**A**gent and **O**bject **T**echnology **Lab**
Dipartimento di Ingegneria dell’Informazione
Università degli Studi di Parma

# Computer Network

# **Data Transmission**

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# Transmission of Information

- Well-understood basics
- From physics
  - Energy
  - Electromagnetic wave propagation
- From mathematics
  - Coding theory

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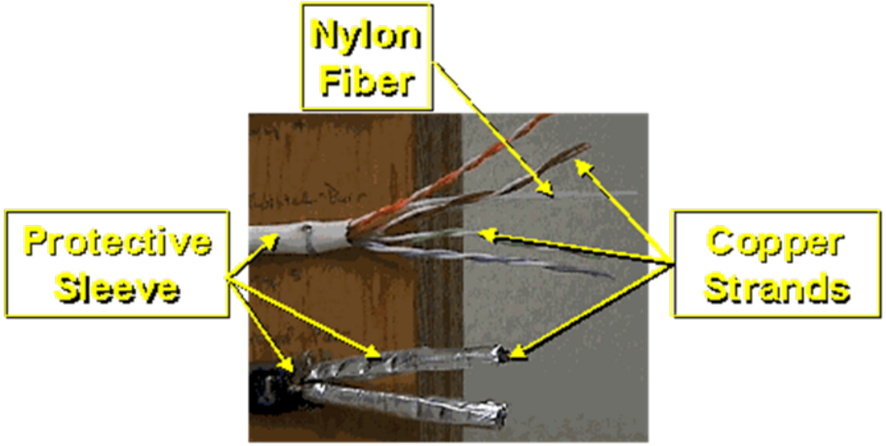
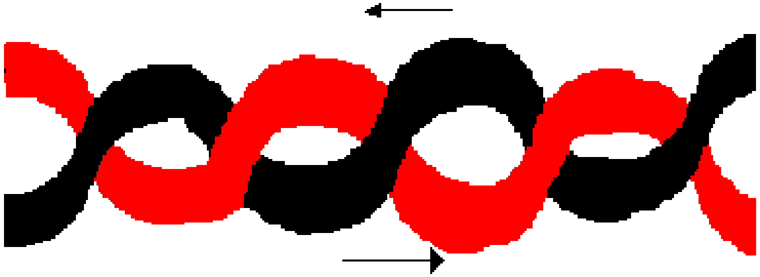
# Kinds of Energy used for Transmission

- Electric current
  - Copper wire
- Light
  - Optical fiber
- Omni-directional electromagnetic waves
  - Radio Frequency
- Directional electromagnetic waves
  - Point-to-point satellite channel
  - Microwave
  - Laser beam
  - Infrared

# Twisted Pair

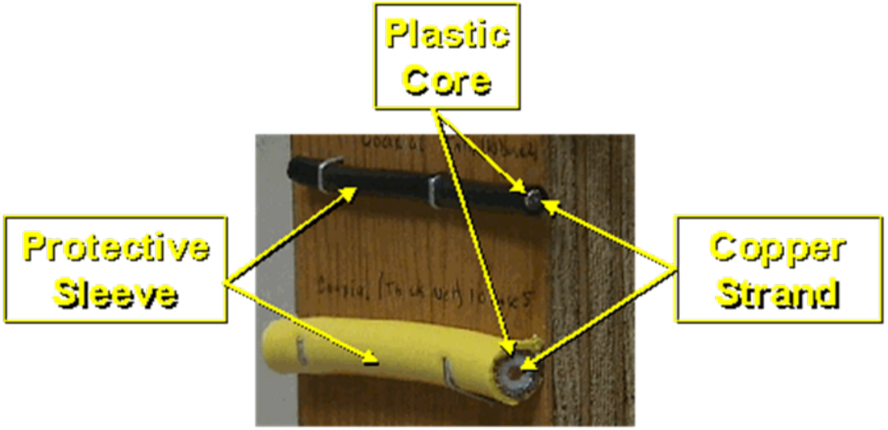
- Used to carry voice as well as data communications
- Consists of two insulated copper wires arranged in a regular spiral pattern to minimize the electromagnetic interference between adjacent pairs
- Two main versions
  - Unshielded Twisted Pair (UTP)
  - Shielded Twisted Pair (STP)

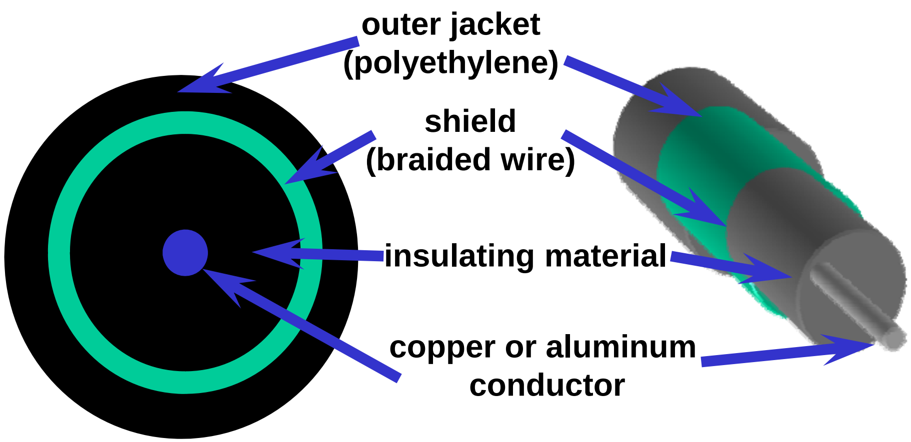


# Coaxial Cable

- Used for cable television, LANs, telephony
  - An inner conductor surrounded by a braided mesh
  - Both conductors share a common center axial, hence the term "co-axial"
- Two versions that vary in diameter and resistance
  - Baseband (50-ohm)
  - Broadband (75-ohm)



