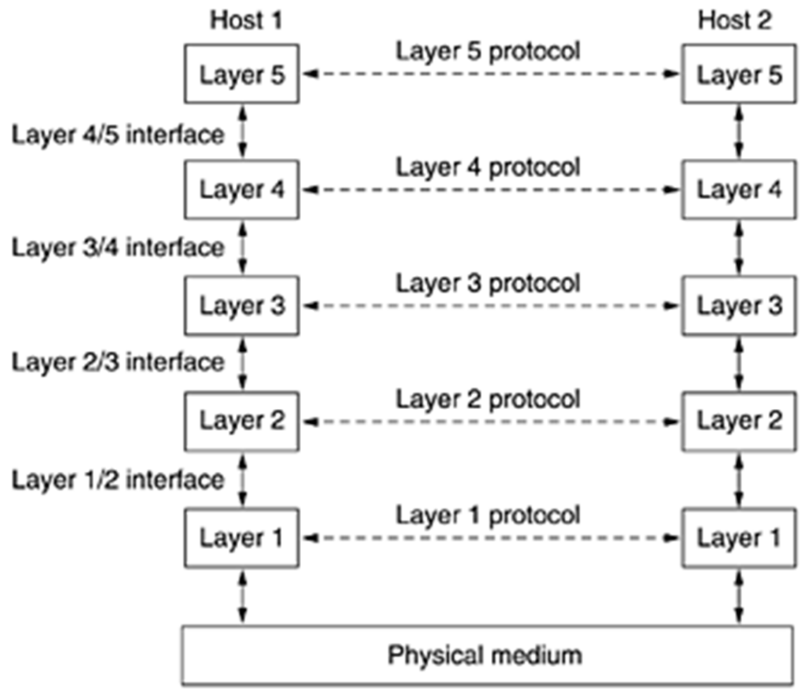
MIEEC

Computer Networks

Lecture note 3

The physical layer

The physical layer as a service



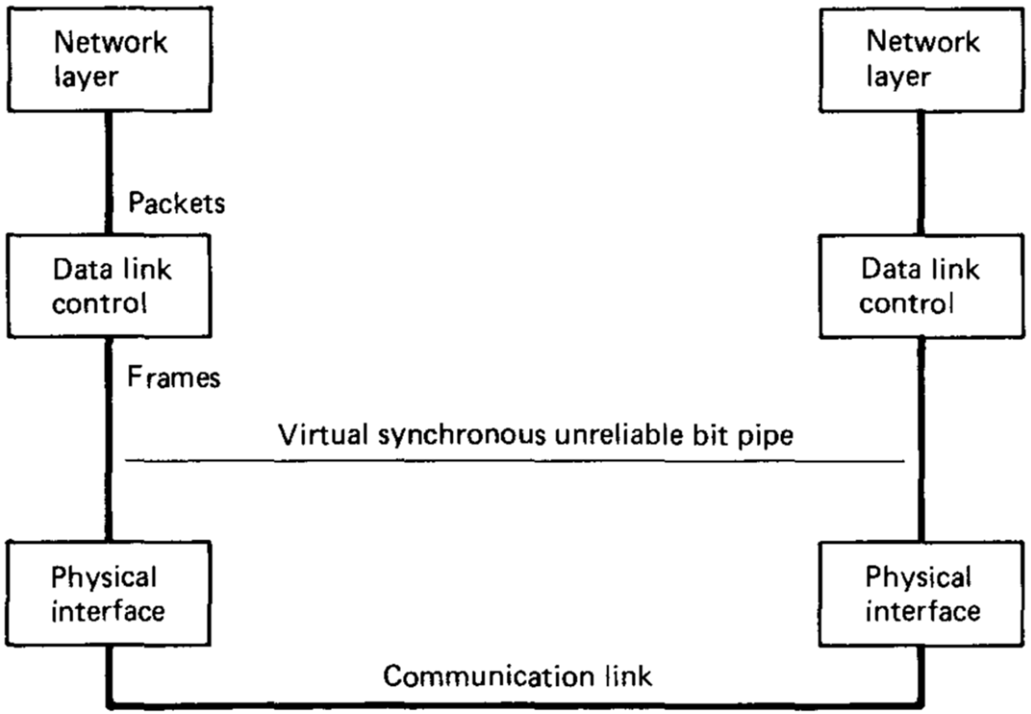
Physical layer service

Service:

- Transmission and reception of digital data
- Virtual bit stream (unreliable)

Implementation:

- Actual communication channels used by the network



Principles of signal transmission

TO THINK

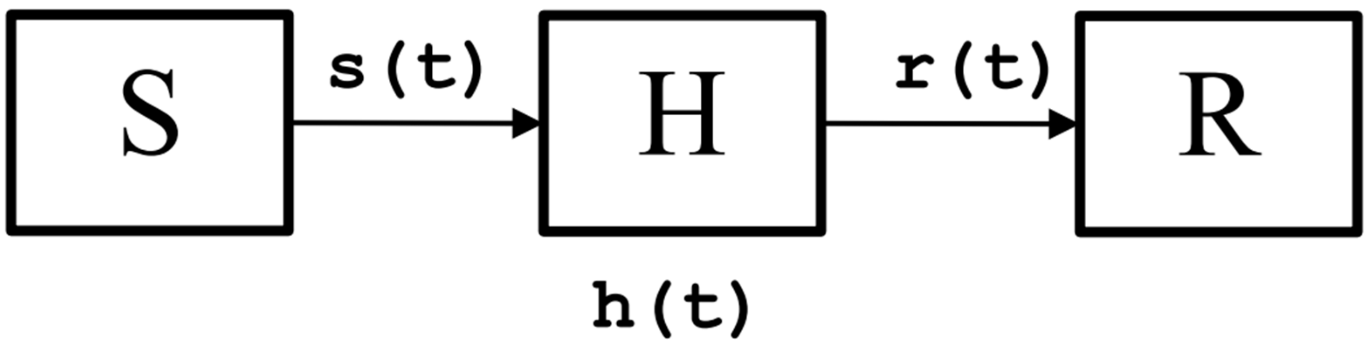
If you transmit 1 bit every T seconds

you get 1/T bit/s

- Why can't you transmit infinite bit/s using a real cable?

Channel transmission

- Source signal s(t)
- Received signal r(t)
- Channel H, impulse response h(t)



Effect of channel on r(s)

- Filter effect on signal

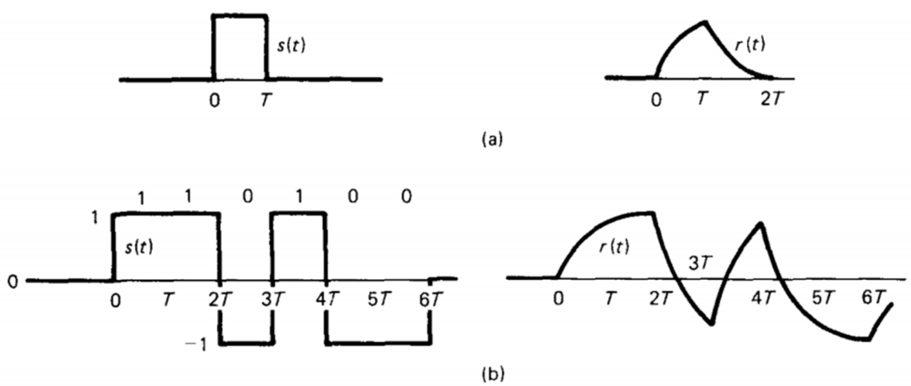


Figure 2.3 Relation of input and output waveforms for a communication channel with filtering. Part (a) shows the response $r(t)$ to an input $s(t)$ consisting of a rectangular pulse, and part (b) shows the response to a sequence of pulses. Part (b) also illustrates the NRZ code in which a sequence of binary inputs (1 1 0 1 0 0) is mapped into rectangular pulses. The duration of each pulse is equal to the time between binary inputs.

