Communication Systems Overview

Lathi & Ding Chapter 1

- Information representation
- Communication system block diagrams
- Analog versus digital systems
- Performance metrics
- Data rate limits

Next week: signals and signal space (L&D chapter 2)
Types of Information

- Major classification of data: analog vs. digital
- Analog signals
  - speech (but words are discrete)
  - music (closer to a continuous signal)
  - temperature readings, barometric pressure, wind speed
  - images stored on film
- Analog signals can be represented (approximately) using bits
  - audio: 8, 16, 24 bits per sample
  - digitized images (can be compressed using JPEG)
  - digitized video (can be compressed to MPEG)
- Bits: text, computer data
- Analog signals can be converted into bits by quantizing/digitizing

The word “bit” was coined in the late 1940s by John Tukey, co-inventor of Fast Fourier Transform
Analog Messages

- Early analog communication
  - telephone (1876)
  - phonograph (1877)
  - film soundtrack (1923, Lee De Forest, Joseph Tykociński-Tykociner)
- Key to analog communication is the amplifier (1908, Lee De Forest, triode vacuum tube)
- Broadcast radio (AM, FM) is still analog
- Broadcast television was analog until 2009
Digital Messages

- Early long-distance communication was digital
  - semaphores, white flag, smoke signals, bugle calls, telegraph
- Teletypewriters (stock quotations)
  - Baudot (1874) created 5-unit code for alphabet. Today baud is a unit meaning one symbol per second.
  - Working teleprinters were in service by 1924 at 65 words per minute
- Fax machines: Group 3 (voice lines) and Group 4 (ISDN)
  - In 1990s the accounted for majority of transPacific telephone use. Sadly, fax machines are still in use.
  - First fax machine was Alexander Bains 1843 device required conductive ink
  - Pantelegraph (Caselli, 1865) set up telefax between Paris and Lyon
- Ethernet, Internet

There is no name for the unit bit/second. I have proposed claudie.
Source encoder converts message into message signal (bits)

Transmitter converts message signal into format appropriate for channel transmission (analog/digital signal)

Channel conveys signal but may introduce attenuation, distortion, noise, interference

Receiver decodes received signal back to message signal

Source decoder decodes message signal back into original message
Source encoder compresses message to remove redundancy

Encryption protects against eavesdroppers and false messages

Channel encoder adds redundancy for error protection

Modulator converts digital inputs to signals suitable for physical channel
Examples of Communication Channels

- Communication systems convert information into a format appropriate for the transmission medium
- Some channels convey electromagnetic waves (signals).
  - Radio (20 KHz to 20+ GHz)
  - Optical fiber (200 THz or 1550 nm)
  - Laser line-of-sight (e.g., from Mars)
- Other channels use sound, smell, pressure, chemical reactions
  - smell: ants
  - chemical reactions: neuron dendrites
  - dance: bees
- Analog communication systems convert (modulate) analog signals into modulated (analog) signals
- Digital communication systems convert information in the form of bits into binary/digital signals
Physical Channels

- Physical channels have constraints on what kinds of signals can be transmitted
  - Radio uses E&M waves at various frequencies
  - Submarine communication at about 20 KHz
  - Cordless telephones: 45 MHz, 900 MHz, 2.4 GHz, 5.8 GHz, 1.9 GHz
- Wired links may require DC balanced codes to prevent voltage buildup
- Fiber optic channels use 4B5B modulation to accommodate time-varying attenuation
- CD and DVD media require minimum spot size but position can be more precise
- The process of creating a signal suitable for transmission is called *modulation* (modulate from Latin “to regulate”*)
AM and FM Modulation

(a) Carrier

(b) Signal

(c) Amplitude modulated

(d) Frequency modulated
Analog vs. Digital Systems

- Analog signals
  Values varies continously

- Digital signals
  Value limited to a finite set
  Digital systems are more robust

- Binary signals
  Have 2 possible values
  Used to represent bit values
  Bit time $T$ needed to send 1 bit
  Data rate $R = 1/T$ bits per second
Sampling and Quantization, I

To transmit analog signals over a digital communication link, we must discretize both time and values.

Quantization spacing is \( \frac{2m_p}{L} \); sampling interval is \( T \), not shown in figure.
Sampling and Quantization, II

- Usually sample times are uniformly spaced.

- Higher frequency content requires faster sampling. (Soprano must be sampled twice as fast as a tenor.)

- Quantization levels are usually uniformly spaced (linear). Logarithmic compression is useful for greater dynamic range.
Simplest digital communication is binary amplitude-shift keying (ASK)

(a) binary signal input to channel; (b) signal altered by channel; (c) signal + noise; (d) signal after detection by receiver
Channel Errors

If there is too much channel distortion or noise, receiver may make a mistake, and the regenerated signal will be incorrect. Channel coding is needed to detect and correct the message.
Pulse Code Modulation (PCM)

To communicate sampled values, we send a sequence of bits that represent the quantized value.

For 16 quantization levels, 4 bits suffice.

PCM can use binary representation of value.

The PSTN uses 8-bit companded PCM (similar to floating point)
Performance Metrics

- Analog communication systems
  - Metric is *fidelity*, closeness to original signal
  - We want $\hat{m}(t) \approx m(t)$
  - A common measure of infidelity is *energy* of difference signal:
    \[ \int_0^T |\hat{m}(t) - m(t)|^2 \, dt \]

- Digital communication systems
  - Metrics are data rate $R$ in bits/sec and probability of bit error
    \[ P_e = P\{\hat{b} \neq b\} \]
  - Without noise, we never experience bit errors
  - With noise, $P_e$ depends on signal power, noise power, data rate, and channel characteristics.
Data Rate Limits

- Data rate $R$ is limited by signal power, noise power, distortion

- Without distortion or noise, we could transmit at $R = \infty$ and error probably $P_e = 0$

- The Shannon capacity is the maximum possible data rate for a system with noise and distortion
  - Maximum rate can be approached with error probability approaching 0
  - For additive white Gaussian noise (AWGN) channels,
    
    $$C = \frac{1}{2}B \log(1 + \text{SNR}) = \frac{1}{2}B \log \left(1 + \frac{P}{N}\right)$$

    - The theoretical result does not tell how to design real systems

- Shannon obtained $C \approx 32 \text{ Kbps}$ for telephone channels ($B = 3700 - 300 = 3400 \text{ Hz}$)

- Modern modems achieve higher rates by using more bandwidth
Next

SDR (software-defined radio) lab on Friday
► We will give you your RTL SDR’s
► Bring your laptops, and headphones
► We’ll get you up and running!

Next week
► (Very brief) review of EE 102A
► Fourier series and Fourier transforms in $2\pi f$
► Vector space perspective on signal processing
► L&D Chapter 2 (skim this, most should look very familiar)