Transmission Media

- Transmission medium
  - Physical path between transmitter and receiver
  - May be guided (wired) or unguided (wireless)
  - Communication achieved by using EM waves
- Characteristics and quality of data transmission
  - Dependent on characteristics of medium and signal
  - Guided medium
    * Medium is more important in setting transmission parameters
  - Unguided medium
    * Bandwidth of the signal produced by transmitting antenna is important in setting transmission parameters
    * Signal directionality
      · Lower frequency signals are omnidirectional
      · Higher frequency signals can be focused in a directional beam
- Design of data transmission system
  - Concerned with data rate and distance
  - Bandwidth
    * Higher bandwidth implies higher data rate
  - Transmission impairments
    * Attenuation
    * Twisted pair has more attenuation than coaxial cable which in turn is not as good as optical fiber
  - Interference
    * Can be minimized by proper shielding in guided media
  - Number of receivers
    * In a shared link, each attachment introduces attenuation and distortion on the line

Guided transmission media

- Transmission capacity (bandwidth and data rate) depends on distance and type of network (point-to-point or multipoint)
- Twisted pair
  - Least expensive and most widely used
  - Physical description
    * Two insulated copper wires arranged in regular spiral pattern
    * Number of pairs are bundled together in a cable
    * Twisting decreases the crosstalk interference between adjacent pairs in the cable, by using different twist length for neighboring pairs
  - Applications
    * Most common transmission media for both digital and analog signals

        - Less expensive compared to coaxial cable or optical fiber
        - Limited in terms of data rate and distance
        - Telephone network
            - Individual units (residence lines) to local exchange (end office)
            - Subscriber loops
            - Supports voice traffic using analog signaling
            - May handle digital data at modest rates using modems
        - Communications within buildings
            - Connection to digital data switch or digital PBX within a building
            - Allows data rate of 64 kbps
    - Transmission characteristics
        - Requires amplifiers every 5-6 km for analog signals
        - Requires repeaters every 2-3 km for digital signals
        - Attenuation is a strong function of frequency
            - Higher frequency implies higher attenuation
        - Susceptible to interference and noise
        - Improvement possibilities
            - Shielding with metallic braids or sheathing reduces interference
            - Twisting reduces low frequency interference
            - Different twist length in adjacent pairs reduces crosstalk
    - Unshielded and shielded twisted pairs
        - Unshielded twisted pair (UTP)
            - Ordinary telephone wire
            - Subject to external electromagnetic interference
        - Shielded twisted pair (STP)
            - Shielded with a metallic braid or sheath
            - Reduces interference
            - Better performance at higher data rates
            - More expensive and difficult to work compared to UTP
    - Category 3 and Category 5 UTP
        - Most common is the 100-ohm voice grade twisted pair
        - Most useful for LAN applications
        - Category 3 UTP
            - Transmission characteristics specified up to 16 MHz
            - Voice grade cable in most office buildings
            - May have data rates up to 16 Mbps over limited distances
            - Typical twist length 7.5 to 10 cm
        - Category 4 UTP
            - Transmission characteristics specified up to 20 MHz
        - Category 5 UTP
            - Transmission characteristics specified up to 100 MHz
            - Data grade cable in newer buildings
            - May have data rates up to 100 Mbps over limited distances
            - Much more tightly twisted, with typical twist length 0.6 to 0.85 cm, for better performance

- Coaxial cable

- Physical description
  * Consists of two conductors with construction that allows it to operate over a wider range of frequencies compared to twisted pair
  * Hollow outer cylindrical conductor surrounding a single inner wire conductor
  * Inner conductor held in place by regularly spaced insulating rings or solid dielectrical material
  * Outer conductor covered with a jacket or shield
  * Diameter from 1 to 2.5 cm
  * Shielded concentric construction reduces interference and crosstalk
  * Can be used over longer distances and support more stations on a shared line than twisted pair
- Applications
  * Most common use is in cable TV
  * Traditionally part of long distance telephone network
  * Can carry more than 10,000 voice channels simultaneously using frequency-division multiplexing
  * Short range connections between devices
- Transmission characteristics
  * Used to transmit both analog and digital signals
  * Superior frequency characteristics compared to twisted pair
  * Can support higher frequencies and data rates
  * Shielded concentric construction makes it less susceptible to interference and crosstalk than twisted pair
  * Constraints on performance are attenuation, thermal noise, and intermodulation noise
  * Requires amplifiers every few kilometers for long distance transmission
  * Usable spectrum for analog signaling up to 500 MHz
  * Requires repeaters every few kilometers for digital transmission
  * For both analog and digital transmission, closer spacing is necessary for higher frequencies/data rates

