Chapter 4: Transmission Media

Overview

- Guided - wire
- Unguided - wireless
- Characteristics and quality determined by medium and signal
- For guided, the medium is more important
- For unguided, the bandwidth produced by the antenna is more important
- Key concerns are data rate and distance
Design Factors

• Bandwidth
  —Higher bandwidth gives higher data rate

• Transmission impairments
  —Attenuation

• Interference

• Number of receivers
  —In guided media
  —More receivers (multi-point) introduce more attenuation

Electromagnetic Spectrum

- ELF (Extremely low frequency)
- VLF (Very low frequency)
- LF (Low frequency)
- MF (Medium frequency)
- HF (High frequency)
- VHF (Very high frequency)
- UHF (Ultra high frequency)
- SHF (Super high frequency)
- EHF (Extremely high frequency)

Frequency (Hertz)

Wavelength in space (meters)
Guided Transmission Media

- Twisted Pair
- Coaxial cable
- Optical fiber

Transmission Characteristics of Guided Media

<table>
<thead>
<tr>
<th>Guided Transmission Media</th>
<th>Frequency Range</th>
<th>Typical Attenuation</th>
<th>Typical Delay</th>
<th>Repeater Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twisted pair (with loading)</td>
<td>0 to 3.5 kHz</td>
<td>0.2 dB/km @ 1 kHz</td>
<td>50 µs/km</td>
<td>2 km</td>
</tr>
<tr>
<td>Twisted pairs (multi-pair cables)</td>
<td>0 to 1 MHz</td>
<td>0.7 dB/km @ 1 kHz</td>
<td>5 µs/km</td>
<td>2 km</td>
</tr>
<tr>
<td>Coaxial cable</td>
<td>0 to 500 MHz</td>
<td>7 dB/km @ 10 MHz</td>
<td>4 µs/km</td>
<td>1 to 9 km</td>
</tr>
<tr>
<td>Optical fiber</td>
<td>186 to 370 THz</td>
<td>0.2 to 0.5 dB/km</td>
<td>5 µs/km</td>
<td>40 km</td>
</tr>
</tbody>
</table>
Twisted Pair

Twisted length

— Separately insulated
— Twisted together
— Often "bundled" into cables
— Usually installed in building during construction

RJ-45

Twisted Pair - Applications

• Most common medium
• Telephone network
  — Between house and local exchange (subscriber loop)
• Within buildings
  — To private branch exchange (PBX)
• For local area networks (LAN)
  — 10Mbps or 10Gbps
  — Strong dependence on cable (quality)
Twisted Pair - Pros and Cons

- Cheap
- Easy to work with
- Low data rate
- Short range

Twisted Pair - Transmission Characteristics

- Analog
  - Amplifiers every 5km to 6km
- Digital
  - Use either analog or digital signals
  - Repeater every 2km or 3km
- Limited distance
- Limited bandwidth (1MHz)
- Limited data rate (100MHz)
- Susceptible to interference and noise
**Near 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

**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 (a bit thicker & heavier)
Categories

- Cat 3
  - up to 16MHz
  - Voice grade found in most offices
  - Twist length of 7.5 cm to 10 cm
- Cat 4
  - up to 20 MHz
- Cat 5
  - up to 100 MHz
  - Commonly pre-installed in new office buildings
  - Twist length 0.6 cm to 0.85 cm
- Cat 5E (Enhanced) – see tables
- Cat 6
  - up to 250 MHz (suitable for up to 1000Base-T, expected for 10GBase-T)
  - Cat 6a up to 500 MHz
- Cat 7
  - up to 1000 MHz

Cat7 vs Cat5 Cable

Notice the difference in shielding
=> higher cost
### Comparison of Shielded and Unshielded Twisted Pair

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Category 3 UTP</th>
<th>Category 5 UTP</th>
<th>150-ohm STP</th>
<th>Category 3 UTP</th>
<th>Category 5 UTP</th>
<th>150-ohm STP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.6</td>
<td>2.0</td>
<td>1.1</td>
<td>41</td>
<td>62</td>
<td>58</td>
</tr>
<tr>
<td>4</td>
<td>5.6</td>
<td>4.1</td>
<td>2.2</td>
<td>32</td>
<td>53</td>
<td>58</td>
</tr>
<tr>
<td>16</td>
<td>13.1</td>
<td>8.2</td>
<td>4.4</td>
<td>23</td>
<td>44</td>
<td>50.4</td>
</tr>
<tr>
<td>25</td>
<td>—</td>
<td>10.4</td>
<td>6.2</td>
<td>—</td>
<td>41</td>
<td>47.5</td>
</tr>
<tr>
<td>100</td>
<td>—</td>
<td>22.0</td>
<td>12.3</td>
<td>—</td>
<td>32</td>
<td>38.5</td>
</tr>
<tr>
<td>300</td>
<td>—</td>
<td>—</td>
<td>21.4</td>
<td>—</td>
<td>—</td>
<td>31.3</td>
</tr>
</tbody>
</table>

