CT111 Introduction to Communication Systems Lecture 3: Energy and Spectral Efficiencies; Fourier Transform

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8th January 2018

Overview of Today's Talk

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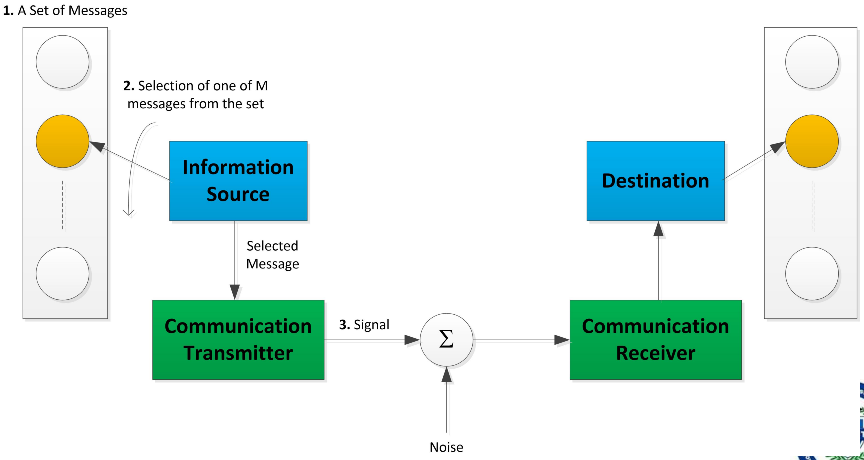
A Model of Digital Communication Systems
A Simple Block Diagram



A Model of Digital Communication Systems

A Simple Block Diagram

Key design parameters:

1. Size M of the message set: determines number of bits N required to convey the message
   - $\rightarrow$ $N = \log_2 M$
2. How fast the messages are selected: determines the number of messages per second
   - $\rightarrow$ the larger the message set size and/or the greater the speed of the message transfer, the bit rate R = the number of bits per second, increases
   - $\rightarrow$ Greater the bit rate R, the greater the information that gets conveyed. However, greater also is the work that the communication system has to do.
3. The power P_s that the communication receiver gets (determined by the power that the transmitter can put in the transmitted signal), the spectral bandwidth W that it has and the power P_n of the noise that the communication channel introduces

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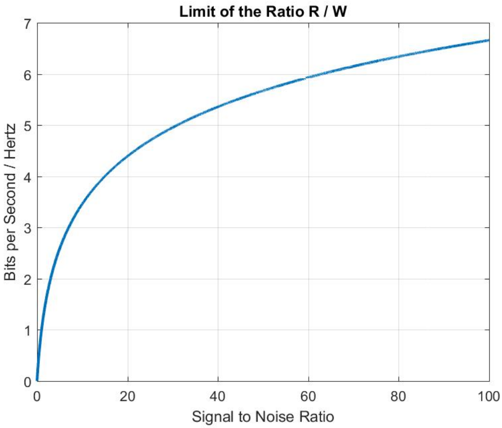
A Fundamental Limit on Communications

Shannon Information Theory

→ The celebrated relationship:

$$R \leq W \log_2 \left(1 + \frac{P_s}{P_n}\right)$$



Bandwidth Efficiency η_B

- As data rate R increases, the pulse width of transmitted signal reduces and therefore the bandwidth B, which is inversely proportional to the transmitted pulse width, increases.
- This cannot be avoided; however some schemes use the available bandwidth more efficiently than the others
- We will denote the ratio R/W as the bandwidth efficiency η_B.
- It is obviously better to have η_B as large as possible. However, there is a cost associated to making η_B large.

Energy Efficiency η_E

- Communication systems are characterized by the signal to noise ratio (SNR) P_s/P_n required to attain a certain performance
- Typically improving η_B (making it large) requires SNR P_s/P_n to be increased
- We will define energy efficiency η_E as $\left(\frac{P_s}{P_n}\right)^{-1}$ required to attain some excellent communication performance (e.g., only one bit out of 10^5 bits is in error on average).
- Greater the required $\frac{P_s}{P_n}$, the smaller the energy efficiency.

Fight between η_E and η_B

- As it often is the case in the life, it is hard to get best of both the worlds.
- An increase in η_B translates to a decrease in η_E and vice versa.

