Principles of Communications

Lecturer:
Weiyao Lin
Department of Electronic Engineering
Shanghai Jiao Tong University

Chapter 1: Introduction

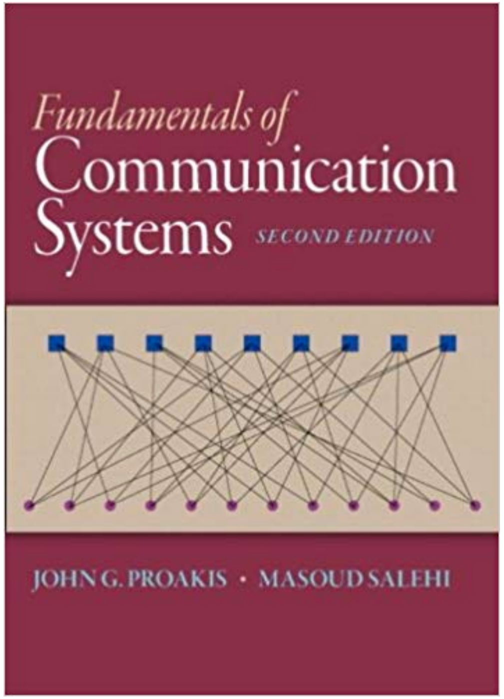
Staff

- Lecturer:
  - Weiyao Lin（林巍峣）
  - Office: Room 1-301, SEIEE Buildings
  - Email: **wylin@sjtu.edu.cn**
  - Web: **https://weiyaolin.github.io/**

- TA: To be confirmed
  - Xiaoyi He（何晓艺）
  - Office: Room 1-301, SEIEE Buildings
  - Email: 515974418@sjtu.edu.cn

Textbook

- “Fundamentals of Communication Systems (2nd Edition)”, by J. G. Proakis and M. Salehi, Pearson prentice Hall 2013



- References:
  - “An introduction to analog and digital communications”, by Simon Haykin, 2nd edition, John Wiley & Sons, 2007
  - "Communications Systems Engineering", by John G. Proakis and Masoudsalehi, 2nd edition, Printice-Hall, 2002.
  - 《通信原理》，韩声栋、蒋铃鸽、刘伟编著，机械工业出版社，2008.6

Textbook 2

- 《通信原理实验教程——基于NI软件无线电教学平台》，杨宇红、袁焱、田砾，清华大学出版社，2015

Class Website and Lecture Notes

- Class Website:
  - https://weiyaolin.github.io/comm/comm.html
  - (backup) https://oc.sjtu.edu.cn/courses/1476
- Lecture notes can also be downloaded from:
  - ftp://public.sjtu.edu.cn
  - Username: 515974418
  - Password: public
    - o Under the folder “communication system”

Lecture notes are very important! The mid and final exam questions are designed based on the lecture notes!

Class WeChat Group

Schedule 1

Week 1	Ch01: Introduction
Week 2	Ch02: Signal, Random Process, and Spectra
Week 3	
Week 4	Ch03: Analog Modulation Ch04: Analog to Digital Conversion
Week 5	
Week 6	Ch05: Signal Space Representation Ch06: Optimal receivers
Week 7	
Week 8	**Tutorial and Mid-term Test (To be confirmed)**

Schedule 2

Week 9	Ch07: Digital Modulation Techniques
Week 10	
Week 11	Ch08: Digital Transmission Through Baseband Channels
Week 12	Ch09: Multicarrier Modulation and OFDM
Week 13	Ch10: Information Theory
Week 14	Ch11: Channel Coding
Week 15	
Week 16	Ch12: Advanced Topics and Course Review

Lab courses

- Yuhong Yang (杨宇红) yangyuhong@sjtu.edu.cn
- Schedule (To be confirmed):
  - Week 4 Wednesday
    - Introduction of LabView and Lab projects
  - Week 9 Wednesday
    - Signal generator, Matched filter, Channel equalization
  - Week 14 Wednesday
    - BPSK/QPSK etc
  - Week 16 Wednesday
    - Exploration Project

Assessment

- Homework: 10%
  - 5 sets of homework
  - 2 points for each homework
- Mid-term test: 10%
  - In-class open book test
- Lab project: 30%
- Final exam: 50%
- Bonus points

Objective

- The primary objective of this course is
  - to introduce the basic techniques used in modern communication systems, and
  - to provide fundamental tools and methodologies in analysis and design of these systems
- After this course, the students are to expected to
  - Understand the principles and technique of modulation, coding and transmission.
  - Analyze the merits and demerits of current communication systems and to eventually design improved new systems

Suggestion

- Prerequisites: signals and systems, random process
- The course focus on the methodologies of system design and analysis, rather than concrete circuits and implementation.
- Pay more attention to essential concepts and physical models

Getting Help

- Attendance is essential
- Ask questions at any time during lecture
- Send an email to TA or myself in advance for consultation

Overview of Comm Systems

- 1.1.Elements of a communication system
- 1.2 Communication Channels
- 1.3. Design tradeoffs of communication systems

What is communications?

