• Transmission Media
  – Physical path between transmitter and receiver
  – Guided or unguided (wireless)
  – Communication is in the form of electromagnetic waves
  – Characteristics and quality of data transmission are determined by characteristics of medium and signal
  – In guided media, medium characteristics is more important, whereas in unguided media, signal characteristics is more important

Figure 3.1 Electromagnetic Spectrum for Telecommunications
1. Guided Transmission Media

- **Twisted Pair**
  - The oldest, least expensive, and most commonly used media
  - Pair of insulated wires twisted together to reduce susceptibility to interference (two straight parallel wires tend to act as an antenna and pick up extraneous signals)
  - Quite highly susceptible to noise & interference
  - Up to 250 kHz analog and few Mbps digital signaling (for long-distance point-to-point signaling)
  - Need repeater every 2-3 km (digital), and amplifier every 5-6 km (analog)
  - May be already installed (telephone usage)
  - Much efforts are undergoing to use it for high-speed (10-100 Mbps) LAN
• **Coaxial Cable**
  - Most versatile medium
    - LANs, Cable TV, Long-distance telephones, VCR-to-TV connections
  - Noise immunity is good
  - Very high channel capacity
    - Few 100 MHz / few 100 Mbps
  - Need repeater/amplifier every few kilometer or so (about the same as with twisted pair)

---

Point-to-point transmission characteristics of guided media

<table>
<thead>
<tr>
<th>Transmission medium</th>
<th>Total data rate</th>
<th>Bandwidth</th>
<th>Repeater spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twisted pair</td>
<td>4 Mbps</td>
<td>3 MHz</td>
<td>2 to 10 km</td>
</tr>
<tr>
<td>Coaxial cable</td>
<td>500 Mbps</td>
<td>350 MHz</td>
<td>1 to 10 km</td>
</tr>
<tr>
<td>Optical fiber</td>
<td>2 Gbps</td>
<td>2 GHz</td>
<td>10 to 100 km</td>
</tr>
</tbody>
</table>

---

Outer conductor is braided shield
Inner conductor is solid metal
Separated by insulating material
Covered by padding
• Optical Fiber
  – Flexible, thin (few to few hundred µm), very pure glass / plastic fiber capable of conducting optical rays
  – Extremely high bandwidth: capable of $\geq 2$Gbps
  – Very high noise immunity, resistant to electromagnetic interference
  – Does not radiate energy/cause interference
  – Very light
  – Need repeaters only 10’s or 100 km apart
  – Very difficult to tap
    • Better security but multipoint not easy
  – Need optical-electrical interface (more expensive than electrical interface)
• Principle of optical fiber transmission
  – Based on the principle of **total internal reflection**

  ![Diagram of light reflection and refraction](image)

  - If $\beta > \alpha$, medium B (water) has a higher optical density than medium A (air)
  - Index of refraction is defined by $\cos(\alpha)/\cos(\beta)$
  - In case the index of refraction < 1 ($\alpha > \beta$), if $\alpha$ is less than a certain critical angle, there is no refracted light. I.e., all the light is reflected. This is what makes fiber optics work.
  - The cladding surrounding the core is also glass but is optically less dense than the core.
• Three types of fiber transmission
  – Step index multimode
    • Variety of angles that reflect. Each angle defines a path or a mode
    • Limited data rate due to the different path lengths

– Single mode
  • The diameter of the core is reduced to the order of wavelength s.t. only a single angle or mode can pass
  • Superior performance
– Graded index multimode

- Use the fact that speed of light depends on the medium; light travels faster through less optically dense media.

- The boundary between core and cladding is not sharply defined; Moving out radially from the core, the material becomes gradually less dense.

![Diagram of fiber with different optical density layers and light waves A and B showing A travels a greater distance but faster than B.]

### Typical fiber characteristics

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>Core diameter (μm)</th>
<th>Cladding diameter (μm)</th>
<th>850 nm</th>
<th>1300 nm</th>
<th>1500 nm</th>
<th>Bandwidth (MHz/km) (Max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Mode</td>
<td>5.0</td>
<td>85 or 125</td>
<td>2.3</td>
<td>0.5</td>
<td>0.25</td>
<td>5000 @ 850 nm</td>
</tr>
<tr>
<td></td>
<td>8.1</td>
<td>125</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graded-index</td>
<td>50</td>
<td>125</td>
<td>2.4</td>
<td>0.6</td>
<td>0.5</td>
<td>600 @ 850 nm</td>
</tr>
<tr>
<td></td>
<td>62.5</td>
<td>125</td>
<td>3.0</td>
<td>0.7</td>
<td>0.3</td>
<td>1500 @ 1300 nm</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>140</td>
<td>3.5</td>
<td>1.5</td>
<td>0.9</td>
<td>200 @ 850 nm</td>
</tr>
<tr>
<td>Step-index</td>
<td>200 or 300</td>
<td>380 or 440</td>
<td>6.0</td>
<td></td>
<td></td>
<td>500 @ 1300 nm</td>
</tr>
</tbody>
</table>
2. Wireless Transmission

• (Terrestrial) Microwave
  – Typically used where laying a cable is not practical (No right-of-way needed)
  – Parabolic dish shaped antenna (≈10 ft dia) transmits/receives electromagnetic waves in the 2-40 GHz range
  – Travels in a straight line (line-of-sight propagation)
  – Maximum distance bet antenna in km
    \[ d = 7.14 \sqrt{(4/3)h} \]
    \( h \): antenna ht in meters
  – High data rates: 100’s Mbps
  – Attenuation
    \[ 10 \log \left( \frac{4 \pi d}{\lambda} \right)^2 \] dB
    \( d \): distance
    \( \lambda \): wavelength
  – Repeaters spaced 10 - 100 km apart
  – Applications
    • Long-distance telephone communication
• **Satellite Microwave**
  - Uses satellite in geostationary (geosynchronous) orbit (≈ 36,000 km)
  - Source transmits signal to satellite which amplifies or repeats it, and retransmits down to destinations
  - Optimum transmission in 1 - 10 GHz range; Bandwidth of 100’s MHz
  - Significant propagation delay ≈ 270ms
  - Total propagation delay is independent of distance between sender and receiver
  - Applications:
    - Long-distance telephones
    - Television distribution
    - Private business networks
• Satellite Microwave (Cont’d)
  – VSAT (Very Small Aperture System)
    • For business data applications requiring high data rates for short periods of time (National Weather Service, news services, credit card verification, automatic tellers, car rental agencies, …)
    • Commonly connects a central location with many remote ones
    • Communication between two sites is via a satellite and allows a low-cost small antenna dishes (≈ 5 ft)
- (Broadcast) Radio
  - Electromagnetic wave in the range 30MHz ~ 1GHz
  - Omnidirectional
  - As with microwave,
    \[ d = 7.14 \sqrt{\frac{4}{3}h} \]  
    where \( h \) is the antenna height in meters
  - Less attenuation than microwave since \( \lambda \) is larger

- Infrared
  - For short-range communication
    - Remote controls for TVs, VCRs, and stereos
    - Indoor wireless LANs
  - Do not pass through solid walls
    - Better security and no interference (with a similar system in adjacent rooms)
  - No government license is needed
  - Cannot be used outdoors (due to the sunshine)