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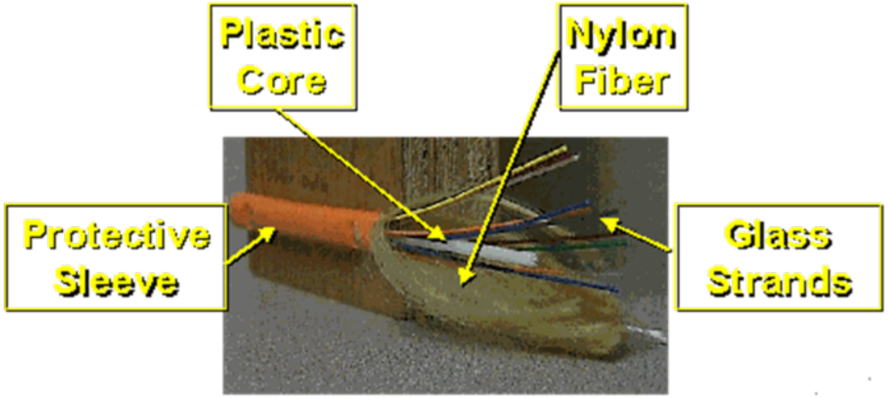
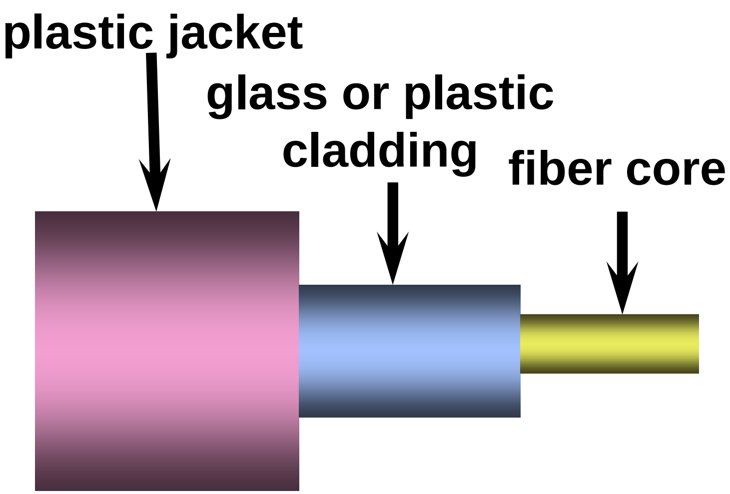
# Twisted Pair Vs. Co-axial Cable

- Twisted pair is more inexpensive and readily available
- Twisted pair is more flexible and has a lighter weight
- Twisted pair is easier to work with and install
- Co-axial cable has a higher bandwidth
- Co-axial cable is much less susceptible to interference than twisted pair

# Optical Fiber

- Thin glass fiber carries light with encoded data
  - Light emitting diode (LED) or laser injects light pulses into fiber
  - Light sensitive receiver (transistor) at other end translates light back into data
- Plastic jacket allows fiber to bend without breaking



# Multi-mode Vs. Single-mode

- A mode is a defined path in which light travels
  - A light signal can propagate through the core of the optical fiber on a single path (**single-mode fiber**) or on many paths (**multi-mode fiber**)
  - The mode in which light travels depends on properties of the fiber, and the wavelength of the light
- Multi-mode fiber
  - Different rays of light bounce along the fiber at different angles
  - Different parts of the signal arrive at different times at the destination
- Single-mode fiber
  - Transmits a single beam of light through the cable
  - The light reflects in only one pattern

# Multi-mode Vs. Single-mode

- Single-mode fiber has the advantage of high information-carrying capacity, low attenuation and low fiber cost
  - Allows faster transmission and longer distances
- Multi-mode has the advantage of low connection and electronics cost that may lead to lower system cost

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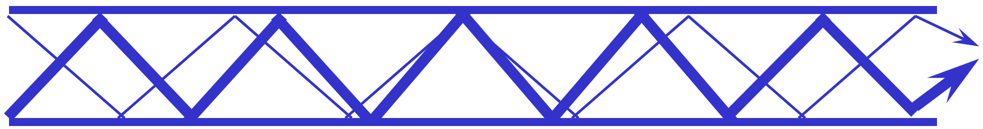
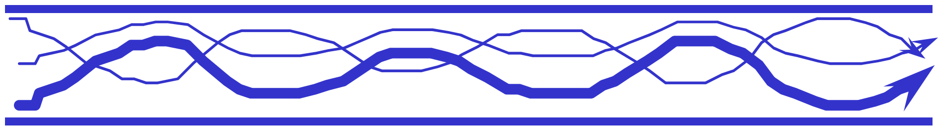
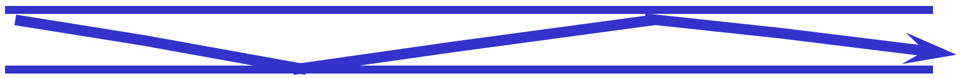
# Multi-mode Vs. Single-mode



**fiber optic multi-mode step-index**



**fiber optic multi-mode graded-index**



**fiber optic single-mode**

# Optical Fibers Vs. Wires

- Fiber optics has several advantages
  - Fiber optic cables have a much **greater bandwidth** than metal cables. This means that they can carry more data
  - Fiber optic cables are **less susceptible** than metal cables to **interference**
  - Fiber optic cables are much **thinner and lighter** than metal wires
  - **Data** can be **transmitted digitally** (the natural form for computer data) rather than analogically
- The main disadvantage of fiber optics
  - Fiber cables are **more expensive** to install
  - Fiber cables are **more fragile** than wire and are difficult to split