- Communications
  - The systems and processes that are used to convey information from a source to a destination, especially by means of electricity or radio waves.
- Telecommunications
  - “tele” = distance
  - The technology of sending signals and message over a distance using electronic equipment, for example, telegraph, telephone, radio, television and cellphone

Historical Review

- 1838: telegraph
- 1876: telephone
- 1895: radio by Marconi
- 1901: trans-atlantic communication

- Early 20th century:
  - Most communication systems are analog.
  - Engineering designs are ad-hoc, tailored for each specific application

Big Questions

- Is there a general methodology for designing communication systems?

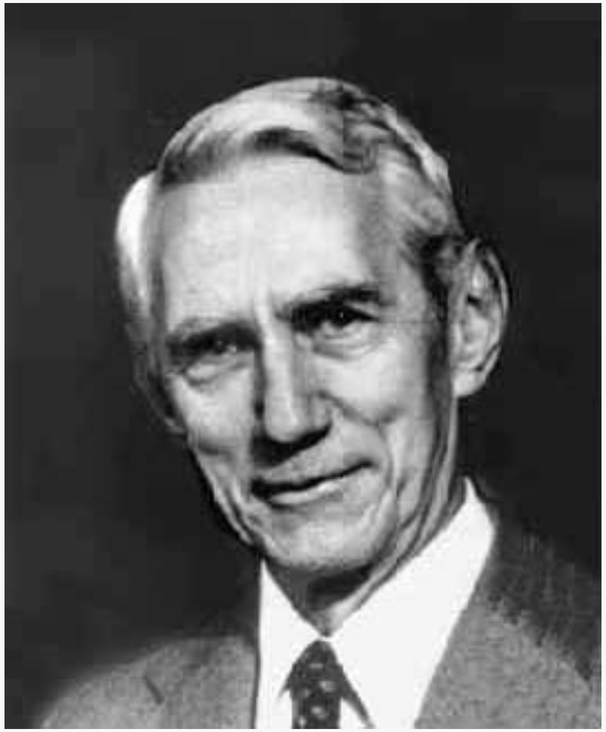
- Is there a limit to how fast one can communicate?

Harry Nyquist (1928)

