Wireless & Mobile Computing

First Semester 3rd Class

Lecture Eight

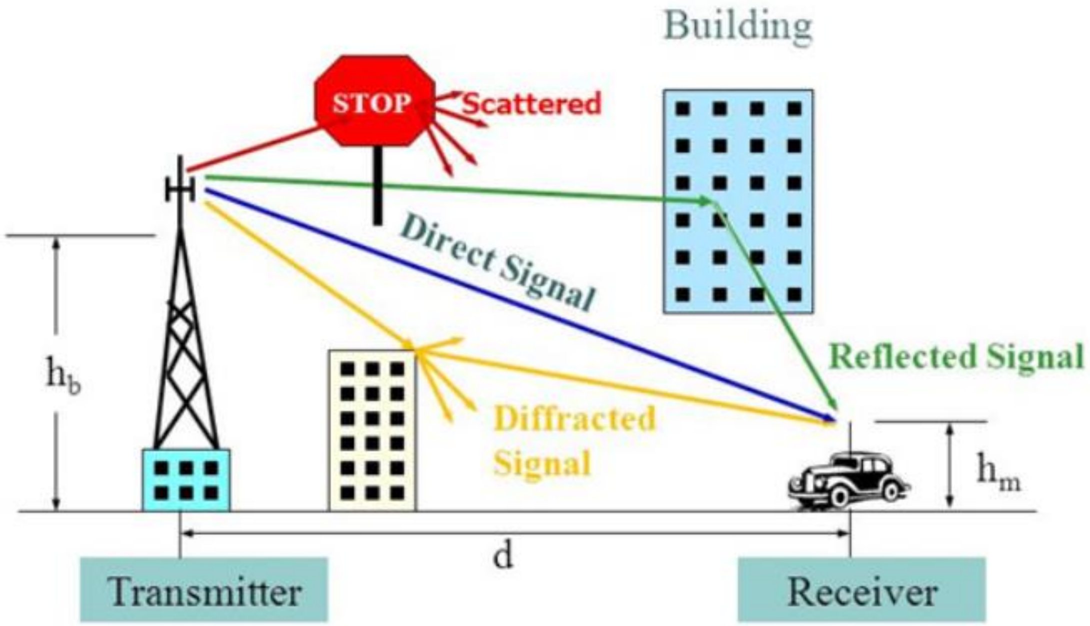
2025/2024

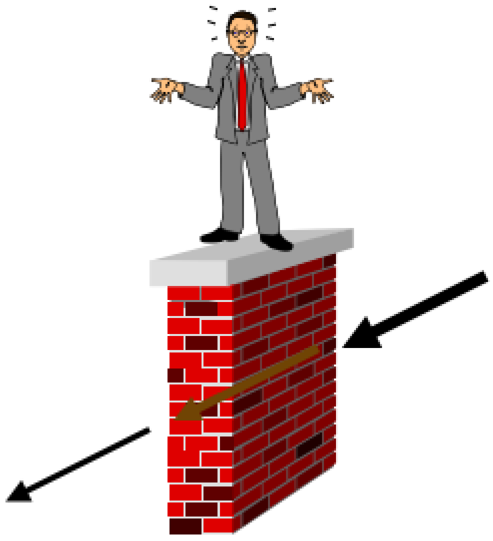
Signal Propagation and Distance Attenuation

- **Introduction to Signal Propagation Definition:**
- **Signal propagation is the movement of electromagnetic waves through space or a medium.**
- **In wireless networks, signals are transmitted from a source (transmitter) and received by a destination (receiver).**
- **Importance in Wireless Communication: Signal propagation determines how far and how reliably information can travel from sender to receiver.**

Signal Propagation and Distance Attenuation

- **Distance Attenuation Definition**:
- Attenuation is the reduction in signal strength as the distance between transmitter and receiver increases.





transmission

Signal Propagation and Distance Attenuation

- **Path Loss**: Path loss is the weakening of signal power over distance, which is a major factor in determining wireless communication range.
- **RADIO WAVE:** is the wireless transmission and reception of electric impulses or signals by means of electromagnetic (EM) waves.
- Waves are present at all frequencies.
- We can utilize only a small part of this total spectrum to transmit communication signals referred to as the Radio Frequency (RF) spectrum and ranges from about 9 KHz to 300 GHz.

