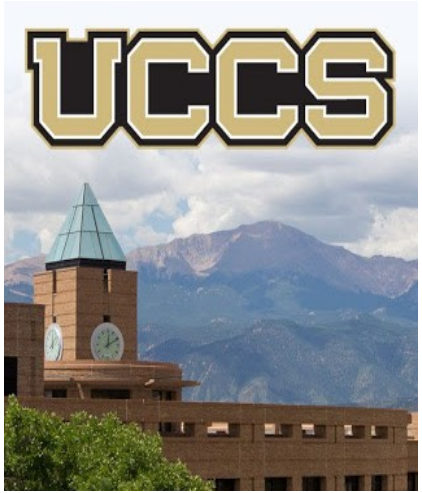
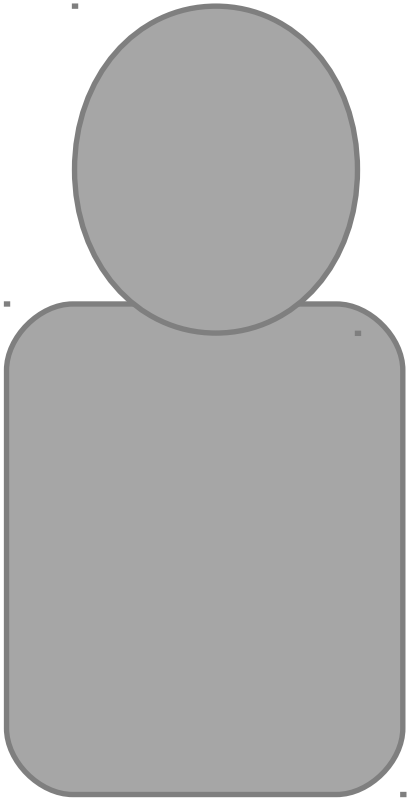


Unit 01.03.03
CS 5220:
COMPUTER COMMUNICATIONS

Digital Communication Fundamentals

XIAOBO ZHOU, Ph.D.

Professor, Department of Computer Science



Interests of Interest

- How long will it take to transmit a message?
  - How many bits are in the message (text, image)?
  - How fast does the network/system transfer information?
- Can a network/system handle a voice (video) call?
  - How many bits/second does voice/video require?
- How long will it take to transmit a message?
- What transmission speed is possible over radio, copper cables, fiber, …?

Bits, numbers, information

- Bit: number with value 0 or 1
  - *n* bits: digital representation for 0, 1, … , 2^n
  - Byte or Octet, $n = 8$
  - Computer word, $n = 16$, 32, or 64
- *n* bits allows enumeration of 2^n possibilities
  - *n*-bit field in a header
  - *n*-bit representation of a voice sample
  - Message consisting of n bits
- The number of bits required to represent a message is a measure of its information content; more bits means more content

Block vs. Stream Information

Block

- Information that occurs in a single block
  - Text message
  - Data file
  - JPEG image
- Size = Bits / block

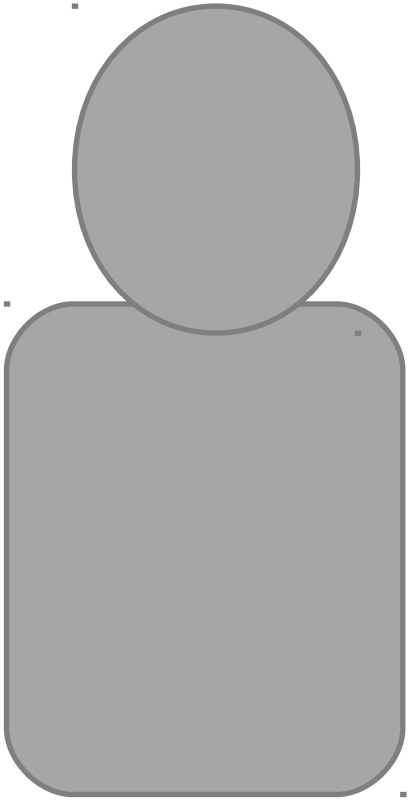
  or bytes/block
  - 1 kbyte = 2^{10} bytes
  - 1 Mbyte = 2^{20} bytes
  - 1 Gbyte = 2^{30} bytes

