Physical Layer – Transmission Media

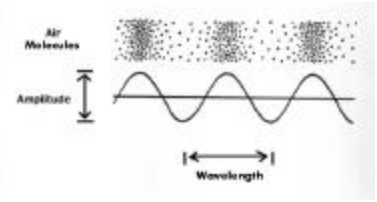
CS442

Transmission Media

- Two basic formats
  - Guided media : wires, fiber optics
    - Medium is important
  - Unguided media : wireless, radio transmission
    - Antenna is important
- Each have tradeoffs over data rate, distance
  - Attenuation : weakening of signal over distance

Mini Electromagnetic Review

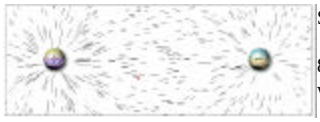
- Take a sound wave…



Frequency (hz) = Number of cycles/second
With a constant wave velocity, frequency = velocity / wavelength
For electromagnetic waves, f = c / w ; c = speed of light

Mini Electromagnetic Review

Same principle with electrical waves:

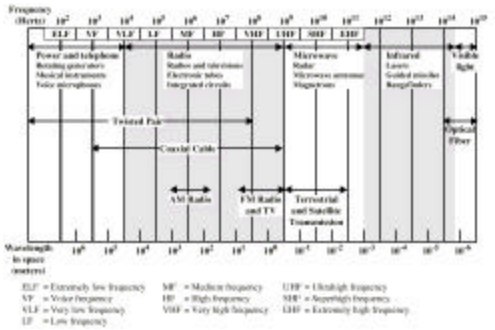


Station at 88.1 FM = 88.1 Mhz

88100000 = 3.0 * 10^8 / w
w = 3.0 * 10^8 / 88100000
= 3.4 meters

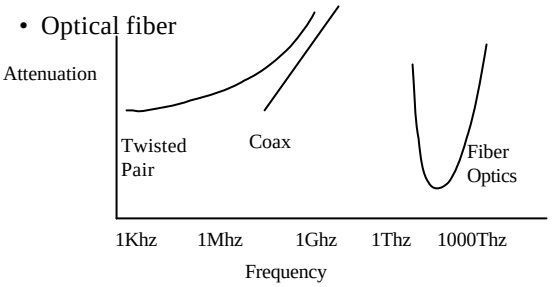
Time to travel this far is 1/f or 0.000000011 seconds

Electromagnetic Spectrum

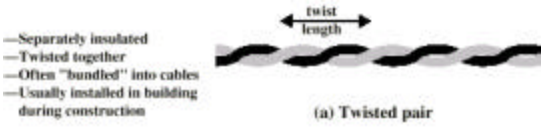


Guided Transmission Media

- Twisted Pair
- Coaxial cable
- Optical fiber



Twisted Pair



Pair of copper wires constitutes a single communication link.
Twists minimize the effects of electromagnetic interference
- emit less emag energy
- less susceptible to emag energy

Twisted Pair - Applications

- Most common medium
- Telephone network
  - POTS
  - Between house and local exchange (subscriber loop), also called the end office. From the end office to Central Office (CO) class 4 → CO class 1 via Public Switched Telephone Network (PSTN)
- Within buildings
  - To private branch exchange (PBX)
- For local area networks (LAN)
  - 10Mbps or 100Mbps
  - Possible to rev up to 1Gbps – Gigabit Ethernet

Twisted Pair - Pros and Cons

- Cheap
- Easy to work with
  - Can use as digital or analog
- Limited bandwidth/data rate
  - Generally 1Mhz and 100Mbps
- Short range
  - 2km for digital, 5km for analog
- Direct relationship between data rate and range
  - Gigabit Ethernet
    - 1000Mbps over 4 Cat5 UTP up to 100 meters
      - IEEE 802.3ab standard in 1999
    - 1000Mbps over 1 Cat5 UTP up to 24 meters

