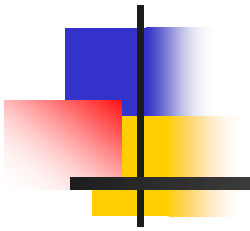
ADVANCED COMMUNICATION SYSTEMS

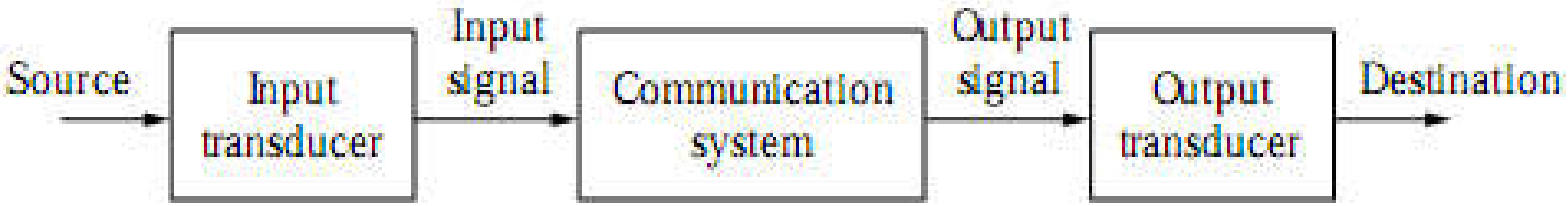


Chapter 1: Fundamentals of Analog and Digital Communications

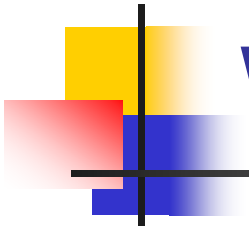
October 2018
Lectured by
Prof. Dr. Thuong Le-Tien

Communications

- Communications = Information Conveying

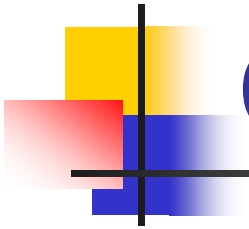


- This course is about communications based on signal concepts in electrical engineering
  - Limited to information in electrical forms
    - not be considered delivering newspapers
  - Primarily cover information transfer at signals and systems levels
    - little deal with circuits, chips, signal processing, microprocessors, protocols, and networks



What exactly is information?

- Information is a word that is too generic for our purposes
  - use the word "message"
    - A physical manifestation of information
- What do communication systems have to do with messages?
  - Communication systems are responsible for producing an "acceptable" replica of message at the destination

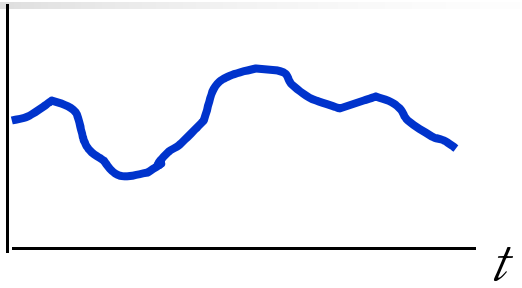


Classify signals

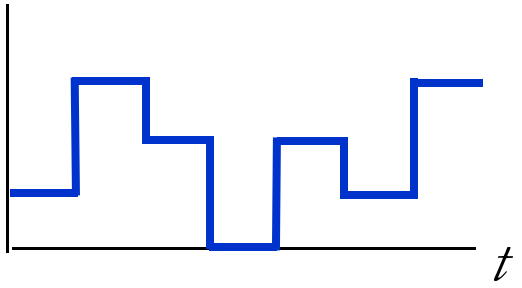
- Messages or signals can be classified in various ways: Periodic/non-periodic; Deterministic/random; Energy/power; the most common one in CS can deal with analog/digital groups
- **Analog**
  - **A physical quantity that varies with "time", usually in a smooth or continuous fashion**
  - **Fidelity describes how close is the received signal to the original signal. Fidelity defines acceptability**
- **Digital**
  - **An ordered sequence of symbols selected from a finite set of discrete elements**
  - **When digital signals are sent through a communication system, degree of accuracy within a given time defines the acceptability**

Examples for basic definitions

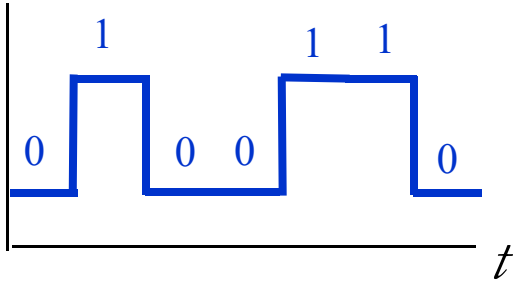
- Analog Signals
  - Values are taken from an infinite set



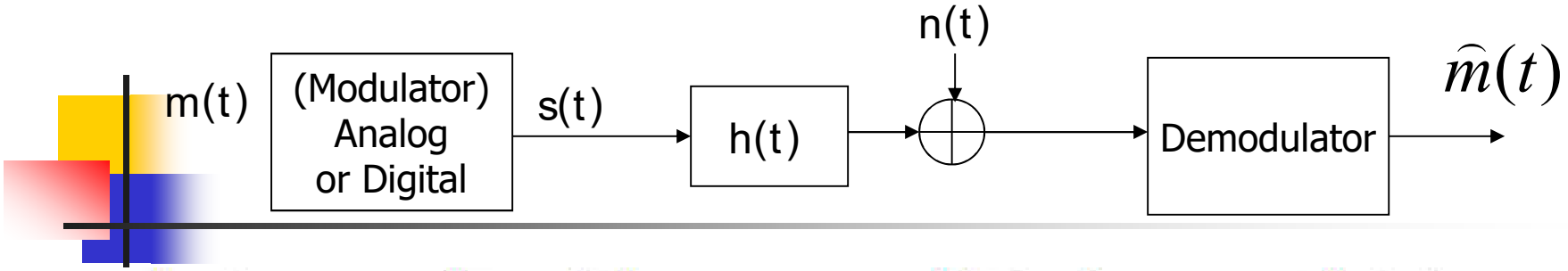
- Digital Signals
  - Values are taken from a discrete set

