea OTN



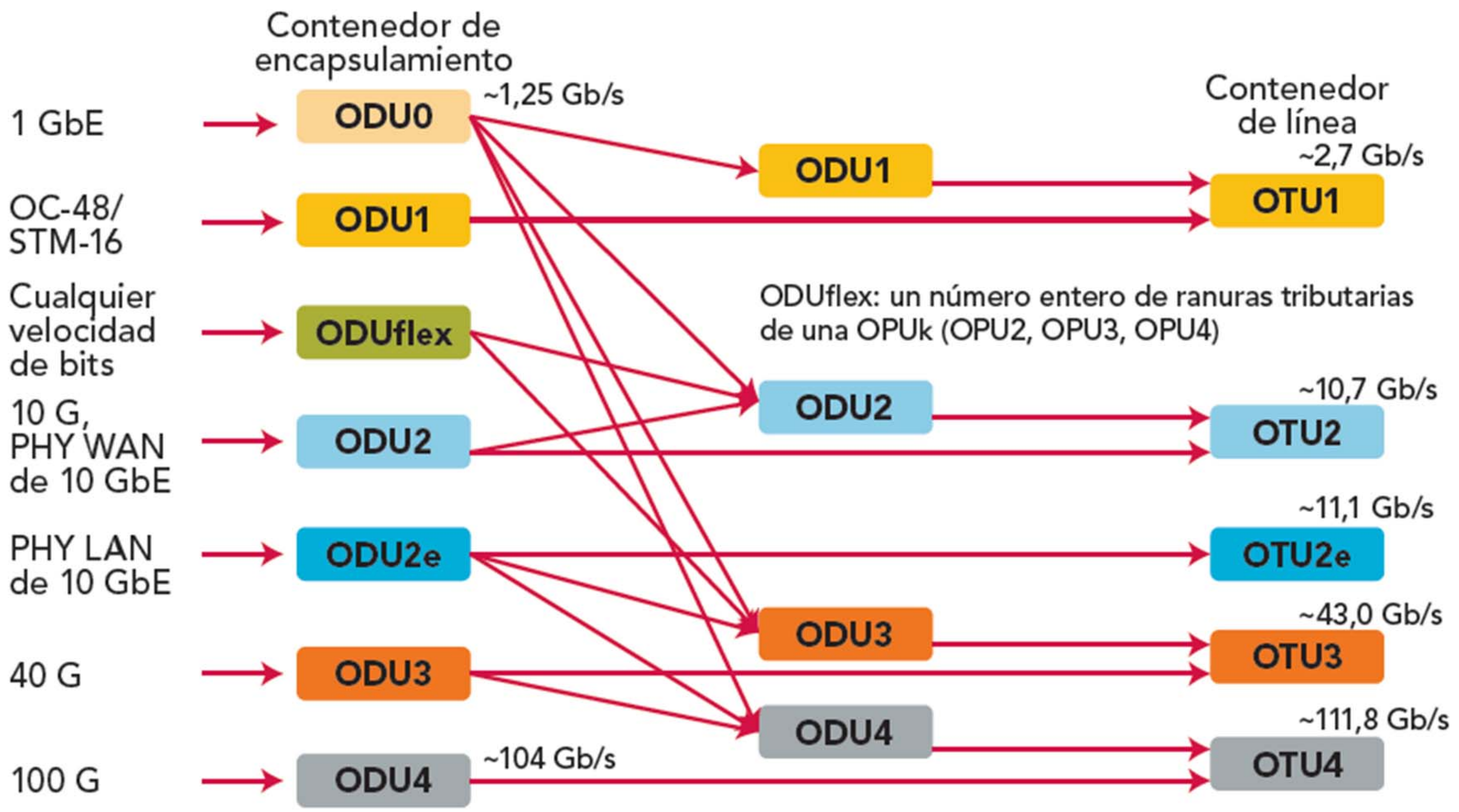
Ports de clients



Velocitats de linea OTN

Señal	Velocidad aproximada de transmisión de datos (Gb/s)	Optimizada para
OTU1	2.66	Transporte de señal SONET OC-48 o SDH STM-16
OTU2	10.70	Transporte de capa física (PHY) de red de área amplia (WAN) de 10 GbE o SONET OC-192 O SDH STM-64
OTU2e	11.09	Transporte PHY de red de área local (LAN) de 10 GbE (para puertos de enrutadores /conmutadores de IP/ Ethernet) a velocidad de línea máxima (10,3 Gb/s)
OTU3	43.01	Transporte de señal de 40 GbE o SONET OC-768, SDH STM-256
OTU3e2	44.58	Transporte de hasta cuatro señales OTU2e
ODU4	112	Transporte de señal de 100 GbE

