**WIFI – TRAINING PROGRAM**

**MODULE – 3**

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

The IEEE 802.11 standard has evolved significantly since its inception, with various amendments defining different Physical (PHY) layer standards. Each standard introduces changes in modulation techniques, coding schemes, channel widths, and spatial streams to achieve higher data rates and improved performance.  Here's a list of the primary 802.11 PHY layer standards and a comparison of their key characteristics

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| Standard | Year of Approval | Frequency Bands(GHz) | Max Channel Width(MHz) | Modulation | Max Data Rate | Key Features |
| 802.11 | 1997 | 2.4 | 20 | DBPSK, DQPSK | 2 | Original standard, very low data rate, largely obsolete. |
| 802.11b | 1999 | 2.4 | 20 | CCK | 11 | First widely adopted standard.Limited data rate. |
| 802.11a | 1999 | 5 | 20 | OFDM (64-QAM) | 54 | Operated in the less congested 5 GHz band, offering higher data rates. |
| 802.11g | 2003 | 2.4 | 20 | OFDM (64-QAM) | 54 | Combined the higher data rates of 802.11a with the longer range |
| 802.11n (Wi-Fi 4) | 2009 | 2.4 & 5 | 20, 40 | OFDM (64-QAM) | 600 | Introduced MIMO for increased data rates and range. |
| 802.11ac (Wi-Fi 5) | 2013 | 5 | 20, 40, 80, 160 | OFDM (256-QAM) | 6933 | MU-MIMO allows the AP to transmit to multiple clients, improving efficiency in dense environments. |
| 802.11ax (Wi-Fi 6) | 2019 | 2.4 & 5 | 20, 40, 80, 160 | OFDMA (1024-QAM) | 9608 | Introduces OFDMA for more efficient spectrum utilization, MU-MIMO for both downlink and uplink, and higher-order modulation. |
| 802.11be (Wi-Fi 7) | 2024 | 2.4, 5, 6 | 20, 40, 80, 160, 320 | OFDMA (4096-QAM) | ~46000 | Aims for even higher throughput, lower latency, and improved reliability. The 6 GHz band availability will be crucial for its full potential. |

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

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| **Category** | **FHSS** | **DSSS** |
| **Abbreviation** | FHSS is Frequency-Hopping Spread Spectrum | DSSS is Direct-Sequence Spread Spectrum |
| **Definition** | FHSS is a type of spread spectrum technology in which the frequency of the transmitted signal changes according to a specific pattern. | DSSS is a type of spread spectrum technology in which the transmitted signal is spread across multiple frequency bands. |
| **Pattern** | In FHSS, the data transmission is encoded and decoded using a specific pattern called **hopset**. | In DSSS, the data transmission is encoded and decoded using a pseudo-random binary sequence or chip code. |
| **Frequency band** | FHSS transmits data using a narrowband carrier that hops among different frequency channels. | DSSS transmits data using a wider frequency band. |
| **Interference resistant** | FHSS is more resistant to interference because it uses frequency hopping, which makes it difficult to intercept the signal. | DSSS is more vulnerable to interference because it uses a wider frequency band. |
| **Susceptibility** | FHSS is less susceptible to multipath fading, it is a phenomenon in which the transmitted signal arrives at the receiver via multiple paths, resulting in a loss of signal quality. | DSSS is more susceptible to multipath fading because it uses a wider frequency band. |
| **Transmission speed** | FHSS has low transmission rates (up to 3 Mbps). | DSSS has high transmission rates (up to 11 Mbps). |
| **Application areas** | It is widely used in a variety of applications, including wireless networking like Bluetooth, mobile communications, and military communications. | It is well-suited for particular applications where the signal must travel over long distances like GPS, and WIFI. |

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

Modulation is the process of encoding digital data onto an analog carrier wave for transmission over the wireless medium. In Wi-Fi, the PHY layer takes the digital bits from the MAC layer and manipulates the characteristics of a radio frequency (RF) signal (the carrier wave) to represent those bits. The receiver then demodulates the received signal to recover the original digital data.