• Optical fiber
  - Thin, flexible material to guide optical rays
  - Cylindrical cross-section with three concentric links
    1. Core
       * Innermost section of the fiber
       * One or more very thin (dia. 8-100 μm) strands or fibers
    2. Cladding
       * Surrounds each strand
       * Plastic or glass coating with optical properties different from core
       * Interface between core and cladding prevents light from escaping the core
    3. Jacket
       * Outermost layer, surrounding one or more claddings
       * Made of plastic and other materials
       * Protects from environmental elements like moisture, abrasions, and crushing
  - Comparison with twisted pair and coaxial cable
    * Capacity
      · Much higher bandwidth
      · Can carry hundreds of Gbps over tens of kms
    * Smaller size and light weight
      · Very thin for similar data capacity

        - Much lighter and easy to support in terms of weight (structural properties)
    - Significantly lower attenuation
    - EM isolation
        - Not affected by external EM fields
        - Not vulnerable to interference, impulse noise, or crosstalk
        - No energy radiation; little interference with other devices; security from eavesdropping
    - Greater repeater spacing
        - Lower cost and fewer error sources
- Applications
    - Long haul trunks
        - Increasingly common in telephone networks
        - About 1500km in length with high capacity (20000 to 60000 voice channels)
    - Metropolitan trunks
        - Average length of about 12 km with a capacity of 100,000 voice channels
        - Mostly repeaterless to join phone exchanges in metro areas
    - Rural exchange trunks
        - Circuit lengths from 40 to 160 km
        - Fewer than 5000 voice channels
        - Connect exchanges of different phone companies
    - Subscriber loops
        - Central exchange to subscriber
        - May be able to handle image and video in addition to voice and data
    - Local area networks
        - 100Mbps to 1Gbps capacity
        - Can support hundreds of stations on a campus
- Transmission characteristics
    - Single-encoded beam of light transmitted by total internal reflection
    - Transparent medium should have higher refractive index compared to surrounding medium

      Refractive Index – The ratio of the speed of light in a vacuum to the speed of light in a medium under consideration
    - Optical fiber acts as a waveguide for frequencies in the range of about 10^{14} to 10^{15} Hz (IR and visible regions of spectrum)
    - Step-index multimode
        - Rays at shallow angles are reflected and propagated along the fiber
        - Other rays are absorbed by the surrounding material
    - Multimode transmission
        - Allows for multiple propagation paths, with different path lengths and time to traverse the fiber
        - Signal elements can be spread over time
        - Limits the rate at which data can be accurately received
        - Best suited for transmission over very short distances
    - Single-mode transmission
        - Reduced fiber core will allow fewer angles to be reflected
        - Single transmission path reduces distortion
        - Typically used for long-distance applications
    - Graded-index multimode
        - Lies in between single-mode and multimode

      · Higher refractive index at the center implies that the rays close to axis advance slowly compared to rays close to the cladding
      · Light in the core curves helically reducing its traveling distance (does not zig zag off the cladding)
      · Shorter path and higher speed makes light at periphery as well as at the axis travel at the same speed
    * Light sources
      1. Light-emitting diode (LED)
         · Cheaper and works over a greater temperature range
         · Longer operational life
      2. Injection laser diode (ILD)
         · More efficient and can sustain greater data rates
  - Wavelength-division multiplexing
    * Multiple beams of light at different frequencies can be transmitted simultaneously
    * Form of frequency-division multiplexing (FDM) commonly known as wavelength-division multiplexing (WDM)

