Wi-Fi Training Program
Assignment Questions -Module 3

Q1. What are the different 802.11 PHY layer standards? Compare their characteristics.

Standard	Frequency Band	Max Data Rate	Modulation Type	Channel Width	Key Features
802.11a	5 GHz	54 Mbps	OFDM	20 MHz	Less interference, shorter range
802.11b	2.4 GHz	11 Mbps	DSSS	22 MHz	Longer range, high interference
802.11g	2.4 GHz	54 Mbps	OFDM + DSSS	20 MHz	Backward compatible with 802.11b
802.11n	2.4/5 GHz	600 Mbps	OFDM + MIMO	20/40 MHz	Introduction of MIMO, better throughput
802.11ac	5 GHz	6.9 Gbps	OFDM + MU-MIMO	20/40/80/160 MHz	Beamforming, multi-user support
802.11ax (Wi-Fi 6)	2.4/5 GHz	~9.6 Gbps	OFDMA + MU-MIMO + 1024-QAM	20/40/80/160 MHz	Higher efficiency, dense environments
802.11be (Wi-Fi 7)	2.4/5/6 GHz	>30 Gbps (est.)	OFDMA + MIMO + 4096-QAM	Up to 320 MHz	Multi-link operation, very high throughput

Q2. What are DSSS and FHSS? How do they work?

DSSS (Direct Sequence Spread Spectrum)

Definition: DSSS is a spread spectrum technique where the data signal is multiplied by a pseudorandom noise (PN) code at a much higher rate than the original signal. This spreads the data over a wider frequency band.

How It Works:

- Each data bit is replaced with a sequence of bits (called "chips") using a spreading code.
- The signal occupies a wider bandwidth, reducing the effects of interference and improving signal robustness.
- At the receiver end, the same PN code is used to decode the signal and retrieve the original data.

Advantages:

- Resistance to narrowband interference
- Higher data integrity and reduced signal fading
- Lower probability of interception

Use Case:

- Used in **IEEE 802.11b** standard (2.4 GHz, up to 11 Mbps)
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FHSS (Frequency Hopping Spread Spectrum)

Definition: FHSS is another spread spectrum technique where the signal rapidly switches ("hops") between different frequencies within a wider band in a pseudorandom sequence.

How It Works:

- The transmitter and receiver hop between predefined frequencies in sync.
- Each transmission occurs over a short period on a given frequency before hopping to the next.
- It minimizes the chance of interference on any single frequency.

Advantages:

- Strong resistance to interference and eavesdropping
- Enhanced security due to unpredictable frequency hops
- Better coexistence with other wireless systems

Use Case:

- Early 802.11 wireless systems (legacy), Bluetooth, and some military communication systems

Q3. How do modulation schemes work in the PHY layer? Compare different modulation schemes and their performance across various Wi-Fi standards.

Modulation Schemes in the PHY Layer

The Physical (PHY) layer in Wi-Fi is responsible for converting digital data into electromagnetic signals for wireless transmission. **Modulation schemes** are used to encode data onto carrier signals by varying certain signal characteristics such as amplitude, frequency, or phase.

These modulation techniques allow multiple bits to be transmitted per symbol, improving **data rate** and **spectral efficiency**.

Common Modulation Schemes in Wi-Fi

Modulation Type	Description	Bits per Symbol	Wi-Fi Standards	Performance
BPSK (Binary Phase Shift Keying)	Varies the phase of the carrier by 180° to represent binary data	1	802.11a/b/g/n	High reliability, low data rate
QPSK (Quadrature Phase Shift Keying)	Uses 4 phase shifts to encode 2 bits per symbol	2	802.11a/b/g/n/ac	Good balance of speed and robustness
16-QAM (Quadrature Amplitude Modulation)	Modifies both amplitude and phase; encodes 4 bits per symbol	4	802.11a/g/n/ac	Higher throughput, moderate noise resistance
64-QAM	Encodes 6 bits per symbol	6	802.11n/ac	High data rates, lower noise immunity
256-QAM	Encodes 8 bits per symbol	8	802.11ac/ax	Very high throughput, requires high signal quality
1024-QAM	Encodes 10 bits per symbol	10	802.11ax	Ultra-high throughput, very sensitive to noise