Unshielded and Shielded TP

- Unshielded Twisted Pair (UTP)
  - Ordinary telephone wire
  - Cheapest
  - Easiest to install
  - Suffers from external EM interference
- Shielded Twisted Pair (STP)
  - Metal braid or sheathing that reduces interference
  - More expensive
  - Harder to handle (thick, heavy)

UTP Categories

- Cat 1
  - Used for audio frequencies, speaker wire, etc. Not for networking.
- Cat 2
  - Up to 1.5Mhz, used for analog phones, not for networking
- Cat 3
  - EIA 568-A Spec from here on up
  - up to 16MHz
  - Voice grade found in most offices
  - Twist length of 7.5 cm to 10 cm
- Cat 4
  - up to 20 MHz
  - Not frequently used today, was used for Token Ring

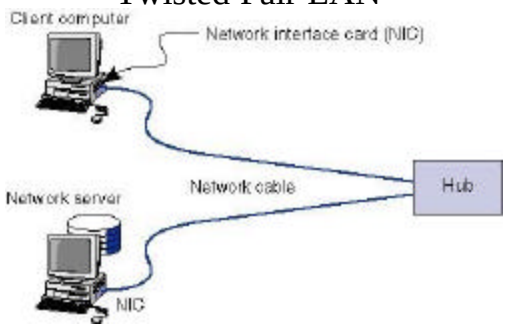
UTP Categories Cont.

- Cat 5
  - up to 100MHz
  - Twist length 0.6 cm to 0.85 cm
  - Commonly pre-installed in new office buildings
- Cat 5e "Enhanced"
  - Up to 100Mhz
  - Specifies minimum characteristics for NEXT (Near End Crosstalk) and ELFEXT (Equal level far end crosstalk)
    - Coupling of signal from one pair to another
    - Coupling takes place when transmit signal entering the link couples back to receiving pair, i.e. near transmitted signal is picked up by near receiving pair
- Cat 6
  - Proposed standard up to 250Mhz
- Cat 7
  - Proposed standard up to 600Mhz

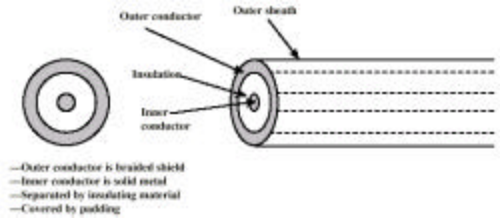
Typical Usage of Twisted Pair

Name	Type	Mbps	m	In…
Cat 1	UTP	1	90	
Cat 2	UTP	4	90	Tkn Ring/Phone
Cat 3	UTP	10	100	10BaseT
Cat 4	STP	16	100	TRing 16
Cat 5	S/UTP	100	200	100BaseT

Twisted Pair LAN



Coaxial Cable



Shielded, less susceptible to noise and attenuation than Twisted Pair.

Coaxial Cable Applications

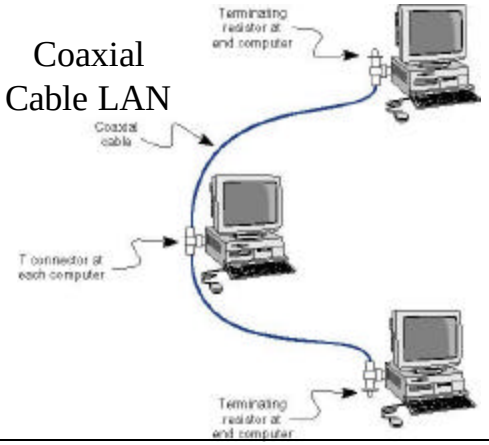
- Most versatile medium
- Television distribution
  - Cable TV
- Long distance telephone transmission
  - Can carry 10,000 voice calls simultaneously
  - Being replaced by fiber optic
- Short distance computer systems links
- Local area networks
  - More expensive than twisted pair, not as popular for LANs