Jerarquia d’assignació OTN



4. Switched Network

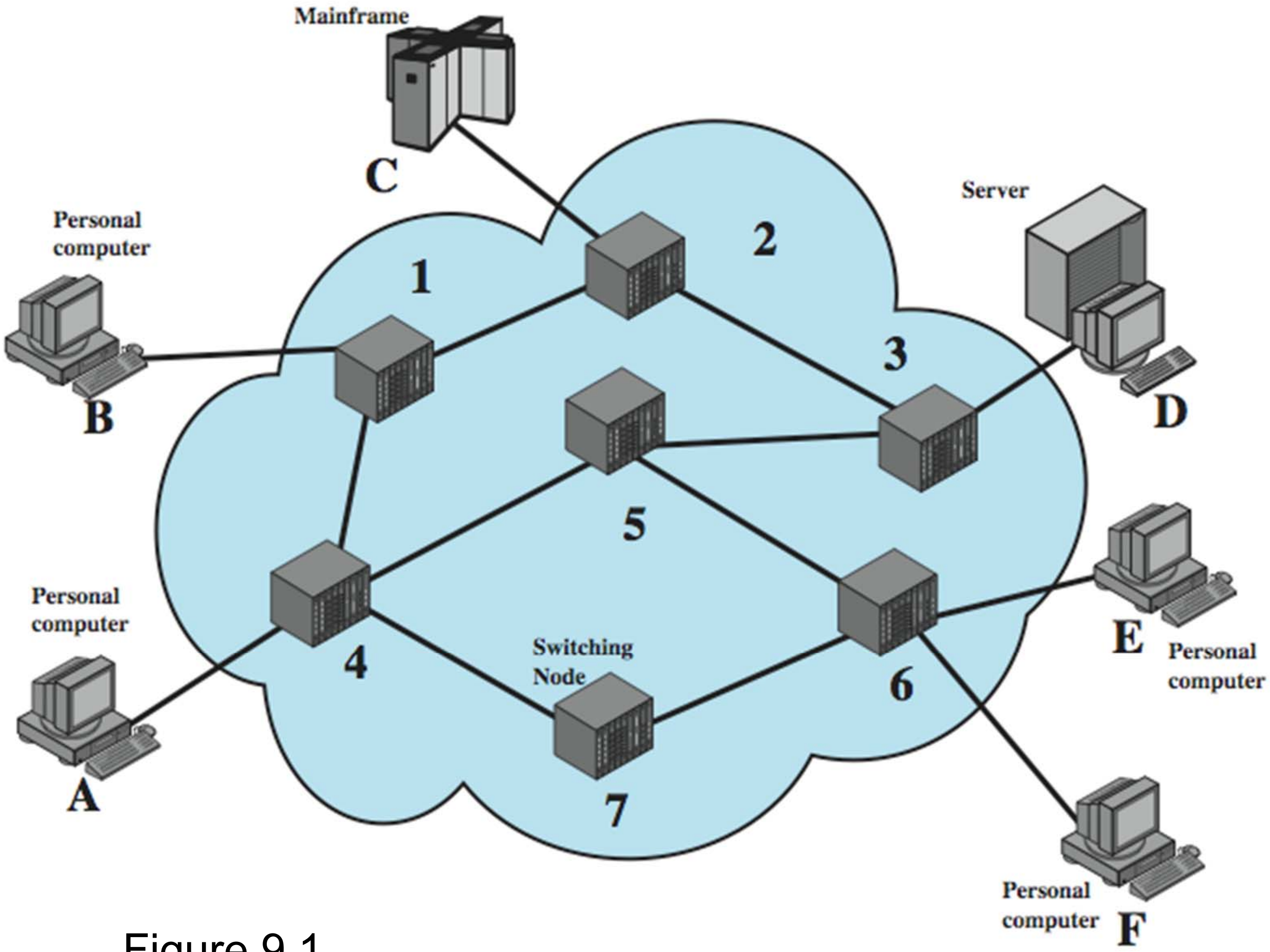


Figure 9.1

Nodes

- a collection of nodes and connections is a communications network
- nodes may connect to other nodes only, or to stations and other nodes
- network is usually partially connected
  - some redundant connections are desirable
- have two different switching technologies
  - circuit switching
  - packet switching

Circuit Switching

- uses a dedicated path between two stations
- has three phases
  - establish
  - transfer
  - disconnect
- inefficient
  - channel capacity dedicated for duration of connection
  - if no data, capacity wasted
- set up (connection) takes time
- once connected, transfer is transparent

Packet Switching