Performance Across Wi-Fi Standards

Wi-Fi Standard	Max Modulation Used	Max Data Rate	Remarks
802.11b	DSSS with QPSK	11 Mbps	Robust, low-speed
802.11g	64-QAM	54 Mbps	Good performance for 2.4 GHz
802.11n	64-QAM	600 Mbps (with MIMO)	Introduced MIMO and channel bonding
802.11ac	256-QAM	1 Gbps+	High throughput in 5 GHz

802.11ax (Wi-Fi 6)	1024-QAM	9.6 Gbps	Optimized for dense environments, better efficiency

Q4. What is the significance of OFDM in WLAN? How does it improve performance?

OFDM (Orthogonal Frequency Division Multiplexing) is a digital modulation technique used in modern WLAN standards (e.g., IEEE 802.11a/g/n/ac/ax) to efficiently transmit high-speed data over wireless channels. It divides a wideband signal into multiple narrowband subcarriers that are transmitted in parallel.

Each subcarrier is modulated independently using techniques like BPSK, QPSK, or QAM, and they are orthogonal to each other—meaning they do not interfere despite being closely spaced.

Significance of OFDM in WLAN

1. **Efficient Use of Spectrum**
   OFDM allows multiple subcarriers to be packed closely together, maximizing the utilization of available bandwidth and increasing throughput.
2. **High Data Rates**
   By transmitting data in parallel across multiple subcarriers, OFDM supports high data rates, suitable for applications like video streaming and large file transfers.
3. **Resilience to Multipath Fading**
   Wireless environments suffer from multipath propagation, where signals reflect and arrive at the receiver at different times. OFDM mitigates this by using **longer symbol durations** and **cyclic prefixes**, reducing inter-symbol interference (ISI).
4. **Adaptive Modulation**
   Each subcarrier in OFDM can be modulated individually based on channel conditions, enabling **dynamic modulation schemes** (e.g., using 64-QAM for strong signals, BPSK for weak signals), which improves reliability and performance.
5. **Simplified Equalization**
   Since each subcarrier occupies a narrow bandwidth, **equalization becomes easier**, as flat fading can be assumed per subcarrier.
6. **Supports MIMO**
   OFDM works efficiently with **Multiple-Input Multiple-Output (MIMO)** systems, further enhancing spectral efficiency and throughput.

Performance Benefits in WLAN

Aspect	Improvement with OFDM
Throughput	Increases due to parallel transmission
Latency	Lower latency in environments with multipath
Efficiency	Better use of spectrum and adaptive modulation
Reliability	Resilient to fading and interference
Scalability	Works well in both low and high-density environments

Q5. How are frequency bands divided for Wi-Fi? Explain different bands and their channels.

Wi-Fi operates primarily within unlicensed radio frequency bands defined by regulatory authorities such as the **FCC (USA)**, **ETSI (Europe)**, and **IEEE**. The most commonly used bands for Wi-Fi are:

- **2.4 GHz Band**
- **5 GHz Band**
- **6 GHz Band** (introduced in Wi-Fi 6E)

Each band is divided into multiple **channels**, with specific characteristics and regulatory constraints.

1. 2.4 GHz Band

- **Frequency Range:** 2.400 – 2.4835 GHz
- **Total Channels:** 14 (though availability varies by region)
- **Channel Width:** 20 MHz
- **Common Channels (Non-Overlapping):** 1, 6, 11 (in the US)

2. 5 GHz Band

- **Frequency Range:** 5.150 – 5.850 GHz (varies slightly by country)
- **Channel Widths:** 20 MHz, 40 MHz, 80 MHz, 160 MHz (bonded channels)
- **Non-Overlapping Channels:** Many, such as 36, 40, 44, 48, etc.

