BLG 337E- Principles of Computer Communications

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14/10/ 2014

-Electromagnetic Spectrum-

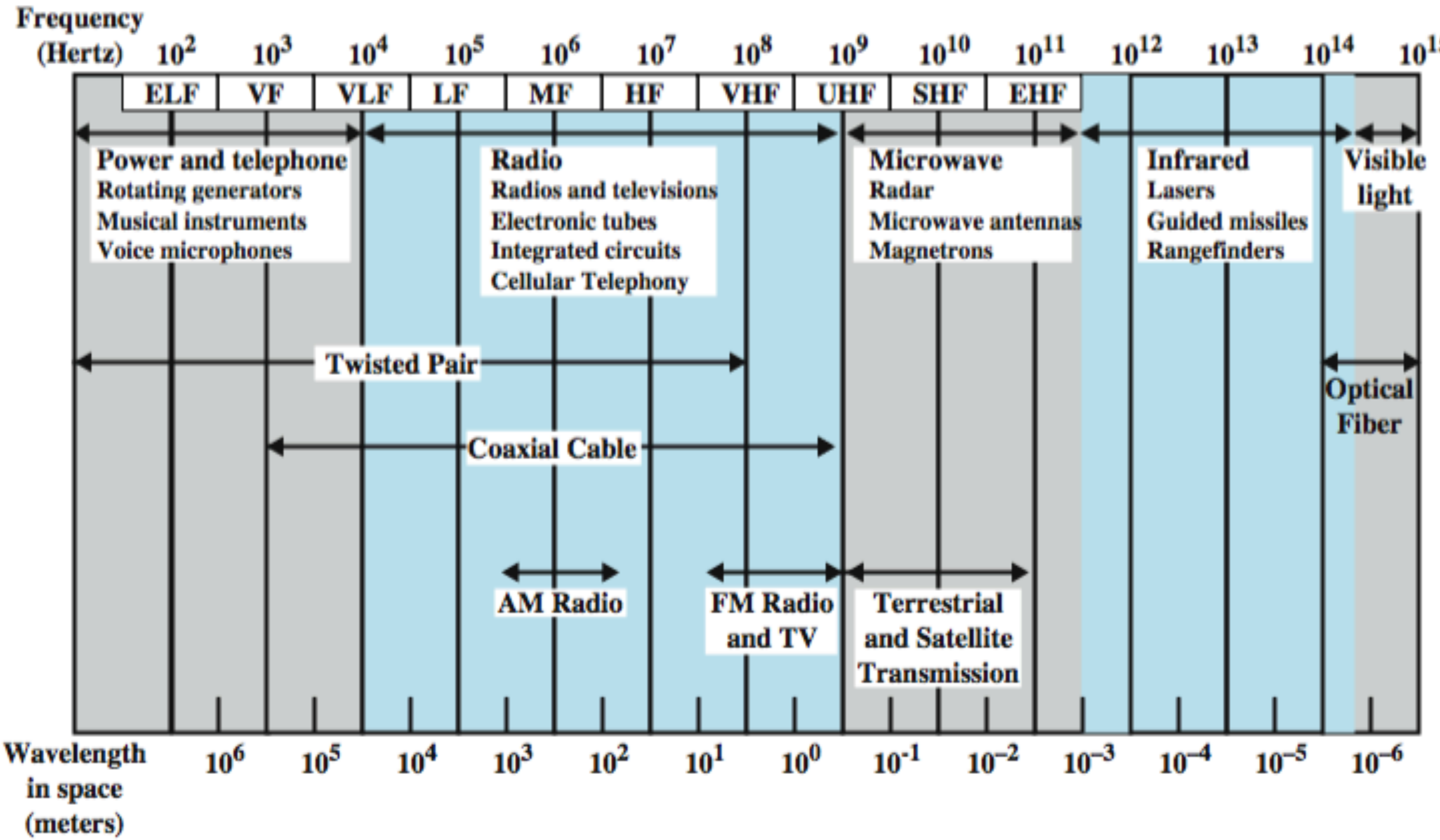
Medium Access

References:

Data and Computer Communications, William Stallings, Pearson-Prentice Hall, 9th Edition, 2010.

-*Computer Networking, A Top-Down Approach Featuring the Internet*, James F.Kurose, Keith W.Ross, Pearson-Addison Wesley, 6th Edition, 2012.

-Google!



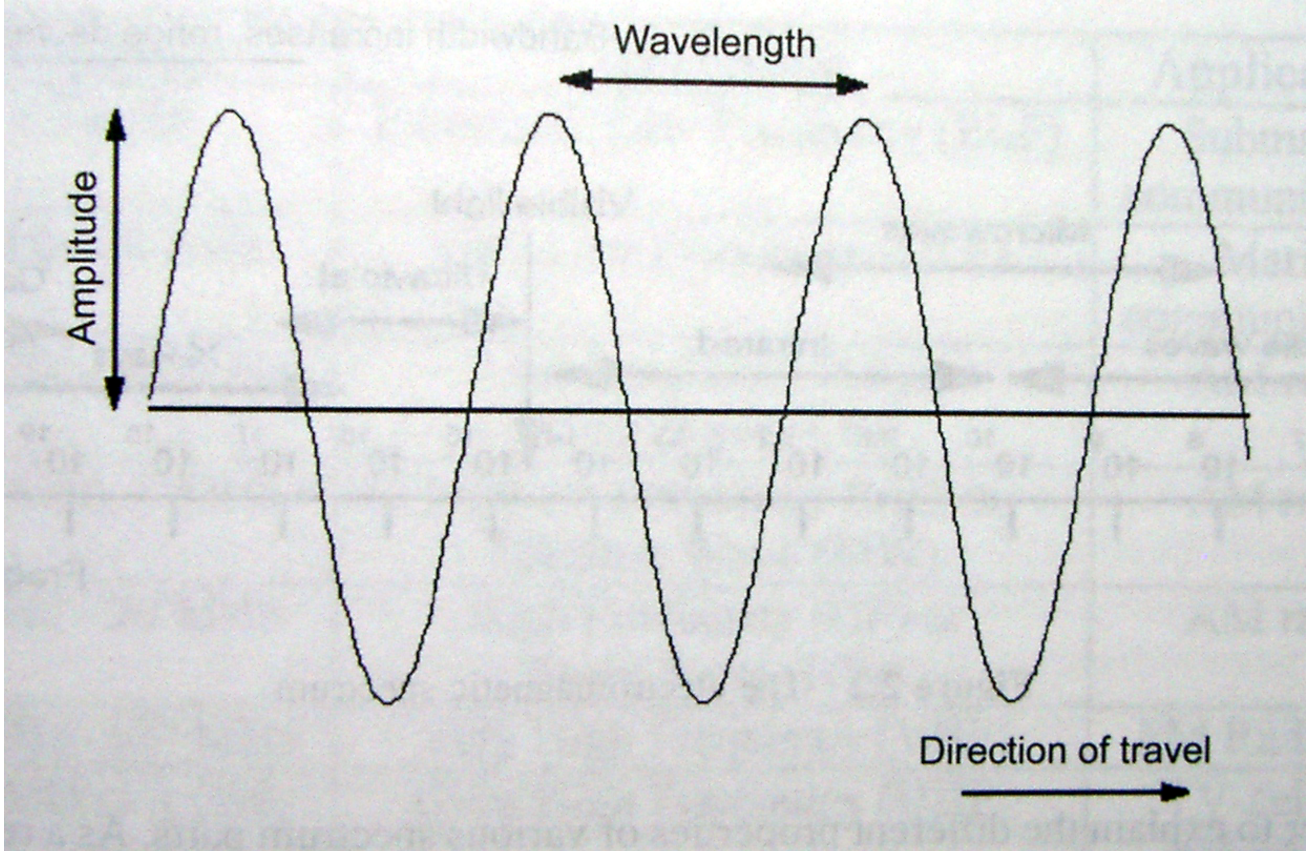
ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

