EEN 344
Communication Systems I
Class Notes

Chapter 1

Introduction to the Course and to Communication Systems

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Introduction to the Course

Credits and Prerequisites

- Credits
  - 3 credits
- Prerequisites
  - EEN 340 - Signals and Systems
  - MAT 326 - Probability & Statistics for Engineers

Textbook

- Main Textbook
  - Simon Haykin, Michael Moher, "An Introduction to Analog and Digital Communications," 2nd edition, Wiley, 2007
- References
  - IEEE Periodicals
  - John G. Proakis, Masoud Salehi, "Communication Systems Engineering," 2nd edition, Prentice Hall, 2002
  - Theodore S. Rappaport, "Wireless Communications: Principles and Practice," 2nd Edition, Prentice Hall, 2002

Grading and Evaluation

- Quiz 1: 20%
- Quiz 2: 20%
- Final Exam: 35%
- Project: 15%
- Homework and Participation: 10%

Syllabus

1. Introduction to communication systems (2 lectures) Chapter 1
2. Fourier representation of signals and systems (5 lectures) Chapter 2
3. Random signals and noise (9 lectures) Chapter 8
4. Amplitude modulation (7 lectures) Chapter 3
5. Angle modulation (7 lectures) Chapter 4
6. Noise in analog communications (9 lectures) Chapter 9
7. Quizzes (2 lectures)
8. Project presentations (2 lectures)
9. Review and Course Evaluation (1 lecture)

Lectures

- I will mix slides with notes on the board
  - Slides: Definitions, results, statements, summaries…
    - The slides will constitute a reasonably coherent but not complete description of the course…
  - Notes on the board: Important results, derivations, comments to the slides, examples…
    - The board notes alone will neither be a coherent nor a complete description
- The textbook is the main source of information for the course
- MATLAB/Simulink ver 7.8, R2009a or later

Course Outcome

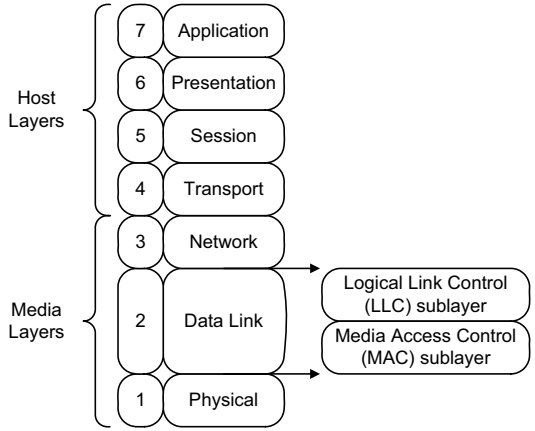
At the end of the course, the students are expected to:

- Understand the basic concepts of communications within the context of the complete communication system.
- Understand the fundamental concepts of analog communications, especially those related to modulation.
- Become proficient in using the most common mathematical methods in order to analyze the performance of the different analog modulation schemes in various environments, especially noisy ones.
- Become proficient in building their own communication models in MATLAB/Simulink and reconciling their simulation results with the mathematical analysis results.
- Develop a problem-solving approach and applying it in group-style projects.
- Develop good communication skills by presenting the project results orally and in writing.
- Develop a curiosity for state-of-the-art technologies especially regarding their relation with classroom lectures and their relation with practical applications.

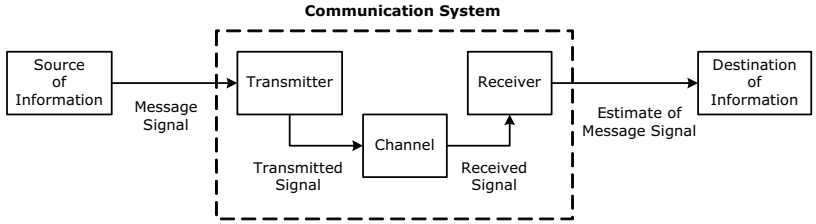
Introduction to Communication Systems

The Big Picture: OSI Model

The Open Systems Interconnection Reference Model (OSI Model) is a layered abstract description for communications and computer network protocol design, developed by ISO and ITU-T.



Elements of a Communication System



- Transmitter
  - Converts the message signal produced by a source into a form suitable for transmission over a channel.
- Channel
  - Transports the message and delivers it to the receiver.
  - The signal gets distorted by channel imperfections, noise and interfering signals. The received signal is a corrupted version of the transmitted signal.
- Receiver
  - Has the task to produce an estimate of the original message.

Transmission Channel Limitations

- Attenuation
  - The signal power progressively decreases with increasing distance.
- Distortion
  - Waveform perturbations caused by imperfect response of the system.
- Interference
  - Contamination by extraneous signals from human sources.
  - Occurs most often in radio systems whose receiving antennas usually intercepts several signals at the same time.
- Noise
  - Random and unpredictable electrical signals produced by processes both internal and external to the system.
  - Filtering reduces noise contamination, but there inevitably remains some amount of the noise that cannot be eliminated.

Broadcast and Point-to-Point

- We communicate in two basic ways:
  - Broadcasting: involves the use of one powerful transmitter and numerous receivers. Information-bearing signals flow only in one direction.
  - Point-to-point: communication process takes place over a link between a single Tx and Rx. Bidirectional flow of information-bearing signals.

Examples: Radio Communications

- Broadcast AM/FM Radio
  - Audio signals
  - Simple implementation and detection
- Broadcast TV
  - Audio and Video Signals
  - Complex implementation and detection
- Point-to-point Communications
  - Line-of-sight radio propagation
  - Satellite, microwave
- Mobile Wireless Communications
  - Similar to point-to-point
  - The operation is dominated by the multipath phenomenon due to reflections of the transmitted signal from objects.

Primary Resources and Operational Requirements

- Communications systems are designed to allow the efficient utilization of
  - Transmitted power (power-limited channels)
    - Wireless channels
    - Satellite channels
    - Deep-space links
  - Channel bandwidth (band-limited channels)
    - Telephone channels
    - Television channels
- Unavoidable presence of noise
  - Unwanted signals that tend to disturb the quality of the received signal.

Communication System Performance

- Communication System-Design Parameters
  - Signal-to-noise ratio (SNR): Quantitative way to account for the beneficial effect of the transmitted power in relation to the degrading effect of noise.
    - The customary practice is to express the SNR in decibels (dB), which is defined as 10 times the logarithm (to base 10) of the power ratio. For example, signal-to-noise ratios of 10, 100, and 1000 are 10, 20, and 30 dB, respectively.
  - Channel bandwidth (BW)
- To improve the system performance
  - SNR must be increased to accommodate a limitation imposed on channel BW.
  - Channel BW must be increased to accommodate a limitation imposed on SNR.

Selected Underpinning Theories of Communication Systems

- Modulation Theory
- Fourier Analysis
- Detection Theory
- Probability Theory and Random Processes

Modulation Theory

- Modulation Theory
  - Signal-processing operation that is accomplished by changing some parameter of a carrier wave in accordance with the message signal.
  - The carrier wave may take
    - Sinusoidal carrier wave, whose amplitude, phase or frequency is varied according to the message signal.
    - Periodic sequence of pulses, whose amplitude, width or position is varied according to the message signal.
  - The spectrum of the modulated signal consists of a band of frequency components clustered around the carrier frequency.

Issues in Modulation Theory

- Time-domain description
- Frequency-domain description
- Detection of the signal and evaluation of the effect of noise on the receiver

Modulation Benefits

- Modulation for Efficient Transmission
  - Signal transmission involves a traveling electromagnetic wave in a guided or unguided medium.
  - The frequency-translation property of continuous-wave (CW) modulation, message information can be impressed on a carrier whose frequency has been selected for the desired transmission method.
  - Line-of-sight radio propagation requires antennas whose physical dimension is about 1/10 of the signal's wavelength.
  - Unmodulated transmission of audio signal containing frequency components down to 100 Hz would thus required antennas up to 300 km long.
  - Modulated transmission at 100 MHz (FM), allows a practical antennas size about one meter.

Modulation Benefits II

- Modulation to Overcome Hardware Limitations
  - Permits the designer to place a signal in some frequency that avoids hardware limitations.
- Modulation to Reduce Noise and Interference
  - Certain types of modulation have the property of suppressing both noise and interference.

Modulation Benefits III

- Modulation for Frequency Assignment
  - Makes possible that multiple stations broadcast in the same area at the same time.
  - Each station is assigned a different carrier frequency to avoid interference between them.
  - The desired signal can be separated from the others by filtering.

Multiple Access Schemes

- Frequency-division multiple access (FDMA)
  - Puts each signal on a different carrier frequency
- Time-division multiple access (TDMA)
  - Puts samples of different signals in non-overlapping time slots
- Code-division multiple access (CDMA)
  - Assigns a unique code to each user
  - The individual transmissions are separated by correlation between them and the codes of the desired transmitting and receiving parties
  - Allows different users to share the same frequency band simultaneously

Fourier Analysis

- Fourier Transform
  - Linear mathematical operation that transforms the time-domain description of a signal into a frequency-domain description without loss of information
  - Provides the mathematical basis for evaluating
    - Frequency-domain description of a modulated signal including its transmission bandwidth
    - Transmission of a signal through a linear system such as a communication channel
    - Correlation (i.e., similarity) between a pair of signals

Detection Theory

- The signal-detection problem
  - Presence of noise
  - Factors such as unknown phase-shift introduced into a carrier due to the transmission channel
- In analog communications
  - The figure of merit for assessing the noise performance of a specific modulation strategy
  - The threshold phenomenon that arises when the transmitted SNR drops below a critical value
  - Performance comparison of one modulation strategy against another

Detection Theory II

- In digital communications
  - The average probability of symbol error
  - Issues of dealing with uncontrollable factors
  - Comparison of one digital modulation scheme against another

Probability Theory and Random Processes

- Probability theory for describing the behavior of randomly occurring events in mathematical terms.
- Statistical characterization of random signals and noise.
- A random signal is a signal about which there is uncertainty.
- A random signal may be viewed as belonging to an ensemble or a group, of signals.
- Each signal within an ensemble has a certain probability of occurrence.
- The ensemble of signals is referred to as random process or stochastic process.

Probability Theory and Random Processes II

- In dealing with probability theory, random signals, and noise, we address the following issues:
  - Basic concepts of probability theory and probabilistic models.
  - Statistical description of a random process in terms of ensemble as well as temporal averages.
  - Mathematical analysis and processing of random signals.