Course on

Computer networks

Physical layer

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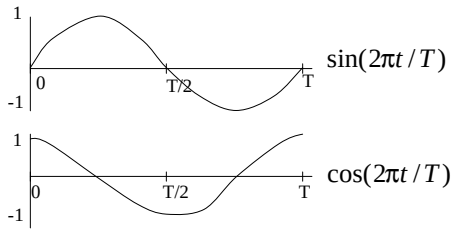
Physical Layer : Overview

1. Theory of data communication
2. Transmission media
3. Wireless transmission
4. Telephone system
5. Narrow band ISDN
6. Broadband ISDN and ATM
7. Cellular radio
8. Satellite communication

Theory of data communication

- Bits (0/1) have to be transmitted over media like
  - coax, telephone cable, satellite channel, etc.
- Questions:
  - how do we send bits over a line?
  - how many bits/sec can we transmit?
- Limits:
  - limited channel frequency (cut-off frequency)
  - noisy channel
- We will first look at what happens to a signal when frequency (bandwidth) is limited
  - ***Fourier analysis*** needed
- We will show two laws on maximum data rate

Theory of data communication



Theory of data communication

Fourier analysis

Periodic signal (f = 1/T) can be written as:

$$g(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft)$$

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)dt \qquad c = \frac{2}{T}\int_0^T g(t)dt$$

$$b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)dt$$

Example: fig 2-1

Theory of data communication

- Note that a_n, b_n and c can be derived using:

$$\int_o^T \sin(2\pi kft)\sin(2\pi nft)dt = \begin{cases} 0 \text{ for } k \neq n \\ T/2 \text{ for } k = n \end{cases}$$

with

$$\int \sin^2 axdx = -\frac{1}{2a}\cos ax \sin ax + \frac{1}{2}x = \frac{1}{2}x - \frac{1}{4a}\sin 2ax$$

Bandwidth limitation

All transmission media diminish signals

- different frequencies in different ways $\rightarrow$ distortion

Example :

- telephone line with cut-off frequency = 3000 Hz

Assume bit rate = b bits/sec

- time to send 8 bits T = 8/b sec
- f (1st harmonic) = 1/T = b/8 Hz
- # harmonies sent = 3000/ (b/8) = 24000/b
- highest bit rate = 9600 (see fig 2-2)

Maximum date rate

Nyquist theorem (1948) for noiseless channels :

maximum baud rate = 2 H $\log_2$V bits/sec
where H = bandwidth of the channel
V = # signal levels

Theorem is based on the fact that a 2H sampling rate is sufficient to reconstruct any signal with highest frequency H

Note that Nyquist theorem does not restrict the bit-rate (# signal levels may be unlimited !!)

Maximum date rate

Adding thermal (Gaussian) noise (with power N)

Signal-to-noise ratio = 10 $\log_{10}$ S/N decibels

S/N	decibel
10	10
100	20
1000	30

Shannon's theorem for noisy channel:
maximum bit rate = H $\log_2$ (1 + S/N)

Example: telephone line, 30 db $\rightarrow$ 30000 bps

Transmission media

- Magnetic media
- Twisted pair
- Coax cable
- Fiber
- Wireless

Magnetic media

Consider carrying ten 8-mm *tapes*, holding 10 gigabyte each, to another place in 1 hour

Bandwidth = …….. bits / sec

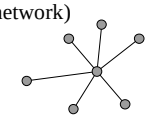
Reuse makes cost / bit of tape very low

The same holds for *optical disks*

However: very poor delay (access time)!

