WiFi Assessment 3 - Module 3

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

Standard	Frequency	Rate	Modulation	Year	Generation Name
802.11	2.4 GHz	2 Mbps	FHSS, DSSS	1997	WiFi 1
802.11b	2.4 GHz	11 Mbps	DSSS	1999	WiFi 2
802.11a	5 GHz	54 Mbps	OFDM	1999	WiFi 3
802.11g	2.4 GHz	54 Mbps	OFDM + DSSS (CCK)	2003	WiFi 3
802.11n	2.4 and 5 GHz	600 Mbps	OFDM	2009	WiFi 4
802.11ac	5 GHz	6.9 Gbps	OFDM (256 QAM)	2013	WiFi 5
802.11ax	2.4 and 5 GHz	9.6 Gbps	OFDMA (1024 QAM)	2019	WiFi 6
802.11ax (6 GHz)	6 GHz	9.6 Gbps	OFDMA (1024 QAM)	2021	WiFi 6E
802.11be	2.4 /5 /6 GHz	46 Gbps	OFDMA (4096 QAM)	Upcoming	WiFi 7

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

DSSS :

- Direct Sequence Spread Spectrum
- Used in 802.11b and 802.11g
- Spread data over a wide frequency band using unique code.
- Each data bit is multiplied by a fast pseudorandom code called a chipping code.
- This spreads the signal across a wider bandwidth.
- At the same receiver side, the same code is used to decode the signal.
- It is fast upto 11 Mbps and works well in noise.
- It is advantageous as it is resistant to interference, good for noisy environments.
- Its disadvantage is it needs more bandwidth than the original data rate.

FHSS :

- Frequency Hopping Spread Spectrum.
- It is used in 802.11
- The core concept is to rapidly change or hop frequencies while transmitting.
- The transmitter hops between many frequencies in a defined pattern.
- Receiver follows the same pattern to collect the data.
- So, hops occur several times within a second.
- Its speed is slow (1-2 Mbps) and works well against jamming.
- Its advantages are it is very secure and resistant to narrow bandwidth interference.
- Its disadvantages are lower data rate and having to sync between sender and receiver.

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

In the PHY layer, modulation schemes convert digital bits into radio signals. Higher order modulation sends more bits per symbol but needs a cleaner signal.

Modulation	**Bits**	**Data Rate**	**Reliability**	**Used in (802.11)**
BPSK	1	Low	Very High	a,g,n
QPSK	2	Low-Med	High	a,g,n
16 QAM	4	Medium	Medium	a,g,n,ac
64 QAM	6	High	Lower	n, ac
256 QAM	8	Very High	Needs clean signal	ac
1024 QAM	10	Ultra High	Needs strong signal	ax
4096 QAM	12	Ultra High	Very sensitive	be

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

OFDM : Orthogonal Frequency Division Multiplexing is a technique used to send high speed data over WiFi by splitting a single channel into multiple small sub channels, and sending parts of the data in parallel.

The analogy is to think that instead of sending one big car of data in one lane, send multiple small cars of data in multiple lanes to deliver faster and more efficiently.

The significance of OFDM in WLAN (WiFi) and how it improves performance are as given below:

- Higher data rates → as more data is sent in parallel there will be faster internet (54 Mbps in 802.11a/g).
- Better Noise Resistance → Each subchannel has a low data rate, making it less sensitive to interference.
- Efficient Spectrum Usage → subcarriers are closely packed with no overlap, using frequency more efficiently.
- Multipath Tolerance → Works well even when signals bounce off walls which means fewer errors indoors.
- Robust in Crowded areas → performs better in cities or rooms with many users or walls.

Hence OFDM is the backbone of modern WiFi, it makes wireless communication, making it more reliable, much faster and more robust to interference.

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

WiFi used radio frequencies divided into bands.

2.4 GHz Band :

- Has 14 Channels, each 20 MHz wide.
- Channels will overlap.
- Only 3 non-overlapping channels : 1, 6 and 11
- Best for range but prone to interference such as microwave and bluetooth.
- Common standards are 802.11b/g/n

5 GHz Band :

- Has 25+ Channels, most are 20/40/80/160 MHz wide.
- Channels are non overlapping.
- Has cleaner signals.
- It is great for speed but limited wall penetration.
- Common Standards are 802.11a/n/ac/ax

6 GHz Band :

- Up to 59 Channels, all non overlapping.
- Ultra clean, super fast and low latency.
- Only works with new routers and devices. Used for WiFi 6E.
- Used in 802.11 ax (WiFi 6E).
- Used in Very fast speed and very low interference requirements.

60 GHz Band :

- Only used for very short range (room to room)
- It is very fast (multi-Gbps) but doesn’t pass wales.
- Has very few channels.
- Used in 802.11ad/ay

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

- A guard interval is a short time gap between transmitted symbols in wireless communication. It is used to prevent interference between two signals due to reflections called multipath interference.

- In WiFi, signals bounce off walls and reach the receiver at slightly different times. Without a guard gap, these echoes can interfere with the next signal, causing errors.

- The two types of guard intervals are Long GI which has a duration of 800 Nanoseconds and Short GI which has a duration of 400 Nanoseconds.