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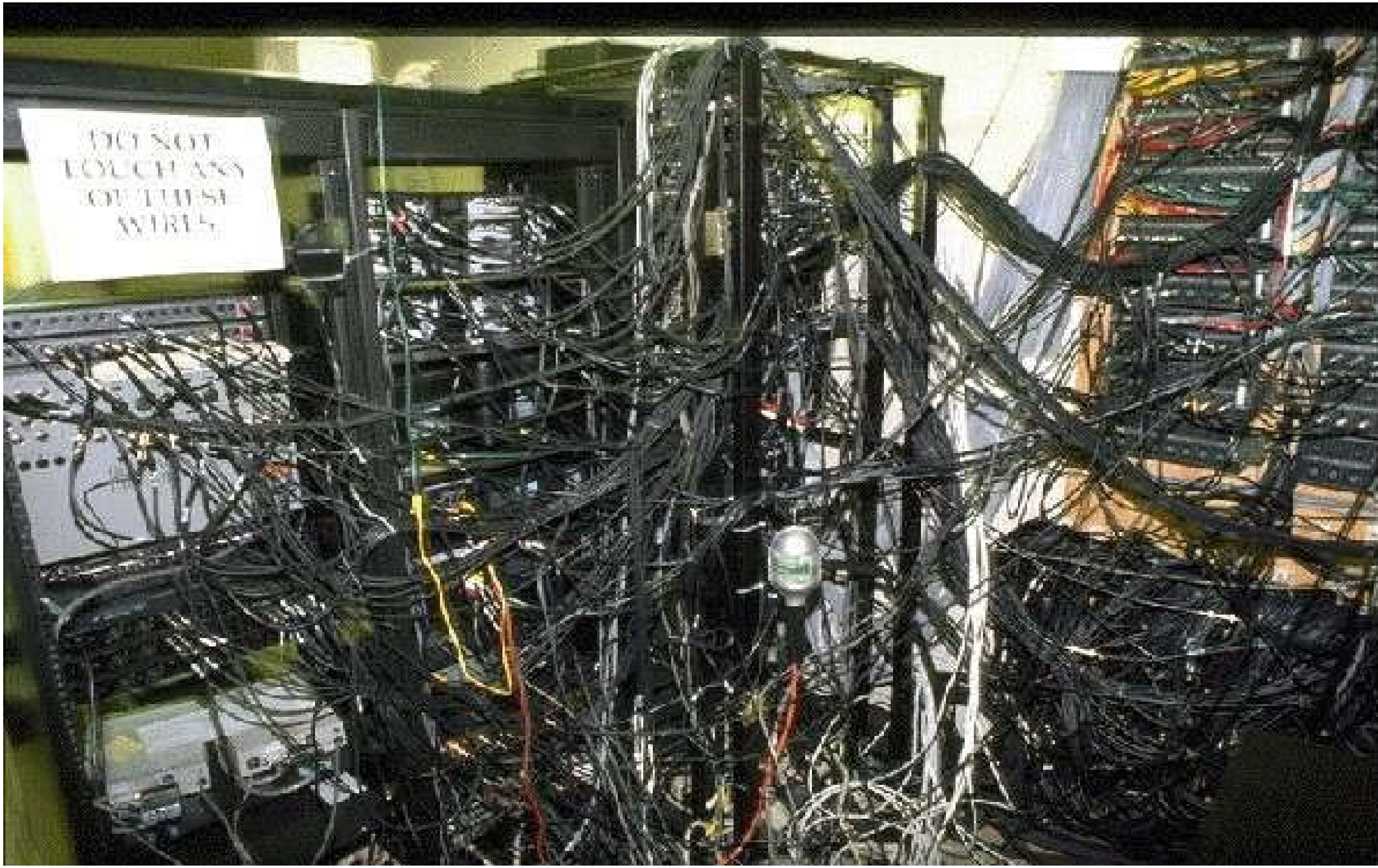
# Wireless

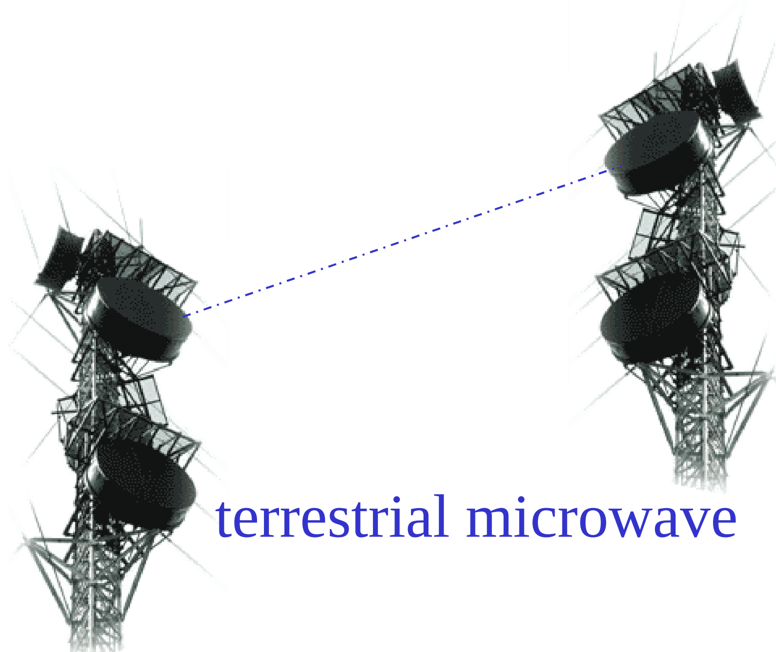


# Wireless

- Conceptually similar to radio, TV, cellular phones
- Data transmitted using electromagnetic waves
  - Can travel through walls and through an entire building
- Transmission and reception are achieved by means of an antenna
  - Directional
    - Transmitting antenna puts out focused beam
    - Transmitter and receiver must be aligned
  - Omni-directional
    - Signal spreads out in all directions
    - Can be received by many antennas
- Transmission can be long distance or short distance
  - Long distance with satellite relay
  - Short distance with wireless computer network

