CSCE 5520- Wireless Networks and Protocols

Homework 1

1. Define wireless communication and explain its importance in today's world. Discuss the advantages and limitations of wireless communication.

Ans:

Wireless communication can be defined has, which involves the transmission of voice and data using electromagnetic waves in space, removing the need for any physical medium connections for example wires/cables. It's helped in developing technology that allows devices to communicate over distances without any direct or physical medium connecting them. They use the electromagnetic waves to travel at the speed of light. These waves have specific frequencies and wavelengths, enabling a wide range of wireless communication forms like radio channels, cellular towers, microwaves, infrared rays and satellite communications.

The wireless communication plays a important role in today's world. It has become the integral part of modern lifestyle with most end-user connectivity being wireless by using smartphones, tablets, and laptops to connect to the internet and with each other without any need for the physical cables. This has led to significant shifts in telecommunication carriers' revenue streams towards wireless services, given rise to the developments in 5G, in vehicular networking and in cognitive networks

Advantages of Wireless Communication

- **Mobility and Flexibility**: Wireless networks allow users to access real-time information and communicate from anywhere and anytime.
- **Ease of Installation**: Without the need for cables, wireless systems can be easier and faster to install.
- **Scalability**: Wireless systems can easily be scaled to increase the users with the use of various devices like Wi-Fi extenders.
- **Cost Efficiency**: The cost involved in building a wireless networks is much when compared to wired network.
- **Man Power**: It requires less man power and time to set it up and running.

Limitations of Wireless Communication

- **Interference and Reliability**: Wireless communication is more susceptible to interference from other signals in the same space
- **Security**: Wireless networks are vulnerable to unauthorized access likes MIM attacks, XSS attacks and many more
- **Bandwidth**: wireless communications offer limited bandwidth, which in turn affects the speed and quality of data transmission.

- **Range**: The effective range of wireless communication is limited by the hardware used and can be it can be reduced by physical obstacles like buildings or objects.

While wireless communications offers numerous advantages, but also comes with limitations that we need to take care to have efficient and reliable connection.

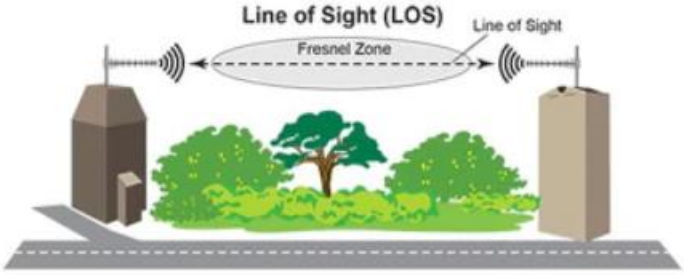
2. Discuss the principles of signal propagation in wireless communication. Explain the concepts of line-of-sight (LOS) and non-line-of-sight (NLOS) propagation and their effects on signal strength and quality.

Ans:

Signal propagation in wireless communication refers to the movement of signals in open space from a transmitter to a receiver through a transmission medium. In this case of wireless communication, the medium is the air or vacuum. The propagation involves the transmission of radio waves which travels at the speed of light from the antenna, tower or cell to devices in the field and vice versa, making the two-way communication possible through electromagnetic waves.

- **Line-of-Sight (LOS) Propagation**: This occurs when the transmitting and receiving antennas are in direct sight of each other, without any physical obstruction between them as show in the below image. LOS propagation is crucial for certain types of wireless communications like those that operate at higher frequencies microwave , satellite communications.
    - **Characteristics LOS communication:**
        - It provides a clear, unobstructed path for the signal,
        - It has lower signal attenuation
        - It has higher quality of communication.