- circuit switching was designed for voice
- packet switching was designed for data
- transmitted in small packets
- packets contains user data and control info
  - user data may be part of a larger message
  - control info includes routing (addressing) info
- packets are received, stored briefly (buffered) and past on to the next node

Packet Switching

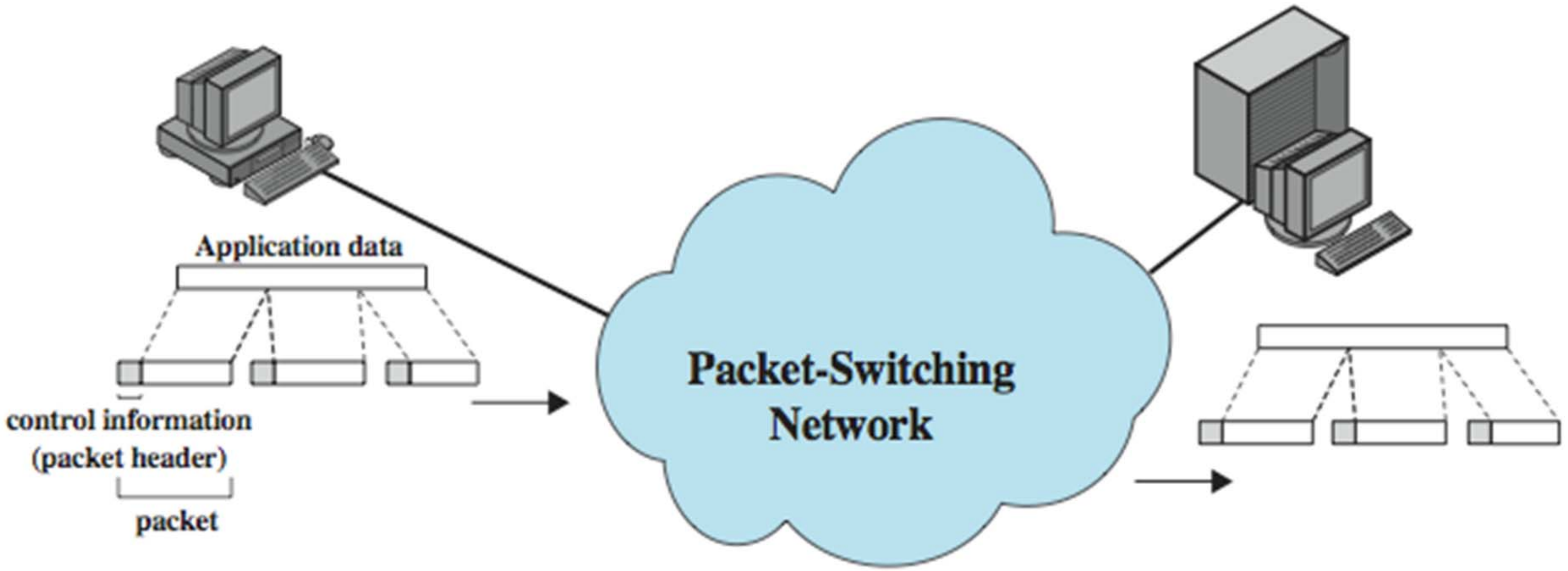


Figure 9.10

Advantages

- line efficiency
  - single link shared by many packets over time
  - packets queued and transmitted as fast as possible
- data rate conversion
  - stations connects to local node at own speed
  - nodes buffer data if required to equalize rates
- packets accepted even when network is busy
- priorities can be used

