Physical Layer Networks

- Fourier Decomposition
- Transmission Media
Fourier Analysis

• Successive summations of harmonics
  • Sin + Cos + constant
• Skin depth
Bandwidth Limitations

- Nyfquist’s theorem
  - max data rate = $2H \log V$ bits/sec
- Example
  - 3 KHz channel = max data rate of 6000 bps
    - For binary data
Noise

• Signal-to-noise-ratio
  • S/N measured in decibels
    • 1 decibel = 1/10 of a Bell
    • 1 Bell = one order of magnitude (10x)
  • Bandwidth characterized as point where S/N is 1/2

• Shannon’s result
  • max bits/sec = H \log (1+ S/N)

• example
  • 3 KHz bandwidth, 30 db S/N
    • Max of 30,000 bits sec.
Magnetic Media

• “Sneaker Net”
  • 75 Gigabyte DLT tapes
    • 1000 tapes
      • = 75 TeraBytes
  • 24 hour overnight shipping
    • = 75 TB/86400 = 868 GB/sec
Twisted Pair

- Analog or digital transmission
- Twists in wire minimize magnetic coupling
  - Category 3
    - Typical for telephone wire
  - Category 5
    - More twists per inch
      - Used for higher speed data communications
- Unshielded Twisted Pair (UTP)
  - Crosstalk
  - External noise
Coaxial

- Baseband coaxial cable
- 50 Ohm typical for digital
- 75 Ohm typical for analog
- Ground braid provides excellent shielding
  - 1-2 Gbit/sec for 1 KM cables
- Broadband
  - Analog (historically anything with more than 4 Khz of bandwidth)
  - Typically standard Cable TV technology
    - 300-450 MHz
    - 100 Kilometers
Broadband

• 2 cable system
  • One transmit, one receive
• Multiple frequencies
  • subsplit: send 5-30 MHz, receive 40-300
  • midsplig: send 5-116, receive 168-300
• Lots of analog broadband exits for cable TV
Fiber Optics

- Cost vs. speed improvement
- Refraction at boundaries
  - Graded Index Fiber
  - Multi-Mode - 50 micron
    - Wide fiber, better light coupling
  - Single Mode - 10 micron
    - Narrow fiber, less light
Fiber Optics

- Communications
  - Three common wavelengths
    - 0.85, 1.30 and 1.55 microns
    - 5 percent loss per kilometer
    - 25,000 to 30,000 GHz wide
Connecting Fiber Networks

- Connectors
  - 10-20% light loss
- Mechanical splices
  - 10% light loss
- Fused splices
  - Can be as good as original
Components

• Transmitters
  • Light Emitting Diodes (LEDs)
    • Slower, less bright, inexpensive, long life
  • Semiconductor laser
    • Fast, brighter, expensive, short life
• Receivers
  • Photodiode
    • Response time of 1 nsec
      • 1 Gbps data rate
Fiber vs. Copper

- Topologies
- Fiber Advantages
  - Faster
  - Low attenuation
    - 30 KM, vs 5 for copper
  - Unaffected by electromagnetic interference
  - Lighter weight
  - Harder to tap
  - Photons do not couple
    - No equivalent of magnetic field
Wireless

- freq * wavelength = speed of light
  - $10^4$--$10^8$ Radio
  - $10^8$--$10^{11}$ Microwave
  - $10^{11}$--$10^{14}$ Infrared
  - $10^{15}$ Visible light
  - $10^{15}$--$10^{16}$ UV
  - $10^{16}$--$10^{22}$ X-Ray
  - $10^{22}$--$10^{24}$ Gamma Ray
Radio Transmission

- Low frequencies pass through obstacles
  - Power falls off due to antenna limits
- Medium and High Frequency
  - Bounce from Ionosphere
  - Multipath problems
- Very High Frequency
  - Line of sight
- Microwave (above 100 MHz)
  - Line of sight
IR and Millimeter waves

- Good for very local use
- Rapidly attenuated
Lightwave transmission

• Air turbulence
Satellite

- Geo-sync--35,800
  - Limited slots
- Medium 5-15k km
  - GPS - tracking issues
- Low earth orbit (LEO)
  - low power transmitters
- Iridium 77--68
  - $5B invested, sold for $25M
Satellite

- L-Ka band 1.6 GHz-30 GHz
  - Weather interferences above 10 GHz
- VSATs
  - Hubs
- Examples
  - Teledesic
    - Internet access 100 Mbps up, 720 down
    - 30 Satellites, 2005, sat-to-sat switching
The Telephone System

- History
  - Local Loops, Inter Offices, Long Lines
- 1984 US AT&t Breakup
  - Local Access and Transport Areas
  - Local Exchange Carriers
  - Inter Exchange Carriers
- Cell Phone rules
  - In each LATA
    - One LEC and one non-LEC
1995 Free-For-All

- Point’s of Presence (POP)
- Most rules eliminated
Corporate Opportunities

• LD now inexpensive in US
• Digital Interfaces
• Corporate Phone switches
• Avoiding the LEC
• Intra-LATA calling
Modem Connections

• How digital is the connection
  • Analog lines
    • Cumulative attenuation, delay distor, noise
  • Digital lines
    • No cumulative affects
Modem Encoding

- Nyquist: 3000Hz line: 6 Khz samples
  - Put more bits per sample
  - Use Phase shift and amplitude
    - 4 phase, 4 values=2 bits, QPSK
    - 4 phase, 4 amp= 16 values= 4 bits QAM-16
    - QAM for 9600 baud
    - V.32 6 bits/sample=64 points
  - Trellis coding
- Error Correcting
- Compression (NMP5, LZ, etc.)
Echo Suppression

- Particularly bad for people speaking
  - Amplifiers make voice connections one way
    - half duplex
    - Bad for data connections
  - Turn off Echo suppression
    - 2.1 Khz in band signal
  - Echo Canceller
    - Add opposite signal
Trunk Signaling

- Frequency Division Multiplexing
- Wave Division Multiplexing-fiber
- Time Division Multiplexing
  - Pulse Code Modulation
  - Standard American T-1
    - 193 bit frame, 24 8 bit channels, one frame
  - European E-1
    - 32 8 bit samples in 2.048 Mbps