WIFI Training Program

Module 3 – Assignment

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

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

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

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

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

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

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

8. What is the difference between OFDM and OFDMA?

9. What is the difference between MIMO and MU-MIMO?

10. What are PPDU, PLCP, and PMD in the PHY layer?

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

12. How is the data rate calculated?

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

The IEEE 802.11 family defines the set of standards for implementing wireless local area network (WLAN) communication. The PHY (Physical) layer in these standards is responsible for modulation, transmission, and reception of data. Several PHY layer standards exist under 802.11, each with distinct characteristics, mainly in terms of data rate, frequency band, modulation techniques, and channel bandwidth.

Here's a comparative overview of major 802.11 PHY layer standards**:**

Standard	Frequency Band	Max Data Rate	Modulation	Channel Bandwidth	MIMO Streams	QAM Modulation
802.11	2.4 GHz	2 Mbps	DSSS, FHSS	20 MHz	None	None
802.11a	5 GHz	54 Mbps	OFDM	20 MHz	None	64-QAM
802.11b	2.4 GHz	11 Mbps	DSSS (CCK)	20 MHz	None	None
802.11g	2.4 GHz	54 Mbps	OFDM	20 MHz	None	64-QAM
802.11n	2.4 & 5 GHz	600 Mbps	OFDM, MIMO	20/40 MHz	Up to 4×4	64-QAM
802.11ac	5 GHz	6.9 Gbps	OFDM, MIMO, MU-MIMO	20/40/80/160 MHz	Up to 8×8	256-QAM
802.11ax	2.4 & 5 GHz	9.6 Gbps	OFDMA, MU-MIMO	20/40/80/160 MHz	Up to 8×8	1024-QAM
802.11be	2.4, 5, 6 GHz	>30 Gbps (target)	OFDMA, MU-MIMO	up to 320 MHz	Up to 16×16	4096-QAM

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

DSSS – Direct Sequence Spread Spectrum

How It Works:

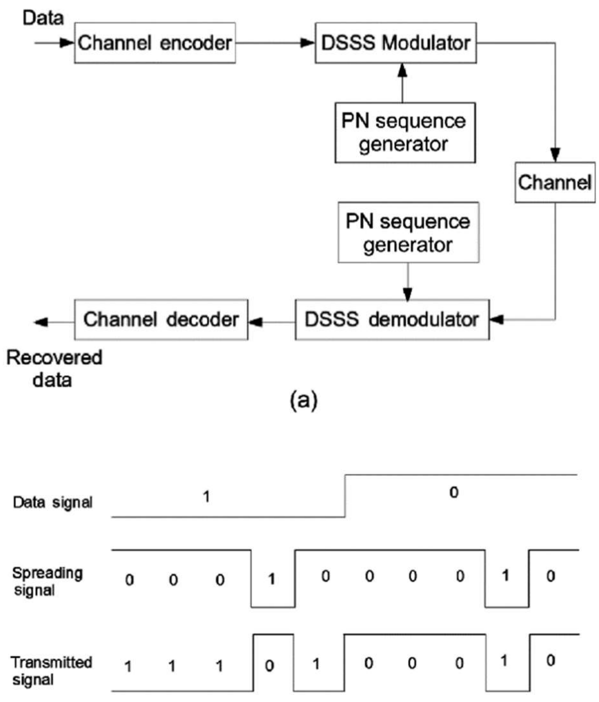
- DSSS spreads the original data signal over a wider frequency band by multiplying it with a pseudo-random noise (PN) code, called a chipping code.
- Each bit in the original data is replaced by multiple smaller bits (chips), forming a higher rate signal.
- A common example is an 11-chip Barker sequence used in 802.11b.
- At the receiver, the same code is used to de spread the signal and retrieve the original data.

Characteristics:

- High resistance to narrowband interference.
- Reduces signal detectability.
- More bandwidth consumption (but allows multiple users to coexist).
- Used in 802.11 and 802.11b (11 Mbps max).

Example:

- Data bit 1 → spread into a chip sequence like 10110111000.
- If interference affects a few chips, the original bit can still be recovered due to redundancy.