### Twisted Pair Categories and Classes

<table>
<thead>
<tr>
<th>Category 3</th>
<th>Category 5</th>
<th>Category 6</th>
<th>Category 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class C</td>
<td>Class D</td>
<td>Class E</td>
<td>Class F</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>16 MHz</td>
<td>100 MHz</td>
<td>200 MHz</td>
</tr>
<tr>
<td>Cable Type</td>
<td>UTP</td>
<td>UTP/FTP</td>
<td>UTP/FTP</td>
</tr>
<tr>
<td>Link Cost</td>
<td>0.7</td>
<td>1</td>
<td>1.2</td>
</tr>
</tbody>
</table>

(Cat 5 = 1)
**Cable Standards**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Mbps</th>
<th>Often used by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1</td>
<td>UTP</td>
<td>1</td>
<td>Modem</td>
</tr>
<tr>
<td>Category 2</td>
<td>UTP</td>
<td>4</td>
<td>Token Ring-4</td>
</tr>
<tr>
<td>Category 3</td>
<td>UTP</td>
<td>10</td>
<td>10Base-T Ethernet</td>
</tr>
<tr>
<td>Category 4</td>
<td>STP</td>
<td>16</td>
<td>Token Ring-16</td>
</tr>
<tr>
<td>Category 5</td>
<td>UTP</td>
<td>100</td>
<td>100Base-T Ethernet</td>
</tr>
<tr>
<td>Category 5</td>
<td>STP</td>
<td>100</td>
<td>100Base-T Ethernet</td>
</tr>
<tr>
<td>Category 5e</td>
<td>UTP</td>
<td>100</td>
<td>1000Base-T Ethernet</td>
</tr>
<tr>
<td>Category 6</td>
<td>UTP</td>
<td>200</td>
<td>1000Base-T Ethernet</td>
</tr>
<tr>
<td>Category 7</td>
<td>STP</td>
<td>600</td>
<td>100GBase-T Ethernet</td>
</tr>
</tbody>
</table>

**Coaxial Cable**

- Outer conductor is braided shield
- Inner conductor is solid metal
- Separated by insulating material
- Covered by padding
Coaxial Cable Applications

• Most versatile medium
• Television distribution
  — Ariel to TV
  — 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

Coaxial Cable - Transmission Characteristics

• Analog
  — Amplifiers every few km
  — Closer if higher frequency
  — Up to 500MHz
• Digital
  — Repeater every 1km
  — Closer for higher data rates
Optical Fiber

- Glass or plastic core
- Laser or light emitting diode
- Specially designed jacket
- Small size and weight

Optical Fiber - Benefits

- Greater capacity
  - Data rates of hundreds of Gbps
- Smaller size & weight
- Lower attenuation
- Electromagnetic isolation
- Greater repeater spacing
  - Tens of km

Light at less than critical angle is absorbed in jacket
Angle of incidence
Angle of reflection
Optical Fiber - Applications

- Long-haul trunks
- Metropolitan trunks
- Rural exchange trunks
- Subscriber loops
- LANs

Optical Fiber - Transmission Characteristics

- Act as wave guide for $10^{14}$ to $10^{15}$ Hz
  - Portions of infrared and visible spectrum
- Light Emitting Diode (LED)
  - Cheaper
  - Wider operating temp range
  - Last longer
- Injection Laser Diode (ILD)
  - More efficient
  - Greater data rate
- Wavelength Division Multiplexing
Optical Fiber Transmis. Modes

(a) Step-index multimode

(b) Graded-index multimode

(c) Single mode

Frequency Utilization for Fiber Applications

<table>
<thead>
<tr>
<th>Wavelength (in vacuum) range (nm)</th>
<th>Frequency range (THz)</th>
<th>Band label</th>
<th>Fiber type</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>820 to 900</td>
<td>366 to 333</td>
<td></td>
<td>Multimode</td>
<td>LAN</td>
</tr>
<tr>
<td>1280 to 1350</td>
<td>234 to 222</td>
<td>S</td>
<td>Single mode</td>
<td>Various</td>
</tr>
<tr>
<td>1528 to 1561</td>
<td>196 to 192</td>
<td>C</td>
<td>Single mode</td>
<td>WDM</td>
</tr>
<tr>
<td>1561 to 1620</td>
<td>185 to 192</td>
<td>L</td>
<td>Single mode</td>
<td>WDM</td>
</tr>
</tbody>
</table>
Optical Fiber

- The human eye
  - **Spectral Response**: Computer selected glass filters are designed to match the meter's detector response to the CIE photopic response (human eye response), which defines the eye's sensitivity to color. The combined spectral response is the product of the filter's transmission and the spectral responsivity of the detector.

http://spectracine.com/sc-700.htm

- what is the wavelength of bright visible light?
Wireless Transmission Frequencies

- 2GHz to 40GHz
  - Microwave
  - Highly directional
  - Point to point
  - Satellite
- 30MHz to 1GHz
  - Omnidirectional
  - Broadcast radio
- $3 \times 10^{11}$ to $2 \times 10^{14}$
  - Infrared
  - Local

