Computer Networks

Physical Layer

Topics

- ✦ Introduction
- ✦ Theory
- ✦ Transmission Media

Purpose of Physical Layer

- ✦ Transport bits between machines
  - – How do we send 0's and 1's across a medium?
  - – Ans: vary physical property like voltage or current
- ✦ Representing the property as a function of time
  - – analyze it mathematically
- ✦ Does the receiver see the same signal generated by the sender?
  - – Why or why not?

Theoretical Basis

- ✦ 19th century: Fourier Analysis (eq 2-1)
- ✦ Any periodic function can be represented by a series of `sines` and `cosines`
- ✦ Treat bit pattern as periodic function
  ex - `01100010`
- ✦ co-efficients to summation terms are called *harmonics*

Transmit

- ✦ Harmonics
  - – *attenuate* (weaken)
  - – *distortion* unevenly
  - – *spectrum* (cutoff)
- ✦ Time depends upon changes/second
  - – *baud*
- ✦ Signal can have more than 1 bit
  - – several volt levels

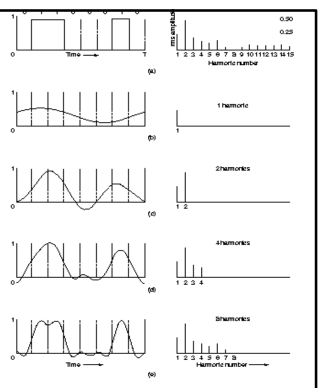

Fig. 2-1. (a) A binary signal and its root-mean-square Fourier amplitudes. (b)-(e) Successive approximations to the original signal.

Bits over Analog Phone Line

Bps	T (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

Fig. 2-2. Relation between data rate and harmonics.

Review

- How many layers are in the OSI reference model? How many in the TCP/IP reference model?
- What are the layer differences?
- What is the purpose of the Physical Layer?

Maximum Data Rate of Channel

- Nyquist's Theorem:
  max data rate = $2H\log_2 V$ bits/sec
  - H is filter bandwidth
  - V discrete levels
- example: noiseless 3000 Hz line (phone)
  - 6000 bps max, with 2 levels
- only need to sample at $2H$, to get all
- noise on channel?

Noise on Channel

- Every channel has background noise
  - *Thermal noise* from agitation of electrons in a conductor. Uniform. "White noise."
  - *Intermodulation noise* different frequencies share the same medium
  - *Crosstalk noise* results from coupling signal paths
    - Ex: Other conversation (faintly) on a telephone
  - *Impulse noise* from sharp, short-lived disturbances
    - Ex: from lightning
- Measure (or quantify) background noise?

Max Data Rate with Noise

- *signal-to-noise* ratio (S/N)
  - use $10 \log_{10}$ S/N (*decibels*, *dB*)
  - ex: S/N = 100 then 20 dB
- Shannon's theorem:
  max data rate = $H\log_2(1+S/N)$ bits/sec
  - ex: 3000 Hz, 30 dB noise (typical phone)
  - max is 30 Kbps!
- Modems use compression

Summary

- Nyquist gives upper bound on sampling
- Nyquist gives max data rate for noiseless channel
  - can always increase by increasing signal levels
- Shannon gives max data rate for channels with noise
  - independent of signal levels!

Transmission Media

- Two types:
  - Guided (a physical path)
  - Unguided (waves propagated, but not in a directed manner)

Magnetic Media

- Put files on tape, floppy disks, …
- Physically carry (“Sneaker Net”)
- Example
  - 8mm video tape holds 7gigabytes
  - box 20”x 20”x 20” holds 1000 tapes
  - 24 hour delivery via FedEx
  - = 1000 x 7GB * 8 / (24 * 3600) = 648 Gbps
  - = 1000 times faster than high-speed ATM

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

- High delay in accessing data

Twisted Pair

- Two copper wires are strung between sites
- “Twisted" to reduce interference
- Can carry analog or digital signals
- Distances of several kilometers
- Data rates of several Mbps common
  - wire thickness and length
  - shielding to eliminate noise (impacts S/N)
- Good, low-cost communication
  - existing phone lines!

Baseband Coaxial

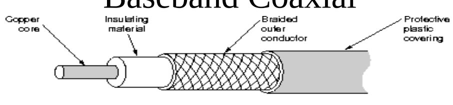

Fig. 2-3. A coaxial cable.

