CSIS 4222

Transmission Media
and
Error Detection

What's the most cost effective way to transmit large quantities of data?

Federal Express!

One of the most common ways of transporting information is via magnetic tape or removable media (DVD, etc.)

Magnetic Media

- Industry standard tape holds 200 GB of data (now some can hold up to 800 GB)
- A 20" × 20" × 20" box can hold 1000 tapes
  - 200 terabytes total (1600 terabits)
- Fed Ex can deliver this box anywhere in the USA in 24 hrs
- The effective bandwidth of this transmission is 1600 Tb/86400 sec = 19 Gbps
- For a destination 1 hour away it increases to over 400 Gbps!!!

"Never underestimate the bandwidth of a station wagon full of tapes hurtling down the highway."

- Andrew Tanenbaum

- 1000 tapes bought in bulk & recycled ≈ $4000
- Shipping ≈ $1000
- Total data shipped = 200 TB
- Cost < 3¢ / GB
- No network on earth can beat this!

Magnetic Media - downside?

- Batch oriented - high delay in accessing data.
- It takes minutes or hours or days to physically transport the cassettes from one location to another

Transmission Media

- Communications requires moving energy (usually light or electricity)
- *Signal:* A disturbance in a transmission medium
- *Propagation:* Movement of a signal along a transmission medium
- The speed of light is the maximum speed a signal can travel.
  - 3×10^8 m/sec in a vacuum
  - 2×10^8 m/sec in copper wire or glass

Transmission Media

Two broad classes:

– *Type of path*:
  follow an exact path, e.g. a wire
  have no specific path, e.g. radio transmission

– *Form of energy*:
  electrical energy for wires,
  radio transmission for wireless,
  light for optical fiber

Physical Media

Guided
- Copper wire (cheapest)
  - Twisted pair (such as telephone wire)
  - Coaxial cable
- Optical fiber (fastest)
  - Flexible
  - Light "stays in"

Unguided
- Air / space
  - Electromagnetic transmission

Considerations for Media

- Cost
- Ease of installation and repair
- Attenuation
- Distortion/Interference
- Security
- Ability to cross public land
- Mobility

Twisted Pair

- Two insulated copper wires twisted together in a helix to reduce interference from other pairs
- Each pair acts as a single communication link
- Multiple pairs bundled into a cable

Twisted Pair

- Carries analog signals
- Analog signals can closely approximate square waves representing bits, so we also think of them as carrying digital data
- Data transmission rate is determined by wire thickness and length

Twisted Pair

- Good, low-cost communication
- Many sites already have twisted pair installed in offices -- existing phone lines
- Unshielded twisted pair (UTP) is extensively used in LANs
- Susceptible to interference and noise
- Spans several kilometers - sharp attenuation

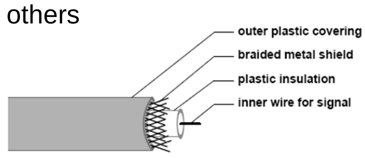
Categories of Twisted Pair Cable

Category	Description	Data Rate (in Mbps)
CAT 1	Unshielded twisted pair used for telephones	< 0.1
CAT 2	Unshielded twisted pair used for T1 data	2
CAT 3	Improved CAT2 used for computer networks	10
CAT 4	Improved CAT3 used for Token Ring networks	20
CAT 5	Unshielded twisted pair used for networks	100
CAT 5E	Extended CAT5 for more noise immunity	125
CAT 6	Unshielded twisted pair tested for 200 Mbps	200
CAT 7	Shielded twisted pair with a foil shield around the entire cable plus a shield around each twisted pair	600

Figure 7.4 Twisted pair wiring categories and a description of each.

Coax Cable

- Copper core surrounded by insulating material and a braided outer conductor for better immunity to electrical noise
- Shared medium – many end systems directly connected and receive whatever is sent by others



Coax Cable

Baseband:

- Uses only a small part of the frequency spectrum and sends only one signal at a time
- Was commonly used in LANs before twisted pair

Broadband:

- Technology used in cable television
- Transmitter shifts digital signal to a specific frequency band and sends analog signal to receivers
- Computer data shares cable with TV channels

Media Using Light Energy

- Optical fibers
- InfraRed transmission
- Point-to-point lasers

Fiber Optics

- The medium consists of a thin, flexible strand of silicon or glass
- The signal consists of pulses of light
  - a pulse of light means ‘1’
  - lack of pulse means ‘0’

Fiber Optics

Three components are required:

- Fiber medium: Current technology carries light pulses for long distances (100’s of kilometers) with virtually no signal loss
- Light source: typically a Light Emitting Diode (LED) or laser diode
- A photo diode light detector, which converts light pulses into electrical signals

Fiber Optics - Advantages

- Tremendously high data rate, almost negligible error rates
- Difficult to make unauthorized taps
- Much thinner than existing copper circuits
  - Phone companies can replace thick copper wiring with fibers having much more capacity for same volume
- Not susceptible to electrical interference
- Greater repeater distances