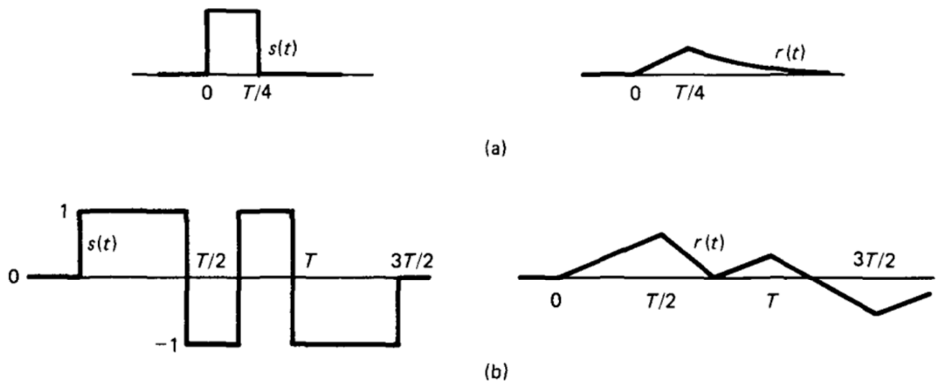
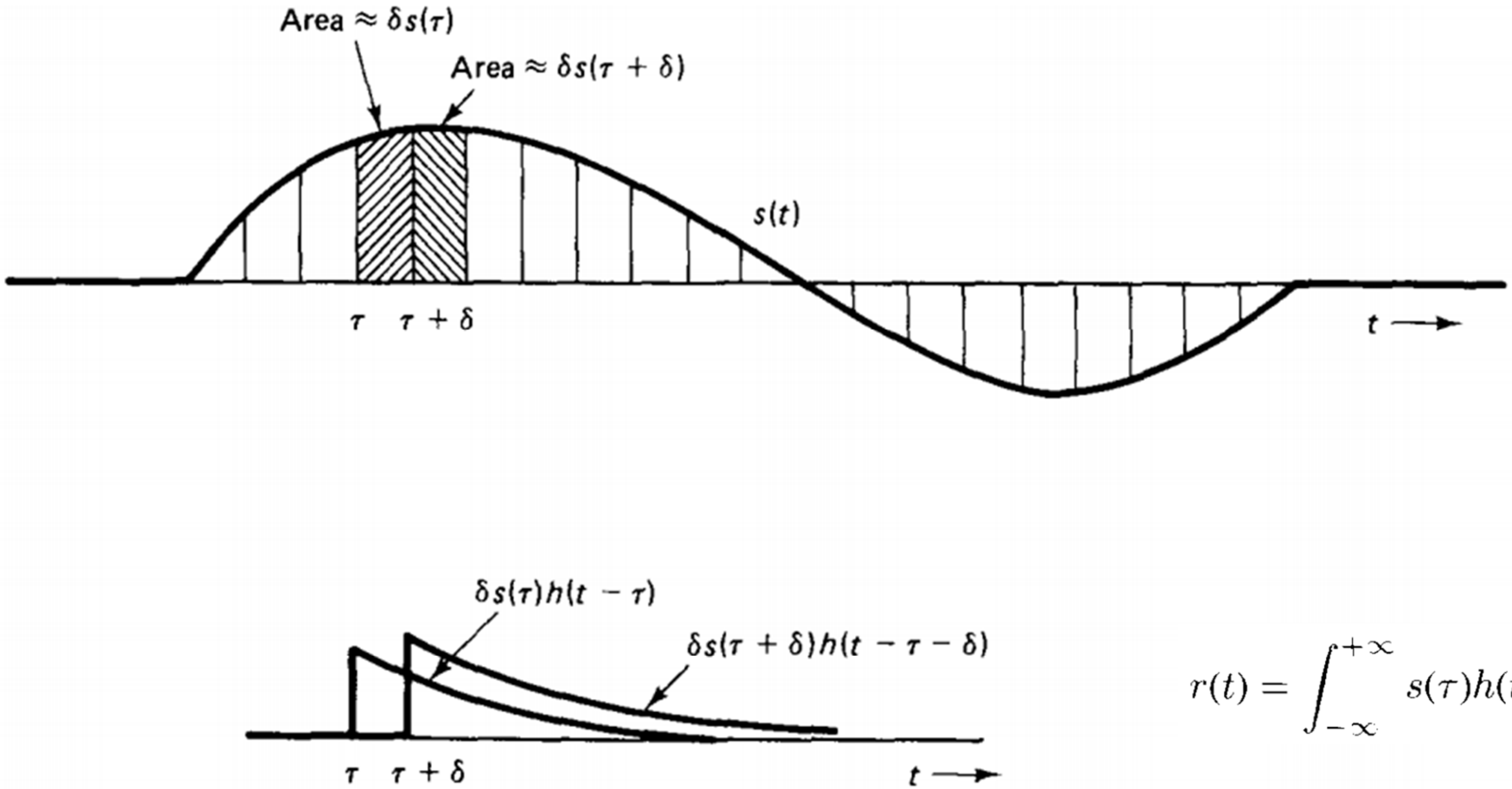


Figure 2.4 Relation of input and output waveforms for the same channel as in Fig. 2.3. Here the binary digits enter at 4 times the rate of Fig. 2.3, and the rectangular pulses last one-fourth as long. Note that the output $r(t)$ is more distorted and more attenuated than that in Fig. 2.3.

r(s): convolution of s(t) and h(t)



$$r(t) = \int_{-\infty}^{+\infty} s(\tau)h(t-\tau)d\tau$$

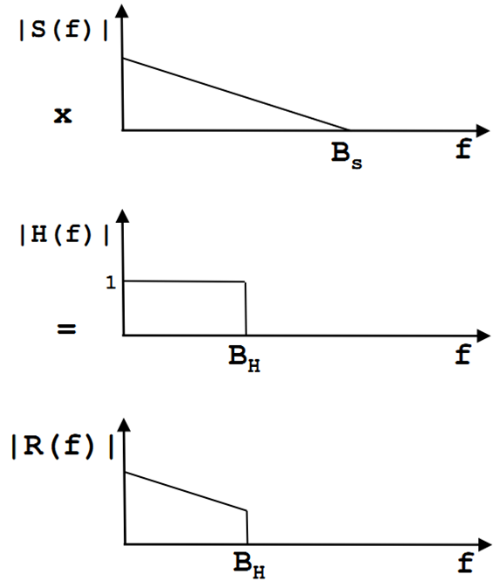
Figure 2.5 Graphical interpretation of the convolution equation. Input $s(t)$ is viewed as the superposition of narrow pulses of width δ. Each such pulse yields an output $\delta s(\tau)h(t-\tau)$. The overall output is the sum of these pulse responses.

R(f): product of S(f) and H(f)

- Fourier transforms

$$S(f) = \int_{-\infty}^{\infty} s(t)e^{-j2\pi ft}dt \quad H(f) = \int_{-\infty}^{\infty} h(\tau)e^{-j2\pi f\tau}d\tau$$