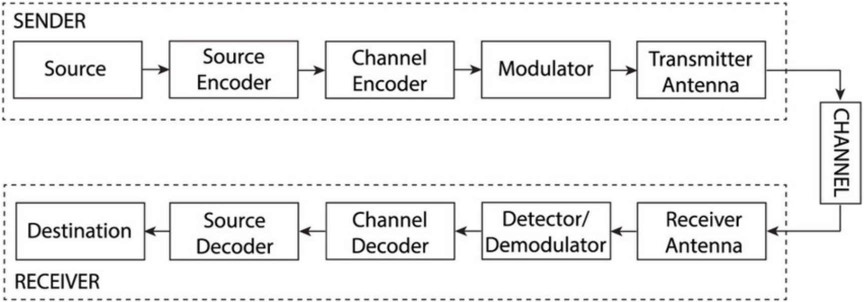
A Study of Communication Systems

Key Topics

1. Messages that are conveyed and what are the ways of converting the messages to signals: encoding and modulation
2. Characteristics of the signals that are used for transmitting the communication signal: Fourier Transform
3. How these signals are received at the receiver *in presence of channel impairments*: demodulation and decoding problem

A Model of a *Digital* Communication Systems

A Practical Block Diagram



Relation to Other Courses

Analog and Digital Communications: Designed to be a precursor to A&D. Several lectures may have some overlap with A&D.

Coding Theory: cover block codes, convolutional codes, Turbo and LDPC codes. Describes the performance analysis and their application in the system design.

Wireless Communications: this course provides a detailed study on the statistical description of the wireless channel. The course also covers multiple wireless (2G/3G/4G) standards. CT-111 will provide an overview of the channel models, and will allow you to understand the basics of these various wireless standards.

Relation to Other Courses

Information Theory: emphasizes the fundamental limits on the communications. In CT111, we will study the algorithms used at the transmitter and the receiver of the digital communication system that attempt to approach these limits.

Estimation and Detection Theory: provides a detailed mathematical background on the algorithms used at the receiver of a communication system. In this class, we will cover a part of this material.

Probability and Statistics for Engineers: this class serves as foundation course for all of the courses listed above. We will utilize some statistical concepts in CT111.

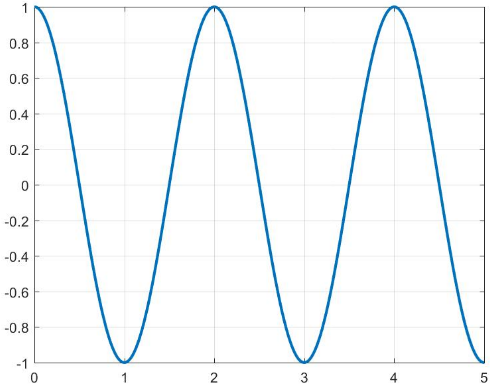
A Standard Form of Communication Signal

Electromagnetic Radiation

- We have talked about how the communication system in our brains is more powerful than any technological communication system devised so far
- However, there is one area where the technology has now outpaced the humans: ability to generate the communication signals that travel far away
- The key signal that makes the long distance communication possible is given by Electromagnetics, and it has a wavy shape that you see when you drop a pebble in a pond

A Standard Form of Communication Signal
Electromagnetic Radiation

- The basic ingredient of a communication signal is a periodic sinusoidal waveform given as: $s_r(t) = A\cos(\Theta(t)) = A\cos(2\pi ft + \theta)$



A Standard Form of Communication Signal

Sinusoidal Electromagnetic Radiation

- The basic ingredient of a communication signal is a periodic sinusoidal waveform, with a cycle duration of T_{cycle} given as: $s_r(t) = A\cos(\Theta(t)) = A\cos(2\pi ft + \theta)$
- A : is called the amplitude of the signal
- f : is the frequency of the signal, and it is the inverse of the cycle duration T_{cycle}. This is measured in Hertz
- $\Theta(t)$: is the phase angle of the signal, measured in radians
- θ : is the initial phase angle (at time $t = 0$)

A Standard Form of Communication Signal

Complex Exponential

- Sinusoidal waveform can be thought of as a component of a more general, complex-valued, waveform:
  $s(t) = A\exp\left(\Theta(t)\right) = A\exp\left(2\pi ft + \theta\right)$
- $s(t) = s_r(t) + js_i(t)$
- $s(t)$: is called the complex *phasor*
- $s_r(t)$: is the real part of this phasor