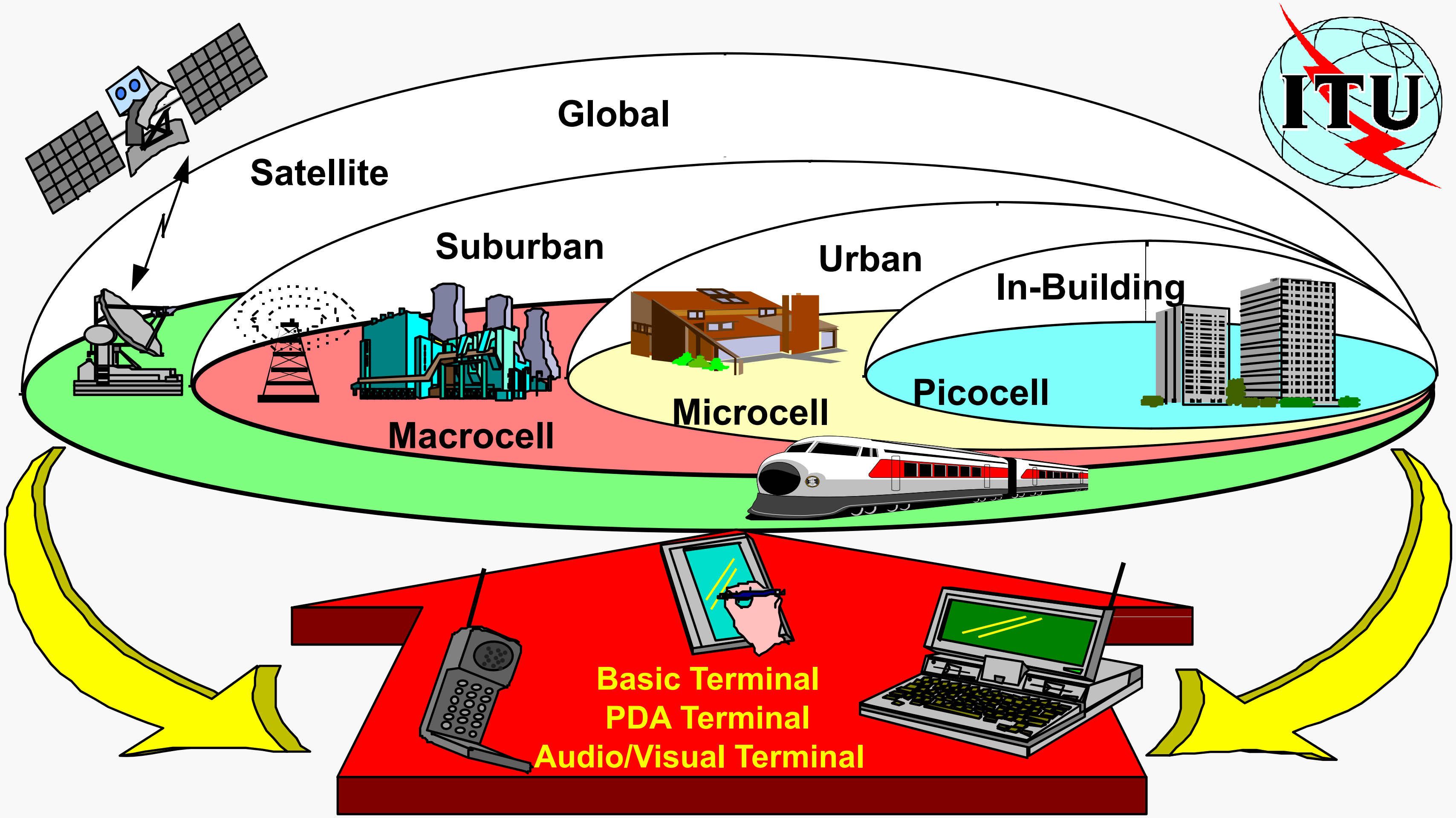
- Analog signals of bandwidth W can be represented by 2W samples/second
- Channels of bandwidth W support transmission of 2W symbols/second
- Nyquist transformed a continuous time problem to a discrete-time problem.
- But did he really solve the communication problems?

Claude Shannon (1948)

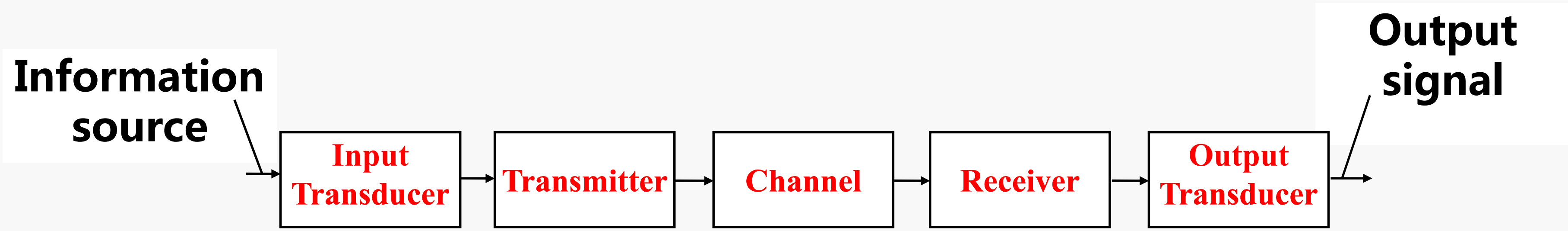
- Shannon's information theory solves all the big questions
- Shannon describes information source and channel with probability
- There exists an entropy rate H bits/sec for each source
- There exists a capacity C bits/sec for each channel
- If and only if H<=C , the information can be transmitted over the channel almost error-free



60 Years Later…



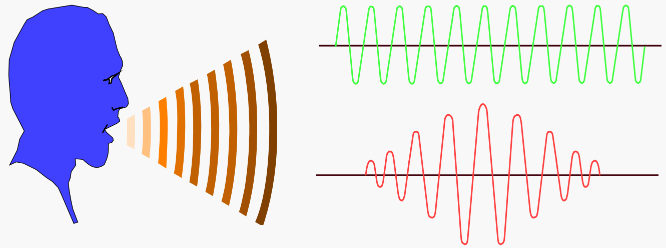
Elements of Communication Systems



- Software
- Hardware
- Communication architecture, with coding and signal processing algorithms