Stream

- Information that is produced & transmitted *continuously*
  - Real-time voice
  - Streaming video
- Bit rate = bits / second
  - 1 kbps = 10^3 bps
  - 1 Mbps = 10^6 bps
  - 1 Gbps = 10^9 bps

Delay – Propagation Delay

- The delay of communication between two nodes has two components, the propagation delay and the transmission delay
- The propagation delay $t_{prop} = d/v$
  - t_{prop} time for signal to propagate across medium
  - d distance between two nodes in meters
  - v speed of light in the transmission medium (3×10^8 m/s in vacuum)



Delay - Transmission Delay

- The transmission delay: $t_{trans} = L/R$
- Overall Delay = $t_{prop} + t_{trans} = d/v + L/R$
  - *L* number of bits in message
  - *R* bandwidth of digital transmission system in bps

Use data compression to reduce L
Use higher bandwidth modem to increase R
Place server closer to reduce d

Compression

- Information usually not represented efficiently
- Data compression algorithms
  - Represent the information using fewer bits
  - Noiseless: original information recovered exactly
    - E.g. `zip`, `compress`, GIF, fax
  - Noisy: recover information approximately
    - E.g., JPEG
    - Tradeoff: # bits vs. quality
- Compression Ratio

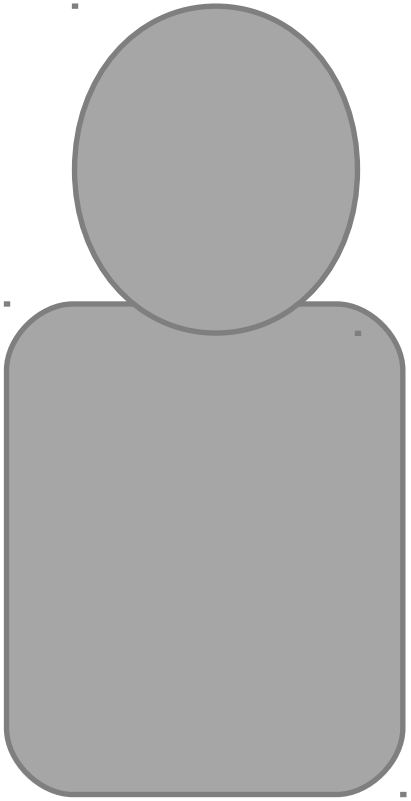
  #bits (original file) / #bits (compressed file)

Examples of Block Information

Type	Method	Format	Original	Compressed(Ratio)
Text	Zip, compress	ASCII	Kbytes-Mbytes	(2-6)
Fax	CCITT Group 3	A4 page 200x100 pixels/in^2	256 kbytes	5-54 kbytes (5-50)
Color Image	JPEG	8x10 in^2 photo 400^2 pixels/in^2	38.4 Mbytes	1-8 Mbytes (5-30)

Examples of Digital Video Signals

Type	Method	Format	Original	Compressed
Video Conference	H.261	176x144 or 352x288 pix @10-30 fr/sec	2-36 Mbps	64-1544 kbps
Full Motion	MPEG2	720x480 pix @30 fr/sec	249 Mbps	2-6 Mbps
HDTV	MPEG2	1920x1080 @30 fr/sec	1.6 Gbps	19-38 Mbps



Trans. of Stream Information

- Constant bit-rate
  - Signals such as digitized telephone voice produce a steady stream: e.g. 64 kbps
  - Network must support steady transfer of signal, e.g. 64 kbps circuit
- Variable bit-rate
  - Signals such as digitized video produce a stream that varies in bit rate, e.g. according to motion and detail in a scene
  - Network must support variable transfer rate of signal, e.g. packet switching or rate-smoothing with constant bit-rate circuit

