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WiFi Training Program

Assignment – Module 3

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

The IEEE 802.11 family of standards defines the **physical (PHY) layer** and **MAC layer** for **wireless local area networks (WLANs)**. Various PHY layer standards under 802.11 have been introduced to improve speed, range, and reliability.

Standard	Frequency Band	Max Data Rate	Modulation	Channel Bandwidth	Year Released	Range (Approx)
802.11a	5 GHz	54 Mbps	OFDM	20 MHz	1999	~35 m indoors
802.11b	2.4 GHz	11 Mbps	DSSS	22 MHz	1999	~40-50 m indoors
802.11g	2.4 GHz	54 Mbps	OFDM	20 MHz	2003	~40 m indoors
802.11n	2.4 & 5 GHz	600 Mbps	OFDM + MIMO	20/40 MHz	2009	~70 m indoors
802.11ac	5 GHz	1.3 Gbps (Wave 1), up to 6.9 Gbps (Wave 2)	OFDM + MIMO	20/40/80/160 MHz	2013	~35 m indoors
802.11ax (Wi-Fi 6)	2.4 & 5 GHz (and 6 GHz in Wi-Fi 6E)	Up to 9.6 Gbps	OFDMA + MU-MIMO	20/40/80/160 MHz	2019	~70–100 m indoors
802.11ad	60 GHz	Up to 7 Gbps	SC/OFDM	2.16 GHz	2012	~1–10 m
802.11be (Wi-Fi 7)	2.4/5/6 GHz	Up to 46 Gbps	OFDMA + MU-MIMO + 4096-QAM	320 MHz	Upcoming (Expected 2024+)	~Similar to Wi-Fi 6E

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

Feature	DSSS (Direct Sequence)	FHSS (Frequency Hopping)
Spreading Method	Spreads signal using chipping code	Rapidly hops across frequencies
How it works	Each bit is transmitted as a sequence of bits (chips); spreads the signal over a wider bandwidth.	Data is divided into small packets and each is transmitted on a different frequency.
Bandwidth Usage	Uses a wider bandwidth	Uses narrowband channels over time
Interference Resistance	High (due to spreading)	High (due to frequency hopping)
Security	Moderate	Better (difficult to predict hopping)
Complexity	More complex hardware	Simpler implementation
Used In	802.11b	Early 802.11 versions (pre-b)
Speed	Higher	Lower

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

   Modulation = Converting digital data into analog signals for transmission.

   In Wi-Fi, it modulates **carrier signals** with **data bits** using schemes like **BPSK**, **QPSK**, **QAM**, etc.

   Higher-order modulation = more bits per symbol = faster data rates (but requires better signal quality).

Modulation	Bits/Symbol	Robustness	Speed	Used In
BPSK	1 bit	Very high	Low	802.11a/b/g/n
QPSK	2 bits	High	Moderate	802.11a/g/n/ac
16-QAM	4 bits	Medium	Higher	802.11a/g/n/ac/ax
64-QAM	6 bits	Lower	High	802.11n/ac
256-QAM	8 bits	Lower	Very High	802.11ac/ax
1024-QAM	10 bits	Low	Ultra High	802.11ax (Wi-Fi 6)
4096-QAM	12 bits	Very Low	Extreme	802.11be (Wi-Fi 7)

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

OFDM (Orthogonal Frequency Division Multiplexing)

✅ **Significance in WLAN**

- Used in **802.11a/g/n/ac/ax** standards.
- Allows high-speed data transmission over wireless channels.
- Helps handle **multipath fading** and **interference** in indoor environments.

Feature	Impact on Performance
Splits bandwidth into subcarriers	Transmits data in parallel → higher efficiency
Orthogonality	Eliminates interference between subcarriers
Resistant to multipath	Reduces signal distortion in indoor spaces
High spectral efficiency	More data in less bandwidth
Supports higher data rates	Enables fast Wi-Fi (e.g., 54 Mbps in 802.11a/g)
Flexible modulation per subcarrier	Adjusts based on channel condition

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

Band	Frequency Range	Common Use	Wi-Fi Standards
2.4 GHz	2.400 – 2.4835 GHz	Longer range, more interference	802.11b/g/n/ax
5 GHz	5.150 – 5.875 GHz	Faster speed, less range	802.11a/n/ac/ax
6 GHz	5.925 – 7.125 GHz	New, low interference	802.11ax (Wi-Fi 6E), Wi-Fi 7
60 GHz	57 – 71 GHz	Ultra-fast, very short range	802.11ad/ay

Channel Breakdown

✅ **2.4 GHz Band**

- Channels: **1 to 14**
- Channel width: **20 MHz**

- Only **3 non-overlapping channels**: **1, 6, 11**
- More congestion due to overlap & other devices (e.g., microwaves, Bluetooth)

✅ **5 GHz Band**

- Channels: **36 to 165** (grouped into UNII-1 to UNII-4)
- Channel width: **20, 40, 80, 160 MHz**
- **More non-overlapping channels** → better performance
- DFS (Dynamic Frequency Selection) used for some channels to avoid radar interference

✅ **6 GHz Band (Wi-Fi 6E / 7)**

- Channels: **Up to 59 channels (20 MHz each)**
- Much **cleaner spectrum**, supports **320 MHz** channels (Wi-Fi 7)
- Requires Wi-Fi 6E/7 compatible devices

✅ **60 GHz Band**

- Used for **very high-speed, short-range** communication (e.g., wireless docking)
- Not common in typical home/office Wi-Fi

6. **What is the role of Guard intervals in WLAN transmission? How does a short Guard interval improve efficiency?**

Guard Interval (GI) = A short time gap inserted between transmitted symbols.

Purpose: Prevent **inter-symbol interference (ISI)** caused by **multipath propagation** (when signals reflect off surfaces and arrive late).