- Copper core, insulating material (“coax”)
- *Baseband* indicates digital transmission
  - as opposed to broadband analog
- To connect, need to touch core:
  - *vampire taps* or *T junction*
- 10 Mbps is typical

Broadband Coax

- *Broadband* means analog over coax
  - telephone folks mean wider than 4 kHz
- Typically 300 MHz, data rate 150 Mbps
- Up to 100 km (metropolitan area!)
- Inexpensive technology used in cable TV
- Divide into MHz channels
- Amplifiers to boost, data only one-way!
  - *Dual cable* systems (still, *root* must transmit)
  - *Midsplit* systems divide into two

Evaluation of Broadband vs. Baseband

- Which is better, broadband or baseband?
- Baseband:
  - simple to install
  - interfaces are inexpensive
  - short range
- Broadband:
  - more complicated
  - more expensive
  - more services (can carry audio and video)

Fiber Optics

- Hair-width silicon or glass
- Signals are pulses of light (digital)
  - Ex: pulse means “1”, no pulse means “0”
- Glass “leaks” light?

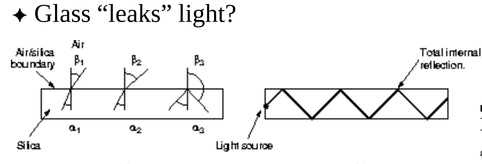

Fig. 2-5. (a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles. (b) Light trapped by total internal reflection.

Fiber Optics

- Three components required:
  - Fiber medium: 100s miles, no signal loss
  - Light source: Light Emitting Diode (LED), laser diode
    - current generates a pulse of light
  - Photo diode light detector: converts light to electrical signals

Fiber Optics

- Advantages
  - Huge data rate (1 Gbps), low error rate
  - Hard to tap (leak light), so secure (hard w/coax)
  - Thinner (per logical phone line) than coax
  - No electrical noise (lightning) or corrosion (rust)
- Disadvantages
  - Difficult to tap, really point-to-point technology
    - training or expensive tools or parts are required
  - One way channel
    - Two fibers needed for *full duplex* communication

Fiber Uses

- long-haul trunks--increasingly common in telephone network (Sprint ads)
- metropolitan trunks--without repeaters (have 8 miles in length)
- rural exchange trunks--link towns and villages
- local loops--direct from central exchange to a subscriber (business or home)
- local area networks--100Mbps ring networks

Wireless Transmission

- 1870's: moving electrons produce waves
  - *frequency* and *wavelength*
- Attach antenna to electrical circuit to send

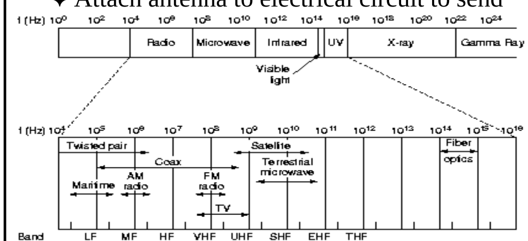

Fig. 2-11. The electromagnetic spectrum and its uses for communication.

Radio Waves

- Easy to generate, travel far, through walls
- Low bandwidth
- Restricted use by regulation

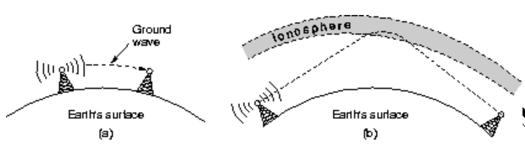

Fig. 2-12. (a) In the VLF, VF, and MF bands, radio waves follow the curvature of the earth. (b) In the HF they bounce off the ionosphere.

Microwave Transmission

- Tight beam, (dish plus transmitter)
- Blocked by walls, absorbed by water (rain)
- Need repeaters
- Inexpensive (buy land and voila! MCI)
- Used extensively: phones, TV …
  - shortage of spectrum!
- Industrial/Scientific/Medical bands
  - not govt regulated
  - cordless phones, garage doors, …

Infrared Transmission

- Short range
- Cheap
- Not through objects
- Used for remote controls (VCR …)
- Maybe indoor LANS, but not outdoors

Lightwave Transmission

- not good in rain or fog
- need very tight focus

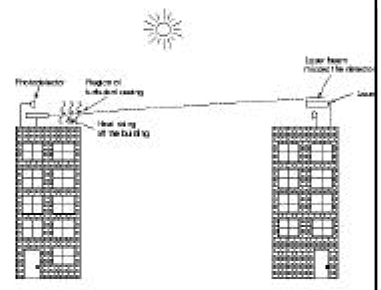

Fig. 2-13. Convection currents can interfere with laser communication systems. A bidirectional system, with two lasers, is pictured here.