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| **Modulation** | **Basic Idea** | **Bits/Symbol** | **Robustness** | **Usage in Wi-Fi Standards** | **Typical Data Rate Impact** |
| **BPSK** (Binary Phase Shift Keying) | 2 phase shifts for 0 and 1 | 1 bit | Very robust, low speed | 802.11b/g/n/ax | |  | | --- | |  |  |  | | --- | | Lowest | |
| **QPSK** (Quadrature Phase Shift Keying) | 4 phase shifts (00, 01, 10, 11) | 2 bits | Good robustness | |  | | --- | | 802.11g/n/ac/ax |  |  | | --- | |  | | |  | | --- | | Medium |  |  | | --- | |  | |
| |  | | --- | | **16-QAM** (Quadrature Amplitude Modulation) |  |  | | --- | |  | | |  | | --- | | 16 amplitude+phase combinations |  |  | | --- | |  | | 4 bits | |  | | --- | | Less robust, faster |  |  | | --- | |  | | |  | | --- | | 802.11g/n/ac/ax |  |  | | --- | |  | | |  | | --- | | High |  |  | | --- | |  | |
| |  | | --- | | **64-QAM** |  |  | | --- | |  | | |  | | --- | | 64 combinations |  |  | | --- | |  | | 6 bits | |  | | --- | | Needs good signal quality |  |  | | --- | |  | | |  | | --- | | 802.11n/ac/ax |  |  | | --- | |  | | Higher |
| |  | | --- | | **256-QAM** |  |  | | --- | |  | | |  | | --- | | 256 combinations |  |  | | --- | |  | | |  | | --- | | 8 bits |  |  | | --- | |  | | |  | | --- | | Very sensitive to noise |  |  | | --- | |  | | |  | | --- | | 802.11ac/ax |  |  | | --- | |  | | |  | | --- | | Very High |  |  | | --- | |  | |
| |  | | --- | | **1024-QAM** |  |  | | --- | |  | | |  | | --- | | 1024 combinations |  |  | | --- | |  | | |  | | --- | | 10 bits |  |  | | --- | |  | | |  | | --- | | Extremely sensitive, very high throughput |  |  | | --- | |  | | |  | | --- | | 802.11ax(Wi-Fi 6) |  |  | | --- | |  | | Extremely High |

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

* The significance of Orthogonal Frequency Division Multiplexing (OFDM) in Wireless Local Area Networks (WLANs) is immense and fundamental.It is the backbone of almost all modern Wi-Fi standards, from 802.11a/g/n/ac/ax/be.
* OFDM revolutionized wireless communication by providing a robust and efficient way to transmit data over the complex and often unpredictable wireless medium, particularly in environments like those found across India with varying levels of interference and signal propagation challenges.

**Significance of OFDM in WLAN:**

1. **Combating Frequency Selective Fading (Multipath):** In wireless environments, signals often take multiple paths to reach the receiver (due to reflections off walls, buildings, terrain – common in diverse Indian landscapes). These multiple paths can interfere with each other, causing **frequency selective fading**, where certain frequencies within the signal bandwidth experience significant attenuation.
2. **Efficient Spectrum Utilization:** OFDM allows for the subcarriers to be very close to each other in frequency, even overlapping slightly. However, they are designed to be **orthogonal**, meaning they are mathematically independent and do not interfere with each other at the receiver. This efficient packing of subcarriers allows OFDM to transmit more data within a given bandwidth compared to older single-carrier modulation techniques.
3. **Robustness Against Narrowband Interference:** Because the data is spread across many subcarriers, narrowband interference will only affect a small portion of the subcarriers. Error correction codes used in conjunction with OFDM can then recover the lost data from the affected subcarriers.
4. **Flexibility and Adaptability:** OFDM allows for dynamic allocation of data rates to different subcarriers based on the channel conditions. Subcarriers experiencing poorer signal quality can be assigned lower modulation schemes (carrying fewer bits per symbol) or even be nullified, while subcarriers with good signal quality can use higher modulation schemes for higher throughput.

**How OFDM Improves Performance:**

1. **Increased Data Rates:** By efficiently utilizing the available spectrum and employing sophisticated modulation schemes on each subcarrier (like QPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM, 4096-QAM in newer standards), OFDM enables the transmission of a large number of bits per second, leading to significantly higher data rates compared to earlier single-carrier systems (like those used in 802.11b).
2. **Improved Reliability and Range:** By mitigating the effects of multipath fading and narrowband interference, OFDM contributes to more reliable wireless connections and can potentially extend the effective range of WLANs, especially in challenging indoor and outdoor environments common in India.
3. **Enhanced Capacity:** The ability to pack more data into the available spectrum and the robustness against interference allow OFDM-based WLANs to support a larger number of concurrent users and devices without significant performance degradation, which is crucial in densely populated areas and high-user environments like educational institutions and offices in India.
4. **Foundation for Advanced Techniques:** OFDM serves as the foundation for even more advanced techniques introduced in later Wi-Fi standards, such as:
   * **MIMO (Multiple-Input Multiple-Output):** OFDM allows for the transmission and reception of multiple spatial streams, further increasing data rates and capacity.
   * **Channel Bonding:** Combining multiple adjacent channels (each utilizing OFDM) to create wider bandwidths and higher throughput.
   * **OFDMA (Orthogonal Frequency Division Multiple Access):** Introduced in Wi-Fi 6, OFDMA builds upon OFDM by allowing the AP to allocate subcarriers to multiple users simultaneously, improving efficiency in dense client environments.
5. **How are frequency bands divided for Wi-Fi ? Explain different bands and their channels.**