Signal Propagation and Distance Attenuation

- **A cycle** is the smallest portion of a waveform that, if repeated, would represent the entire waveform. Waveforms can be described as having the following properties:

1. a = Amplitude

- The measurement of a waveform above a center reference. With electromagnetic (EM) waves that can be modeled as a "ray" this is usually measured in volts or watts.

2. v = Velocity of Propagation

- The velocity of propagation of a wave is the velocity that a wave travels through a medium, and is usually measured in meters per second.

3. τ = Period

- The period of a wave is the time it takes for one cycle to pass a fixed point and is usually measured in seconds. It is designated by the Greek letter tau (τ).

Signal Propagation and Distance Attenuation

4. λ =Wavelength

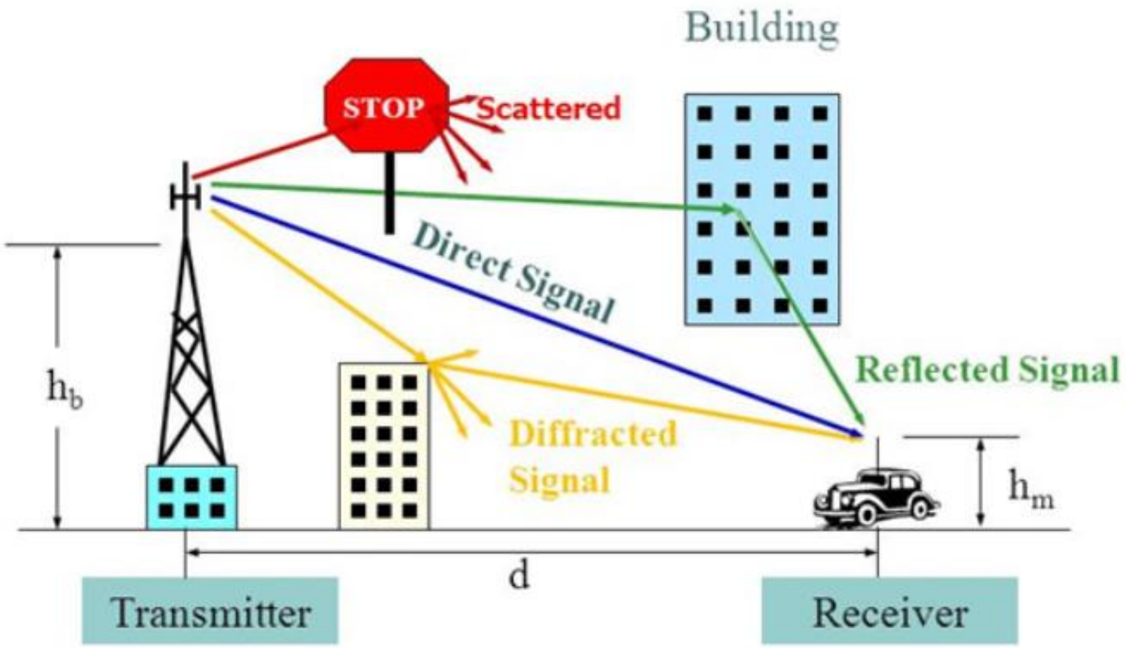
- The wavelength of a wave is the distance that the wave will propagate in one cycle and is usually measured in meters and designated by the Greek letter lambda (λ).