Coaxial Cable Characteristics

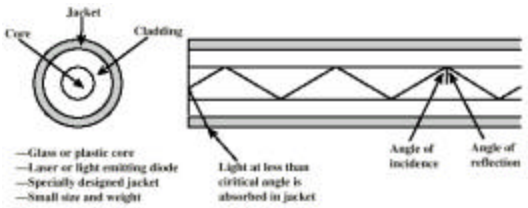
- Analog – Broadband Coaxial Cable
  - Amplifiers every few km, closer if higher frequency
  - Up to 500MHz
  - Cable TV, Cable Modems (~10Mbps)
- Digital – Baseband Coaxial Cable
  - Repeater every 1km
  - Closer for higher data rates

Name	Type	Mbps	m	In…	
RG-58	Coax	10	185	10Base2, "ThinNet"	
RG-8	Coax	10	500	10Base5, "ThickNet"	

Coaxial Cable LAN



Optical Fiber



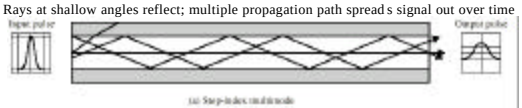
Breakthrough in data transmission systems!
Core: Thin strands of glass
Cladding: Glass with different optical properties than core
Jacket: Plastic/Insulation

Optical Fiber - Benefits

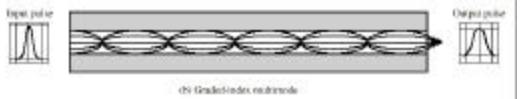
- Greater capacity
  - Data rates of hundreds of Gbps
  - Tbps demonstrated using WDM
- Smaller size & weight
  - Order of magnitude smaller than TP/Coax
- Lower attenuation
- Electromagnetic isolation
  - Not vulnerable to interference, impulse, crosstalk!
- Greater repeater spacing
  - Often 10's of kilometers
- Hard to tap

Optical Fiber Transmission Modes

Rays at shallow angles reflect; multiple propagation path spreads signal out over time



Gradient refraction in core allows light to curve helically, more coherent at end



Shrink core to allow only a single angle or mode, light reflect in only one pattern

Wireless or Radiated Transmission

- Unguided media
- Transmission and reception via antenna
  - Desirable to make antenna one-quarter or one-half the wavelength
- Directional
  - Focused beam
  - Careful alignment required
- Omnidirectional
  - Signal spreads in all directions
  - Can be received by many antennas

Frequencies

- 2GHz to 40GHz
  - Microwave
  - Highly directional
  - Point to point
  - Satellite
- 30MHz to 1GHz
  - Omnidirectional
  - Broadcast radio
- 3×10^{11} to 2×10^{14}
  - Infrared
  - Local
- Higher frequencies → Higher data rates

Terrestrial Microwave

- Typically parabolic dish, focused beam, line of sight
- Max distance between antenna:

  d=7.14 * Sqrt(hK) ; K=4/3,
  ; h=antenna ht in meters
  ; d=distance in km

  so two 1 meter antenna can be 7.14*Sqrt(4/3)=8.2 km apart
- Applications
  - Long haul telecommunications, television. May need repeaters
  - Short range for BN or closed-circuit TV

Terrestrial Microwave

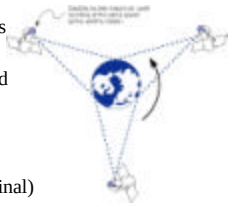
- Data rate increases with frequency
  - 2 Ghz Band → 7 Mhz Bandwidth → 12 Mbps
  - 6 Ghz Band → 30 Mhz Bandwidth → 90 Mbps
  - 11 Ghz Band → 40 Mhz Bandwidth → 135 Mbps
  - 18 Ghz Band → 220 Mhz Bandwidth → 274 Mbps
- Attenuation

$$Loss = 10\log\left(\frac{4pd}{l}\right)^2 dB$$

  - Loss varies with the square of the distance
  - TP/Coax: loss varies with log of distance / linear in dB
  - Therefore, we don't need as many repeaters with microwave
- Interference and Raindrop Attenuation
  - Frequency bands strictly regulated
  - Use lower frequency to avoid raindrop problem