Electromagnetic Waves

- Predicted by British physicist James Maxwell in 1865, and observed by German physicist Heinrich Hertz in 1887
- These waves are created by the movement of electrons and have the ability to propagate through space.
  - using appropriate antennas, transmission and reception of electromagnetic waves through space becomes feasible.
  - the speed of electron vibration determines the wave’s frequency.
- Hertz: how many times the wave is repeated in 1 sec. (to honor Heinrich Hertz)

Wavelength and Amplitude

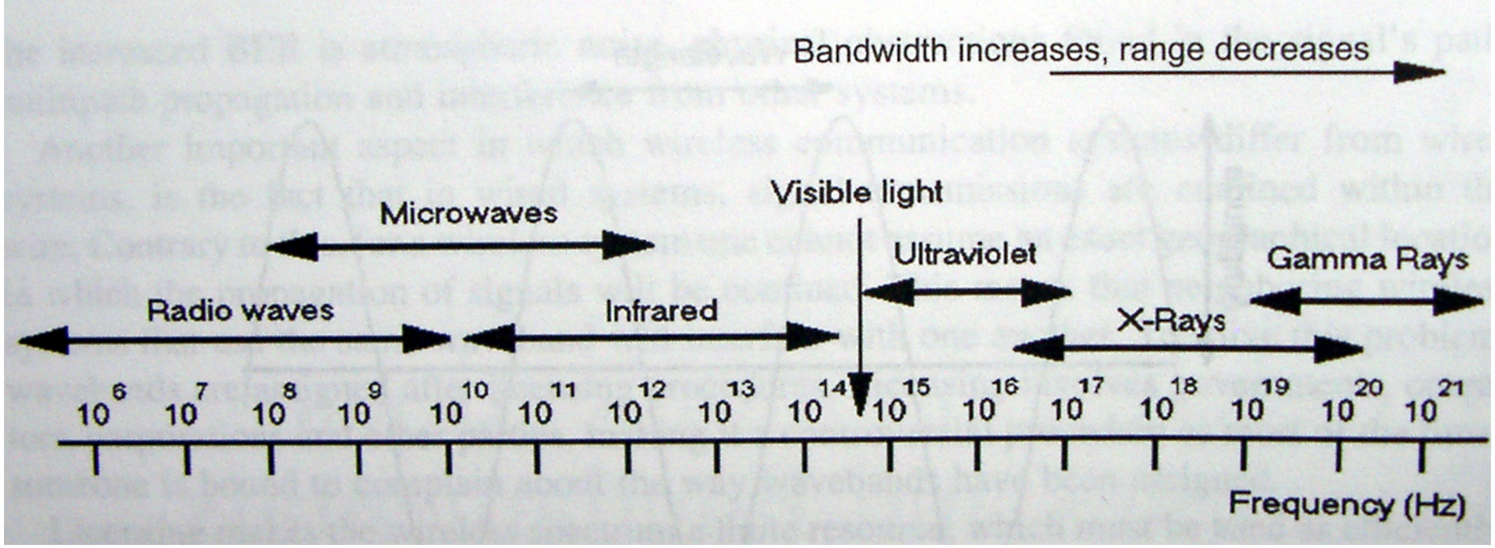
- l = wavelength, f = frequency, c = speed of light



Wavelength and Amplitude of an Electromagnetic wave

Electromagnetic Spectrum

- spectrum: range of electromagnetic radiation
- band: spectrum parts



The Electromagnetic Spectrum

Radio Waves

Frequency	Band name	Applications
< 3 KHz	Extremely Low Frequency (ELF)	Submarine communications
3 KHz -30 KHz	Very Low Frequency (VLF)	Marine communications
20 KHz -300 KHz	Low Frequency (LF)or Long Wave (LW)	AM radio
300 KHz -3 MHz	Medium Frequency (MF) or Medium Wave (MW)	AM radio
3 MHz - 30 MHz	High Frequency (HF) or Short Wave (HW)	AM radio
30 MHz -300 MHz	Very High Frequency (VHF)	FM Radio-TV
300 MHz - 3 GHz	Ultra High Frequency (UHF)	TV-cellular telephony
3 GHz - 30 GHz	Super High Frequency (SHF)	Satellites
30 GHz - 300 GHz	Extra High Frequency (EHF)	Satellites-radars

The various radio bands and their common use

- HF band enables worldwide transmission:
  - HF signals are reflected off the ionosphere and thus can travel very large distances

Microwaves

- small wavelengths compared to radio waves
- easily attenuated by objects

Frequency	Band name	Applications
0.4 GHz - 1.5 GHz	L	Broadcasting-cellular
1.5 GHz - 5.2 GHz	S	Cellular
3.9 GHz - 6.2 GHz	C	Satellites
5.2 GHz - 10.9 GHz	X	Fixed wireless-satellite
10.9 GHz - 36 GHz	K	Fixed wireless-satellite
36 GHz - 46 GHz	Q	Fixed wireless
46 GHz -56 GHz	V	Future satellite
56 GHz -100 GHz	W	Future cellular

