Computer Networks

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Syllabus

- Basic Concepts
- OSI Model
- Data-Link Layer
- Local Area Networks
- Network Layer
- Transport Layer
- Application Layer

Bibliography

- Textbook
  - Computer Networks, Andrew S. Tanenbaum, 4^{th} edition, Prentice Hall, 2002, ISBN-10: 0130661023, ISBN-13: 978-0130661029.
- Reference
  - Computer Networking: A Top-Down Approach, James F. Kurose and Keith W. Ross, 5^{th} edition, Addison Wesley, 2009, ISBN: 0-13-607967-9.

Outline

- Network
- Network Types
- Network Topology
- Switching
- Transmission
- Digital Encoding
- Modulation
- Multiplexing
- Network Delays
- Transmission Modes
- Transmission Media

Definition

A computer network, often simply referred to as a network, is a group of computers and devices interconnected by communications channels that facilitate communications among users and allows users to share resources (from Wikipedia).

- Goal: Information Exchange
  - Data
  - Voice
  - Video

Network Types

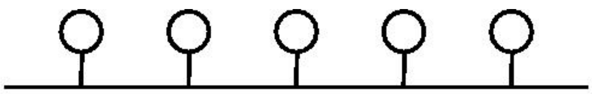
- Broadcast Network
  - Each communication is receieved by all network users
  - Examples: Radio Network, TV Network
- Point-to-Point Network
  - The communication is between two network users
  - Examples: Public Switched Telephone Network (PSTN), Internet

Network Topology

- Bus
- Ring
- Star
- Tree
- Mesh

Bus Topology

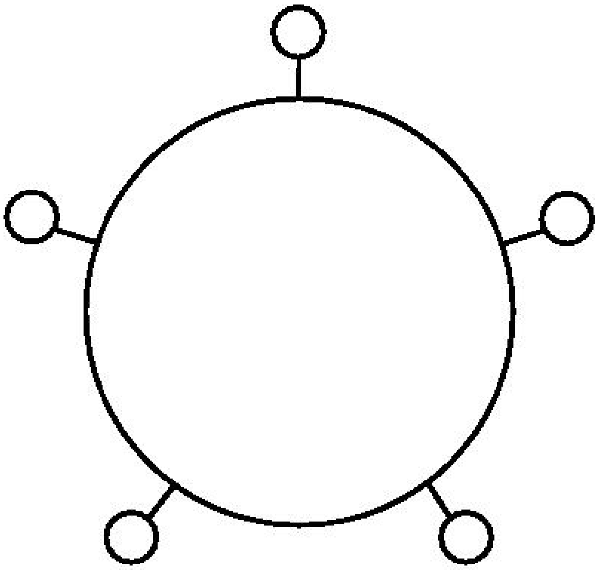
- All hosts are connected to the same bus
- The bus can handle a single communication at a given time
- Cannot be used when the number of hosts is large
- Each communication could be listened by each host
- Similar to the FSB (Front Side Bus) of a PC



Bus Topology

Ring Topology

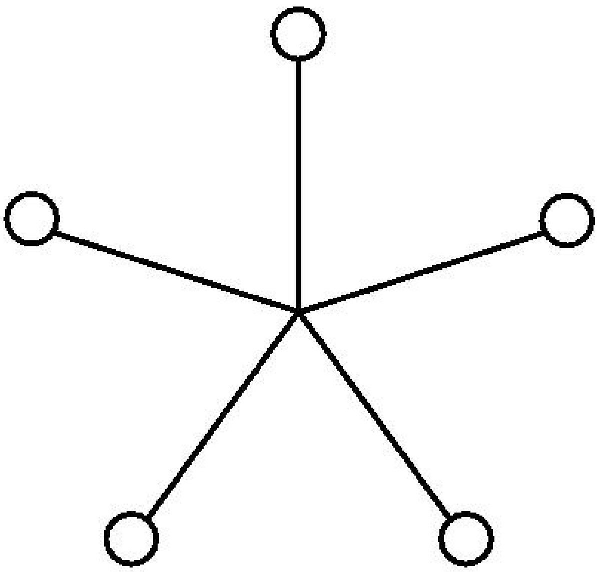
- All hosts are connected to the same ring
- Data travels in only one direction



Ring Topology

Star Topology

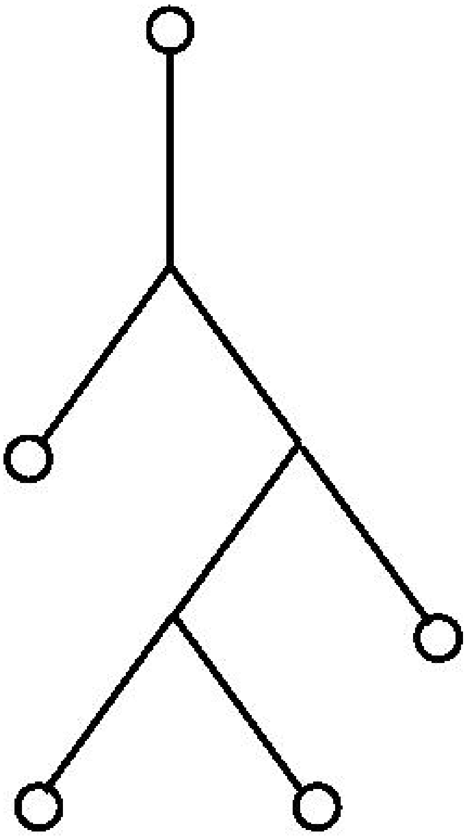
- All hosts are connected to a central node
- Single point of failure
- Broadcasting
- Switching



Star Topology

Tree Topology

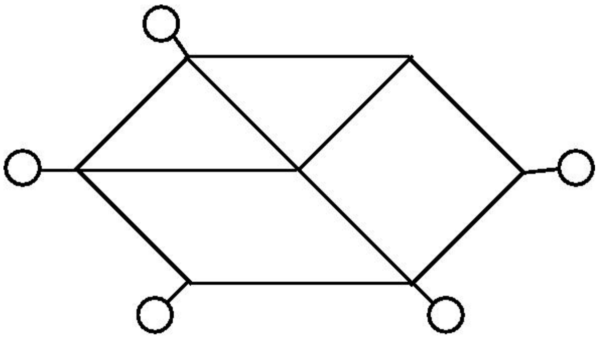
- There is a one and only one path between each two nodes
- No tolerant to failures
- Two isolated sub-trees in case of link failure



Tree Topology

Mesh Topology

- The shortest path is used for the communication
- Tolerant to failures
- Economic Solution



Mesh Topology

Switching

- How is data transferred through the network?
- Circuit Switching
- Message Switching
- Packet Switching
- Cell Switching

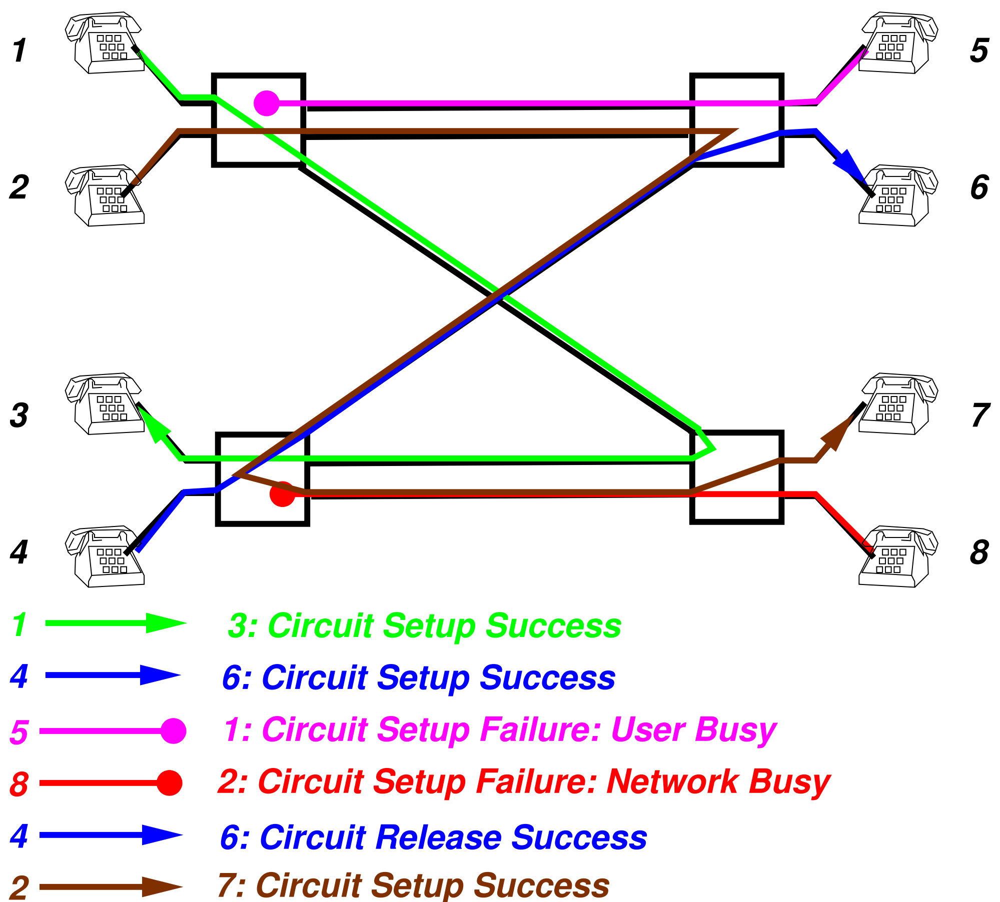
Switching

- Circuit Switching
  - Public Switched Telephone Network (PSTN)
- Message Switching
  - Mail/Email
- Packet Switching
  - Internet
- Cell Switching
  - Asynchronous Transfer Mode (ATM)