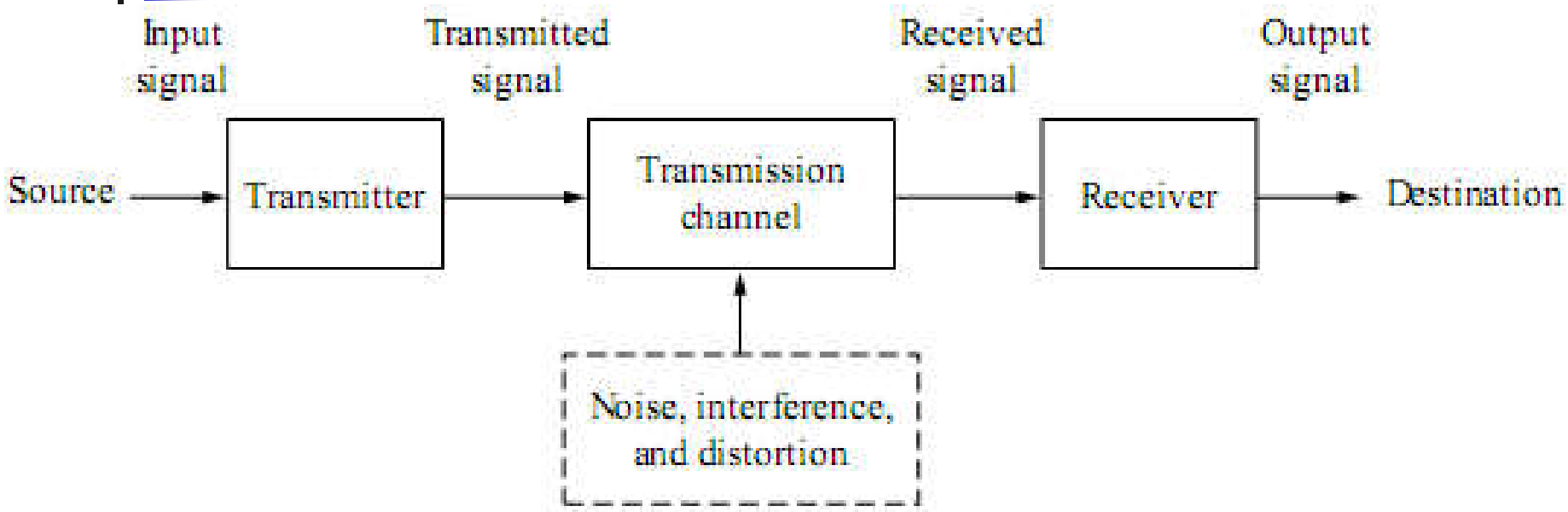


- Binary Signals
  - Digital signals with just two discrete values



Elements of Communication Systems





Transmitter

- ***Modulation**
- ***Coding**

Channel

- ***Attenuation**
- ***Noise**
- ***Distortion**
- ***Interference**
- ***Fading**

Receiver

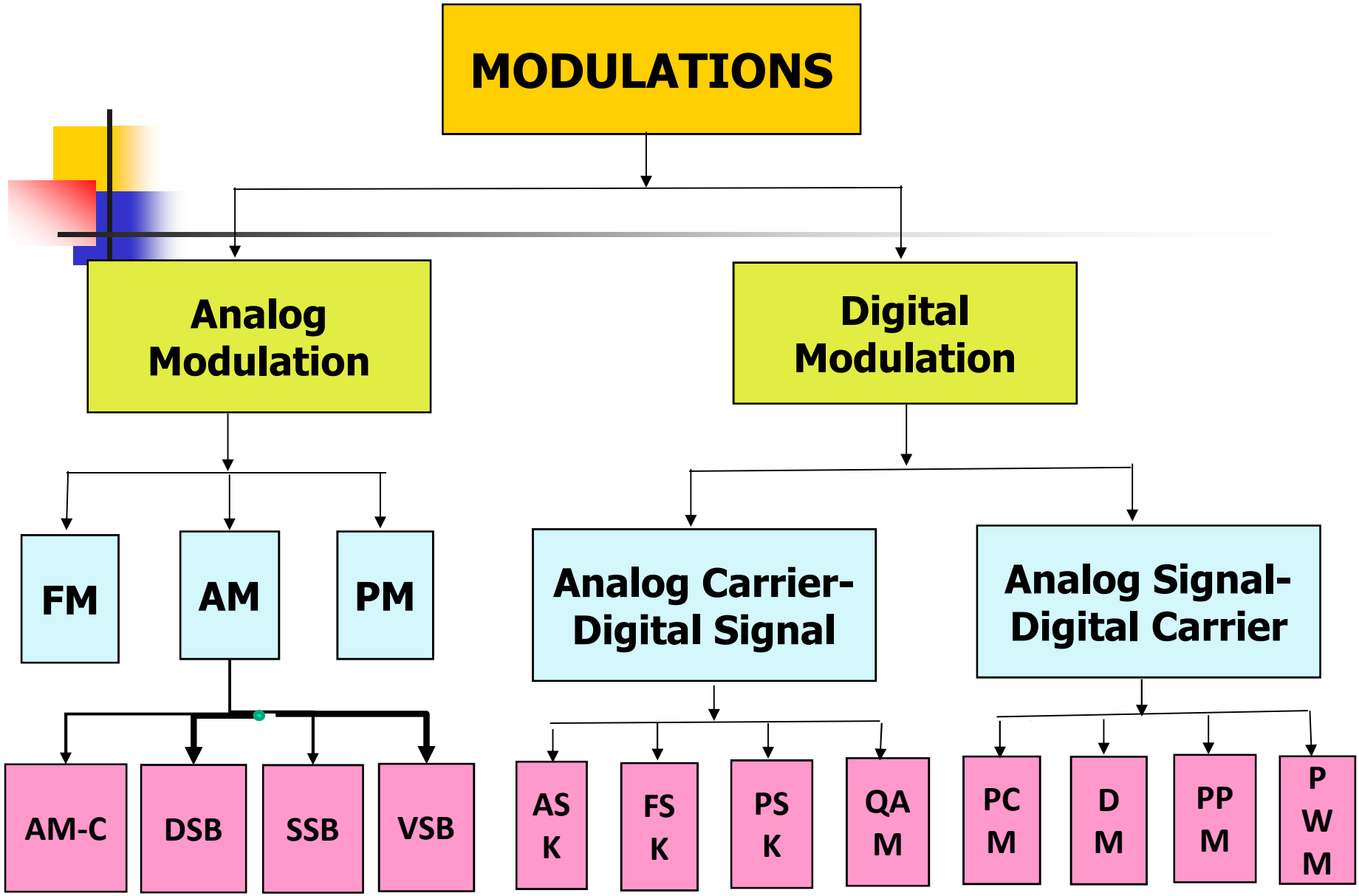
- ***Detection (Demod+Decod)**
- ***Filtering (Equalization)**