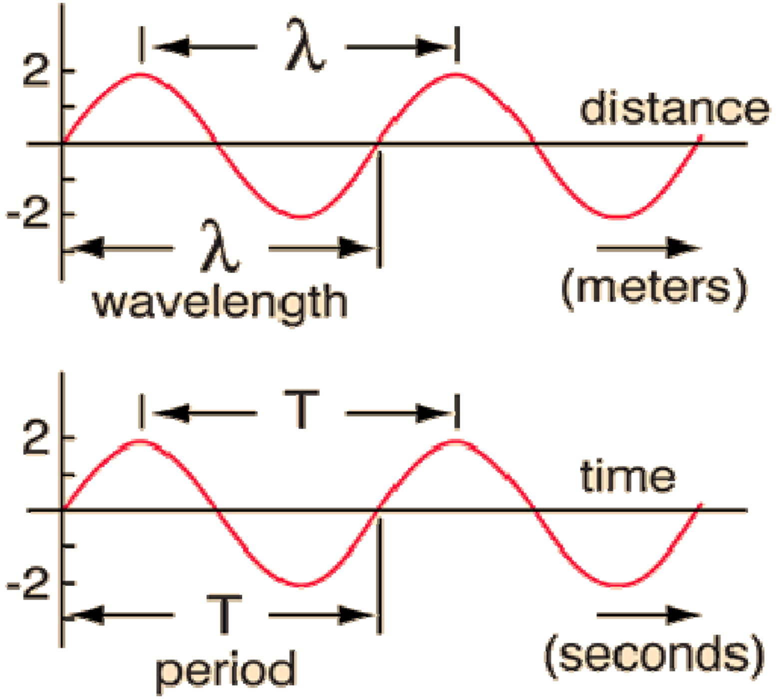
5. f = Frequency

- The frequency of a wave is the rate at which individual cycles pass a given point and is usually measured in cycles per second or Hertz (Hz), who discovered EM waves. All of these properties except amplitude are related by the following formula: **$f = 1/\tau = v/\lambda$**
- The velocity of propagation for EM waves is is equal to the speed of light **(3×10^8 m/s).**
- Substituting this constant for velocity yields the following: **$f = (3 \times 10^8 \text{ m/s}) / \lambda$**

Signal Propagation and Distance Attenuation

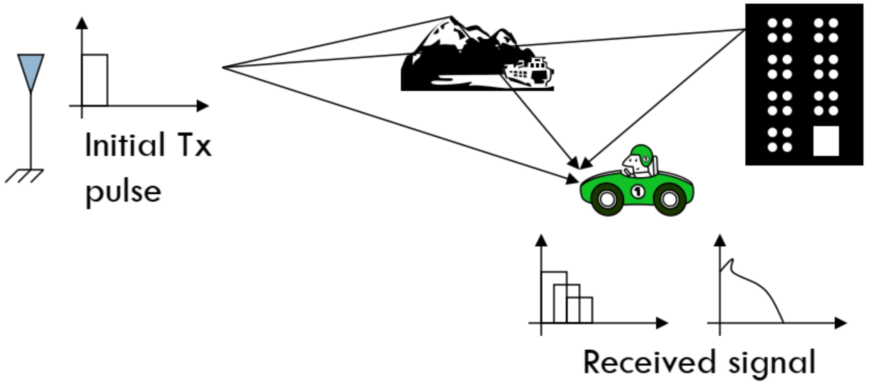
- **Signal Propagation** In a radio system, the path between the transmit and the receive antennas has obstacles. 1) Reflection occurs when a radio wave hits a smooth surface that is much greater than a wavelength and effectively bounces off.





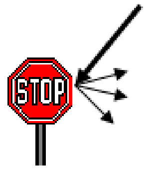
Signal Propagation and Distance Attenuation

- **Multipath Propagation:**
- Signals travel multiple paths due to reflection, diffraction, and scattering.
- This can cause interference, fading, and phase shifts at the receiver.
- **Multipath** Receiver gets combined radio waves from different directions with different path delays
- Received signal is very dependent on location - different phase relationships can cause signal fading and delay spread
- Causes **inter-symbol interference (ISI)** in digital systems, limits maximum symbol rate