Circuit Switching

- End to end dedicated communication circuit
- Established for the call duration
- End to end physical circuit must be established before data transfer
- Example: Telephone Network

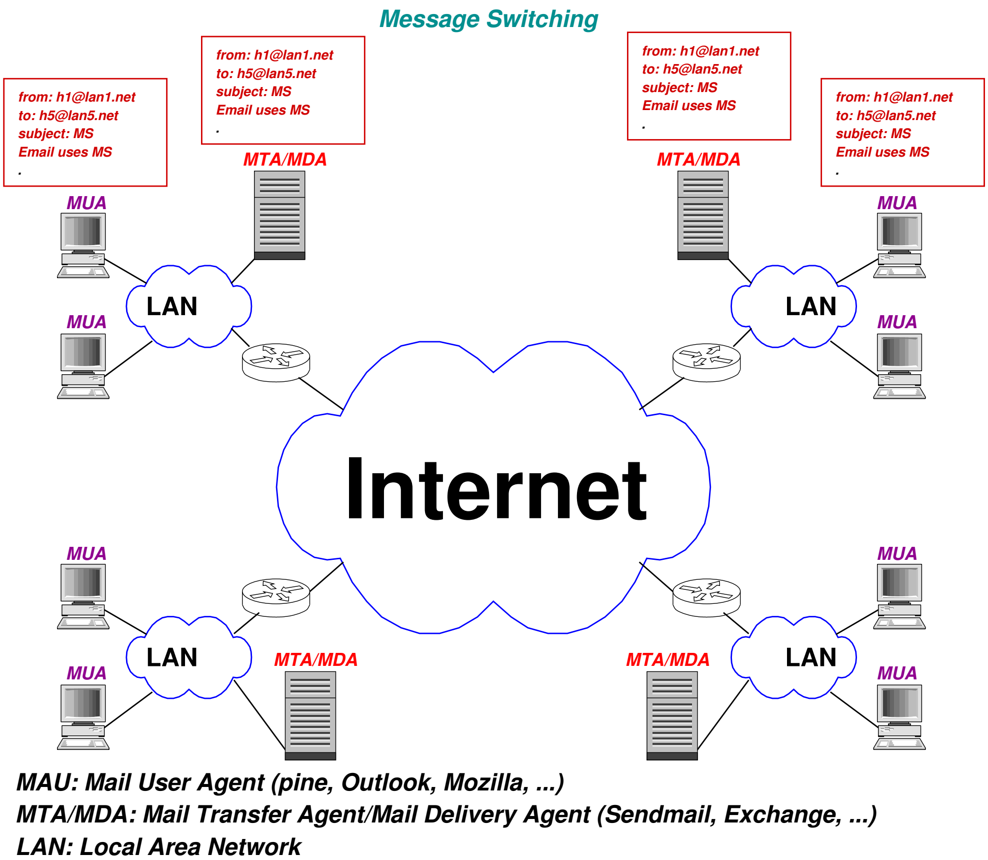
Circuit Switching



Message Switching

- Does not require circuit setup before conversation
- Messages are stored and then forwarded
- Store-and-forward
- No restriction on the size of transferred messages
  - Intermediate nodes must have huge storage space
- Example: Mail/Email

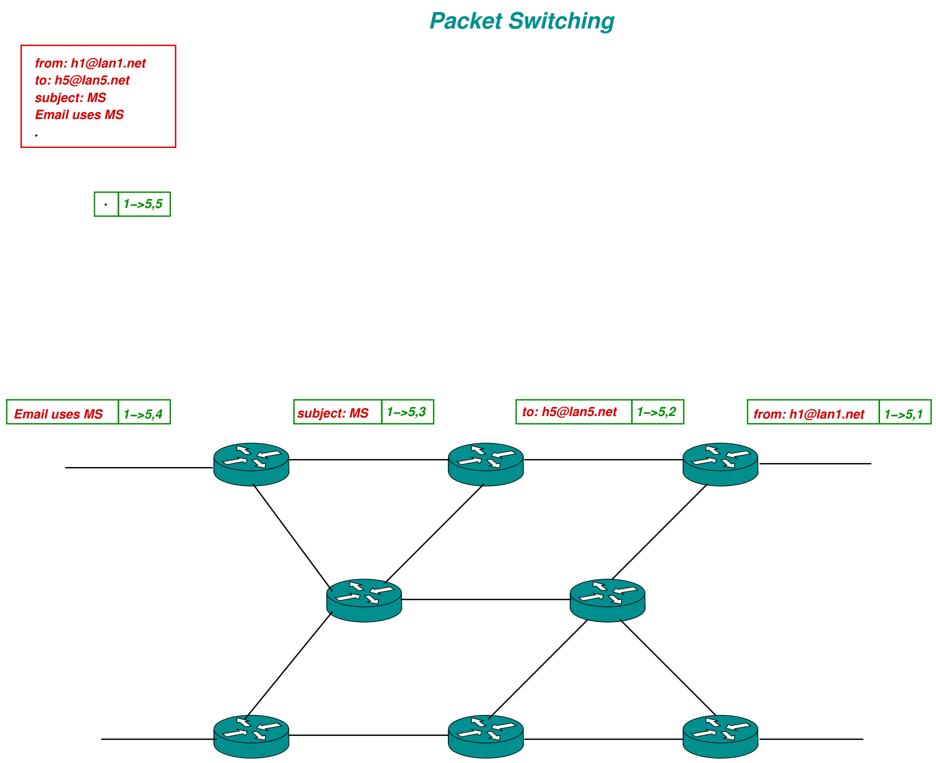
Message Switching



Packet Switching

- Invented to overcome message switching problems
- Messages are segmented into packets
- Packets have a maximum size
- Pipeline: first packet could be transmitted before the arrival of the second one
- Example: Internet

Packet Switching



Cell Switching

- Similar to packet switching
- Messages/Packets are segmented into cells
- Cells have fixed size
- Padding bytes in the last cell
- Good for real time traffic (transmission time is fixed for each cell)
- Example: ATM

Transmission Link Characteristics

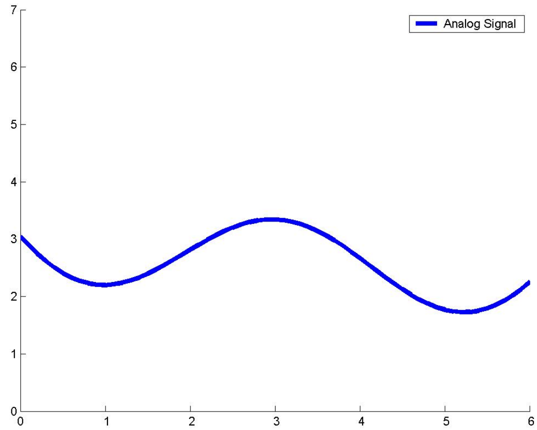
- Simplex
  - Transmission in one direction
  - Radio, TV
- Half-Duplex
  - Transmission in both directions, but in only one direction at a given time
  - Walkie Talkie
- Full-Duplex
  - Transmission in both directions simultaneously
  - Telephone

Signal

- A signal is a varying quantity (voltage, air pressure,) that can be expressed as a continuous function of an independent variable usually time
- Used for data representation
- Digital Signal
  - Discrete time signal
  - Discrete values (+5V and 5V)

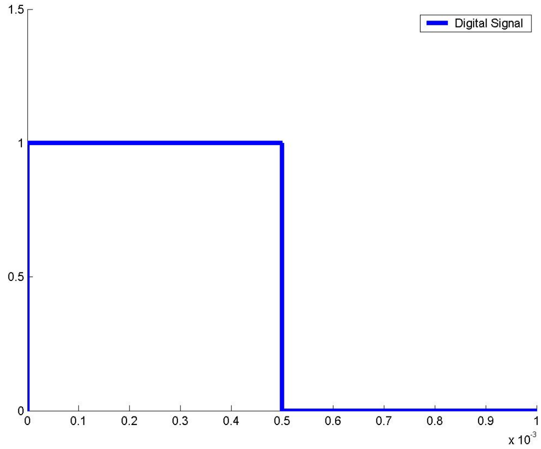
Analog Signal

- Continuous time signal
- Amplitude varies continuously



Digital Signal

- Discrete time signal
- Discrete values (+5V and 5V)



Fourier Analysis

A periodic signal $g(t)$ with frequency f can be written as follows:

$$g(t) = \frac{c}{2} + \sum_{n=1}^{\infty} a_n sin(2\pi nft) + \sum_{n=1}^{\infty} b_n cos(2\pi nft)$$

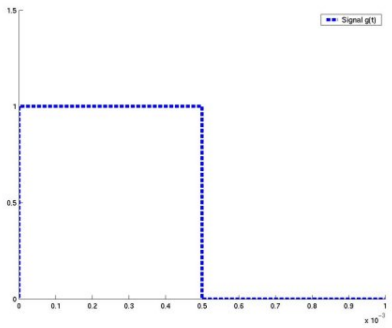
$$c = \frac{2}{T}\int_0^T g(t)dt$$

$$a_n = \frac{2}{T}\int_0^T g(t)sin(2\pi nft)dt$$

$$b_n = \frac{2}{T}\int_0^T g(t)cos(2\pi nft)dt$$

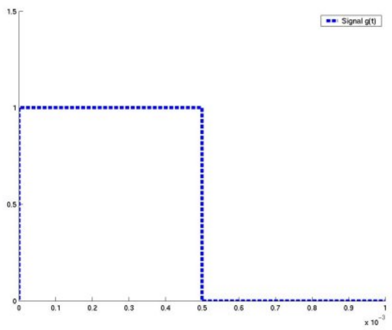
if the signal is not periodic, we can apply Fourier on portions of the signal.

