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

1. 802.11a

Frequency Band: 5 GHz

Max Data Rate: 54 Mbps

Modulation: Orthogonal Frequency Division Multiplexing (OFDM)

Range: Shorter range (compared to 2.4 GHz) due to higher frequency.

Applications: Primarily for higher-speed, less congested networks.

Key Features:

20 MHz channel width.

Better performance in terms of throughput and reduced interference than 2.4 GHz bands.

Pros: Less interference, higher speeds.

Cons: Shorter range, higher susceptible to obstacles.

2. 802.11b

Frequency Band: 2.4 GHz

Max Data Rate: 11 Mbps

Modulation: Complementary Code Keying (CCK)

Range: Longer range compared to 802.11a, especially in environments with obstructions.

Applications: Early consumer devices, IoT, and low-speed applications.

Key Features:

Uses 22 MHz wide channels.

Pros: Longer range, more penetration through walls.

Cons: Lower data rates, more interference from other devices (microwaves, Bluetooth).

3. 802.11g

Frequency Band: 2.4 GHz

Max Data Rate: 54 Mbps

Modulation: OFDM (backward compatible with 802.11b CCK).

Range: Similar to 802.11b.

Applications: General consumer networks and high-speed data applications.

Key Features:

Compatible with 802.11b.

20 MHz channel width.

Pros: Good speed and range balance.

Cons: Same interference issues as 802.11b due to the 2.4 GHz band.

4. 802.11n (Wi-Fi 4)

Frequency Band: 2.4 GHz and 5 GHz (dual-band)

Max Data Rate: 600 Mbps (using 40 MHz channels, 4 spatial streams).

Modulation: OFDM

Range: Better range than 802.11a/g due to MIMO (Multiple Input Multiple Output) technology.

Applications: High-speed internet access, video streaming, file sharing.

Key Features:

Uses MIMO to improve throughput by sending multiple data streams simultaneously.

Channel bonding (up to 40 MHz).

Backward compatibility with 802.11a/b/g.

Pros: High speeds, better range, and reliability.

Cons: Susceptible to interference in the 2.4 GHz band.

5. 802.11ac (Wi-Fi 5)

Frequency Band: 5 GHz (primarily)

Max Data Rate: Up to 6 Gbps (using 160 MHz channels, 8 spatial streams).

Modulation: 256-QAM (Quadrature Amplitude Modulation), OFDM

Range: Similar to 802.11a, but improved with higher modulation and wider channels.

Applications: High-speed data applications (HD video streaming, high-throughput data).

Key Features:

80 MHz and 160 MHz channel widths.

MU-MIMO (Multi-User MIMO) to support simultaneous communication with multiple devices.

Backward compatibility with 802.11n.

Pros: Extremely high throughput, minimal interference (since it operates on the 5 GHz band).

Cons: Shorter range and higher cost.

6. 802.11ax (Wi-Fi 6)

Frequency Band: 2.4 GHz and 5 GHz (and support for 6 GHz with Wi-Fi 6E)

Max Data Rate: Up to 9.6 Gbps (with 160 MHz channels, 8 spatial streams).

Modulation: 1024-QAM, OFDM

Range: Improved range due to better efficiency in high-density environments.

Applications: High-density areas (stadiums, office buildings), internet of things (IoT), ultra-high-speed internet.

Key Features:

Orthogonal Frequency Division Multiple Access (OFDMA) for improved efficiency.

Target Wake Time (TWT) for better battery life in IoT devices.

Backward compatibility with 802.11a/b/g/n/ac.

Supports 6 GHz band (Wi-Fi 6E).

Pros: Extremely high speeds, better efficiency, improved battery life.

Cons: Still limited by range due to high-frequency operation.

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

**1. DSSS (Direct Sequence Spread Spectrum)**

DSSS spreads the signal by multiplying it with a pseudorandom noise (PN) code, also known as a chipping code, which has a much higher frequency than the original signal.

**Working:**

The original data is combined with a chipping sequence (e.g., 11-bit code for each bit of data).

This process spreads the signal over a broader frequency band.

At the receiver, the same chipping code is used to reconstruct the original data by correlating the received signal with the code.

**2. FHSS (Frequency Hopping Spread Spectrum)**

FHSS spreads the signal by rapidly switching (hopping) between different frequencies in a predetermined sequence.

**Working:**

The transmitter and receiver synchronize on a hopping pattern (a sequence of frequencies).

The signal transmits small chunks of data over each frequency, hopping periodically.

If a frequency is jammed or has interference, the system just hops to the next frequency.

**3. PHY Layer – Modulation Schemes**

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

**BPSK**

* **Bits per symbol**: 1
* **Data rate**: Low
* **Reliability**: Very High
* **Used in**: 802.11a, g, n

**QPSK**

* **Bits per symbol**: 2
* **Data rate**: Low-Medium
* **Reliability**: High
* **Used in**: 802.11a, g, n

**16-QAM**

* **Bits per symbol**: 4
* **Data rate**: Medium
* **Reliability**: Medium
* **Used in**: 802.11a, g, n, ac

**64-QAM**

* **Bits per symbol**: 6
* **Data rate**: High
* **Reliability**: Lower
* **Used in**: 802.11n, ac

**256-QAM**

* **Bits per symbol**: 8
* **Data rate**: Very High
* **Reliability**: Needs clean signal
* **Used in**: 802.11ac

**1024-QAM**

* **Bits per symbol**: 10
* **Data rate**: Ultra High
* **Reliability**: Needs strong signal
* **Used in**: 802.11ax

**4096-QAM**

* **Bits per symbol**: 12
* **Data rate**: Ultra High
* **Reliability**: Very sensitive
* **Used in**: 802.11be

**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 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

● 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.

**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/a

**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.

**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 sub.

● 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 once

● Speed is shared among users hence slower than MIMO.

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

**PPDU** :

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.
* Consists of Legacy fields such as L-STF, L-LTF, L-SIG.
* Frame also consists 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 up to 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.
* Consists 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.
* Uses 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 = ( NSD \* NBPSCS \* R + NSS ) / ( TDFT + TGI )

NSD → Number of data sub carriers

NBPSCS → Number of coded bits per subcarrier per stream

R → Coding

NSS → Number of spatial stream

TDFT → OFDM symbol duration

TGI → Guard Interval duration

Total symbol duration = TDFT + TGI