- Received signal

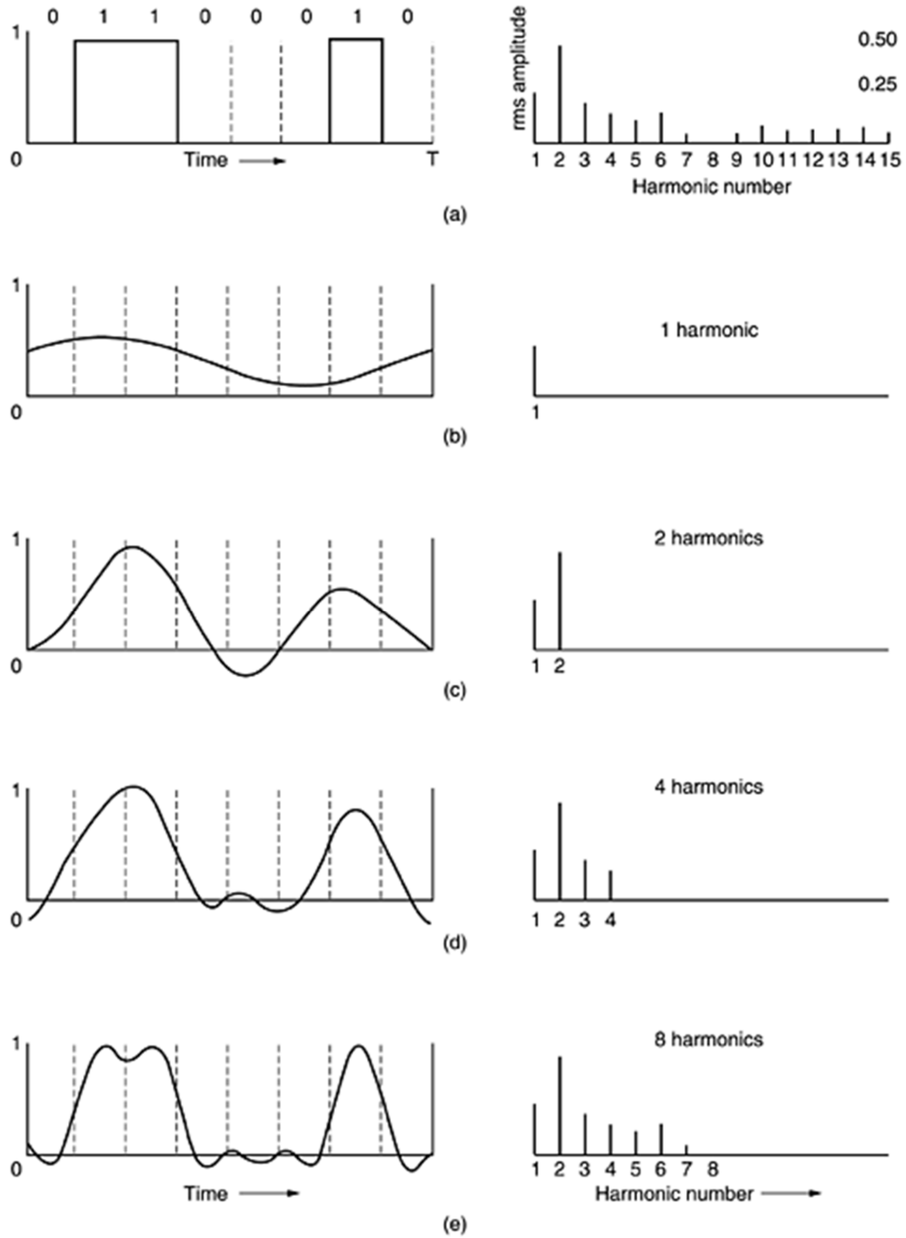


$$r(t) = \int_{-\infty}^{\infty} H(f)S(f)e^{j2\pi ft}df$$

$$R(f) = H(f)S(f)$$

Bandwidth-limited signals

- a) : signal and frequency components
- b)-e) : bandwidth-limited versions of a)



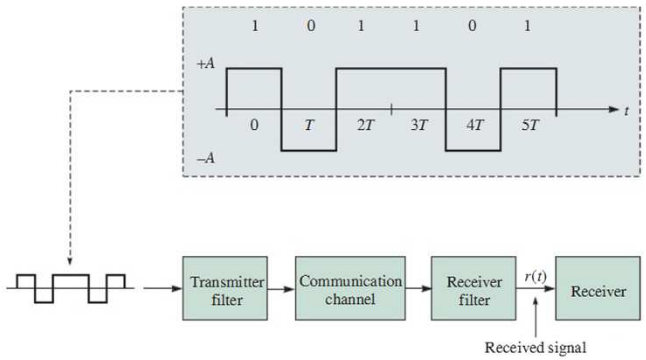
TO THINK

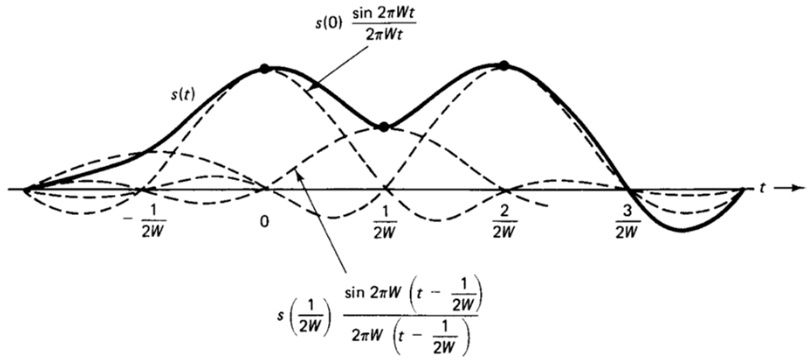
How can you retrieve digital information from a band-limited signal?

How many bit/s can a bandwidth-limited channel deliver?

Channel capacity: Nyquist signaling rate

- Bandwidth-limited signal r(t)
  - Bandwidth B
- Zero inter-symbol interference at k*1/2B
  - Sync pulse
- Nyquist rate
  - C=2B samples/s





Channel capacity: Nyquist signaling rate

- Example
  - Square wave -5V (0) +5V (1)
  - Goes through a B_H=3kHz channel
  - C=2*3kHz=6kbit/s

- Distinguish the two concepts:
  - Nyquist **signaling** rate / channel capacity
  - Nyquist **sampling** rate / signal reconstruction

Channel capacity: Hartley

- M levels, $\log_2 (M)$ bits/sample
  - $C=2B \log_2 (M)$
  - This is the bit rate
- Baud rate
  - Symbols per second
  - 2B Baud/s
  - each symbol has M levels
  - resulting in $\log_2 (M)$ bits per symbol

TO THINK

Why can't you transmit at infinite bitrate by increasing M to infinity?

- $C=2B \log_2 (M)$
- B constant, finite
- Infinity <=> extremely large

Channel capacity: Shannon

- Noise
  - Higher noise => more difficult to distinguish between levels
- For a given technology
  - Higher noise => lower M
  - Lower noise => higher M

Channel capacity: Shannon

- Theoretical limit
  - Of the channel capacity
  - With noise
- Shannon-Hartley theorem
  - $C = W \log_2 \left(1 + \frac{P_r}{N_0 W}\right)$
  - C: capacity
  - W: band-pass channel bandwidth, sampling rate
  - P_r: signal power at the receiver
  - N_0: noise per bandwidth unit, white noise
    - Example 10^{-9} W/Hz

Channel capacity: Shannon

- Signal to noise ratio: $SNR = \frac{P_r}{N_0 W}$
- Number of levels M (Hartley)
  - $M = \sqrt{1 + \frac{P_r}{N_0 W}}$
- Example
  - Band-pass channel W = 100 kHz
  - $\frac{P_r}{N_0 W} = 7 \Rightarrow C = 100k \log_2(1+7) = 300kbit/s$
  - $\frac{P_r}{N_0 W} = 255 \Rightarrow C = 100k \log_2(1+255) = 800kbit/s$

Reminder: power, decibel

- $P_{dBW} = 10\log_{10} P$
- $P_{dBm} = 10\log_{10}(\frac{P}{1mW})$

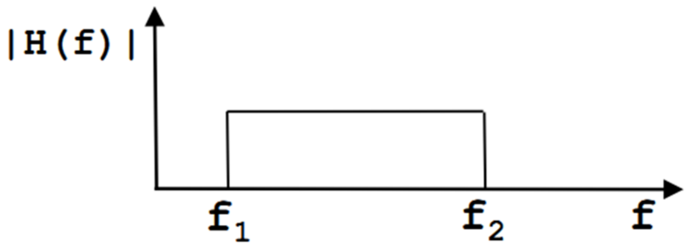
- $\mathrm{P} = 100mW$

  $\Rightarrow\ P_{dBW} = 10\log_{10}(100\ * 10^{-3}) = -10\ dBW$

  $\Rightarrow\ P_{dBm} = 10\log_{10}(100) = 20\ dBm$

Transmission techniques for band pass channels

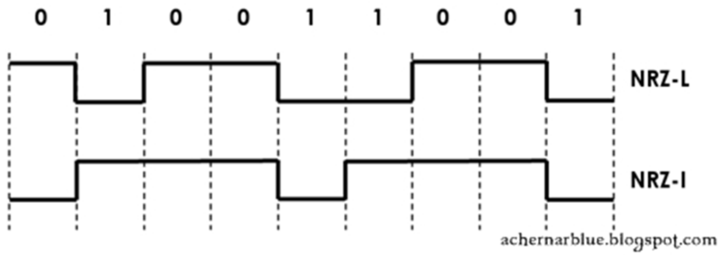
- Most physical channels are band pass
  - |H(0)| = 0, reject DC component

