Lecture 2: Modern Communications Systems

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Communication Systems Overview

L&D 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)

Based on Notes from John Gill

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
  - ▶ 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
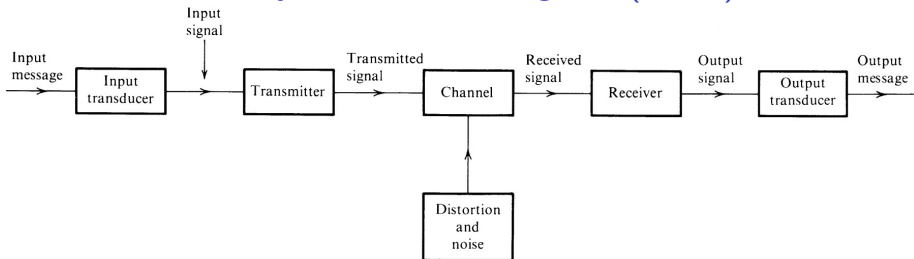
Analog Messages

▶ 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 Bain 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 *claude*.

Communication System Block Diagram (Basic)

- ▶ 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

Communication System Block Diagram (Advanced)
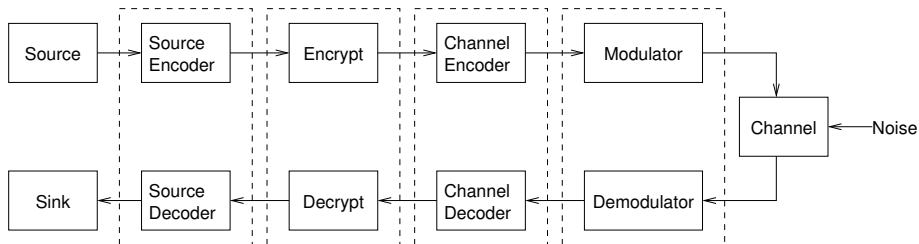
- ▶ Source encoder compresses message to remove redundancy
- ▶ Encryption protects against eavesdroppers and false messages
- ▶ Channel encoder adds redundancy for error protection
- ▶ Modulator converts digital inputs to signals suitable for physical channel

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 build up
- ▶ 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
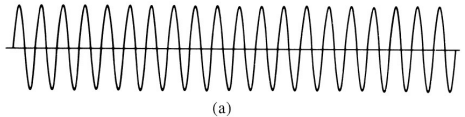
(b) Signal
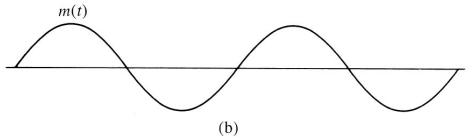
(c) Amplitude modulated
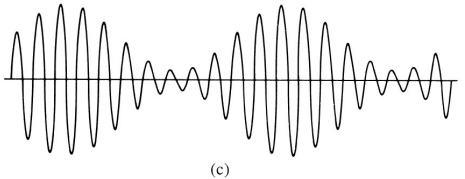
(d) Frequency modulated
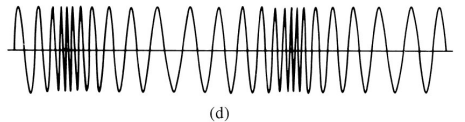
Analog vs. Digital Systems

▶ 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
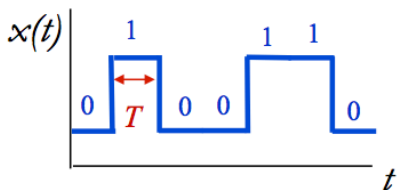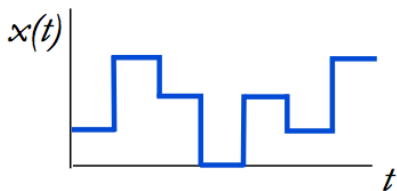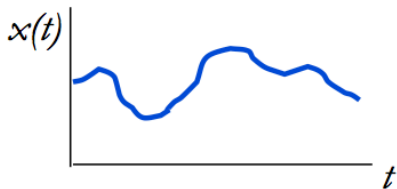
Sampling and Quantization, I

To transmit analog signals over a digital communication link, we must discretize both time and values.
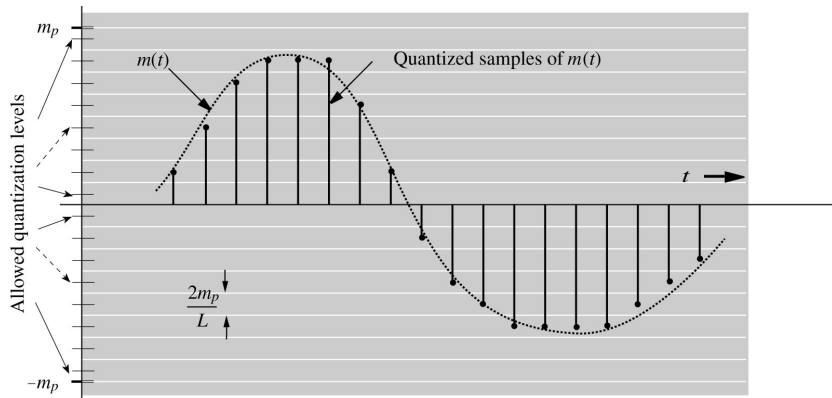
Quantization spacing is $\dfrac{2m_p}{L}$; sampling interval is T, not shown in figure.

