**VISHAL G MODULE 3 WIFI ASSIGNMENT**

1. **what are the different 802.11 PHY layer standards? Compare their characteristics**

**802.11b**  
Released in 1999, 802.11b operates in the 2.4 GHz band and provides data rates up to 11 Mbps using DSSS and CCK modulation. It became widely adopted due to its lower cost and longer range. However, it suffers from interference from other 2.4 GHz devices like microwaves and Bluetooth.

**802.11a**  
802.11a operates in the 5 GHz band and offers speeds up to 54 Mbps using OFDM. It avoids the crowded 2.4 GHz range, offering better performance in interference-prone areas. However, its shorter range and higher cost limited widespread adoption during its early years compared to 802.11b.

**802.11g**  
802.11g combined the best of 802.11a and b. It operates in the 2.4 GHz band but uses OFDM to deliver up to 54 Mbps, maintaining backward compatibility with 802.11b. It gained popularity for its speed and compatibility, although interference in the 2.4 GHz band remains a concern.

**802.11n**  
802.11n significantly increased Wi-Fi speeds up to 600 Mbps by using MIMO technology and wider 40 MHz channels. It operates in both 2.4 GHz and 5 GHz bands, improving flexibility and range. Backward compatibility and higher throughput made it a major upgrade in wireless networking.

**802.11ac**  
802.11ac operates solely in the 5 GHz band and offers speeds up to 6.9 Gbps. It introduced advanced features like MU-MIMO and 160 MHz channels for higher throughput. Ideal for HD streaming and gaming, it became the backbone of modern high-performance Wi-Fi networks.

**802.11ax (Wi-Fi 6)**  
Launched in 2019, 802.11ax, also called Wi-Fi 6, operates in both 2.4 GHz and 5 GHz bands and supports data rates up to 9.6 Gbps. It introduced OFDMA, improved MU-MIMO, and QAM-1024 for better efficiency, especially in dense environments. It's designed for modern smart homes and enterprise networks.

1. **What are DSSS and FHSS? How do they work?**

**DSSS (Direct Sequence Spread Spectrum)**  
DSSS is a modulation technique used in wireless communication, including the early 802.11b standard. It works by spreading the signal across a wider frequency band than the original data signal using a pseudo-random noise (PN) code. Each bit of data is represented by multiple bits (called chips), increasing redundancy and resistance to interference. If a portion of the signal is lost or corrupted due to noise or collision, the original data can still be reconstructed. DSSS improves security, reduces interference, and enhances signal reliability, though it consumes more bandwidth.

**FHSS (Frequency Hopping Spread Spectrum)**  
FHSS is another spread spectrum technique where the carrier frequency rapidly changes, or "hops," between many frequency channels in a predefined sequence. Used in early wireless standards like Bluetooth and some legacy Wi-Fi modes, FHSS transmits small chunks of data on one frequency before hopping to another. This reduces the risk of interference and signal jamming, as the transmission doesn’t stay long on any single frequency. It’s robust against narrowband interference and is well-suited for environments with many competing wireless devices.

1. **How do Modulation schemes work in the PHY layer? Compare different Modulation schemes and their performance across various Wi-Fi standards.**

In the PHY (Physical) layer of Wi-Fi, modulation schemes are used to convert digital data (bits) into analog signals for transmission over the air. Modulation alters properties of a carrier signal—such as amplitude, frequency, or phase—to encode data. The choice of modulation affects the speed, range, and robustness of wireless communication. Higher-order modulation schemes transmit more bits per symbol, increasing data rates but requiring stronger signals (less noise and interference) to decode correctly. The PHY layer dynamically adapts modulation based on signal quality to optimize performance.

802.11b uses DSSS with DBPSK (1 Mbps) and DQPSK/CCK (up to 11 Mbps). It provides good range but low speed.

802.11a/g adopt OFDM and support BPSK, QPSK, 16-QAM, and 64-QAM, allowing speeds up to 54 Mbps with better spectral efficiency.

802.11n adds MIMO and supports up to 64-QAM, pushing speeds to 600 Mbps.

802.11ac enhances this with 256-QAM, enabling multi-gigabit speeds with better bandwidth usage.

802.11ax (Wi-Fi 6) introduces 1024-QAM, offering higher data rates and efficiency in crowded environments.

802.11be (Wi-Fi 7) is expected to use 4096-QAM, drastically boosting throughput but requiring excellent signal conditions.

