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Wifi Training Assessment 3

Q1) What are the different 802.11 PHY layer standards? Compare their characteristics

802 refers to the family of standards dealing with LAN and MAN. 802.11 is the set of MAC and PHY layer standards for implementing WLANs.

There are many standards and family in 802.11:

1) 802.11-1997 (Legacy mode): This is the oldest standard introduced and is now obsolete.
   Frequency Band: 2.4GHz
   Modulation Technique: DSSS, FHSS
   Max Data Rate: 2Mbps
   Channel Width: 20MHz
2) 802.11a – 1999 : Built upon original standard.
   Frequency Band: 5GHz
   Modulation Technique: OFDM
   Max Data Rate: 54Mbps
   Channel Width: 20MHz
3) 802.11b : This is a direct extension of the modulation technique from original standard. Disadvantage of 802.11b devices is interference issues with other products in 2.4GHz band.
   Frequency Band: 2.4GHz
   Modulation Technique: DSSS,
   Max Data Rate: 11Mbps
   Channel Width: 22MHz
4) 802.11g : This standard was built as a need for higher speeds and reduction in manufacturing costs. This was built upon both 802.11a/b. It uses the 2.4GHz band like b, but uses OFDM Modulation like a.
   Frequency Band: 2.4 GHz
   Modulation Technique: OFDM
   Max Data Rate: 54 Mbps
   Channel Width: 20 MHz
5) 802.11n (Wi-Fi 4) : This standard brought enhancements and improvement to WLAN range, reliability and throughput.

Frequency Band: 2.4 GHz and 5 GHz
Modulation Technique: OFDM, MIMO
Max Data Rate: 600 Mbps (with 4 spatial streams)
Channel Width: 20 MHz / 40 MHz

6) 802.11ac (Wi-Fi 5) : This standard provides throughput in 5GHz band. This was required to satisfy the need to new usage models which require high throughput like wireless displays, campus and auditorium deployments, HDTV, etc.
Frequency Band: 5 GHz
Modulation Technique: OFDM, MU-MIMO, 256-QAM
Max Data Rate: Up to 6.9 Gbps (Wave 2, 8 streams)
Channel Width: 20 MHz / 40 MHz / 80 MHz / 160 MHz

Q2) What is FHSS and DSSS and how do they work?

FHSS (Frequency Hopping Spread Spectrum) : It is a wireless communication technique where the transmitter rapidly switches frequencies among many available channels in a pseudorandom sequence during transmission.

The transmitter and receiver use a shared, pseudorandom sequence to rapidly switch (or "hop") between multiple frequencies within a wide band. At each time interval (called a hop), both switch to the next frequency in the sequence to send and receive parts of the signal. This synchronized hopping makes the communication more resistant to interference and eavesdropping since any disruption would only affect a small portion of the transmission.

DSSS (Direct Sequence Spread Spectrum) : It is a wireless communication technique where the data signal is spread over a wide frequency band by combining it with a high-rate pseudorandom code. This spreading increases the signal's resistance to interference, noise, and eavesdropping. DSSS transmits multiple short "chips" for each data bit, making it more reliable even in noisy environments. It was used in early 802.11b Wi-Fi and other wireless systems operating in the 2.4 GHz band.

Q3) How do modulation schemes work in the PHY layer? Compare different modulation schemes and their performance across various Wifi standards.

Modulation schemes are used to convert digital data to analog signal and vice versa. The reverse process is known as demodulation.

There are various means of performing modulation:
1) Amplitude: For 0 and 1, two different amplitude level can be used for each.

2) Frequency: just like the abovementioned, different frequency can be used to denote 0 and 1 respectively.

3) Phase: Different phase can be used for 0 and 1.

Various examples:

1) BPSK – Binary Phase Shift Keying : This is the phase modulation scheme where the data to be sent is keyed according to the phase. If the data passed is 0, then the phase of the analog signal will be 0deg and if the data is 1, the phase of the analog signal is 180deg.

   Standard using BPSK : 802.11a/b/g/n
   Performance : Slow
2) QPSK – Quadrature PSK : This is an advanced version of PSK, where instead of 1 bit, we read 2 bits at a time and instead of just 2 phase, we use 4 phases.
   00 – 0deg
   01 – 90deg
   11 – 180deg
   10 – 270deg

   Standard : 802.11a/g/n/ac
   Performance: balanced robustness and speed

3) 16-QAM – 16 Quadrature Amplitude Modulation : 16-QAM is a digital modulation scheme that combines amplitude and phase variations to transmit 4 bits per symbol, increasing the data rate significantly compared to QPSK and BPSK. 16-QAM means the data consists of 16 unique combinations which are plotted using constellation diagram.
   Standard : 802.11a/g/n/ax/ac
   Performance : High
4) 64-QAM : Same as 16 but with 64 unique combinations that are plotted using constellation diagram and uses 6 bits per symbol.
   Standard : 802.11n/ac

Q4) What is the significance of OFDM in WLAN? How does it improve performance?

