Module 3

Wi-Fi Training Program

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

STANDARD	FREQ. BAND (GHz)	MAX. DATA RATE (Mbps/Gbps)	CHANNEL WIDTH (MHz)	MOUDLATION	YEAR	RANGE (m) Indoor	FEATURES
802.11	2.4	2 Mbps	20	DSSS, FHSS	1997	20	It was used many years ago.
802.11a	5	54 Mbps	20	OFDM	1999	25	Has high speed, low interference and shorter range.
802.11b	2.4	11 Mbps	20	DSSS	1999	35	It has more range than 802.11a, but is slower.
802.11g	2.4	54 Mbps	20	OFDM	2003	38	It has compatible backwards with 802.11b
802.11n	2.4/5	600 Mbps	20/40	OFDM+MIMO	2009	70	This is the standard where MIMO was introduced with improved speed and range.
802.11ac	5	6.93 Gbps	20/40/80/160	OFDM+ MU-MIMO	2013	35	It has high throughput
802.11ad	60	7 Gbps	2.16 Ghz	SC, OFDM	2012	10	It has very high speed but has very short range.
802.11ax	2.4/5	9.6 Gbps	20/40/80/160	OFDMA, MU-MIMO	2019	40	It has high efficiency and supports many users

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

DSSS refers to Direct Sequence Spread Spectrum and FHSS refers to Frequency Hopping Spread Spectrum.

They are used for wireless communication over radio frequencies.

DSSS working:

1. Every bit of data signal is multiplied by a high-rate pseudorandom code which is called a chipping sequence.
2. This will result in spreading the signal over a wider bandwidth than the original data signal with less interference and noise.
3. When the receiver receives the signal, he uses the same pseudorandom code to de-spread the signal and recover the original data.

<u>Advantages:</u>

- It has wide bandwidth.
- Improves the security.
- Reduces the power consumption.

FHSS working:

FHSS rapidly switches the carrier frequency among many frequency channels in a pseudorandom sequence. Data is transmitted in small bursts on each frequency. Both sender and receiver must hop together in sync using the same sequence.

1. The sender and receiver must agree on a hopping pattern (pseudorandom sequence of frequencies).
2. The transmitter will hop between different frequencies at regular intervals which reduces interference.
3. The receiver will lo follow the same pattern as the transmitter, so that the receiver correctly decodes the signal.

<u>Advantages:</u>

- Low interference.
- Improved security
- Lower bandwidth.

Q3. How do modulation schemes work in the PHY Layer? Compare the different modulation schemes and their performance.

- It is the process of altering a carrier signal to encode data for transmission. It is used to convert digital data into radio waves for wireless transmission.
- Each modulation technique will entail a trade-off between speed, reliability, and signal strength.
- Digital bits (0s and 1s) are mapped to analog signal changes (amplitude, frequency, or phase).

- The receiver demodulates the signal, interpreting those changes back into bits.

PSK-Phase Shift Keying, QAM-Quadrature Amplitude Modulation

MODULATION	**BITS/SYMBOLS**	**DESCRIPTION**	**STANDARDS WHICH USE THIS**	**Max. theoretical DATA RATE**
BPSK (binary)	1	Simple but slow	802.11 a/b/g/n/ac/ax	Low and is used when signal is bad.
QPSK (quadrature)	2	Improved data rate over BPSK	802.11 a/g/n/ac/x	Moderate
16-QAM	4	More bits/symbol but less robust	802.11 a/g/n/ac/x	High
64-QAM	6	High throughput but need a clean signal	802.11n/ac	Very high
256-QAM	8	It is used in high-quality signal environments.	802.11ac	Very high
1024-QAM	10	It was introduced in WiFI 6 which is 802.11 ax	802.11ax	Very high
4096-QAM	12	As discussed in the technical session, it is introduced in WiFi 7	802.11be	Ultra-high

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

Orthogonal Frequency Division Multiplexing is a modulation technique used in modern WLAN (Wi-Fi) standards like 802.11a/g/n/ac/ax. It has enabled faster and more reliable Wi-Fi.

It splits a high-speed data stream into multiple lower data stream, each of has its own subcarrier (separate frequency).

(I can use the example of multiple lanes on a highway = many small files sent at the same time on different subcarriers of the same highway)

<u>Working:</u>

1. The available channel bandwidth (e.g., 20 MHz) is divided into multiple narrow subcarriers (e.g., 64 for 802.11a/g).
2. Each subcarrier will carry a portion of the data using simple modulation (like BPSK, QPSK, QAM).
3. All the subcarriers are transmitted simultaneously, but don't interfere due to their orthogonality.
4. At the receiver's end, the signal is split back and reassembled using FFT (Fast Fourier Transform).

<u>It improves performance due to the following reasons:</u>

Resistance to multipath fading:

OFDM handles reflections well, ideal for indoor Wi-Fi with walls/objects.