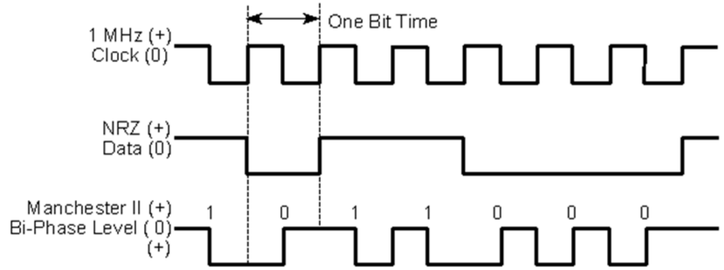


- Two major techniques are used:
  - Coding
  - Modulation

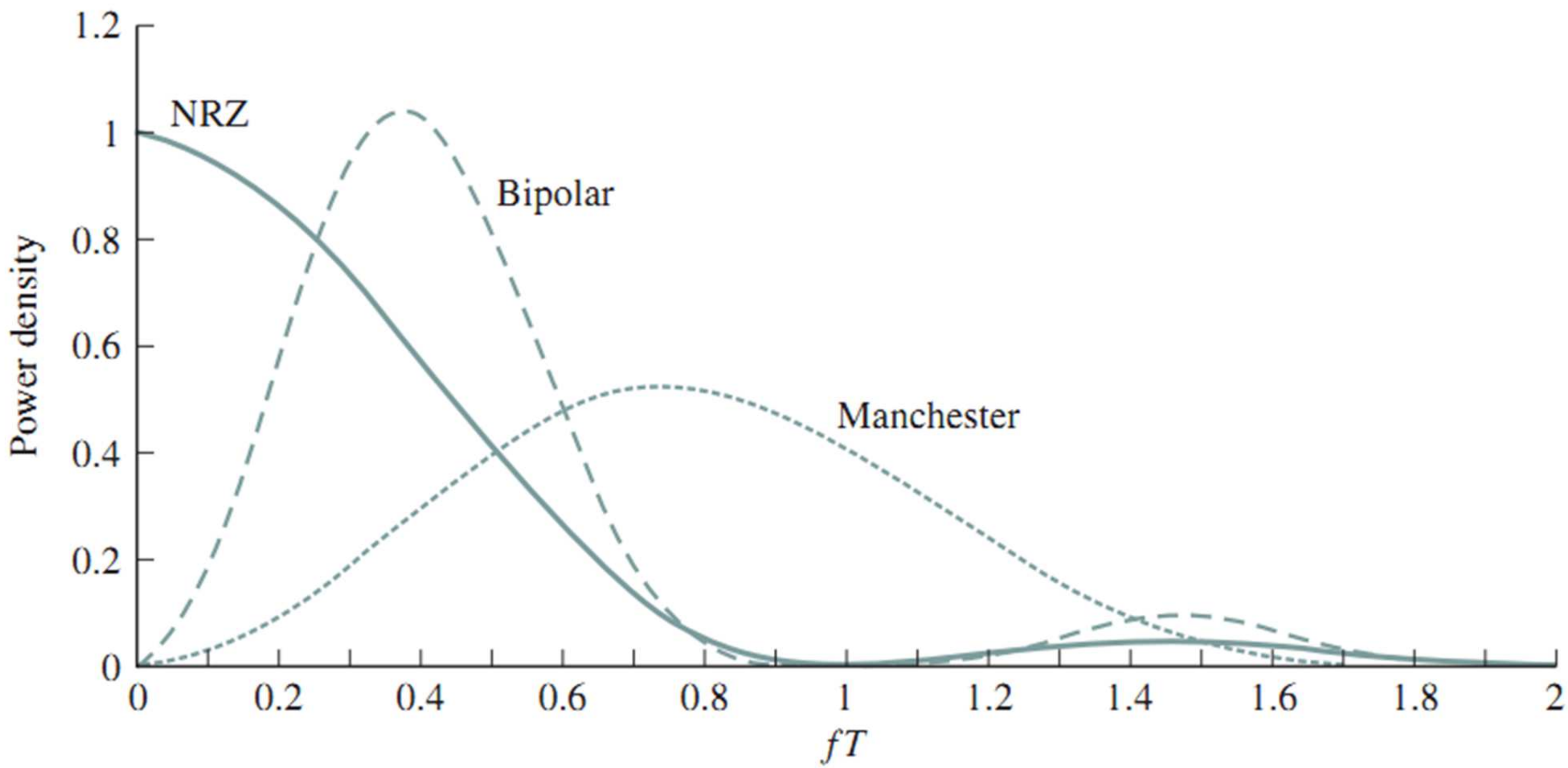
Coding, common codes

- NRZ-L, non-return to zero with levels
  - Two voltage levels, one for “1” and one for “0”
- NRZ-I, inverted
  - A change of level represents a “1”
- Manchester
  - Transition in the middle of the bit
  - “1”: + to –   ;   “0”: – to +
  - Ethernet (IEEE 802.3)
- And many more codes





Spectral Power Density



TO THINK

How can you transmit bits using a continuous carrier?