Satellites

- Satellite typically in geosynchronous orbit
  - 36,000 km above earth; satellite never "moves"
  - antenna doesn't need to track
  - only about 90 are possible
- Satellite typically a repeater
- Satellite broadcasts to area of earth
- International agreements on use
- Weather effects certain frequencies
- One-way delay of 250ms !

Comparison of Satellite and Fiber

- Propagation delay very high
- One of few alternatives to phone companies for long distances
- Uses broadcast technology over a wide area
  - everyone on earth could receive a message!
- Easy to place unauthorized taps into signal
- Fiber tough to building, but anyone with a roof can lease a satellite channel.

Analog vs. Digital Transmission

- Compare at three levels:
  - Data--continuous (audio) vs. discrete (text)
  - Signaling--continuously varying electromagnetic wave vs. sequence of voltage pulses.
  - Transmission--transmit without regard to signal content vs. being concerned with signal content. Difference in how attenuation is handled.

Shift towards digital transmission

- improving digital technology
- data integrity.
- easier to multiplex
- easy to apply encryption to digital data
- better integration :voice, video and digital data.

Analog Transmission

- Phone System
  - see fig 2-15
  - Local phones are connected to a central office over a 2-wire circuit, called local-loop
  - Today analog signal is transmitted in local-loop

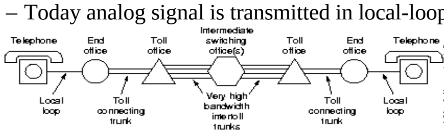

Fig. 2-15. Typical circuit route for a medium-distance call.

Digital Data/Analog Signals

- Must convert digital data to analog signal before be transmitted
- Modem(Modulator & Demodulator) (Fig 2-17)

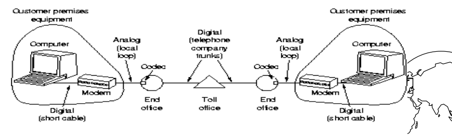

Fig. 2-17. The use of both analog and digital transmission for a computer to computer call. Conversion is done by the modems and codecs.

Modulation Modes

- amplitude-shift
- frequency-shift
- phase-shift modulation
  - shift by 45, 135, 225, 315 degree(2 bits/interval).

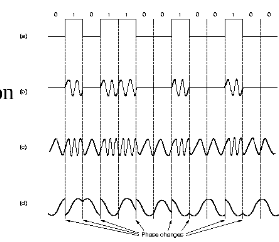

Fig. 2-18. (a) A binary signal. (b) Amplitude modulation. (c) Frequency modulation. (d) Phase modulation.

An example of modulation

- 30 degree phase shifts
- eight of frequencies have one amplitude
- four of frequencies have two amplitudes
- Result: 8 + 4 * 2 = 16 values = 4 bits
- When 2400 baud : 2400*4=9600bps

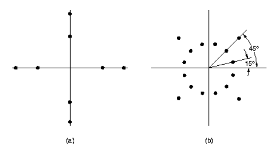

Fig. 2-19. (a) 3 bits/baud modulation. (b) 4 bits/baud modulation.

Analog Data/Analog Signals

- Can actually transmit analog data in a similar manner with amplitude-, phase- and frequency-modulated waves.
- Frequency-division multiplexing can be used.

A physical layer example

- RS-232-C
  - Pins, signals, and protocols for the interaction between DTE and DCE.
  - DTE:Data Terminal Equipment, computers or terminals
  - DCE:Data Circuit Terminating Equipment, modems
  - Specifies a 25-pin DB-25 connector

Digital Transmission

- Analog circuits require amplifiers, and each amplifier adds distortion and noise to the signal.
- Digital amplifiers regenerate an exact signal
- Integrate all traffic

Clock synchronization

- With digital transmission, one problem that continually arises is clock synchronization.
- Possibilities:
  - use a separate channel to transmit timing info.
  - include timing information in the data signal
    - Manchester encoding

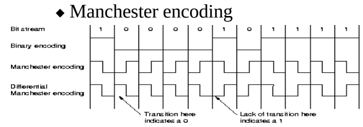

Fig. 4-20. (a) Binary encoding. (b) Manchester encoding. (c) Differential Manchester encoding.