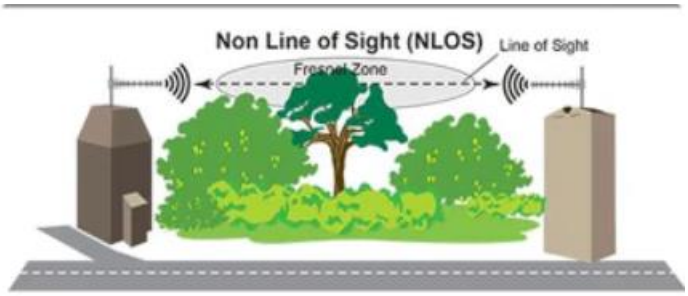
    Transmitter Antenna ----> Clear path ----> Receiver Antenna



- **Non-Line-of-Sight (NLOS) Propagation**: NLOS communication happens when there is no direct visual path between the transmitter and receiver. This is common in urban environments where buildings, trees, and other obstacles can block the direct signal path. NLOS propagation relies on different techniques like diffraction, scattering, and reflection to reach the receiver.
    - **Characteristics NLOS communication:**
        - This makes signals to bend around obstacles, reflect off surfaces, or scatter in multiple directions.

- It enables communication even without a clear LOS.
- It will have higher signal attenuation, multipath propagation
- Decreased signal strength and quality.

Transmitter Antenna ----> Obstructed path ----> Receiver Antenna



Effects on Signal Strength and Quality

- **Signal Strength**: LOS propagation will have stronger signal strength due to the direct path, minimizing losses and attenuation. In contrast, NLOS propagation
- **Signal Quality**: The quality of the signal in LOS propagation is typically higher, with less interference and distortion.

3. Explain the concept of fading in wireless communication. Discuss the different types of fading, such as path loss, shadowing, and multipath fading. Provide examples of each type.

Fading is a common in wireless communication. It refers to the change or attenuation of a signal's strength as it moves away from the transmitter towards the receiver. This change can be due to several different factors like propagation environment, distance between the transmitter and receiver, and the obstacles between them. Fading significantly impacts the quality and reliability communication. We can classify them into following types:

Types of Fading

1. **Path Loss**: In this type of fading the reduction in signal strength is due to the distance it traveled. The further the signal travels from the transmitter, the more energy it loses, resulting in less energy received signal. This is a basic issue in wireless communication, as signals must often cover large distances to reach the receiver.

   Example: In a citys the signal transmitted from a cell tower may experience significant path loss before reaching a mobile device several kilometers away, especially if it has to obstacles like buildings and other structures in between.

2. **Shadowing**: It is other type of fading, it occurs when an object obstructs the direct path between the transmitter and receiver, causing the signal blocked or significantly weakened. This type of fading is characterized by large obstacles like buildings or mountains which can create "shadows" where the signal strength is significantly reduced.

Example: The mobile device travelling in mountain areas experiences a sudden drop in signal quality as the direct path to the cell tower is obstructed by the mountains.

3. **Multipath Fading**: This occurs when the transmitted signal reaches the receiver through different paths due to reflection, diffraction, or scattering. The signal can reflect from buildings, vehicles and other objects, leading to multiple copies of the signal arriving at the receiver at slightly different times. This can lead constructive or destructive interference, where the signals either amplify or cancel each other out.

4. **Example:** When a TV broadcast signal reflected by multiple buildings in an urban area, causing blurry images or loss of signal on the TV screen due to the receiver picking up multiple delayed versions of the same signal.

Each type of fading has unique challenges in terms of the wireless communication, which requires different type of method for overcoming it. Path loss can also be countered with increase in the power control and using the directional antennas to focus the signal's energy more effectively. Understanding the types of fading is very important for getting the high-quality, reliable wireless communication.

4. Discuss the concept of multiple access in wireless communication. Explain the differences between time-division multiple access (TDMA), frequency-division multiple access (FDMA), and code-division multiple access (CDMA).

Ans:

The concept of multiple access in wireless communication refers to the ability of multiple users/devices to use the same communication medium. This is important in wireless communication systems to increase the use of available spectrum and to support a large number of users. There are different techniques available having their unique advantages and applications. There are three primary multiple access methods: Time-Division Multiple Access, Frequency-Division Multiple Access, and Code-Division Multiple Access.

Time-Division Multiple Access:

It is abbreviated has TDMA. It works by dividing the time into several time slots and then assigning each time slot to a different user in the network to use. This type of access allows multiple users to share the same frequency channel by taking turns transmitting their signals in their time slots.

- **Characteristics:**
    - TDMA efficiently utilizes the available bandwidth.
    - It minimizes interference among users by using different times.
    - It requires precise time synchronization between the transmitter and receiver.