Flexible modulation per subcarrier:

Each subcarrier can be adaptively modulation based on channel quality. This ensures efficient use of spectrum and maximises throughput while maintaining link reliability.

Wide bandwidths are supported:

It easily extends to 20, 40, 80, or 160 MHz in modern Wi-Fi

Low inter-symbol interference:

Using a guard interval (cyclic prefix) reduces overlap between symbols and absorbs delays caused by multipath.

High Spectral efficicency:

The subcarriers are packed tightly which allow higher data rates in limited bandwidth.

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

Wi-Fi operates on specific frequency bands that are divided into channels to allow multiple devices to communicate without interfering with each other.

Frequency bands are regulated internationally, and different Wi-Fi standards use different parts of the spectrum.

BAND	FREQUENCY RANGE (GHz)	COMMON STANDARDS	CHANNEL WIDTH (MHz)	NON-OVERLAPPING CANNELS	ADVANTAGES	DISADVANTAGES
2.4 GHz	2.4 – 2.4835	802.11b/g/n/ax	20 (14 channels: 1 to 11 are commonly used)	1, 6 and 11	Long range and wall penetration	Prone to interference as it is shared with bluetooth and and microwaves
5 GHz	5.150 – 5.825	802.11a/n/ac/ax	20, 40, 80, 160 (More than 25 channels)	**UNII-1 (Indoor)**: Channels 36–48 **UNII-2 (DFS, radar coexistence)**: Channels 52–64 **UNII-2e (DFS)**: Channels 100–144 **UNII-3 (Outdoor)**: Channels 149–165	High speed, Less congestion and more overlapping channels	Short range and some of the channels require Dynamic Frequency Selection (DFS)
6 GHz	5.925 – 7.125	802.11ax Wi-Fi 6E, 802.11be Wi-Fi 7,	20 (59 channels are available)	Many	It has high speed, low latency and low interference	Only supported on Wi-Fi 6e devices and in countries that have given approval.
60 GHz	57 - 71	802.11ad/ay	Few	Few	Very high speed, Minimal interference.	Few channels, very short range, poor penetration

Q6. What is the role of Guard Intervals in wireless transmission? How does a short guard interval improve efficiency?

- A Guard Interval is a short time gap inserted between consecutive symbols during wireless transmission.
- It is important is OFDM (Orthogonal Frequency Division Multiplexing) based transmissions used in Wi-Fi standards 802.11a/g/n/ac/ax.
- Multipath propagation occurs when a single transmitted signal arrives at the receiver's end via multiple paths due to reflections from wall, furniture and other surfaces.
- Inter-Symbol Interference occurs as a result of the above and one symbol interferes with the other.
- Guard Interval provides a brief pause in between till the next symbol starts.

<u>Working:</u>

- Data is divided into multiple subcarriers and sent simultaneously.
- A Cyclic Prefix (a copy of the end part of the signal) will be added at the beginning of each symbol.
- The Cyclic Prefix acts as the Guard Interval, absorbing the multipath signals so that the necessary part is received.

<u>Types of Guard Intervals:</u>

LONG GI:

1. Duration: 800ns
2. Default in 802.11a/g/n/ac/ax
3. Best suited for heavy multipath environment.

SHORT GI:

1. Duartion: 400ns
2. Optional in 802.11n/ac/ax
3. Best suited for low multipath environment.

<u>Short GI improves efficiency by:</u>

1. Having less overhead between symbols.
2. More symbols are transmitted which means increased data throughput.

Example: 802.11n

- Long GI (800 ns): 65 Mbps
- Short GI (400 ns): 72.2 Mbps (approx. 11% gain)

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

The PHY layer frame deals with how bits are transmitted (timing, modulation, synchronization, etc.)

A PHY layer frame (also called a PPDU – PLCP Protocol Data Unit) is the actual bitstream that goes over the air. It wraps the MAC layer frame (called the PSDU) and adds all the physical-layer signaling and control required to transmit it.

1. Preamble

Used for timing synchronization, frequency offset correction, and channel estimation.

Fields are:

- Short Training Field (STF): It detects signal
- Long Training Field (LTF): Used for channel estimation and timing
- Signal Field (SIG): Contains information about the rate, length and modulation

2. PLCP Header (PHY Header)

- Communicates how the rest of the frame should be interpreted.
- Fields include:

    1. Rate: Modulation and coding rate
    2. Length: Length of the data section (in bytes)
    3. Service: Reserved, scrambler seed
    4. Tail: for termination bits for error correction
    5. Optional: CRC, Parity, etc.

3. Data Field (PSDU)

- The actual payload being transmitted.
- Contains the MAC frame

4. Tail and Pad bits:

- CRC (Frame Check Sequence)
- Padding
- Tail bits (for convolutional coding)

Q8. What is the difference between OFDM and OFDMA?