Ensures that delayed versions of previous symbols do not interfere with current ones.

Parameter	Standard GI	Short GI (SGI)
Duration	800 ns	400 ns
Data Rate Impact	Normal	~10–11% increase
Efficiency	Lower	Higher
Risk of ISI	Lower	Slightly higher (in noisy/multipath environments)

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

The PHY frame includes two main sublayers:

1. **PMD (Physical Medium Dependent) Sublayer**
2. **PLCP (Physical Layer Convergence Protocol) Sublayer**

Component	Description
PMD	Handles actual transmission & reception over the physical medium (modulation, RF signals).
PLCP	Prepares MAC data for transmission. Adds timing & synchronization info.
PLCP Preamble	Helps receiver detect and synchronize with incoming signal.
PLCP Header	Contains rate, length, modulation info.
PSDU	MAC Protocol Data Unit (MPDU) – actual data payload from MAC layer.
PPDU	Entire PHY frame (PLCP + PSDU). This is what is transmitted over the air.

8. What is the difference between OFDM and OFDMA?

<u>OFDM (Orthogonal Frequency Division Multiplexing)</u>

- Used in: **802.11a/g/n/ac**
- **Single user at a time**
- Splits signal into **multiple subcarriers**
- All subcarriers are used by **one user** during transmission
- Efficient for **high data rates**, but **not ideal for multiple users simultaneously**

<u>OFDMA (Orthogonal Frequency Division Multiple Access)</u>

- Used in: **802.11ax (Wi-Fi 6)** and **Wi-Fi 7**
- **Multiple users at once**
- Divides subcarriers into **Resource Units (RUs)**
- Each user gets a portion of subcarriers → **parallel user transmission**
- Great for **low latency**, **efficient bandwidth use**, and **IoT/multi-user environments**

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

Feature	MIMO	MU-MIMO
Stands for	Multiple Input, Multiple Output	Multi-User MIMO
Users served	One at a time	Multiple simultaneously
Streams per user	Multiple	One or more per user
Efficiency	Good for single-user speed	Great for multi-user environments
Direction	Uplink/downlink (single-user)	Downlink (802.11ac), Both (802.11ax)

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

PPDU (PLCP Protocol Data Unit)

- The **complete frame** transmitted over the air.
- Formed by the **PLCP** adding headers to the **MAC layer frame (PSDU)**.
- Contains:
    - **Preamble**
    - **PLCP Header**
    - **PSDU (MAC data)**

PLCP (Physical Layer Convergence Protocol)

- Sub-layer of PHY that **prepares MAC data** for transmission.
- Functions:
    - Adds **preamble** and **PLCP header**.
    - Ensures receiver can **synchronize** and **decode** data.
- Bridges MAC and lower physical sub-layer (PMD).

PMD (Physical Medium Dependent)

- Responsible for **actual modulation, transmission, and reception** of bits.
- Interacts with the **physical medium** (radio waves).
- Converts digital signals to analog and vice versa.

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

- **PPDU (PLCP Protocol Data Unit)** is the **complete PHY layer frame** that's transmitted over the air.
- Its **format depends on the Wi-Fi generation (standard)**.

Wi-Fi Standard	PPDU Type	Key Features
802.11a/g	Legacy PPDU	Simple, fixed structure: preamble + header + PSDU
802.11n	HT PPDU	Supports MIMO, short guard interval, aggregation
802.11ac	VHT PPDU	Wider channels, higher-order MIMO & 256-QAM
802.11ax (Wi-Fi 6)	HE PPDU	OFDMA, MU-MIMO, BSS coloring, 1024-QAM
802.11b	DSSS/CCK	Structure containing SYNC, SFD, Signal, Service, Length, CRC, PSDU

✅ **Legacy PPDU (802.11a/g)**

| Short Training Field | Long Training Field | Rate| Length | Parity | Tail | PSDU |

✅ **HT PPDU (802.11n)**

- Types: Mixed Mode & Greenfield

| HT SIG1 | HT-STF | HT-LTF | HT SIG2 | Service | Length | Tail | CRC | PSDU |

✅ **VHT PPDU (802.11ac)**

| L-STF | L-LTF | L-SIG | VHT-SIG-A1 | VHT-SIG-A2 | VHT STF | VHT LTF | VHT SIG-B | Service | Length | Tail | CRC | PSDU |

✅ **HE PPDU (802.11ax)**

- Types: SU, MU, EXT SU, Trigger-based

| L-STF | L-LTF | L-SIG | HE-SIG-A | HE-SIG-B | HE STF | HE LTF | Service | Length | Tail | CRC | PSDU |

✅ **DSSS/CCK PPDU (802.11b)**

| SYNC | SFD | Signal | Service | Length | CRC | PSDU |

12. How is the data rate calculated?

How Data Rate is Calculated (WRT the Formula Diagram)

The formula shown in the image is:

Data Rate = (NSD × NBPSCS × R × NSS)/(TDFT + TGI)

Symbol	Meaning
NSD	Number of **data subcarriers** (e.g., 980 for 80 MHz in 802.11ax)
NBPSCS	Number of **coded bits per subcarrier** (depends on modulation)
R	**Coding rate** (e.g., 5/6, 3/4) – fraction of data bits to total bits
NSS	**Number of spatial streams**
TDFT	**OFDM symbol duration** (e.g., 12.8 µs for Wi-Fi 6)
TGI	**Guard Interval duration** (e.g., 0.8 µs or 0.4 µs)

✅ **Formula Means:**

- The **numerator** represents the **total bits transmitted per OFDM symbol**, considering modulation, coding, and parallel spatial streams.
- The **denominator** represents the **total time per OFDM symbol**, including the **guard interval** (used to prevent inter-symbol interference).