Frequency bands for Wi-Fi are divided into specific ranges of the radio spectrum allocated for unlicensed use by wireless devices. These bands are further subdivided into channels, which are smaller segments of the spectrum used for individual Wi-Fi networks to operate without (ideally) interfering with each other.

The primary Wi-Fi frequency bands globally are **2.4 GHz** and **5 GHz**. More recently, the **6 GHz** band has also been introduced with Wi-Fi 6E and Wi-Fi 7.

**2.4 GHz Band:**

* **Frequency Range (Generally):** 2.400 GHz to 2.4835 GHz
* **Channel Width:** Typically 20 MHz, but can also use 40 MHz channel bonding in 802.11n and later standards.
* **Number of Channels:** In most parts of the world, including India, the 2.4 GHz band is divided into 14 channels, spaced 5 MHz apart. However, not all channels are universally legal or non-overlapping.
* **Non-Overlapping Channels (Crucial for minimizing interference):** With 20 MHz wide channels, only **three** channels are truly non-overlapping: **Channel 1 (2.412 GHz), Channel 6 (2.437 GHz), and Channel 11 (2.462 GHz)**. Using these non-overlapping channels for adjacent Wi-Fi networks is essential for reducing interference and improving performance, especially in densely populated areas of India.
* **Channel Usage in India:** India generally permits the use of channels 1 to 13 in the 2.4 GHz band. Channel 14 is usually not allowed.
* **Characteristics:**
  + Longer range and better penetration through walls and obstacles compared to 5 GHz.
  + More susceptible to interference from other devices operating in the 2.4 GHz band, such as Bluetooth devices, microwave ovens, cordless phones, and other Wi-Fi networks (a significant concern in crowded urban environments in India).
  + Limited number of non-overlapping channels can lead to congestion.

**5 GHz Band:**

* **Frequency Range (Generally):** Approximately 5.150 GHz to 5.875 GHz. This band is further divided into several sub-bands with varying regulations and channel availability.
* **Channel Width:** Supports wider channels compared to 2.4 GHz, including 20 MHz, 40 MHz, 80 MHz, and even 160 MHz in 802.11ac and 802.11ax/be.
* **Number of Channels:** The 5 GHz band offers a significantly larger number of channels compared to 2.4 GHz. The exact number depends on the specific sub-band and the channel width used.
* **Channel Usage in India:** India has its own regulations regarding the 5 GHz band, which may differ slightly from other regions. Generally, several UNII (Unlicensed National Information Infrastructure) bands are available. It's important to consult the specific regulations from the Wireless Planning & Coordination (WPC) Wing of the Department of Telecommunications in India for precise channel availability and power limits. However, commonly used ranges include:
  + **UNII-1 (5.150 - 5.250 GHz):** Lower power limits, often for indoor use.
  + **UNII-2 (5.250 - 5.350 GHz):** Higher power limits, often with DFS (Dynamic Frequency Selection) requirements to avoid interference with radar systems.
  + **UNII-2 Extended (UNII-2e) (5.470 - 5.725 GHz):** Also with DFS requirements.
  + **UNII-3 (5.725 - 5.850 GHz):** Generally higher power limits.

* **Non-Overlapping Channels:** Due to the wider frequency range and channel spacing, the 5 GHz band offers a much larger number of non-overlapping channels, even with wider channel widths. This significantly reduces interference between different Wi-Fi networks.
* **Characteristics:**
  + Shorter range and greater attenuation by walls and obstacles compared to 2.4 GHz.
  + Less susceptible to interference from common household devices.
  + Larger number of non-overlapping channels leads to less congestion and better performance, especially in densely populated areas of India.
  + Wider channel widths enable significantly higher data rates.
  + DFS requirement on some channels can sometimes lead to temporary channel changes if radar activity is detected.