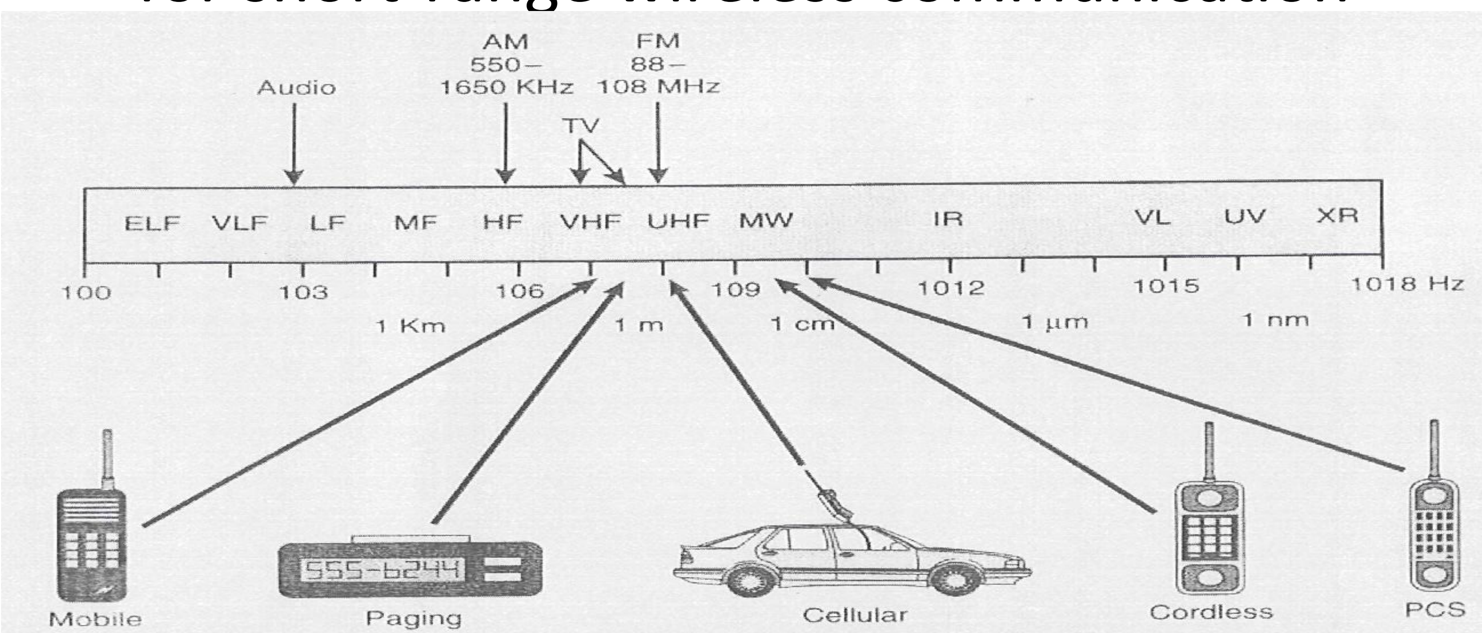
The various microwave bands and their common use

Infrared

- emitted by very hot objects
  - such as human body (night vision applications)
  - frequency depends on the temperature of the emitting body
- line-of-sight, point-to-point
  - of no use outdoors (interfered by heat of sun)
- short-rang: 10 meters
- IrDA: Infrared Data Association

Microwave and Infrared Bands

- Most wireless networking traffic is in the microwave frequency bands.
  – some licensed, some unlicensed
- Infrared:
  – for short-range wireless communication



Spectrum Regulation

- ITU = Int'l Telecommunications Union
  - a worldwide spectrum regulation org.
  - the world is split into 3 parts:
    - American continent
    - Europe, Africa, and former Soviet union
    - rest of Asia and Oceania
- Rules of assigning spectrum
  - lottery
  - auction
  - comparative bidding
    - such as pricing, technology, etc.

Licensed Microwave Band

- Examples: cellular, paging, PCS
- Use of a license is typically in an order of 10 years.
  - A company can’t have the license and not use it.
  - Bandwidth is regarded as a resource that the public wants and needs.

Unlicensed Microwave Band

- Also on the same microwave band, but no license required.
  - To avoid interfering primary (licensed) users, spreading spectrum is required.
  - Two types:
    - FHSS: Frequency-hopping spread spectrum
    - DSSS: Direct sequence spread spectrum
- Also known as ISM band.
  - industrial, scientific, and medical

Model of Wireless Propagation

Free space path loss

Slow/fast fading

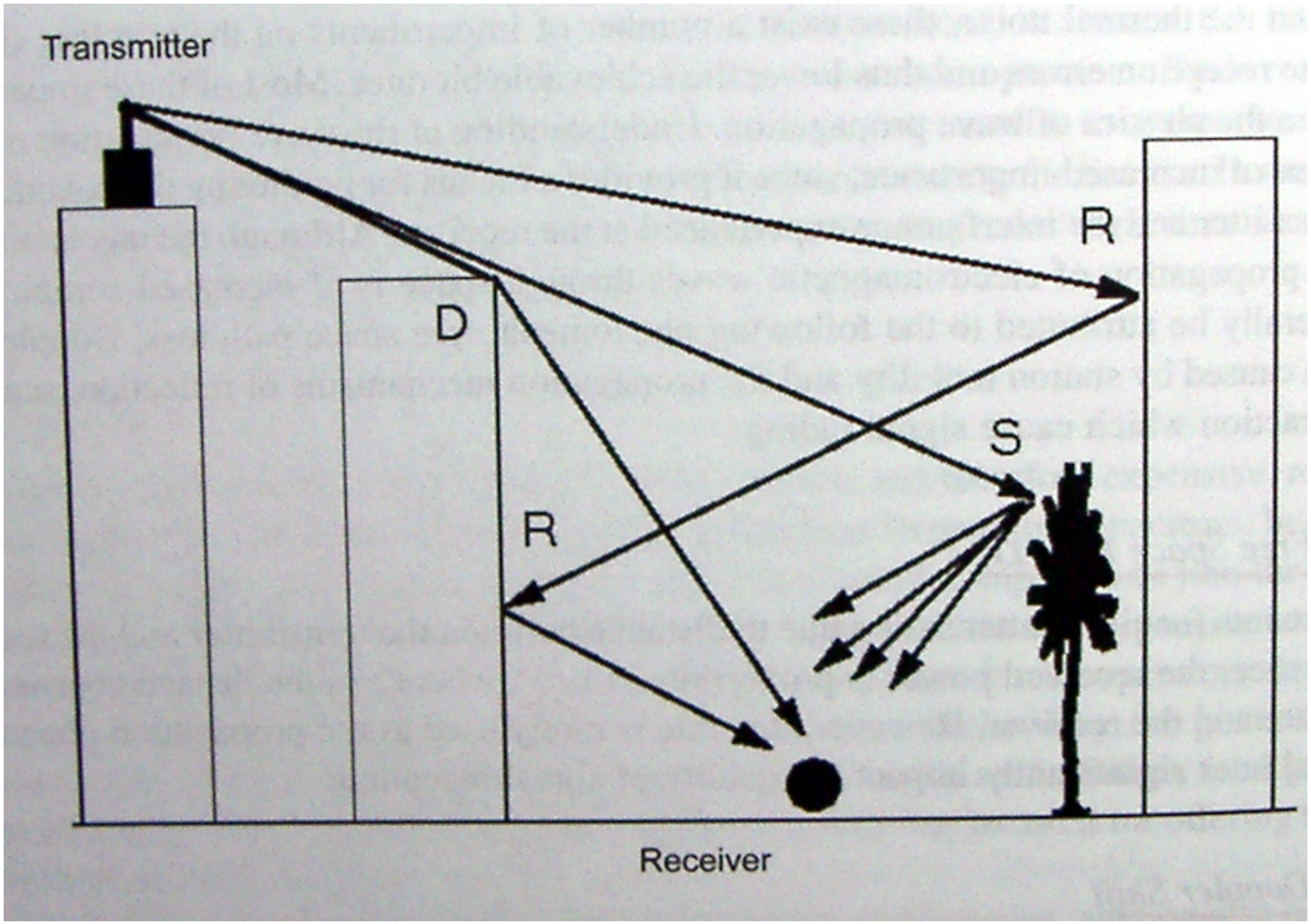
Shannon's Formula (Recap)