Fourier Analysis



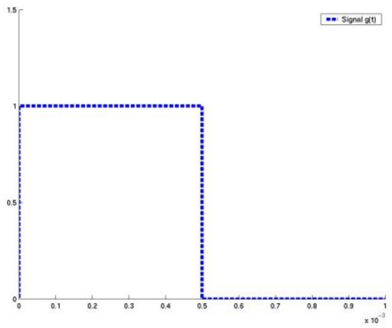
$$
\begin{aligned}
a_n &= \frac{2}{T}\int_0^T g(t) sin(2\pi nft) dt \\
&= \frac{2}{T}\int_0^{\frac{T}{2}} sin(2\pi nft) dt \\
&= \frac{2}{T}\left[-\frac{1}{2\pi nf} cos(2\pi nft)\right]_0^{\frac{T}{2}} \\
&= \frac{2}{T}\left(-\frac{1}{2\pi nf}\left(cos(2\pi nf\frac{T}{2}) - cos(0)\right)\right) \\
&= -\frac{2}{T}\frac{1}{2\pi nf}\left(\left(cos(2\pi nf\frac{T}{2}) - cos(0)\right)\right) \\
&= -\frac{1}{n\pi}\left(cos(n\pi) - 1\right) \\
&= \frac{1}{n\pi}\left(1 - cos(n\pi)\right)
\end{aligned}
$$

Fourier Analysis



$$
\begin{aligned}
b_n &= \frac{2}{T}\int_0^T g(t) cos(2\pi nft) dt \\
&= \frac{2}{T}\int_0^{\frac{T}{2}} cos(2\pi nft) dt \\
&= \frac{2}{T}\left[\frac{1}{2\pi nf} sin(2\pi nft)\right]_0^{\frac{T}{2}} \\
&= \frac{2}{T}\left(\frac{1}{2\pi nf}\left(sin(2\pi nf\frac{T}{2}) - sin(0)\right)\right) \\
&= \frac{2}{T}\frac{1}{2\pi nf}\left(sin(2\pi nf\frac{T}{2}) - sin(0)\right) \\
&= \frac{1}{n\pi}\left(sin(n\pi) - 0\right) \\
&= 0
\end{aligned}
$$

Fourier Analysis

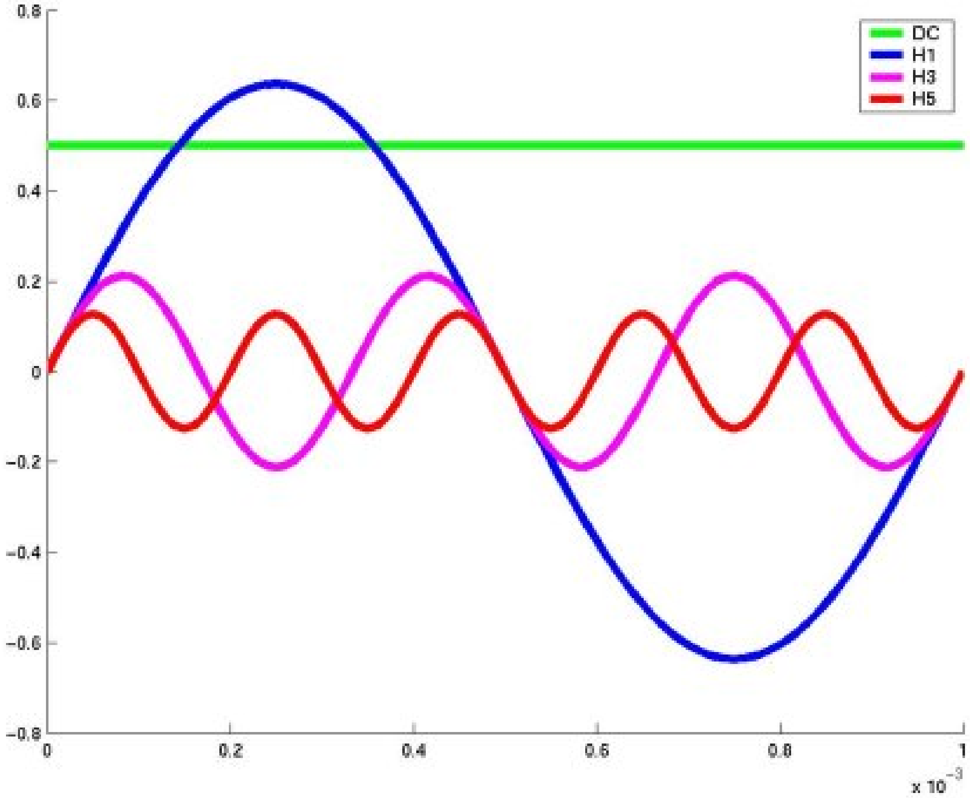


$$
\begin{aligned}
c &= \frac{2}{T}\int_0^T g(t)dt \\
&= \frac{2}{T}\Big[t\Big]_0^{\frac{T}{2}} \\
&= \frac{2}{T}\Big(\frac{T}{2} - 0\Big) \\
&= \frac{2}{T}\frac{T}{2} \\
&= 1
\end{aligned}
$$

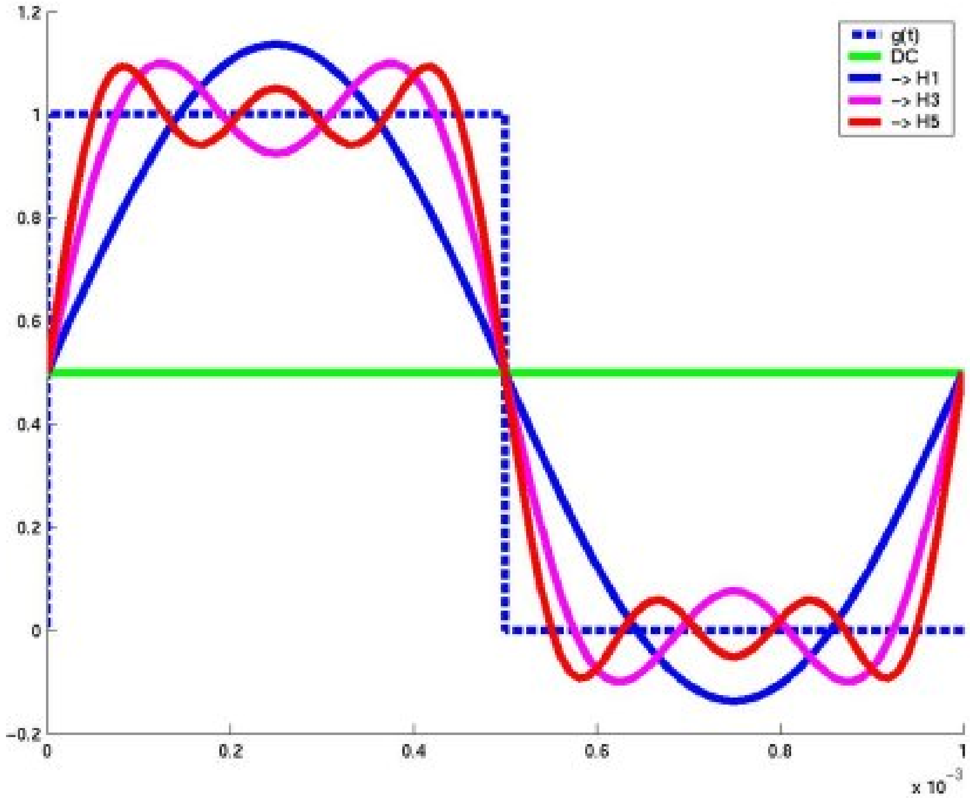
Fourier Analysis

$$
\begin{aligned}
g(t) &= \frac{c}{2} + \sum_{n=1}^{\infty} a_n sin(2\pi nft) + \sum_{n=1}^{\infty} b_n cos(2\pi nft) \\
a_n &= \frac{1}{n\pi}\Big(1 - cos(n\pi)\Big) \\
b_n &= 0 \\
c &= 1 \\
g(t) &= \frac{1}{2} + \sum_{n=1}^{\infty} \frac{1}{n\pi}\Big(1 - cos(n\pi)\Big) sin(2\pi nft) + 0 \\
g(t) &= \frac{1}{2} + \frac{2}{\pi} sin(2\pi ft) + \frac{2}{3\pi} sin(6\pi ft) + \frac{2}{5\pi} sin(10\pi ft) + ...
\end{aligned}
$$