- Source : voice, picture, text, etc
- Input Transducer: Converts the original message into an appropriate electrical form – e.g. microphone, video cameras
- Transmitter: Couples the electric message to the channel
- Channel: Medium carring the message between the two points- twisted pair, coax, wireless or optical
- Receiver: Extracts the original electric signal among many signals in the channel
- Output Transducer: Recovers the message from the electric signal – e.g loudspeaker

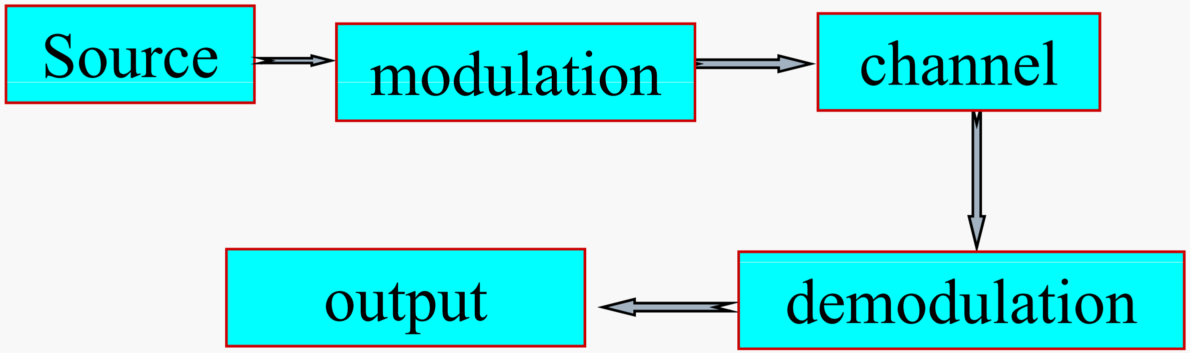
- Analog Communications
  - The transmitter sends a waveform from an infinite variety of waveform shapes
  - The receiver is to reproduce the transmitted waveform with high fidelity, which is usually measured in terms of SNR



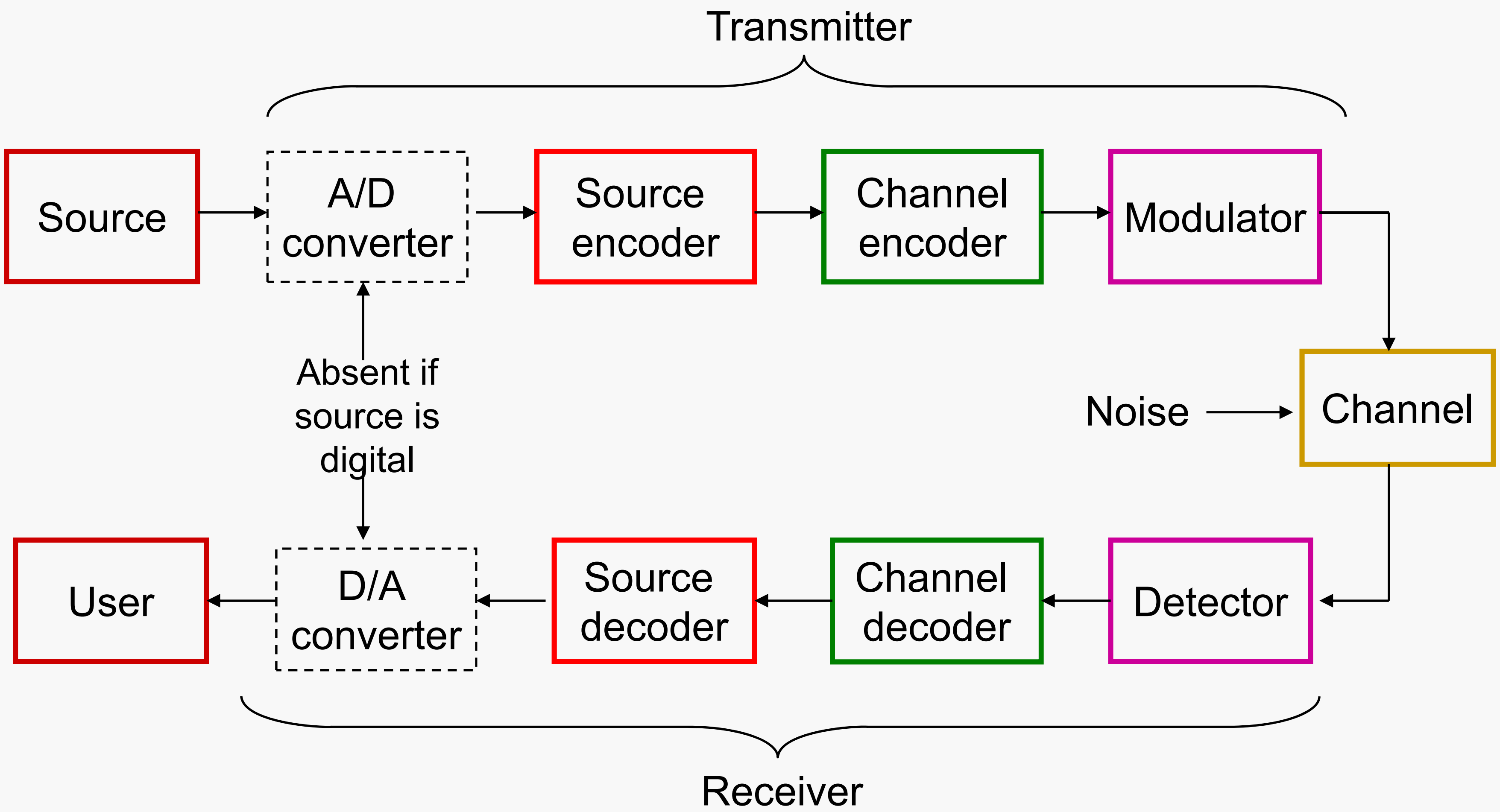
- Digital Communications
  - Signals made up of discrete symbols selected from a finite set
  - Fidelity or Accuracy is specified in terms of bit error rate (Probability of making a bit error)