UTP: Unshielded twisted pair

- Twisted copper wire - reduces electromagnetic interference
- Usually four pairs per plastic sheet
- Each flow of a building wired from a central point (star-network)



- Category-5 UTP: 100 Mbps

Coax cable

Baseband coax cable (fig. 2.3) :

- 50 Ohm ; digital transmission
- used for LANs
- cheap
- long distances
- 1-km cable support data rates of 1-2 Gbps

Coax cable

Broadband coax cable

- 75 Ohm; analog transmission
- used for cable tv nets (tv channel requires 6 MHz)
- very long distances: analog amplifiers needed at regular intervals
- 100 km - up to 450 MHz, shorter distances much higher (GHz)
- much of it in place
- new services being offered
- duplex problem (amplifiers are unidirectional) see fig. 2-4

Intermezzo: computing versus communication

Computing: improvement factor 10 / decade

- 1975 CDC 6600: 100 nsec instruction time
- 1995 Cray: 1 nsec instruction time

Communication: improvement factor 100 /decade

- 1975 ARPANET 56 kbps
- 1995 optical communication 500 Mbps

Note: current computer performance increase 55%/year = factor 80/decade !!

Intermezzo: computing versus communication

Furthermore

- computing improvements become problematic
- communication:lots of room; 100 Gbps-1Tbps

Conclusion:

networks should try to avoid computing at all costs, no matter how much communication bandwidth is wasted

However: I do not have to share my computer with thousands of other people

Glass Fiber optics

Light is reflected if incoming angle > critical angle (see fig 2-5)

- single-mode (very tin fiber => wave guide): several Gbps over 30 km without repeaters
- multi-mode (each light ray travelling different path, due to reflections)

Attenuation = $10 \log_{10} \frac{\text{transmitted power}}{\text{received power}}$ (in db) (see fig 2-6)

Glass fiber options

How to connect computers:

- passive tap
  - combination of LED and photodiode fused onto the main fiber
  - broken LED does not break the chain
- active (repeater) tap (fig 2-9)
  - converting: light - electrical - light
  - repeater makes arbitrary long rings possible
- passive star using an silica cylinder which merges all the light signals (fig 2-10)

Comparing fiber and copper wire

Fiber:

- high bandwidth
- few repeaters / km
- no electromagnetic interference
- no corrosion
- lightweight
- difficult to tap (both an advantage and disadvantage !!)
- however unidirectional
  - use two frequency bands, or
  - use two wires, or
  - use time-slots (half-duplex)

Wireless transmission

Computers and connectors everywhere

Battery is the real problem

Electromagnetic spectrum (see fig 2-11)

$\lambda = cT = c/f$

$c = 3.\ 10^8$ m/sec in air / vacuum

= 30 cm per nanosecond

c = 20 cm per nanosecond in copper and fiber

$df = \frac{c\, d\lambda}{\lambda^2}$

Wireless transmission

Short wave lengths result in very high bandwidth

E.g.. λ = 1.30 micron band (fig 2.6)

$d\lambda = 0.17.\ 10^{-6}\text{m} \Rightarrow$

df = 30 THz

Telephone system

PSTN : Public Switched Telephone Network

- originally designed to transmit human voice
- low transmission rate
- high error rate
  - 1 per 10^5 bits for dial-up line
  - what happens if we sent 100 Mbits/sec or 1Gbps?

However: PSTN is needed to make non-local connections; e.g., for connecting LANs

Telephone system

Organisation

Hierarchical network (fig 2-14, 2-15) with three components:

- *Switching offices*
- *Local loops*

  Twisted pair cables
- *Trunks* : connecting switching offices
  - mostly digital transmissions over fiber or microwave links
  - multiplexing many channels on same wire

Digital versus analog

Using computers and digital electronics, digital signalling becomes possible within the telephone system

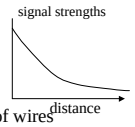
Advantages:

- no information loss
- lower error rate
- high data rates; combining digital voice, tv, etc.
- cheaper: no exact analog waveform has to be reproduced
- easier to maintain; easier to track communication problems

Local loop

Transmission problems:

- Attenuation is frequency dependent
- Delay is also frequency dependent
- Noise
  - thermal
  - cross talk, caused by inductive coupling of wires
    - you may here a voice in the background
  - impulse noise caused by power line spikes