1. **What is the significance of OFDM in WLAN? How does it improve performance?**

Orthogonal Frequency Division Multiplexing (OFDM) is a key modulation technique used in modern WLAN standards like 802.11a, g, n, ac, ax, and beyond. Its primary significance lies in its ability to efficiently transmit high-speed data over wireless channels that suffer from multipath fading and interference. OFDM divides the channel into many closely spaced subcarriers, each carrying a portion of the data. These subcarriers are orthogonal, meaning they don’t interfere with each other despite overlapping in frequency, allowing for more data to be transmitted simultaneously.

OFDM improves WLAN performance by increasing spectral efficiency and robustness against signal degradation. By splitting data into parallel streams across subcarriers, it reduces the impact of narrowband interference and allows better handling of multipath reflections common in indoor environments. It also supports higher-order modulation (e.g., QAM), enabling greater throughput. OFDM's resistance to interference and its support for high-speed, high-capacity transmission make it ideal for modern applications like video streaming, online gaming, and dense network environments.

1. **How are frequency bands divided for WiFi? Explain different bands and their channels.**

Wi-Fi operates on multiple frequency bands that are divided into smaller channels to allow multiple devices to communicate simultaneously without interfering with each other. Each band has a specific range of frequencies allocated by regulatory bodies (like the FCC or ETSI) for unlicensed wireless use. The most commonly used bands are 2.4 GHz, 5 GHz, and 6 GHz (introduced with Wi-Fi 6E)

2.4 GHz Band  
The 2.4 GHz band covers frequencies from 2.400 GHz to 2.4835 GHz and provides 14 channels, each 20 MHz wide. However, only 3 channels (1, 6, 11) are non-overlapping, making this band more prone to interference from other Wi-Fi networks and household devices (like microwaves and Bluetooth). It offers longer range but lower speed and is ideal for simple browsing in large areas.

5 GHz Band  
The 5 GHz band spans 5.150 GHz to 5.825 GHz and includes up to 25 non-overlapping channels (depending on country regulations). Channels are 20 MHz wide but can be bonded to form 40 MHz, 80 MHz, or 160 MHz channels for higher throughput. This band experiences less interference, supports faster data rates, and is ideal for HD streaming and gaming, though it has a shorter range than 2.4 GHz.

6 GHz Band (Wi-Fi 6E and Wi-Fi 7)  
Introduced with Wi-Fi 6E, the 6 GHz band ranges from 5.925 GHz to 7.125 GHz, offering up to 59 new 20 MHz channels. It’s cleaner with no legacy Wi-Fi interference, supports wider channels (up to 320 MHz in Wi-Fi 7), and delivers ultra-high speeds with low latency. However, it has the shortest range and is limited by newer hardware compatibility.

1. **What is the role of Guard intervals in WLAN transmission? How does a short Fuard interval improve efficiency?**

Guard intervals are short time gaps inserted between OFDM symbols to prevent interference caused by multipath propagation, where signals take multiple paths to reach the receiver. Without a guard interval, delayed versions of the signal could interfere with the next symbol, causing data errors. By introducing this gap, devices can absorb delayed echoes and correctly decode the signal, improving reliability and reducing inter-symbol interference (ISI).

A Short Guard Interval (SGI), typically 400 nanoseconds instead of the standard 800 nanoseconds, reduces the overhead between symbols. This allows more symbols to be transmitted in the same amount of time, thus increasing data throughput by around 10%.

1. **Describe the structure of 802.11 PHY layer frame. What are its key components.**

The PHY frame is composed of the PLCP (Physical Layer Convergence Protocol) preamble and header, followed by the PSDU (PLCP Service Data Unit), which contains the actual MAC layer frame (payload).

Key Components of 802.11 PHY Layer Frame

Preamble – Used for synchronization and channel estimation. It helps the receiver lock onto the signal, detect the start of the frame, and prepare for data decoding.

PLCP Header – Contains information such as the length of the frame, modulation scheme, and coding rate. It is always transmitted at a basic rate so all receivers can interpret it.

PSDU (Data) – This is the payload part that carries the MAC frame, which includes headers and user data. It is modulated and coded according to the information specified in the PLCP header.

1. **What is the difference between OFDM and OFDMA?**

OFDM (Orthogonal Frequency Division Multiplexing) is a technique where data is divided into multiple parallel data streams and transmitted simultaneously over many orthogonal subcarriers. It is used in Wi-Fi standards like 802.11a/g/n/ac. In OFDM, a single user occupies all subcarriers during a transmission, making it efficient for high-speed data but less effective for multiple users sharing the channel.