CHARACTERISTIC	OFDM	OFDMA
DEFINITION	A modulation technique that splits a high-speed data stream into multiple lower-speed substreams and transmits them in parallel over orthogonal subcarriers.	An extension of OFDM that allows multiple users to share the subcarriers simultaneously in the same time slot.
USED IN	Wi-Fi standards like 802.11a/g/n/ac/ax and cellular networks (LTE, 5G)	Wi-Fi 6 (802.11ax), Wi-Fi 7, LTE, and 5G
ACCESS TYPE	Single user	Multi-user
LATENCY	High	Low
UPLINK SUPPORT	Single user at a time	Multi users can upload at a time
SPECTRAL EFFICIENCY	Moderate	Higher and more efficient for small packets)
RESOURCE ALLOCATION	All subcarriers to on suer	Resource Units are allocated to various users
BEST SUITED FOR	Large packets and single user	Dense environments and small IoT devices

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

FEATURE	**MIMO**	**MU-MIMO**
ABBREVIATION	Multiple Input Multiple Output	Multi-user Multiple Input Multiple Output
DEVICES SUPPORTED	One device can be connected at a time	Multiple devices are supported at the same time
STREAMS USED	Multiple streams to one user	Streams are split between users
STANDARDS	Wi-Fi 4 (802.11n) and higher	Wi-Fi 5 (802.11ac), Wi-Fi 6 (802.11ax)
NETWORK EFFICIENCY	Good for a single user	Great for multiple user environment
BEAMFORMING	It is optional	It is essential
UPLINK SUPPORT	No	Yes (Wi-Fi 8 onwards)
BEST SUITED FOR	High speed and single-device	Busy network with multiple active users
CONFIGURATIONS	2X2, 4X4	4X4 MU-MIMO

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

PPDU is the complete data unit that the physical layer transmits over the air. It encapsulates data from the MAC layer and includes physical layer headers and trailers.

Components of PPDU:

- Preamble: It is used for synchronization and channel estimation.
- PLCP Header: It contains transmission params
- PSDU (PLCP Service Data Unit): This is the actual MAC frame (data).

Purpose:

It prepares and formats the data for transmission.

It ensures correct timing and decoding at the receiver.

PLCP: (Physical Layer Convergence Protocol)

PLCP is a sublayer of the PHY layer that adapts the MAC frame for transmission over the physical medium. It acts as a bridge between the MAC layer and the physical transmission layer.

Functions:

- Accepts the MAC layer frame (MPDU).
- Adds a PLCP header and preamble.
- Passes the resulting PPDU to the PMD sublayer for transmission.

PLCP Header Includes:

- Modulation and coding scheme
- Length of the payload
- Service field and tail bits

Purpose:

- Ensures that the physical layer can interpret and transmit MAC frames efficiently and reliably.

PMD (Physical Medium Dependent):

PMD handles the actual transmission and reception of radio signals through antennae or air.

Characteristics:

- Directly interacts with the physical medium (air).
- Responsible for modulation, encoding, and RF signaling
- Converts digital bits from PLCP into modulated waveforms, and vice versa at the receiver.

Functions:

- Sends/receives waveforms using modulation schemes (BPSK, QAM, etc.)
- Controls radio front-end
- Applies transmit power, frequency, and bandwidth settings

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

The PPDU (Physical Layer Protocol Data Unit) is the final data unit prepared by the physical layer for wireless transmission. It has evolved over years to support throughput, efficiency and performance.

PPDU = Preamble + PHY Header (PLCP) + PSDU (MAC Frame)

Wi-Fi Standard	Wi-Fi generation	PPDU types
802.11a/g	1	Legacy OFDM PPDU
802.11n	4	HT-mixed PPDU, HT-Greenfield PPDU
802.11ac	5	VHT PPDU
802.11ax	6	HE SU PPDU, HE MU PPDU, HE EXT PPDU
802.11be	7	EHT PPDU

1. Legacy OFDM PPDU (802.11a/g - Wi-Fi 1/3)

- Preamble: Synchronization.
- Signal Field: Modulation and data rate info.
- Data Field: Encapsulated MAC frame.

2. HT PPDU (802.11n Wi-Fi 4)

- Supports HT-Mixed and HT-Greenfield modes.

<u>HT-Mixed PPDU:</u>

- Compatible with legacy devices.
- Includes both legacy and HT fields.

<u>HT-Greenfield PPDU:</u>

- No legacy fields (not backward compatible).
- Lower overhead.

3. VHT PPDU (802.11ac Wi-Fi 5)

- VHT-SIG: Contains MCS, bandwidth, coding.
- Supports wider channels (up to 160 MHz), 8 spatial streams.

Q12. How is the data rate calculated?

The data rate in Wi-Fi refers to the speed at which data is transmitted over the wireless medium. It is influenced by various parameters such as modulation type, coding rate, channel width, number of spatial streams, and guard interval.

Formula: Data Rate (Mbps) (Number of Bits per Symbol)×(Code Rate)×(Symbol Rate)×(Number of S patial Streams)