Analog Data/Digital Signals

- Although most local loops are analog, end offices increasingly use digital circuits for inter-trunk lines. A codec (coder/decoder) is a device that converts an analog signal into a digital signal.
- To convert analog signals to digital signals, many systems use Pulse Code Modulation (PCM)

Multiplexing

- Problem: Given a channel of large capacity, how does one subdivide the channel into smaller logical channels for individual users? Multiplex many conversations over same channel.
- Three flavors of solution:
  1.Frequency division multiplexing (FDM)
  2.Time division multiplexing (TDM)
  3.Statistical multiplexing

Frequency division multiplexing

- Divide the frequency spectrum into smaller subchannels, giving each user exclusive use of a subchannel (e.g., radio and TV).
- Problem?
  A user is given all of the frequency to use, and if the user has no data to send, bandwidth is wasted -- it cannot be used by another user.

FDM in Telephone System (Fig 2-24)

- Phone system limits the bandwidth per voice grade lines to 3kHz(4KHz is allocated to each channel,500 Hz of guard bandwidth on each end of the spectrum)
- One common organization of channels:
  1.Bundle 12 voice grade lines into a unit called a group.(A group carries signals in the 60-108 kHz spectrum.)
  2.Combine 5 groups into supergroup.
  3.Combine 5 supergroups into amastergroup

Time division multiplexing

- Use time slicing to give each user the full bandwidth, but for only a fraction of a second at a time (analogous to time sharing in operating systems).
- Problem?
  if the user doesn't have data to sent during his time slice, the bandwidth is not used (e.g., wasted).

Pulse Code Modulation

- Why modulation?
  TDM can be handled entirely in digital electronics. But it can only be used for digital data.
- PCM
  1.PCM samples the 4kHz signal 8,000 times per second. (Nyquist theorem)
  2.Each sample measures the amplitude of the signal, converting it into an n-digit integer value.
  3.The digital channel carries these n-digit encodings.

T1 carrier(fig 2-26)

- Multiplexes 24 voice channels over one digital channel.
- Sample 24 analog inputs in round-robin.
- Each encoding consists of 7 bits of sampled data, plus 1 bit of signaling information.
- Each subchannel carries (7 bits X 8000 samples) = 56kbps of data, plus 8000 bps of signaling info(a digital data rate of 64kbps).
- Sample are 193 bit units.
  193=24 X 8 +1 (extra bit of information carries synchronization information)

Nyquist's Theorem

- Nyquist proved:
  If an arbitrary signal has been run through a low-pass filter of bandwidth H,the filtered signal can be completely reconstructed by making only 2H samples per second.
- Sampling the 4kHz bandwidth signal at 2H = 8 thousand times per second.

Statistical multiplexing

- Allocate bandwidth to arriving packets on demand.
- Advantage:
  leads to the most efficient use of channel bandwidth because it only carries useful data. Channel bandwidth is allocated to packets that are waiting for transmission, and a user generating no packets doesn't use any of the channel resources.

Switching

- Circuit Switching
  Used in current telephone system
- Message Switching
- Packet Switching
  Used in the next generation telephone system--broadband ISDN system

Circuit Switching

(Fig2-35)

- 1.Once a call has been completed, the user sees a set of virtual wires between communicating endpoints.
- 2.The user sends a continuous stream of data, which the channel guarantees to deliver at a known rate.
- 3.Data transmission handled elegantly using TDM or FDM.
- 4.Call setup required before any data can be sent.
- 5.Call termination required when parties complete call.

Message Switching

- No physical copper path is established in advance between communicating endpoint.
- Entire message stored at each node. Each message is received in its entirety,inspected for errors and then forwarded.
- A network using this technique is called a store-and-forward network.

Packet Switching

- Data is sent in individual messages (packets).
- Each message is forwarded from switch to switch, eventually reaching its destination.
- Each switch has a small amount of buffer space to temporarily hold messages. If an outgoing line is busy, the packet is queued until the line becomes available.

Packet vs Circuit

No set up time	Set up time
Better channel utilization	May have quiet periods
Less deterministic quality of service	Known delay or capacity characteristics.
Billing is difficult	Easy to bill for a connection

Specifics Not Mentioned

- ISDN
- Broadband ISDN / ATM
- Cellular Phones, pagers