Outline: Computer Networks

- Sending data between two computers
- Sending data among many computers
- Network Protocols
  - software for networks
- Real-life networks
  - LANs
  - WANs
  - Internetworking
  - The Internet

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Today's Lecture: Point-to-Point Networks

- Hardware
  - signals
  - channels
  - comm processors
  - connection media
- Software
  - point-to-point network protocols

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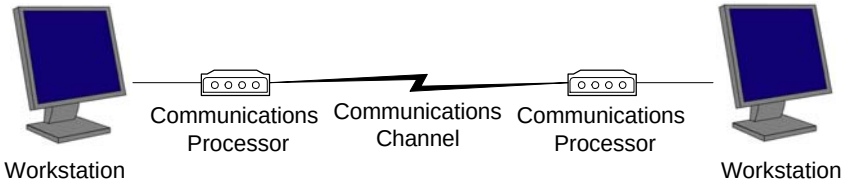
A simple point-to-point network



- processors convert data into signals
- signals are transported through channels
- channels utilize one or more connection media

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Data: Analog vs. Digital

- Analog data
  - can take on any value within a continuous range
  - Examples:
    - human voice
    - Boston's temperature
- Digital data
  - can take on only a finite set of discrete values
  - Examples:
    - data stored in binary computers
    - the US standard sizes of clothes

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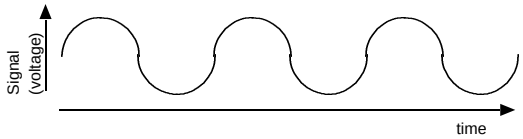
Analog transmission: Waves

- Frequency (pitch)
  - How many times per second the waveform repeats
- Amplitude (volume)
  - The maximum height
- Phase
  - How far from the beginning of the cycle (as a fraction of 360 degrees)



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Digital transmission: Pulses

- Every pulse transmits one bit of information
- Amplitude
  - is either low or high
- Frequency
  - how many pulses per second

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Four possibilities

- Analog data to analog transmission
  - simple (e.g. microphone, videocamera)
- Analog data to digital transmission
  - First convert to digital data
  - codecs
- Digital data to analog transmission
  - modems
- Digital data to digital transmission
  - simple (e.g. serial port)

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Why consider digital transmission?

- Both waves and pulses are difficult to transmit over long distances
  - laws of physics cause distortions over copper wire
- However…
  - It is easier to reconstruct a distorted pulse
    - We simply need to decide whether it is a 0 or a 1
  - Than it is a distorted wave…
    - Distortions are usually re-amplified and stay with it

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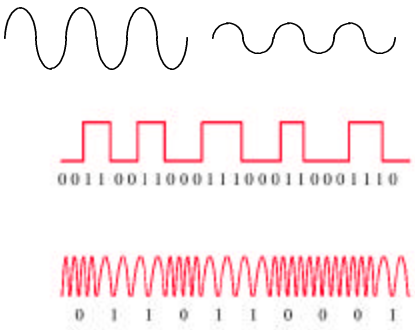
Digital data <--> analog transmission: Modems

- Digital data <--> analog signals
- Amplitude modulation
  - Higher amplitude is 1
  - Lower amplitude is 0
- Frequency modulation
  - Higher frequency is 1
  - Lower frequency is 0



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Analog data <--> digital transmission: Codecs

- Sample the waveform to determine height
- Nyquist formula
  - # of samples per second = double max. frequency of signal
- Human voice coding
  - Maximum frequency is 4000Hz (except for opera singers)
  - Sample at 8000Hz
  - Encode each sample with k bits
    - PCM (telephones): k= 8
    - Compact Disc: k = 16
- How much hard disk space to record a one minute voice mail message?

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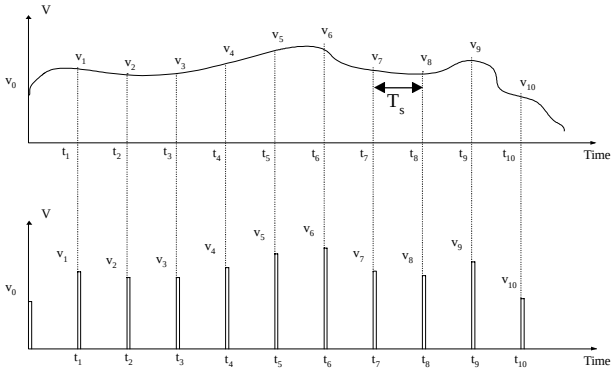
Sampling of an analog signal