(b)

FHSS – Frequency Hopping Spread Spectrum

How It Works:

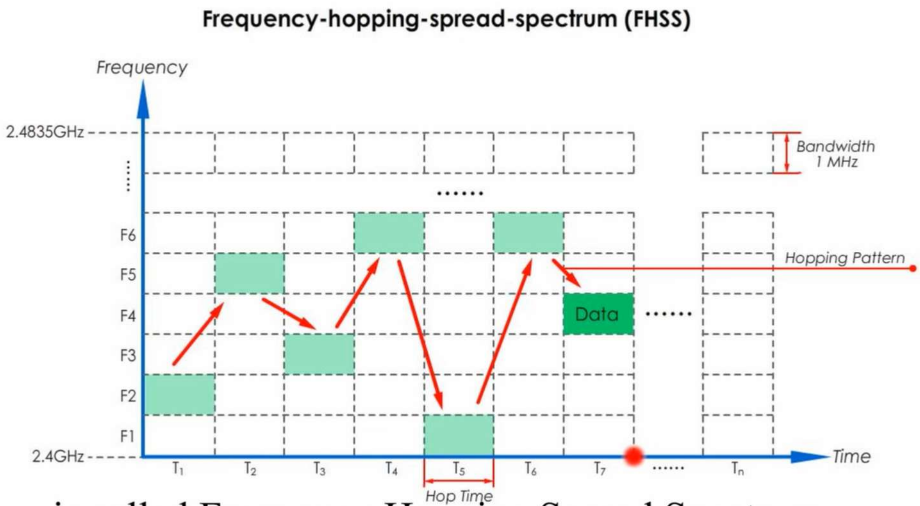
- FHSS transmits the signal by rapidly switching (hopping) the carrier frequency over a sequence of channels.
- Both transmitter and receiver use the same hopping pattern, determined by a pseudo-random sequence.
- Each hop transmits part of the data for a short duration before switching to the next frequency.

Characteristics:

- Resistant to frequency-specific interference and jamming.
- More robust in noisy environments.
- Lower data rate compared to DSSS.
- Used in early 802.11 implementations (but not in 802.11b or later).

Example:

- Channel sequence: 2.412 GHz → 2.437 GHz → 2.462 GHz...
- Signal "hops" every few milliseconds.



is called Frequency Hopping Spread Spectrum.

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

Modulation:

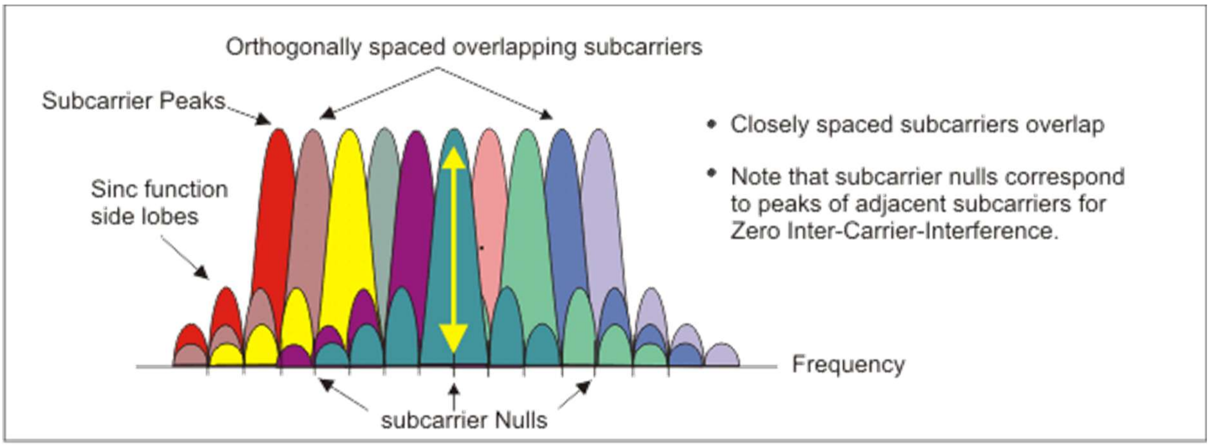
Modulation changes the amplitude, frequency, or phase of the carrier signal to represent digital data. The Goal is to transmit more bits per second without increasing the frequency range too much. Each symbol can carry multiple bits depending on the modulation type. Advanced schemes send more bits per symbol so that we can increase the speed but they also require stronger SNR.