- Shorter GI means less waiting time and it gives more useful data per second, this boots efficiency and throughput by 10%. It is advantageous when the environment is clean with less reflection and disadvantageous if there is a lot of multipath like indoors with walls.

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

It is the physical level structure of a wifi packet and how bits are actually sent over the air using radio waves. Each WiFi PHY frame consists of several fields that help devices sync, decode, and receive data properly.

This helps in ensuring compatibility across devices, allows error correction and reliable decoding, and ensures wifi operates smoothly in noisy environments.

Key components of PHY frame are:

- Preamble → to synchronize with the signal
- Signal field → modulation/coding rate is used. (Contains modulation scheme, data rate and payload length).
- Service → reserved bits for future use.
- Payload → Actual user data that is to be transmitted.
- Tail bits → help decoder return to a known state.
- Pad bits → extra bits to align the data bits (also known as padding).

8. What is the difference between OFDM and OFDMA?

OFDM : Orthogonal Frequency Division Multiplexing. Used in Wifi standards like 802.11a/g/n/ac.

- It splits channels into multiple small subcarries.
- Each subcarrier is part of the data.
- These subcarriers are orthogonal (no interference between them).
- Only one user at a time.
- Higher latency
- Full channel is given to a user.

OFDMA : Orthogonal Frequency Division Multiple Access. Used in Wifi 6 (802.11ax).

- It splits the channel into subcarriers.
- It divides them among multiple users at once.
- Each user gets a portion of the RU (resource unit) of the subcarrier.
- Multiple users at a time.
- Lower latency.
- Channel is shared between users.

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

MIMO : Multiple Input, Multiple Output.

- Used in 802.11n, 802.11ac and beyond.
- Uses multiple antennas at both sender and receiver.
- Sends multiple data streams to one device at the same time.
- Streams to one device at a time.
- Has high speed for one user.

MU-MIMO : Multi User Multiple Input, Multiple Output.

- Used WiFi 5 (downlink only) and WiFi 6 (both uplink and downlink).
- Uses multiple antennas at both sender and receiver.
- Sends different data streams to multiple devices at once.
- Streams to multiple devices at onces
- Speed is shared among users hence slower than MIMO.

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

PPDU : PLCP Protocol Data Unit.

The PPDU is the complete packet that is sent over the air by the WiFi hardware. It includes all the necessary information to help the receiver understand and decode the signal correctly.

It contains the Preamble used for synchronization, PLCP header which consists of data rate and length, Payload which is the actual data.

Without PPDU, the receiver wouldn't know where the data begins, how fast to read it, or how much data is coming.

PLCP : Physical Layer Convergence Protocol.

PLCP is a publayer of the PHY layer that interfaces between the MAC and the lower PHY layers (PMD).

It accesses the MAC PDU, adds necessary headers and preambles, converts MPDU into a PPDU and ensures synchronization and decoding parameters are available to the receiver.

It includes fields such as Preamble, signal field which is used for modulation and coding info, service field which is used by decoder, length field which states how many bits are incoming and CRC to check errors in the header.

PMD : Physical Medium Dependent.

The lowest sublayer of the PHY layer that handles actual signal transmission and reception over the air.

It controls the modulation, chooses appropriate frequency channels, converts digital data into analog radio signals and controls antennas, amplifiers and RF front end.

PMD is where the radio frequency conversion takes place and without it, data would not be able to change from digital to analog form.

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

HT PPDU :
- High throughput PPDU
- Uses MIMO, 40 MHz and short GI.
- Works on WiFi 4.
- Maximum of 600 Mbps.
- Consist of Legacy fields such as L-STF, L-LTF, L-SIG.
- Frame also consist of HT-SIG, HT-STF, HT-LTFs.
- Data consists of MAC frames and CRC.

VHT PPDU :
- Very high throughput PPDU.
- Uses MU MIMO
- Works on 256 QAM. (Higher speed).
- Supports upto 8 antennas.
- Maximum speed of 6.9 Gbps.
- Frame consists of similar Legacy fields.
- Frame also consists of VHT-SIG-A, VHT-STF, VHT-LTFs, VHT-SIG-B

HE PPDU :
- High Efficiency PPDU.
- Uses OFDMA, UL/DL MU, BSS coloring.
- Consist of various types of HE such as Single User, Multi user, extended range and trigger based for UL.
- BSS Coloring to reduce interference.
- Better battery life with Target Wake Time (TWT).
- Maximum speed of 9.6 Gbps.

EHT PPDU :

- Extremely High Throughput.
- It is very similar to HE.
- Used 320 MHz bandwidth.
- 4096 QAM
- Very similar to HE, but with new EHT specific fields.
- Uses Multi Link operation : combines channels across bands.
- Max theoretical rate : 46 Gbps.
- It is also backward compatible with older devices.

12. How is the data rate calculated?

Data Rate = (N_{SD} * N_{BPSCS} * R + N_{SS}) / (T_{DFT} + T_{GI})

N_{SD} → Number of data sub carriers
N_{BPSCS} → Number of coded bits per subcarrier per stream
R → Coding
N_{SS} → Number of spatial stream
T_{DFT} → OFDM symbol duration
T_{GI} → Guard Interval duration

Total symbol duration = T_{DFT} + T_{GI}