Welcome!

ELEC 4190 – Digital Communications

Introduction

Outline

- Communication systems
- Communication channels
- Modulation
- Limits on digital transmission

- Recommended reading: Proakis and Salehi – Chapter 1
- Extra reading: https://en.wikipedia.org/wiki/History_of_telecommunication

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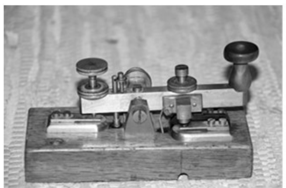
Communication Systems

- What is a Communication System?
  A system to send information from a source that generates messages to one or more destinations
- Examples of Communication Systems:
  Telegraph, Telephone, Radio, TV, Satellites, Cellular Networks, Internet, ...



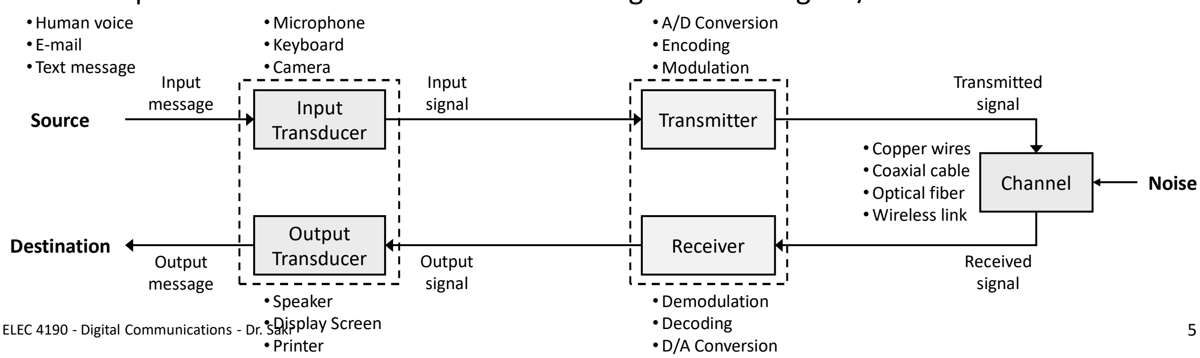




Wikipedia

Elements of a Communication System

- Input transducer: converts input message into an electric waveform (input signal)
- Transmitter: transforms the input signal into a form for efficient transmission
- Channel: a physical medium to send the electric signals over a distance
- Receiver: recovers the message signal from the received signal and removes distortions caused by the channel
- Output transducer: converts the electric signal to its original/intended form



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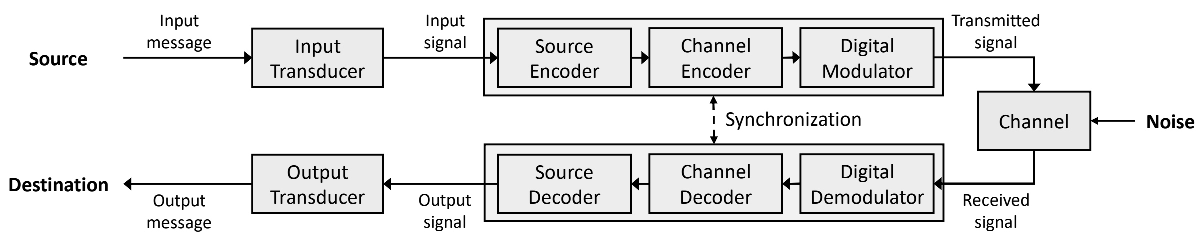
Elements of a Digital Communication System

- Source coding: converts input signal of either an analog or a digital source into a sequence of binary digits
- Channel coding: adds some redundancy in the binary information sequence that can be used at the receiver to overcome the effects of noise and interference
- Digital modulation: maps the binary information sequence into signal waveforms
- Synchronization



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Digital Communications

*Digital communication is the transfer and reception of data in the form of a **digital** bitstream or a **digitized** analog signal transmitted over a point-to-point or point-to-multipoint communication channel. [Wikipedia]*

- Almost all communication networks devices are now digital
- Examples:
  - Wireless networks, Internet, MP3 players, smartphones, HDTV, GPS, and satellite TV and radio
  - Entertainment (e.g., wireless video on demand), education (e.g., online interactive multimedia courses), information (e.g., 3-D video streaming), and business (e.g., mobile commerce)