Common Modulation Schemes in Wi-Fi:

Standard	Modulation Used	Key Technologies	Max Data Rate	Performance Summary
802.11b	BPSK, QPSK (with DSSS)	DSSS	11 Mbps	Very stable but low throughput
802.11g/a	BPSK, QPSK, 16-QAM, 64-QAM (with OFDM)	OFDM	54 Mbps	Higher speeds with moderate complexity
802.11n	BPSK to 64-QAM	OFDM, MIMO, channel bonding (20/40 MHz)	600 Mbps	MIMO introduced, significant speed increase
802.11ac	BPSK to 256-QAM	OFDM, MU-MIMO, wider channels (80/160 MHz)	6.9 Gbps	Gbps performance, supports multiple users
802.11ax	BPSK to 1024-QAM	OFDMA, MU-MIMO, spatial reuse, TWT	9.6 Gbps	Efficient in dense environments, high throughput

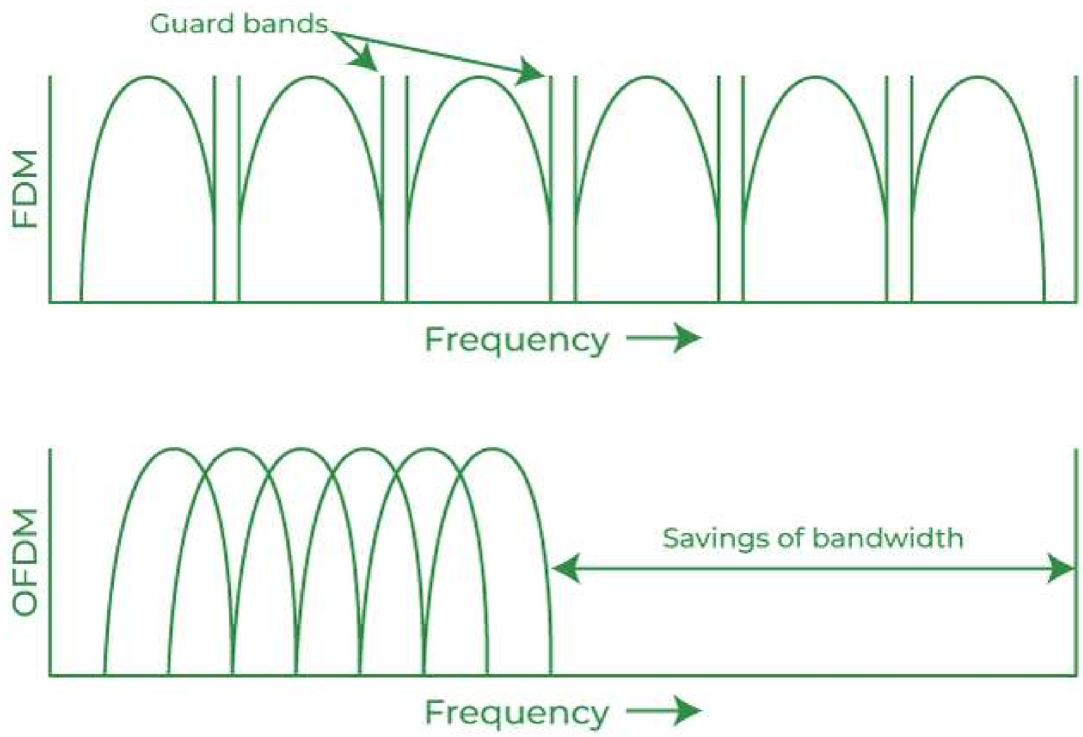
Q4) What is the significance of OFDM in WLAN? How does it improve performance?

OFDM (Orthogonal Frequency Division Multiplexing) is a multi-carrier modulation technique where the available bandwidth is divided into multiple narrowband subcarriers, each carrying a part of the data stream in parallel. All subcarriers are mathematically orthogonal to each other, preventing interference.



OFDM Signal Frequency Spectra

FDM VS OFDM:



Aspect	OFDM Impact
High Data Rates	Enables transmission of multiple symbols simultaneously using many subcarriers, increasing **spectral efficiency**.
Multipath Resistance	Subcarriers are narrowband and experience **flat fading**, making OFDM more resilient to **multipath effects** (reflections).
Inter-symbol Interference (ISI) Reduction	A **cyclic prefix** is added to each symbol to mitigate ISI, ensuring clean decoding at the receiver.
Efficient Bandwidth Use	Subcarriers are placed very close with **orthogonal spacing**, maximizing use of available spectrum.
Flexible Modulation per Subcarrier	Each subcarrier can use different modulation schemes (BPSK, QPSK, 16-QAM, etc.) based on channel conditions.