Stream Quality-of-Service (QoS) Issues

Network Transmission Impairments

- Delay: Is information delivered in timely fashion?
- Jitter: Is information delivered in sufficiently smooth fashion?
- Loss: Is information delivered without loss? If loss occurs, is delivered signal quality acceptable?
- Applications & application layer protocols developed to deal with these impairments

A Transmission System

Transmitter

- Converts information into *signal* suitable for transmission
- Injects energy into communications medium or channel
  - Telephone converts voice into electric currenn; Modem converts bits into tones

Receiver

- Receives energy from medium
- Converts received signal into form suitable for delivery to user
  - Telephone converts current into voice; Modem converts tones into bits

Transmission Impairments

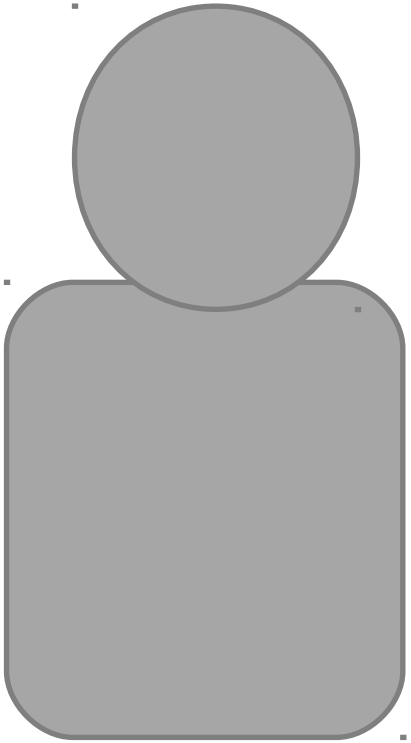
Communication Channel

- Pair of copper wires
- Coaxial cable
- Radio
- Light in optical fiber
- Infrared

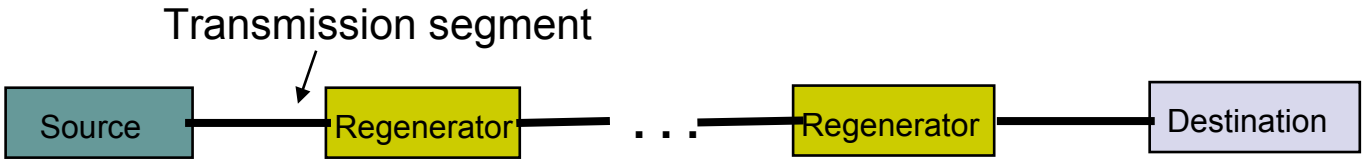
Transmission Impairments

- Signal attenuation
- Signal distortion
- Spurious noise
- Interference from other signals

Digital Long-Distance Communications

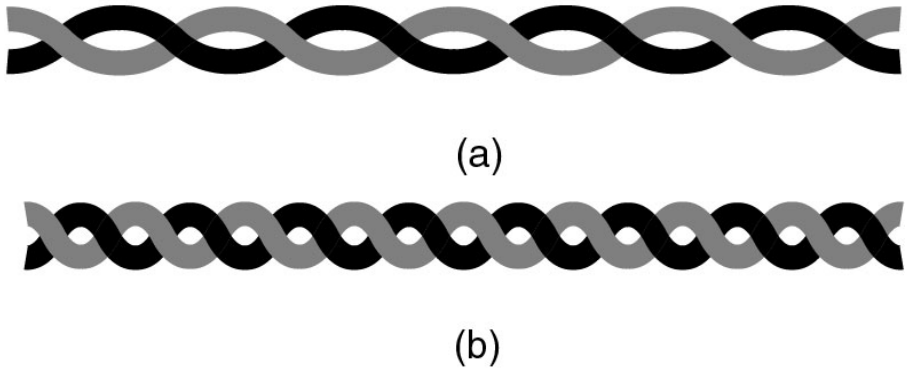


- Regenerator (repeater) recovers original data sequence and retransmits on next segment
- Each regeneration is like the first time!
- Can redesign so error probability is very small



Twisted Pair

- A twisted pair consists of two insulated copper wires, typically about 1mm thick; twisted together to reduce the susceptibility to interference.
- More twists per cm leads to less crosstalk and better quality over longer distance



(a) Category 3 UTP (16 MHz). (b) Category 5 UTP (100 MHz).

