

# Antennas and Propagation

## Chapter 5

### 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
- Reception pattern
  - Receiving antenna's equivalent to radiation pattern

### 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

### Antenna Gain

- Antenna gain
  - Power output, in a particular direction, compared to that produced in any direction by a perfect omnidirectional antenna (isotropic antenna)
- Effective area
  - Related to physical size and shape of antenna

### Antenna Gain

- Relationship between antenna gain and effective area

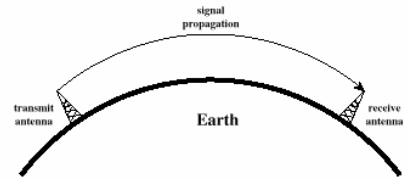
$$G = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi f^2 A_e}{c^2}$$

- $G$  = 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

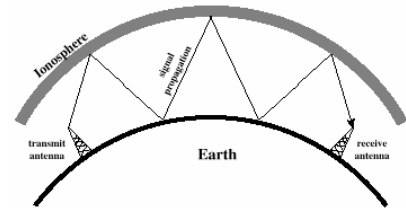
## Ground Wave Propagation



## Ground Wave Propagation

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

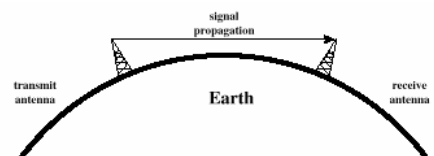
## Sky Wave Propagation



## 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

## Line-of-Sight Propagation



## Line-of-Sight Propagation

- 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  

$$d = 3.57\sqrt{Kh}$$
  - $d$  = 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:

$$3.57(\sqrt{Kh_1} + \sqrt{Kh_2})$$

- $h_1$  = height of antenna one
- $h_2$  = height of antenna two

## LOS Wireless Transmission Impairments

- Attenuation and attenuation distortion
- Free space loss
- Noise
- Atmospheric absorption
- Multipath
- Refraction
- Thermal noise

## 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

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

- $P_t$  = signal power at transmitting antenna
  - $P_r$  = signal power at receiving antenna
  - $\lambda$  = carrier wavelength
  - $d$  = propagation distance between antennas
  - $c$  = speed of light ( $\approx 3 \times 10^8$  m/s)
- where  $d$  and  $\lambda$  are in the same units (e.g., meters)

## Free Space Loss

- Free space loss equation can be recast:

$$\begin{aligned} L_{dB} &= 10 \log \frac{P_t}{P_r} = 20 \log \left( \frac{4\pi d}{\lambda} \right) \\ &= -20 \log(\lambda) + 20 \log(d) + 21.98 \text{ dB} \\ &= 20 \log \left( \frac{4\pi f d}{c} \right) = 20 \log(f) + 20 \log(d) - 147.56 \text{ dB} \end{aligned}$$

## Free Space Loss

- Free space loss accounting for gain of other 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

## Free Space Loss

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

$$\begin{aligned} L_{dB} &= 20 \log(\lambda) + 20 \log(d) - 10 \log(A_t A_r) \\ &= -20 \log(f) + 20 \log(d) - 10 \log(A_t A_r) + 169.54 \text{ dB} \end{aligned}$$

## 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 =  $1.3803 \times 10^{-23}$  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

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

$$= -228.6 \text{ dBW} + 10 \log T + 10 \log B$$

## Noise Terminology

- 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

## Expression $E_b/N_0$

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

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

- 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

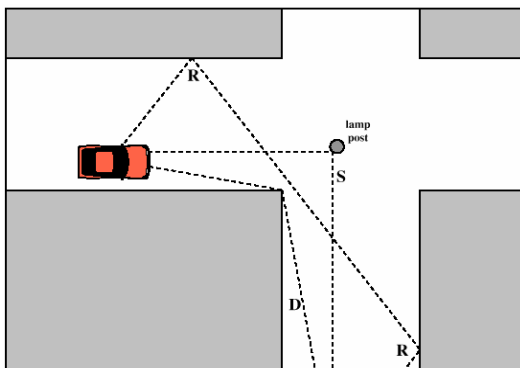


Figure 5.10 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]

## 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

## The 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
- Slow fading
- Flat fading
- Selective fading
- Rayleigh fading
- Rician fading

## 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

- Diversity is based on the fact that individual channels experience independent fading events
- Space diversity – techniques involving physical transmission path
- Frequency diversity – techniques where the signal is spread out over a larger frequency bandwidth or carried on multiple frequency carriers
- Time diversity – techniques aimed at spreading the data out over time