How OFDM Improves WLAN Performance:

Feature	Benefit
Parallel Transmission	Sends more data at once, boosting throughput
Robust in Noisy Channels	Narrow subcarriers make it less sensitive to noise
Adaptability	Can adapt modulation per subcarrier for optimization
Channel Efficiency	Minimizes guard bands; uses spectrum tightly
Better Coverage and Reliability	Works well even in indoor, multipath-rich environments

Use in Wi-Fi Standards:

- 802.11a/g/n/ac/ax all use OFDM.
- 802.11n onward uses MIMO + OFDM, greatly increasing data rates.
- 802.11ax (Wi-Fi 6) uses OFDMA, an extension of OFDM that allows subcarrier allocation to multiple users simultaneously.

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

Wi-Fi Band	Spectrum Width	Channel Widths Supported	Non-overlapping Channels	Characteristics
2.4 GHz	~83.5 MHz	20 MHz (primarily), 40 MHz (802.11n optional)	3 × 20 MHz (Channels 1, 6, 11 with 2414, 2437, 2462 MHz centre frequencies)	- High range - Low data rate - Good wall penetration - Suitable for congested areas
5 GHz	~700 MHz	20 MHz, 40 MHz, 80 MHz, 160 MHz	25+ (20 MHz), 2 (40 MHz), 4 (80 MHz), 8 (160 MHz)	- Moderate range - Higher throughput - Used indoors/outdoors (via U-NII) - Channels with/without DFS
6 GHz	~1200 MHz	20 MHz, 40 MHz, 80 MHz, 160 MHz, 320 MHz	50+ (20 MHz), 29 (40 MHz), 14 (80 MHz), 7 (160 MHz), 3 (320 MHz)	- High data rate - No DFS - Best for AR/VR, OFDMA - Limited range due to attenuation
60 GHz	~14 GHz	20 MHz–2.16 GHz	3 (20/40 MHz), 25 (80/160 MHz), 59 (320 MHz), 4 (2.16 GHz)	- Ultra high speed - Very short range - Easily absorbed

Qn 6: What is the role of Guard Intervals in WLAN transmission? How does a short Guard Interval improve efficiency?

Role of Guard Intervals in WLAN Transmission

Guard Intervals (GIs) are essential in Wireless Local Area Network (WLAN) systems, especially those based on OFDM (Orthogonal Frequency Division Multiplexing), such as IEEE 802.11a/g/n/ac/ax. Here's their primary role:

1. Mitigating Multipath Interference:
   In real-world environments, transmitted signals reflect off walls, furniture, or other objects, creating delayed signal copies (multipath propagation). These delayed copies can overlap with subsequent OFDM symbols, causing Inter-Symbol Interference (ISI).
2. Insertion of a Cyclic Prefix:
   Instead of inserting a blank gap, a portion of the end of an OFDM symbol is copied and added at the beginning of the same symbol. This is the Guard Interval—a cyclic prefix.
3. Preserving Orthogonality for FFT:
   This technique helps the receiver's FFT (Fast Fourier Transform) process correctly distinguish between subcarriers by preserving orthogonality, even in the presence of multipath delays.
4. Maintaining Data Integrity:
   By absorbing delayed echoes within the GI, the main data part of the OFDM symbol remains clean, ensuring better decoding accuracy and reduced error rates.

A short Guard Interval (GI) improves efficiency in WLAN transmission by reducing the time overhead between OFDM symbols. In OFDM-based systems like IEEE 802.11n/ac/ax, each symbol includes a Guard Interval that helps mitigate inter-symbol interference caused by multipath propagation. The standard GI is 0.8 microseconds, but using a short GI of 0.4 microseconds reduces this overhead, allowing more data symbols to be transmitted in the same time frame. This increase in symbol rate leads to higher throughput—typically up to a 10% improvement—without changing the underlying modulation or channel width. However, short GI is only effective in environments with low delay spread, where the risk of multipath interference is minimal.