Antennas

- Electrical conductor (or system of..) used to radiate electromagnetic energy or collect electromagnetic energy
- Transmission
  - Radio frequency energy from transmitter
  - Converted to electromagnetic energy
  - By antenna
  - Radiated into surrounding environment
- Reception
  - Electromagnetic energy impinging on antenna
  - Converted to radio frequency electrical energy
  - Feed to receiver
- Same antenna often used for both
Radiation Pattern

- Power radiates in "all" directions
- Not same performance in all directions
  - directional
  - omni directional
  - isotropic

- Isotropic antenna is (theoretical) point in space
  - Radiates in all directions equally
  - Gives spherical radiation pattern
Radiation Pattern

- omni directional

Radiation Pattern

- Beamwidth of antenna
  - angular separation between the half points (3dB points)
  - vertical plane
  - horizontal plane

source cisco.com
**Parabolic Reflective Antenna**

- Used for terrestrial and satellite microwave
- Parabola is locus of point equidistant from a line and a point not on that line
  - Fixed point is called **focus**
  - Line is **directrix**
- Revolve parabola about axis to get paraboloid
  - Cross section parallel to axis gives parabola
  - Cross section perpendicular to axis gives circle
- Source placed at focus will produce waves reflected from parabola in parallel to axis
  - Creates (theoretical) parallel beam of light/sound/radio
- On reception, signal is concentrated at focus, where detector is placed
Antenna Gain

- Measure of directionality of antenna
- Power output in particular direction compared with that produced by isotropic antenna
- Measured in decibels (dB)
- Results in loss in power in another direction
- Effective area relates to size and shape
  —Related to gain

Terrestrial Microwave

- Parabolic dish
- Focused beam
- Line of sight
- Long haul telecommunications
- Higher frequencies give higher data rates
**Satellite Microwave**

- Satellite is relay station
- Satellite receives on one frequency, amplifies or repeats signal and transmits on another frequency
- Requires geo-stationary orbit
  - Height of 35,784km
- Television
- Long distance telephone
- Private business networks

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**Satellite Point to Point Link**

(a) Point-to-point link
**Satellite Broadcast Link**

- Multiple receivers
- Transmitter
- Multiple receivers
- Satellite antenna

**Broadcast Radio**

- Omnidirectional
- FM radio
- UHF and VHF television
- Line of sight
- Suffers from multipath interference
  - Reflections
Infrared

- Modulate non-coherent infrared light
- Line of sight (or reflection)
- Blocked by walls
- No licenses required
- Typical use
  - TV remote control
  - IRD port

Wireless Propagation

- Signal travels along three routes
  - Ground wave
    - Follows contour of earth
    - Up to 2MHz
    - AM radio
  - Sky wave
    - Amateur radio, BBC world service, Voice of America
    - Signal reflected from ionosphere layer of upper atmosphere
    - (Actually refracted)
  - Line of sight
    - Above 30Mhz
    - May be further than optical line of sight due to refraction
    - More later...
**Ground Wave Propagation**

(a) Ground-wave propagation (below 2 MHz)

**Sky Wave Propagation**

(b) Sky-wave propagation (2 to 30 MHz)
**Refraction**

- Velocity of electromagnetic wave is a function of density of material
  - \(~3 \times 10^8\) m/s in vacuum, less in anything else
- As wave moves from one medium to another, its speed changes
  - Causes bending of direction of wave at boundary
  - Towards more dense medium
- Index of refraction (refractive index) is
  - \(\frac{\sin(\text{angle of incidence})}{\sin(\text{angle of refraction})}\)
  - Varies with wavelength
- May cause sudden change of direction at transition between media
- May cause gradual bending if medium density is varying
  - Density of atmosphere decreases with height
  - Results in bending towards earth of radio waves
Optical and Radio Horizons

Line of Sight Transmission

- **Free space loss**
  - Signal disperses with distance
  - Greater for lower frequencies (longer wavelengths)

- **Atmospheric Absorption**
  - Water vapour and oxygen absorb radio signals
  - Water greatest at 22GHz, less below 15GHz
  - Oxygen greater at 60GHz, less below 30GHz
  - Rain and fog scatter radio waves

- **Multipath**
  - Better to get line of sight if possible
  - Signal can be reflected causing multiple copies to be received
  - May be no direct signal at all
  - May reinforce or cancel direct signal

- **Refraction**
  - May result in partial or total loss of signal at receiver
**Free Space Loss**

- **Graph**
  - Y-axis: Loss (dB)
  - X-axis: Distance (km)
  - Lines for different frequencies: f = 3400 GHz, f = 30 GHz, f = 3 GHz, f = 300 MHz, f = 30 MHz

**Multipath Interference**

- **Images**
  - (a) Microwave line of sight
  - (b) Mobile radio

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CS420/520 Axel Krings
Summary

• looked at data transmission issues
• frequency, spectrum & bandwidth
• analog vs digital signals
• transmission impairments