# Wireless


satellite microwave


terrestrial microwave


broadcast radio


infrared

# Radio Waves

- Electromagnetic radio waves can be used to transmit computer data to facilitate wireless networking
- Each computer on the network attaches to an antenna which transmits and receives RF signals
- Advantages of radio waves
  - Can travel long distances
  - Pass through obstacles well at low frequencies
- Disadvantages:
  - Subject to interference from motors and other electrical equipment
  - Absorbed by rain

# Microwave

- Transmission is aimed in a single direction to prevent others from intercepting the signal
  - Stations are placed ~30 km apart
- Carries more information than low-frequency RF transmission
- Microwaves cannot penetrate metal structures
  - Stations must be visible to each other
- Many long-distance telephone companies use microwave as their transmission medium

# Infrared

- Uses transmitters/receivers (transceivers) that modulate non-coherent infrared light
- Transceivers must be within line of sight of each other (directly or via reflection )
  - Infrared does not penetrate walls
- Infrared transmission uses low frequency light waves to carry data through the air
- Its main limits
  - Limited to a small area (e.g., a single room)
  - Requires line-of-sight
  - Cannot be used outdoors

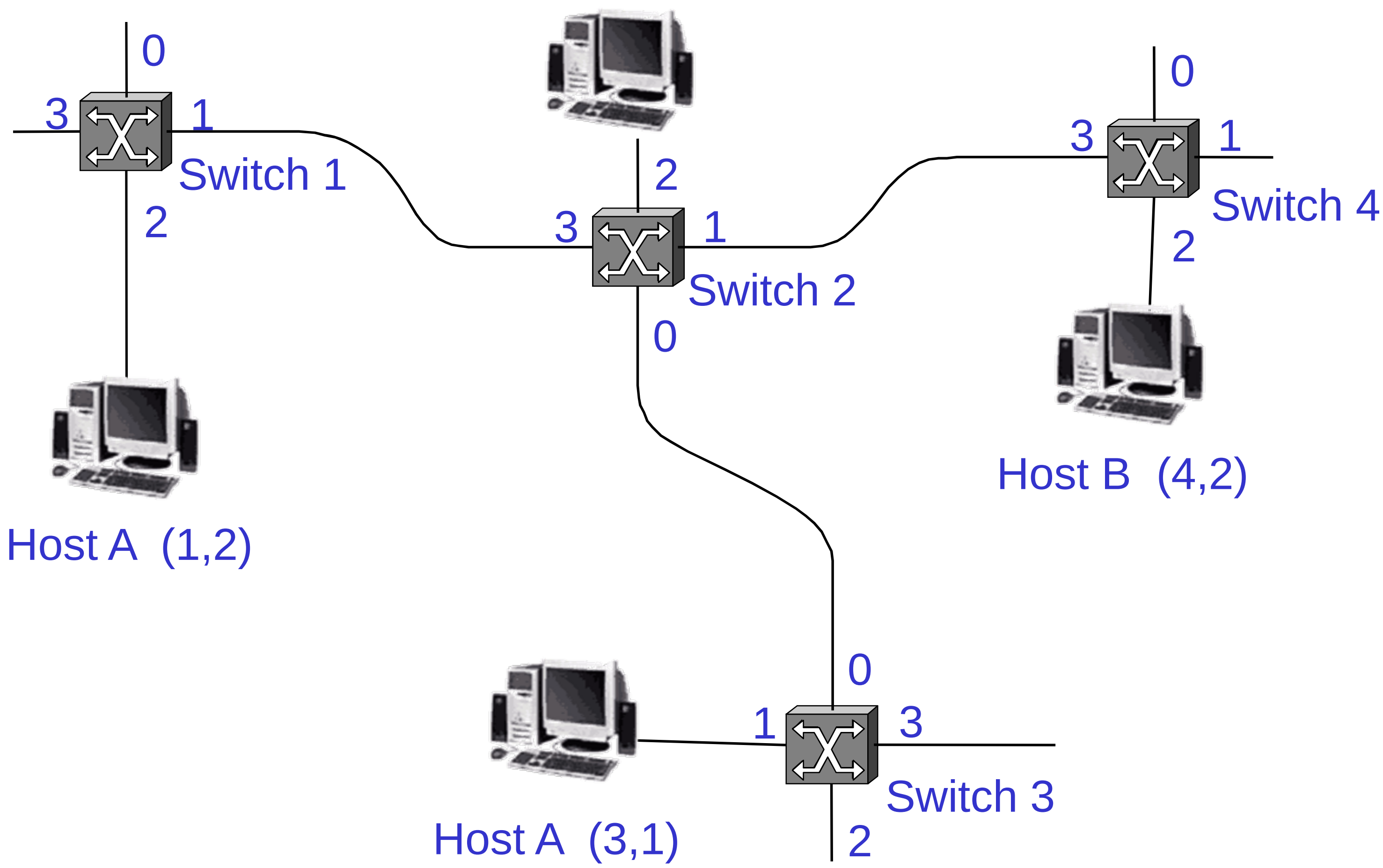
# Transmission Physical Limits

- Propagation delay
  - Time required for signal to travel across media (speed is always less than $3 \cdot 10^8$ m/s)
- Bandwidth
  - Maximum times per second the signal can change

