Communication Theory

English Grades

Chapter 0

Introduction

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Definition: Communication System

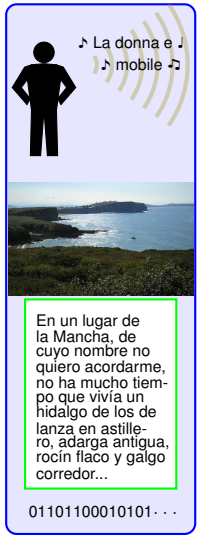
- Purpose of a communications system: *transmission*
- Transmission: *process of **sending**, transporting, **information** from one point (source) to another point (destination) through a channel or transmission medium*

- Taxonomy (format of the information to be transmitted)
  - Analog system: analog signal (continuous time waveform)
    - ★ Information / electrical signal conversion: Transducer
      - Example: output from a microphone (voice signal)

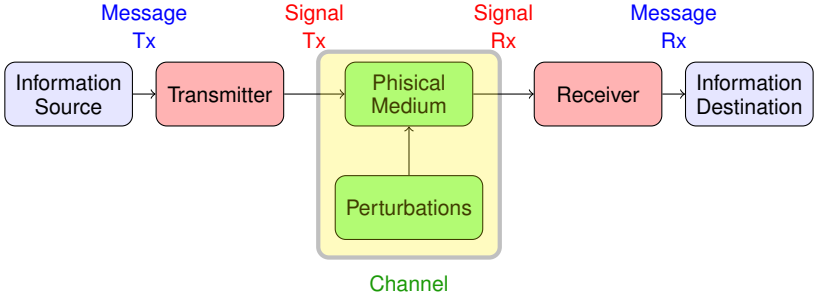
BLADE RUNNER (Roy Batty): *"I've seen things you people wouldn't believe: attack ships on fire off the shoulder of Orion. I watched C-beams glitter in the dark near the Tannhauser gate. All those moments will be lost in time, like tears in the rain... Time to die."*

  - Digital system: digital signal (1001110101001010...)
    - ★ Posterior conversion to electrical or electromagnetic signal (Modulation)

Physical manifestation of information



Functional diagram of a communications system



Source of information

- Message: physical manifestation of the information
- Classification (depending on the format):
  - Analog Source
    - ⋆ Messages: continuous waveform
    - ⋆ Transducer: conversion to electrical/electromagnetic signal

RESERVOIR DOGS (Mr. White): *"If you get a customer, or an employee, who thinks he's Charles Bronson, take the butt of your gun and smash their nose in. Everybody jumps. He falls down screaming, blood squirts out of his nose, nobody says fucking shit after that."*

    - ⋆ Objective of the transmission: *Fidelity*
  - Digital Source
    - ⋆ Information contained in a set of symbols (finite alphabet)
      - Example: bits (alphabet $\{0, 1\}$)
        Information: 01100011011100101110100101010...
    - ⋆ are sent in discrete time at a certain rate
      - Symbol rate (symbols/s, baud) / bit rate (bits/s)
    - ⋆ Objective of the transmission: *Error probability* ↓

Examples of information signals (messages)

- Audio signals (electrical signal at microphone output)

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- Digital signals

$$B_b[n] = 0100110010001010010010100100100000011101010100101\cdots$$

$$B_b[n] = 1101010101001010000101111001001010010101010010100\cdots$$

Transmitter

- Conversion of the information signal into an electrical/electromagnetic signal that will be transmitted through the communications channel
- **Modulation**: conversion of information into a signal suitable for the characteristics of the channel
  - Relative knowledge of the channel
    - In particular, the usable frequency band
- Transmission strategies
  - Baseband transmission (BB)
    - Available frequency band is centered at zero Hz
  - Pass band transmission (PB)
    - Available frequency band is centered at a freq. $f_c \neq 0$ Hz

Channel

- Physical struture that is used to send the information
  - Cable, optical fiber, radio spectrum, $\cdots$
- Usual model: linear time-invariant system (impulse response $h(t)$)

$$r(t) = s(t) * h(t) = \int_{-\infty}^{\infty} s(\tau)\, h(t-\tau)\, d\tau \overset{\mathcal{FT}}{\leftrightarrow} R(j\omega) = S(j\omega) \times H(j\omega)$$

- Ideal channel: delay and attenuation

$$r(t) = k_0 \times s(t - t_0)$$

attenuation term $k_0 < 1$ and delay term t_0 sec.

  - Channel response

$$h(t) = k_0 \times \delta(t - t_0) \overset{\mathcal{FT}}{\leftrightarrow} H(j\omega) = k_0 \times e^{-j\omega t_0}$$

Time domain: delta function - Frequency domain: constant module, linear phase

- Undesired effects
  - Linear distortion
  - Nonlinear distortion
  - Noise (thermal, impulsive,...)