3. 6 GHz Band (Wi-Fi 6E)

- **Frequency Range:** 5.925 – 7.125 GHz (depending on country regulations)
- **Channel Widths:** 20 MHz to 160 MHz
- **Number of Channels:** Over 50 additional non-overlapping channels

Q6. What is the role of Guard Intervals in WLAN transmission? How does a short Guard Interval improve efficiency?

In WLAN (Wireless Local Area Network) transmissions, particularly those using **OFDM (Orthogonal Frequency Division Multiplexing)** such as IEEE 802.11 standards (e.g., 802.11a/g/n/ac), the **Guard Interval (GI)** plays a crucial role in mitigating **intersymbol interference (ISI)**.

Role of Guard Interval:

- **ISI Prevention**: In a multipath environment, signals can arrive at the receiver at slightly different times due to reflections. The GI is a short period inserted between OFDM symbols to absorb these delayed signals, reducing ISI.
- **Maintains Orthogonality**: By allowing delayed signals to die out before the next symbol arrives, GIs help maintain the orthogonality of the subcarriers in OFDM, which is essential for correct demodulation.

How a Short Guard Interval Improves Efficiency:

- A **standard GI is typically 800 nanoseconds (ns)** in 802.11a/g/n/ac.
- A **short GI is 400 ns** (optional in 802.11n and later).
- By reducing the GI duration from 800 ns to 400 ns, more data symbols can be transmitted in the same time frame.

Efficiency Gains:

- Reduces the **overhead** associated with each OFDM symbol.
- Can **increase throughput by approximately 10%**, depending on the channel conditions and implementation.
- Best used in environments with **minimal multipath effects** or short delay spreads to avoid increased error rates.

Q7: Describe the structure of an 802.11 PHY layer frame. What are its key components?

The **802.11 PHY (Physical) layer frame** is responsible for the transmission and reception of raw data bits over a physical medium (like radio waves). The structure of a PHY layer frame consists of several parts that help in synchronization, decoding, and data delivery.

Key Components of an 802.11 PHY Layer Frame:

1. **Preamble:**
    - Helps receivers detect the signal, synchronize, and prepare for data reception.
    - Contains:

- **Short Training Field (STF):** For signal detection and coarse frequency offset estimation.
- **Long Training Field (LTF):** For channel estimation and fine frequency correction.
- **Signal Field (SIG):** Carries information about the modulation rate, length of the data, and other transmission parameters.

2. **Header (PLCP - Physical Layer Convergence Protocol Header):**
   - Provides metadata about the frame such as:
     - Data rate
     - Frame length
     - Service field
     - Parity or CRC
   - Ensures the MAC layer knows how to interpret the data.
3. **Data (PSDU - PLCP Service Data Unit):**
   - Contains the actual MAC layer data payload.
   - Encapsulates:
     - MAC header
     - MAC payload (user data)
     - Frame Check Sequence (FCS)

Q8: What is the difference between OFDM and OFDMA?

Aspect	OFDM	OFDMA
Full Form	Orthogonal Frequency Division Multiplexing	Orthogonal Frequency Division Multiple Access
Resource Allocation	All subcarriers are assigned to a single user at a time	Subcarriers are divided among multiple users simultaneously
User Access	Single-user system	Multi-user system
Efficiency	Less efficient for small or bursty data packets	Highly efficient, especially for multiple users or IoT
Latency	Higher latency due to sequential user access	Lower latency with parallel user access
Usage	Used in Wi-Fi 5 (802.11ac)	Used in Wi-Fi 6 (802.11ax)

Q9: What is the difference between MIMO and MU-MIMO?

Aspect	MIMO	MU-MIMO
Full Form	Multiple Input Multiple Output	Multi-User Multiple Input Multiple Output
User Support	Communicates with one device at a time	Communicates with multiple devices simultaneously
Antenna Usage	Uses multiple antennas for one data stream at a time	Uses multiple antennas to serve several streams to different users
Efficiency	Good for single high-bandwidth users	Better for networks with many users
Technology Generation	Introduced in Wi-Fi 4 (802.11n)	Introduced in Wi-Fi 5 (802.11ac) and enhanced in Wi-Fi 6
Latency	Higher, as users wait for their turn	Lower, due to parallel transmission

Q10: What are PPDU, PLCP, and PMD in the PHY layer?