OFDMA (Orthogonal Frequency Division Multiple Access) is an enhancement of OFDM used in 802.11ax (Wi-Fi 6) and beyond. It divides the subcarriers into smaller groups called Resource Units (RUs), allowing multiple users to transmit simultaneously within the same channel. OFDMA improves spectral efficiency, reduces latency, and is highly effective in dense environments with many devices. It’s ideal for IoT and mobile users with varying bandwidth needs.

1. **What is the difference between MIMO and MU-MIMO?**

MIMO is a wireless technology that uses multiple antennas at both the transmitter and receiver ends to send and receive more than one data stream simultaneously. It improves throughput, range, and signal reliability by using spatial multiplexing, where different streams are sent over different antennas. MIMO is used in Wi-Fi standards like 802.11n and 802.11ac (Wave 1), but it typically serves only one user at a time.

MU-MIMO is an advanced form of MIMO introduced in 802.11ac Wave 2 and enhanced in 802.11ax (Wi-Fi 6). Unlike traditional MIMO, MU-MIMO allows a router or access point to transmit data to multiple users simultaneously, instead of serving them one at a time. This significantly boosts network efficiency and reduces wait time, especially in busy networks with many users.

1. **What are PPDU, PLCP and PMD in the PHY Layer?**

PPDU (PLCP Protocol Data Unit)  
PPDU is the complete physical layer frame that is transmitted over the air. It includes the PLCP preamble, PLCP header, and the PSDU (payload). PPDU is the final output of the PHY layer, ready for modulation and transmission. It encapsulates the data from the MAC layer and prepares it for wireless delivery.

PLCP (Physical Layer Convergence Protocol)  
The PLCP is a sublayer of the PHY layer that acts as a bridge between the MAC and PMD sublayers. It formats the MAC layer data into a compatible structure for transmission by the physical medium. It adds the preamble and header for synchronization, signal parameters, and length information, enabling the receiver to decode the incoming signal properly.

PMD (Physical Medium Dependent)  
The PMD sublayer is responsible for the actual modulation, transmission, and reception of radio signals over the wireless medium. It interacts directly with the physical hardware (like antennas and RF circuits) to transmit the PPDU bits as electromagnetic waves. PMD handles signal generation, frequency conversion, and bit-level operations at the hardware level.

1. **What are the types of PPDU? Explain the PPDU frame format across different Wi-Fi generations.**

The Short Preamble PPDU is used in 802.11b networks and is designed to reduce overhead and improve data throughput. It includes a shorter synchronization field and a PLCP header that is sent at a higher data rate.

The Long Preamble PPDU is the default format in 802.11b and is used for maximum compatibility with older devices. It includes a long synchronization field and a PLCP header sent at the lowest supported data rate (typically 1 Mbps), making it easier for all devices to detect and decode the signal.

**802.11b PPDU (DSSS PPDU)**  
Uses DSSS/CCK with Long/Short Preamble, PLCP Header (rate, length), and PSDU (MAC data). Supports up to 11 Mbps.

**802.11a/g PPDU (OFDM PPDU)**  
Uses OFDM with a Preamble for synchronization, Signal Field for control info (rate, length), and Data Field for MAC payload. Supports speeds up to 54 Mbps.

**802.11ac PPDU (VHT PPDU)**  
Adds VHT-SIG A/B, VHT-STF, VHT-LTF.  
Supports 8 spatial streams, 160 MHz, 256-QAM, MU-MIMO, and is backward compatible.

**802.11n PPDU Types**

Legacy PPDU: Backward compatible with 802.11a/g.

Mixed Format PPDU: Combines legacy and HT fields.

**802.11ax PPDU (HE PPDU)**

1024-QAM, OFDMA, BSS coloring, and 6 GHz band for high efficiency.

**12. How is Data Rate calculated.**

Data Rate (throughput) in wireless communication systems like Wi-Fi or LTE is calculated using the Modulation and Coding Scheme (MCS) Index, which defines the following parameters:

1. Modulation Type (e.g., BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM)
2. Coding Rate (e.g., 1/2, 2/3, 3/4, 5/6)
3. Number of Spatial Streams
4. Channel Bandwidth (e.g., 20 MHz, 40 MHz, 80 MHz)
5. Guard Interval (e.g., 800 ns, 400 ns)

Data Rate depends on few major components including Number of Data Subcarriers, Number of Coded Bits per Subcarrier per person, Coding, Number of spatial Streams also including OFDM Symbol duration.

Data Rate = (No of data subcarriers \* Number of coded bits per subcarrier \* Coding \* number of Spatial Streams) / (OFDM Symbol duration \* Guard Interval Duration)