Digital vs. Analog Transmission

- Advantages:
  - Digital transceivers are cheaper, faster, and more power efficient
  - Higher spectral efficiency (e.g., high-level digital modulation)
  - Error correction (e.g., error coding)
  - Resistant to channel impairments (e.g., multipath fading, etc.)
  - More efficient multiple access strategies
  - Better security and privacy (e.g., encryption)
- Drawbacks:
  - Synchronization and carrier phase and frequency recovery is not an easy task
  - High degree of signal processing: not a major drawback today

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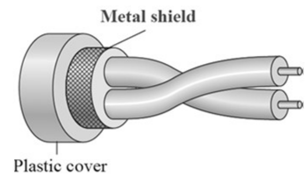
Communication Channels

- Provides the connection between the transmitter and the receiver
- In telecommunications, transmission media can be divided into two broad categories:
  - Guided (wired): e.g., twisted-pair cable, coaxial cable, and fiber-optic cable
  - Unguided (radio): free space

Guided-transmission Media

- Twisted-pair cable:
  - Two insulated conducting (typically copper) wires, twisted to reduce crosstalk (electrical signals from other adjacent wires) and noise
  - Can be shieled (i.e., STP) or unshielded (i.e., UTP)
  - Used for telephone networks and Ethernet networks



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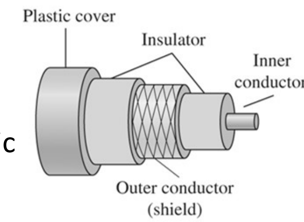
Guided-transmission Media (cont.)

- Coaxial cable:
  - A central core conductor of solid or stranded wire (usually copper) and an outer conductor of metal foil, braid, or a combination of two, separated by a dielectric insulating material



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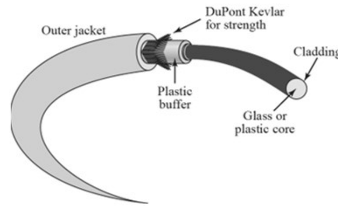
  - The outer conductor is also enclosed in an insulating sheath, and the whole cable can be protected by a plastic cover
  - Compared to twisted pair cables:
    - Much better immunity to crosstalk and interference, much larger bandwidths (hundreds of MHz), but yield higher levels of attenuation
  - Used for the distribution of television signals in cable TV systems and local area networks

Guided-transmission Media (cont.)

- Fiber-optic cable:
  - A very fine cylinder of glass (core) surrounded by a concentric layer of glass (cladding)
  - Uses the nature of light:
    - Light travels in a straight line as long as it is moving through a single uniform substance
    - If a light traveling in a substance enters another substance (of a different density), the ray changes direction
  - Huge bandwidth, low transmission losses, immunity to electromagnetic interference, small size and weight, ruggedness, and flexibility
  - Used in in backbone networks, and can provide nearly error-free transmission rates up to several hundred Gbps over tens of kilometers



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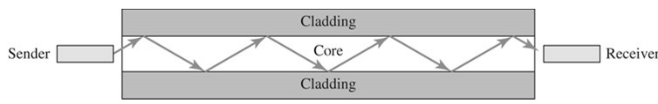

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Wireless (Radio) Channels

- Signals are broadcast through free space and are available to anyone who has a device capable of receiving them
- Radio encompasses the electromagnetic spectrum in the range of 3 kHz to 300 GHz
- Example: industrial, scientific, and medical (ISM) bands
  - e.g., 902-928 MHz, 2.4-2.4835 GHz, 5.725-5.825 GHz
  - Used for Wi-Fi, Bluetooth devices, and cordless phones
  - Equipment must tolerate any interference generated by other ISM equipment
  - Users have no regulatory protection

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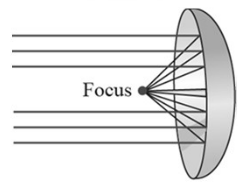

Parabolic dish antenna

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Wireless (Radio) Channels (cont.)