Fourier Analysis



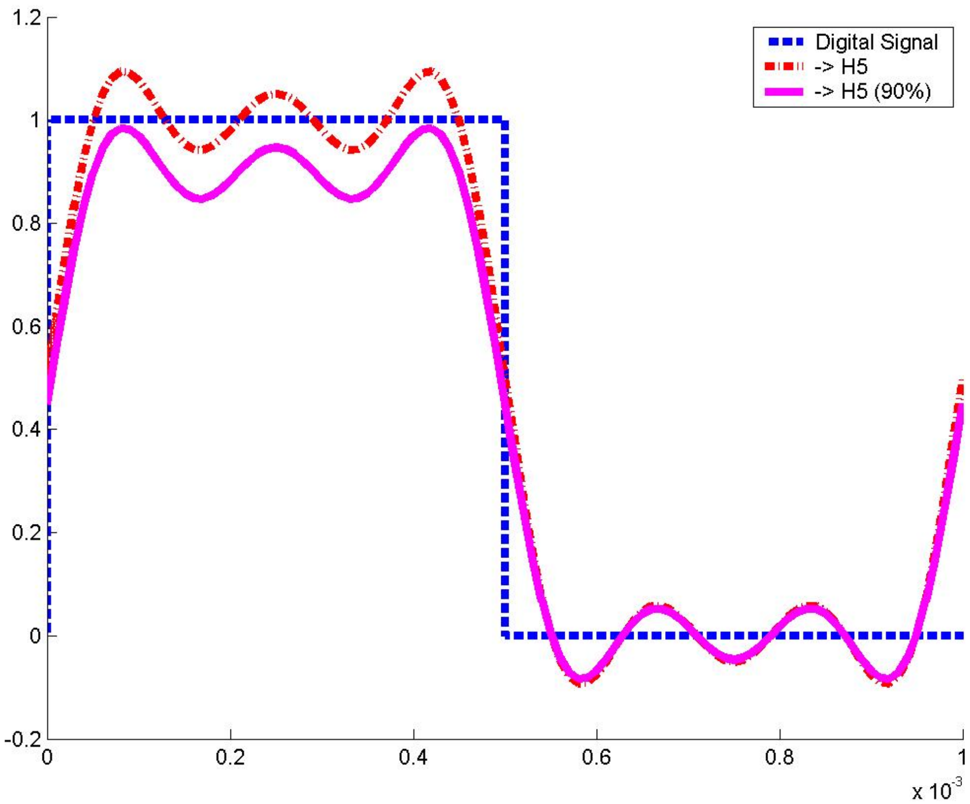
Fourier Analysis



Fading/Attenuation

- Fading/Attenuation
  - Diminution of the amplitude of the signal
  - Depends on:
    - Frequency of the signal
    - Transmission media
    - Circuit length

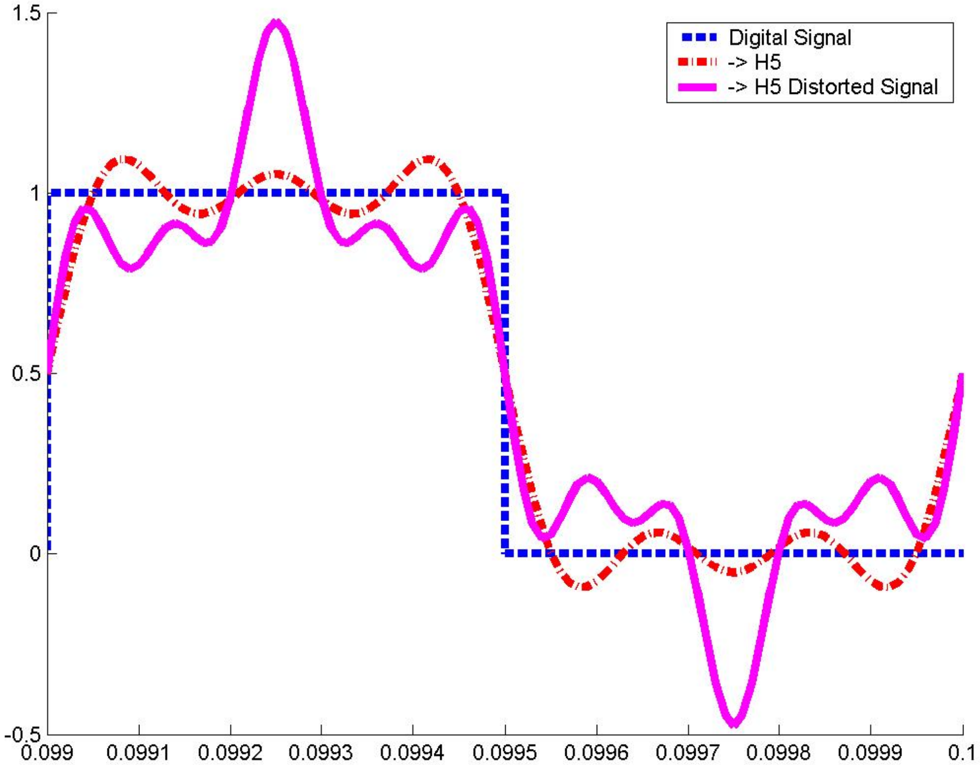
Fading/Attenuation



Distortion

- Distortion
  - Signal deformation
  - The signal is constituted by many harmonics with different frequencies
  - Harmonics are transmitted with different speeds
  - Received signal will be distorted

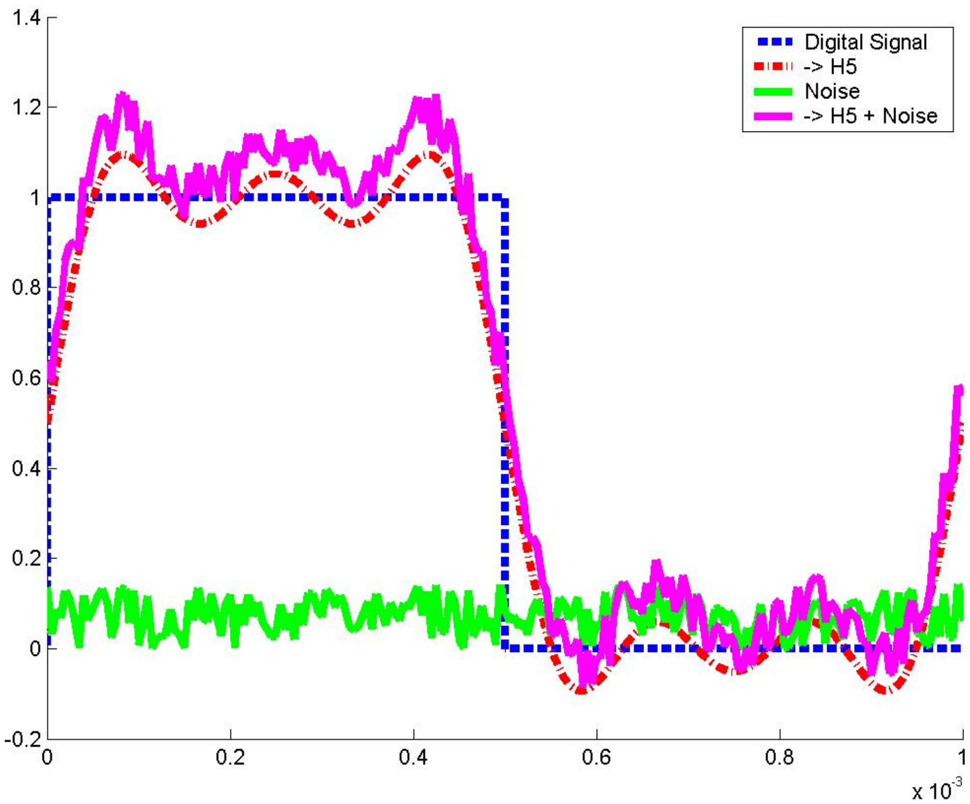
Distortion



Noise

- Noise
  - Presence of parasite signal
  - Gaussian Noise
    - Random motion of electrons
    - Emission of electromagnetic waves
  - Constant signal
  - Its power is proportional to temperature

Distortion



Signal Transmission

- Analog Transmission
  - Analog signal is used to transmit Information
- Digital Transmission
  - Digital signal is used to transmit Information

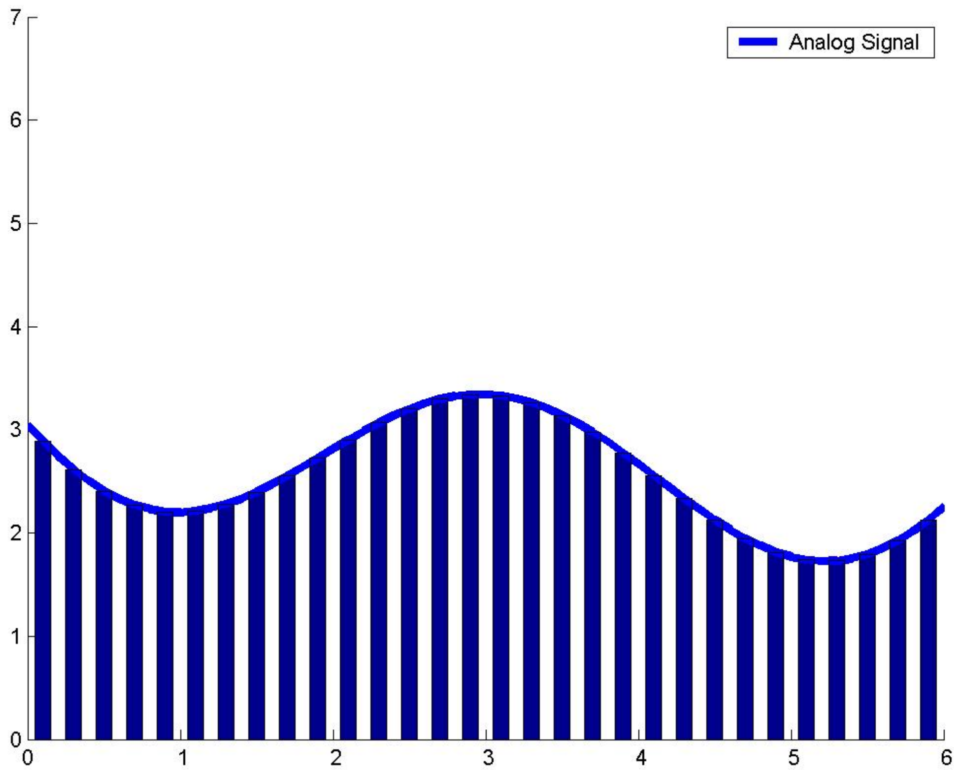
Analog Transmission

- Analog Signal over Analog Channel
  - Signal directly transmitted (base band)
  - Analog Modulation (broadband)
- Digital Signal over Analog Channel
  - Modem: modulator demodulator
    - Amplitude Modulation
    - Frequency Modulation
    - Phase Modulation
    - Combined Modulation

Digital Transmission

- Digital Signal over Digital Channel
  - Manchester Code
    - Bit 1: top-down transition
    - Bit 0: bottom-up transition
- Analog Signal over Digital Channel
  - Codec
  - PCM : Pulse Code Modulation
  - Sampling
  - Quantization
  - Coding

Sampling



Nyquist Theorem

- Nyquist Theorem
  - A signal with a maximal frequency H must be sampled at a frequency $2H$
  - Maximum rate: $2Hlog_2 Vbit/s$
  - V: number of discrete levels of the signal
- Example:
  - A modem uses AM-PSK modulation (Phase Shift Key) with 8 levels, PSTN bandwidth is $3100Hz$
  - $C = 2Hlog_2 V$
  - $C = 2 * 3100 * log_2 8$
  - $C = 2 * 3100 * 3$
  - $C = 18600bit/s$

Analog Transmission

- Analog Transmission
  - Communication by exchanging analog signals
- Amplifier to amplify the signal
  - Original signal can not be reconstituted
  - Noise signal is also amplified!
  - Signal looses its quality with distance
  - Fading/Attenuation and noise dont affect so much voice transmission but data transmission may be seriously affected (data corruption)

Digital Transmission

- Digital signal with two states on and off
- Digital transmission is done by impulsions
- Repeater to regenerate the signal
  - Initial signal is reconstituted exactly
  - Noise is eliminated
  - Fading/Attenuation does not affect so much digital signal
    - An faded/attenuated signal has always a series of on and off pulses

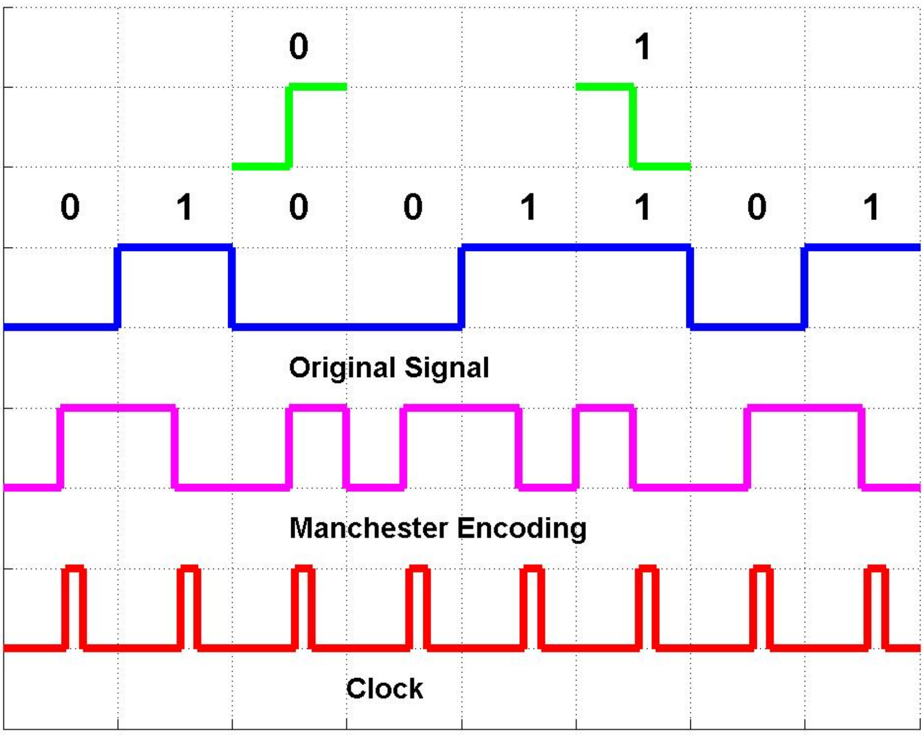
Digital Transmission

- Radio, TV have analog transmission systems
  - Why use digital transmission?
  - Cheap LSI/VLSI technology
  - Data Integrity
  - Efficiency
    - Best use of bandwidth
    - Easy multiplexing with digital techniques
  - Security
  - Cryptography and authentication
  - Integration
    - Similar processing of analog and digital data
  - Good quality (Noise elimination)

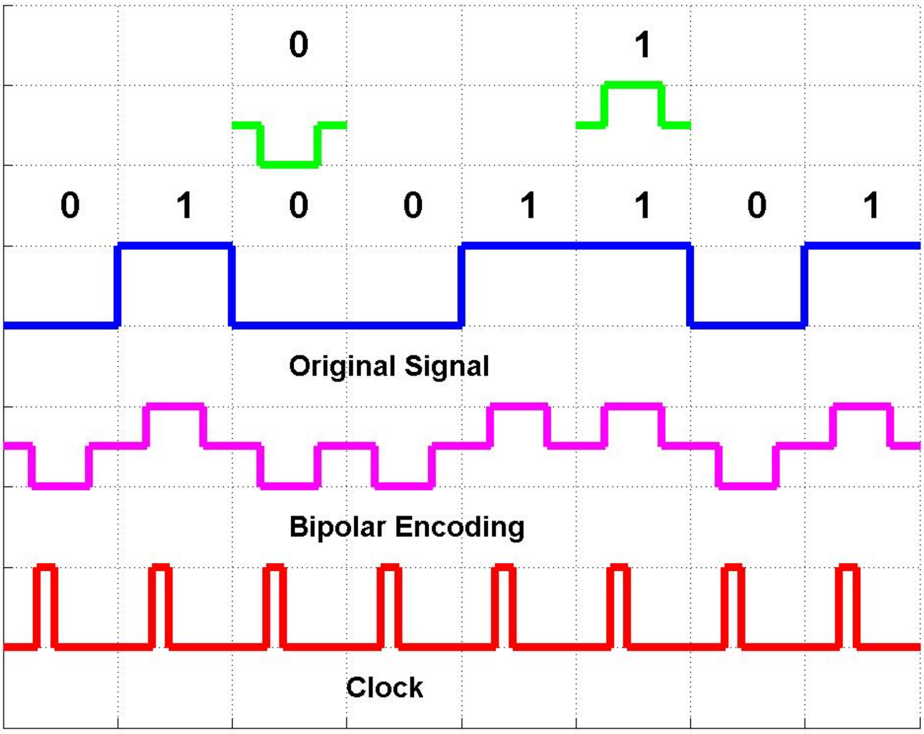
Digital Encoding

- Manchester Encoding
  - 0: Bottom-Up Transition
  - 1: Top-Down Transition
- Bipolar Encoding
  - 0: -V
  - 1: +V
- NRZ Encoding (No Return to Zero)
  - 0: -V
  - 1: +V
- NRZI Encoding (No Return to Zero Inverted)
  - 0: Transition
  - 1: No transition

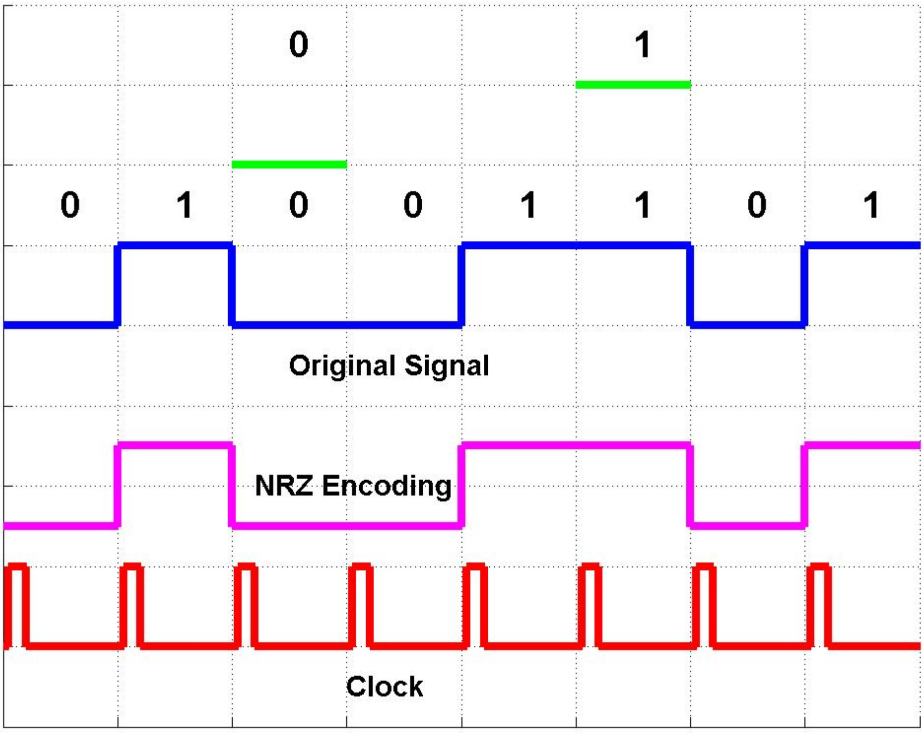
Manchester Encoding



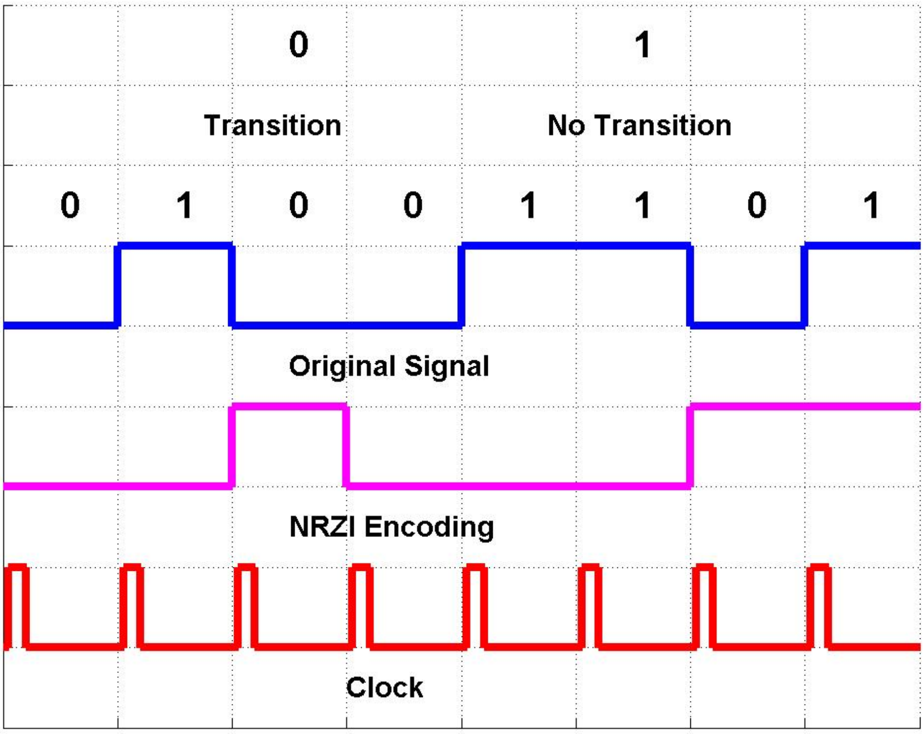
Bipolar Encoding



NRZ Encoding



NRZI Encoding



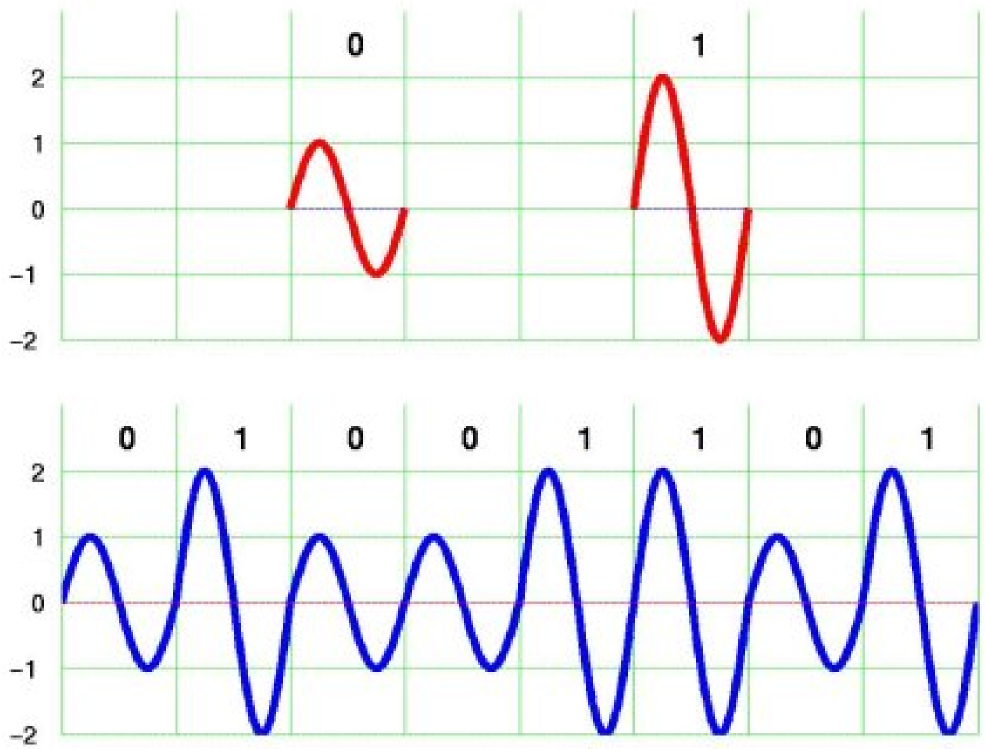
Modulation

- Modification of the characteristics of the carrier using the amplitude of base band signal
- Process allowing the transmission
  - Analog signal with a higher frequency
  - Digital signal over analog channel
- Carrier
  - P(t) = A sin(2wFt + P)
    - A : amplitude
    - F : frequency
    - P : phase

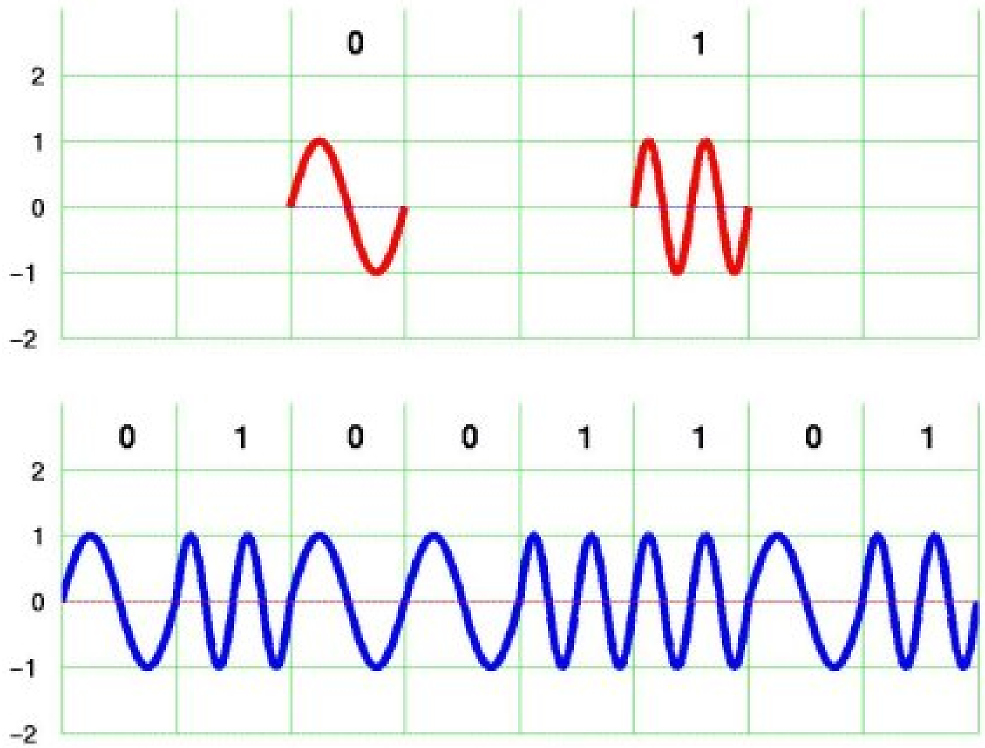
Modulation

- Amplitude Modulation
  - Two different amplitudes are used to represent bit 0 and bit 1
- Frequency Modulation
  - Two different frequencies are used to represent bit 0 and bit 1
- Phase Modulation
  - Two different phases are used to represent bit 0 and bit 1

