**1. 802.11 PHY Layer Standards and Comparison**

* **802.11** (1997): Operates at 2.4 GHz, 1–2 Mbps using FHSS or DSSS.
* **802.11b**: 2.4 GHz, up to 11 Mbps, DSSS with better range but lower speed.
* **802.11a**: 5 GHz, 54 Mbps using OFDM, better speed but lower range.
* **802.11g**: 2.4 GHz, up to 54 Mbps, OFDM, combining 'b' range with 'a' speed.
* **802.11n**: 2.4/5 GHz, up to 600 Mbps, MIMO and channel bonding.
* **802.11ac**: 5 GHz only, up to multi-Gbps, MU-MIMO, 256-QAM modulation.
* **802.11ax (Wi-Fi 6)**: 2.4, 5, and 6 GHz, highly efficient, uses OFDMA and 1024-QAM.

**2. DSSS and FHSS**

* **DSSS (Direct Sequence Spread Spectrum)**:  
  Each bit is spread into a longer code (chipping code). It makes the signal resilient to interference and harder to intercept.
* **FHSS (Frequency Hopping Spread Spectrum)**:  
  The transmitter and receiver rapidly jump between different frequencies following a sequence. It avoids interference but needs synchronization.

**3. Modulation Schemes in PHY Layer**

Modulation is the process of encoding data into a carrier signal by changing its properties.  
Types:

* **BPSK (Binary Phase Shift Keying)**: Low speed, high reliability.
* **QPSK (Quadrature PSK)**: Doubles speed vs. BPSK.
* **16-QAM, 64-QAM, 256-QAM, 1024-QAM**: Higher speeds by packing more bits per symbol, but needs a clean (low noise) environment.  
  **Performance**: Higher QAM = Higher speed, but weaker range due to noise sensitivity.

**4. Significance of OFDM in WLAN**

OFDM splits a high-speed data stream into multiple slower sub-streams, each transmitted over a separate carrier.  
**Advantages**:

* Reduces inter-symbol interference (ISI).
* Better handling of multipath reflections.
* Increases reliability and throughput at high speeds.

**5. Frequency Bands in Wi-Fi**

* **2.4 GHz Band**: 14 channels (mostly overlapping). Channels 1, 6, and 11 are non-overlapping.
* **5 GHz Band**: 25+ non-overlapping channels. Cleaner spectrum, less interference.
* **6 GHz Band (Wi-Fi 6E)**: New band with wide, clear channels for extremely high speeds.

**6. Guard Intervals in WLAN**

A Guard Interval (GI) is a short time inserted between transmissions to avoid interference due to signal reflections (multipath).

* **Normal GI**: 800 ns.
* **Short GI**: 400 ns.  
  Using a short GI improves efficiency (~10% faster) but requires clean, controlled environments (low reflections).

**7. 802.11 PHY Layer Frame Structure**

* **Preamble**: Used for synchronization and channel estimation.
* **Header**: Contains information about the transmission (modulation, rate).
* **Payload**: Actual data.
* **Tail and Padding**: To complete frame and maintain alignment.

**8. OFDM vs. OFDMA**

* **OFDM**: One user occupies the entire channel at a time.
* **OFDMA**: Divides the channel into Resource Units (RUs) so multiple users can send/receive simultaneously.  
  OFDMA greatly increases efficiency, especially with small packets.

**9. MIMO vs. MU-MIMO**

* **MIMO (Multiple Input, Multiple Output)**: Multiple antennas send/receive parallel streams to/from one user, boosting single-user speed.
* **MU-MIMO (Multi-User MIMO)**: Multiple antennas serve multiple users simultaneously, improving overall network capacity.

**10. PPDU, PLCP, and PMD in PHY Layer**

* **PPDU (PLCP Protocol Data Unit)**: Complete frame sent over the air, including PLCP and MAC payload.
* **PLCP (Physical Layer Convergence Protocol)**: Converts MAC frames into a format suitable for transmission.
* **PMD (Physical Medium Dependent)**: Actual transmission/reception at the hardware (antenna, radio) level.

**11. Types of PPDU and Frame Formats**

* **Legacy PPDU**: Used by 802.11a/g, simple structure.
* **HT PPDU**: 802.11n added training fields and aggregation for better MIMO.
* **VHT PPDU**: 802.11ac enhanced for high-throughput with wider bandwidths.
* **HE PPDU**: 802.11ax (Wi-Fi 6) designed for efficiency and dense environments using OFDMA and MU-MIMO.

Each PPDU type adds features like longer preambles or additional signaling fields depending on technology generation.

**12. Data Rate Calculation**

Data Rate =  
**(Number of Bits per Symbol × Number of Subcarriers × Coding Rate × Number of Spatial Streams) / Symbol Duration**

**Factors affecting data rate**:

* Modulation type (BPSK, QPSK, QAM).
* Channel width (20, 40, 80, 160 MHz).
* MIMO streams.
* Guard Interval (short or normal)