Datagram Diagram

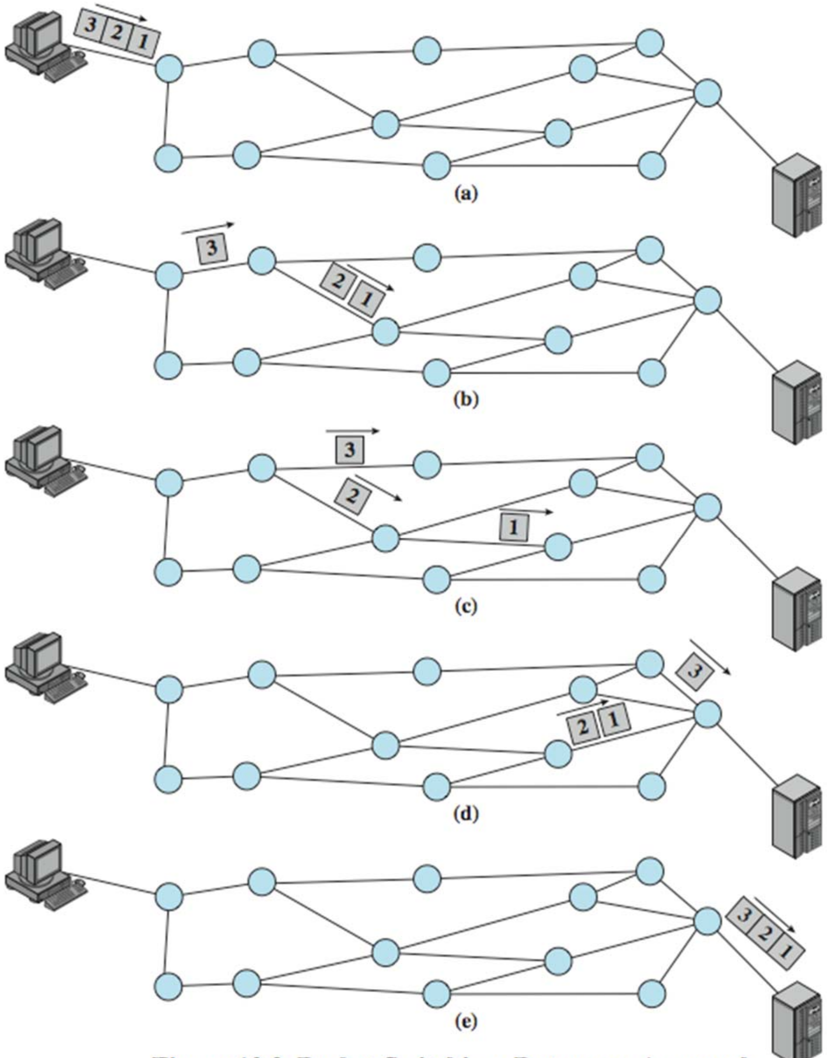


Figure 10.9 Packet Switching: Datagram Approach

Figure 9.11

Virtual Circuit Diagram

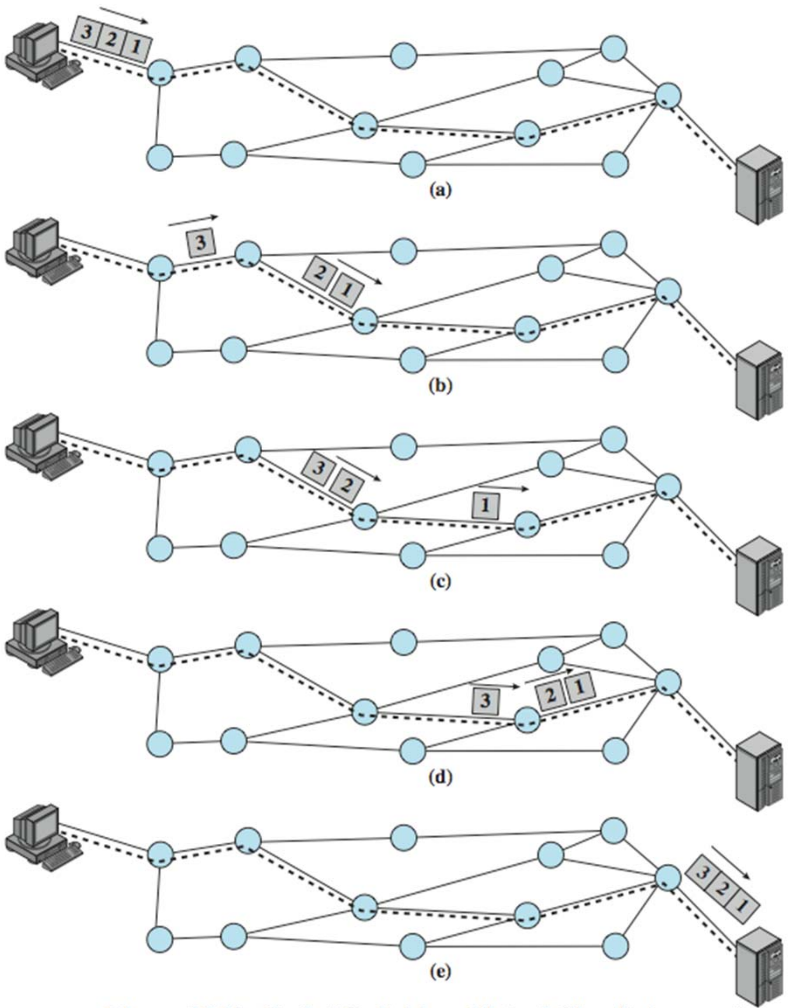


Figure 10.10 Packet Switching: Virtual-Circuit Approach

Figure 9.12

Virtual Circuits v Datagram

- virtual circuits
  - network can provide sequencing and error control
  - packets are forwarded more quickly
  - less reliable
- datagram
  - no call setup phase
  - more flexible
  - more reliable

