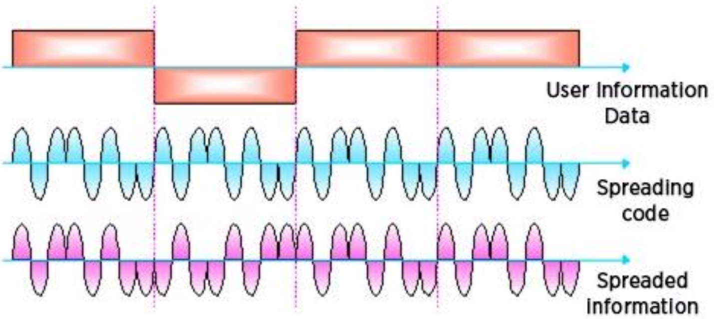
1. Different 802.11 PHY Layer Standards and Their Characteristics

| Wi-Fi Standard | Frequency Band | Maximum Data Rate | Modulation Technique | Channel Width | Release Year |
|---|---|---|---|---|---|
| **802.11a** | 5 GHz | 54 Mbps | OFDM, FHSS | 20 MHz | 1999 |
| **802.11b** | 2.4 GHz | 11 Mbps | DSSS | 22 MHz | 1999 |
| **802.11g** | 2.4 GHz | 54 Mbps | OFDM | 20 MHz | 2003 |
| **802.11n** | 2.4 / 5 GHz | 600 Mbps | OFDM + MIMO | 20 / 40 MHz | 2009 |
| **802.11ac** | 5 GHz | 6.9 Gbps | OFDM + MU-MIMO (Downlink only) | 20 / 40 / 80 / 160 MHz | 2013 |
| **802.11ax (Wi-Fi 6)** | 2.4 / 5 GHz | 9.6 Gbps | OFDMA + MU-MIMO | 20 / 40 / 80 / 160 MHz | 2019 |
| **802.11be (Wi-Fi 7)** | 2.4 / 5 / 6 GHz | >30 Gbps | OFDMA + MU-MIMO | Up to 320 MHz | 2024 (ongoing) |

2. DSSS and FHSS

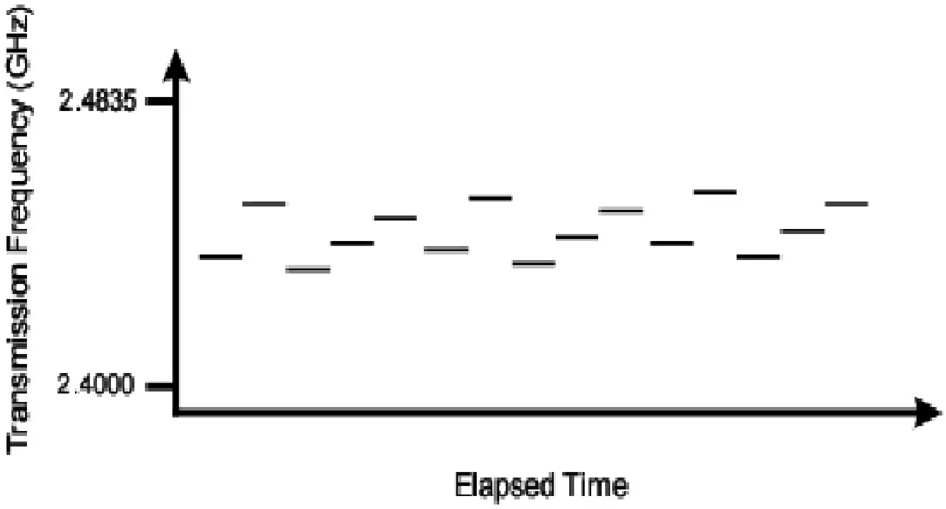
DSSS (Direct Sequence Spread Spectrum)

- Spreads data using a pseudo-random noise (PN) sequence.
- Each bit is represented by multiple chips (bit spreading).
- Increases resistance to interference.
- Used in 802.11b.




FHSS (Frequency Hopping Spread Spectrum)

- Data is transmitted by hopping rapidly across multiple frequencies.
- Improves security and reduces interference.
- Used in early versions of 802.11.




