Summary on Digital Communications

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)

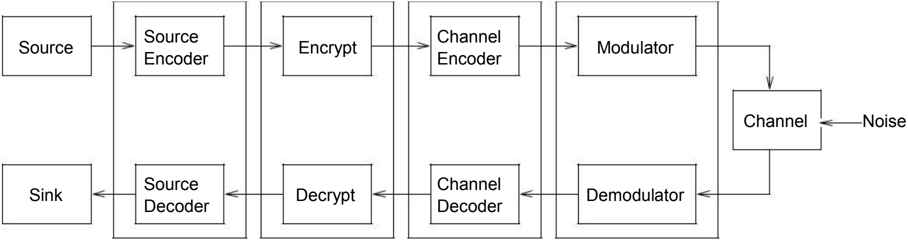
◮ Bits: text, computer data

◮ Analog signals can be converted into bits by quantizing/digitizing

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

Communication System Block Diagram (Advanced)



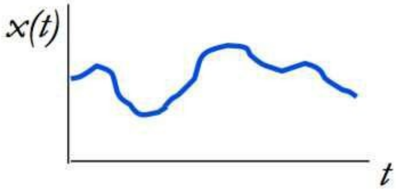
- Source encoder compresses message to remove redundancy
- Encryption protects against eavesdroppers and false messages
- Channel encoder adds redundancy for error protection
- Modulator converts digital inputs to signals suitable for physical channel

Examples of Communication Channels

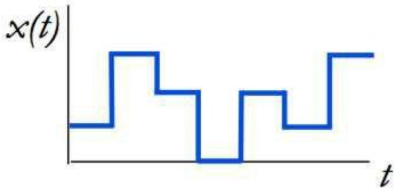
- Communication systems convert information into a format appropriate for the transmission medium
- Some channels convey electromagnetic waves (signals).
  - Radio (20 KHz to 20+ GHz)
  - Optical fiber (200 THz or 1550 nm)
  - Laser line-of-sight (e.g., from Mars)
- Other channels use sound, smell, pressure, 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

Analog vs. Digital Systems

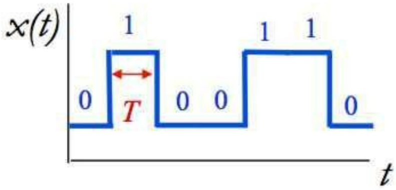
- **Analog signals**
  Values varies continously



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

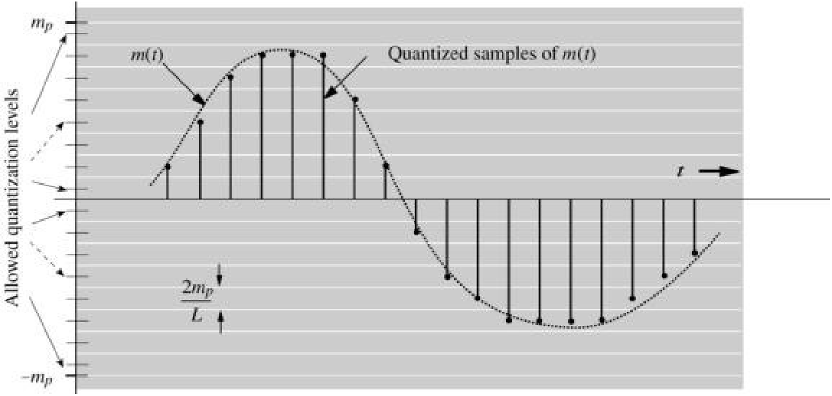


- **Binary signals**
  Have 2 possible values
  Used to represent bit values
  Bit time T needed to send 1 bit Data rate R = 1/T bits per second



Sampling and Quantization, I

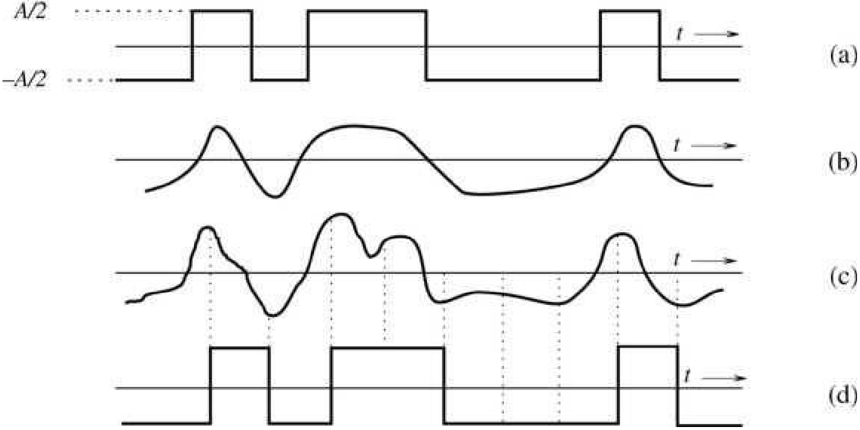
To transmit analog signals over a digital communication link, we must discretize both time and values.



Quantization spacing is $\frac{2m_P}{L}$; sampling interval is T , not shown in figure.

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

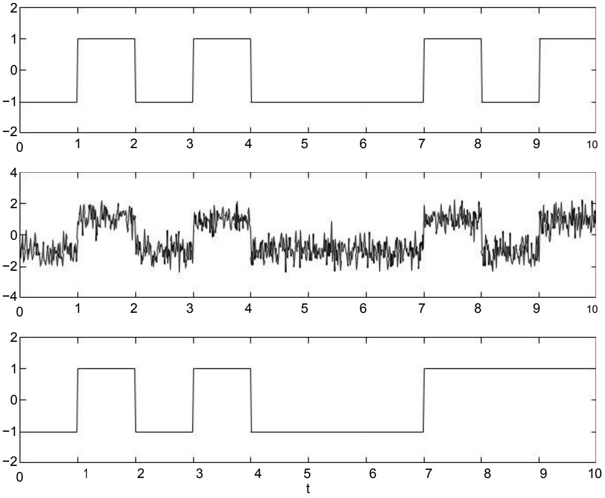
Channel Errors

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.

A

B

C



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,

$$C = \frac{1}{2} B \log(1 + SNR) = \frac{1}{2} B \log\left(1 + \frac{\overline{P}}{N}\right)$$

  - The theoretical result does not tell how to design real systems
- Shannon obtained $C \approx 32$ Kbps for telephone channels ($B = 3700 - 300 = 3400$ Hz)
- Modern modems achieve higher rates by using more bandwidth