# Transmission Measures

- Delay
  - Amount of time required for a bit of data to travel from one end to the other of the communication media
- Throughput
  - Number of bits per second that can be transmitted. This value includes all bits transmitted (data, control, and so on), even retransmitted bits
  - The **effective** throughput is the number of data bits transmitted within a given time period

# Transmission Measures



- Delay
  - The amount of time required for a bit of data to travel through the network
    - Propagation
    - Switching
    - Queuing delay

$$D = D_0 / (1 - U)$$

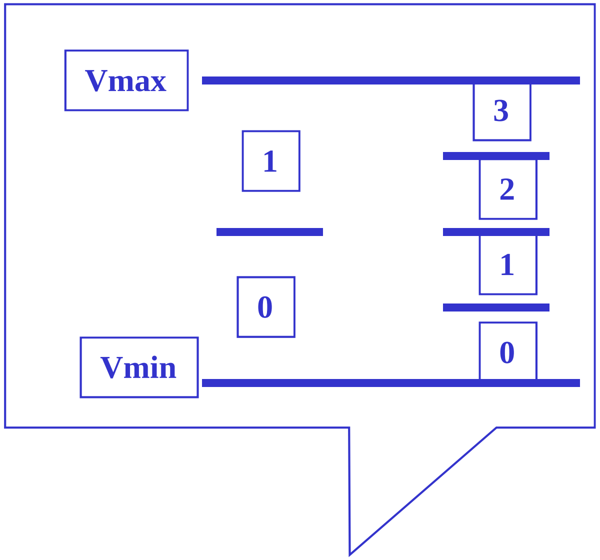
Where

- $U$ = utilization i.e., ratio of throughput to capacity
- $D_0$ = propagation and switching delay

# Nyquist's Theorem

- The Nyquist's theorem establishes a connection between the throughput and the bandwidth

$$D = 2B \cdot \log_2 K$$




Where

- D is maximum data rate
- B is bandwidth
- K is the number of values used to encode data

- The Shannon's theorem gives the correct data rate limit for real systems (with noise)

$$C = B \cdot \log_2(1 + S/N)$$

Where

- C is the effective channel capacity in bits per second
- B is bandwidth
- S is the average power (signal)
- N is the noise

# Example: Phone Cable

- $B = 3100$ Hz

$$10 \log_{10} S/N = 30$$
$$\log_{10} S/N = 3$$
$$S/N = 10^3 = 1000$$

- $S/N = 30$ dB $= 1000$

- $C = 3100 \log_2 (1+1000) = 30894$ bps

# Transmission of Data

- Network hardware encodes information for transmission
- Two types of encoding
  - Analog
  - Digital
- Computer networks use the second type

# The World Was Once Analog

- Many familiar devices use analog technology
  - Early telephone systems
  - AM or FM radio
  - Stereo
  - Television
  - ...
- Analog is simple, but inaccurate
  - Analog device always distorts the input and adds noise
- Sending an analog signal across a wire
  - Modulation
  - Signal loss - amplifiers

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# The Digital Revolution

- The revolution began when engineers devised ways to combine transistors in an integrated circuit
- Information, including audio and video, can be encoded in digital form
  - Inside a computer, all information is represented by numbers
  - Internet provides digital communication
  - Digital recording, television, …
- Advantages are:
  - The signal is exact
  - Signals can be checked for errors
  - Noise/interference are easily filtered out
  - A variety of services can be offered over one line
  - Higher bandwidth is possible with data compression

# Digital Encoding

- The signal-encoding rule will determine what form an electrical signal will take to represent a 1 or a 0
  - Dozens of rule sets have been proposed. Each has its advantages and disadvantages
  - In the simplest encoding scheme, a particular voltage level represents one value and a different (or zero) voltage represents a different value

# Digital Encoding

- The digital encoding technique should consider at least the following aspects
  - Small bandwidth in order to allow many signals to be transmitted on a given communication channel
  - Low DC level as signals with high one are attenuated more and we would like to transmit the signal to large distances
  - As many changes in the voltage in order to allow synchronization between the transmitter and the receiver without the addition of extra information, but by using the voltage level changes to achieve this goal

