Introduction

- An antenna is an electrical conductor or system of conductors
  - Transmission - radiates electromagnetic energy into space
  - Reception - collects electromagnetic energy from space

- In two-way communication, the same antenna can be used for transmission and reception
Radiation Patterns

- Radiation pattern
  - Graphical representation of radiation properties of an antenna
  - Depicted as two-dimensional cross section

- Beam width (or half-power beam width)
  - Measure of directivity of antenna
  - Angle within which power radiated is at least half of that in most preferred direction

- Reception pattern
  - Receiving antenna’s equivalent to radiation pattern

- Omnidirectional vs. directional antenna
Types of Antennas

- Isotropic antenna (idealized)
  - Radiates power equally in all directions

- Dipole antennas
  - Half-wave dipole antenna (or Hertz antenna)
  - Quarter-wave vertical antenna (or Marconi antenna)

- Parabolic Reflective Antenna
  - Used for terrestrial microwave and satellite applications
  - Larger the diameter, the more tightly directional is the beam
**Antenna Gain**

- **Antenna gain**
  - Power output, in a particular direction, compared to that produced in any direction by a perfect omnidirectional antenna (isotropic antenna)

- **Expressed in terms of effective area**
  - Related to physical size and shape of antenna
Antenna Gain

- Relationship between antenna gain and effective area

\[ G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2} \]

- \( G \) = antenna gain
- \( A_e \) = effective area
- \( f \) = carrier frequency
- \( c \) = speed of light (\( \approx 3 \times 10^8 \) m/s)
- \( \lambda \) = carrier wavelength
Propagation Modes

- Ground-wave propagation
- Sky-wave propagation
- Line-of-sight propagation
Ground Wave Propagation
Ground Wave Propagation

- Follows contour of the earth
- Can Propagate considerable distances
- Frequencies up to 2 MHz
- Example
  - AM radio
Sky Wave Propagation
Sky Wave Propagation

- Signal reflected from ionized layer of atmosphere back down to earth
- Signal can travel a number of hops, back and forth between ionosphere and earth’s surface
- Reflection effect caused by refraction
- Examples
  - Amateur radio
  - CB radio
  - International broadcasts
Line-of-Sight Propagation
Line-of-Sight Propagation

- Above 30 MHz neither ground nor sky wave propagation operates
- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz not reflected by ionosphere
  - Ground communication – antennas within effective line of site due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums
Line-of-Sight Equations

- Optical line of sight
  \[ d = 3.57 \sqrt{h} \]

- Effective, or radio, line of sight
  \[ d = 3.57 \sqrt{K h} \]

- \( d \) = distance between antenna and horizon (km)
- \( h \) = antenna height (m)
- \( K \) = adjustment factor to account for refraction, rule of thumb \( K = 4/3 \)
Line-of-Sight Equations

Maximum distance between two antennas for LOS propagation:

\[ 3.57 \left( \sqrt{K h_1} + \sqrt{K h_2} \right) \]

- \( h_1 \) = height of antenna one
- \( h_2 \) = height of antenna two
LOS Wireless Transmission Impairments

- Attenuation
  - Free space loss
- Distortion
- Dispersion
- Noise
- Other effects:
  - Atmospheric absorption
  - Multipath
  - Refraction
Attenuation

- Strength of signal falls off with distance over transmission medium

- Attenuation factors for unguided media:
  - Received signal must have sufficient strength so that circuitry in the receiver can interpret the signal
  - Signal must maintain a level sufficiently higher than noise to be received without error
  - Attenuation is greater at higher frequencies, causing distortion
Free Space Loss

- Free space loss, ideal isotropic antenna

\[
\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi fd)^2}{c^2}
\]

- \(P_t\) = signal power at transmitting antenna
- \(P_r\) = signal power at receiving antenna
- \(\lambda\) = carrier wavelength
- \(d\) = propagation distance between antennas
- \(c\) = speed of light \((\approx 3 \times 10^8 \text{ m/s})\)

where \(d\) and \(\lambda\) are in the same units (e.g., meters)
Free Space Loss

Free space loss equation can be recast:

$$L_{dB} = 10 \log \frac{P_t}{P_r} = 20 \log \left( \frac{4\pi d}{\lambda} \right)$$

$$= -20 \log(\lambda) + 20 \log(d) + 21.98 \text{ dB}$$

$$= 20 \log \left( \frac{4\pi fd}{c} \right) = 20 \log(f) + 20 \log(d) - 147.56 \text{ dB}$$
Free Space Loss

- Free space loss accounting for gain of antennas

\[
\frac{P_t}{P_r} = \frac{(4\pi)^2 (d)^2}{G_r G_t \lambda^2} = \frac{(\lambda d)^2}{A_r A_t} = \frac{(cd)^2}{f^2 A_r A_t}
\]

- \( G_t \) = gain of transmitting antenna
- \( G_r \) = gain of receiving antenna
- \( A_t \) = effective area of transmitting antenna
- \( A_r \) = effective area of receiving antenna

- In the above formula, the powers correspond to that of the input signal at the transmitter and output at the receiver, respectively
Free Space Loss

Free space loss accounting for gain of other antennas can be recast as

\[ L_{dB} = 20 \log(\lambda) + 20 \log(d) - 10 \log(A_t A_r) \]

\[ = -20 \log(f) + 20 \log(d) - 10 \log(A_t A_r) + 169.54 \text{dB} \]
Path Loss Exponents