Satellite Microwave

- Satellite is relay station
- Satellite receives on one frequency, amplifies or repeats signal and transmits on another frequency/frequencies (transponder channels)
- Typically geo-stationary orbit
  - Height of 35,784km or 22,236 miles
  - 4 degree spacing in 4/6Ghz Band
  - 3 degree spacing in 12/14 Ghz Band
- Applications
  - TV, telephone
  - Private business networks
  - VSAT (Very Small Aperture Terminal)
    - Large corp. with distributed sites
    - Small receiver to Ku-band satellite to Big earth hub
    - Used by RCA in late 1994 for Direct Broadcast System



Satellite Transmission Characteristics

- Optimum Frequency Range 1-10Ghz
  - Below 1Ghz, natural noise. Above 10Ghz, attenuation from the atmosphere
  - Most applications use the 5.925-6.425 Ghz range uplink, 4.2-4.7Ghz range downlink (4/6 Ghz Band)
- Propagation delay
  - 35784000m / 3.0 * 10^8 m/s → 0.12 seconds one way
  - About quarter second propagation delay round trip, noticeable for phone conversations, problem for two-way communications
    - Error /flow control?
    - Low orbit satellites a solution? (Iridium, Tachyon)

Broadcast Radio

- 30Mhz to 2 Ghz
- Omnidirectional
  - Use loop or wire antenna instead of dish
- Applications
  - Range covers FM radio, UHF and VHF television
  - 802.11b operates in the 2.4Ghz ISM band
- Due to lower frequencies than microwave, less problems with attenuation
- Same equation for antenna distance, attenuation as microwave
- Drawbacks
  - Suffers from multipath interference, Reflections
  - Possible security concerns

Infrared

- Modulate noncoherent infrared light
- Line of sight (or reflection)
- Blocked by walls
- Problems
  - Short range, usually 50-75 feet maximum
  - Low speed, 1-4 Mbps
- e.g. TV remote control, IRD port
  - For networks, typically only used to connect wireless hubs due to the need for direct line-of-sight

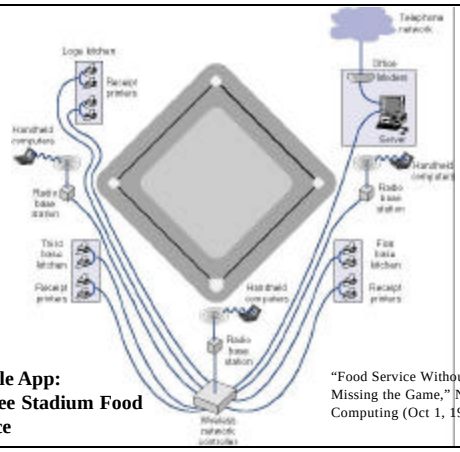
Media Selection

Guided Media

Media	Network Type	Cost	Transmission Distance	Security	Error Rates	Speed
Twisted Pair	LAN	Low	Short	Good	Low	Low-high
Coaxial Cable	LAN	Mod.	Short-Mod	Good	Low	Low-high
Fiber Optics	any	High	Mod.-long	V. Good	V.Low	High-V.High

Radiated Media

Media	Network Type	Cost	Transmission Distance	Security	Error Rates	Speed
Radio	LAN	Low	Short	Poor	Mod	Low
Infrared	LAN, BN	Low	Short	Poor	Mod	Low
Microwave	WAN	Mod	Long	Poor	Low-Mod	Mod
Satellite	WAN	Mod	Long	Poor	Low-Mod	Mod



Sample App: Yankee Stadium Food Service

"Food Service Without Missing the Game," Network Computing (Oct 1, 1996)