Transmitter

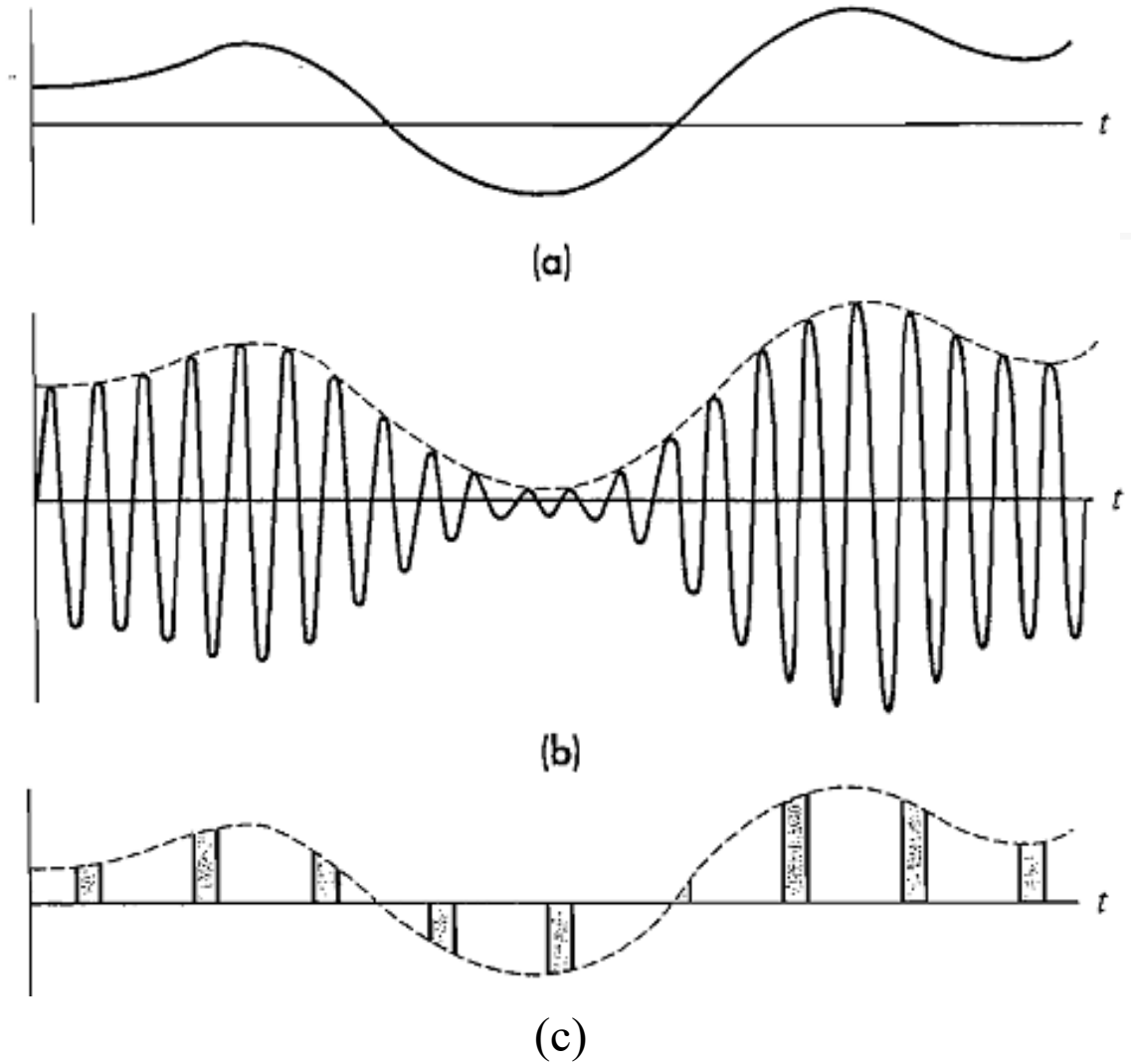
What does modulation do?

- Modulate messages (analog) or Encode bits (digital) into amplitude, frequency, or phase of a carrier signal.
- Also makes transmitted signal robust against channel impairments (Noise, Interferences, Fading, Distortions, etc.)