1. PPDU (PLCP Protocol Data Unit):

- It's the **final frame** that gets transmitted over the air.
- It includes all physical layer information like preamble, header, and payload.
- Formed by adding the PLCP header and preamble to the PSDU (which contains MAC layer data).

2. PLCP (Physical Layer Convergence Procedure):

- A **sublayer** in the PHY layer that prepares data from the MAC layer for transmission.
- Adds necessary headers and control information.
- Helps the receiver synchronize and decode the signal properly.
- **Key Tasks:**
  - Frame formatting
  - Timing synchronization
  - Error checking

3. PMD (Physical Medium Dependent):

- The **lowest sublayer** in the PHY layer.
- Responsible for the **actual transmission and reception of bits** over the physical medium (radio waves).

- Deals with modulation, signal generation, and frequency translation.

Q11: What are the types of PPDU? Explain the PPDU frame format across different Wi-Fi generations.

Types of PPDU and Their Formats:

1. Legacy PPDU (802.11a/g):

- **Used in:** Wi-Fi 3 and earlier standards
- **Structure:**
    - Legacy Short Training Field (L-STF)
    - Legacy Long Training Field (L-LTF)
    - Legacy Signal Field (L-SIG)
    - Data (Payload)
- **Features:** Basic single-user support with limited modulation schemes and bandwidth (20 MHz)

2. High Throughput (HT) PPDU (802.11n):

- **Used in:** Wi-Fi 4
- **Structure:**
    - Legacy Fields (L-STF, L-LTF, L-SIG)
    - HT-SIG
    - HT Short Training Field (HT-STF)
    - HT Long Training Fields (HT-LTFs)
    - HT Data
- **Features:** Supports MIMO, 40 MHz bandwidth, and aggregation, offering improved throughput over legacy PPDU.

3. Very High Throughput (VHT) PPDU (802.11ac):

- **Used in:** Wi-Fi 5
- **Structure:**
    - Legacy Fields (L-STF, L-LTF, L-SIG)
    - VHT-SIG A

- VHT Short Training Field (VHT-STF)
- VHT Long Training Fields (VHT-LTFs)
- VHT-SIG B
- VHT Data

- **Features:** Supports MU-MIMO (downlink), 80/160 MHz channel bandwidths, and 256-QAM modulation for higher data rates.

4. High Efficiency (HE) PPDU (802.11ax):

- **Used in:** Wi-Fi 6
- **Types of HE PPDUs:**
  - HE SU (Single User)
  - HE MU (Multi-User)
  - HE Trigger-Based
  - HE Extended Range (HE ER)
- **Structure (Example: HE SU):**
  - Legacy Fields (L-STF, L-LTF, L-SIG)
  - HE-SIG-A
  - HE-STF
  - HE-LTFs
  - HE-SIG-B (only for MU PPDU)
  - HE Data
- **Features:** Introduces OFDMA, MU-MIMO (uplink and downlink), BSS coloring, Target Wake Time (TWT), and 1024-QAM modulation. These enhancements significantly improve spectral efficiency and network capacity.

Q12: How is the data rate calculated?

The data rate, often referred to as the bitrate or bandwidth, is the amount of data transmitted over a communication channel in a given time period. It is typically expressed in bits per second (bps), kilobits per second (kbps), megabits per second (Mbps), etc.

To calculate the data rate, you need to consider the following factors:

1. **Bit Depth (or Data Width)**: The number of bits used to represent one unit of data. For example, if you're transmitting 8 bits (1 byte) of data per sample, the bit depth is 8.
2. **Sample Rate**: The number of samples transmitted per second. For example, if you're sampling data from a sensor 1000 times per second, your sample rate is 1000 Hz (samples per second).
3. **Number of Channels**: If you're transmitting data from multiple channels (for example, a multi-sensor system), you multiply the data rate by the number of channels.

Formula

The general formula to calculate the data rate is:

Data Rate=Bit Depth×Sample Rate×Number of Channels