00011011110

Analog Communication Systems



Digital Communication Systems



- Source coding
  - Source encoder maps the digital signal generated at the source output into another signal in digital form
  - The objective is to eliminate or reduce redundancy so as to provide an efficient representation of the source output
- Channel coding
  - Channel coding provides protection against transmission error. This is done by inserting redundant data in a prescribed fashion
  - Channel encoder inserts redundant information in a very selective manner.
- Thus, in source coding, we remove redundancy, whereas in channel coding, we introduce controlled redundancy.

Why Digital Communications?

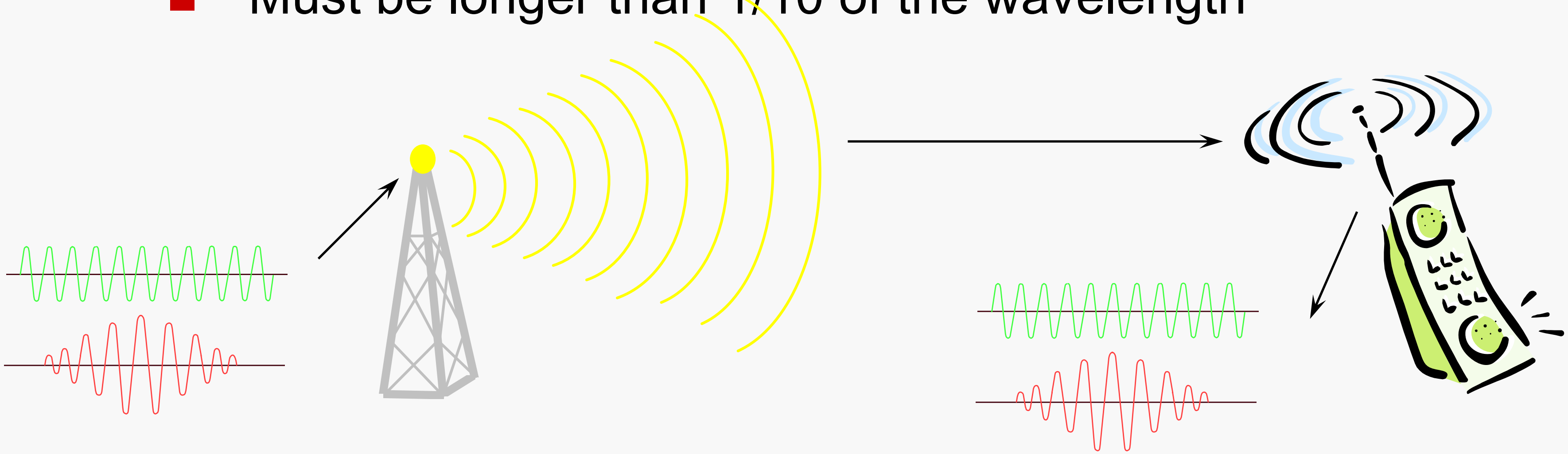
- Robustness to channel noise and external Interference
  - Many signal processing techniques are available to improve system performance: source coding, channel (error-correction) coding, equalization
- Security of information during its transmission from source to destination
  - various encryption, coding techniques available
- Integration of diverse sources information into a common format
  - Allow integration of voices, video, and data on a single system
- Low cost DSP chips
  - Very cheap VLSI designs