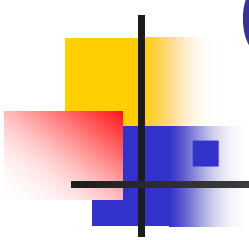
- Coding in digital communication systems
  - Source coding – remove redundancy
  - Channel coding – add redundancy, lower BER
  - Encryption Coding – hide information


MODULATIONS
Analog Modulation
Digital Modulation
FM
AM
PM
AM-C
DSB
SSB
VSB
Analog Carrier-Digital Signal
Analog Signal-Digital Carrier
ASK
FSK
PSK
QAM
PCM
DM
PPM
PWM

Example about Modulation



(a) Modulating Signal; (b) Sinusoidal carrier with amplitude modulation
(c) Pulse-train carrier with amplitude modulation

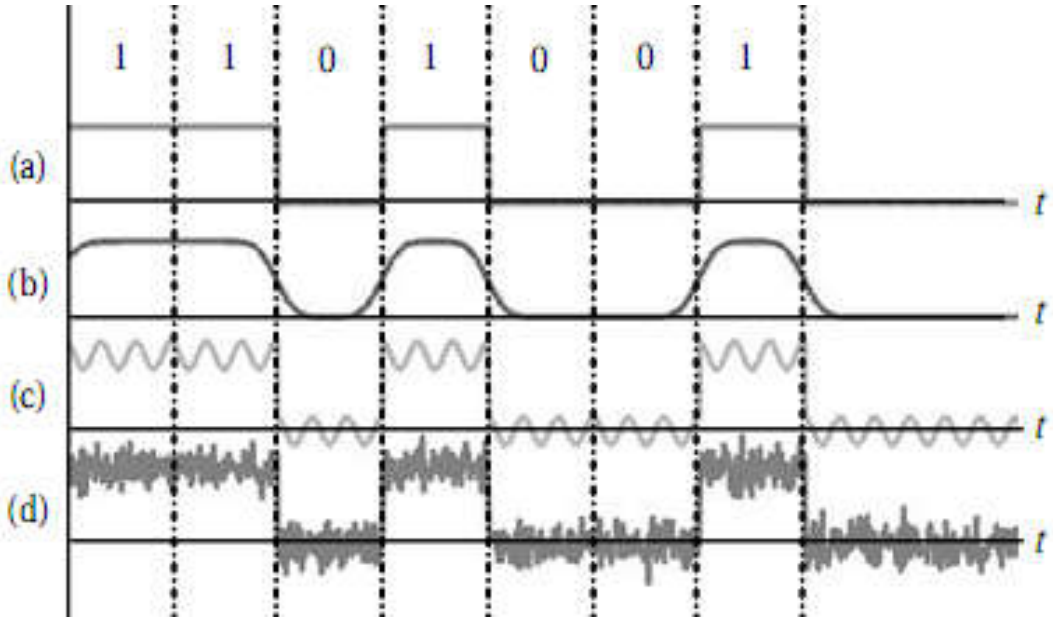


Channels

- Channel introduces impairments
  - Noise
    - Thermal noise is the most significant
    - Additive white Gaussian noise (AWGN)
  - Distortion
    - Inter-symbol interference (ISI)
  - Attenuation and fading
    - Constant attenuation
    - Variable attenuation
  - Interference
    - Crosstalk

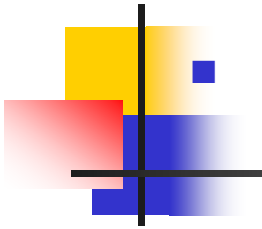
Receiver

- What does Demodulation/Detection do?
  - Extracts messages (analog systems) or bits (digital systems) from the received signal
  - Mitigates channel impairments by making use of equalizers
  - Decodes the signal, especially if channel coding was performed at the transmitter



(a) Transmitted signal
(b) Effects of distortion
(c) Effects of interference
(d) Effects of noise

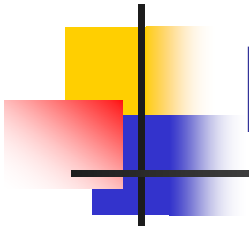
Fundamental Limitations



- If practical implementation is not a concern and we don't worry about feasibility, is there something else that limits acceptable communications?
- Bandwidth
  - Channel must be able to allow signal to pass through
  - Channels usually have limited bandwidth
  - Can we reduce signal bandwidth? Do "something" at source (reduce redundancy, compression, etc.)
- Noise
  - Can we reduce it? - Filters
  - Can we reduce its effects? - Equalizers
  - Do something at the transmitter and receiver
- Signal to Noise Ratio (SNR): Match Filters

Performance Criterion

- How a "good" communication system can be differentiated from a "sloppy" one?
- For analog communications
  - How close is $\hat{m}(t)$ to $m(t)$? Fidelity!
  - SNR is typically used as a performance metric
- For digital communications
  - Data rate and probability of error (BER)
  - No channel impairments, no errors
  - With noise, error probability depends upon data rate, signal and noise powers, modulation scheme



Limits on data rates

- Shannon obtained formulas that provide fundamental limits on data rates (1948)
- Without channel impairments, an infinite data rate is achievable with probability of error approaching zero
- For bandlimited AWGN channels, the "capacity" of a channel is:

$$C = B \log_2(1+SNR) = 3.32B \log_{10}(1+SNR) \text{ Bits/second}$$

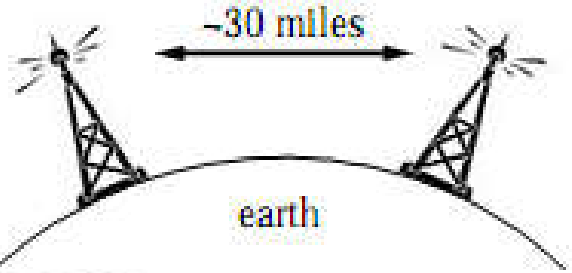
MODULATION FOR MULTIPLEXING

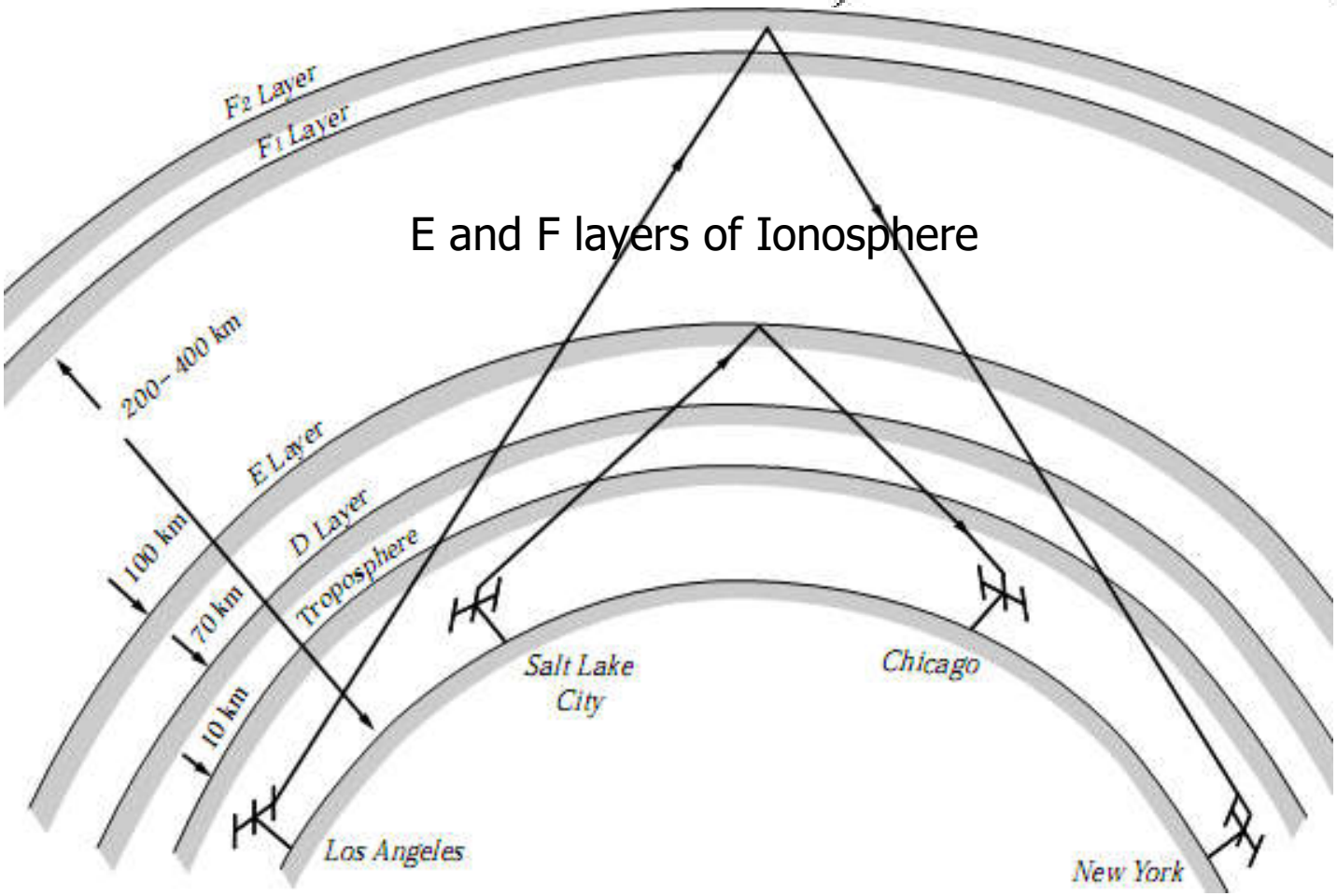
Multiplexing is the process of combining several signals for simultaneous transmission on a channel

- Frequency–Division Multiplexing, FDM, uses CW modulation to put each signal on a different carrier frequency.
- Time-Division Multiplexing, TDM, uses pulse modulation to put Samples of different signals in nonoverlapping time slots
- Code-Division Multiple Access, CDMA, assigns a unique code to each Digital (cellular) user

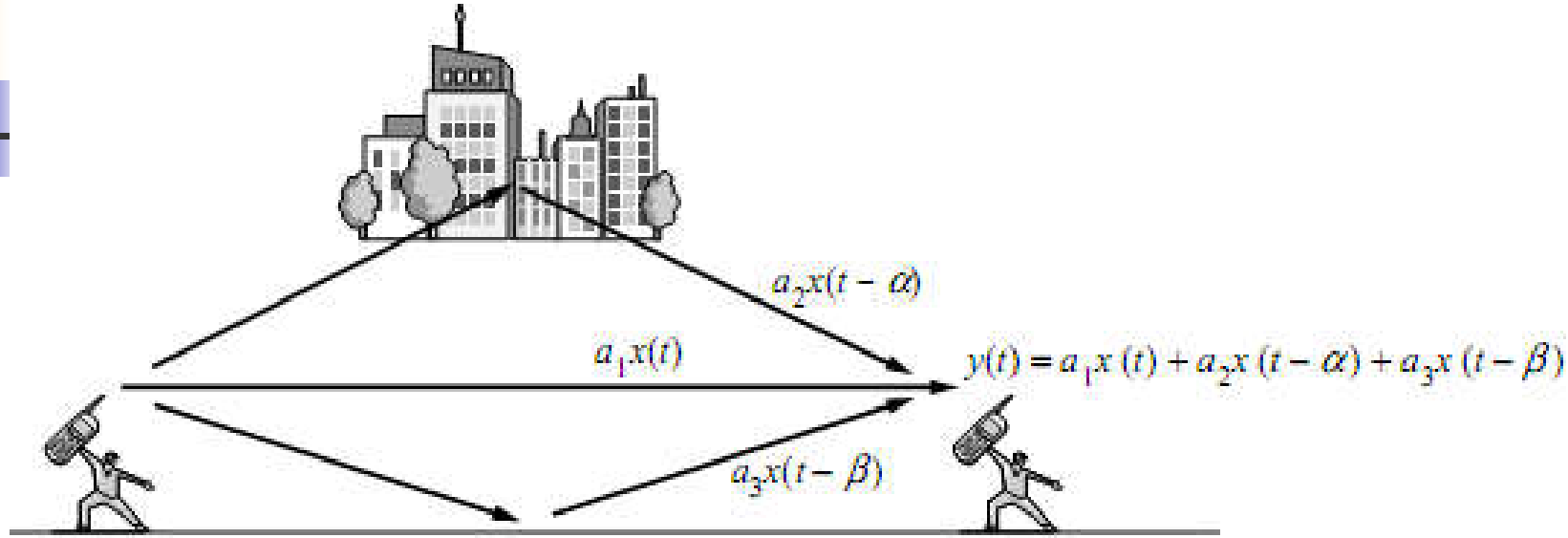
Electromagnetic wave propagation over wireless channels

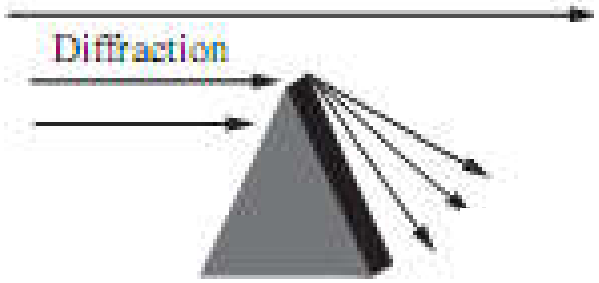
Line of Sight and Sky wave propagations

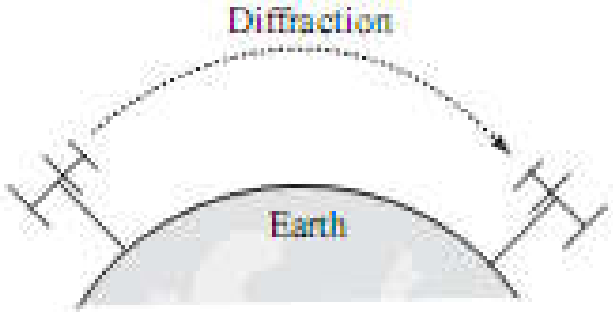


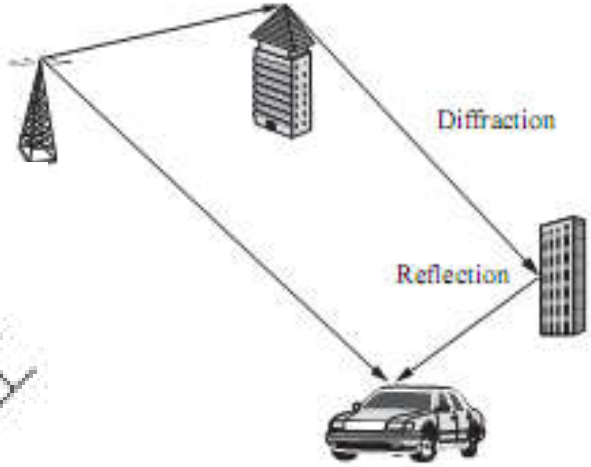


Multipath interference caused by a signal being reflected off the terrain and a building

