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Module 3 - Assignment

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

Sl. No	Standard	Bandwidth	Frequency Band	Channel Architecture	Maximum Data Rate	Range
1	802.11	20 MHz	2.4 GHz	DSSS, FHSS	2 Mbps	20 m
2	802.11b	21 MHz	2.4 GHz	CCK, DSSS	11 Mbps	35 m
3	802.11a	22 MHz	5 GHz	OFDM	54 Mbps	35 m
4	802.11g	23 MHz	2.4 GHz	OFDM, DSSS	54 Mbps	70 m
5	802.11n	20, 40 MHz	2.4 & 5 GHz	OFDM	600 Mbps	70 m
6	802.11ac	20, 40, 80, 160 MHz	5 GHz	OFDM	6.93 Gbps	35 m
7	802.11ad	2.16 GHz	60 GHz	SC, OFDM	6.76 Gbps	10 m
8	802.11af	6, 7, 8 MHz	50–790 MHz	SC, OFDM	26.7 Mbps	>1 km
9	802.11ah	1, 2, 4, 8, 16 MHz	900 MHz	SC, OFDM	40 Mbps	1 km

where,
DSSS - Direct Sequence Spread Spectrum - Spreads the data over a wider frequency band using a chipping code.
CCK - Complementary Code Keying - Uses unique code sequences to represent data bits more efficiently.
OFDM - Orthogonal Frequency Division Multiplexing - Divides the channel into multiple sub-carriers that carry data in parallel.
SC - Single Carrier - Transmits the entire signal over a single carrier frequency, unlike OFDM.

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

DSSS :

- DSSS, or Direct Sequence Spread Spectrum, is a wireless data transmission method that involves spreading the signal across a wide range of frequencies using a spreading code.
- Before transmission, the spreading code is combined with the data signal, and the receiver uses the same code to extract the original data signal.
- The DSSS spreading code is typically a long, complex sequence of 1s and 0s generated by a mathematical algorithm.
- This sequence is combined with the original data signal via a process known as "chipping," which involves multiplying each bit of the data signal by a corresponding bit from the spreading code.
- It is more resistant to interference and noise.
- The spreading code is used at the receiver to "de-chip" the signal and extract the original data signal.
- The receiver must be synchronized with the transmitter at all times so that it knows which spreading code is being used.
- Since, the original data signal is reconstructed from multiple bits of the spreading code, some parts of the signal can be lost while the overall transmission remains unaffected.

FHSS:

- Frequency Hopping Spread Spectrum, is a wireless data transmission method that involves constantly changing the frequency of the transmitted signal across a wide frequency range.
- This is accomplished by segmenting the frequency spectrum into multiple channels and rapidly switching between them at regular intervals.
- The transmitter and receiver are synchronized so that they both know which frequency is currently in use.
- FHSS signals cause little interference in narrowband communications.
- FHSS's frequency hopping pattern is typically pseudorandom, which means it appears random but is actually determined by a mathematical algorithm.

- This reduces the possibility of unauthorized users intercepting or jamming the signal.
- It is used in different applications such as wireless LANs, wireless sensors, and military communications.

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

Modulation:

- Modulation is the process of encoding digital data onto radio waves for transmission.
- The PHY layer of the OSI model handles this process in Wi-Fi.
- Modulation changes aspects of a carrier wave (like amplitude, frequency, or phase) to represent binary data.
- There are two types of modulation namely Digital and Analog modulation.

Modulation	Bits per Symbol	Used In	Speed	Reliability
BPSK	1	802.11a/b/g/n	Low	Very reliable (strong signals)
QPSK	2	802.11a/g/n/ac	Low–Medium	Good in moderate SNR
16-QAM	4	802.11a/g/n/ac	Medium	Needs better SNR
64-QAM	6	802.11n/ac	High	Needs high SNR
256-QAM	8	802.11ac	Very high	Very sensitive to noise
1024-QAM	10	802.11ax (Wi-Fi 6)	Ultra high	Excellent signal required
4096-QAM	12	802.11be (Wi-Fi 7)	Extremely high	Requires perfect conditions

where,

BPSK - Binary Phase Shift Keying - The carrier signal changes phase between 0° and 180° to represent a 0 or 1.

QPSK - Quadrature Phase Shift Keying - Uses 4 phase shifts (0°, 90°, 180°, 270°) to encode 2 bits per symbol.

QAM - Quadrature Amplitude Modulation - Combines phase and amplitude changes.
SNR - signal to noise ratio

Observations:

- Higher modulations (QAM) = higher speed, but need stronger, cleaner signals.
- Lower-order modulations (like BPSK or QPSK) = Lower speeds, More robust in poor signal or long-distance conditions.

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

OFDM:

- OFDM stands for Orthogonal Frequency Division Multiplexing.
- It is one of the key technologies behind modern Wi-Fi (used in standards like 802.11a/g/n/ac/ax).
- It plays a critical role in improving speed, reliability, and efficiency of wireless communication.

