CT111 Introduction to Communication Systems
Lecture 9: Digital Communications

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Overview of Today's Talk

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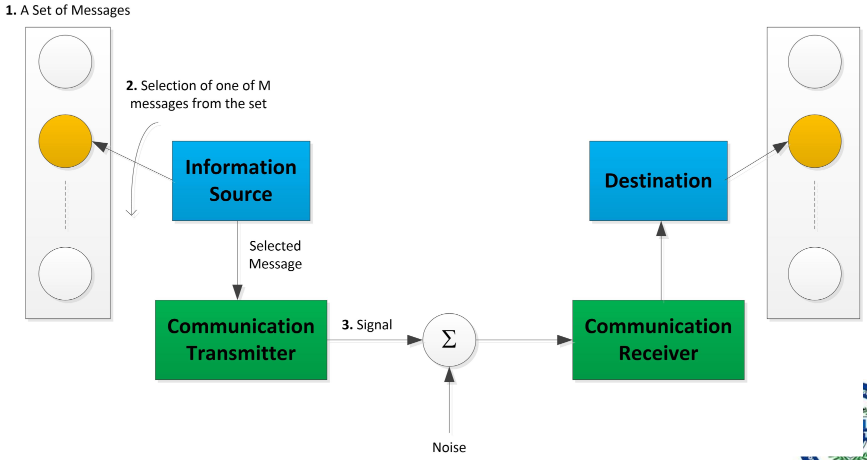
1. Introduction
2. Models and Functionalities
3. Detailed Block Diagrams
4. Analog to Digital Conversion
   - Sampling in Time Domain

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
   - → $N = \log_2 M$
2. How fast the messages are selected: determines the number of messages per second
   - → 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
   - → 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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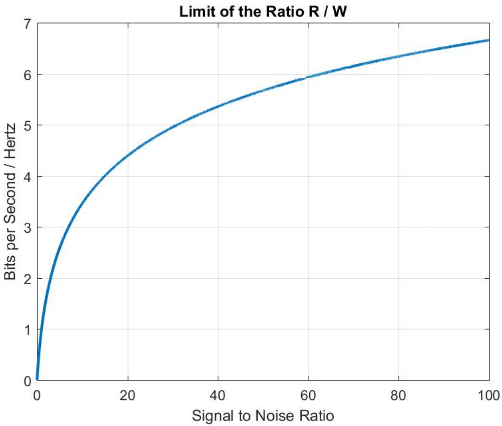
A Fundamental Limit on Communications
Shannon Information Theory

→ 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.
- Trade-off between bandwidth and energy efficiencies can be viewed as the *equivalence* between the power and the bandwidth
  - If the system designer has a fixed transmit power (i.e., the design is limited or handicapped by the transmit power), this limit can be overcome to some extent by increasing the bandwidth
  - Vice versa, if the bandwidth is limited, the power can be increased to obtain the desired data rate

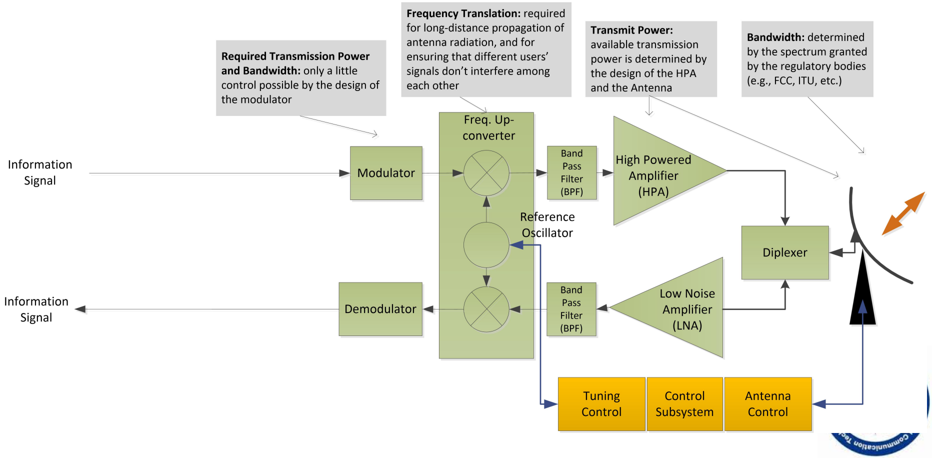
Comparison

of a Digital with Analog Method of Communication

- In both the digital and the analog communications. . .
  - the information (or the message) signal that is getting transferred over the communication link is often analog
  - Actual (physical) signal that is transmitted over the communication channel is also almost always *analog*, i.e., continuous in time and often continuous in the amplitudes (voltage)
- It is the modulation scheme that determines whether the communication system is called analog or digital.
  - In digital communications, the analog information signal is digitized (discrete-time and discrete-levels of amplitude), and it is this digitized message that modulates the transmitted analog signal
  - In analog communication, the analog information directly modulates the transmitted analog signal