Frequency-Division Multiple Access:

It is abbreviated has FDMA. It's different when compared to TDMA has use different frequency for different user instead of time as in TDMA. So, it basically allocates a unique frequency band for each user within the spectrum.

- **Characteristics:**
    - Each user wil have exclusive access to their own frequency band

- It will not have any interference from other users.
- This method is straightforward and easy to implement.
- It requires guard bands between frequency channels to prevent overlap and interference.
- It is not efficient has spectrum is small compared to the number of user and devices we have. So, It's less effective to use compared to other types.

Code-Division Multiple Access:

It is abbreviated has CDMA. It allows all users to occupy the same frequency spectrum simultaneously but separates those using unique spreading codes. These codes are orthogonal to each other, meaning that they can be used to separate and extract the individual signals at the receiver despite their simultaneous presence on the same frequency band.

- **Characteristics:**
  - It efficiently uses of the spectrum
  - It is robustness to interference and multipath fading.
  - It requires complex signal processing to encode and decode the signals.

Each of these multiple access techniques has there own advantages and are suited for different uses Like TDMA is more effective in scenarios where time synchronization can be maintained, but bandwidth is limited. FDMA is well suited for the applications where the communication system have huge bandwidth for allocating dedicated frequency bands to each user. In case of CDMA , it particularly useful in environments which has high user density.

5. A wireless communication system operates at a frequency of 2.4GHz and has a bandwidth of

20MHz. If the signal-to-noise ratio (SNR) is 25dB, determine the maximum achievable data rate using

Shannon's equation.

Ans:

using Shannon's equation:

$$R = B \log_2(1+SNR_{Linear})$$

Given Values:

- Frequency: 2.4 GHz
- Bandwidth : 20 MHz = 20 x 10^6 Hz.
- Signal-to-Noise Ratio (SNR in dB): 25 dB.

Convert SNR dB to Linear Scale: The SNR in dB is converted to a linear scale because Shannon's equation requires the SNR in linear terms.

$SNR_{linear}=10^{SNR_{db}}/10$

$= 10^{25/10} = 10^{2.5} = 316.22776 = 316.23$

Apply Shannon's Equation:

$$R = B \log_2(1+SNR_{Linear})$$

$$= 20 * 10^6 \log_2(1+316.23)$$
$$= 166.187 * 10^6 \text{ bps}$$
$$= 166.2 \text{ Mbps}$$

∴ Maximum Data Rate= 166.2 Mbps

6. A communication system uses a bandwidth of 4000Hz and is transmitting a signal with four levels.

Determine the maximum achievable data rate using Nyquist's formula.

Ans:

Nyquist's Formula:

$R=2*B* \log_2(M)$

Given Values:

- Bandwidth (B) = 4000 Hz,
- Number of levels (M) = 4.

Apply Nyquist's formula:

$$R = 2*B* \log_2(M)$$

$$= 2 *4000* \log_2 4$$
$$= 2 *4000* \log_2 2^2$$
$$= 2 *4000*2* \log_2 2$$
$$= 4*4000*1$$
$$= 16000 \text{ bps}$$
$$= 16 \text{ Kbps}$$

∴ Maximum data rate = R= 16 Kbps

7. Consider a noiseless channel with a bandwidth of 80KHz. We need to send 1120Kbps over a channel. How many signal levels are required?

Ans:

We can use Nyquist's formula as we have data rate and bandwidth and need to find the Signal levels.

Nyquist's Formula:

$R=2*B* \log_2(M)$

$\text{Log}_2(M) = R /(2*B)$

$M= 2^{R/(2*B)}$

Given Values:

- Bandwidth (*B*) = 80 KHz
- Data Rate (*R*) = 1120 Kbps

Apply Nyquist's formula:

$$M = 2^{R/(2*B)}$$

$$= 2^{1120*1000/2*80*1000}$$

$$= 2^{112/16}$$

$$= 2^{7}$$

$$= 128$$

$\therefore$ Required no. of signa levels are$(M) = 128$

8. A wireless communication system operates at a frequency of 2.4GHz and has a transmission power of 20dBm. The receiver sensitivity is -90dBm. The path loss exponent for the environment is measured to be 3.5. Calculate the maximum distance between the transmitter and receiver that allows successful communication, assuming free space path loss model.