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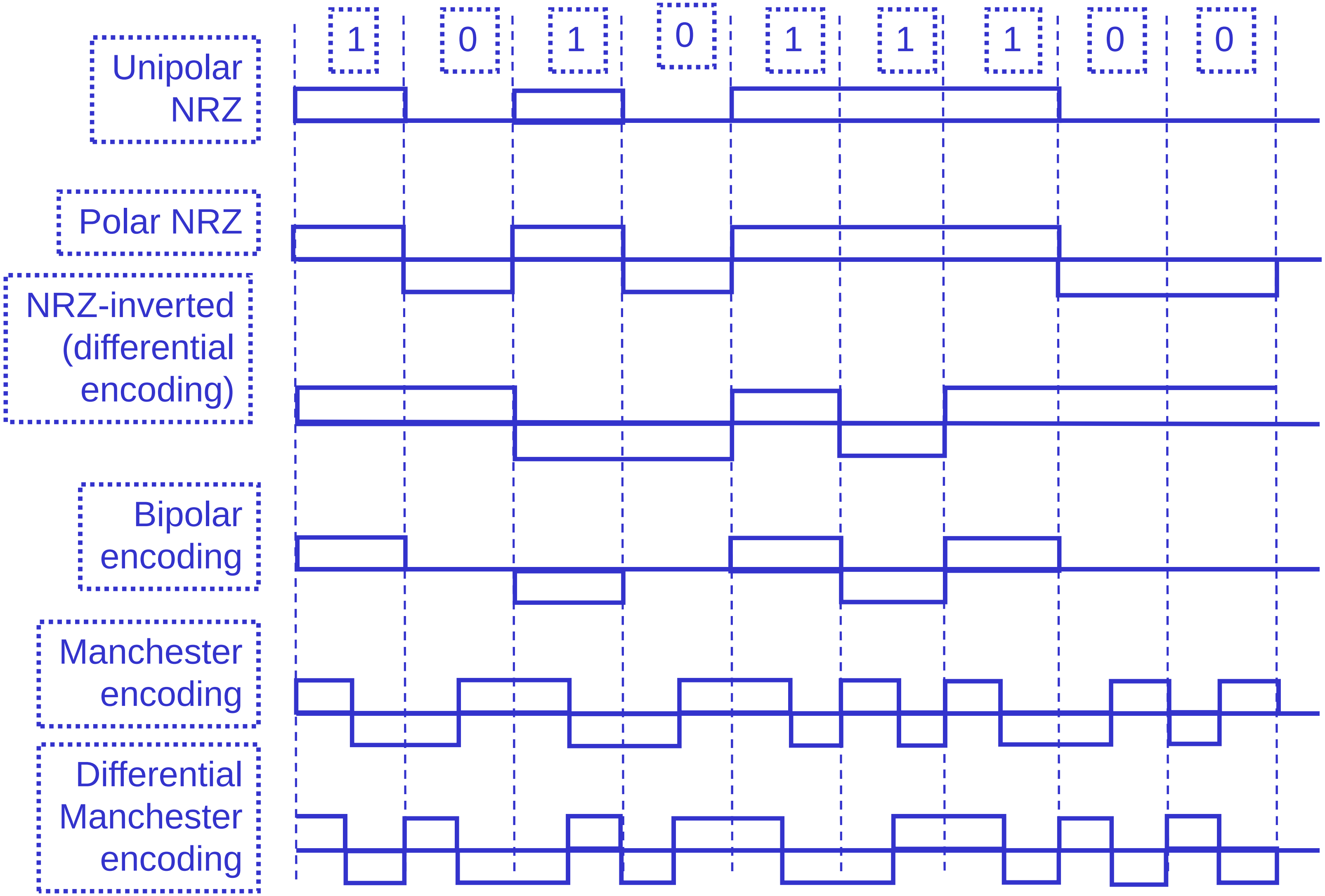
# Digital Encoding Methods

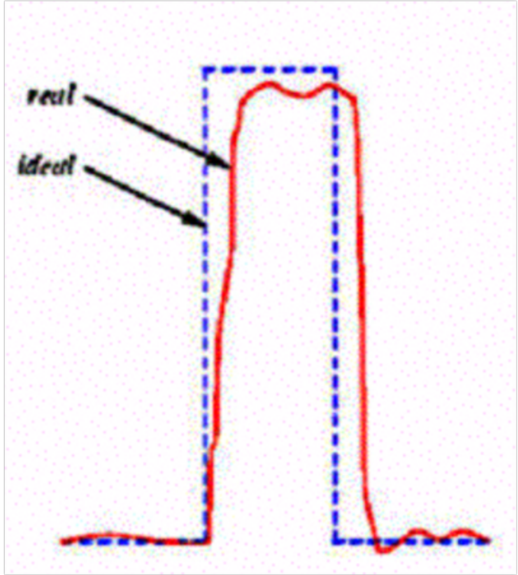
| Method | Format |
|---|---|
| Unipolar NRZ | 1 = positive voltage (+V)<br>0 = 0 voltage |
| Polar NRZ | 1 = positive voltage (+V/2)<br>0 = negative voltage (-V/2) |
| NRZ- inverted (differential coding) | 1 = enforcing a transition<br>0 = no transition |
| Bipolar encoding | 1 = alternating polarity from pulse to pulse<br>0 = no pulse |
| Manchester encoding | 1 = transition from high to low in middle of an interval<br>0 = transition from low to high in middle of an interval |
| Differential Manchester encoding | 1 = no transition at the beginning of an interval<br>0 = transition at the beginning of an interval<br>Always a transition in middle of an interval |

# Digital Encoding Examples



# Cable Length Baud Rate Limit

- Electric energy dissipates as it travels along
- Wires have resistance, capacitance, and inductance which distort signals
- Magnetic or electrical interference distort signals
- Distortion can result in loss or misinterpretation



# Distortion Components

- Attenuation
  - Depends on the transmission medium
  - Attenuation is an increasing function of frequency
- Delay distortion
  - Propagation velocity varies with frequency
- Noise
  - Depends on the transmission medium and on the external environment

# Noise

- Thermal
  - Due to thermal agitation of electrons
  - Uniformly distributed (white noise)
- Intermodulation
  - Signals that are the sum and difference of original frequencies sharing a medium
- Crosstalk
  - A signal from one line is picked up by another
- Impulse
  - Irregular pulses or spikes (external electromagnetic interference)
  - Short duration
  - High amplitude

# Error Handling

- Data can be corrupted during transmission
  - Bits lost
  - Bit values changed
- Frame includes additional information (one or more bits) to detect/correct errors
  - Set by sender
  - Checked by receiver
- Statistical guarantee

# Error Handling

- The number (R) of incorrect bits that can be detected

$$R = H - 1$$

Where

  - H is the Hamming distance, i.e., the minimum number of bits that two codes differ

- The number (C) of incorrect bits that can be recovered

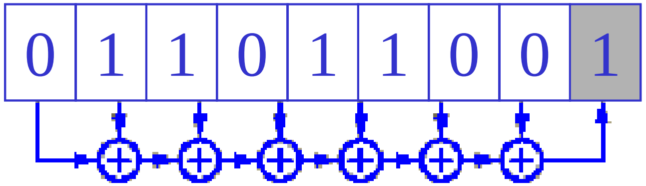
$$C \leq (H - 1) / 2$$

# An Example

| | Code’ (H = 1) | Code’’ (H = 2) | Code’’’ (H = 3) |
|---|---|---|---|
| A | 01 | 001 | 10001 |
| B | 10 | 010 | 00010 |
| C | 11 | 111 | 11100 |

# Error Detection and Recovery: Parity bit

- One additional bit per character
- Two forms
  - Even parity
  - Odd parity




- Cannot handle error that changes two bits

# Error Detection and Recovery: Checksum

- Treat data as sequence of integers
- Compute and send arithmetic sum
- Handle multiple bit errors
- Cannot handle all errors

$$
\begin{array}{r}
00001 \\
00010 \\
00011 \\
00001 \\
\hline
00111
\end{array}
$$

# What is the Problem?

| Byte | Checksum | Byte | Checksum |
|---|---|---|---|
| 00001 | 1 | 00011 | 3 |
| 00010 | 2 | 00000 | 0 |
| 00011 | 3 | 00001 | 1 |
| 00001 | 1 | 00011 | 3 |
| 00111 | 7 | 00111 | 7 |

# Error Detection and Recovery: Cyclic Redundancy Check

- Mathematical function building a M + R bits frame whose value is exactly divisible by a fixed number P (R bits)

$$M|R \,/\, P = 0$$

- More complex to compute, however it can be computed by a circuit consisting of exclusive-or and shift gates

- Handles more errors

# An Example

- M = 1010001101
- P = 110101
- R = M|00000 % P = 01110
- M|R = 1010001101|01110

# Why Use Analog Transmission?

- Already in place
- Significantly less expensive
- Fully sufficient for transmission of voice signals
- Lower attenuation rates

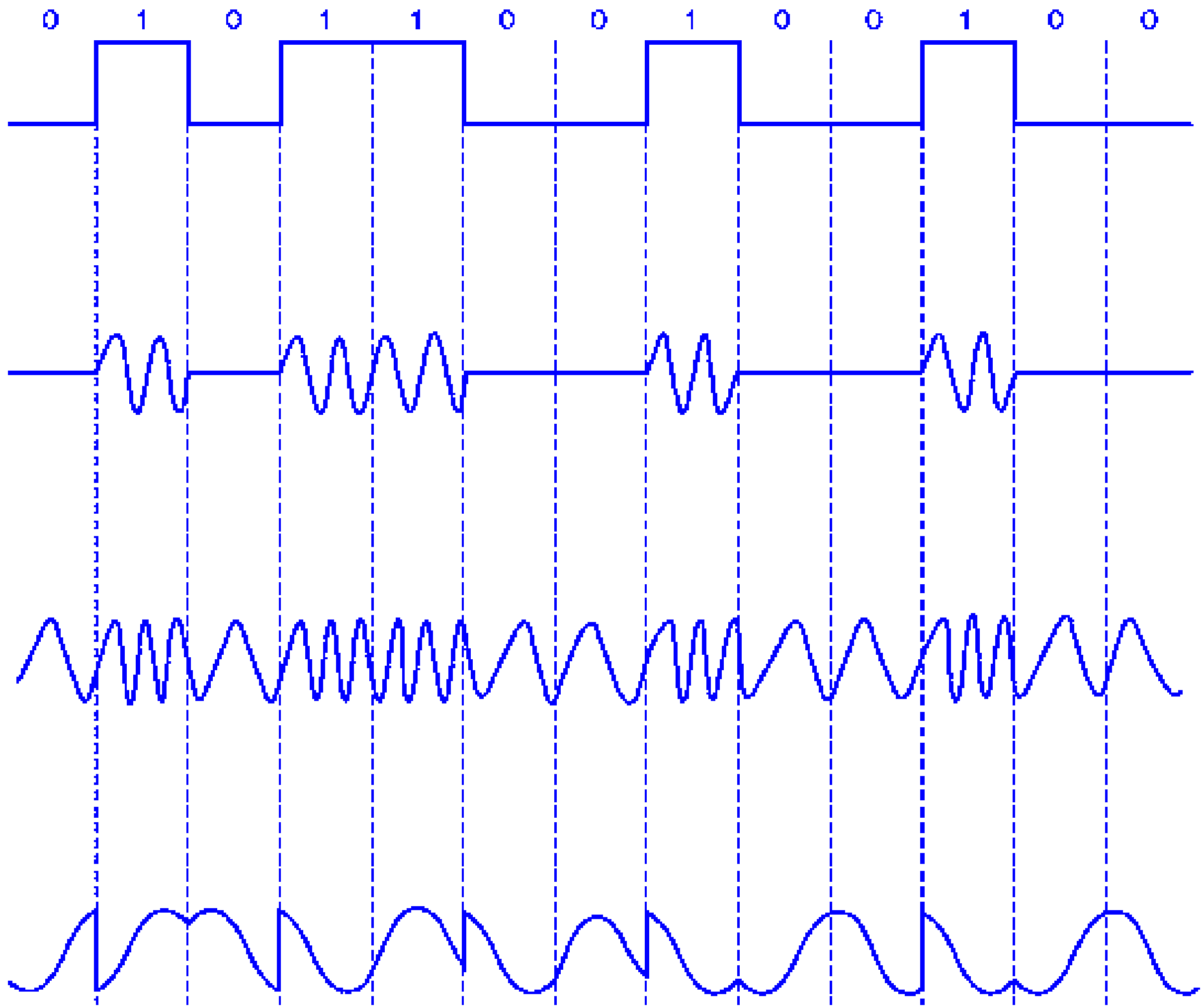
# Long Distance Transmission

- An oscillating signal travel farther than direct current
- For long distance communication
  - Send a sine (carrier) wave
  - Change (modulate) the carrier to encode data
    - Amplitude modulation (AM radio)
    - Frequency modulation (FM radio)
    - Phase shift modulation (data)