- Advantages:
  - Allows the realization and deployment of mobile systems
  - Cheaper to install and operate compared to wired networks
  - Can provide coverage almost everywhere and at anytime
  - Ease of introducing new terminals and deployment in emergency situations
- Disadvantages:
  - Spectrum is scarce and it is not possible to procure additional capacity
  - Interference is a major degradation in radio systems
  - Wireless channels are extremely random and unpredictable, thus can be unreliable sometimes
  - Signals can be easily intercepted in wireless systems
  - Data rates are usually lower compared to wired communication

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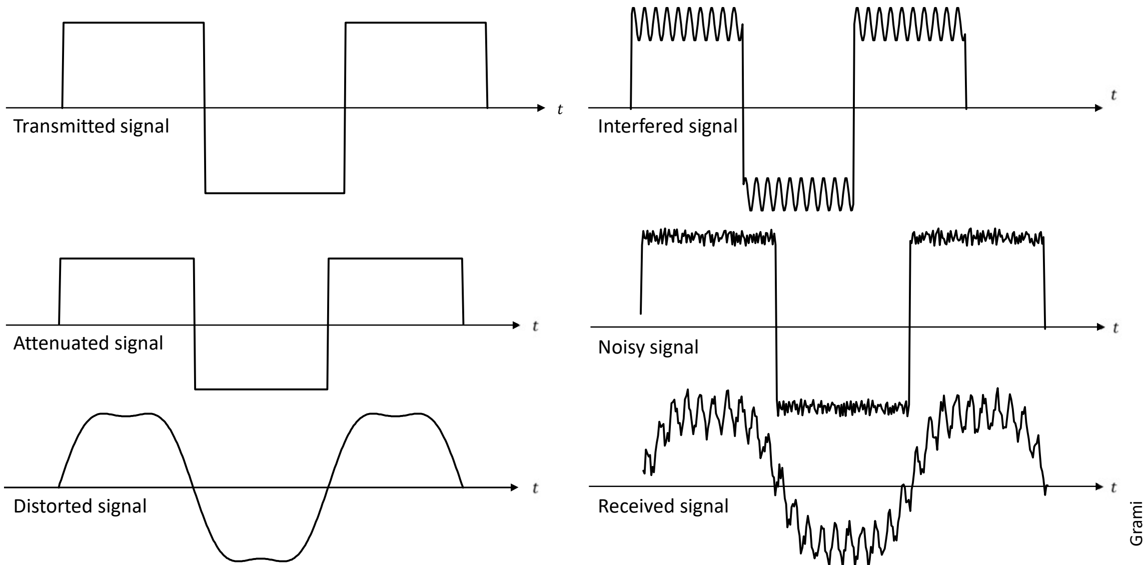
Transmission Impairments

- Channels behave as an imperfect filter that attenuates and distorts the transmitted signal
  - That is, the received signal is different from the transmitted one
- Examples:
  - Attenuation: loss due to dissipation of radiated power over distance
  - Distortion: changes of signal form or shape (e.g., changes in amplitude and phase due to multipath fading)
  - Interference: signals received from other sources
  - Noise: unwanted, ever-present, random waves (e.g., additive noise generated internally by components used to implement the communication system)
    - AWGN is a very common channel model applied to a broad class of communication channels (i.e., $r(t) = s(t) + n(t)$ where $n(t)$ is a Gaussian random process)

Example



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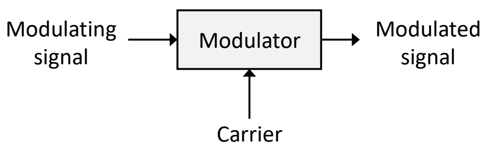
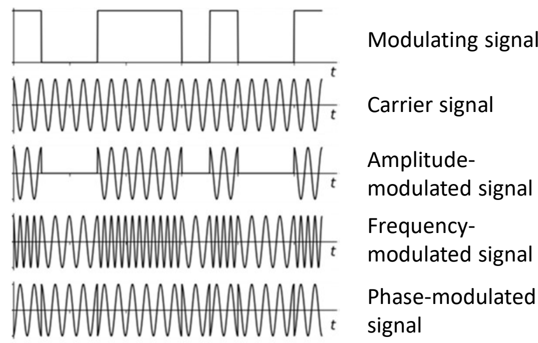
Modulation

- Input signals at the transmitter (analog or digital) are called baseband signals because they are generally lowpass

