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
- VF = Voice frequency
- VLF = Very low frequency
- MF = Medium frequency
- LF = Low frequency
- HF = High frequency
- VHF = Very high frequency
- UHF = Ultrahigh frequency
- SHF = Superhigh frequency
- EHF = Extremely high frequency

Frequency (Hertz) | ELF | VF | VLF | LF | MF | HF | VHF | UHF | SHF | EHF |
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</tbody>
</table>

Wavelength (meters) | 10^8 | 10^9 | 10^10 | 10^11 | 10^12 | 10^13 | 10^14 |
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<td>SHF</td>
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<tr>
<td>EHF</td>
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</tr>
</tbody>
</table>

- Power and telephone: Rotating generators, Musical instruments, Voice microphones
- Radio: Radios and televisions, Electronic tubes, Integrated circuits, Cellular Telephony
- Microwave: Radar, Microwave antennas, Magnetrons
- Infrared: Lasers, Guided missiles, Rangefinders
- Optical Fiber
Guided Transmission Media

- Twisted Pair
- Coaxial cable
- Optical fiber

<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 (multipair 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>

THz = terahertz = 10¹² Hz
Twisted Pair

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

Twisted Pair - Applications

• Telephone network
  — Between house and local exchange (subscriber loop)
• Within buildings
  — To private branch exchange (PBX)
• For local area networks (LAN)
  — 10Mbps to 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 (NEXT)

- 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

Figure 4.4 Signal Power Relationships (from System A viewpoint)
Figure 4.5 Category 6A Channel Requirements

NEXT = near-end crosstalk
ACR = attenuation-to-crosstalk ratio
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)

Twisted Pair Categories and Classes

<table>
<thead>
<tr>
<th>Bandwidth</th>
<th>Category 5e Class D</th>
<th>Category 6 Class E</th>
<th>Category 6A Class E_A</th>
<th>Category 7 Class F</th>
<th>Category 7_A Class F_A</th>
</tr>
</thead>
<tbody>
<tr>
<td>MHz</td>
<td>100 MHz</td>
<td>250 MHz</td>
<td>500 MHz</td>
<td>600 MHz</td>
<td>1,000 MHz</td>
</tr>
<tr>
<td>Cable Type</td>
<td>UTP</td>
<td>UTP/FTP</td>
<td>UTP/FTP</td>
<td>S/FTP</td>
<td>S/FTP</td>
</tr>
<tr>
<td>Insertion loss (dB)</td>
<td>24</td>
<td>21.3</td>
<td>20.9</td>
<td>20.8</td>
<td>20.3</td>
</tr>
<tr>
<td>NEXT loss (dB)</td>
<td>30.1</td>
<td>39.9</td>
<td>39.9</td>
<td>62.9</td>
<td>65</td>
</tr>
<tr>
<td>ACR (dB)</td>
<td>6.1</td>
<td>18.6</td>
<td>19</td>
<td>42.1</td>
<td>44.1</td>
</tr>
</tbody>
</table>

UTP = Unshielded twisted pair
FTP = Foil twisted pair
S/FTP = Shielded/foil twisted pair
ACR = Attenuation-to-crosstalk ratio
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>10GBase-T Ethernet</td>
</tr>
</tbody>
</table>

Cat7 vs Cat5 Cable

Notice the difference in shielding
=> higher cost
Coaxial Cable

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

Coaxial Cable Applications

- 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

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**Figure 4.3 Attenuation of Typical Guided Media**

(a) Twisted pair (based on [REEV95])

(b) Coaxial cable (based on [BELL90])

(c) Optical fiber (based on [FREE02])

(d) Composite graph
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 over tens of kilometers have been demonstrated

- Smaller size and lighter weight
  - Considerably thinner than coaxial or twisted pair cable
  - Reduces structural support requirements

- Lower attenuation

- Electromagnetic isolation
  - Not vulnerable to interference, impulse noise, or crosstalk
  - High degree of security from eavesdropping

- Greater repeater spacing
  - Lower cost and fewer sources of error
Categories of Application

- Five basic categories of application have become important for optical fiber:
  - Long-haul trunks
  - Metropolitan trunks
  - Rural exchange trunks
  - Subscriber loops
  - Local area networks

Figure 4.6 Optical Communication
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 Transmission 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>192 to 185</td>
<td>L</td>
<td>Single mode</td>
<td>WDM</td>
</tr>
</tbody>
</table>

WDM = wavelength division multiplexing

Attenuation in Guided Media
**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/ze-700.htm](http://spectracine.com/ze-700.htm)

- what is the wavelength of bright visible light?

**Wireless Transmission Frequencies**

1GHz to 40GHz
- Referred to as microwave frequencies
- Highly directional beams are possible
- Suitable for point to point transmissions
- Also used for satellite communications

30MHz to 1GHz
- Suitable for omnidirectional applications
- Referred to as the radio range

3 x 10^{11} to 2 x 10^{14}
- Infrared portion of the spectrum
- Useful to local point-to-point and multipoint applications within confined areas
**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

- isotropic antenna

source cisco.com

Radiation Pattern

- omni directional

source cisco.com
Radiation Pattern

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

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
  - typical size of 3m diameter
- Focused beam
  - Line of sight
- Long haul telecommunications
  - Series of microwave relay towers
- Higher frequencies give higher data rates

**Terrestrial Microwave Applications**

- Used for **long haul telecommunications service** as an alternative to coaxial cable or optical fiber
- Used for both **voice and TV transmission**
- **Fewer repeaters but** requires **line-of-sight** transmission
- 1-40GHz frequencies, with higher frequencies having higher data rates
- Main source of loss is **attenuation** caused mostly by distance, rainfall and interference
**Typical Digital Microwave Performance**

<table>
<thead>
<tr>
<th>Band (GHz)</th>
<th>Bandwidth (MHz)</th>
<th>Data Rate (Mbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>7</td>
<td>12</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>90</td>
</tr>
<tr>
<td>11</td>
<td>40</td>
<td>135</td>
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<tr>
<td>18</td>
<td>220</td>
<td>274</td>
</tr>
</tbody>
</table>

**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
Satellite Point to Point Link

(a) Point-to-point link

Satellite Broadcast Link

(b) Broadcast link
Transmission Characteristics

- The optimum frequency range for satellite transmission is 1 to 10 GHz
  - Below 1 GHz there is significant noise from natural sources
  - Above 10 GHz the signal is severely attenuated by atmospheric absorption and precipitation

- Satellites use a frequency bandwidth range of 5.925 to 6.425 GHz from earth to satellite (uplink) and a range of 3.7 to 4.2 GHz from satellite to earth (downlink)
  - This is referred to as the 4/6-GHz band
  - Because of saturation the 12/14-GHz band has been developed
Broadcast Radio

- Broadcast radio is omnidirectional and microwave is directional
- **Radio** is the term used to encompass frequencies in the range of 3kHz to 300GHz
- **Broadcast radio** (30MHz - 1GHz) covers:
  - FM radio and UHF and VHF television band
  - Data networking applications
- Limited to **line of sight**
- Suffers from **multipath interference**
  - Reflections from land, water, man-made objects

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)

Line of Sight Propagation

(c) Line-of-sight (LOS) propagation (above 30 MHz)
**Refraction**

- Velocity of electromagnetic wave is a function of density of material
  - \( \sim 3 \times 10^8 \text{ m/s} \) 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

![Free Space Loss Graph](image)
Multipath Interference

(a) Microwave line of sight

(b) Mobile radio

Summary

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