Communication Channels

- Carries signal – could be a pair of wires, optical fiber, free space, underwater acoustic channel
- Presents distorted signal to the receiver
- Effects include
  - Attenuation: signal power typically decreases as distance
  - Noise (e.g. additive white Gaussian noise or AWGN)
  - Filtering:
    - channel can have a bandwidth that is small compared to the signal bandwidth (e.g. in a telephone channel)
    - Transmitted pulses will be changed in shape and smeared out in time causing Inter-Symbol Interference or ISI
  - Fading
    - Signal amplitude can change in a random fashion
    - Fading is very important in wireless communications

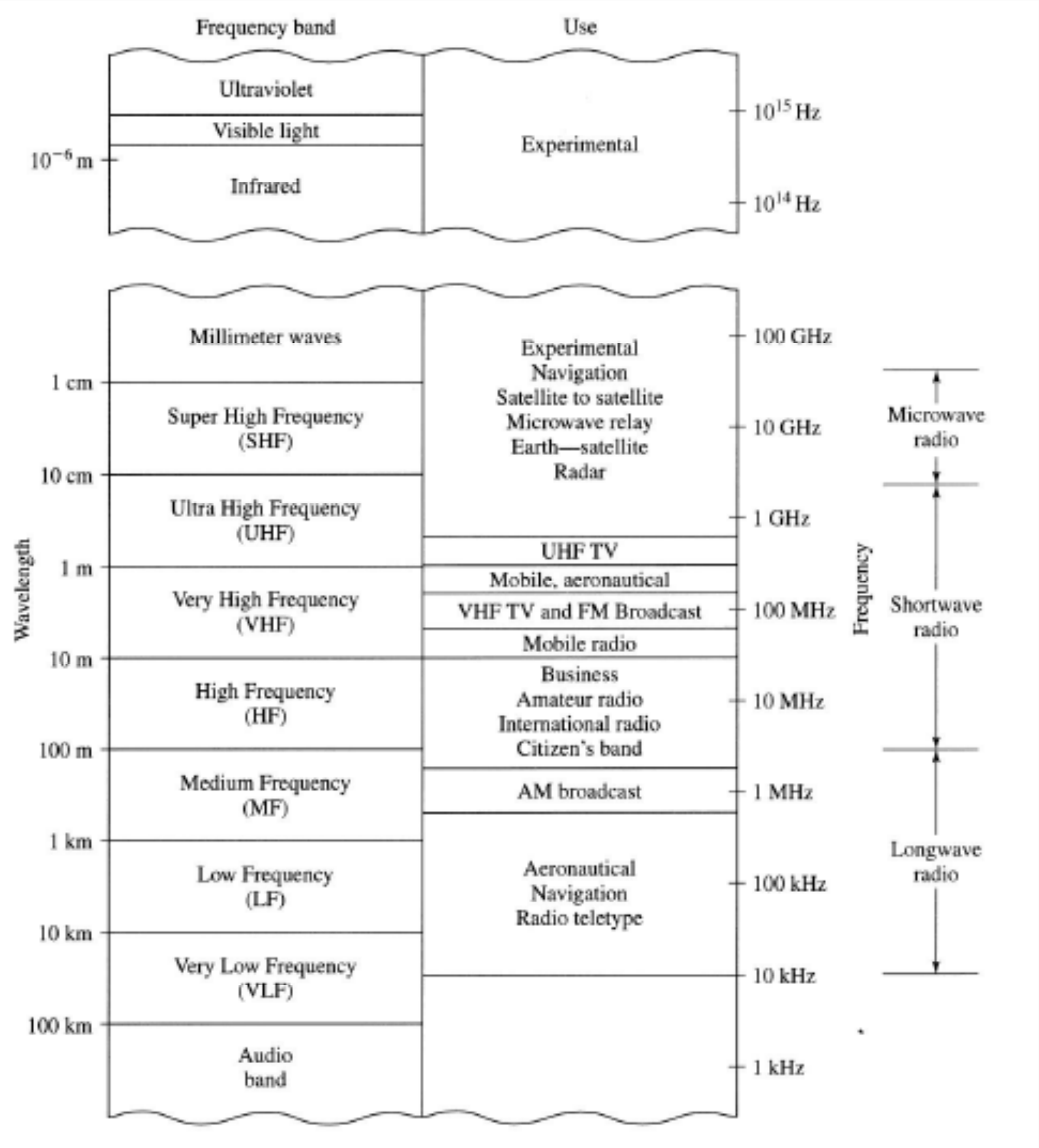
Wireless Electromagnetic Channels

- EM energy is radiated to the propagation medium (e.g. free space) by an antenna
- The size and configuration of the antenna depends on the frequency of operation
  - Must be longer than 1/10 of the wavelength