*Modulation is the process of **varying** one or more properties of a [**high-frequency**] periodic waveform, called the **carrier signal**, with a separate [**baseband**] signal called the **modulation signal** that typically contains **information** to be transmitted. [Wikipedia]*

- Carrier parameters include amplitude, frequency, or phase



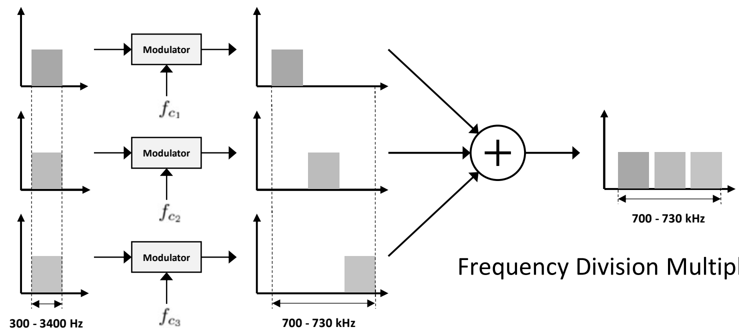


Why Modulation?

- Reduce the antenna size:
  - To transmit an electromagnetic wave efficiently, transmit antenna size should be a fraction of the wavelength of the transmit signal → e.g., $L = \lambda/4$
  - This is impractical for most baseband signals
- Example:
  - For a speech signal (100-3000 Hz), the corresponding wavelength is 100-3000 km → too large for an antenna size
  - If the same signal is transmitted over a 100 MHz carrier, the corresponding wavelength is 3 m → a practical antenna size

Why Modulation? (cont.)

- Multiplexing:
  - Simultaneous transmission of multiple signals without interfering with each other by carrying each baseband signal over a different carrier frequency
  - Carrier frequencies are chosen sufficiently apart from each other to avoid overlap, e.g., radio and TV stations



Frequency Division Multiplexing (FDM)

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Types of Modulation

		Modulating Signal		
		Analog	Digital	
Carrier	Analog	**Analog CW Modulation** ▪ Amplitude Modulation (AM) ▪ Angle Modulation: • Frequency Modulation (FM) • Phase Modulation (PM)	**Digital CW Modulation** ▪ Amplitude Shift Key (ASK) ▪ Frequency Shift Key (FSK) ▪ Phase Shift Key (PSK) ▪ Quadrature Amplitude Modulation (QAM)	Continuous Wave (CW) Modulation
	Digital	**Analog Pulse Modulation** ▪ Pulse Amplitude Modulation (PAM) ▪ Pulse Width Modulation (PWM) ▪ Pulse Position Modulation (PPM)	**Digital Pulse Modulation** ▪ Pulse Code Modulation (PCM) ▪ Delta Modulation (DM)	Pulse Modulation
		Analog Modulation	Digital Modulation	

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Limits on Digital Transmission

- Channel capacity is the maximum achievable transmission bit rate (measured in bit per sec or bps) with an arbitrarily small error rate
  - Lower bit error rate (i.e., fractions of bits received in error) means a more reliable system
- For digital transmissions, it is possible to design a system that operates with zero bit error rate even though the channel is noisy
- This can be determined by two primary parameters in any communication system
  - Channel bandwidth (measured in Hz)
  - Signal-to-noise ratio (SNR) (unitless or measured in dB) at the receiver
    - A minimum ratio of signal power (measured in W) to noise power (measured in W) at the receiver is required to recover the transmitted signal

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Shannon Capacity

- For AWGN channels, theoretical channel capacity can be calculated by

$$C = \underbrace{W}_{\text{Channel bandwidth}} \log_2(1+\underbrace{SNR}_{\text{Signal-to-noise ratio (i.e., } P/N_0W\text{)}}) \text{ bps}$$

  - This is an upper limit, there are many other impairments in real channels
  - If the information rate R from the source is less than C, then it is theoretically possible to achieve reliable (error-free) transmission through the channel

What is the capacity of a telephone voice channel that uses frequencies from 300 to 3400 Hz and an SNR of 35 dB?

What can you do as an engineer to increase the channel capacity?

What is the data rate if there is no noise?

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Summary

- By now you should know:
  - The elements of communication systems
  - Different types of communication channels
  - Why modulation is important
  - Classification of modulation techniques
  - Channel impairments and how they affect channel capacity