Receiver

- Converts the received signal into information
- Objective: To recover the transmitted information with a given quality
  - Analog signals: received signal is *similar* to the transmitted signal (fidelity)
    - ⋆ Quantitative figure of merit: signal to noise ratio (S/N)
  - Digital signals: a bounded number of bit errors
    - ⋆ Quantitative figure of merit: bit error probability (BER)
- **Demodulation**
  - Reverse process of modulation
    - ⋆ Information signal recovery (analog / digital)
    - ⋆ Rejection of disturbances (as much as possible)
    - ⋆ Reversal of the channel distortions

Analog and digital communications systems

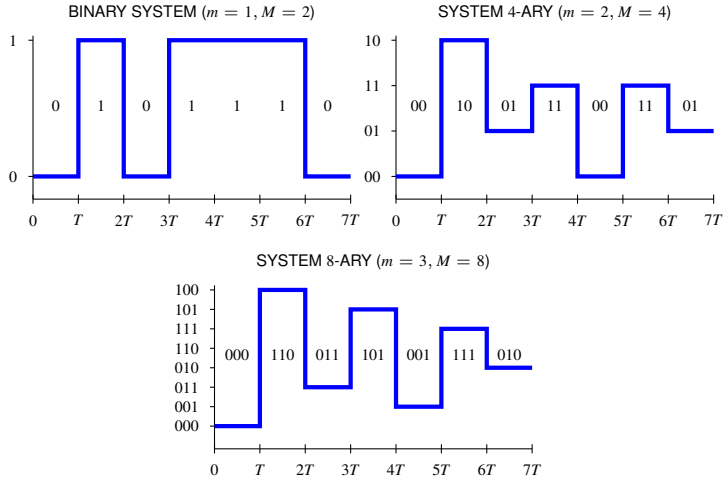
- Analog communications system
  - Designed to send a continuous waveform as data

- Digital communications system
  - Designed to send as information a sequence of symbols belonging to a finite alphabet (M possible values for each symbol)
    - ★ Most common example: Bits ($M = 2$): $\{0, 1\}$
      - Information: 011000110111001101010111001001101 0...
  - Transmission at a given speed (symbol rate): R_s symbols/s
    - ★ One symbol is transmitted every $T = \frac{1}{R_s}$ seconds
  - Symbols must be converted into electrical signals for transmission
    - ★ Each symbol is associated with a waveform
    - ★ Simplest case: $T = \frac{1}{R_s}$ second waveforms

- Preponderance of digital communication systems

Digital Modulation - Simpler Example

- A block of m bits (symbol) is associated with a voltage level
  - M-ary system (with $M = 2^m$ possible symbols)



Design and analysis of communication systems

- Communications systems transmit information
  - Conversion of information into a suitable signal $s(t)$
  - Transmission of this "*modulated*" signal through a certain medium (channel)
  - Processing of the received signal (with distortions, $r(t) \neq s(t)$) to extract the information
- Transmitter and receiver tasks
  - Generate and process signals
- Design and analysis of a communications system
  - Characterization of signals
  - Model for signal processing or transformation

Signals

- Definition: functions that represent variations of a physical quantity over time
- Classification according to the nature of the independent variable
  - Continuous time signals: $x(t)$, with $t \in \boldsymbol{R}$
  - Discrete time signals: $x[n]$, with $n \in \mathbb{Z}$
- Classification according to the nature of the signal
  - Deterministic
    - Completely known at any instant of time
    - Examples: Signaling, encryption codes or coding
  - Stochastic (Random)
    - Unknown at any instant of time
    - Available knowledge: statistical characteristics
    - Examples: Information signals, noise and interference
- Systems: transform signals

Characterization of signals and systems - Program

- Deterministic signals
  - Time Domain: **Systems and Circuits**
    - ★ mean value
    - ★ Energy/Power
      - Energy signal: $E_x < \infty$ ($P_x = 0$)
      - Power signal: $0 < P_x < \infty$ ($E_x = \infty$)
    - ★ Effective value: DC value with the same power
    - ★ Basic signals (impulses, pulses, sinusoids, exponentials, sincs,...)
    - ★ Basic operations (displacement, scaling,...)
    - ★ Linear and invariant systems: impulse response $h(t)$
      - Convolution: $y(t) = x(t) * h(t)$
  - Frequency domain: **Linear systems**
    - ★ Periodic signals ($T_0 = \frac{2\pi}{\omega_0}$): Fourier Series Expansion
    - ★ Aperiodic signals: Transf. Fourier $x(t) \leftrightarrow X(j\omega) \mid x[n] \leftrightarrow X\left(e^{j\omega}\right)$
    - ★ Linear and invariant systems: resp. at frequency $H(j\omega) = \mathcal{FT}\{h(t)\}$
      - Product: $Y(j\omega) = X(j\omega)\, H(j\omega)$

Characterization of signals and systems - Program

- Stochastic signals
  - **Statistics**
    - ★ Random variables and random processes (time domain)
- **Communication Theory**
  - Analysis of stochastic processes in the frequency domain
  - Application: design and analysis of communication systems