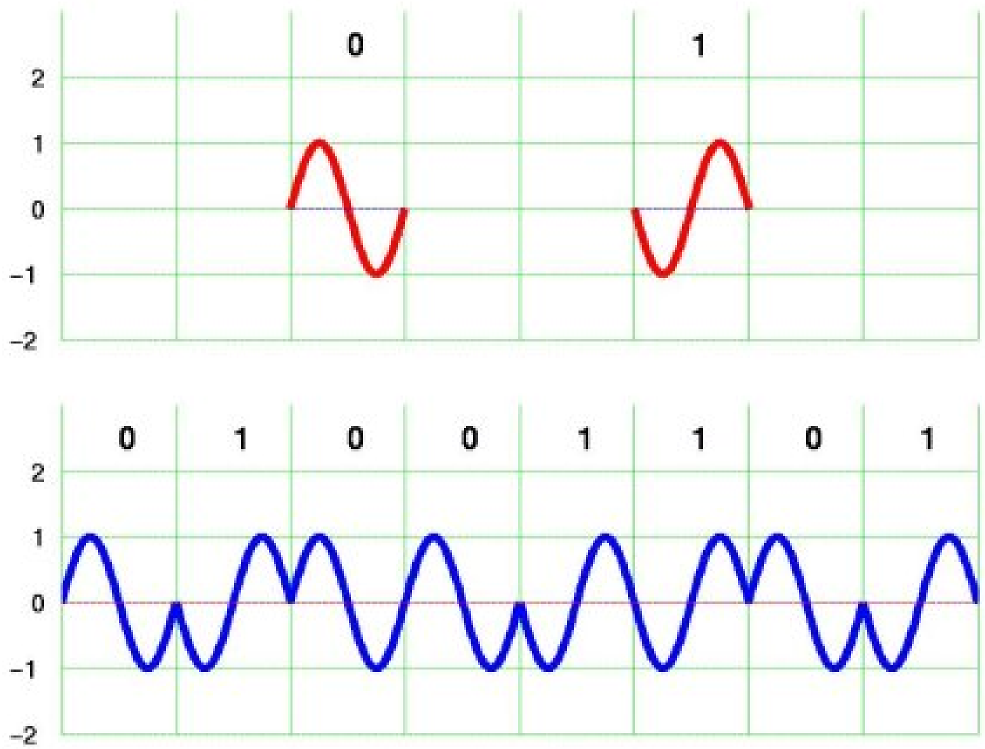
Amplitude Modulation



Frequency Modulation



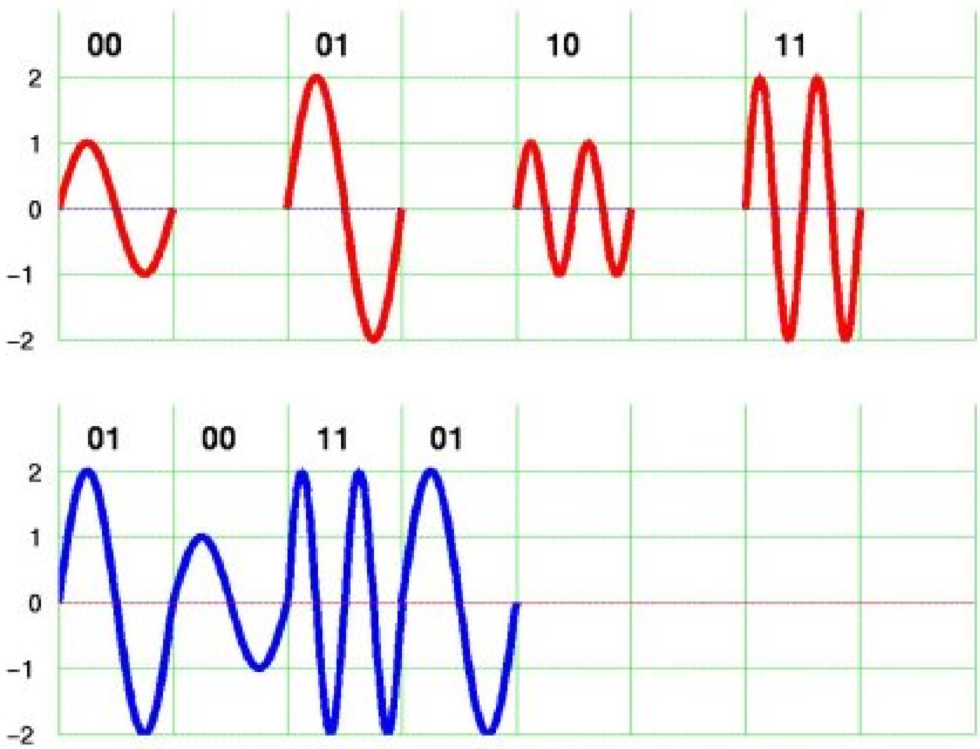
Phase Modulation



Combined Modulation

- Simultaneous use of two or more of former modulation methods
  - Amplitude Modulation + Frequency Modulation
  - Amplitude Modulation + Phase Modulation
  - Frequency Modulation + Phase Modulation
  - All the three methods
- Transmission of many bits simultaneously

Combined Modulation



Capacity

- Baud
  - Number of signal transitions per second
  - Unity: baud
- Bits per second
  - Number of transmitted bits per second
  - Unity: bit/s
- 2 different levels (0 and 1)
  - $Capacity(bits/s) = capacity(bauds)$
- 4 different levels (00, 01, 10, 11)
  - $Capacity(bits/s) = 2 * capacity(bauds)$

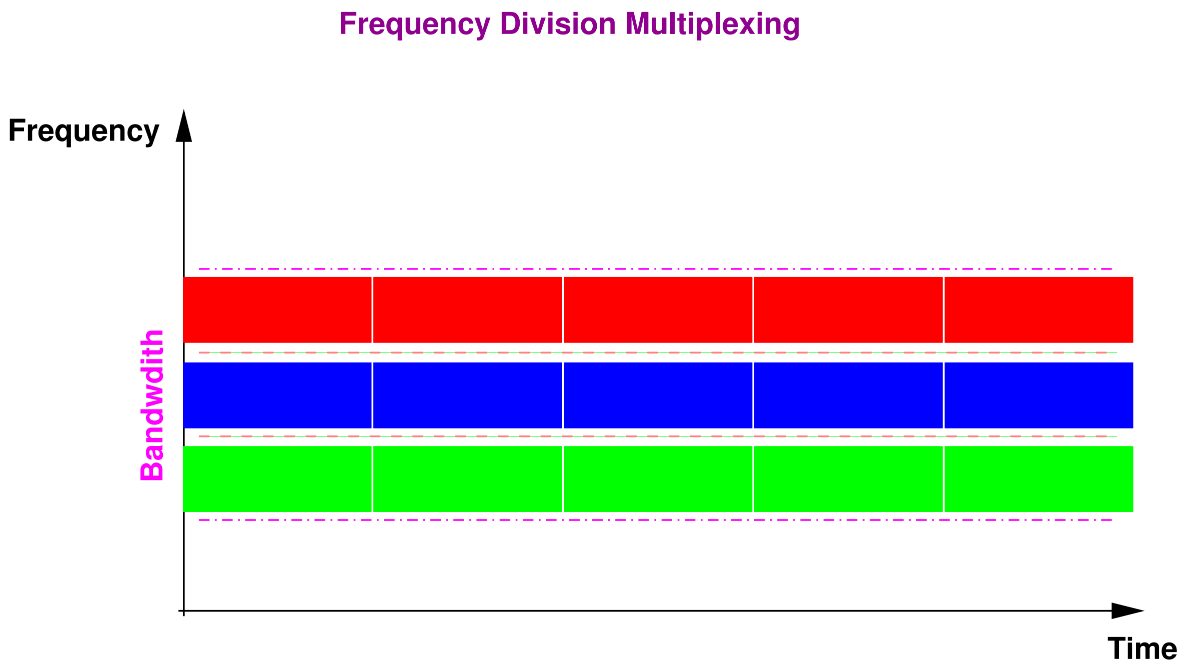
Capacity

- Shannon Theorem
  - $C = Blog_2(1 + \frac{S}{N})$
    - C: Capacity
    - B: Bandwidth
    - SNR: Signal/Noise Ratio
- $SNR = 10log_{10}(\frac{S}{N})$
  - $\frac{S}{N} = 10^{(\frac{SNR}{10})}$
- Example:
  - Twisted Pair
  - $SNR = 20dB$
  - Bandwidth $3000Hz$
  - $\frac{S}{N} = 10^{(\frac{20}{10})} = 10^2 = 100$
  - $C = 3000log_2(1 + 100)$
  - $C = 19963bit/s$

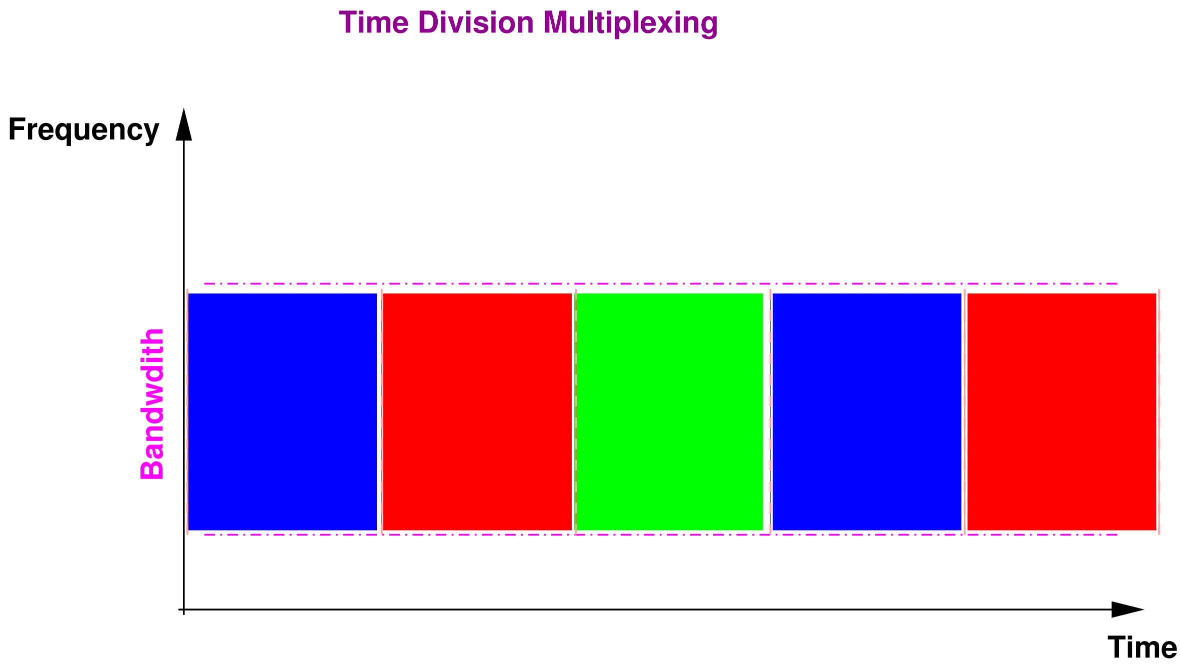
Multiplexing

- Goal
  - Transmission of many signals over one transmission media
- Analog Multiplexing
  - Frequency Division Multiplexing (FDM)
  - Wave-length Division Multiplexing (WDM)
  - Code Division Multiplexing (CDM)
- Digital Multiplexing
  - Time Division Multiplexing (TDM)

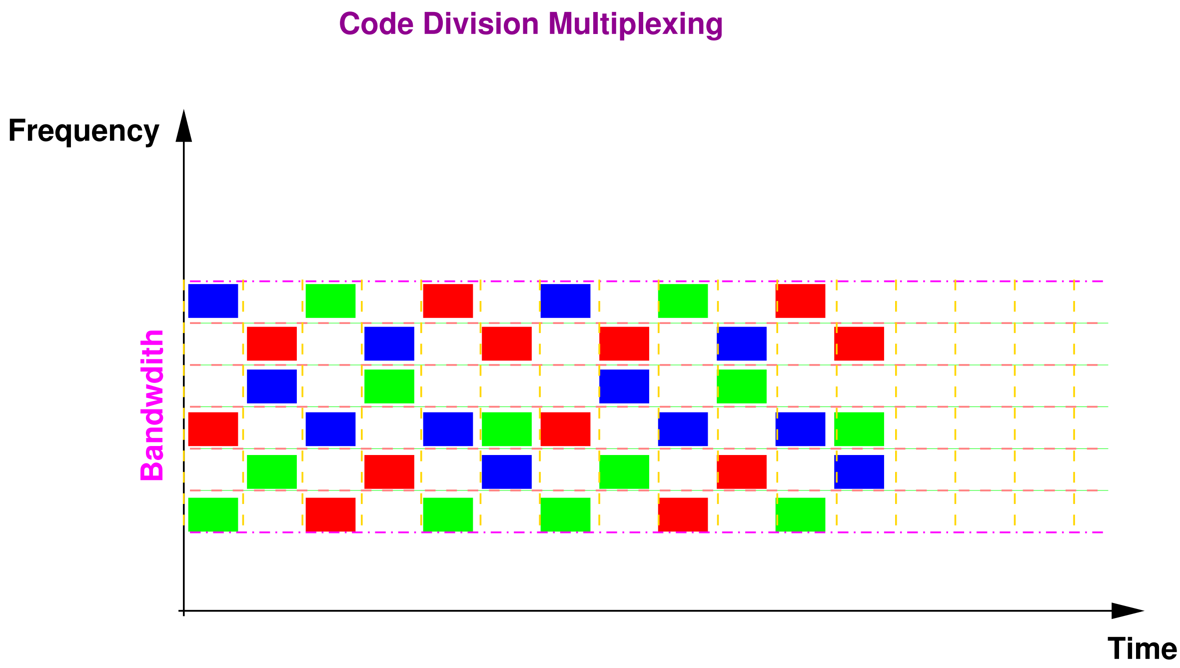
Frequency Division Multiplexing



Time Division Multiplexing



Code Division Multiplexing - Frequency Hopping



Network Delays

- Transmission Delay
- Propagation Delay
- Processing Delay
- Queueing Delay

Transmission Delay

- It is the amount of time required to put the data into the wire
- It depends on the length of the data and the bandwidth of the link
- $DT = \frac{N}{B}$
  - N : the number of bits in the data
  - B : bandwidth (capacity) of the link expressed in *bps* (bit per second) (also b/s)
- Example: What is the transmission delay for a 64 bytes packet over a 10Mbps link?
- Answer: $DT = \frac{N}{B} = \frac{64*8}{10*10^6} = 512 * 10^{-7} = 51.2\mu s$

Propagation Delay

- It is the amount of time required for the signal to travel from one end of the link to the other end
- It depends on the length of the link and speed of the signal on the transmission media
- $DP = \frac{L}{S}$
  - L : the length of the link (unit: meter)
  - S : the speed of the signal in the transmission media expressed in m/s
  - The speed of light in a vaccum is $3 * 10^8 m/s$.
  - The speed of electricity in a copper media is $2 * 10^8 m/s$.
- Example: What is propagation delay in $1km$ copper cable?
- Answer: $DP = \frac{L}{S} = \frac{1*10^3}{2*10^8} = 0.5 * 10^{-5} = 0.05\mu s$

Processing Delay

- It is the amount of time required by a network node to process a packet
  - It includes the time for reading control information
  - It includes the time for looking up the outgoing link
- It is usually negligible compared to other delays

Queueing Delay

- It is the amount of time spent by a packet inside the queue on the outgoing link waiting for its turn.
- It depends on the size of packets scheduled for transmission before it.
- It depends on the bandwith of the outgoing link
- Example: What is the maximum queueing delay in a $100MB$ queue of an outgoing link of $1Mbps$?
- Answer: $DQ = \frac{100*1024*1024*8}{10^6} = 838.860800s$

End-to-end Delay

- It is the total amount of time required for a packet to travel from the sender to the receiver
- It is the sum of transmission, propagation, processing, and queueing delays in each node and link on the path fromthe sender to the receiver

Transmission Modes

- Parallel Transmission
  - Many bits are sent simultaneously using many parallel communication lines
  - Data could be sent byte by byte
  - Used for short distance links
- Serial Transmission
  - Bits are sent one after other
  - One communication link is used
  - Sender and receiver need to be synchronized
  - Two approaches to resolve the problem
    - Asynchronous Transmission, Synchronous Transmission

Asynchronous Transmission

- Synchronization is assured at the character level
- Data is sent character by character (byte by byte)
- Each character is preceded by one or many bits (start bits) that indicate the start of the transmission and succeeded by one or many bits (stop bits) that indicate the end of the transmission
- Sender and receiver clocks are independents
- Synchronization is not always maintained between sender and receiver
  - Synchronization is established at the start of the exchange using Start bits and lost after the reception of the Stop bits

Asynchronous Transmission

- Advantages
  - Character corruption does not affect previous character and next character
  - Good for applications producing character at irregular intervals (keyboard)
- Drawbacks
  - Transmission success depends on the knowledge of Start bits
  - A non negligible proportion of bits are transmitted for control purposes only (3 / 11)
  - Low rate

Synchronous Transmission

- Clocks of the sender and receiver must be identical
  - Additional line to transport clock signal
  - Automatic Synchronization using coding
  - Block Synchronization
- Data is sent block by block
- Each block is preceded with one or more synchronization characters
  - SYN character (ASCII Code 22) is used

Synchronous Transmission

- Advantages
  - Good useful bits / transmitted bits ratio
  - High rate
- Drawbacks
  - One error affects a whole block
  - Generated characters are stored waiting for block construction

Transmission Media

- Characteristics
  - Fading/Attenuation
    - Function of the distance and the frequency of the signal
    - dB/km at different frequencies
  - Noise
  - Propagation
- Each transmission media has a limited frequency band
  - Maximal rate is limited by this frequency
    - Sound: 100Hz to 7kHz
    - Telephone: 300Hz to 3400Hz
    - Twisted pair: 300Hz to 3400Hz
    - Video: 4MHz

Twisted Pair

- Analog Transmission
  - Amplifier: 5km to 6km
- Digital Transmission
  - Repeater: 2km to 3km
- Limited Distance
- Bandwidth (1MHz)
- Limited rate (100MHz)
- Unshielded Twisted Pair (UTP)
  - Cat 3(16MHz), Cat 4(20MHz), Cat 5(100MHz)
- Shielded Twisted Pair (STP)

Coaxial Cable

- TV
  - Antenna
  - TV cable
- Long distance telephone transmission
  - 10 000 simultaneous calls
- Local Area Networks
- Base band Cable (50 ohms)
  - Digital Transmission
  - Repeater: 1km
  - 1 to 2Gbit/s (1km)
- Broadband Cable (75 ohms)
  - Analog Transmission
  - Amplifiers: some kms
  - 300 to 450MHz (100 km)

Fiber Optics

- Mono-mode Fiber
- Multi-mode Fiber
- Use of light impulsions (no electrical signals)
- Huge capacity
  - Hundreds of Gbit/s
- Small size
- Low attenuation
- Electromagnetic isolation
- Repeater
  - 10s km