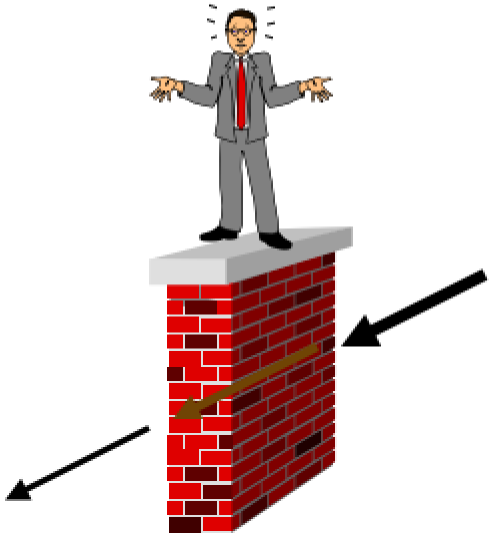
Signal Propagation and Distance Attenuation

- 2) Diffraction (or shadowing) occurs when the path between the transmitter and receiver is blocked by a dense object that is much greater than a wavelength, forming secondary waves behind the obstruction.
- 3) Scattering occurs when a radio wave hits either a rough surface or a surface with dimensions of a wavelength or less, causing reflected energy to scatter.



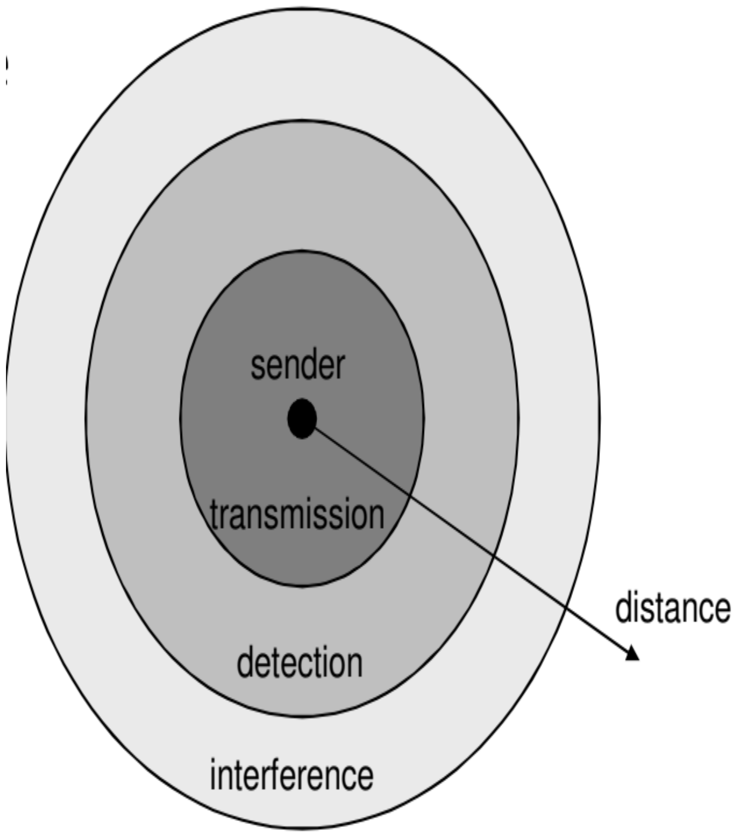
scattering


diffraction


transmission

Signal Propagation and Distance Attenuation

- **Signal propagation ranges**
- Transmission range
- communication possible
- low error rate
- Detection range
- detection of the signal possible
- no communication possible
- Interference range
- signal may not be detected
- signal adds to the background noise



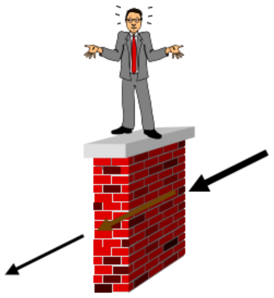
Signal Propagation and Distance Attenuation

- **Attenuation**
- Strength of signal falls off with distance over transmission medium
- Attenuation factors for wireless 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

