Wifi Training Assignment 3

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Problem1:

802.11 (Legacy):

- Frequency: 2.4 GHz
- Data Rate: Up to 2 Mbps
- Modulation: DSSS / FHSS
- Notes: First standard, low speed

802.11a:

- Frequency: 5 GHz
- Data Rate: Up to 54 Mbps
- Modulation: OFDM
- Notes: High speed, less interference

802.11b:

- Frequency: 2.4 GHz
- Data Rate: Up to 11 Mbps
- Modulation: DSSS (CCK)
- Notes: Popular early Wi-Fi standard

802.11g:

- Frequency: 2.4 GHz
- Data Rate: Up to 54 Mbps
- Modulation: OFDM
- Notes: Backward compatible with 802.11b

802.11n:

- Frequency: 2.4 GHz & 5 GHz
- Data Rate: Up to 600 Mbps
- Modulation: OFDM + MIMO

- Notes: Introduced MIMO, better speed & range

802.11ac (Wi-Fi 5):

- Frequency: 5 GHz
- Data Rate: Up to ~7 Gbps
- Modulation: OFDM + MIMO + MU-MIMO
- Notes: High throughput, beamforming

802.11ad:

- Frequency: 60 GHz
- Data Rate: Up to ~7 Gbps
- Modulation: Single carrier / OFDM
- Notes: Ultra-high speed, very short range

802.11ax (Wi-Fi 6):

- Frequency: 2.4, 5, 6 GHz
- Data Rate: Up to ~9.6 Gbps
- Modulation: OFDMA, 1024-QAM
- Notes: High efficiency, IoT ready

802.11be (Wi-Fi 7):

- Frequency: 2.4, 5, 6 GHz
- Data Rate: Up to ~46 Gbps
- Modulation: OFDMA, 4096-QAM, Multi-link
- Notes: Extreme speed, future-ready

Problem2:

DSSS:

- Each bit multiplied by fast pseudo-random spreading code.
- Spreads signal over wide frequency band.
- Receiver de-spreads signal using same code.
- Resistant to interference.
- Provides some level of security.
- Used in 802.11b, GPS, CDMA.

FHSS:

- Signal rapidly hops between different frequencies.
- Transmitter and receiver synchronized in hopping pattern.
- Avoids interference by hopping away from bad channels.
- Harder to intercept, provides good security.
- Used in Bluetooth, early WLANs.

DSSS vs FHSS Comparison:

- DSSS spreads data over wide band using code; FHSS hops frequencies.
- Both are resistant to interference.
- DSSS is moderate in complexity; FHSS is moderate to high.
- DSSS has higher data rates; FHSS lower.
- DSSS used in Wi-Fi (802.11b); FHSS used in Bluetooth.

Problem3:

- Modulation is used in the PHY layer to convert digital bits into analog waveforms for wireless transmission.
- It modifies a carrier signal's amplitude, frequency, or phase to represent data.
- Enables efficient use of bandwidth and improves data transfer rates.
- Higher-order modulation sends more bits per symbol, increasing speed.
- Trade-off: Higher modulation = more data but more prone to noise.

Different Modulation Schemes:

- ASK (Amplitude Shift Keying)
  - Changes amplitude of the carrier to represent bits
  - Simple, but highly affected by noise
  - Low data rate
  - Rarely used in modern Wi-Fi
- FSK (Frequency Shift Keying)
  - Shifts frequency between discrete values for 0 and 1
  - Good noise immunity
  - Low to moderate data rate

    - Used in Bluetooth, RFID
- BPSK (Binary Phase Shift Keying)
    - Two phase states: one bit per symbol
    - Very robust against noise
    - Low data rate
    - Used in early Wi-Fi (802.11)
- QPSK (Quadrature Phase Shift Keying)
    - Four phase shifts: two bits per symbol
    - Better data rate than BPSK
    - Good noise immunity
    - Used in Wi-Fi (802.11b/g/n)
- 16-QAM (Quadrature Amplitude Modulation)
    - Combines amplitude + phase shifts
    - 16 symbols = 4 bits per symbol
    - Higher data rate, less noise tolerance
    - Used in 802.11n/ac
- 64-QAM
    - 64 symbols = 6 bits per symbol
    - Very high data rate
    - Requires cleaner signal (lower noise)
    - Used in 802.11ac/ax
- 256-QAM
    - 256 symbols = 8 bits per symbol
    - Extremely high data rate
    - Very sensitive to noise
    - Used in Wi-Fi 6 (802.11ax), LTE-Advanced
- OFDM (Orthogonal Frequency Division Multiplexing)
    - Splits signal into many smaller sub-carriers
    - Each sub-carrier is modulated (e.g., with QAM)
    - Highly resistant to interference and multipath
    - Used in all modern Wi-Fi (802.11a/g/n/ac/ax)

Problem4:

- OFDM stands for Orthogonal Frequency Division Multiplexing.
- It is a key technology used in modern WLAN standards like 802.11a, 802.11g, 802.11n, 802.11ac, and Wi-Fi 6 (802.11ax).

- Significance of OFDM in WLAN:
    - Efficient use of bandwidth:
        - Splits the available channel into multiple smaller sub-channels (called subcarriers).
        - Each subcarrier carries part of the data stream, increasing overall efficiency.
    - High data rates:
        - Allows parallel transmission of data over many subcarriers.
        - Supports higher-order modulations (like 64-QAM, 256-QAM) on each subcarrier for even higher throughput.
    - Resistance to interference and noise:
        - Subcarriers are orthogonal (mathematically independent), which prevents overlapping and reduces interference.
    - Reduced multipath fading effects:
        - Multipath (signals reflecting off walls, furniture, etc.) is handled well by OFDM.
        - Reduces signal distortion and data errors in indoor environments.
    - Robust in noisy environments:
        - Each subcarrier has a lower data rate, making them more robust to noise and channel imperfections.
    - Flexibility:
        - Can dynamically allocate subcarriers to users or data streams.
        - Enables features like MIMO (Multiple Input Multiple Output) for even better performance.
    - Power efficiency:
        - Lower symbol rate per subcarrier reduces power consumption in some scenarios.

Problem5:

2.4 GHz Band:

- Frequency range: 2.400 GHz – 2.4835 GHz
- Used in 802.11b, 802.11g, 802.11n
- Typically 14 channels (depends on country).
- Channel width: 20 MHz (some use 40 MHz with bonding).
- Only 3 non-overlapping channels: 1, 6, 11.
- Better range, penetrates walls well.

- Good for basic use (browsing, IoT).
- Very crowded (used by Bluetooth, microwaves).
- Lower data rates compared to higher bands.

5 GHz Band:

- Frequency range: 5.150 GHz – 5.825 GHz.
- Used in 802.11a, 802.11n, 802.11ac, 802.11ax.
- Wider channels: 20 MHz, 40 MHz, 80 MHz, even 160 MHz.
- Has many non-overlapping channels (~25+).
- Higher data rates, less interference.
- Supports wider bandwidths for faster speeds.
- Shorter range than 2.4 GHz.
- Weaker penetration through walls.

6 GHz Band (Wi-Fi 6E):

- Frequency range: 5.925 GHz – 7.125 GHz
- Used in Wi-Fi 6E and Wi-Fi 7.
- Extremely wide channels: 20/40/80/160 MHz.
- Huge capacity, ultra-fast speeds.
- Less congestion (new, fewer devices).
- Very low latency, good for gaming, VR, AR.
- Shortest range among the three bands.
- Requires new compatible devices.

Problem6:

- Guard Interval is a small time gap inserted between data symbols during WLAN transmission.
- It prevents interference between consecutive symbols caused by delayed signal reflections.
- Delayed signals from the previous symbol are absorbed in this interval, so they do not interfere with the next symbol.
- In WLAN, common Guard Intervals are 800 nanoseconds (standard) and 400 nanoseconds (short).

- Short Guard Interval (SGI) of 400 ns reduces the waiting time between symbols.
- SGI increases data throughput by around 10–11% compared to the standard interval.
- It is especially useful in environments with less interference and reflections.
- SGI is supported in modern Wi-Fi standards like 802.11n, 802.11ac, and 802.11ax.
- The trade-off is that SGI may lead to more errors in noisy or reflective environments.
- Using SGI improves overall efficiency and makes Wi-Fi faster in optimal conditions.

Problem7:

- The 802.11 PHY layer frame is the physical layer packet format used for wireless transmission.
- It consists of several fields that prepare and carry the data over the wireless medium.
- The frame starts with a preamble, which helps the receiver synchronize with the incoming signal.
- The preamble contains the Short Training Field (STF) for signal detection and Automatic Gain Control (AGC).
- Following the STF, the Long Training Field (LTF) is used for channel estimation and synchronization.
- After the preamble, the Signal field provides information about the rate, length, and modulation scheme of the data.
- The Signal field ensures that the receiver knows how to correctly interpret the data portion of the frame.
- The data field follows the signal field and contains the actual MAC frame payload and its physical layer header.
- The data field is modulated according to the modulation scheme indicated in the signal field.
- The PHY layer frame ends with a CRC (Cyclic Redundancy Check) for error detection of the Signal field.
- Some PHY layers (like in 802.11n/ac/ax) may include additional components like pilot signals for maintaining synchronization during data transmission.
- Overall, the PHY frame ensures reliable, synchronized, and accurate transmission of data over the wireless medium.

Problem8:

- OFDM stands for Orthogonal Frequency Division Multiplexing, and OFDMA stands for Orthogonal Frequency Division Multiple Access.
- OFDM is used to split the data into multiple smaller subcarriers and send them in parallel to increase robustness against interference.
- OFDMA is an enhancement of OFDM, where the subcarriers are further divided and allocated to multiple users simultaneously.
- In OFDM, all subcarriers are assigned to a single user at a time, while in OFDMA, multiple users share different sets of subcarriers at the same time.
- OFDM is efficient for high-speed data transmission to a single device but not ideal for multiple users.
- OFDMA improves network efficiency, especially in environments with many devices.
- OFDMA reduces latency by allowing multiple users to transmit/receive data at the same time.
- OFDM is used in older Wi-Fi standards like 802.11a/g/n/ac.
- OFDMA is introduced in Wi-Fi 6 (802.11ax) for better multi-user handling.
- OFDMA is more suitable for dense environments like offices, stadiums, or smart homes with many connected devices.

Problem9:

- MIMO stands for Multiple Input Multiple Output, and MU-MIMO stands for Multi-User Multiple Input Multiple Output.
- MIMO uses multiple antennas at both the transmitter and receiver to send and receive multiple data streams to a single device.
- MU-MIMO extends this concept by sending multiple data streams to multiple devices at the same time.
- In MIMO, the entire bandwidth is dedicated to one user at a time.
- In MU-MIMO, the bandwidth is shared, allowing multiple users to use the same frequency simultaneously.
- MIMO improves speed and reliability for individual connections.
- MU-MIMO increases overall network capacity and efficiency, especially in multi-user environments.
- MIMO is used in Wi-Fi standards like 802.11n.
- MU-MIMO is introduced in Wi-Fi 5 (802.11ac Wave 2) and improved in Wi-Fi 6 (802.11ax).
- MU-MIMO reduces network congestion and latency when many devices are connected.
- MIMO benefits single-user throughput, while MU-MIMO benefits multi-user throughput.

Problem10:

- PPDU stands for Physical Protocol Data Unit; it is the complete frame that is transmitted over the air at the PHY layer.
- PPDU includes both the PLCP header and the data payload prepared for transmission.
- PLCP stands for Physical Layer Convergence Protocol; it prepares the MAC layer data for transmission over the physical medium.
- PLCP adds headers, preamble, and other necessary information to help synchronize and decode the incoming signal.
- PMD stands for Physical Medium Dependent sublayer; it is responsible for the actual transmission and reception of radio signals over the wireless medium.
- PMD handles modulation, coding, and conversion of digital data to analog signals and vice versa.
- PLCP sits between the MAC layer and the PMD sublayer, acting as an interface.
- PLCP helps the receiver understand how to interpret the incoming signal, such as data rate and length.
- PMD deals with the physical aspects like frequency, power levels, and antenna usage.
- Together, PPDU, PLCP, and PMD ensure that data is correctly formatted, transmitted, and received over Wi-Fi networks.

Problem11:

PPDU stands for Physical Protocol Data Unit, which is the complete frame transmitted over the air in Wi-Fi communication.

Different Wi-Fi generations (like 802.11a/b/g/n/ac/ax) use different types of PPDU formats to suit their technologies and features.

Main types of PPDU are: Legacy PPDU, HT PPDU, VHT PPDU, HE PPDU.

Legacy PPDU is used in older Wi-Fi standards like 802.11a/g.

Legacy PPDU includes preamble, signal field, and data field.

HT PPDU (High Throughput) is used in 802.11n standard.

HT PPDU includes legacy preamble for backward compatibility and new HT-specific fields like HT-SIG and HT-Training fields for MIMO.

VHT PPDU (Very High Throughput) is used in 802.11ac standard.

VHT PPDU adds VHT-specific fields like VHT-SIG, VHT-STF, and VHT-LTF to support features like wider channels (up to 160 MHz) and MU-MIMO.

HE PPDU (High Efficiency) is introduced in Wi-Fi 6 (802.11ax).

HE PPDU is optimized for dense environments and includes new fields like HE-SIG and longer preambles for better reliability.

HE PPDU supports OFDMA and uplink/downlink MU-MIMO for multi-user efficiency.

Each newer PPDU format adds fields to support higher data rates, better spectral efficiency, and compatibility with older devices.

All PPDU formats generally consist of: preamble (for synchronization), header, and data payload.

Backward compatibility is maintained in PPDU design, so newer devices can still communicate with older ones.

Problem12:

- Data rate in Wi-Fi is calculated based on several factors: channel bandwidth, modulation scheme, coding rate, number of spatial streams, and guard interval.
- Channel bandwidth: Wider bandwidth (e.g., 20 MHz, 40 MHz, 80 MHz, 160 MHz) allows more data to be transmitted per second.
- Modulation scheme: Higher-order modulation (like BPSK, QPSK, 16-QAM, 64-QAM, 256-QAM, 1024-QAM) carries more bits per symbol.
- Coding rate: Error correction codes add redundancy. Common rates are 1/2, 2/3, 3/4, 5/6 — higher rates mean less redundancy and more useful data.
- Number of spatial streams: MIMO technology allows multiple streams of data to be sent simultaneously, increasing total throughput.
- Guard interval: Shorter guard intervals (e.g., 400 ns vs. 800 ns) reduce the time between symbols, increasing the data rate.

Data Rate = Number of Subcarriers × Bits per Symbol × Coding Rate × Number of Spatial Streams × Symbol Rate