Fiber Uses

Telephone
- Long-haul trunks -- common in telephone networks

Internet
- The prevalent medium in the backbone of the Internet

Local area networks
- 100Mbps ring networks (expensive)

Typical Guided Media

Media	Data rate	Bandwidth	Repeater spacing
CAT 3	10 Mbps	16 MHz	2 – 10 km
CAT 5e	100 Mbps/ 1Gbps	100 MHz	2 – 10 km
Coax	500 Mbps	1 GHz	1 – 10 km
Optical fiber	10 Gbps	2 GHz	10 – 100km

Infrared (IR) Communication

- Electromagnetic radiation that falls outside the range that is visible to a human eye Like visible light, infrared disperses quickly
- IR commonly used to connect to a nearby peripheral
  - Does not pass thru solid objects

Point-to-Point Laser

A pair of devices with a beam that follows the line-of-sight
- Requires a clear, unobstructed path between the communicating sites
- The sending and receiving equipment must be aligned precisely to insure that the sender's beam hits the sensor in the receiver
- Laser technology is useful in cities to transmit from building to building

Wireless Transmission

Most common form of unguided communication uses electromagnetic energy in the Radio Frequency (RF) range Terrestrial Radio Channels:
- Easy to generate
- Travels long distances
- Penetrates buildings
- Omnidirectional
- Subject to interference from electrical equipment
- Government licensed by the FCC (in the USA)

Electromagnetic (Radio) Communication

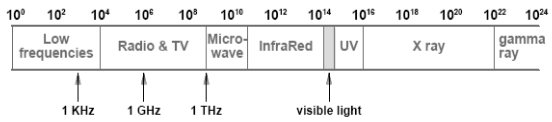


Figure 7.9 Major pieces of the electromagnetic spectrum with frequency in Hz shown on a log scale.

RF communications spans approximately 3 KHz to 300 GHz, and includes radio and television broadcast, satellite and microwave

Signal Propagation

Classification	Range	Type Of Propagation
Low Frequency	< 2 Mbps	Wave follows earth's curvature, but can be blocked by unlevel terrain
Medium Frequency	2 to 30 Mbps	Wave can reflect from layers of the atmosphere, especially the ionosphere
High Frequency	> 30 Mbps	Wave travels in a direct line, and will be blocked by obstructions

Terrestrial

Non-terrestrial

Figure 7.10 Electromagnetic wave propagation at various frequencies.

Types of Satellites

Orbit Type	Description
Low Earth Orbit (LEO)	Has the advantage of low delay, but the disadvantage that from an observer's point of view on the earth, the satellite appears to move across the sky
Medium Earth Orbit (MEO)	An elliptical (rather than circular) orbit primarily used to provide communication at the North and South Poles
Geostationary Earth Orbit (GEO)	Has the advantage that the satellite remains at a fixed position with respect to a location on the earth's surface, but the disadvantage of being farther away

Figure 7.11 The three basic categories of communication satellites.

GEO Communication Satellites

- The distance required for a geostationary orbit is 35,785 kilometers (22,236 miles)
- At the speed of light, the trip takes:

$$\frac{2 \times 35.8 \times 10^{6} \, meters}{3 \times 10^{8} \, meters/sec} = 0.238 \, sec$$

- A propagation delay of approximately 0.2 seconds can be significant for some applications

Low Earth Orbit (LEO) Satellites

- Low Earth Orbit (LEO) satellites are typically placed at altitudes of 500-600 kilometers or higher
- LEO satellites are used in clusters (array deployment) that communicate and forward messages, as needed

  For example, when a user in Europe sends a message to a user in the USA
    - A ground station in Europe transmits the message to the satellite currently above it
    - The cluster of satellites forward the message to the satellite in the cluster that is currently over a ground station in the USA
    - Finally, the satellite currently over the USA transmits the message to a ground station

Tradeoffs Among Media Types

Choice of media involves a complex evaluation of multiple factors:

- Cost: materials, installation, operation, and maintenance
- Data rate: bits per second that can be sent
- Delay: time for signal propagation or processing
- Affects on signal: attenuation and distortion
- Environment: susceptibility to interference and electrical noise
- Security: susceptibility to eavesdropping

Measuring Transmission Media

The two most important performance measures of a transmission medium:

- Propagation delay
  - time required for a signal to traverse the medium
- Channel capacity
  - maximum data rate that the medium can support

Nyquist's sampling theorem gives the relationship between bandwidth and maximum data transmission speed

$$D = 2B \log_2 K$$

where

D = maximum data rate
B = hardware bandwidth
K = number of states used to encode data

Bad News

Nyquist's Theorem specifies an absolute maximum that cannot be achieved in practice due to various types of background noise (thermal, intermodulation, impulse)

Shannon's Theorem

Gives capacity of data channels with noise:

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

where

C = the effective channel capacity in bps
B = hardware bandwidth
S = the average signal power
N = the noise power