T_s: sampling period

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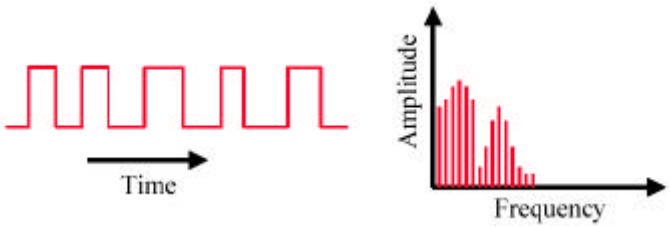
Understanding the concept of Bandwidth: Frequency vs. time domain

- Any signal can be viewed as a sum of sine waves of different strengths and frequencies
- Each signal has an equivalent representation in the frequency domain
  - What frequencies are present and what is their strength



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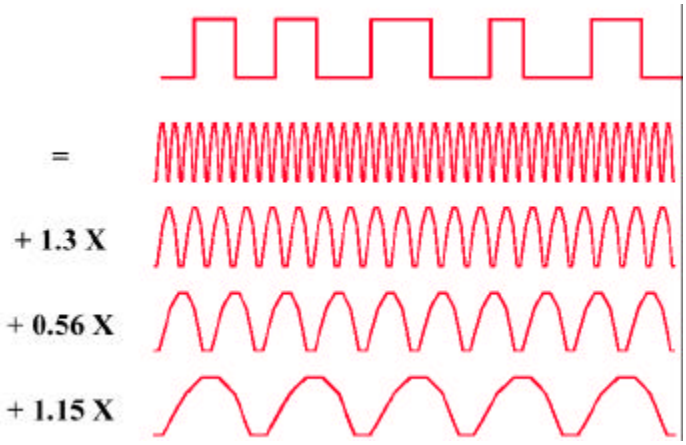
Signal = Sum of waves



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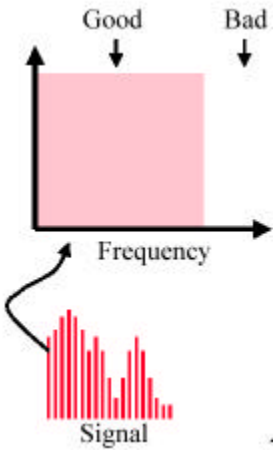
Channel Bandwidth

- Range of frequencies that can pass through the channel
- Depends on the properties of the medium
- Only signals whose frequency-spectrum fits within that range can be transmitted without distortion



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Bandwidth: A new colloquial term for the 21st century

- In "everyday" speak, bandwidth refers to maximum data transmission rate
- How the two connect:
  - Faster transmission rates require pulses that change faster between 0 and 1
  - Such pulses are "decomposed" into sine waves of a wider frequency range
  - And thus require channels that can fit more frequencies in order to be transmitted

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Capacity Estimation: Connecting the signal and data domains

- Carrier Bandwidth W
- Signal/Noise ratio S/N
- Shannon's formula
  - max data rate (bps) = $W \log_2\left(1+\frac{S}{N}\right)$
- For voice grade phone line
  - W = 4000Hz
  - S/N ratio is approx. 1000
  - max. data rate = $4000 \times \log_2(1001) = 4000 \times 10 = 40 Kbps$
  - Current modem speeds are starting to approach this data rate!
  - Data compression can create an effective data rate that's higher

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Multiplexing

- Allow the use of a single channel for multiple signals
- Somehow divide the channel bandwidth among the signals
  - Frequency Division Multiplexing
  - Time Division Multiplexing

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Frequency Division Multiplexing (FDMA)

- Divide the available frequencies into channels
  - Soprano, alto, tenor, bass
- Send different data streams on each channel
  - Can "modulate" a signal to another frequency range
    - Must have same size range of frequencies as original signal
  - Example: human voice in 40-4000Khz range
    - Modulate it to the 20,400-24,400 range
  - Basic idea: play a 33RPM record at 78RPM
    - But modulation is a little more complicated than that

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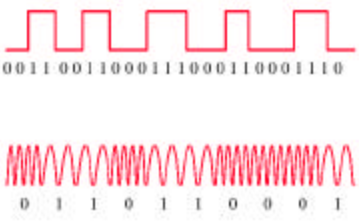
Frequency modulation: example



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Frequency Division Multiplexing (FDMA) (Cont'd)

- Create filters that "listen" to just one channel each
  - When you "tune" a radio, it locks into the channel (band of frequencies) for a particular station
  - Telephone company can put several phone calls on the same wire connecting central offices, and remove individual phone calls on the other end
  - This is not the source of "cross-talk" you sometimes hear!
    - Why not?