- E.g. sinusoidal

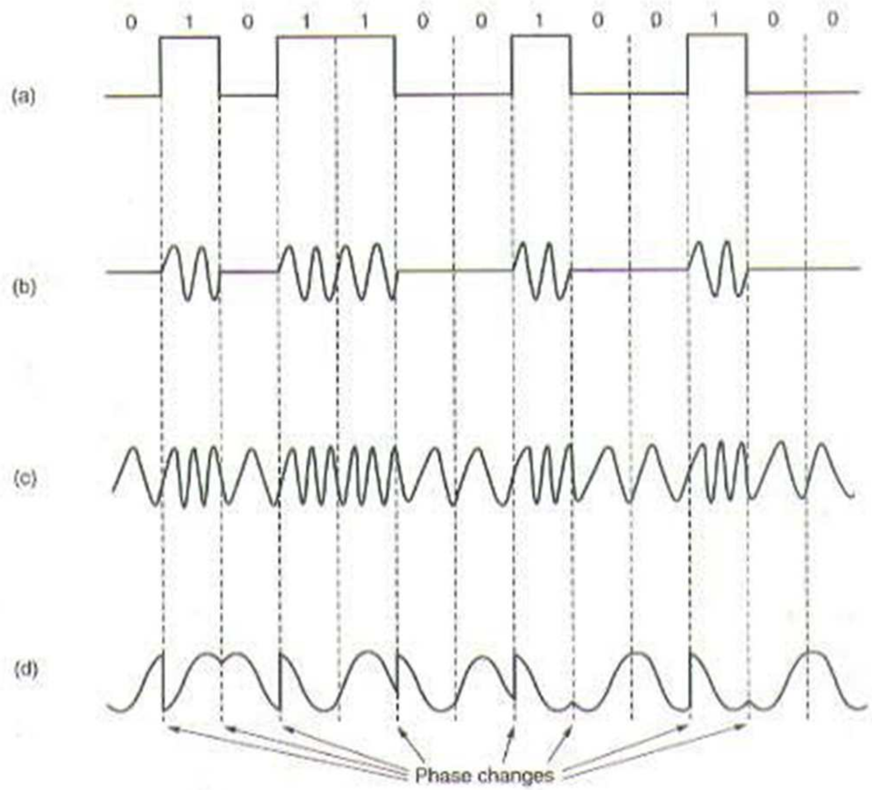
Types of modulation

a) binary signal

b) Amplitude modulation

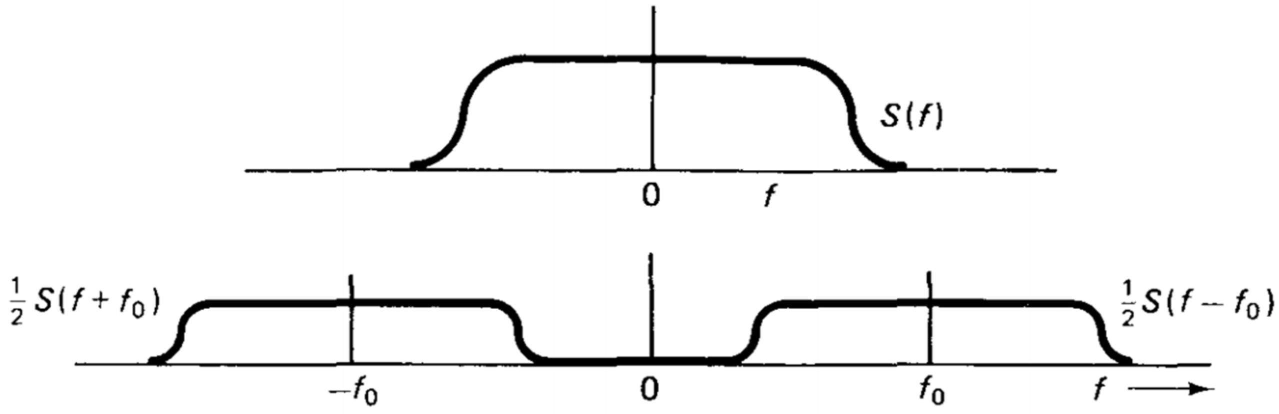
c) Frequency modulation

d) Phase modulation



Spectrum of an AM signal

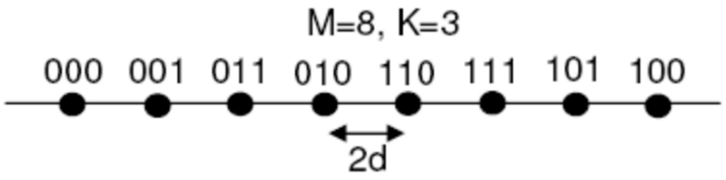
- Top: original signal



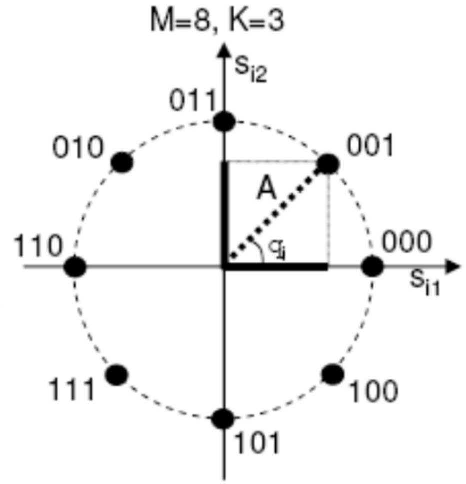
- Bottom: amplitude-modulated signal

Amplitude and phase modulations

- Pulse-Amplitude Modulation (M-PAM)
  - $s(t) = A_i \cos(2\pi f_c t)$
  - Information coded in the amplitude of the carrier

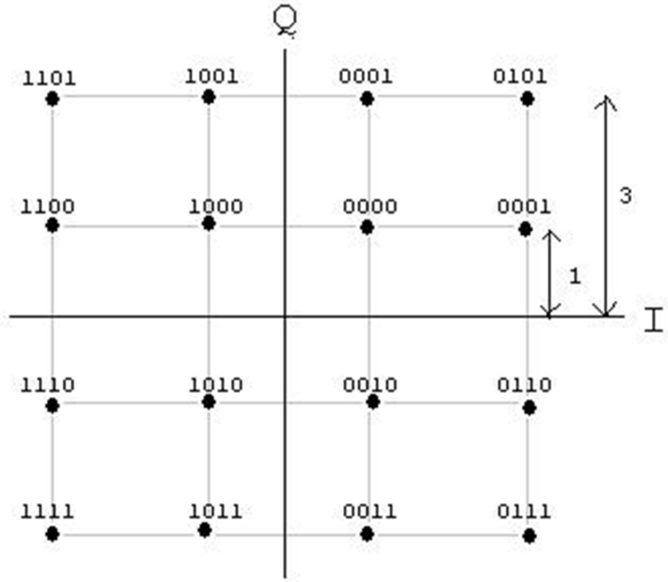


- Phase-shift keying (M-PSK)
  - $s(t) = \mathrm{A}\cos(2\pi f_c t + \theta_i)$
  - Information coded in the phase of the carrier



Quadrature amplitude modulation

- M-QAM
- Information coded in both amplitude and phase
  - $s(t) = \mathrm{A_i}\cos(2\pi f_c t + \theta_i)$
  - M=?
  - K=?



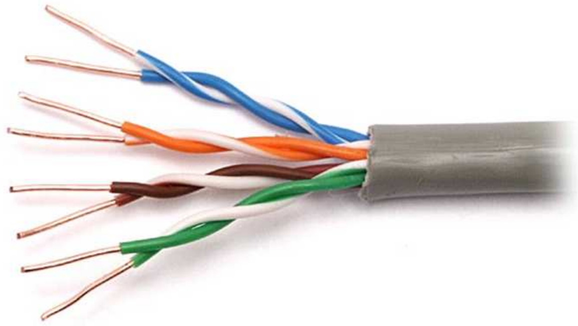
Guided Transmission

TO THINK

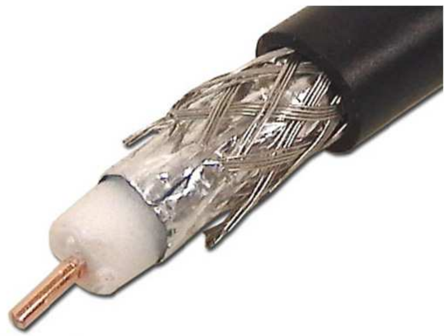
How to transmit a sequence of bits from sender to receiver using two wires?

Types of cables

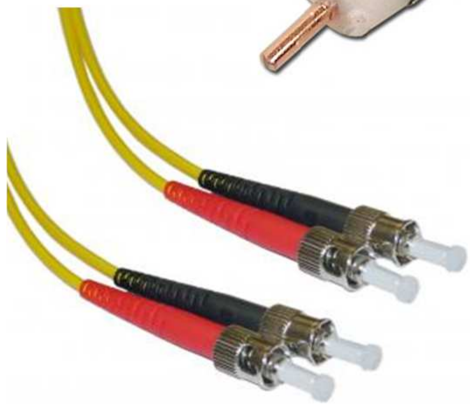
- Unshielded twisted pair



- Coaxial cable



- Fiber optics cable



Twisting and crosstalk

- a) Cat. 3 UTP

(a)

(b)

- b) Cat. 5 UTP

UTP Bandwidth / Ethernet

Cat3	UTP[6]	16MHz[6]	10BASE-T and 100BASE-T4 Ethernet[6]
Cat4	UTP[6]	20MHz[6]	16 Mbit/s[6] Token Ring
Cat5	UTP[6]	100MHz[6]	100BASE-TX & 1000BASE-T Ethernet[6]
Cat5e	UTP[6]	100MHz[6]	100BASE-TX & 1000BASE-T Ethernet[6]
Cat6	UTP[6]	250MHz[6]	1000BASE-T Ethernet
Cat6e		250MHz (500MHz according to some)	Not a standard; a cable maker's own label.
Cat6a		500MHz	10GBASE-T Ethernet