- an upper bound on the bit rate W of any channel of bandwidth H Hz:

  $W = H \log_2(1 + S/N)$

  S/N = signal to thermal noise ratio
- However, in real world, the upper bound is difficult to achieve due to:
  - free space path loss
    - proportional to r^{-2}, where r is the distance between transmitter and receiver (sometimes at higher exponent)
  - Doppler shift
    - a signal transmitter and receiver are moving relative to one another
  - slow/fast fading

Slow Fading



Reflection (R), Diffraction (D), Scattering (S)

Definitions

- Reflection:
  - when an electromagnetic wave falls on an object with dimension very large compared to the wave's wavelength
- Scattering:
  - when obstructed by objects with dimensions in the order of the wavelength
- Diffraction (or shadowing):
  - when the wave falls on an impenetrable object
  - in which case, the secondary waves are formed behind the obstructing body

Fast Fading: Multipath Effect

- waves traveling along different paths may be completely out of phase when they reach the antenna (thereby canceling each other)

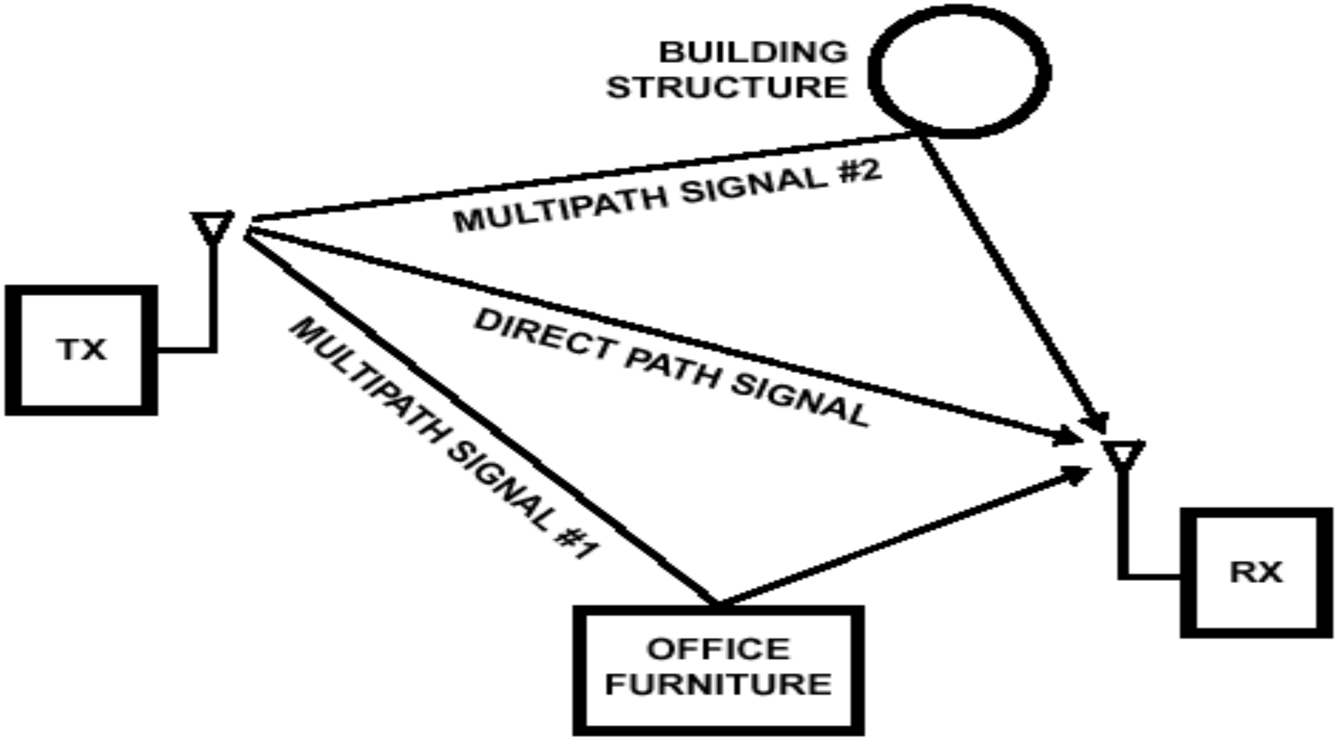
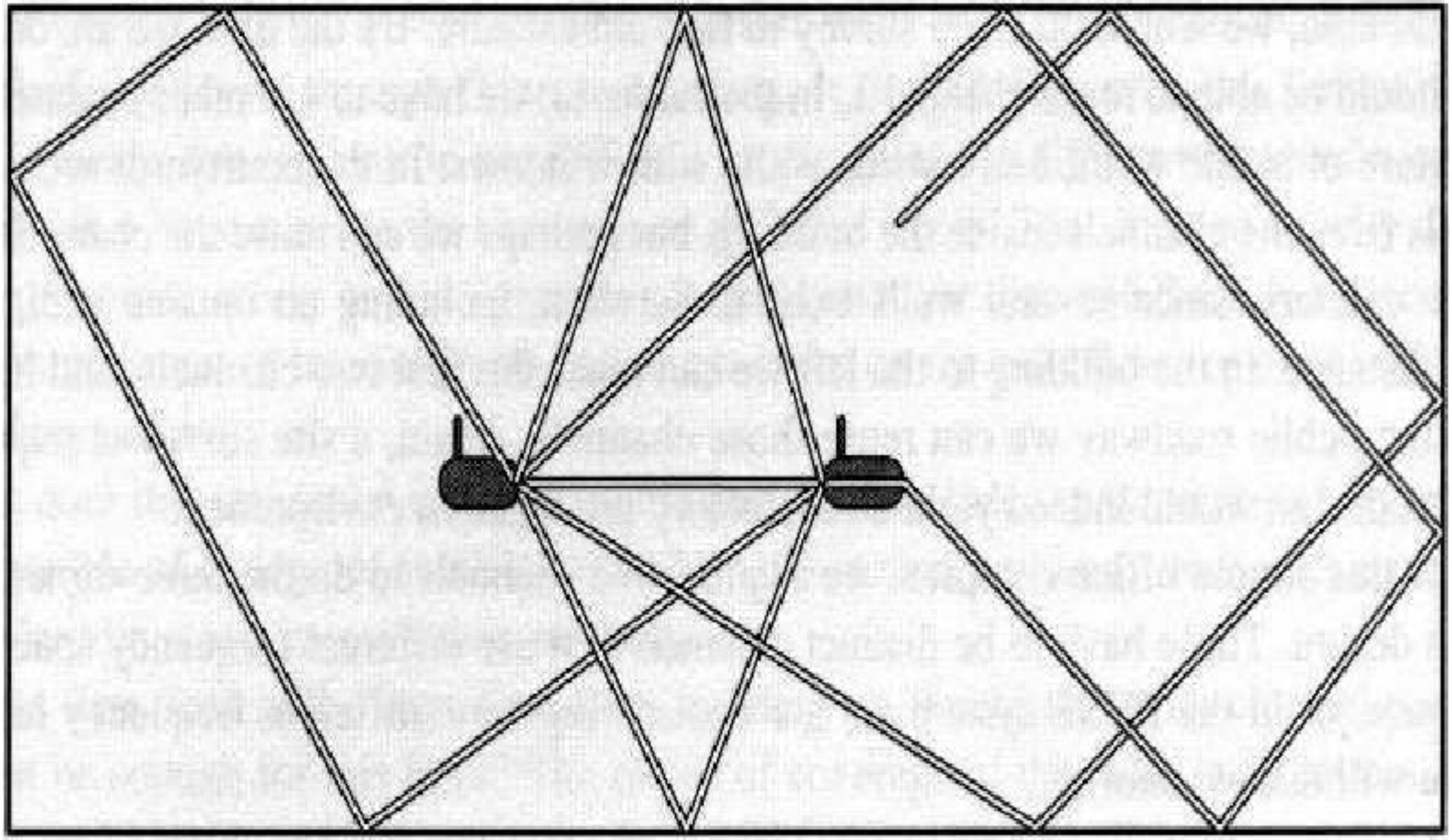