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Time Division Multiplexing (TDMA)

- Time slice among the data streams
- Each data stream uses whole bandwidth during its time slice
- Usually used for digital signals
  - Becoming common even for phone calls
    - Analog signal from your home to central office
    - Converted to digital
    - Send digitally between central offices, using TDMA
    - Converted back to analog
    - Analog signal from other central office to other home

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Connection Media

- Twisted pair copper cables
  - 300BPS - 10MBPS
  - Why twisted?
- Coaxial cable
  - Higher bandwidth, up to 200MBPS
  - More expensive and difficult to wire
- Fiber optic cables
  - 10GBPS and higher data rates possible

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Connection Media (Cont'd)

- **Wireless**
  - Broadcast signals through the air
    - up to 100MBPS (~ like coaxial cable)
    - Scarce resource; use regulated by FCC
    - Can easily add another wire, but can't easily add more wireless capacity

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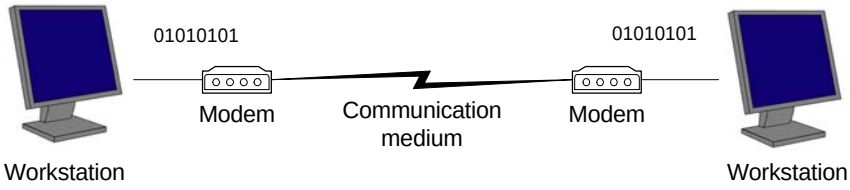
Example 1: Digital data -- analog transmission



- **Modem converts data to signal suitable for communication medium**
- **For example:**
  - audio signal for telephone network (high/low pitched sounds represent 1s and 0s resp.)
  - light waves for fiber optic network (pulses of different amplitude/color represent 1s and 0s resp.)

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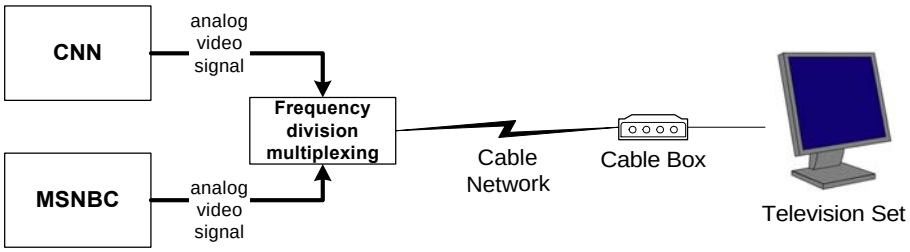
Example 2:
Analog data -- analog transmission

Cable TV network



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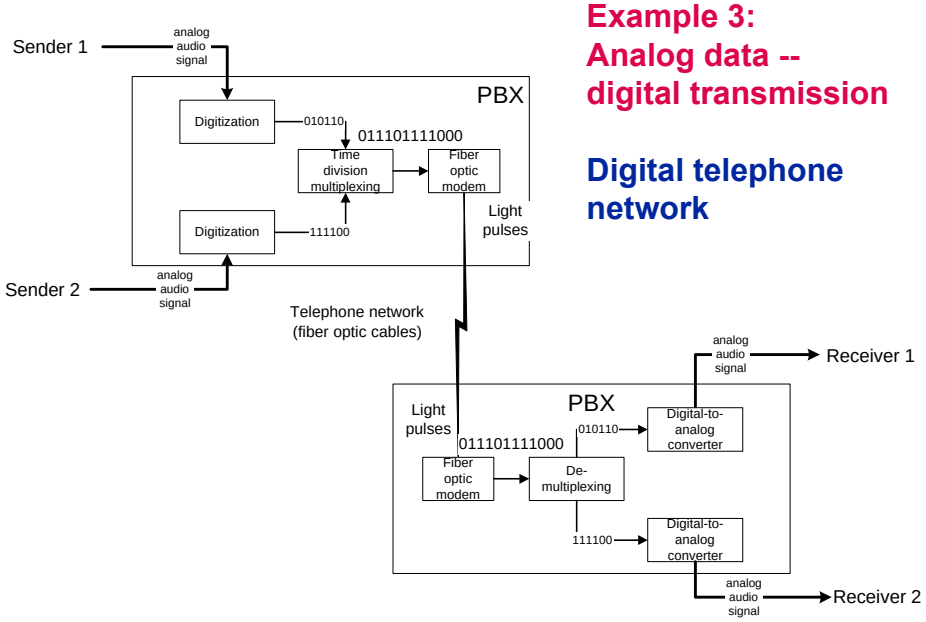
Example 3:
Analog data -- digital transmission