Wireless Transmission

- Transmission and reception are achieved using an antenna
  - Transmitter sends out the EM signal into the medium
  - Receiver picks up the signal from the surrounding medium
- Directional transmission
  - Transmitter sends out a focused EM beam
  - Transmitter and receiver antennae must be carefully aligned
  - More suitable for higher frequency signals
- Omnidirectional transmission
  - Transmitted signal spreads out in all directions
  - May be received by many antennae
- Frequency ranges for wireless transmission
  1. 2 GHz – 40 GHz
     - Microwave frequencies
     - Highly directional beams for point-to-point communications
     - Also used for satellite communication
  2. 30 MHz – 1 GHz
     - Broadcast radio range
     - Suitable for omnidirectional purposes
  3. 3×10^{11} HZ – 2×10^{14} Hz
     - Infrared portion of the spectrum
     - Useful for local point-to-point and multipoint applications within confined areas
     - TV remote
- Terrestrial microwave
  - Physical description

    * Parabolic dish antenna, about 3m in diameter
    * Fixed rigidly with a focused beam along line of sight to receiving antenna
    * With no obstacles, maximum distance (d, in km) between antennae can be

$$d = 7.14\sqrt{Kh}$$

      where h is antenna height and K is an adjustment factor to account for the bend in microwave due to earth's curvature, enabling it to travel further than the line of sight; typically $K = \frac{4}{3}$
    * Two microwave antennae at a height of 100m may be as far as

$$7.14 \times \sqrt{133} = 82km$$

    * Long distance microwave transmission is achieved by a series of microwave relay towers
  – Applications
    * Long haul telecom service
    * Fewer repeaters than coaxial cable but needs line of sight
  – Transmission characteristics
    * Frequencies in the range of 2 – 40 GHz
    * Higher frequency implies higher bandwidth leading to higher data rates
    * Loss L due to attenuation over distance d at wavelength λ is expressed as

$$L = 10\log\left(\frac{4\pi d}{\lambda}\right)^2 \text{ dB}$$

      · Loss varies as the square of distance
      · For twisted pair and coaxial cable, loss varies logarithmically with distance
    * Repeaters may be placed further apart compared to coaxial cable
    * Attenuation may increase with rainfall, especially above 10 GHz
    * Interference is a problem, leading to regulated assignment of frequencies

• Satellite microwave
  – Physical description
    * Communication satellite is a microwave relay station between two or more ground stations (also called earth stations)
    * Satellite uses different frequency bands for incoming (uplink) and outgoing (downlink) data
    * A single satellite can operate on a number of frequency bands, known as *transponder channels* or *transponders*
    * Geosynchronous orbit (35,784 km)
    * Satellites cannot be too close to each other to avoid interference
      · Current standard requires a 4° displacement in the 4/6 GHz band and 3° displacement at 12/14 GHZ
      · This limits the number of available satellites
  – Applications
    * Television/telephone/private business networks
    * VSAT – Very small aperture terminals
      · Used to share a satellite capacity for data transmission
  – Transmission characteristics
    * Optimum frequency range in 1–10 GHZ
    * Below 1 GHz, significant noise from galactic, solar, and atmospheric noise, and terrestrial electronic devices

    * Above 1 GHz, signal attenuated by atmospheric absorption and precipitation
    * Most satellites use 5.925–6.425 GHz band for uplink and 4.2–4.7 GHz band for downlink (4/6 band)
    * Propagation delay of about a quarter second due to long distance
      · Problems in error control and flow control
      · Inherently broadcast, leading to security problems

- Broadcast radio
  - Physical description
    * Omnidirectional transmission
    * No need for dish antennae
  - Applications
    * Frequencies from 3 kHz to 300 GHz
    * Radio/Television/Data networking
  - Transmission characteristics
    * 30 MHz to 1 GHz (UHF band) used for broadcast communications
    * Ionosphere transparent to radio waves above 30 MHz
      · Transmission limited to line of sight
      · Distant transmitters do not interfere with each other due to reflection from atmosphere
    * Less sensitive to attenuation from rainfall
    * Maximum distance between transmitter and receiver is given by same equation as microwave; same for attenuation
    * Impairment due to multipath interference
      · Reflection from land, water, natural, man-made objects
- Infrared
  - Limited to short distances and highly directional
  - Cannot penetrate walls
  - No licensing; no frequency allocation issues