⇒ ***Distortion results***

- especially for digital signals (having high frequency components!)
- analog coding required ⇒ modem required

Modem (modulator/demodulator)

Modulation methods (see fig 2-18)

- amplitude modulation
- frequency modulation (FKS : frequency key shifting)
- phase modulation

Bandwidth limits signal to about 2400-4800 baud

(i.e. signal changes per second; note that for a perfect 3 kHz line we could sample upto 6 kHz)

Multiple bits per signal change required

⇒ Constellation patterns (see fig 2-19)

Modem standards

- V.32 : 9600 bps : 4 bits / baud
- V.32 bis : 14k4 bps : 6 bits / baud
- V.34 : 28k8 bps
- V.90 : 57k6 bps (newest standard)
- *Trellis coding* : adding parity through usage of 128 points in the constellation pattern i.s.o. 64 points
- Compression schemes:
  - MNPs : run-length encoding (runs of zero's may be very common)
  - V.42 bis : *Ziv-Lempel* compression
- Divide bandwidth (3000 Hz) into 512 bands of 20 bps
  - allows avoiding noisy bands

Modem-computer interface

RS-232-C : digital serial interface

- connects computer and modem
  - computer: DTE data terminal equipment
  - modem: DCE data circuit-terminating equipment

Mechanical specifications:

- 25 pin connector

Electrical specifications:

- logical 0 : > 4V ; logical 1 : < -3V
- < 20 kbps
- L < 15 meters

Modem-computer interface

Functional specifications ; e.g. :

- computer on : DTR = 1 (pin 20 ; fig 2-21)
- modem on : DSR = 1 (pin 6)
- modem carrier detect : CD = 1 (pin 8)
- data are transmitted on pin 2 and 3

Null modem : connecting 2 DTEs

New standards RS.449 : see fig 2-22

Future ? ? Update local Loops

- Fiber into home
  - FTTH: fiber to the home => currently too expensive
- Fiber to the curb (see fig 2-23)
  - combined with short twisted pairs
  - combined with cable TV network

Future: Unclear !

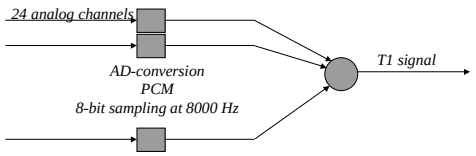
Trunks and Multiplexing

FDM : frequency division multiplexing (fig 2-24)
WDM : wavelength division multiplexing (fig 2-25)
(just FDM for fibers)
These techniques require analog circuitry
TDM : time division multiplexing
can only be used in the digital domain

Analog signals (local loop) are sampled (using PCM: pulse code modulation) and time multiplexed
8000 samples / sec ⇔ 125 microseconds/sample

TDM carriers

N. America : T1 carrier (fig 2-26)
- 1.544 Mbps
- 24 x 8 + 1 = 193 bits per frame ; 1 frame per 125 microseconds
- 8000 x 8 = 64 k bits/second per channel



TDM carriers

Outside N. America : E1 carrier
- 2.048 Mbps
- 32 channels
- 32 x 8 bits per frame
30 data and 2 signalling channels

Multiplexing T1 streams (fig 2-28)

SONET Synchr. Optical Network

Common standard for TDM
- SONET networks consists of (fig 2.29)
  - source and destination multiplexers
  - repeaters
  - switches
  - all connected by fiber
- 51.84 Mbps or multiples (compare ATM)
- 90 x 9 x 8 bits per frame (see fig 2.30)

SONET multiplexing

- SONET is a synchronous network
  - payload may start in the middle of the frame
- some bytes are used for :
  - framing, parity, voice channels, error monitoring, IDs, clocking and synchronisation

Standards:
- STS-1 one SONET channel of 51.84 Mbps
- STS-3 three channels: 155.52 Mbps (= ATM)
- STS-12 twelve channels: 622.08 Mbps