OFDM (Orthogonal Frequency Division Multiplexing) is a key modulation technique used in modern WLAN (Wi-Fi) standards like 802.11a/g/n/ac/ax, and it plays a crucial role in improving speed, reliability, and efficiency of wireless communication.

OFDM splits a high-speed data stream into multiple lower-speed sub-streams, and transmits them simultaneously over many closely spaced orthogonal subcarriers (mini-channels within the main channel). Each subcarrier carries a portion of the data, modulated using schemes like BPSK, QPSK, or QAM.

OFDM has many performance improvement in WLAN. Some of them include :
1) Improved data rates: Because multiple subcarrier allows parallel transmission, boosting overall throughput

2) Resistance to multipath fading: OFDM handles signal reflections well, reducing ISI

3) Efficient use of bandwidth

4) Adaptability: Each subcarrier can use different modulation

5) Lower symbol rate

Q5) How are frequency bands divided for wifi? Explain different bands and their channels.

Frequeny bands in wifi:

1) 2.4GHz : It has 14 channels, each being 20MHz wide. Except channels 1,6,11, all other channels are overlapping. This means that the 3 channels are non overlapping and are used to avoid interference
2) 5ghz: It has channels with width being 20,40,80,160 mhz wide. There are more non-overlapping channels to avoid interference, high speed but are of shorter range.
3) 6GHz: Introduced in wifi 6e and 7. Wider channel widths like 160mhz in 6e and 320mhz in 7.

Q6) What is the role of guard intervals in WLAN transmission? How does a short guard interval improve efficiency?

Guard intervals are used to avoid inter-symbol interference (ISI) in signals.

Short guard interval means using a smaller time gap compared to standard interval. (400ns in short guard, 800ns in standard interval)

Because the time gap is shorter, it means we can send more data in the newly found time. This means higher data rate but at the cost of increased exposure to interference.

Q7) Describe the structure of 802.11 PHY layer frame. What are its key components?

802.11 phy layer frame consists of :
1) Preamble: Prepares the receiver for incoming data.

Depending on the generation of 802.11, the preamble consists of different sub-components. For eg, 802.11b preamble consists of SYNC bits and SFD (start) bits, while 802.11a/g consist of STF (short training field) and LTF (long training field). STF is for time synchronisation and LTF is for channel estimation.

2) Header: Gives the receiver necessary information about how to decode the data.

Just like preamble, head is also different based on the generation. In 802.11b, header consists of :

- Signal bits: Indicates data rate
- Service bits: Reserved bits for future use
- Length: frame length
- CRC: Used for error detection for receiver.

In 802.11a/g, header (now called SIGNAL field) consists of:

- Rate: Specifies modulation scheme (BPSK/QPSK/QAM)
- Length: Packet duration for timing
- Parity: Error detection bit
- Tail: Ensures signal integrity

3) PSDU (Payload): The actual data contents (MAC) frame encoded in the specified encoding scheme in the header.

Q8) What is the difference between OFDM and OFDMA?

OFDM:

Used in**:** Wi-Fi 4 (802.11n), Wi-Fi 5 (802.11ac)

Divides the channel into many closely spaced subcarriers and sends data for one user at a time across all subcarriers in parallel.

Key Features:

- High data rates
- Each transmission uses the entire channel
- Efficient for single-user communication
- Idle subcarriers waste bandwidth if data is small

OFDMA:
Used in: Wi-Fi 6 (802.11ax) and Wi-Fi 7
Like OFDM, it splits the channel into subcarriers—but now these are grouped into Resource Units (RUs) and allocated to multiple users at the same time.

Key Features**:**

- Multiple users share the channel simultaneously
- Great for low-latency and high-efficiency
- Reduces contention and improves performance in crowded networks
- More suitable for IoT and dense environments

Q9) What is the difference between MIMO and MU MIMO

Feature	**MIMO**	**MU-MIMO**
Full form	Multiple Input, Multiple Output	Multi-User Multiple Input, Multiple Output
Number of users	One at a time	Multiple users at once
Efficiency	Less efficient in crowded networks	Much more efficient
Introduced in	Wi-Fi 4 (802.11n)	Wi-Fi 5 (802.11ac) and enhanced in Wi-Fi 6
Direction	Uplink/Downlink (single user)	Uplink and/or Downlink (multi-user)

Q10) What are PPDU, PLCP and PMD in phy layer?

PPDU (Physical Layer protocol data unit): It is the complete PHY layer frame consisting of preamble, header and psdu

PLCP (Physical Layer Convergence Procedure): The PLCP is a sublayer of the PHY layer that adapts the MAC layer data (PSDU) to be suitable for physical transmission.

It does three main things:

- Adds a preamble and PLCP header to the data
- Prepares the PSDU for modulation
- Ensures that the receiver can interpret how to decode the upcoming signal

PMD (Physical Medium Dependant): The PMD is the sublayer that handles the actual transmission and reception of signals over the wireless medium.

It is responsible for:

- Modulating/demodulating the signal (e.g., BPSK, QAM)
- Handling RF operations (antenna, frequencies, signal levels)
- Sending/receiving the bits over the air

Q11) What are the types of PPDU? Explain PPDU frame format in different wifi generations?

Generally, PPDU Consists of : Preamble, Header and PSDU

802.11b (DSSS/CCK):

preamble consists of SYNC bits and SFD (start) bits

header consists of :

- Signal bits: Indicates data rate
- Service bits: Reserved bits for future use
- Length: frame length
- CRC: Used for error detection for receiver.

PSDU is the data

802.11a/g (OFDM):

Preamble consist of STF (short training field) and LTF (long training field). STF is for time synchronisation and LTF is for channel estimation.

header (now called SIGNAL field) consists of:

- Rate: Specifies modulation scheme (BPSK/QPSK/QAM)
- Length: Packet duration for timing
- Parity: Error detection bit
- Tail: Ensures signal integrity

PSDU is the payload/data

802.11n (HT PPDU – MIMO SUPPORT):

HT stands for High Throughput

Preamble consist of:

- HT-SIG1: Contains MCS, bandwidth and other transmission parameters
- HT-STF (HT Short Training Field): Helps improve MIMO channel estimation
- HT-LTF(HT Long Training Field): Used for MIMO channel estimation and equalization

Header consists of:

- HT-SIG2: Second part of the HT-SIG, containing additional info like STBC, coding, and guard interval.

- Service: Reserved bits for future user
- Length: Indicates PSDU length in bytes
- Tail: Used for convolutional decoding
- CRC: Error detection

In addition to this, 802.11n is also backwards compatible with 802.11a/g, this is possible due to the additional legacy preamble:

- L-STF (Legacy Short Training Field): Used for AGC (Automatic Gain Control) and coarse timing synchronization.
- L-LTF (Legacy Long Training field): Used for channel estimation.
- L-SIG (Legacy Signal Field): Provides rate, length, and modulation
- information for legacy devices.

802.11ac PPDU (VHT – VERY HIGH THROUGHPUT MODE):

Preamble consist of:

- VHT-SIG-AI & VHT-SlG-A2: Provide information on MCS, bandwidth, spatial streams, and coding.
- VHT-STF (VHT Short Training Field): Helps improve MIMO channel estimation.
- VHT-LTF (VHT Long Training Field): Used for channel estimation for MU-MIMO and beamforming.

Header consist of:

- VHT-SIG-B: Contains information about the length of the PSDU, primarily for MU-MIMO.
- Service: Reserved bits for future use and scrambler initialization
- Tail: Used for convolutional decoding.
- CRC: Provides error detection.

802.11ax PPDU (HE – HIGH EFFICIENCY MODE):

Preamble consist of:

- HE-SIG-A: Contains information about MCS, bandwidth, and spatial streams
- HE-SIG-B: used for MU-MIMO and OFDMA (only in MU transmissions)
- HE-STF (HE Short Training Field): Improves AGC convergence
- HE-LTF (HE Long Training Field): Helps in channel estimation

Header consists of:

- Service: Reserved bits for future use and scrambler initialization

- Tail: Used for convolutional decoding.
- CRC: Provides error detection.

Q12) How is data rate calculated?

Formula:
Data rate = (NDSxBPSxCRxNSS)/SD

Where,

NDS – Number of Data Subcarriers

BPS – Bits per Symbol

CR – Coding Rate

NSS – Number of Spatial Streams

SD – Symbol Duration