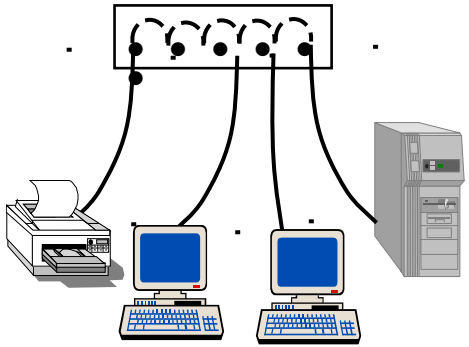
Twisted Pair Bit Rates

Data rates of 24-gauge twisted pair

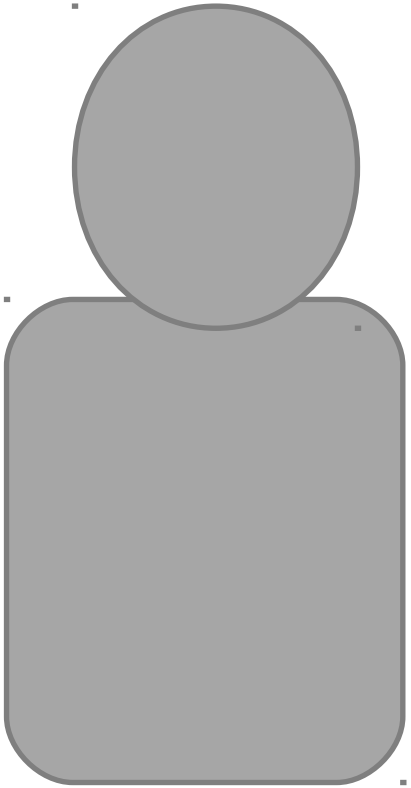
Standard	Data Rate	Distance
T-1	1.544 Mbps	18,000 feet, 5.5 km
DS2	6.312 Mbps	12,000 feet, 3.7 km
1/4 STS-1	12.960 Mbps	4500 feet, 1.4 km
1/2 STS-1	25.920 Mbps	3000 feet, 0.9 km
STS-1	51.840 Mbps	1000 feet, 300 m

- Twisted pairs can provide high bit rates at short distances
- Asymmetric Digital Subscriber Loop (ADSL)
  - High-speed Internet Access
  - Lower 3 kHz for voice
  - Upper band for data
  - 64 kbps inbound
  - 640 kbps outbound
- Much higher rates possible at shorter distances
  - Strategy for telephone companies is to bring fiber close to home & then twisted pair