Packet Size

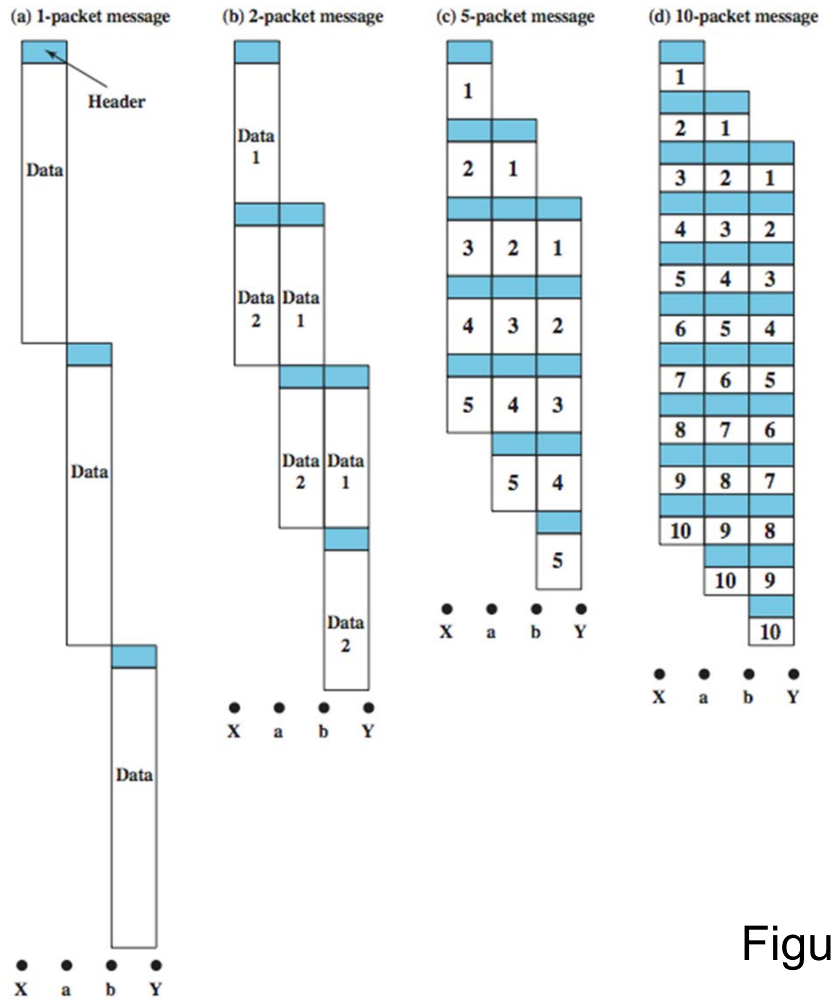
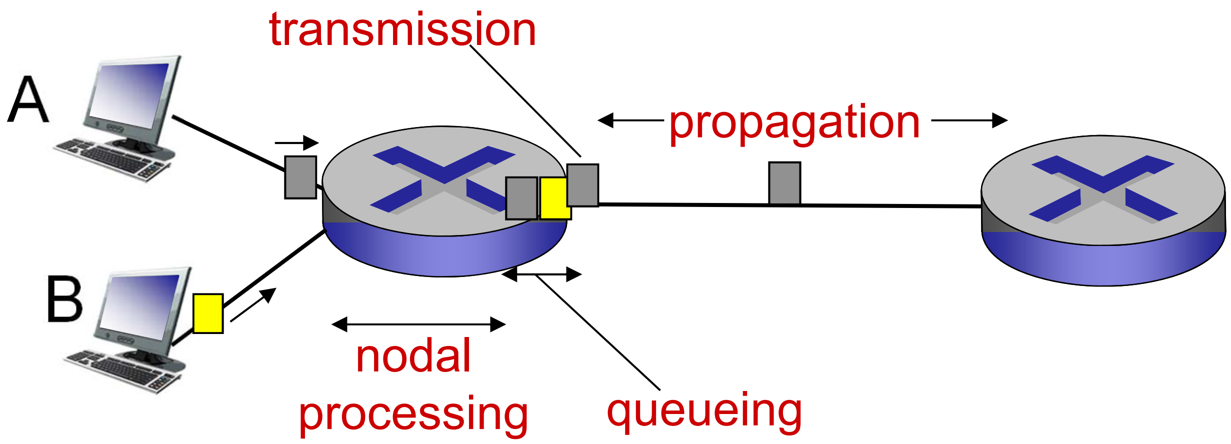


Figure 9.13

2.3 Fonts del retard de paquets

Four sources of packet delay



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{proc}: nodal processing

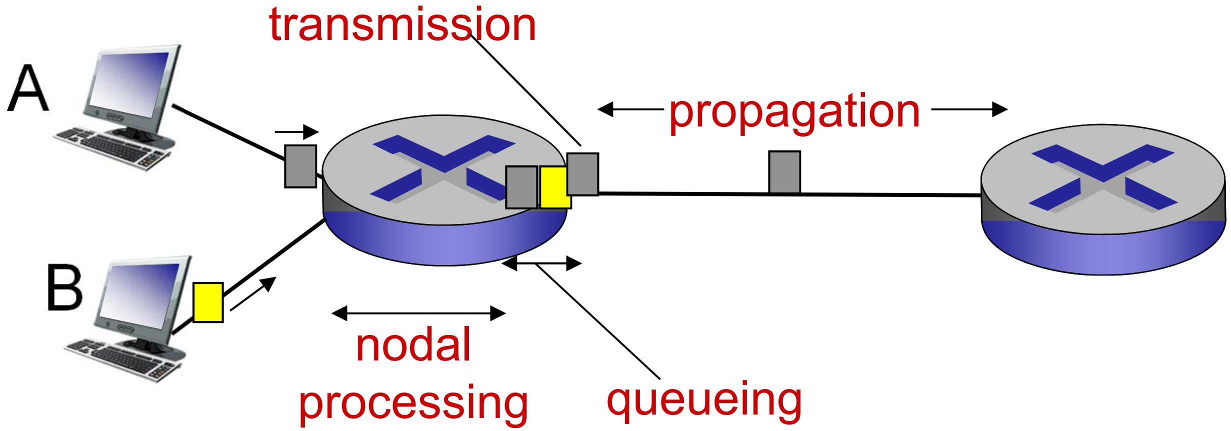
- check bit errors
- determine output link
- typically < msec

d_{queue}: queueing delay

- time waiting at output link for transmission
- depends on congestion level of router

Book: Computer Networking: A Top Down Approach, Seventh Edition by KUROSE James F. and ROSS Keith W. , 2017. Chap 1.