# Modulation

- Amplitude Modulation (AM)
  - Strength of signal encodes 0 or 1
  - One cycle of wave needed for each bit
  - Data rate limited by carrier bandwidth
- Frequency Modulation (FM)
  - Frequency of signal encodes 0 or 1
  - More resistant to noise than AM
  - Less attractive because it requires more analog bandwidth than AM
- Phase Modulation (PM)
  - Section of wave is omitted at phase shift
  - Data bits determine size of omitted section
  - Change of phase encoded K bit
  - Data rate higher than carrier bandwidth

# Modulation



# Modem

- Hardware device used for long distance communication that
  - Modulates an analog carrier signal to encode digital information
  - Demodulates such a carrier signal to decode the transmitted information
- The goal of a modem is to produce a signal that can be
  - Transmitted easily
  - Decoded to reproduce the original digital data

# Modem

- A modem is based on two circuits
  - For modulating an outgoing signal (modulator)
  - For demodulating an incoming signal (demodulator)
- Two modems are use between a couple of computer connected through an analog line:
  - Use a constant-frequency signal known as a carrier signal
  - Sender converts a series of binary voltage pulses into an analog signal by modulating the carrier signal
  - Receiver translates the analog signal back into digital data

# Types of Modem

- Conventional
  - Use four wires and transmit modulated electrical wave
- Optical
  - Use glass fibers and transmit modulated light
- Wireless
  - Use air/space and transmit modulated radio frequency wave
- Dialup
  - Use voice telephone system and transmit modulated audio tone

# Types of Modem

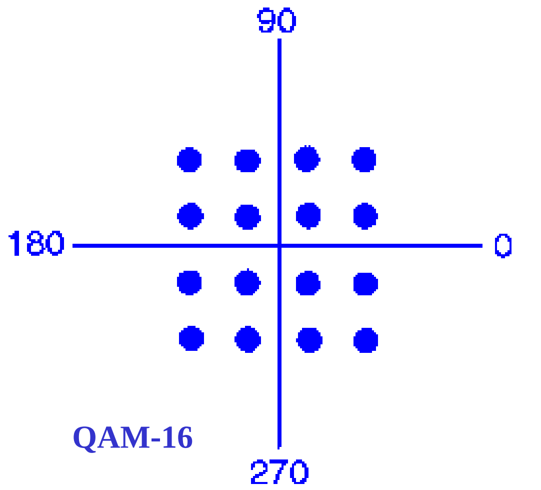
- Full-duplex modem
  - Two way communication
  - Simultaneous transmission
  - Four wires
- Half-duplex modem
  - Two way communication
  - No simultaneous transmission
  - Two wires

# V.34 Modem Standard

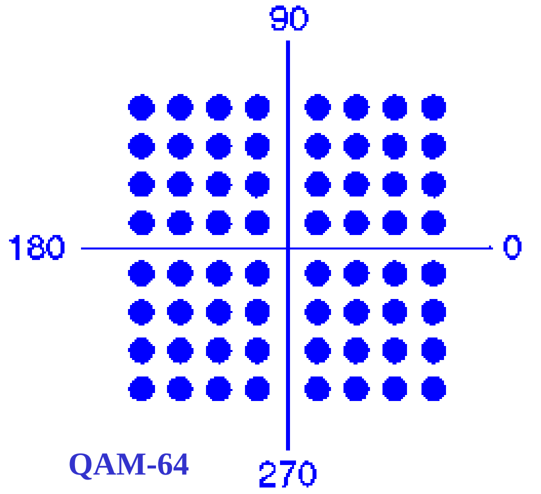
- Traditional modem standards assume that both ends of a modem session have an analog connection to the public switched telephone network
- Data signals are converted from digital to analog and back again, limiting transmission speeds to 33.6Kbps with current V.34 modems
- Analog modems use two methods of transferring data: Phase Modulation (PM) and Amplitude Modulation (AM) and their combination: Quadrature Amplitude Modulation (QAM)

# Quadrature Amplitude Modulation

- With QAM we can transmitted in both the phase shift of PM and in the signal magnitude of AM at the same time
  - The graphical representation of QAM is called a constellation
  - The following constellations show what it would look like for 4-bits and 6-bits of information per point
  - Each point can also be called a symbol



QAM-16



QAM-64

## Was Shannon Wrong?

- The maximum data transfer rate considering the least amount of realistic noise on the telephone lines is 35Kbps according to Shannon’s theory
- But current modem technology (modem V.90 – V92) exceed this limit (56Kbps)
- Today's telephone network is increasingly digital

# Was Shannon Wrong?

- Digital lines still have noise, and are still subject to Shannon's limit, but they have less noise and a higher ceiling
- Several companies have created techniques that take advantage of the digital portion of the phone network to achieve higher speeds than were possible with a purely analog pathway
- These new techniques treat the phone system as a mostly digital network that just happens to have an analog portion
- By eliminating one of the analog-to-digital conversions in the downstream path, modems can reach speeds up to 56Kbps

# Was Shannon Wrong?