Ethernet LANs

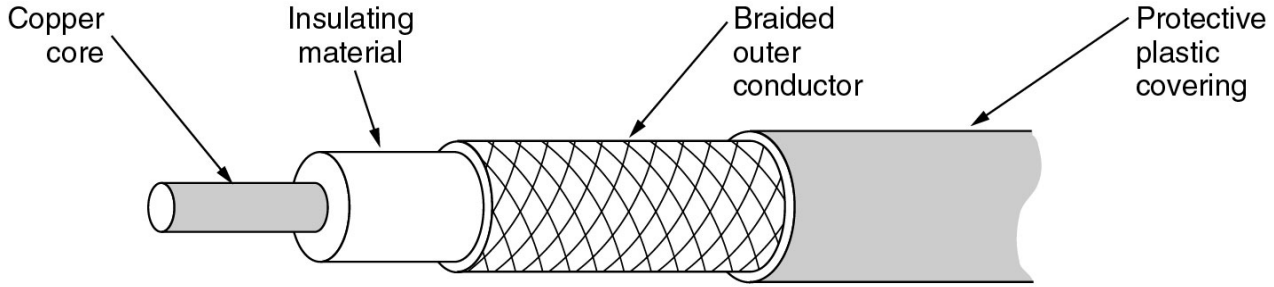


- Category 3 unshielded twisted pair (UTP): ordinary telephone wires
- Category 5 UTP: tighter twisting to improve signal quality
- Shielded twisted pair (STP): to minimize interference; costly
- 10BASE-T Ethernet
  - 10 Mbps, Baseband, Twisted pair
  - Two Cat3 pairs
  - Manchester coding, 100 meters
- 100BASE-T4 *Fast* Ethernet
  - 100 Mbps, Baseband, Twisted pair
  - Four Cat3 pairs
  - Three pairs for one direction at-a-time
  - 100/3 Mbps per pair;
  - 3B6T line code, 100 meters
- Cat5 & STP provide other options

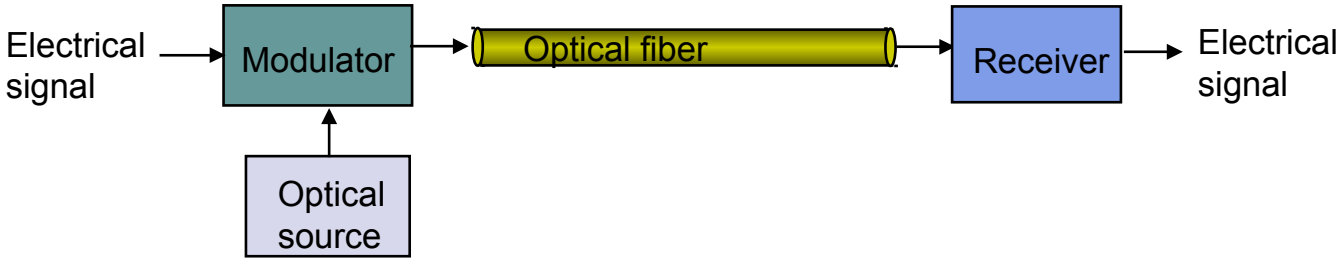


Coaxial Cable

- A good combination of high bandwidth and excellent interference immunity
  - Higher bandwidth than twisted pair
  - Cable TV distribution;
  - Long distance telephone transmission
  - Used in the original Ethernet LAN medium



Optical Fiber



- Light sources generate pulses of light that are transmitted on optical fiber
  - Very long distances (>1000 km), and very high speeds (>40 Gbps/wavelength)
  - Nearly error-free (Bit-Error-Rate of 10^{-15})
- Profound influence on network architecture
  - Dominates long distance transmission
  - Distance less of a cost factor in communications
  - Plentiful bandwidth for new services

Optical Fiber Properties

Advantages

- Very low attenuation
- Noise immunity
- Extremely high bandwidth
- Security: very difficult to tap without breaking
- No corrosion
- More compact & lighter than copper wire

Disadvantages

- New types of optical signal impairments & dispersion
  - Wavelength dependence
- Limited bend radius
  - If physical arc of cable too high, light lost or won't reflect
  - Will break
- Difficult to splice
- Mechanical vibration becomes signal noise

Bit Rates of Digital Transmission Systems

System	Bit Rate (Bandwidth)	Observations
Telephone twisted pair	33.6-56 kbps	4 kHz telephone channel
Ethernet twisted pair	10 Mbps, 100 Mbps	100 meters of unshielded twisted copper wire pair
Cable modem	500 kbps-4 Mbps	Shared CATV return channel
ADSL twisted pair	64-640 kbps in, 1.536-6.144 Mbps out	Coexists with analog telephone signal
2.4 GHz radio	2-11 Mbps	IEEE 802.11 wireless LAN
28 GHz radio	1.5-45 Mbps	5 km multipoint radio
Optical fiber	2.5-10 Gbps	1 wavelength
Optical fiber	>1600 Gbps	Many wavelengths

Summary of the Lesson

- Different digital transmission systems have various bit rate, cost, bit-error-rate, and usages.