Four sources of packet delay



$$d_{nodal} = d_{proc} + d_{queue} + d_{trans} + d_{prop}$$

d_{trans}: transmission delay:
- L: packet length (bits)
- R: link *bandwidth (bps)*
- $d_{trans} = L/R$

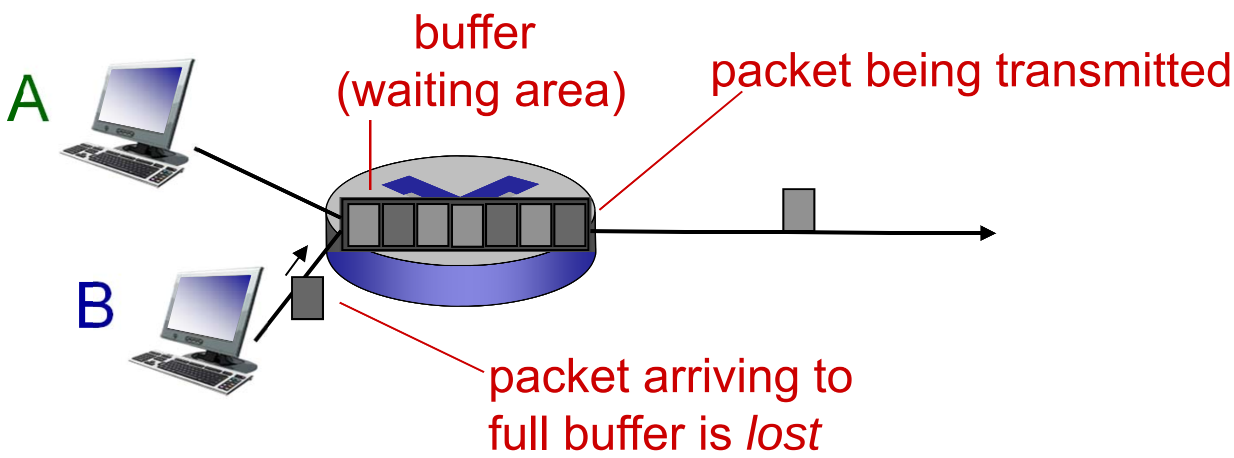
d_{prop}: propagation delay:
- d: length of physical link
- s: propagation speed (~3x10^8 m/sec)
- $d_{prop} = d/s$

d_{trans} and d_{prop} *very* different

Book: Computer Networking: A Top Down Approach, Seventh Edition by KUROSE James F. and ROSS Keith W. , 2017. Chap 1.

Packet loss

- queue preceding link in buffer has finite capacity
- packet arriving to full queue dropped
- lost packet may be retransmitted by previous node, by source end system, or not at all