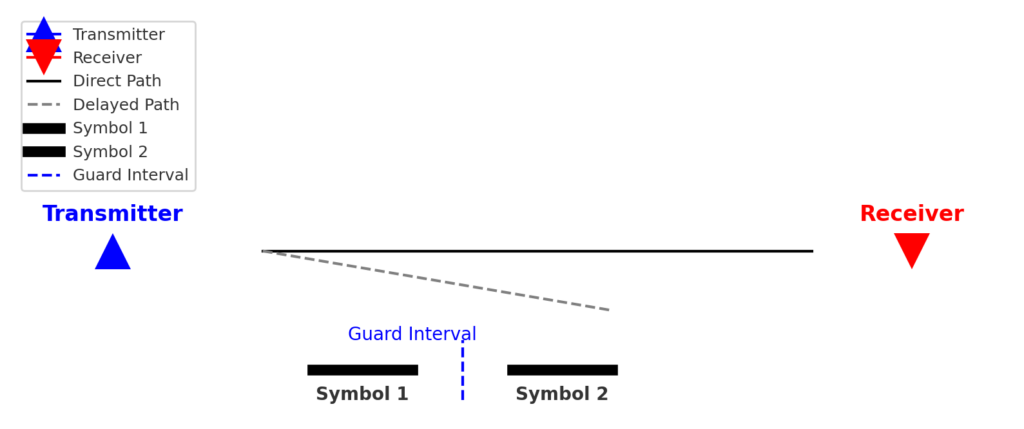
**6 GHz Band:**

* **Frequency Range (Generally):** 5.925 GHz to 7.125 GHz (subject to regional regulations).
* **Channel Width:** Supports very wide channels, including 20 MHz, 40 MHz, 80 MHz, and 160 MHz.
* **Number of Channels:** Offers a substantial number of non-overlapping channels due to its wide bandwidth.
* **Channel Usage in India:** The 6 GHz band is relatively new for unlicensed use, and regulations are still evolving in many regions, including India. The Wireless Planning & Coordination (WPC) Wing in India will determine the specific frequency range and channel availability for Wi-Fi in the 6 GHz band. As of my last update, the full 1200 MHz of the 6 GHz band might not be entirely available for unlicensed use in India, or specific power limits and conditions might apply. It's crucial to consult the latest WPC regulations for accurate information.
* **Characteristics:**
  + Offers the highest potential speeds and lowest latency due to wider channels and less congestion.
  + Range is generally similar to or slightly less than the upper 5 GHz bands.
  + Requires devices that support Wi-Fi 6E or Wi-Fi 7.
  + Availability and usage in India will depend on the final regulatory framework and the adoption of compatible devices.

1. **What is the role of Guard Intervals in WLAN transmission ? How does a short Guard Interval improve efficiency ?**

A **guard interval** is a short period of time inserted between transmitted symbols to prevent interference. In wireless communication, data is modulated into symbols, which are groups of bits representing digital information. When these symbols travel through a wireless medium, they can be affected by reflections from surfaces or obstacles. These reflections cause the original signal to arrive multiple times through different paths—a phenomenon known as **multi-path interference**.

To prevent this interference from corrupting data, a guard interval is introduced. This interval acts as a buffer between symbols, ensuring that any delayed signals arriving via different paths won’t overlap with the next symbol and cause errors.



**How a Short Guard Interval Improves Efficiency:**

Modern Wi-Fi standards allow for the use of **short Guard Intervals (SGI)**, typically half the duration of the normal or long Guard Interval. Using a short GI can improve transmission efficiency in wireless environments where the delay spread is relatively small. Here's how:

1. **Reduced Overhead:** The Guard Interval adds overhead to each transmitted OFDM symbol because it's a portion of the transmission time that doesn't carry new data (the cyclic prefix is a repetition). By shortening the GI, the proportion of the total transmission time dedicated to actual data increases. This means that for the same overall transmission time, more data can be sent.
2. **Increased Data Rates:** The reduction in overhead directly translates to the potential for higher data rates. With a shorter GI, more OFDM symbols can be transmitted per unit of time, leading to increased throughput.
3. **Improved Spectral Efficiency:** By packing more data into the same amount of time, a short GI improves the spectral efficiency of the wireless link, allowing more bits to be transmitted per Hertz of bandwidth.
4. **Describe the structure of an 802.11 PHY layer frame. What are its key components?**

The structure of an 802.11 PHY (Physical) layer frame is designed to ensure reliable transmission of data over the wireless medium. It consists of a preamble, a header, and the actual data payload.