3. Modulation Schemes in the PHY Layer

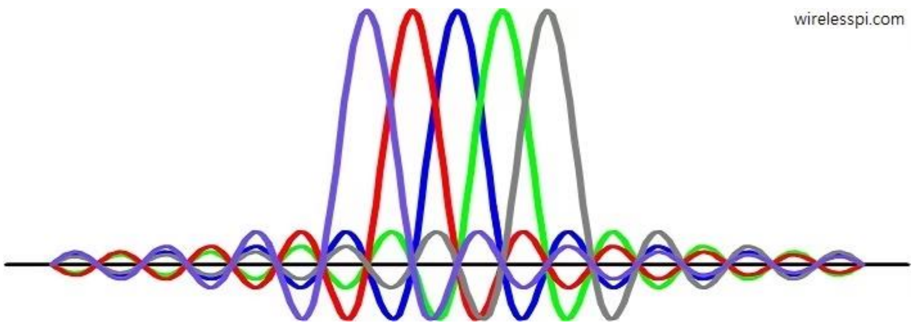
| Modulation Scheme | Bits per Symbol | Description | Used in | Performance |
|---|---|---|---|---|
| **BPSK** | 1 | Binary Phase Shift Keying | 802.11a/b/n | Robust but low data rate |
| **QPSK** | 2 | Quadrature Phase Shift Keying | 802.11a/g/n | Improved throughput |
| **16-QAM** | 4 | Quadrature Amplitude Modulation | 802.11n/ac | Higher speed, less robust |
| **64-QAM** | 6 | Quadrature Amplitude Modulation | 802.11n/ac | High throughput |
| **256-QAM** | 8 | Quadrature Amplitude Modulation | 802.11ac | Very high speed, requires high SNR |
| **1024-QAM** | 10 | Quadrature Amplitude Modulation | 802.11ax | Maximum throughput, very sensitive to noise |

4. Significance of OFDM in WLAN

OFDM splits a wide channel into multiple orthogonal subcarriers.

- Each subcarrier carries a portion of data, reducing interference.

- Resistant to multipath fading and interference.
- Increases data throughput and reliability.
- Used in 802.11a/g/n/ac/ax.
- Each subcarrier in OFDM is mathematically orthogonal to the others.
- This means that at the peak of one subcarrier's signal, all other subcarriers are zero (no interference).




5. Frequency Bands and Channel Division in Wi-Fi

| **Band** | **Frequency Range** | **Channel Range** | **Used In** | **Characteristics** |
|---|---|---|---|---|
| **2.4 GHz** | 2.4 – 2.4835 GHz | 1–14 | 802.11b/g/n/ax | Long range, fewer non-overlapping channels (1, 6, 11) |
| **5 GHz** | 5.15 – 5.825 GHz | 36–165 | 802.11a/n/ac/ax | More bandwidth, less congestion |
| **6 GHz** | 5.925 – 7.125 GHz | 1–233 | 802.11ax/be (Wi-Fi 6E/7) | Future-focused, high-speed, less interference |

6. Role of Guard Intervals in WLAN

The Guard Interval (GI) is a mechanism used to prevent inter-symbol interference (ISI) in environments with multipath propagation. It introduces a time gap between symbols to ensure that delayed signals do not overlap with subsequent ones. The standard Guard Interval is typically 800 ns, while a shorter Guard Interval of 400 ns is also available. The primary benefits of using a short GI include reducing the time between symbols, which helps to increase network efficiency and can lead to an approximate 11% gain in throughput. This shorter interval is particularly effective in environments with low multipath delay spread, where the reduced time gap between symbols does not compromise the quality of the signal.

7. Structure of 802.11 PHY Layer Frame

The main components of a wireless frame include the PLCP Preamble, PLCP Header, and the PSDU (MAC Frame). The PLCP Preamble helps the receiver synchronize with the transmitted signal, ensuring proper reception. The PLCP Header contains essential information such as the data rate, frame length, and other metadata. The PSDU, or MAC Frame, carries the actual data payload. Newer wireless standards, such as 802.11n, 802.11ac, and 802.11ax, introduce additional fields that include MIMO information, channel bandwidth, and settings for Guard Interval and modulation to optimize performance and adapt to various network conditions.