- The free space path loss model is idealized

\[ \frac{P_t}{P_r} = Ad^\alpha \]

- Here the exponent \( \alpha \) depends on the transmission environment
  - Urban vs suburban, medium-city vs large-city, obstructed vs unobstructed, indoors vs outdoors
  - Generally between 2 and 4
  - Obtained empirically

- Two-ray, ten-ray, and general statistical models
Distortion

- Signals at higher frequencies attenuate more than that at lower frequencies.
- Shape of a signal comprising of components in a frequency band is distorted.
- To recover the original signal shape, attenuation is equalized by amplifying higher frequencies more than lower ones.
Dispersion

- Electromagnetic energy spreads in space as it propagates.
- Consequently, bursts sent in rapid succession tend to merge as they propagate.
- For guided media such as optical fiber, fundamentally limits the product $R \times L$, where $R$ is the rate and $L$ is the usable length of the fiber.
- Term generally refers to how a signal spreads over space and time.
Categories of Noise

- Thermal Noise
- Intermodulation noise
- Crosstalk
- Impulse Noise
Thermal Noise

- Thermal noise due to agitation of electrons
- Present in all electronic devices and transmission media
- Cannot be eliminated
- Function of temperature
- Particularly significant for satellite communication
Thermal Noise

Amount of thermal noise to be found in a bandwidth of 1Hz in any device or conductor is:

\[ N_0 = kT \text{ (W/Hz)} \]

- \( N_0 \) = noise power density in watts per 1 Hz of bandwidth
- \( k \) = Boltzmann's constant = \( 1.3803 \times 10^{-23} \text{ J/K} \)
- \( T \) = temperature, in kelvins (absolute temperature)
Thermal Noise

- Noise is assumed to be independent of frequency
- Thermal noise present in a bandwidth of $B$ Hertz (in watts):

$$N = kTB$$

or, in decibel-watts

$$N = 10 \log k + 10 \log T + 10 \log B$$

$$= -228.6 \text{ dBW} + 10 \log T + 10 \log B$$
Other Kinds of Noise

- Intermodulation noise – occurs if signals with different frequencies share the same medium
  - Interference caused by a signal produced at a frequency that is the sum or difference of original frequencies
- Crosstalk – unwanted coupling between signal paths
- Impulse noise – irregular pulses or noise spikes
  - Short duration and of relatively high amplitude
  - Caused by external electromagnetic disturbances, or faults and flaws in the communications system
  - Primary source of error for digital data transmission
Expression $E_b/N_0$

- Ratio of signal energy per bit to noise power density per Hertz

$$\frac{E_b}{N_0} = \frac{S \times R}{N_0} = \frac{S}{kTR}$$

- The bit error rate for digital data is a function of $E_b/N_0$
  - Given a value for $E_b/N_0$ to achieve a desired error rate, parameters of this formula can be selected
  - As bit rate $R$ increases, transmitted signal power must increase to maintain required $E_b/N_0$
Other Impairments

- Atmospheric absorption – water vapor and oxygen contribute to attenuation
- Multipath – obstacles reflect signals so that multiple copies with varying delays are received
- Refraction – bending of radio waves as they propagate through the atmosphere
Fading

- Variation over time or distance of received signal power caused by changes in the transmission medium or path(s)

- In a fixed environment:
  - Changes in atmospheric conditions

- In a mobile environment:
  - Multipath propagation
Multipath Propagation

- **Reflection** - occurs when signal encounters a surface that is large relative to the wavelength of the signal.
- **Diffraction** - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave.
- **Scattering** – occurs when incoming signal hits an object whose size is in the order of the wavelength of the signal or less.
Figure 5.10 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]
Effects of Multipath Propagation

- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Intersymbol interference (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit
Types of Fading

- Fast fading
  - Changes in signal strength in a short time period

- Slow fading
  - Changes in signal strength in a short time period

- Flat fading
  - Fluctuations proportionally equal over all frequency components

- Selective fading
  - Different fluctuations for different frequencies

- Rayleigh fading
  - Multiple indirect paths, but no dominant path such as LOS path
  - Worst-case scenario

- Rician fading
  - Multiple paths, but LOS path dominant
  - Parametrized by K, ratio of power on dominant path to that on other paths
Error Compensation Mechanisms

- Forward error correction
- Adaptive equalization
- Diversity techniques
Forward Error Correction

- Transmitter adds error-correcting code to data block
  - Code is a function of the data bits
- Receiver calculates error-correcting code from incoming data bits
  - If calculated code matches incoming code, no error occurred
  - If error-correcting codes don’t match, receiver attempts to determine bits in error and correct
Adaptive Equalization

- Can be applied to transmissions that carry analog or digital information
  - Analog voice or video
  - Digital data, digitized voice or video
- Used to combat intersymbol interference
- Involves gathering dispersed symbol energy back into its original time interval
- Techniques
  - Lumped analog circuits
  - Sophisticated digital signal processing algorithms
Diversity Techniques

- **Space diversity:**
  - Use multiple nearby antennas and combine received signals to obtain the desired signal
  - Use collocated multiple directional antennas

- **Frequency diversity:**
  - Spreading out signal over a larger frequency bandwidth
  - Spread spectrum

- **Time diversity:**
  - Noise often occurs in bursts
  - Spreading the data out over time spreads the errors and hence allows FEC techniques to work well
  - TDM
  - Interleaving