Sampling and Quantization, II

▶ Usually sample times are uniformly spaced (although, this is not always true). Higher frequency content requires faster sampling. (Soprano must be sampled twice as fast as a tenor.)
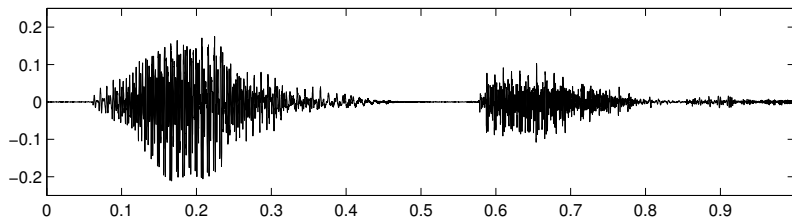
▶ Quantization levels can be uniformly spaced, but nonuniform (logarithmic) spacing is often used for voice.

Digital Transmission and Regeneration

Simplest digital communication is binary amplitude-shift keying (ASK)
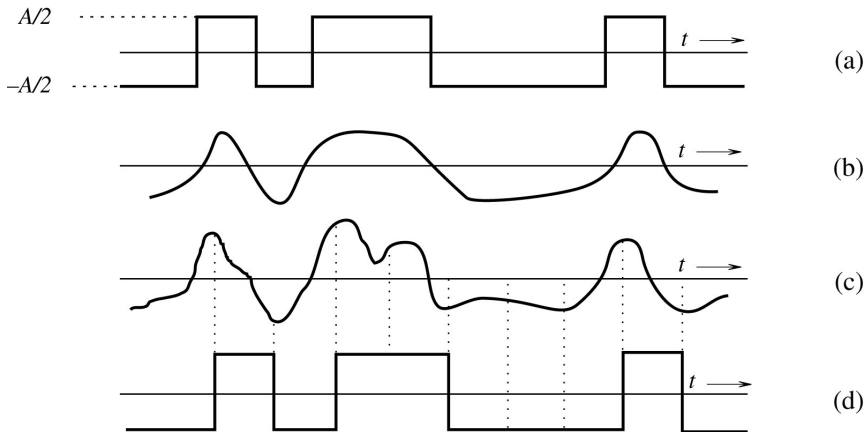
(a) binary signal input to channel; (b) signal altered by channel;
(c) signal + noise; (d) signal after *detection* by receiver

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.
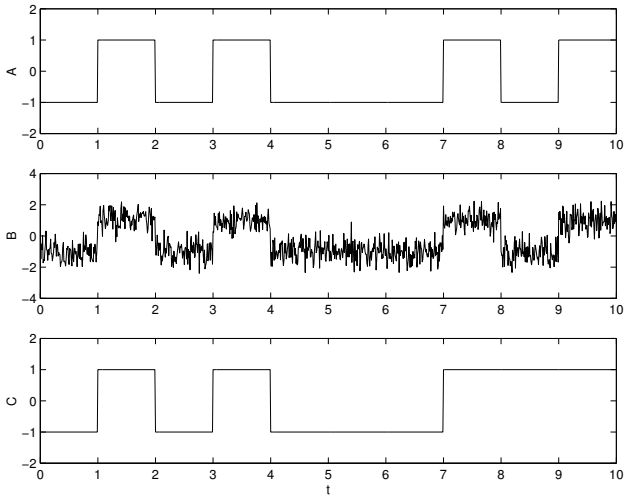
Pulse Code Modulation (PCM)

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 companded PCM (similar to floating point)

Digit	Binary equivalent	Pulse code waveform
0	0000	
1	0001	
2	0010	
3	0011	
4	0100	
5	0101	
6	0110	
7	0111	
8	1000	
9	1001	
10	1010	
11	1011	
12	1100	
13	1101	
14	1110	
15	1111	

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 $P_e = \mathrm{P}\{\hat{b} \neq b\}$

 ▶ Without noise, never make bit errors

 ▶ With noise, P_e depends on signal and 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

  ▶ This maximum rate can be approached with bit probability close to 0
  ▶ For additive white Gaussian noise (AWGN) channels,

  $$C = B \log_2(1 + \text{SNR})$$

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

▶ Shannon obtained $C = 32$ Kbps for telephone channels

▶ Get higher rates with modems/DSL (use much more bandwidth)

▶ Nowhere near capacity in wireless systems

Next

RTL SDR Lab 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 EE102A

- ▶ Fourier series and Fourier transforms in $2\pi f$

- ▶ Vector space perspective of signal processing

- ▶ L&D Chapter 2 (skim this, most of this should look very familiar)