Radio spectrum:

The set of all frequencies from 0Hz to infinity is known as the radio spectrum and is used for many different applications



Spectrum Regulation

- Radio waves travel or propagate through a common channel that everybody shares
- That is for a particular frequency only one person, user or company can use it – otherwise there will be interference and chaos!
- The government effectively owns the radio spectrum and regulates it
- The government of different countries must coordinate the regulation of the spectrum
  - ITU (International Telecommunication Union)

Spectrum Regulation – Licensed

Service/system	Frequency span
AM radio	535-1605 kHz
FM radio	88-108 MHz
Broadcast TV	54-88 MHz, 174-216 MHz, 470-806 MHz
Broadband wireless	746-764 MHz, 776-794 MHz
3G systems	1.7-1.85MHz, 2.5-2.69 MHz
1G and 2G cellular phones	806-902 MHz, 1.85-1.99 GHz
Satellite digital radio	2.32-2.325 GHz
Multichannel multipoint distribution service (MMDS)	2.15-2.68 GHz
Digital broadcast satellite (Satellite TV)	12.2-12.7 GHz
Local multipoint distribution service (LMDS)	27.5-29.5 GHz, 31-31.3 GHz
Fixed wireless services	38.6-40 GHz

Spectrum Regulation– Unlicensed

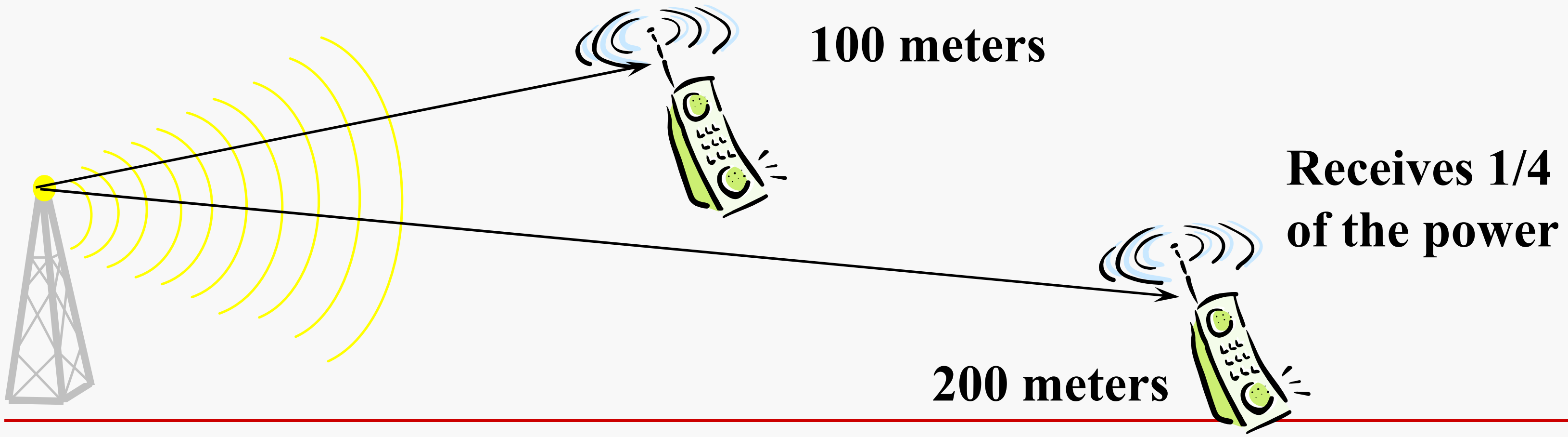
Band	Frequency
ISM band I (Cordless phones, 1G WLAN)	902-928 MHz
ISM band II (Bluetooth, 802.11b/g WLAN)	2.4-2.4835 GHz
U-NII band I (Indoor systems, 802.11a WLAN)	5.15-5.25 GHz
U-NII band II (short-range outdoor systems, 802.11a WLAN)	5.25-5.35 GHz
U-NII band II (Long-range outdoor systems, 802.11a WLAN)	5.725-5.825 GHz