Signal Propagation and Distance Attenuation

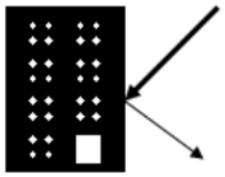
- Radio signals are effected by
- Ground terrain
- Atmosphere
- Objects
- Interference with other signals
- Distance (path loss)

- Basic mechanisms
- Transmission (propagation through a medium)
- Scattering (small objects less than wavelength)
- Reflection (objects much larger than wavelength)
- Waves may be reflected by stationary or moving objects
- Diffraction at the edges



transmission

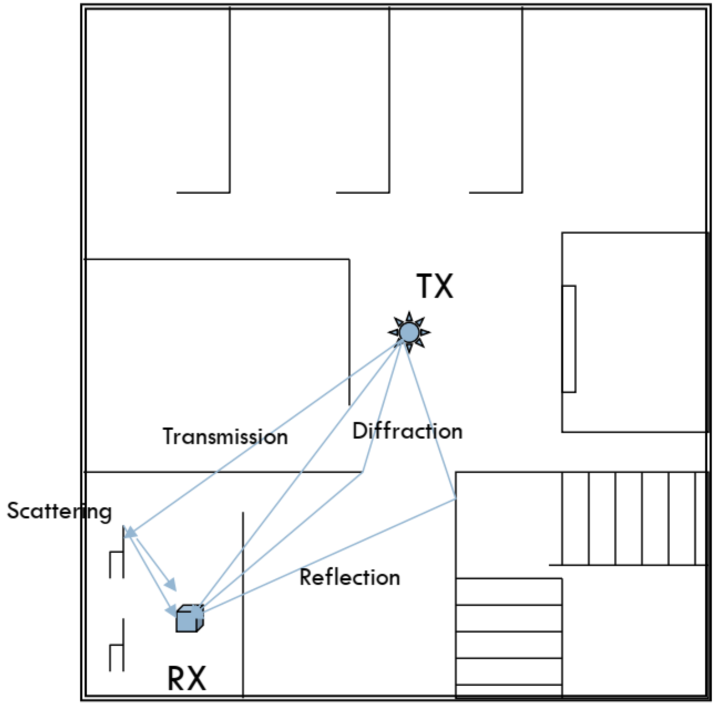
scattering



reflection

Signal Propagation and Distance Attenuation

- Signal is attenuated by a reflection factor
- Attenuation depends on
- Nature of material
- Frequency of the carrier
- Angle of incidence
- Nature of the surface



- Usually transmission *through an object* leads to larger losses (absorption) than reflection
- Multiple reflections can result in a weak signal

The Radio Channel

- Three main issues in radio propagation

1. Coverage

- How far does the signal propagate over a given terrain التضاريس at a particular frequency?
- Power or received signal strength (RSS)

2. Performance

- Bit error rate
- Statistics of fading – amplitudes and durations

3. Data rate (capacity)

- Multipath structure

The Radio Channel

- A **fading channel** is a type of communication channel where the **signal strength** varies over time or space due to multiple factors, leading to **fading** in the received signal.
- This phenomenon is common in **wireless communication** due to signal interference, environmental obstacles, and the movement of either the sender or receiver, causing variations in the received signal's amplitude, phase, and frequency.

The Radio Channel

- **Types of Fading**

1. **Small-Scale Fading (Multipath Fading)**:
    1. Caused by **multipath propagation**, where transmitted signals take different paths to reach the receiver (e.g., reflecting off buildings or other objects).
2. **Large-Scale Fading (Shadow Fading): Caused by large obstructions like buildings or hills that block the line-of-sight between transmitter and receiver.**
3. **Doppler Fading**: Caused by the **relative movement** between the transmitter and receiver or by moving objects within the propagation path.