Block Diagram

of an *Analog* Communication Transceiver



Block Diagram
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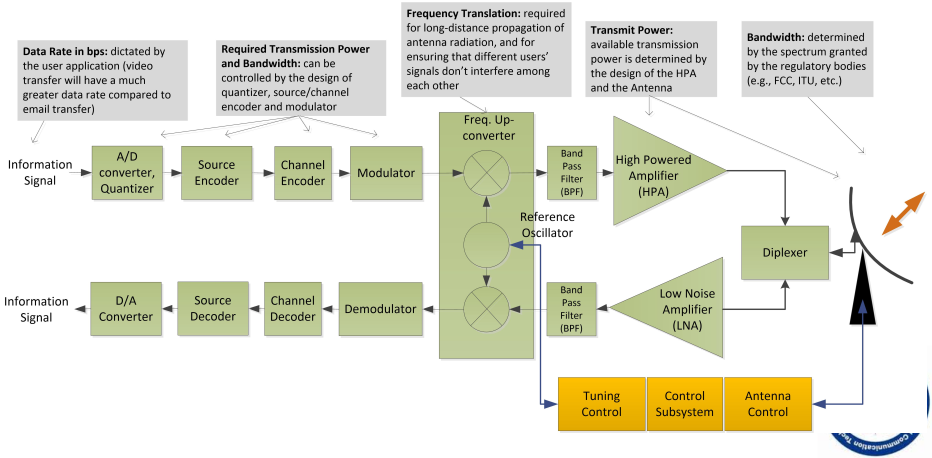

Why Digital Communications
Instead of Analog

Compared to analog communication systems, the digital communications. . .

1. Allows approaching the Shannon Capacity bound more closely (results that are only 0.04 dB away from Shannon bound have been obtained)
2. Provides a better tradeoff of bandwidth efficiency against energy efficiency (i.e., exchange the power with the bandwidth).
3. Has a better ability to compensate for the effect of noise (any noise introduces irrecoverable distortion in the analog signal. In comparison, the a digital receiver needs to distinguish only a finite number of transmitted data. Thus, it is possible to completely remove the effect of noise)
4. Allows use of many performance enhancing signal processing techniques, such as source coding, channel coding, encryption, etc.

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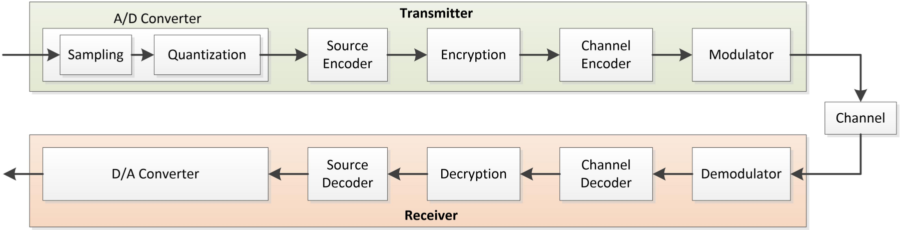
Why Digital Communications
Instead of Analog

In addition

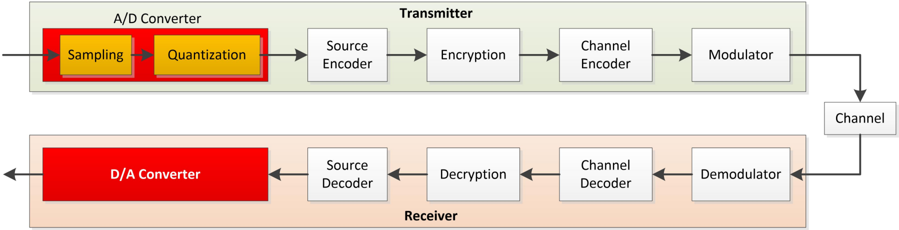
- Digital technology, for which the primary currency is bits (Digital Integrated Circuits (ICs), and in general, the computers and the smartphones and their networks), has become very powerful and are inexpensive to manufacture.
- Digital Communications allows integration of voice, video and data on a single packet networking system.

Digital Communication Transceiver
Block Diagram



Digital Communication Transceiver
Block Diagram

- We will now be looking at the process of quantization of an analog information source



Discrete-Time Representations of Continuous-Time Signals

- Examples of Continuous Time (C-T) signals: video, voice, image, etc.
- Sampling theorem says that if the C-Tsignal is band limited, it can be exactly recovered by its time domain samples taken sufficiently close together
  - $\rightarrow$ Sampling analog signals makes them discrete in time
  - $\rightarrow$ For band-limited signal, the ideal sampling scheme introduces no distortion

Sampling Theorem

- Let $x(t)$ be a band-limited signal with Fourier Transform $X(f)$ which is zero if $|f| > B$
- Time domain signal $x(t)$ can be perfectly reconstructed from its uniformly spaced samples provided these samples are taken at a rate $R > 2B$. Here, $2B$ is called the Nyquist Rate
- If time-domain samples are collected at a rate less than $2B$, aliasing occurs and it is not possible to perfectly reconstruct the analog signal from its samples
- We have studied the proof of sampling theorem in an earlier lecture.