FIGURE 2. MULTIPATH

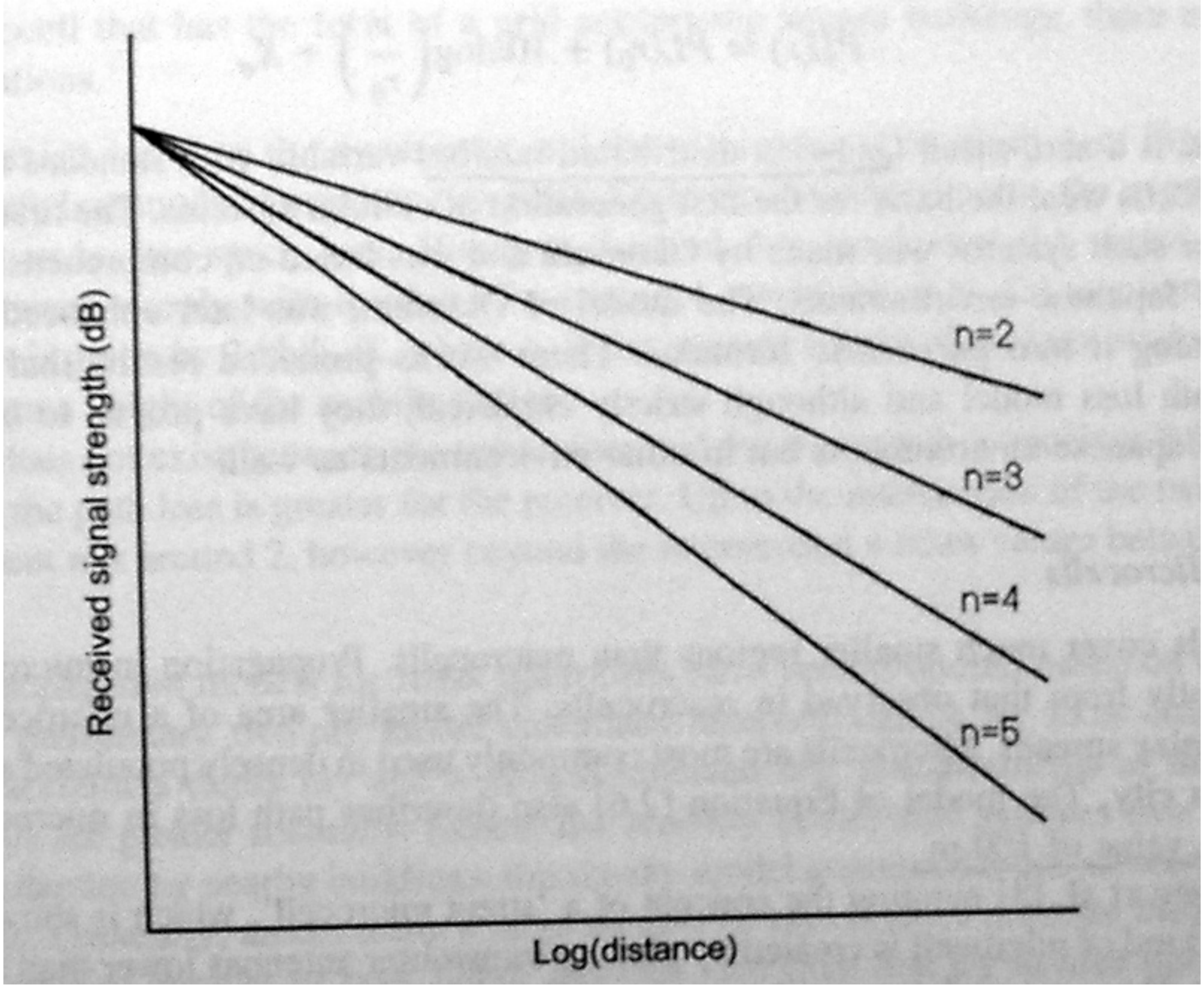


Multipath example indoors.