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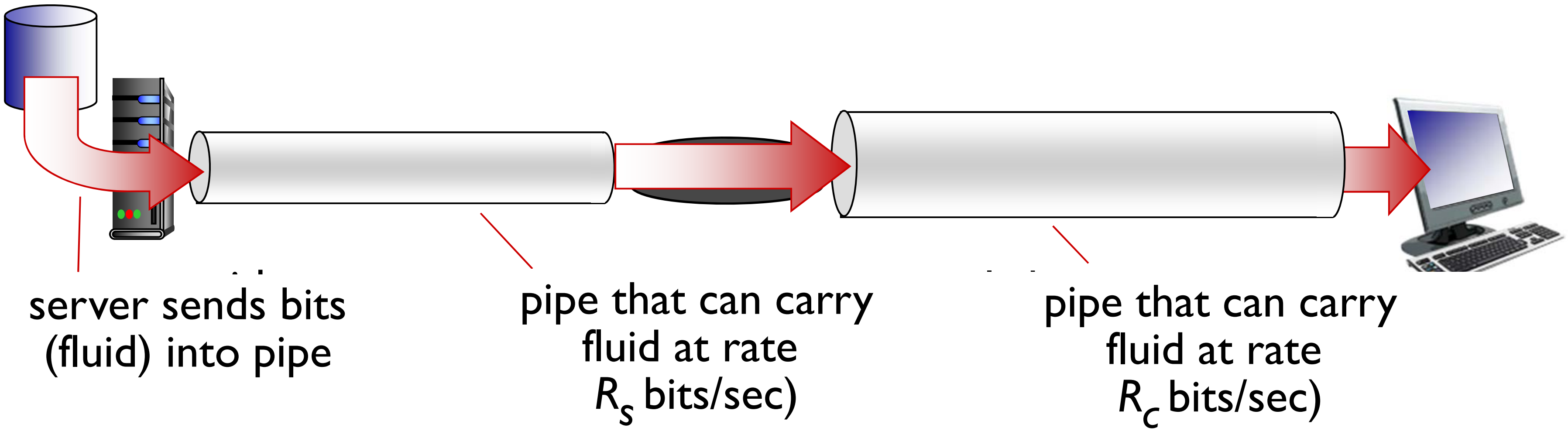
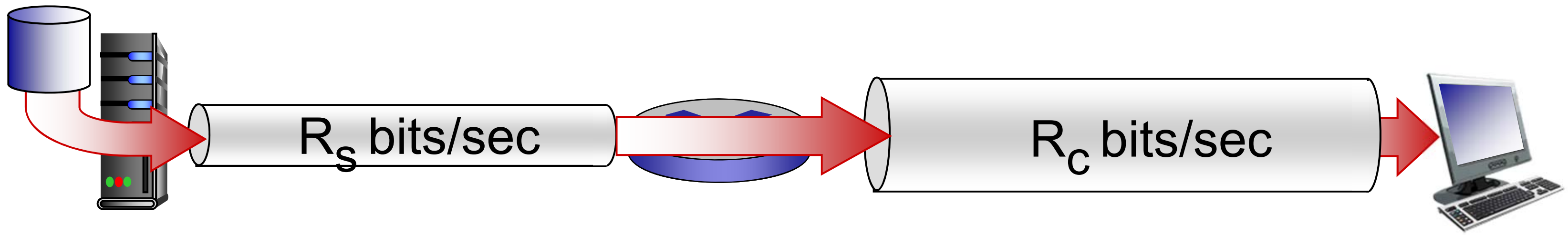
Throughput

- *throughput:* rate (bits/time unit) at which bits transferred between sender/receiver
  - *instantaneous:* rate at given point in time
  - *average:* rate over longer period of time

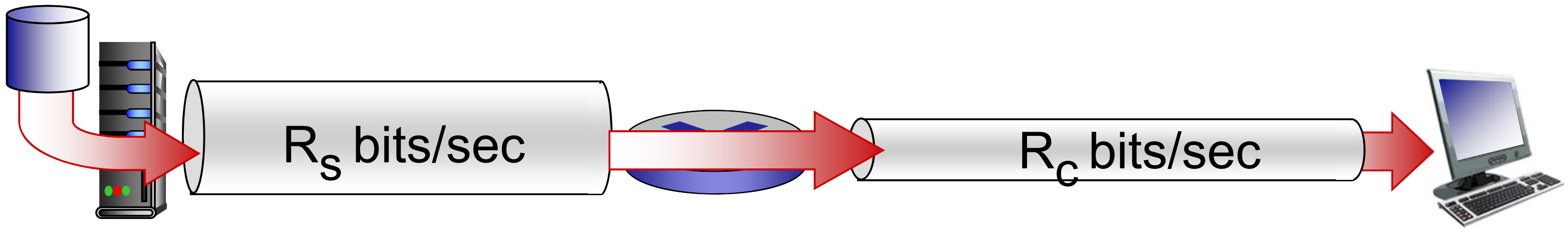


Throughput (more)

- $R_s < R_c$ What is average end-end throughput?



- $R_s > R_c$ What is average end-end throughput?



bottleneck link

link on end-end path that constrains end-end throughput