Working:
Instead of sending all data on one high-speed channel, OFDM splits the data into multiple slower parallel streams, each sent on its own narrow subcarrier, which are as follows:

a. Orthogonal (mathematically spaced to avoid interference)
b. Sent simultaneously
c. Each modulated with BPSK, QPSK, or QAM

How OFDM Improves WLAN Performance:

- OFDM handles reflections well, which is common in indoors.
- It allows parallel data transmission using many subcarriers — boosting throughput.
- Subcarriers are tightly packed with no overlap, maximizing use of bandwidth.

- Supports forward error correction (FEC) to recover from transmission errors.
- Can operate well even in noisy or interference-prone environments.

Example:
In 802.11a/g/n:
OFDM uses 64 subcarriers (48 for data, 4 for pilot, rest for guard bands)
Each subcarrier carries its own modulated data stream. This allows even small chunks of the signal to be decoded, improving reliability.

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

Frequency band:
- These determine the specific range of electromagnetic frequencies used in wireless communication.
- These allow devices to connect to the internet without the physical cables, ensuring seamless mobility.
- Wifi frequency bands are very crucial in determining how wireless network operates, its connection, speed and range.
- In Wi-Fi we have primarily 2 frequency bands which are
    a. 2.4 GHz
    b. 5 GHz

2.4GHz:
- Longer range , better penetration through the walls.
- Slower speeds - upto 600 MBps.
- Higher vulnerability to interference.
- has only fewer non-overlapping channels.
- use cases: IoT devices, browsing.

5GHz:
- Shorter range, less penetration.
- Higher speeds - upto 1300 Mbps or more .

- Less prone to interference.
- has a large number of non-overlapping channels.
- use cases : Streaming high definition videos , online gaming etc.

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 :

- A Guard Interval is a small time gap inserted between transmitted data symbols in a Wi-Fi transmission.
- Its main purpose is to prevent inter-symbol interference (ISI) — which occurs when delayed echoes (multipath reflections) from one symbol interfere with the next.

Need:

- In real-world wireless environments (e.g., homes, offices, campuses), signals bounce off walls and objects. These echoes can overlap with the next symbol, causing data errors.
- The Guard Interval absorbs these echoes, giving time for the signal to settle before the next symbol starts.

Types:

GI Type	Duration	Used In
Long GI	800 ns	Default in 802.11a/g/n/ac
Short GI (SGI)	400 ns	Optional in 802.11n/ac/ax

How Short Guard Interval Improves Efficiency?

- Good signal quality.
- Low multipath interference.
- Short to moderate distance from AP.
- Reduces wasted time between symbols.

- Increases the number of symbols transmitted per second.
- Leads to ~10–11% throughput improvement.

Example:
Each OFDM symbol consists of:
Data part: 3.2μs
Guard Interval (GI): 0.8 μs or 0.4 μs
So total time per symbol is:

GI Type	Symbol Time (μs)
Long GI	3.2 + 0.8 = 4.0 μs
Short GI	3.2 + 0.4 = 3.6 μs

So, each symbol takes less time with a short GI. Thus, higher speed.

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

802.11 PHY layer frame :
- The PHY layer frame is also called the PPDU — PLCP Protocol Data Unit.
- It wraps around the MAC layer frame and adds key transmission instructions.

Key Components of a PHY Layer Frame:
1. Preamble :
- Like a "heads up" — tells the receiver, “Incoming signal!”
- Helps the receiver detect and synchronize with the signal. It includes:
  - Synchronization bits
  - Training sequences to lock timing and frequency.

2. PLCP Header:
- Like a cover page — explains how to read the data that follows.
- Tells the receiver how to decode the frame. Contains:
  - Data rate

- Length of payload
- Modulation type
- Coding scheme

3. PSDU (Payload) :
   - The actual message you're sending.
   - This is the actual data from the MAC layer (MAC frame).
   - It includes: addresses, sequence number, data, etc.

4. Tail / Padding:
   - Ensures the signal ends cleanly or aligns with encoding.
   - Used for alignment or completing final encoding blocks.

8. What is the difference between OFDM and OFDMA?

Feature	OFDM	OFDMA
Full Form	Orthogonal Frequency Division Multiplexing	Orthogonal Frequency Division Multiple Access
Used In	Wi-Fi 4/5 (802.11a/g/n/ac)	Wi-Fi 6 (802.11ax)
Channel Structure	Splits channel into many subcarriers	Splits channel into subcarriers grouped into Resource Units (RUs)
User Allocation	All subcarriers serve one user at a time	Multiple users use different RUs simultaneously
Design Focus	Single-user transmission	Multi-user transmission
Latency	Higher in multi-user environments	Lower, especially with small data packets
Ideal Usage	Large data transfers (e.g., video, downloads)	High-density deployments, IoT devices
Efficiency in Crowded Networks	Less efficient	Greatly improved performance
Channel Allocation Flexibility	Cannot allocate parts of channel to different users simultaneously	Can allocate parts of channel to different users simultaneously