- Multipath propagation delay can degrade performance in indoor/outdoor environment.
  - When the path length differences are short, the effect is smaller.
- multipath fading is also referred as ***fast fading***
  - When LOS (line of sight) exists, this kind of fading is known as ***Ricean Fading***
  - When LOS does not exist, this kind of fading is known as ***Rayleigh Fading***

Propagation Models

- We say that the relative strength of signal x, P(x), to that of signal y, P(y), is D dB, if
  - **$D = 10 \log_{10}(P(x)/P(y))$**
- In free space, the average path loss (PL) at a distance of r is (in dB):
  - **$PL(r) = PL(r_0) + 10n \log(r/r_0)$**
  - r_0 = reference distance (typically 1 Km for macrocells; and 100 m for microcells)
  - n = environmental factor (typically >= 2)
- To take into account of the shadowing effect
  - **$PL(r) = PL(r_0) + 10n \log(r/r_0) + X_\delta$**
  - X_δ = zero-mean Gaussian random variable with standard deviation δ



Log-Log form

Multiple Access

defining how nodes in a wireless
network to share a common medium

Objectives

- MAC layer is to define how a user access a channel when he needs one.
  - Random access: ALOHA and CSMA
  - Ordered access: Token bus and Token Ring
  - Deterministic access: FDMA, TDMA, and CDMA
  - Combinations: TDMA-over-FDMA, TDD-CDMA, and TDMA/CSMA

FDMA

- frequency division multiple access

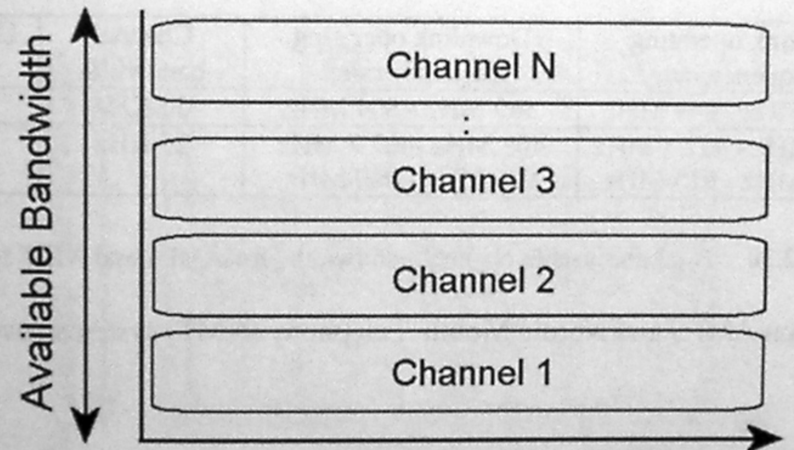


Figure 2.29 Illustration of FDMA

System	Uplink operating frequency range	Downlink operating frequency range	Channel bandwidth	Usable channel bandwidth
AMPS	824 MHz - 849 MHz	869 MHz - 894 MHz	30 KHz	24 KHz
NMT	453 MHz - 457.5 MHz 890 MHz - 915 MHz	463 MHz -467.7 MHz 935 MHz - 960 MHz	25 KHz	9.4 KHz

Figure 2.30 Total and usable channel bandwidths for AMPS and NMT systems

** NMT = nordic Mobile Telephony

TDMA

- time division multiple access

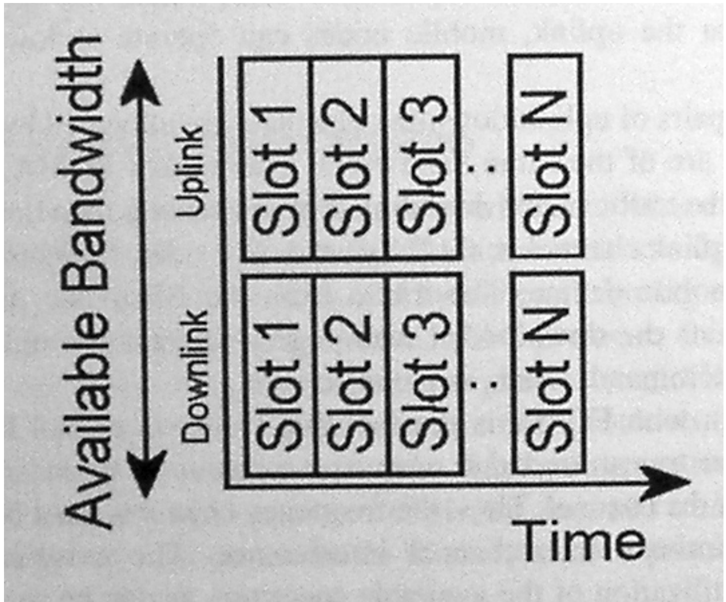


Figure 2.31 Illustration of FDD-TDMA

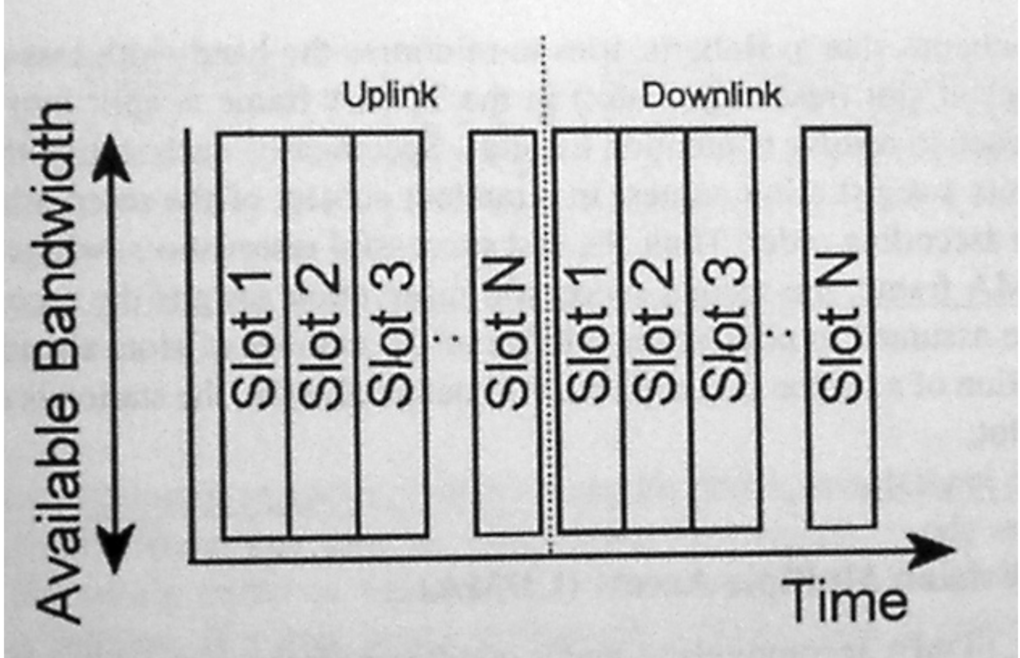


Figure 2.32 Illustration of TDD-TDMA

CDMA

- code division multiple access
  - each station has a “station code”
  - each bit is encoded by station code
    - code 1 is mapped to 1
    - code 0 is mapped to -1