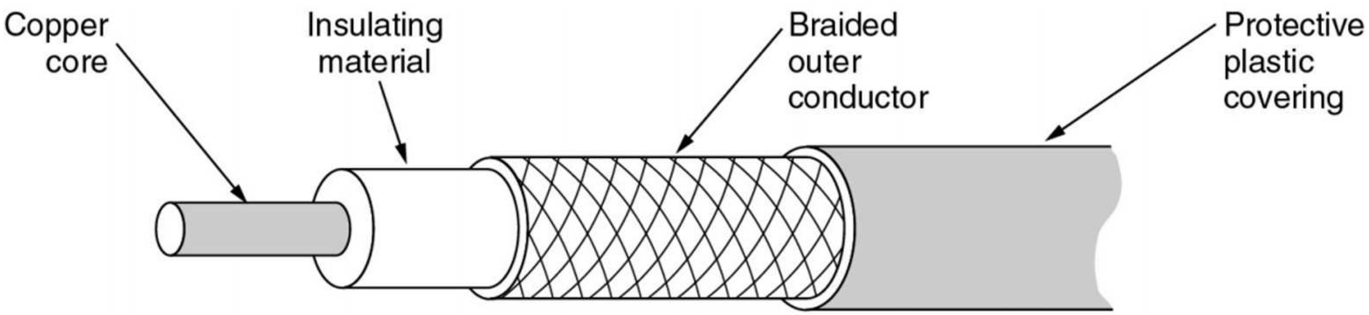
Typical attenuation: 2-25dB/100m

Attenuation and gain

- $P_r = P_t \ * Gain$
  - In Watts
- $10\log_{10}(P_r) = 10\log_{10}(P_t) + 10\log_{10}(Gain)$
  - In dB
  - $P_{rdBW} = P_{tdBW} + Gain_{dB}$
  - $P_{rdBm} = P_{tdBm} + Gain_{dB}$
- Example
  - $Gain = 0.01\ , P_{tdBm} = 30\ dBm = 1W$
  - $Gain_{dB} = 10\log_{10}(0.01) = -20\ dB$
  - $P_{rdBm} = P_{tdBm} + Gain_{dB} = 30\ dBm\ - 20dB = 10dBm = 10mW$
  - $Gain_{dB} = -20dB \Rightarrow Attenuation_{dB} = 20dB$

Coaxial cable

- Same principle as UTP but with:
  - Higher bandwidth
  - Better immunity to noise
  - Lower attenuation

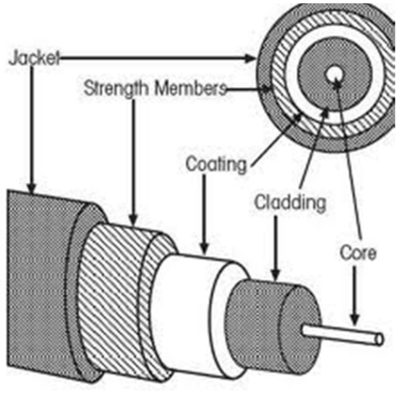


  - Higher cost

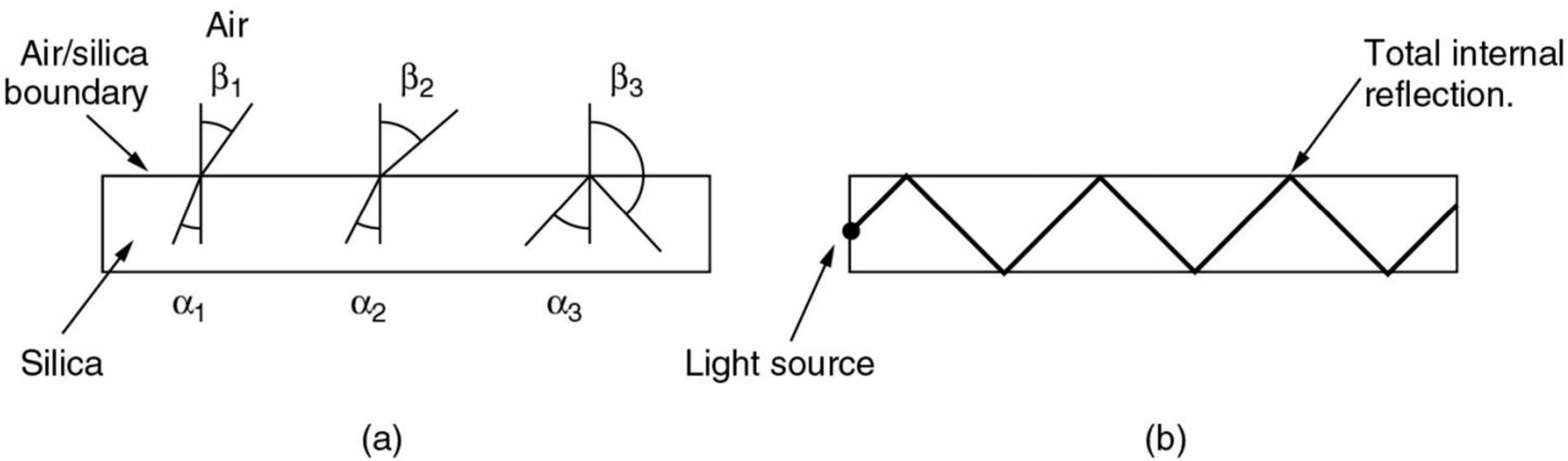
TO THINK

Fiber optics: how different is it from copper?

Fiber optics

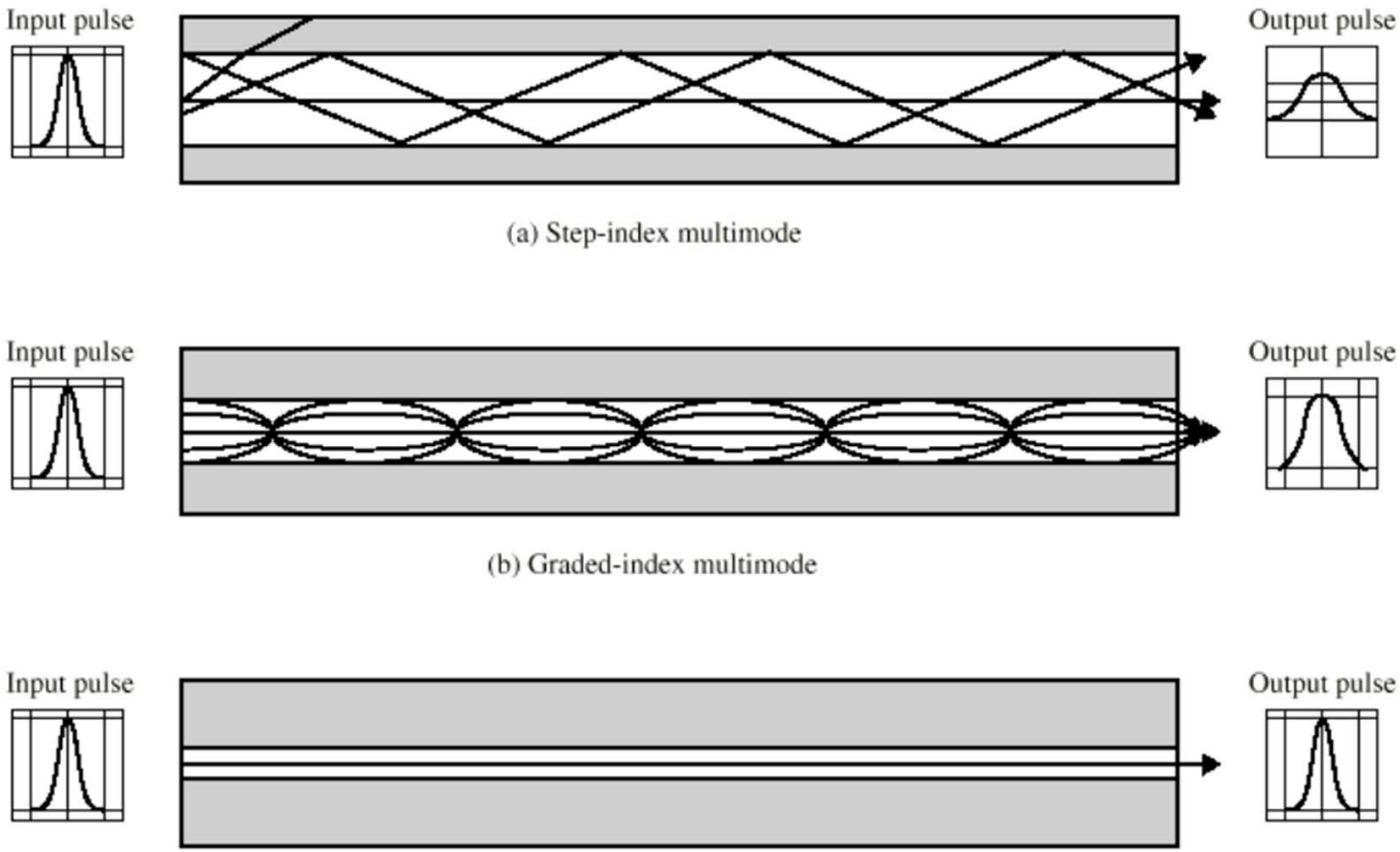


- Refraction and Reflection
  - at the core/cladding boundary



  - Reflection if: incidence angle > critical angle
    - Total internal reflection
    - Propagation through reflection