Qn 7: Describe the structure of an 802.11 PHY layer frame. What are its key components?

Structure of an 802.11 PHY Layer Frame and Its Key Components

The IEEE 802.11 PHY (Physical) layer frame, also known as the PPDU (PLCP Protocol Data Unit), is the format in which data is transmitted over the wireless medium. It is created by the PHY layer using data passed down from the MAC layer. The exact structure may vary slightly between standards (e.g., 802.11a/b/g/n/ac/ax), but the core components remain conceptually similar.

Key Components of the 802.11 PHY Frame:

1. **Preamble**
    - Used for synchronization between transmitter and receiver.
    - Helps the receiver detect the signal and synchronize timing and frequency.
    - Contains:
        - **Short Training Field (STF)**: Aids in signal detection and coarse frequency offset estimation.
        - **Long Training Field (LTF)**: Used for channel estimation and fine frequency offset correction.
        - **Signal Field (SIG)**: Carries information like modulation, coding rate, and length of the payload.
2. **Header (PHY Header or PLCP Header)**
    - Contains transmission parameters such as:
        - Data rate
        - Length of payload
        - Modulation scheme
        - Coding rate
    - Helps the receiver interpret the upcoming payload correctly.
3. **Payload (PSDU – PLCP Service Data Unit)**
    - This is the actual MAC frame data passed from the MAC layer.
    - It includes:
        - MAC header
        - Frame body (user data)
        - FCS (Frame Check Sequence)

Qn 8: What is the difference between OFDM and OFDMA?

Aspect	OFDM (Orthogonal Frequency Division Multiplexing)	OFDMA (Orthogonal Frequency Division Multiple Access)
1. Basic Principle	Splits a high-rate stream into many low-rate parallel streams over orthogonal subcarriers	Allows multiple users to simultaneously transmit/receive on different subcarrier sets
2. User Access	Only one user can access the channel at a time	Multiple users can access the channel concurrently
3. Introduced In	IEEE 802.11a/g/n/ac	IEEE 802.11ax (Wi-Fi 6), 802.11be (Wi-Fi 7)
4. Efficiency	Inefficient for small packets or many users	Efficient for IoT, mixed traffic, and dense networks
5. FFT Size	Uses smaller FFT sizes	Uses larger FFT sizes for finer RU granularity
6. Medium Access	CSMA/CA (contention-based access)	Centralized scheduling via Trigger Frames
7. Spectral Efficiency	Moderate	High
8. Latency in Dense Networks	Increases	Lower latency due to parallel access
9. Synchronization	Easier receiver synchronization	Requires tight synchronization across users
10. Ideal For	High throughput to single user	Scalable multi-user environments
11. Data Allocation	Full bandwidth to one device	Bandwidth divided into RUs (Resource Units) based on demand
12. Uplink Control	Contention-based access by devices	Trigger Frames from AP allocate RUs
13. Power Control	Basic	Subcarrier-level water-filling possible per RU
14. Scalability	Limited in dense environments	Highly scalable for dense deployments

Qn 9 What is the difference between MIMO and MU-MIMO?

Aspect	**MIMO (Multiple Input, Multiple Output)**	**MU-MIMO (Multi-User MIMO)**
Introduction	Introduced in 802.11n (Wi-Fi 4)	Introduced in 802.11ac (downlink), 802.11ax (DL/UL)
Data Streams	Offers spatial multiplexing for one user	Offers spatial multiplexing for multiple users
Users Served	Only one user per transmission interval	Multiple users can be served simultaneously
Efficiency	Depends on channel estimation (CSR) and interference cancellation	Efficient in dense networks with multiple users
Transmit and Receive Antennas	Uses multiple transmit and receive antennas	Same, but uses spatial beamforming to direct streams to different users
Data Handling	Each spatial stream carries independent data	AP uses precoding to minimize crosstalk between users
Streams Separation	Streams separated using spatial diversity and channel estimation	Uses spatial beamforming and advanced scheduling
Channel Estimation	Receiver must estimate channel and cancel interference for correct data	Advanced scheduling and Channel State Information (CSI) required
Uplink/Downlink	Applied to both uplink and downlink	Primarily used in downlink in 802.11ac; in uplink and downlink in 802.11ax
Scheduling	Not required	Scheduler required to group users based on channel orthogonality

Qn 10 What are PPDU, PLCP, and PMD in the PHY layer?

PPDU, PLCP, and PMD in the PHY Layer

In the Physical (PHY) layer of the IEEE 802.11 standard (Wi-Fi), there are several key components related to the transmission and reception of data. These include the PPDU, PLCP, and PMD. Here's a breakdown of each.

PPDU (PLCP Protocol Data Unit)

- Definition: The PPDU is the complete data unit at the PHY layer, which is transmitted over the wireless medium.
- Role: It encapsulates the data from the MAC layer into a format that can be transmitted by the PHY layer.
- Structure: The PPDU consists of several parts:
    - Preamble: Used for synchronization and channel estimation (includes STF, LTF, SIG).
    - PLCP Header: Contains information about the transmission parameters like data rate, length, and modulation.
    - Payload (PSDU): The actual data being transmitted from the MAC layer.

PLCP (Physical Layer Convergence Protocol)

- Definition: The PLCP is a protocol that defines how the data is formatted and transmitted at the PHY layer.
- Role: It serves as the interface between the MAC layer and the physical transmission in the wireless medium. The PLCP prepares the MAC data (the PSDU - MAC frame) for transmission.
- Components:
    - PLCP Header: It includes information like the data rate and the length of the data to be transmitted.
    - PLCP Service Data Unit (PSDU): The actual payload, which is the MAC frame data.
- Function: The PLCP header is added to the PSDU from the MAC layer, and the combined frame becomes the PPDU for transmission.

PMD (Physical Medium Dependent)

- Definition: The PMD layer defines the specific characteristics of the physical medium being used for transmission, such as the radio frequency, modulation technique, and signal encoding.
- Role: It is responsible for the actual transmission and reception of data over the physical medium (air in the case of wireless communication).
- Components:
    - Transmitter: It converts the digital data (from the PLCP) into a radio signal using modulation techniques (e.g., BPSK, QPSK, QAM).
    - Receiver: It receives the radio signal and decodes it into digital data.
- Example: For Wi-Fi, the PMD layer would specify the modulation scheme (e.g., OFDM, DSSS) and the channel frequency.

Relationship Between PPDU, PLCP, and PMD:

- The PPDU is the entire data unit that is transmitted over the wireless medium, which includes both the PLCP header and the payload (PSDU).
- The PLCP is the part of the PPDU that contains the header and the data unit (PSDU) that is transmitted to the PMD layer.
- The PMD layer is responsible for the physical transmission and reception of the PPDU through the medium, handling modulation, encoding, and ensuring data is sent over the air.

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

Types of PPDU (Physical Protocol Data Unit)

The PPDU (Physical Layer Protocol Data Unit) is the unit of data transmitted over the air in Wi-Fi networks. Its structure varies across different Wi-Fi generations due to advancements in modulation, encoding, and the addition of new features like MIMO and OFDMA. Each Wi-Fi generation defines a distinct PPDU frame format, accommodating the different transmission technologies.

Below is an explanation of the types of PPDUs and their respective frame formats across different Wi-Fi generations.

Basic PPDU Frame Format Across Wi-Fi Generations

The basic PPDU frame format remains largely consistent, but its components evolve with each generation.

General PPDU Structure:

- Preamble: Used for synchronization, and signal detection, and includes portions like Short Training Field (STF), Long Training Field (LTF), and Signal Field (SIG).
- PLCP Header: Contains information such as the data rate, channel coding, and modulation used.
- PSDU (PLCP Service Data Unit): Contains the payload (actual data) from the MAC layer.

PPDU Frame Format in Different Wi-Fi Generations

Wi-Fi 4 (802.11n):

- **Modulation**: **OFDM** (Orthogonal Frequency Division Multiplexing).
- **Maximum Data Rate**: Up to **600 Mbps** with 4 spatial streams.
- **PPDU Format**:
  - Preamble: Contains STF, LTF, and SIG fields.
  - PLCP Header: Used to convey information like data rate and channel width (20/40 MHz).
  - PSDU: The MAC data that will be transmitted. This can support up to 4 spatial streams (MIMO).
- **Key Feature**: **MIMO** (Multiple Input, Multiple Output) is introduced, allowing the use of multiple antennas for increased throughput.

Wi-Fi 5 (802.11ac):

- **Modulation**: **256-QAM** and **OFDM**.
- **Maximum Data Rate**: Up to **3.5 Gbps** with 8 spatial streams.
- **PPDU Format**:
    - Preamble: Contains STF, LTF (Long Training Field for the 8 streams), and SIG fields.
    - PLCP Header: Includes information on the data rate, the number of spatial streams, and channel width (up to 160 MHz).
    - PSDU: The MAC data that is transmitted, now supporting more streams with MIMO.
- **Key Feature**: Introduction of MU-MIMO (Multi-User MIMO), allowing the AP to serve multiple users simultaneously.

Wi-Fi 6 (802.11ax):

- **Modulation**: **1024-QAM** and **OFDM** with **OFDMA**.
- **Maximum Data Rate**: Up to **9.6 Gbps** with **8 spatial streams**.
- **PPDU Format**:
    - Preamble: Includes STF, LTF, and SIG, similar to previous standards.
    - PLCP Header: Enhanced with information about OFDMA, resource units (RUs), and subcarrier allocation for multi-user access.
    - PSDU: The payload transmitted from the MAC layer, with more efficient resource unit (RU) allocation across multiple users.
- **Key Feature**: **OFDMA** allows more efficient use of spectrum, enabling the AP to allocate portions of the channel to different users simultaneously. It also supports **MU-MIMO** for both uplink and downlink.

Wi-Fi 7 (802.11be) (future generation):

- **Modulation**: **4096-QAM** and **OFDM** with **OFDMA** and **MIMO**.
- **Maximum Data Rate**: Expected up to **30 Gbps** with **16 spatial streams**.
- **PPDU Format**:
    - Preamble: Enhanced preambles to support higher speeds and dense environments.
    - PLCP Header: Includes information about OFDMA, MU-MIMO, channel bandwidth (up to 320 MHz), and QAM modulation.
    - PSDU: The payload contains the data with enhanced channel access for simultaneous multi-user operation.
- **Key Feature**: Enhanced MU-MIMO, OFDMA, and Wider Channels will improve network efficiency and high throughput in dense environments.

Detailed PPDU Frame Structure by Generation:

Wi-Fi 4 (802.11n) PPDU Format:

- **Preamble**:
    - STF: Short Training Field (used for synchronization).
    - LTF: Long Training Field (used for channel estimation).
    - SIG: Signal field (includes information about the data rate, modulation, etc.).
- **PLCP Header**:
    - Contains **data rate**, **channel coding** information, and modulation scheme.
- **PSDU**:
    - The actual **MAC frame** data.

Wi-Fi 5 (802.11ac) PPDU Format:

- **Preamble**:
    - STF, LTF (for 8 streams), SIG fields for **channel estimation** and **data rate signalling**.
- **PLCP Header**:
    - Information about **data rate**, **channel width**, and **spatial streams**.
- **PSDU**:
    - Larger payload supporting **8 spatial streams**.

Wi-Fi 6 (802.11ax) PPDU Format:

- **Preamble**:
  - STF, LTF (adjusted for higher efficiency with MU-MIMO), SIG.
- **PLCP Header**:
  - More detailed **OFDMA**, **RU mapping**, and **MIMO** related data.
- **PSDU**:
  - The **data transmission** with **multiple RUs**.

Wi-Fi 7 (802.11be) PPDU Format:

- **Preamble**:
  - Improved STF, LTF, SIG fields to accommodate **higher data rates** and **16 spatial streams**.
- **PLCP Header**:
  - Extensive **OFDMA**, **MU-MIMO**, and **QAM modulation** information.
- **PSDU**:
  - Payload with large amounts of data supporting **higher throughput** and **multi-user access**.

Qn 12 How is the Data Rate Calculated?

$$\text{Data Rate} = \frac{\overbrace{N_{SD}}^{\text{Number of Data Subcarriers}} * \overbrace{N_{BPSCS}}^{\text{Number of Coded Bits per Subcarrier per Stream}} * \overbrace{R}^{\text{Coding}} * \overbrace{N_{SS}}^{\text{Number of Spatial Streams}}}{\underbrace{T_{DFT}}_{\text{OFDM Symbol Duration}} + \underbrace{T_{GI}}_{\text{Guard Interval Duration}}}$$