The Radio Channel

- **Effects of Fading**
- **Signal Interference**: Fading can cause signals to interfere with each other, leading to unpredictable variations in signal strength.
- **Bit Error Rates**: Increased bit error rates in data transmission due to signal degradation.
- **Communication Reliability**: Fading reduces the reliability of the communication link, making it challenging to maintain a consistent signal, especially in mobile or high-movement environments.

dB vs absolute power

- In wireless communications and signal processing, dB (decibels) and absolute power are two ways of expressing signal power, but they serve different purposes.
- **1. Absolute Power:**
- **Definition**: Absolute power is the actual power level of a signal, typically measured in units like **watts (W)**, **milliwatts (mW)**, or **microwatts (µW)**.
- **Use Case**: Absolute power provides a direct measure of the energy used or transmitted in the system. It's knowing the exact power output, receiver sensitivity, or energy usage in a system.
- **Example**: A transmitter outputs 0.1 W (100 mW) to an antenna.

dB vs absolute power

2. **dB (Decibels):**

- **Definition**: dB is a logarithmic ratio used to express power levels relative to a reference level, rather than an absolute value. It represents how much a signal has increased or decreased compared to a baseline.
- **Relative Power**: dB by itself is a relative measurement. For example, saying a signal is "3 dB stronger" means it has twice the power of the reference signal.
- **Absolute Power** in dB: Absolute power levels can also be expressed using dB notation by specifying a reference point, such as dBm (relative to 1 mW) or dBW (relative to 1 W).

dB vs absolute power

- **dB Units for Absolute Power:**
- **dBm**: Represents power relative to 1 milliwatt.
  - Formula:
  - Power (dBm)=10·$\log_{10}$ * (Power (mW)\1 mW)
  - **Example**: 100 mW = 20 dBm.
- **dBW**: Represents power relative to 1 watt.
  - Formula:
  - Power (dBW)= 10·$\log_{10}$* (Power (W)\1 W)
  - **Example**: 0.1 W = -10 dBW.

Path Loss

- Example 1: Express 2W in dBm and dBW
- dBm: 10 log10 (2 W / 1 mW) = 10 log10(2000) = 33 dBm
- dBW: 10 log10 (2 W / 1 W) = 10 log10(2) = 3 dBW.
- **Path Loss Models**
- Path loss refers to the reduction in power density of a radio signal as it travels from the transmitter to the receiver through a medium.
- It is a measure of how much a signal’s power weakens or "attenuates" over distance and through various obstacles like buildings, trees, and other environmental factors.
- Path loss is a crucial concept in wireless communication because it affects the coverage, signal quality, and capacity of wireless systems.

Path Loss

- **Key Factors Contributing to Path Loss**

1. **Distance**: The greater the distance between the transmitter and receiver, the greater the path loss. In free-space propagation, path loss follows an **inverse square law**, meaning it increases with the square of the distance.
2. **Frequency**: Higher frequencies generally experience more path loss than lower frequencies, as they are more easily absorbed and scattered by obstacles.
3. **Obstacles**: Physical barriers like walls, buildings, trees, and terrain can cause reflection, scattering, and absorption, contributing to additional loss.
4. **Environmental Conditions**: Weather (e.g., rain, fog) and atmospheric conditions can also absorb or scatter the signal, further increasing path loss.
5. **Multipath Fading**: In urban areas, signals take multiple paths to reach the receiver, which can cause constructive or destructive interference, impacting signal strength.

Path Loss

- **Path Loss Models**
- Various models help predict path loss in different environments. These models are used in network design to plan coverage and optimize performance:
- **Free-Space Path Loss Model**: Assumes an unobstructed line of sight (LoS) between transmitter and receiver.
- **Log-Distance Path Loss Model**: Accounts for environmental factors and uses an exponent to represent different levels of loss in different environments.
- **Hata Model**: Empirical model used for urban and suburban environments, based on frequency, distance, and environmental conditions.
- **Okumura-Hata Model**: Extended version of the Hata Model for urban areas, commonly used for planning cellular networks.

Path Loss

- Assumption
- Transmitter and receiver are in free space
- No obstructing objects in between
- The earth is at an infinite distance!
- The transmitted power is *Pt*
- The received power is *Pr*
- The *path loss* is *Lp* = *Pt* (dB) – *Pr* (dB)
- Isotropic antennas
- Antennas radiate and receive equally in all directions with unit gain