Propagation

- Free-space propagation model

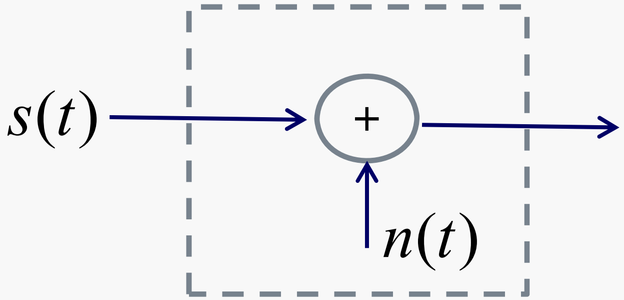
$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d}\right)^2$$

  - P_t : transmit power
  - P_r : receive power
  - G_t : transmit antenna gain
  - G_r : receive antenna gain
  - λ : wavelength
  - d : distance



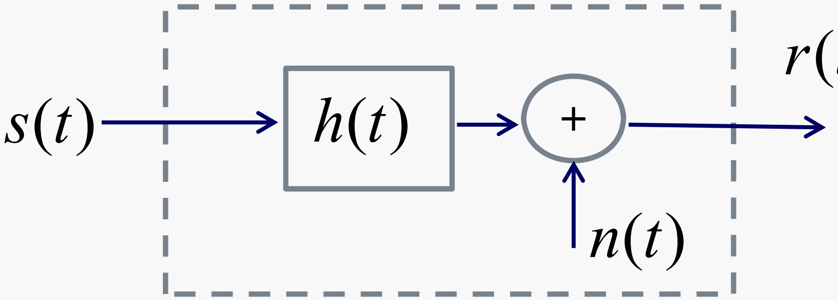
Mathematical Models

- The additive noise channel



$$r(t) = s(t) + n(t)$$

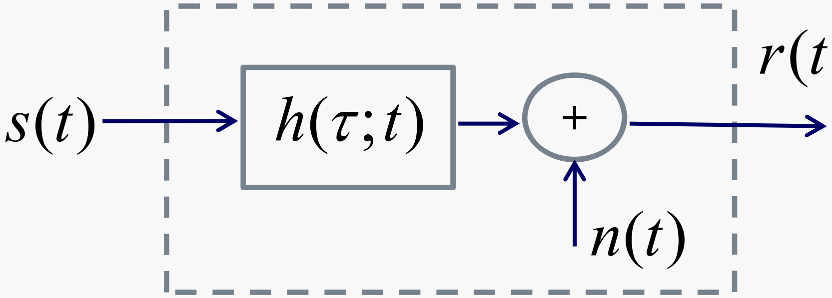
- Linear filter channel



$$r(t) = s(t) * h(t) + n(t)$$

$$= \int_0^{\infty} h(\tau)s(t-\tau)d\tau + n(t)$$

Linear time-variant filter channel



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

- Consider a multi-path signal propagation

$$h(\tau;t) = \sum_{k=1}^{L} a_k(t)\delta(t-\tau_k)$$

These three channel models are used throughout this course for the analysis and design of communication systems

What are the Features of a Good Communication System?

- Small signal power (measured in Watts or dBW)
- Large data rate (measured in bits/sec)
- Small bandwidth (measured in Hertz)
- Low distortion (measured in SNR or bit error rate)
- Low cost – with digital communications, large complexity does not always result in large cost

In practice, there must be <u>tradeoffs</u> made in achieving these goals

Tradeoff (1): Data Rate vs. Bandwidth

- Bandwidth efficiency

$$\text{bandwidth efficiency} = \frac{\text{data rate } R}{\text{bandwidth } W} \text{ bits/sec/Hz}$$

- We want large bandwidth efficiency
- Increased data rate leads to shorter data pulses which leads to larger bandwidth
- This tradeoff cannot be avoided
- Some modulation schemes use bandwidth more efficiently than others

Tradeoff (1): Fidelity vs. Signal Power

- Energy Efficiency

$$\text{energy efficiency} = \frac{\text{bit energy}}{\text{noise power spectral density}} = E_b/N_o$$

- We want small Eb/No to save power
- One way to get an error free signal would be to use huge amounts of power to blast over the noise – not practical
- Some types of modulation achieve relative error free transmission at lower power than others

Tradeoff (3): Bandwidth Efficiency vs. Energy Efficiency

- It is possible for a system designer to trade between bandwidth efficiency and energy efficiency
  - Binary modulation sends only one bit per use of the channel; M-ary modulation can send multiple bits, but is more vulnerable to errors
  - Error correction coding: inserting redundant bits improves bit error rate, but increases bandwidth
- This is the fundamental tradeoff in digital communications.