S/N is the *signal-to-noise ratio*

Voice Grade Lines

Signal-to-noise ratio is approximately *30 dB*
($dB = 10\log_{10} S/N$, so *30 dB* has $S/N = 1000$)
Effective capacity is

$$3000 \log_2 (1 + 1000) \approx 30000 \text{ bps}$$

Conclusion: dialup modems have little hope of exceeding *28.8* Kbps

The Bottom Line

- Nyquist's theorem says finding a way to encode more bits per cycle will improve the data rate
- Shannon's theorem says that no amount of clever engineering can overcome the fundamental physical limits of a real transmission system

More Bad News

All data communications systems are susceptible to errors

- *Interference*:
  Electromagnetic radiation emitted from devices
- *Attenuation:*
  Energy dissipates with distance
- *Distortion:*
  Wires have resistance, capacitance, and inductance which distort signals
  Magnetic or electrical interference distorts signals
- Distortion can result in loss or misinterpretation of signals

Transmission Errors

Spike:
Extremely short duration interference often the cause of a single bit error

Burst errors:
Longer duration interference or distortion can produce

Erasure:
An ambiguous signal that is neither clearly 1 nor 0

Example Transmission Errors

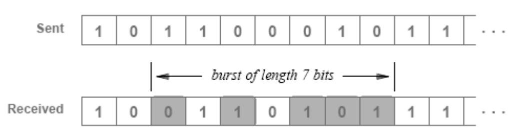


Figure 8.2 Illustration of a burst error with changed bits marked in gray.

Strategies for Handling Errors

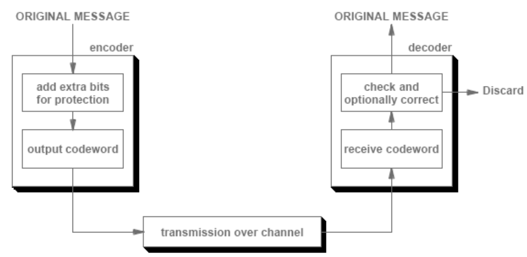


Figure 8.3 The conceptual organization of a forward error correction mechanism.

Example Block Error Code: Single Parity Checking

A type of *Forward Error* Checking

- add extra information to data that allows a receiver to detect when an error has occurred

SPC defines a block to be a single byte

- On the sending side, an encoder adds an extra bit, called a parity bit, to each byte before transmission
- A receiver uses parity bit to check whether bits in the byte are correct

Single Parity Bit

Original Data	Even Parity	Odd Parity
0 0 0 0 0 0 0 0	0	1
0 1 0 1 1 0 1 1	1	0
0 1 0 1 0 1 0 1	0	1
1 1 1 1 1 1 1 1	0	1
1 0 0 0 0 0 0 0	1	0
0 1 0 0 1 0 0 1	1	0

Figure 8.4 Data bytes and the corresponding value of a single parity bit when using even parity or odd parity.

Channel Coding Strength

No channel coding scheme is ideal

- Changing enough bits will always transform to a valid codeword

SPC is a weak form of channel coding

- can detect errors but cannot correct errors

- Even parity can only detect errors where an odd number of bits are changed
  - If a burst error occurs with two, four, six, or eight bits changed, the receiver will incorrectly classify the incoming byte as valid

Error Correction with Row and Column (RAC) Parity

Consider a 3×4 array with a parity bit added for each row and each column

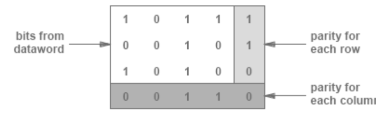
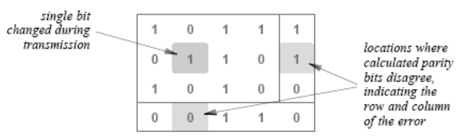


Figure 8.7 An example of row and column encoding with data bits arranged in a 3×4 array and an even parity bit added for each row and each column.

Error Correction with RAC Parity

Assume that one of the bits is changed during transmission

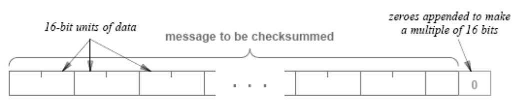
- a single bit error will cause two calculated parity bits to disagree with the parity bit received



The 16-Bit Internet Checksum

The Internet checksum treats data in a message as a series of 16-bit integers

- Algorithm allows a message to be arbitrarily long
- To compute a checksum, the sender adds the numeric values of the 16-bit integers and it transmits the result
- To validate the message, a receiver performs the same computation



Cyclic Redundancy Check (CRC)

Used in high-speed data networks

Arbitrary Length Message	As with a checksum, the size of a dataword is not fixed, which means a CRC can be applied to an arbitrary length message
Excellent Error Detection	Because the value computed depends on the sequence of bits in a message, a CRC provides excellent error detection capability
Fast Hardware Implementation	Despite its sophisticated mathematical basis, a CRC computation can be carried out extremely fast by hardware

Figure 8.10 The three key aspects of a CRC that make it important in data networking.