Orthogonal Chip Codes, CDMA example

$$\begin{bmatrix} H_n & H_n \\ H_n & -H_n \end{bmatrix}$$

2 codes

1 1

1 -1

4 codes

1 1 1 1

1 1 -1 -1

1 -1 1 -1

1 -1 -1 1

Coding:

M1 10 -> 1 1 1 1 -1-1-1-1

M2 01 -> -1-1 1 1 1 1-1-1

M3 11 -> 1-1 1-1 1-1 1-1

M4 00 -> -1 1 1-1-1 1 1-1

Combined signal:

0 0 4 0 0 0 0 -4

Decoding:

M1 (1,1,1,1)*(0,0,4,0)=4>0 => 1

(1,1,1,1)*(0,0,0,-4)=-4<0 => 0

M2 (1,1,-1,-1)*(0,0,4,0)=-4<0 => 0

(1,1,-1,-1)*(0,0,0,-4)=4>0 => 1

M3 (1,-1,1,-1)*(0,0,4,0)=4>0 => 1

(1,-1,1,-1)*(0,0,0,-4)=4>0 => 1

M4 (1,-1,-1,1)*(0,0,4,0)=-4<0 => 0

(1,-1,-1,1)*(0,0,0,-4)=-4<0 =>0

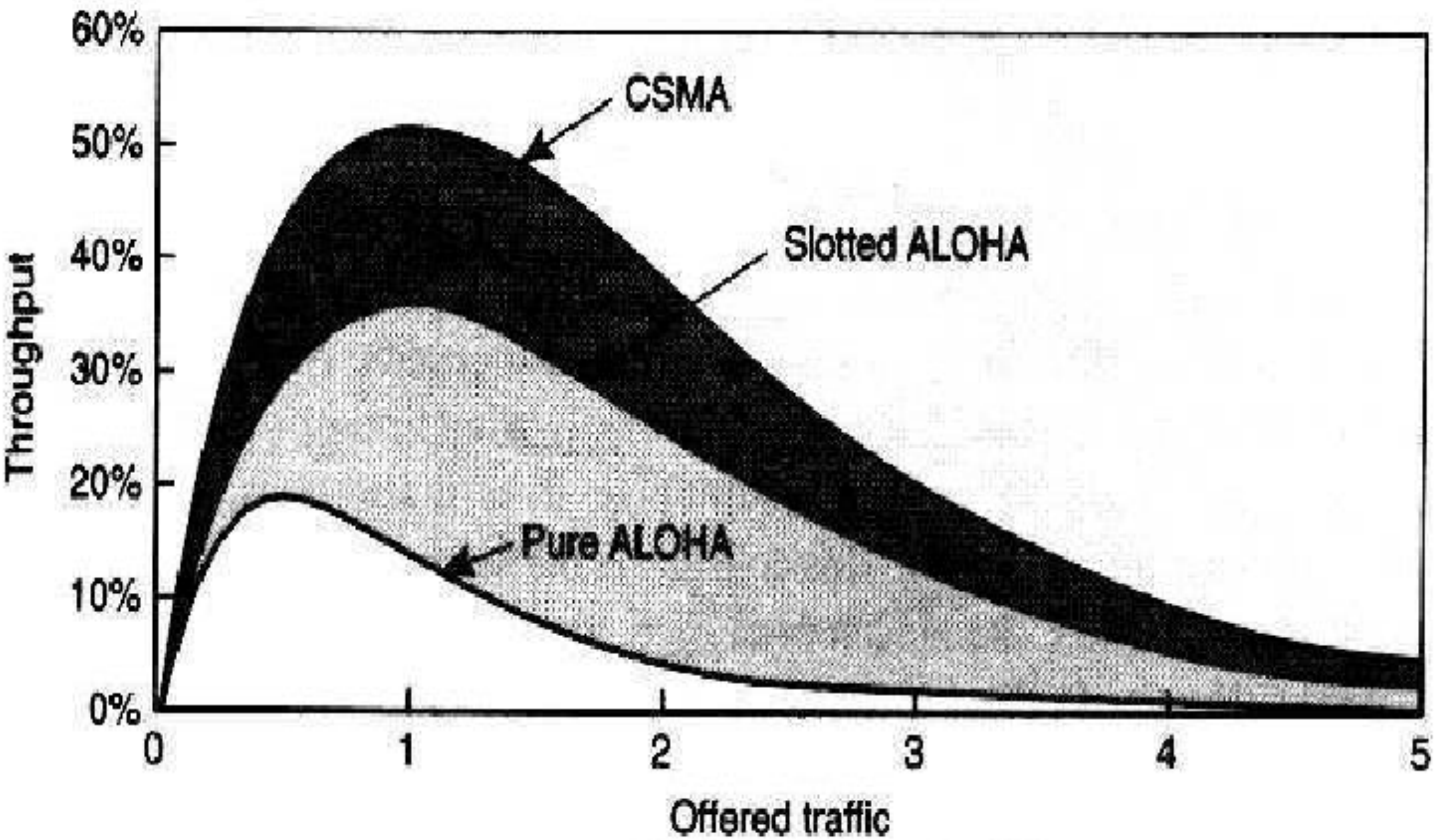
ALOHA

- A type of packet-radio network.
- The first well-known wireless network as well as network system.
- Very simple, but not efficient!

- Variations:
  - pure-ALOHA: whenever desired, send the packet
  - slotted-ALOHA: further divide time axis into slots

CSMA

- Before sending, sense the carrier.



