

Transmission Media, Antennas and Propagation

Chapter 5

Classifications of Transmission Media

- Transmission Medium
 - Physical path between transmitter and receiver
- Guided Media
 - Waves are guided along a solid medium
 - E.g., copper twisted pair, copper coaxial cable, optical fiber
- Unguided Media
 - Provides means of transmission but does not guide electromagnetic signals
 - Usually referred to as wireless transmission
 - E.g., atmosphere, outer space

Unguided Media

- Transmission and reception are achieved by means of an antenna
- Configurations for wireless transmission
 - Directional
 - Omnidirectional

General Frequency Ranges

- Microwave frequency range
 - 1 GHz to 40 GHz
 - Directional beams possible
 - Suitable for point-to-point transmission
 - Used for satellite communications
- Radio frequency range
 - 30 MHz to 1 GHz
 - Suitable for omnidirectional applications
- Infrared frequency range
 - Roughly, 3×10^{11} to 2×10^{14} Hz
 - Useful in local point-to-point multipoint applications within confined areas

Terrestrial Microwave

- Description of common microwave antenna
 - Parabolic "dish", 3 m in diameter
 - Fixed rigidly and focuses a narrow beam
 - Achieves line-of-sight transmission to receiving antenna
 - Located at substantial heights above ground level
- Applications
 - Long haul telecommunications service
 - Short point-to-point links between buildings

Satellite Microwave

- Description of communication satellite
 - Microwave relay station
 - Used to link two or more ground-based microwave transmitter/receivers
 - Receives transmissions on one frequency band (uplink), amplifies or repeats the signal, and transmits it on another frequency (downlink)
- Applications
 - Television distribution
 - Long-distance telephone transmission
 - Private business networks



Broadcast Radio

- Description of broadcast radio antennas
 - Omnidirectional
 - Antennas not required to be dish-shaped
 - Antennas need not be rigidly mounted to a precise alignment
- Applications
 - Broadcast radio
 - VHF and part of the UHF band; 30 MHz to 1GHz
 - Covers FM radio and UHF and VHF television



Introduction to Antenna

- 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)
- λ = carrier wavelength

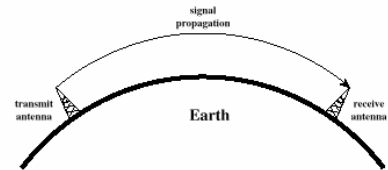


Propagation Modes

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



Ground Wave Propagation

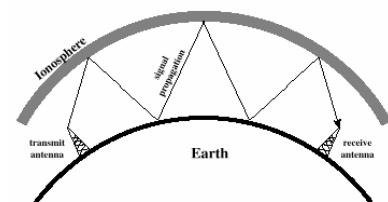


Ground Wave Propagation

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



Sky Wave Propagation

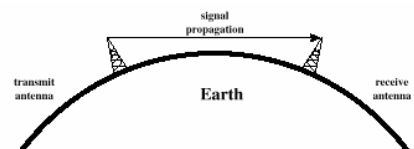


Sky Wave Propagation

- 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
 - Voice of America



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



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LOS Wireless Transmission Impairments

- Attenuation and attenuation distortion
- Free space loss: signal disperses with distance
- 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
 - Amplifiers are introduced to amplify high frequencies



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
 - λ = carrier wavelength
 - d = propagation distance between antennas
 - c = speed of light ($\approx 3 \times 10^8$ m/s)
- where d and λ 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

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

- 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
- Uniformly distributed across the frequency spectrum and hence is often referred to as **white noise**
- 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 = 1.3803×10^{-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
 - Due to the nonlinearity of the transmission system
- 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
 - A primary source of error for digital data transmission

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

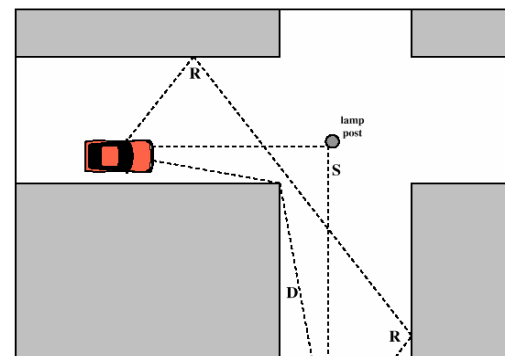


Figure 5.10 Sketch of Three Important Propagation Mechanisms: Reflection (R), Scattering (S), Diffraction (D) [ANDE95]

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