8. Difference Between OFDM and OFDMA

| Feature | OFDM | OFDMA |
|---|---|---|
| Subcarrier Use | Entire channel per user | Subcarriers shared among users |
| Efficiency | Good for single-user | High for multiple simultaneous users |
| Latency | Higher | Lower |
| Standard Used | 802.11a/g/n/ac | 802.11ax/be |

9. Difference Between MIMO and MU-MIMO

| Feature | MIMO | MU-MIMO |
|---|---|---|
| Users | One user at a time | Multiple users simultaneously |
| Streams | Multiple spatial streams | Streams distributed among users |
| Used In | 802.11n/ac | 802.11ac/ax |
| Benefit | Increases single-user throughput | Improves multi-user performance |

10. PPDU, PLCP, and PMD

The PPDU (PHY Protocol Data Unit) is the complete data unit transmitted over the air, encompassing the preamble, header, and payload. The PLCP (Physical Layer Convergence Protocol) is responsible for preparing MAC frames for transmission by adding necessary headers and the preamble. The PMD (Physical Medium Dependent) layer manages the actual transmission of data through the hardware components, such as antennas and RF (Radio Frequency) components, facilitating the physical transmission of the signal.

11. Types of PPDU and Frame Formats

| Wi-Fi Generation | PPDU Types | Description |
|---|---|---|
| 802.11b | Long/Short Preamble | Legacy format with simple headers; uses DSSS modulation |
| 802.11a/g | Legacy | OFDM-based; fields include STF, LTF, Signal, Data (PSDU) |
| 802.11n | HT-Mixed, HT-Greenfield | Adds MIMO support; HT-Mixed is backward-compatible with 802.11a/g |
| 802.11ac | VHT PPDU | Very High Throughput; supports MU-MIMO, wider bandwidth |
| 802.11ax | HE SU, HE MU, HE EXT | High Efficiency; introduces OFDMA |
| 802.11be | EHT SU, EHT MU | Extremely High Throughput; supports up to 320 MHz channels, 16 spatial streams, enhanced OFDMA and MU-MIMO |

802.11b Preamble and Header Fields

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

Preamble

- SYNC (128/56 bits): Syncs receiver with the signal.
- SFD (16 bits): Marks the start of the frame.

Header

- Signal (8 bits): Indicates data rate.
- Service (8 bits): Reserved for future use.
- Length (8 bits): Frame length in bytes.
- CRC (8 bits): Error check for header.

802.11a/g Preamble and Header Fields

| | | | | | | |
|---|---|---|---|---|---|---|
| STF | LTF | Rate | Length | Parity | Tail | PSDU |

Preamble

- STF: Syncs timing.
- LTF: Estimates channel.

Header (SIGNAL field)

- Rate: Modulation type.
- Length: Packet duration.
- Parity: Error bit.
- Tail: Ensures clean decoding.

802.11n Preamble and Header Fields

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

Legacy Preamble

- L-STF: Gain control and timing.
- L-LTF: Channel estimation.
- L-SIG: Info for legacy devices.

HT Preamble

- HT-SIG1: MCS, bandwidth, etc.
- HT-STF: Improves MIMO estimation.
- HT-LTF: MIMO channel estimation.

HT Header

- HT-SIG2: More signal info.
- Service: Reserved/init. bits.
- Length: PSDU length.
- Tail: Decoder reset.
- CRC: Error detection.

802.11ac Preamble and Header Fields

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

VHT Preamble

- VHT-SIG-A1/A2: MCS, streams, bandwidth.
- VHT-STF: MIMO estimation.
- VHT-LTF: Channel estimation & beamforming.

VHT Header

- VHT-SIG-B: PSDU length info.
- Service: Reserved/init. bits.
- Tail: Decoder reset.
- CRC: Error detection.

802.11ax Preamble and Header Fields


Preamble

- HE-SIG-A: MCS, bandwidth, streams.
- HE-SIG-B: MU-MIMO & OFDMA info.
- HE-STF: AGC improvement.
- HE-LTF: Channel estimation.

HE Header

- Service: Reserved/init. bits.
- Tail: Decoder reset.
- CRC: Error detection.