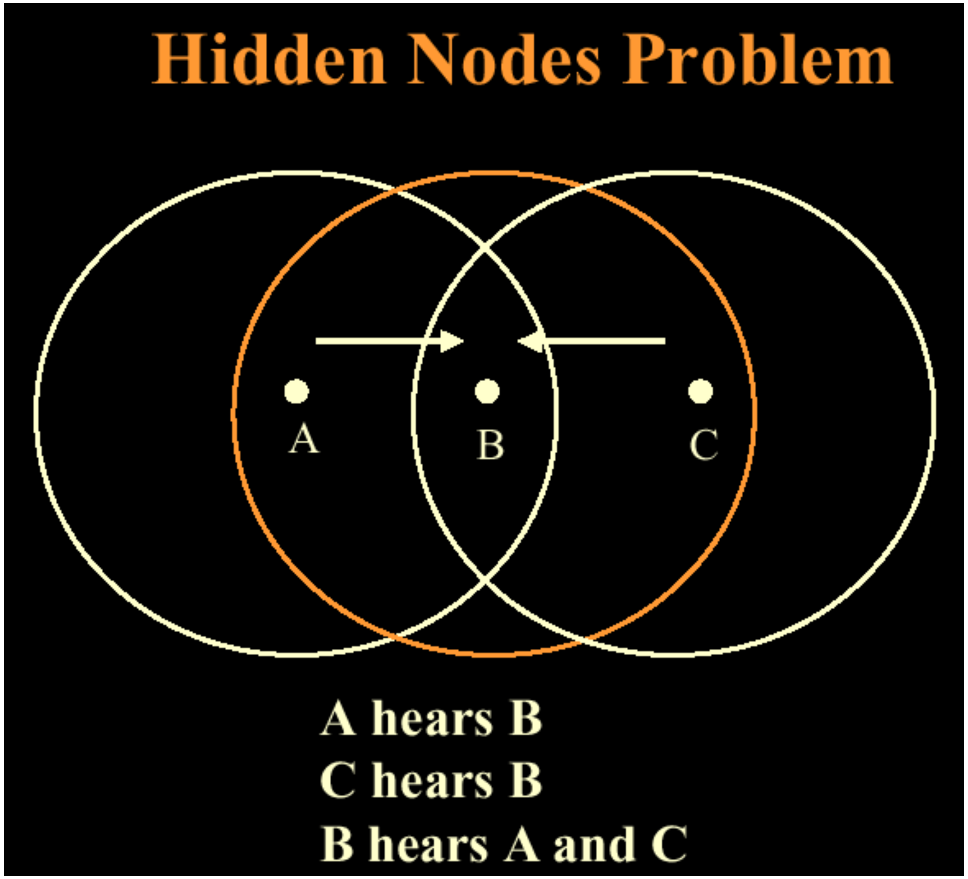
Performance of CSMA.

Persistent and Non-persistent CSMA

- Persistent CSMA:
  - when the medium is busy, a station can persistently wait for the medium to become idle, and then transmit with a probability p
  - This is called 1-persistent or p-persistent CSMA.
- Non-persistent CSMA:
  - A station can stop monitoring the wireless medium, and listen to the medium again at predefined time.

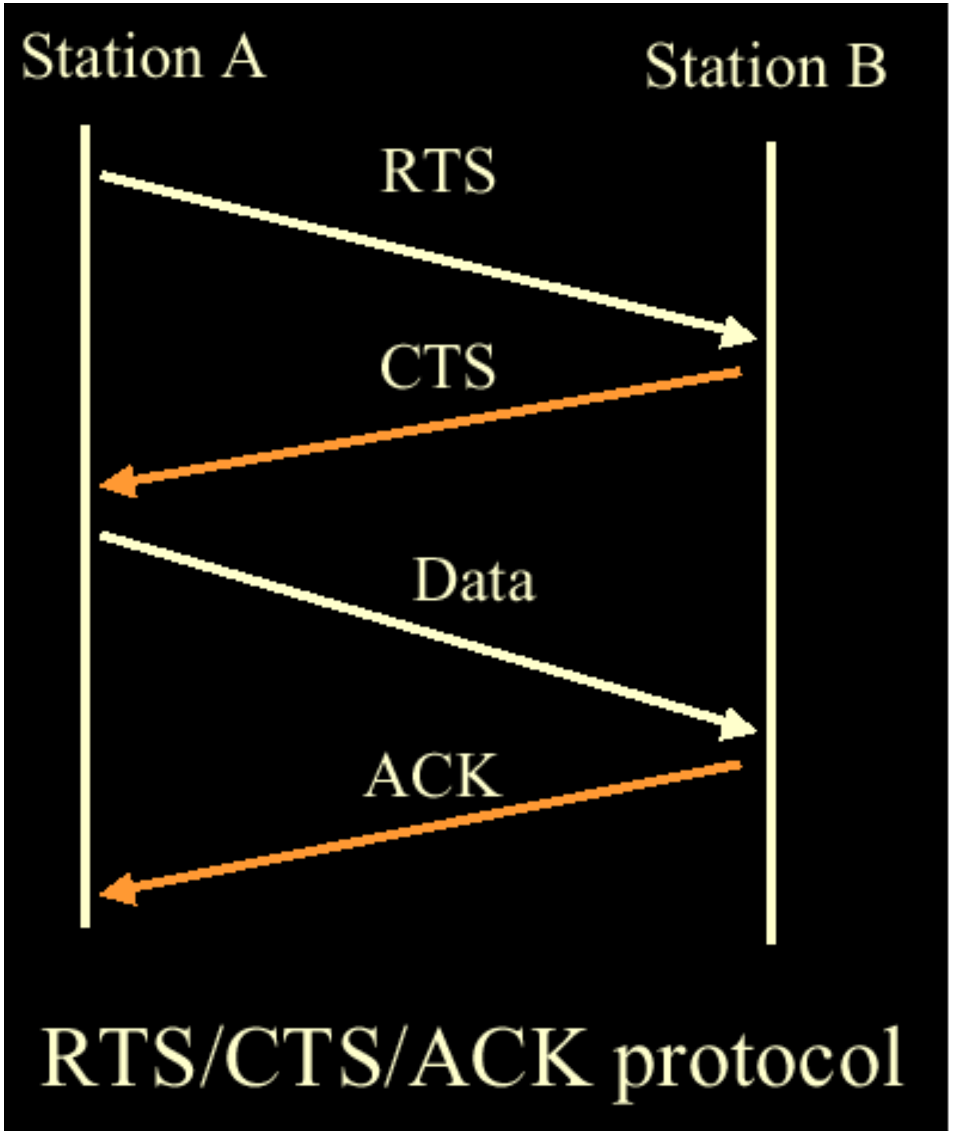
Hidden-Node Problem

- CSMA has the following problem:
  - when two nodes are too far away, carrier sensing is difficult



CSMA/CA

- CA = collision avoidance
  - sender first does carrier sense
  - sender broadcasts RTS (request to send) to receiver
  - receiver broadcasts CTS (clear to send) to sender
  - then send data packet


Station A
Station B
RTS
CTS
Data
ACK
RTS/CTS/ACK protocol

Comparison and Summary

- Random access: CSMA
  - under light load: fast response time
  - under heavy load: throughput declines
  - simplicity
- Deterministic protocols: TDMA, FDMA
  - guaranteed bandwidth
  - larger average delay
  - small delay variance
- Hybrid: CSMA/TDMA
  - adaptive, higher overhead