Ans:

Given Values:

- Transmission Power = (P_t) = 20 dBm
- Receiver Sensitivity = -90 dBm
- Path Loss Exponent (n) = 3.5
- Frequency = f = 2.4 GHz = 2.4 10^9 Hz

Path loss= $P_L = P_T$ – Receiver Sensitivity

$= 20 – (- 90)$

$= 20 + 90$

$= 110$ dBm

Path loss Exponent (https://semfionetworks.com/blog/free-space-path-loss-diagrams/):

$P_L = 20* \log_{10}(d) - 20* \log_{10}(\lambda) - 21.98$

⇨ $20* \log_{10}(d) = P_L + 21.98 + 20*\log_{10}(3*10^8/2.4 * 10^9)$

$20*\log_{10}(d) = P_L - 21.98 – 18.06$

$20*\log_{10}(d) = 110 - 21.98 – 18.06$

$20 * \text{Log}_{10}(d) = 69.96$

$\text{Log}_{10}(d) = 3.498$

d= $10^{3.498}$ = 3147.74

∴ Maximum distance (d) is 3147.74m

9. Suppose that a CDMA system has four orthogonal codes as follows:

v1 = (1, -1, 1, -1) x 0

v2 = (-1, -1, 1, 1)

v3 = (1, 1, 1, -1)

v4 = (1, -1, -1, 1)

Sender 1 and receiver 1 data is encoded with v1, sender2 and receiver2 with v2, and so on.

Suppose that the following data signals are to be transmitted simultaneously:

Sender 1 => 0 1 0 1 0 1

Sender 2 => 1 1 0 0 1 1

Sender 3 => 0 0 0 1 0 0

Sender 4 => 1 1 1 0 0 0

Show by means of a diagram the encoding of the individual data signals, the generation of the composite signal, and how each receiver interprets the correct signal.

1. **Sender 1:** Data is encoded with *v*1:

   0→−1×*v*1=(−1,1,−1,1)

   1→1×*v*1=(1,−1,1,−1)

   Encoded sequence: (−1,1,−1,1) (1,−1,1,−1) (−1,1,−1,1) (1,−1,1,−1) (−1,1,−1,1) (1,−1,1,−1)

2. **Sender 2:** Data is encoded with *v*2:

   - 1→1×*v*2=(−1,−1,1,1)
   - 0→−1×*v*2=(1,1,−1,−1)
   - Encoded sequence: (−1,−1,1,1) (−1,−1,1,1) (1,1,−1,−1) (1,1,−1,−1) (−1,−1,1,1) (−1,−1,1,1)

3. **Sender 3:** Data is encoded with *v*3:

   - 0→−1×*v*3=(−1,−1,−1,1)

- 1→ 1xv3 = (1,1,1,-1)
- Encoded sequence:
  (−1,−1,−1,1) (−1,−1,−1,1) (−1,−1,−1,1) (1,1,1,−1) (−1,−1,−1,1) (−1,−1,−1,1)

4. **Sender 4:** Data is encoded with 4*v*4:
   - 1→1×*v*4=(1,−1,−1,1)
   - 0→-1xv4=(-1,1,1,-1)
   - Encoded sequence: (1,−1,−1,1) (1,−1,−1,1) (1,−1,−1,1) (−1,1,1,−1) (−1,1,1,−1) (−1,1,1,−1)

Composite Signal =

0				1				0				1				0				1			
-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1	-1	1	-1	1	1	-1	1	-1
-1	-1	1	1	-1	-1	1	1	1	1	-1	-1	1	1	-1	-1	-1	1	1	1	-1	-1	1	1
-1	-1	-1	1	-1	-1	-1	1	-1	-1	-1	1	1	1	1	-1	-1	-1	-1	1	-1	-1	-1	1
1	-1	-1	1	1	-1	-1	1	1	-1	-1	1	-1	1	1	-1	-1	1	1	-1	-1	1	1	-1
-2	-2	-2	4	0	-4	0	2	0	0	-4	2	2	2	2	-4	-4	2	0	2	-2	-2	2	0

Composite Signal diagram: