Name: Devansh Srivastava

Registration number: 21BCE0527

Wi-Fi Training Programme

Module 3

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

Ans: Different types of 802.11 PHY layer standards are-

1. **802.11 (Legacy)**: 2.4 GHz band, data rates up to 2 Mbps, used FHSS and DSSS
2. **802.11b**: 2.4 GHz band, up to 11 Mbps, used DSSS only
3. **802.11a**: 5 GHz band, up to 54 Mbps, introduced OFDM
4. **802.11g**: 2.4 GHz band, up to 54 Mbps, combined DSSS and OFDM
5. **802.11n**: Dual-band (2.4/5 GHz), up to 600 Mbps, introduced MIMO
6. **802.11ac**: 5 GHz only, up to 3.5 Gbps, added MU-MIMO and wider channels
7. **802.11ax (Wi-Fi 6)**: Dual-band, up to 9.6 Gbps, introduced OFDMA and 1024-QAM
8. **802.11be (Wi-Fi 7)**: Multi-band, up to 30 Gbps, uses 4096-QAM and multi-link operation

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

DSSS- Direct Sequence Spread Spectrum, or DSSS, employs a pseudo-random chipping sequence to spread the data stream over a larger frequency band. Many chips represent each bit, providing redundancy and interference resistance. The receiver employs the same chipping sequence to extract the original data. Good signal quality is achieved with DSSS in heavy channels.

FHSS- Frequency Hopping Spread Spectrum, or FHSS, takes advantage of rapid frequency switching among prearranged channels that the transmitter and receiver share to communicate data. It switches among various frequencies, remaining on one for a short time before jumping to the next. This renders FHSS hard to intercept and immune to narrowband interference. It is, however, compared to DSSS, less likely to provide lower data rates.

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

Ans: Modulation schemes determine how digital data is encoded onto radio waves:

- **BPSK (Binary Phase Shift Keying)**: Simplest form, encodes 1 bit per symbol, very robust but low data rate
- **QPSK (Quadrature Phase Shift Keying)**: Encodes 2 bits per symbol, doubling BPSK's data rate with similar robustness

- **16-QAM (Quadrature Amplitude Modulation)**: Encodes 4 bits per symbol, higher data rate but requires better SNR
- **64-QAM**: Encodes 6 bits per symbol, used in 802.11a/g/n
- **256-QAM**: Encodes 8 bits per symbol, used in 802.11ac
- **1024-QAM**: Encodes 10 bits per symbol, used in 802.11ax
- **4096-QAM**: Encodes 12 bits per symbol, used in 802.11be

Higher-order modulations provide more information per symbol but call for higher signal quality. Wi-Fi selects the modulation dynamically according to signal conditions and defaults to more secure schemes when signals are poor.

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

Ans: OFDM (Orthogonal Frequency Division Multiplexing) divides a channel into multiple closely-spaced subcarriers that transmit data in parallel. Each subcarrier operates at a much lower data rate than the total channel bandwidth would allow.

OFDM significantly improves WLAN performance by:

- Reduces inter-symbol interference by using longer symbol periods
- Subcarriers overlap without interfering, utilizing bandwidth efficiently
- Can adjust modulation per subcarrier based on channel conditions
- Enables parallel data transmission across multiple subcarriers

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

Ans: Wi-Fi operates in several frequency bands:

1. Wi-Fi uses **2.4 GHz, 5 GHz, and 6 GHz** bands.
2. **2.4 GHz**: 14 channels; only **1, 6, and 11** are non-overlapping; prone to interference.
3. **5 GHz**: More channels, less congestion, supports higher speeds.
4. **6 GHz (Wi-Fi 6E)**: Latest band, clean spectrum, wider channels, ideal for modern high-speed Wi-Fi.

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

Ans: A Guard Interval (GI) is a short delay between symbols transmitted to avoid inter-symbol interference due to multipath propagation.

Role of Guard Intervals:

- Avoids symbols from colliding due to reflections arriving at different times
- Permits echoes of previous symbol to decay before processing next symbol

- Essential in environments with numerous reflective surfaces

Short Guard Interval Improvement:

- Typical GI is 800ns in majority of Wi-Fi standards
- Short GI is 400ns (added in 802.11n)
- 802.11ax added even shorter 1.6µs GI choices
- Shorter GI boosts throughput by minimizing overhead time between symbols
- Average efficiency gain is about 10% with short GI
- But shorter GI needs improved signal quality and performs best in environments with lower multipath interference

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

Ans: The 802.11 PHY layer frame (PPDU) typically consists of:

1. **Preamble**:
   → Synchronization field containing a pattern of bits for timing synchronization
   → Allows receivers to detect signal presence and align timing
2. **PHY Header** (PLCP Header):
   → Contains information about the frame like modulation type, coding rate, and length
   → Typically transmitted at lowest data rate for maximum reliability
3. **Data Field**:
   → Contains the actual MAC frame (MPDU) being transmitted
   → May include multiple MPDUs in newer standards (A-MPDU)
   → Transmitted at the negotiated data rate

8. What is the difference between OFDM and OFDMA?

OFDM	**OFDMA**
1. It stands for Orthogonal Frequency Division Multiplexing	1. It stands for Orthogonal Frequency Division Multiple Access
2. One user at a time uses all subcarriers	2. Multiple users share subcarriers at the same time
3. Less efficient in high user density	3. Highly efficient in multi-user environments
4. Higher latency	4. Lower latency due to parallel user access
5. Used in 802.11a/g/n/ac (Wi-Fi 5 and earlier)	5. Used in 802.11ax (Wi-Fi 6 and newer)

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

MIMO (Multiple Input Multiple Output)	**MU-MIMO (Multi-User MIMO)**
1. Communicates with one device at a time.	1. Communicates with multiple devices simultaneously.
2. It is introduced in 802.11n (Wi-Fi 4).	2. It is introduced in 802.11ac Wave 2 (Wi-Fi 5), improved in Wi-Fi 6.
3. Improves speed for a single device.	3. Improves efficiency across multiple users.
4. Sends multiple data streams to one device	4. Splits data streams between several devices.
5. Can cause delays in crowded networks.	5. Reduces network congestion in busy environments.
6. High speed for one, slower for others waiting.	6. Distributes speed fairly among users.
7. Limited interference handling.	7. Better interference management with beamforming.
8. Uses multiple antennas for one device.	8. Uses antennas to target multiple devices.
9. Higher latency in busy networks.	9. Lower latency, especially in Wi-Fi 6.

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

Ans: **PPDU (PLCP Protocol Data Unit)**

- It is the complete data packet that is transmitted over the air.
- Formed by combining PLCP and MAC layer data.
- Different PPDU formats exist (e.g., Legacy, HT, VHT, HE) based on Wi-Fi standard.

PLCP (Physical Layer Convergence Protocol)

- Responsible for preparing MAC data for transmission over the physical medium, it is positioned in between the MAC and PMD.
- It assists the receiver with synchronizing and decoding the signal by inserting a header and preamble.
- Ensures a smooth flow from the MAC layer to the physical media

PMD (Physical Medium Dependent)

- Handles the actual transmission of bits over the wireless medium.

- Converts digital data into radio signals and vice versa.
- Deals with frequency, modulation, and RF hardware aspects.

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

Ans: PPDU types have evolved across Wi-Fi generations:

1. Legacy (802.11a/b/g):

- Simple format with short/long preamble options
- Basic PLCP header with rate, length, and parity information

2. HT-PPDU (802.11n):

- Added Mixed Mode and Greenfield formats
- Supporting up to 4 spatial streams
- Introduced 40 MHz channels

3. VHT-PPDU (802.11ac):

- More complex preamble with VHT-SIG fields
- Supporting up to 8 spatial streams
- Channels up to 160 MHz wide

4. HE-PPDU (802.11ax):

- Multiple formats: SU, MU, Trigger-based, and Extended Range
- Complex signaling fields to support OFDMA
- Additional fields for resource allocation

5. EHT-PPDU (802.11be):

- Extended bandwidths up to 320 MHz
- Support for 16 spatial streams
- Multi-link operation elements

12. How is the data rate calculated?

Ans: Data Rate=

```
((Number of Subcarriers) * (Number of Bits per Subcarrier) * (Number of Spatial Streams))/(Guard Interval + Symbol Duration).
```

- **Number of Subcarriers:** This refers to the number of individual channels used to transmit data within the Wi-Fi signal.

- **Number of Bits per Subcarrier:** This indicates how much data (in bits) can be carried on each subcarrier.
- **Number of Spatial Streams:** This refers to the number of independent data streams that can be transmitted simultaneously using multiple antennas.
- **Guard Interval:** This is a short period of time added to the end of each symbol to prevent interference between consecutive symbols.
- **Symbol Duration:** This is the time it takes to transmit one symbol.