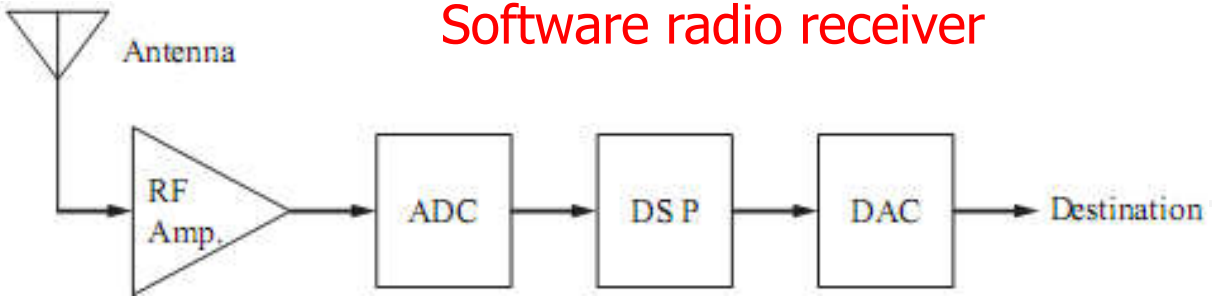




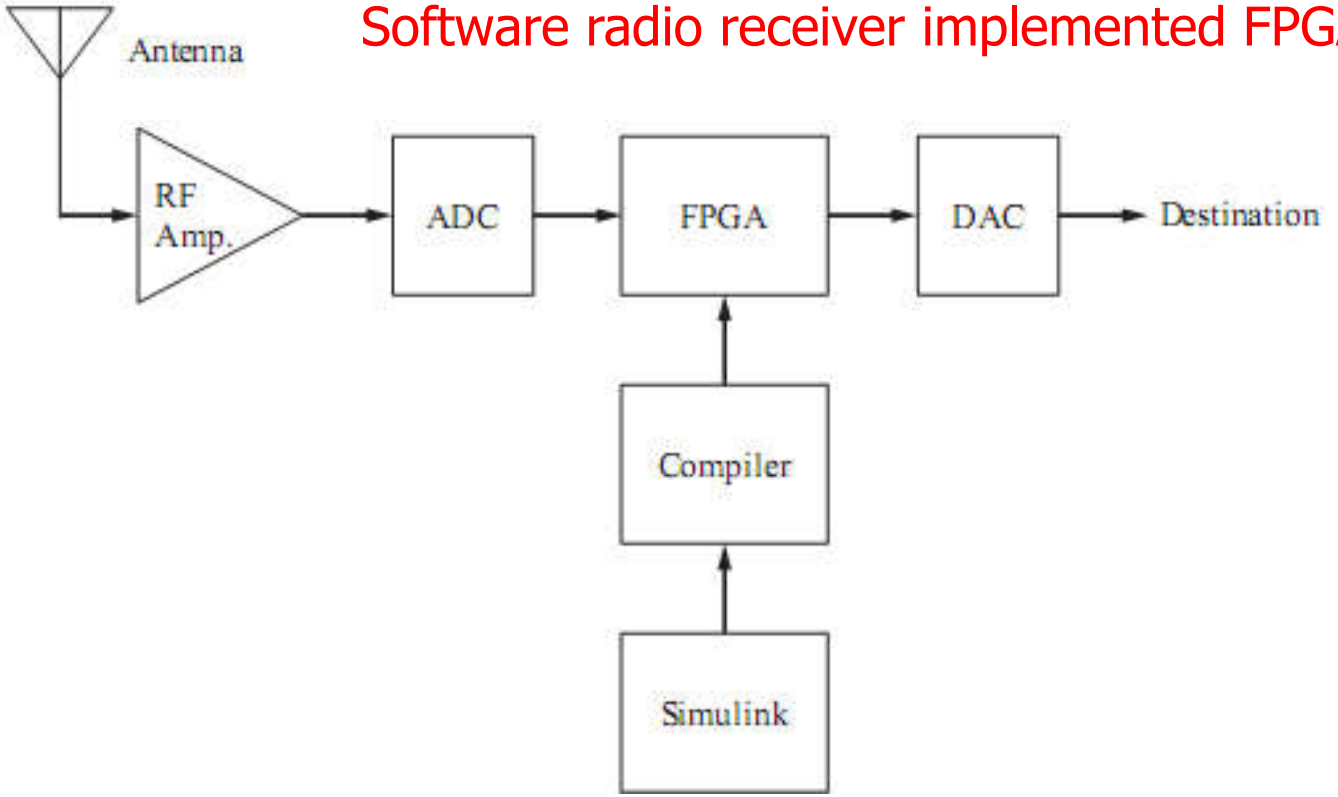




Software radio receiver

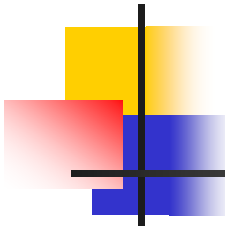


Software radio receiver implemented FPGA



FREQUENCY BANDS WITH DESIGNATIONS

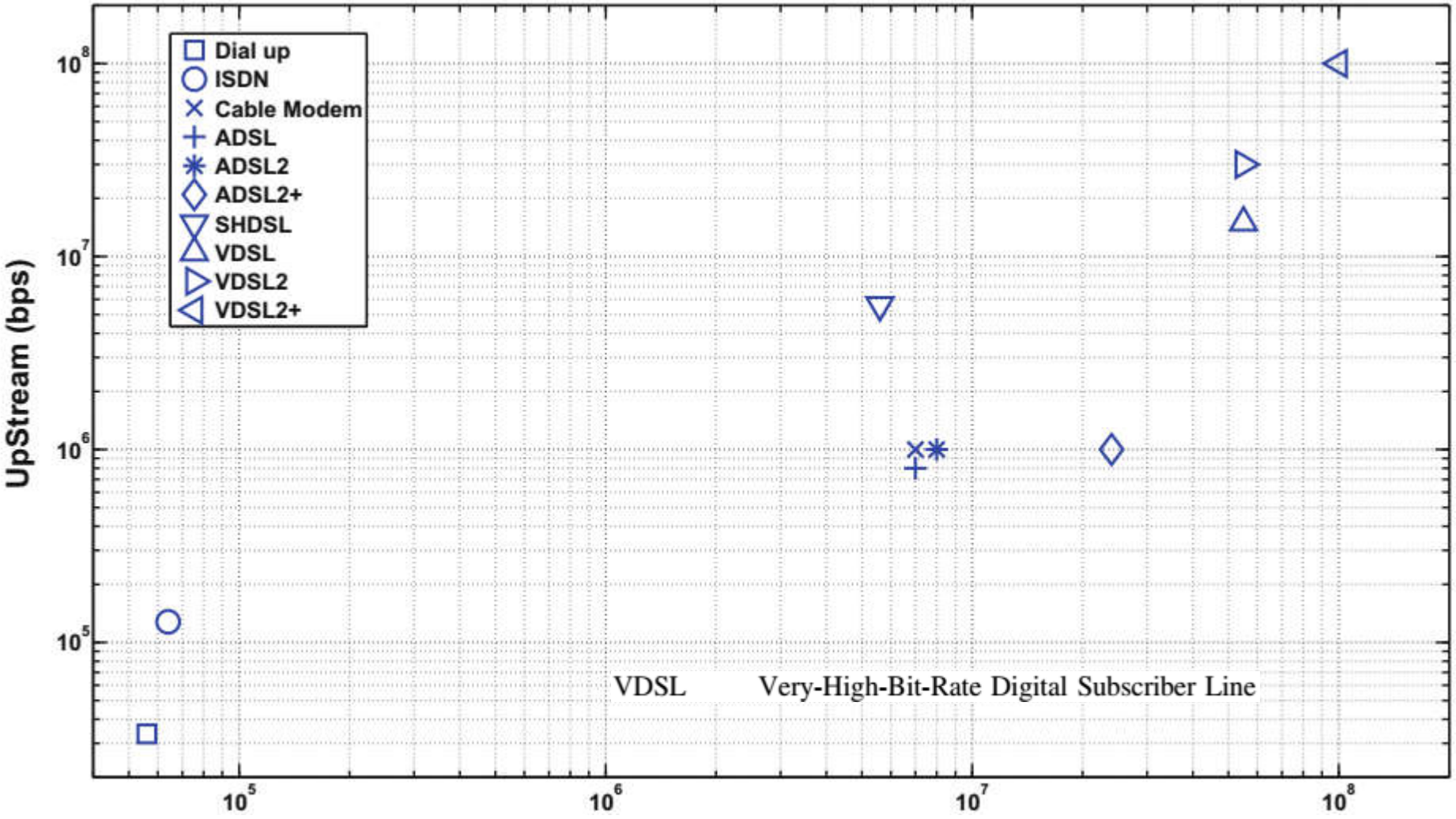
Frequency band	Name	Microwave band (GHz)	Letter designation
3–30 kHz	Very low frequency (VLF)		
30–300 kHz	Low frequency (LF)		
300–3000 kHz	Medium frequency (MF)		
3–30 MHz	High frequency (HF)		
30–300 MHz	Very high frequency (VHF)		
0.3–3 GHz	Ultrahigh frequency (UHF)	1.0–2.0	L
		2.0–3.0	S
3–30 GHz	Superhigh frequency (SHF)	3.0–4.0	S
		4.0–6.0	C
		6.0–8.0	C
		8.0–10.0	X
		10.0–12.4	X
		12.4–18.0	Ku
		18.0–20.0	K
		20.0–26.5	K
30–300 GHz	Extremely high frequency (EHF)	26.5–40.0	Ka
43–430 THz	Infrared (0.7–7 μm)		
430–750 THz	Visible light (0.4–0.7 μm)		
750–3000 THz	Ultraviolet (0.1–0.4 μm)		