Fiber modes and distortion



(a) Step-index multimode

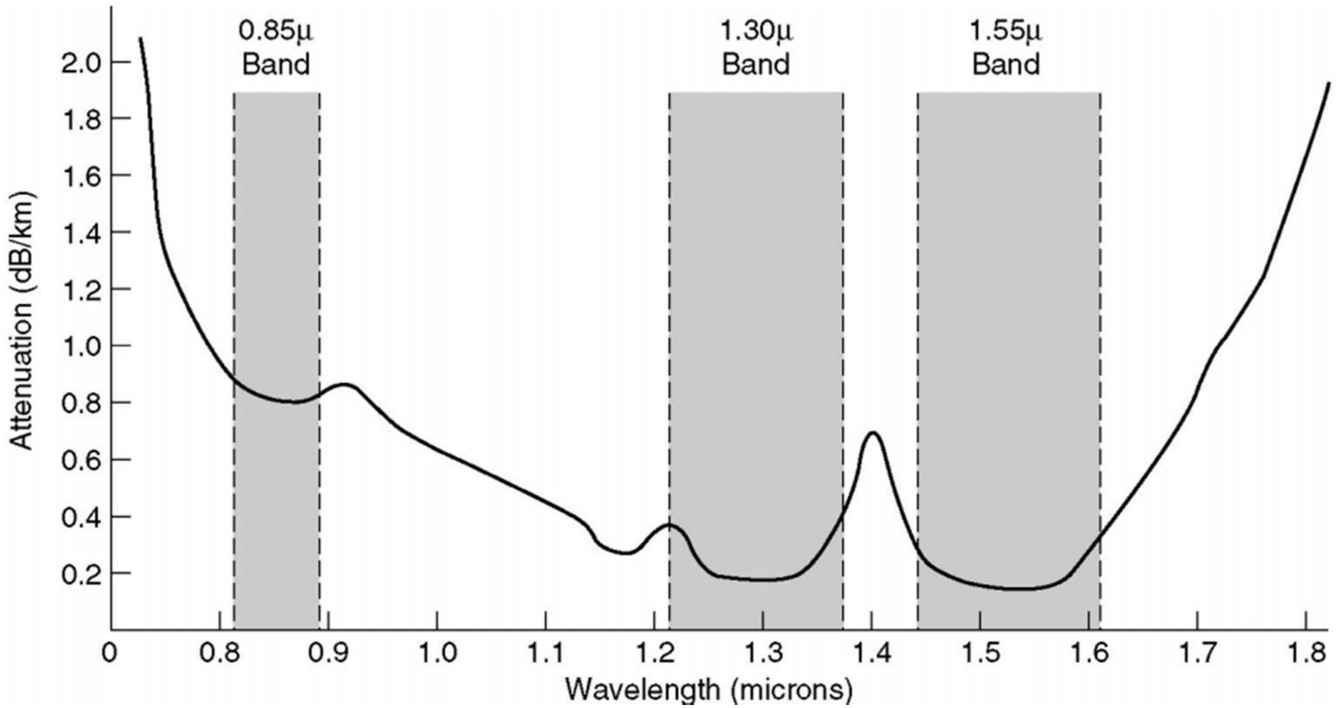
(b) Graded-index multimode

(c) Single mode

Wavelength, attenuation, bandwidth, coding

- SNR => bitrates
- Explore lower attenuation bands
- 30 GHz bandwidth, < 1dB/km

- NRZ, pulse on(“1”), pulse off (“0”)
  - Amplitude modulation?