(fig. 2-31 / 2.32)

Switching

Two different techniques are used inside the telephone system (fig 2-34 / 2-35):

1. **Circuit switching**
- dedicated path established between source and destination
- long set-up time : O(10 sec)
- no congestion change : guaranteed bandwidth
- unused bandwidth is wasted

Switching

2. **Packet switching**
- store-and-forward technique used
- no dedicated path
- packet size should be limited in order not to block switches and/or overflow buffers

Comparison : fig 2-36

Switch hierarchy

To built a hierarchy we need switches

Crossbar switches (fig 2-38)
- simplex: n^2 crosspoints
- duplex: n (n-1)/2 cross points
- example n=1000 => 0.5M crosspoints

Switch hierarchy

Space division switches (fig 2-39)
- first/third stage N/n crossbars with n.k crosspoints each
- second stage k crossbars with $(N/n)^2$ crosspoints each
- Total # cross points = $2 kN + k(N/n)^2$
- Much lower #crosspoints; however blocking possible

Solution use Clos networks (if k=2n-1 no blocking !)

Switch hierarchy

Time division multiplexing (fig 2-40)

Using internal Ram routing table

Assume n inputs / outputs, T microsec RAM delay, 125 microsec switching time $\Rightarrow$ $n \leq 125 / 2T$

If more inputs / outputs needed use parallel (multiple RAMs) solution

Narrow band ISDN

ISDN *Integrated Services Digital Network* (1984)

Goal: integration of voice and data communication, and support all kinds of other services

Architecture (see fig 2-41) : digital bit pipe using TDM

Mainly offered:
- A 64 kbps digital PCM channel (voice or data)
- B 16 kbps digital channel for signalling

Narrow band ISDN

Packages :
- 2A + 1B (=144 kbps)
- 25A + 1B US (~ 1.5 Mbps) fits in T1
- 30A + 1B Europe (~ 2.0 Mbps) fits in E1

Perspective : N-ISDN ?

Perhaps saved by internet?
- At least 144 kbps is better than what modem can deliver

Broadband ISDN

Uses ATM (asynchr. transfer mode)

- 155 Mbps (suitable for HDTV); why 155 ?
- 53 byte cells (including a 5 byte header)

Paradigm shift: from circuit to packet switching

Requires new cabling and packet / cell switches:

- local loops require fiber, UTP category 5, or coax
- all space and time division switches have to be replaced

Virtual circuits versus circuit switching

B-ISDN allows virtual circuits: all switches along a path from source to destination make table entries and reserve resources (fig 2-43)

- permanent circuit (like lease line); no set-up time
- switched circuit (like phone call)

Difference with circuit switching using space division switches:

- unused capacity can be used by other connections
- (no fixed FDM bands or time slots)
- easier and faster switching

ATM Asynchronous Transfer Mode

Cells arrive randomly from different sources (compare e.g. T1, fig 2-44)

Switching goals:

- low loss rate < 10^{-12} (~ 1 cell/hour)
- no reordering

Switches can use input or output queuing to handle output channel hazards (fig 2-46/47)

Examples:

- 8x8 knockout switch(fig 2-48)
- Batcher-Banyan switch (fig 2.49-2.52)

Wireless

Read yourself about Cellular Radio (2.7) and Communication Satellites (2.8)

2.7.4 Digital Cellular Telephones:

- GSM: Global Systems for Mobile communications
  - Europe
  - 0.9 and 1.8 GHz
  - FDM and TDM
  - 50 x 200 kHz bands, each band TDM for multiple users

Wireless

2.8.1 Satellites

- Geosynchronous: 36.000 km above equator
- long end-to-end transmission time (typically 270msec)
- VSAT: very small aperture terminals
- 3.7 - 30.5 GHz (fig 2-55)

2.8.2 Low orbit satellites

Exercises

From chapter two try the following:

- 1-4, 7, 8, 14, 16, 20, 22, 34, 41, 44