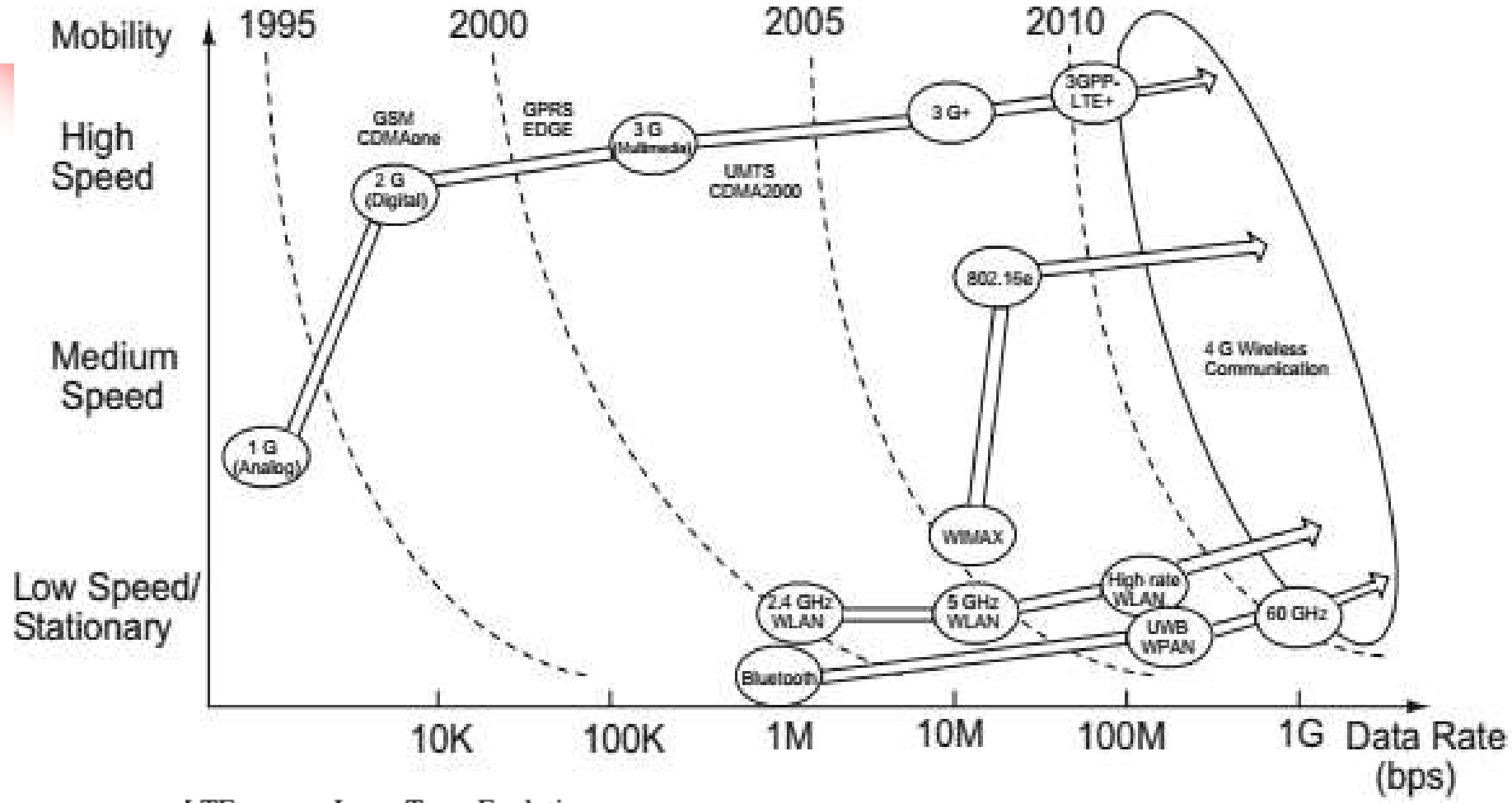
Use		Frequency
Radio navigation		6–14 kHz; 90–110 kHz
Loran C navigation		100 kHz
Standard (AM) broadcast		540–1600 kHz
ISM band	Industrial heaters; welders	40.66–40.7 MHz
Television:	Channels 2–4	54–72 MHz
	Channels 5–6	76–88 MHz
FM broadcast		88–108 MHz
Television	Channels 7–13	174–216 MHz
	Channels 14–83	420–890 MHz
	(In the United States, channels 2–36 and 38–51 are used for digital TV broadcast; others were reallocated.)	
Cellular mobile radio	AMPS, D-AMPS (1G, 2G)	800 MHz bands
	IS-95 (2G)	824–844 MHz/1.8–2 GHz
	GSM (2G)	850/900/1800/1900 MHz
	3G (UMTS, cdma-2000)	1.8/2.5 GHz bands
Wi-Fi (IEEE 802.11)		2.4/5 GHz
Wi-MAX (IEEE 802.16)		2–11 GHz
ISM band	Microwave ovens; medical	902–928 MHz
Global Positioning System		1227.6, 1575.4 MHz
Point-to-point microwave		2.11–2.13 GHz
Point-to-point microwave	Interconnecting base stations	2.16–2.18 GHz
ISM band	Microwave ovens; unlicensed spread spectrum; medical	2.4–2.4835 GHz 23.6–24 GHz 122–123 GHz 244–246 GHz

COMMUNICATION EVOLUTION

Data rate Comparison between different wireline Internet Accesses



Evolution of Wireless Communications



LTE Long Term Evolution

HSDPA High Speed Downlink Packet Access

NFC Near Field Communication

Universal Mobile Telecommunications System (UMTS)