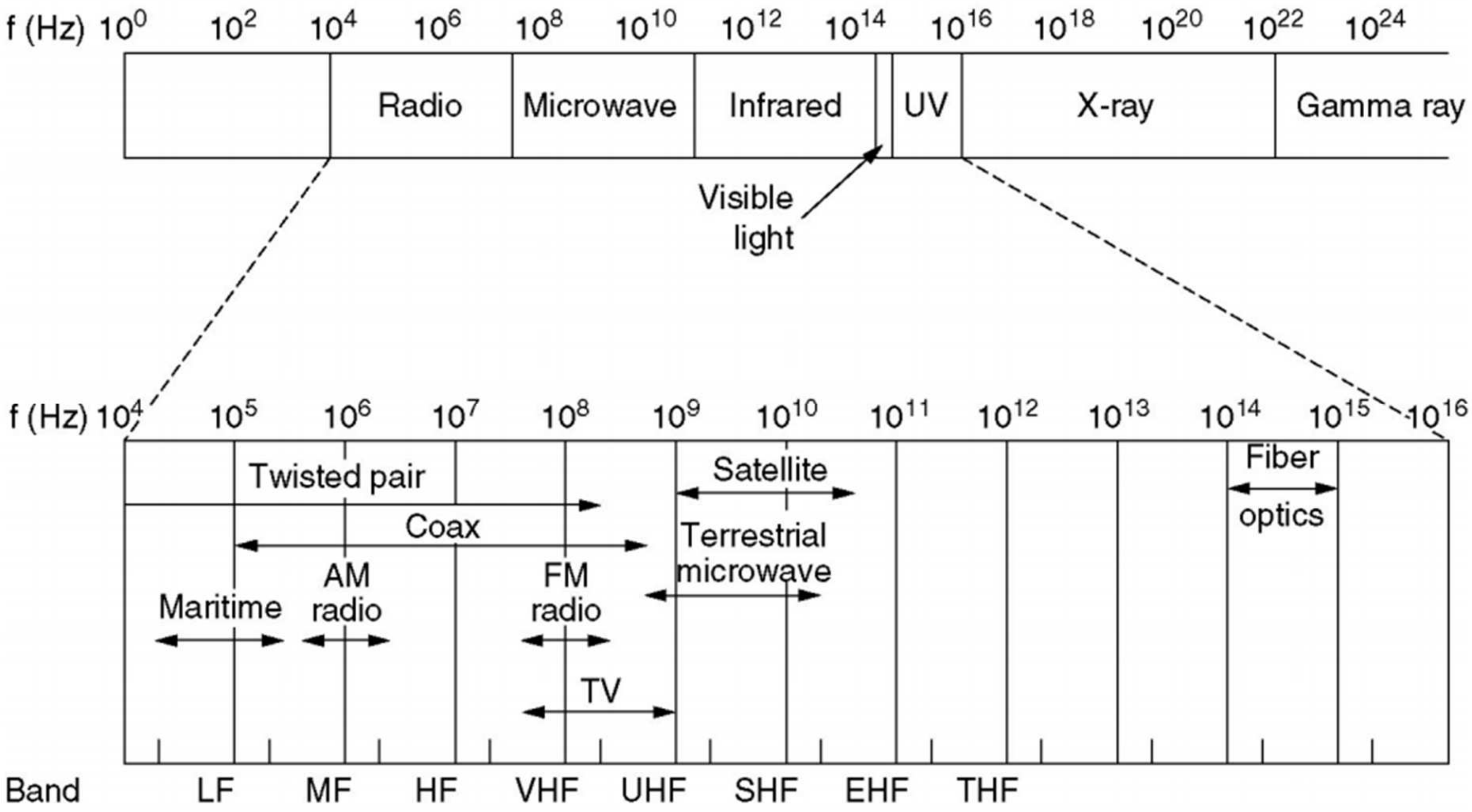


Wavelength and propagation delay

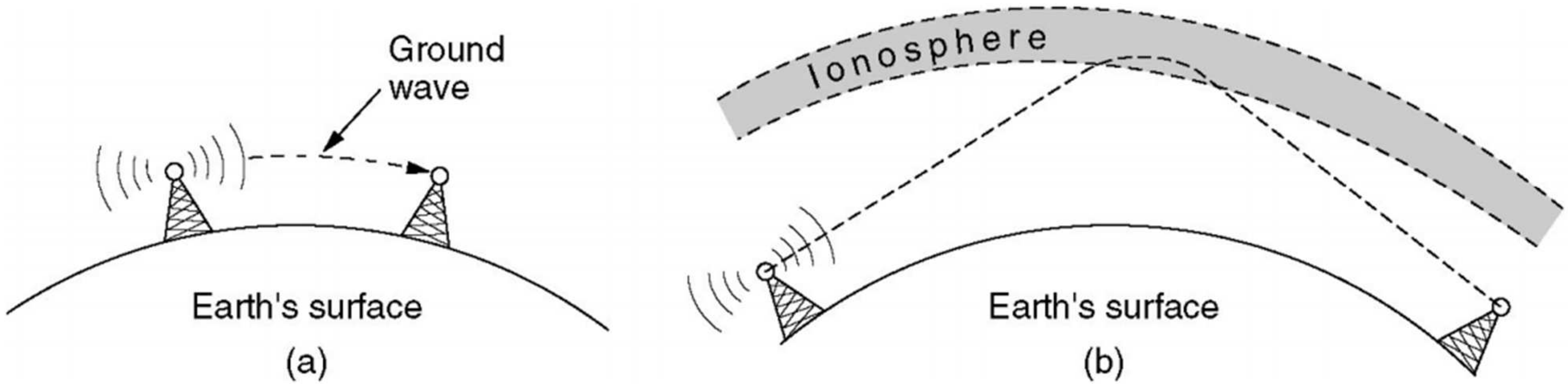
- $\lambda = \nu T\ ,\ or\ \lambda f = \nu$
  - λ wavelength
  - ν speed of the wave (light, etc)
  - f frequency
  - T period
- Speed of light in free space
  - $c = 3 * 10^8 m/s$
- Propagation delay ($\mu s/km$)
  - Free space 3.3 $\mu s/km$
  - Coaxial cable 4 $\mu s/km$
  - UTP 5 $\mu s/km$
  - Optical fiber 5 $\mu s/km$
    - (notice the increasing propagation delay)

Wireless Transmission

Electromagnetic (EM) spectrum



Radio transmission



- (a) VLF, LF, MF follow the Earth's surface
- (b) HF, VHF are absorbed by the Earth or bounce off the ionosphere

TO THINK

What are the different issues that affect attenuation in wireless transmission?

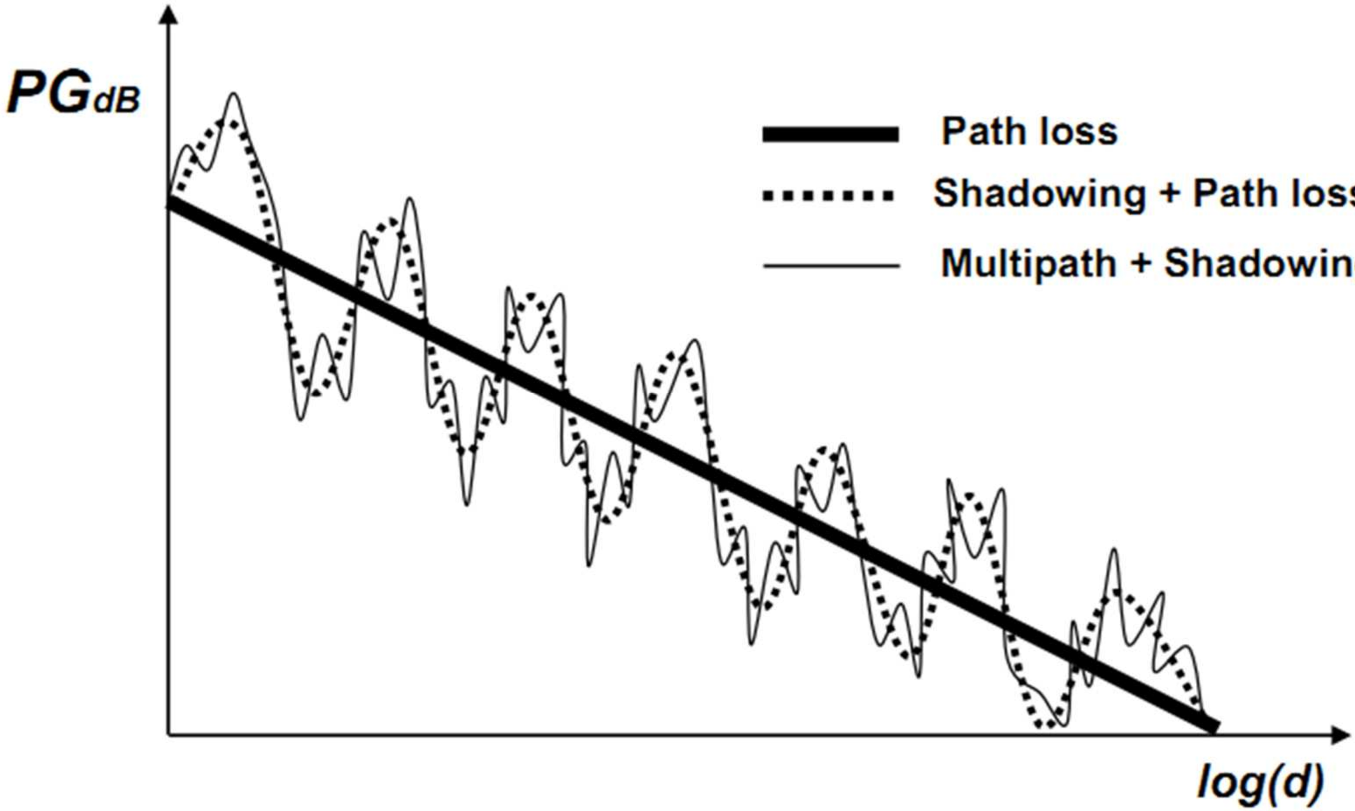
Free space model

- Channel gain in free space $\frac{P_r}{P_s} = \left(\frac{\lambda\sqrt{G_l}}{4\pi d}\right)^2$
  - Gl: gain of antennas
  - d: sender-receiver distance
- $PG_{dB} = 10\log_{10}\left(\frac{P_r}{P_s}\right) =$

$$= 20\log_{10}\lambda\sqrt{G_l}/4\pi d - 20\log_{10} d = b - 20x$$

- $PL_{db} = -10\log_{10}\lambda^2 G_l/(4\pi d)^2$

Propagation issues



Shadowing: large obstacle (building, hill); slow fading
Multipath: multiple paths overlapping; fast fading

Path loss example

- What's the sender power Ps
  - For receiver power Pr = 0.1μW?
  - And 900 or 3000MHz at 10, 100, 1000 m distance?

f_c (MHz)	λ $\left(\frac{c}{f_c}\right)$ (cm)	d (m)	PL_{dB} $\left(-10\ log\frac{\lambda^2 G_l}{(4\pi d)^2}\right)$ (dB)	$P_{s_{dBm}}$ $(P_{r_{dBm}} + PL_{dB})$ (dBm)	P_s $\left(10^{\frac{P_{s_{dBm}}}{10}-3}\right)$ (W)
900	33	10	51.5	11.5	0.014
		100	71.5	31.5	1.42
		1000	91.5	51.5	142
3000	10	10	62	22	0.158
		100	82	42	15.8
		1000	102	62	1579

Capacity of wireless channel

$P_r(d) = (d_0/d)^3\, P_t$, for $d_0 = 10m$

d (m)	$\gamma = P_r(d)/(N_0 B)$	$SNR = \gamma_{dB} = 10\ log\gamma$ (dB)	$C = B\ log_2(1+\gamma)$ $(kbit/s)$	Efficiency (bit/s/Hz)
50	267	24	242	8
100	33	15	153	5.1
500	0.27	-6	10	0.3
1000	0.033	-15	1.4	0.05

Table 2.6: Shannon capacities for wireless channels. The limiting capacities of wireless channels depend on the channel bandwidth and on the power received. The capacity C of the channel and its efficiency are given for a transmitted power $P_s = 1\,W$, $d_0 = 10\ m$, a narrow bandwidth of $30\ kHz$ and a noise power spectral density $N_0 = 10^{-9}\ W/Hz$. The capacity decreases significantly as the distance between the sender and the receiver increases

HOMEWORK

- Review slides

- Read:
  - Tanenbaum 2.1,2.2, 2.3, 2.5, 2.7, 2.8
  - Bertsekas – 2.1, 2.2

- Do your Moodle homework