**I. Preamble:**

The preamble is transmitted at the beginning of each frame and serves several crucial purposes for the receiver:

* **Synchronization:** Allows the receiver to detect the start of a new frame and synchronize its timing and frequency with the transmitter. This is especially important in the dynamic and often noisy RF environments encountered in India.
* **Automatic Gain Control (AGC) Training:** Helps the receiver adjust its signal amplification to an optimal level for the incoming signal.
* **Channel Estimation:** Enables the receiver to estimate the characteristics of the wireless channel (e.g., multipath delay spread, frequency response). This information is then used to equalize the received signal and compensate for channel distortions.

The preamble has evolved across different 802.11 standards. Common elements include:

* **Legacy Preamble (used in 802.11a/b/g):**
  + **Synchronization (SYNC):** A short sequence of repeating symbols for initial signal detection and coarse frequency offset correction.
  + **Start Frame Delimiter (SFD):** A specific pattern that marks the end of the synchronization sequence and the beginning of the signal field.
  + **Signal (SIGNAL) field:** Encodes information about the data rate and length of the subsequent data portion of the frame, allowing the receiver to prepare for demodulation and decoding.
* **HT Preamble (High Throughput, used in 802.11n):** Designed to support MIMO and higher data rates. It includes:
  + **Legacy Preamble (L-PREAMBLE):** For backward compatibility with 802.11a/b/g devices.
  + **HT-SIG (HT-SIGNAL) field:** Contains information specific to HT operation, such as modulation and coding scheme (MCS), channel width, and guard interval.
  + **HT-STF (HT Short Training Field):** For improved AGC and timing synchronization in MIMO scenarios.
  + **HT-LTF (HT Long Training Field):** For channel estimation in MIMO systems, allowing the receiver to understand the different spatial channels.
* **VHT Preamble (Very High Throughput, used in 802.11ac):** Further enhancements for wider bandwidths and higher MIMO orders. It includes:
  + **Legacy Preamble (L-PREAMBLE):** For backward compatibility.
  + **L-SIG (Legacy SIGNAL) field:**
  + **VHT-SIG-A (VHT-SIGNAL-A) field:** Contains common parameters for the VHT transmission.
  + **VHT-STF (VHT Short Training Field):** For improved AGC and timing synchronization in VHT.
  + **VHT-LTF (VHT Long Training Field):** For channel estimation in VHT MIMO.
  + **VHT-SIG-B (VHT-SIGNAL-B) field:** Contains user-specific information in MU-MIMO transmissions.
* **HE Preamble (High Efficiency, used in 802.11ax):** Designed for high-density environments and OFDMA. It includes:
  + **Legacy Preamble (L-PREAMBLE):** For backward compatibility.
  + **L-SIG (Legacy SIGNAL) field:**
  + **HE-SIG-A (HE-SIGNAL-A) field:** Contains common parameters for the HE transmission, including information about OFDMA and resource unit allocation.
  + **HE-STF (HE Short Training Field):** For improved AGC and timing synchronization in HE.
  + **HE-LTF (HE Long Training Field):** For channel estimation in HE MIMO.
  + **HE-SIG-B (HE-SIGNAL-B) field (optional):** Contains user-specific information in MU-MIMO and OFDMA transmissions.
* **EHT Preamble (Extremely High Throughput, used in 802.11be):** Continues to evolve for even higher data rates and efficiency. It builds upon the HE preamble with further enhancements.

**II. Header (or SIGNAL field and subsequent SIG fields):**

The header, following the preamble, contains crucial information about the data payload and how it is encoded. This allows the receiver to correctly demodulate and decode the data. Key information typically included in the header fields (like SIGNAL, HT-SIG, VHT-SIG, HE-SIG) includes:

* **Data Rate:** Specifies the modulation and coding scheme (MCS) used for the data payload. This informs the receiver how many bits are encoded per symbol.
* **Frame Length:** Indicates the duration or the number of bytes in the subsequent data payload.
* **Guard Interval (GI) Length:** Specifies the duration of the guard interval used for this transmission.
* **Channel Width:** Indicates the bandwidth of the channel being used (e.g., 20 MHz, 40 MHz, 80 MHz, 160 MHz, 320 MHz).
* **Spatial Stream Information:** In MIMO transmissions, this indicates the number of spatial streams used.
* **Coding Information:** Details about the error correction coding scheme (e.g., convolutional coding, LDPC) used to protect the data.
* **Basic Service Set Identifier (BSSID) related information:** Sometimes partially included or referenced.
* **Other control information specific to the 802.11 amendment.**

**III. Data Payload (or Data field):**

This is the actual information being transmitted. It contains the data from the MAC layer, which could be user data, control information, or management frames. The data payload is encoded according to the parameters specified in the header.