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

Feature	MIMO	MU-MIMO
Full Form	Multiple Input, Multiple Output	Multi-User Multiple Input, Multiple Output
Used In	Wi-Fi 4 (802.11n) and above	Wi-Fi 5 (802.11ac) and Wi-Fi 6 (802.11ax)
Antenna Usage	Multiple antennas at transmitter and receiver	Multiple antennas serving multiple users simultaneously
Data Streams	Multiple data streams to one device	Parallel data streams to multiple users
Technology Type	Single-user technology	Multi-user technology
Simultaneous Device Support	Cannot send data to multiple clients at the same time	Can serve multiple clients simultaneously
Throughput Benefit	Boosts throughput for one user	Improves overall network efficiency and capacity
Signal Reliability	Improves signal strength through spatial diversity	Reduces wait time for clients in busy networks
Uplink/Downlink Support	Downlink only	Downlink in Wi-Fi 5, Uplink & Downlink in Wi-Fi 6
Best Suited For	Single device needing high speed	High-density environments with many connected devices

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

1. PPDU :
   - PLCP Protocol Data Unit
   - The actual frame transmitted over the air at the PHY layer.
   - It contains:
     1. The PLCP preamble (for sync & channel estimation),
     2. The PLCP header (info about the frame),
     3. The PSDU (the MAC layer data payload).
   - It is the complete package that includes instructions + data.

2. PLCP :
   - Physical Layer Convergence Protocol
   - It is a sublayer of the PHY layer.
   - It is Responsible for:
     a. Converting the MAC frame into the PPDU.
     b. Adding the preamble and PHY header.
     c. Helps the receiving station synchronize and understand how to decode the incoming data.

3. PMD :
- Physical Medium Dependent
- This is the lowest part of the PHY layer.
- Handles the actual transmission and reception of radio signals.
- Converts digital data into radio waves (modulation) and vice versa (demodulation).
- Deals with: Frequency,Modulation types,Signal power, antenna functions, etc.

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

PPDU (Physical Layer Protocol Data Unit):
- The PPDU is the complete frame sent over the air by the PHY layer in a Wi-Fi transmission.
- It includes everything needed for a receiving device to successfully synchronize, decode, and interpret the signal.

General PPDU Structure:
A typical PPDU consists of:
a. Preamble – Used for synchronization and to help the receiver estimate the channel.
b. PHY Header – Contains control information that helps in decoding.
c. PSDU (Payload) – The actual data coming from the MAC layer.

Types of PPDUs Across Wi-Fi Standards:
Legacy PPDU (802.11a/b/g)
a. Used in early Wi-Fi versions.
b. Simple structure: preamble, header, and data.
c. Designed for single-user communication only.
d. Lower efficiency and no support for modern features like MIMO or wider channels.

HT PPDU (High Throughput – 802.11n / Wi-Fi 4)

a. Introduced MIMO, enabling multiple parallel data streams.
b. Supports 20 MHz and 40 MHz channels.
c. Includes HT-SIG fields to describe MIMO configuration.
d. Can use shorter guard intervals (400 ns) to improve throughput.

VHT PPDU (Very High Throughput – 802.11ac / Wi-Fi 5)

a. Adds support for MU-MIMO and channel widths up to 160 MHz.
b. Includes VHT-SIG-A and VHT-SIG-B fields with more detailed modulation and user-specific data.
c. Uses 256-QAM for faster data rates.
d. Much more efficient than HT, especially for multiple users.

HE PPDU (High Efficiency – 802.11ax / Wi-Fi 6/6E)

a. Designed to handle dense environments with many devices.
b. Supports advanced features like OFDMA, BSS coloring, Target Wake Time (TWT), and UL/DL MU-MIMO.
c. Comes in several formats:
   HE SU PPDU – for single-user transmission.
   HE MU PPDU – for multi-user scenarios.
   HE TB PPDU – for random uplink access.
   HE ER PPDU – for long-distance coverage (extended range).
d. Contains HE-SIG-A and HE-SIG-B to convey complex configuration info.

12. How is the data rate calculated?

Data rate:

- The data rate refers to the speed at which data is transmitted over the network.
- It is typically measured in Mbps or Gbps .
- In Wi-Fi, it depends upon several factors like:
  a. modulation scheme,
  b. channel width

c. number of spatial streams
d. and coding rate

Formula:
Data Rate=(Modulation Rate)×(Number of Spatial Streams)×(Channel Width)×(Coding Rate)

where ,

- Modulation determines how many bits are carried by each symbol(ex: BPSK -1 bit , QPSK -2 bits etc.)
- Multiple data streams to be sent simultaneously and each stream can carry independent data. (Ex: 1 stream: Data is sent to/from one antenna & 2 streams: Data is sent to/from two antennas, doubling the rate)
- The width of the channel determines the number of subcarriers available for transmission.(ex: 20 MHz , 40MHz etc.)
- Coding Rate refers to the error correction applied to the transmission and is represented as a ratio.(Ex: 1/2: 50% of the data is used for error correction.)