Digital telephone network



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Understanding DSL

- Copper wires have bandwidth much higher than what is needed to carry telephone-quality voice
- Telephone companies explicitly limit that bandwidth using TDM
- DSL is a technology that simply utilizes the full bandwidth of a copper wire to send data
- Capacity: 1.5 – 8 Mbps downstream and 1- 1.5 Mbps upstream

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DSL (continued)

- *Advantage:* can use existing phone lines
- *Limitations:*
  - a home must be close to a switching node (3.5 – 5.5 km), hence, not available for many customers;
  - top speeds only on short lines
  - unreliability
  - limited interoperability of the DSL equipment
  - certain limitations on the density of users (determined by the limitation on the number of twisted pairs in a cable)

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Cable Networks

- Historically designed to distribute one-way analog video signals
  - Tree-&-branch structure: coaxial backbone, feeder lines
  - Individual subscriber drops, similar to LANs
  - Operated over 350MHz spectrum, carrying 50 analog video channels at 6MHz
- To create 2-way architecture:
  - Upgrade one-way amplifiers to 2-way amplifiers
  - Upgrade coax backbone to fiber optic cables
  - Result: upper frequency limit increased to 550 or 750MHz
  - Shared architecture: each distribution node serves 2000 customers
  - Further segmentation to improve performance: 200-500 per node

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Cable Modems

- Data travels on coaxial cable in the CATV frequency spectrum (used for video channels).
- Data carried on 2 channels: up- and downstream
- Capacity:
  - downstream: up to 30 Mbps (more realistic 1-3 Mbps)
  - upstream: up to 10 Mbps (more realistic 0.5-2.5 Mbps)

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Cable Modems (cont.)

- ***Advantages***:
  - uses existing coaxial cables
  - high bandwidth: up to 30 Mbps in theory
- ***Limitations***:
  - shared bandwidth: individual data rate drops with the number of users;
  - poor security (because of sharing)
  - slow development and adoption of industry standards (DOCSIS)

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Network Protocols

- Rules of behavior
  - What, when, and how should A send messages to B and vice versa?
- Behaviors that a protocol governs
  - Access initiation
  - Flow control
  - Acknowledgment handling
  - Failure handling
  - Error handling

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Node to Node Communication

- Called the "Link Layer"
- Assume some communication medium
  - A wire
  - Radio waves
- Assume some way of sending bits through medium
  - Represent bits as signals, as above
- The communication is unreliable
  - The message may not get through (failure)
  - The message may be garbled (error)
- Goals
  - Get data from A to B
  - Know whether it got there intact

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Access Initiation

- Asynchronous (no clock)
  - Sender sends a start signal, then data, then a stop signal
- Synchronous
  - When the clock ticks, sender sends data
  - When the clock ticks again, sender sends next data

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Flow Control

- Half Duplex
  - Each station either sends or receives, not both
  - Can switch roles in next time period
- Full Duplex
  - Stations both send and receive simultaneously

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Acknowledgments

- Sender sends data
- Communication channel unreliable
  - Message may be lost
  - Or garbled (modified)
- How does sender know if it was received?
  - Receiver can send ACK

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Error Detection and Handling

- Error may be acceptable, but if not...
- Detection
  - Send data
  - Also send some property of the data
    - Parity: even or odd number of 1s in data?
    - Checksum: total number of 1s
  - Receiver checks that data it receives has designated property
  - To be sure, send whole message back
    - Wait for confirmation
- Recovery
  - Additional property may be enough to reconstruct
    - CRC (cyclic redundancy check)
    - Hamming codes
- Send NACK if error unrecoverable

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Failure Detection and Handling

- If NACK received
  - send the message again
- If no response received
  - Retry, or give up

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