WIFI TRANING MODULE 5 ASSESSMENT SOLUTION

-BY SAKTHI KUMAR S

1. What are the key features of Wi-Fi 6, 6E and 7 and how do they differ from previous standards like Wi-Fi 5 (802.11ac)?

Feature	Wi-Fi 5 (802.11ac)	Wi-Fi 6 (802.11ax)	Wi-Fi 6E (802.11ax in 6 GHz)	Wi-Fi 7 (802.11be)
Frequency Bands	5 GHz only	2.4 GHz & 5 GHz	2.4, 5 & 6 GHz	2.4, 5 & 6 GHz
Channel Widths	20/40/80/160 MHz	20/40/80/160 MHz	Up to 160 MHz (more clear channels)	Up to 320 MHz
Max Theoretical Speed	~3.5 Gbps	~9.6 Gbps	~9.6 Gbps	Up to 46 Gbps
Modulation Scheme	256-QAM	1024-QAM	1024-QAM	4096-QAM
Spatial Streams	Up to 8	Up to 8	Up to 8	Up to 16
MU-MIMO	Downlink only	Uplink & Downlink	Uplink & Downlink	Uplink & Downlink (Enhanced, up to 16 users)
OFDMA	No	Yes	Yes	Yes (improved with multi-RU support)
Beamforming	Explicit	Improved Explicit	Improved	Advanced Beamforming
Target Wake Time (TWT)	No	Yes	Yes	Yes
Latency	Higher	Lower	Lower	Ultra-low (<5ms)
BSS Coloring	No	Yes	Yes	Yes
Preamble Puncturing	No	No	No	Yes (to avoid interference by using partial channels)

Multi-Link Operation (MLO)	No	No	No	Yes (simultaneous links across bands)
Typical Use Cases	Streaming, browsing	Dense environments (offices, schools)	High-performance AR/VR, low-latency apps	Cloud gaming, 8K video, AR/VR, high-density enterprise

Key Innovations Across Versions

- Wi-Fi 6: Introduced OFDMA, 1024-QAM, uplink MU-MIMO, and TWT for efficiency in crowded environments.
- Wi-Fi 6E: Extended Wi-Fi 6 into the 6 GHz band with more bandwidth and less interference.
- Wi-Fi 7: Major leap with MLO, 320 MHz channels, 4096-QAM, and preamble puncturing for adaptive use of the spectrum.

2. Explain the role of OFDMA in Wi-Fi 6 and how it improves network efficiency.

OFDMA in Wi-Fi 6

- Orthogonal Frequency Division Multiple Access divides a channel into smaller sub-channels called Resource Units (RUs).
- Multiple users can transmit simultaneously on different RUs, reducing contention and overhead.
- Increased efficiency, lower latency, and better performance especially in high-density environments like stadiums or offices.
- It is an advanced version of OFDM (used in Wi-Fi 5), allowing multiple users to transmit and receive data simultaneously on different subcarriers.

Working Principle:

- A Wi-Fi channel (e.g., 20 MHz) is divided into smaller sub-channels called Resource Units (RUs).
- Each RU can be allocated to a different device.
- Multiple devices can send or receive data at the same time using their assigned RUs.

Aspect	Without OFDMA (Wi-Fi 5)	With OFDMA (Wi-Fi 6)
Channel Usage	Entire channel used by one device at a time	Channel shared by multiple devices
Idle Time	High (due to contention & waiting)	Low (scheduled parallel access)
Latency	Higher	Lower
Efficiency	Low in crowded networks	High in crowded networks
Power Usage	Higher (devices always listening/contending)	Lower (TWT + scheduled access)

Benefits of OFDMA which improves network efficiency are as follows:

1. Maximizes use of each channel by serving multiple clients simultaneously.
2. Devices don't have to wait for their turn; ideal for real-time applications like VoIP or gaming.
3. Better Performance in High-Density Environments for places like airports, stadiums, or enterprise offices.
4. Works with TWT to let devices sleep and only wake for their time slot.

3. Discuss the benefits of Target Wake Time (TWT) in Wi-Fi 6 for loT devices.

Target Wake Time (TWT) is a Wi-Fi 6 feature that allows devices and access points (APs) to schedule specific times for communication. This reduces the need for devices to remain constantly awake and listening to the channel.

- It Schedules communication time between AP and client.
- IoT devices can sleep longer and only wake at scheduled times, drastically reducing power consumption.
- Improved battery life and network scalability.
- Benefits: Power Savings, Extended Battery Life, Reduced Channel Contention, Predictable, Communication Windows, Scalability

Working Principle:

- The AP and client agree on a schedule (TWT agreement).
- The client sleeps most of the time and only wakes up at its scheduled time to transmit or receive data.
- After the exchange, the device goes back to sleep mode.

4. Explain the significance of the 6 GHz frequency band in Wi-Fi 6E.

Significance of 6 GHz Band in Wi-Fi 6E:

1. Additional Spectrum: Up to 1200 MHz

- More channels: The 6 GHz band provides up to 14 additional 80 MHz or 7 additional 160 MHz channels (depending on region).
- Impact: Supports high-bandwidth applications like 8K video streaming, AR/VR, cloud gaming, and enterprise-grade Wi-Fi without congestion.

2. Less Interference

- Clean airspace: The 6 GHz band is exclusive to Wi-Fi 6E+ devices no legacy Wi-Fi (like Wi-Fi 4 or 5), no Bluetooth, no microwaves.
- Benefit: Less noise and interference lead to faster, more reliable connections.

3. High Capacity & Performance

- Ideal for high-density environments like offices, campuses, and stadiums.
- More spectrum = more simultaneous high-speed connections without degradation.

4. Low Latency Applications

GHz enables real-time, low-latency communication, perfect for:

- AR/VR headsets, VoIP/video calls, Smart factories and IoT automation

As more devices support 6 GHz, networks can segregate traffic:

- IoT and legacy devices stay on 2.4/5 GHz
- High-speed devices use 6 GHz

6. Better Security (WPA3 by Default)

- Wi-Fi 6E mandates WPA3 encryption, enhancing network security and privacy.

5. Compare and contrast Wi-Fi 6 and Wi-Fi 6E in terms of range, bandwidth, and interference.

Feature	Wi-Fi 6 (802.11ax)	Wi-Fi 6E (802.11ax extended to 6 GHz)
Frequency Bands	2.4 GHz & 5 GHz	2.4 GHz, 5 GHz & 6 GHz
Range	Better at 2.4 GHz, decent at 5 GHz	Shorter range at 6 GHz due to higher frequency and lower wall penetration
Bandwidth Availability	Limited 160 MHz channels (overlap in crowded areas)	Wider spectrum: up to 1200 MHz, supports up to 7 non-overlapping 160 MHz channels
Interference	Moderate to high (shared with legacy devices and other technologies like Bluetooth, microwaves)	Very low: 6 GHz band is clean, no legacy device interference
Device Compatibility	Backward compatible with Wi-Fi 4/5/6	Only works with Wi-Fi 6E-enabled devices
Ideal Use Case	General use, good balance of range and speed	High-performance use: AR/VR, 8K streaming, low-latency gaming in interference-free space

- Wi-Fi 6 is better for wider coverage, including older devices.
- Wi-Fi 6E is ideal for high-speed, low-latency needs in clean and close-range environments (e.g., enterprise offices, living rooms with many connected devices).

6. What are the major innovations introduced in Wi-Fi 7 (802.11be)?

Major Innovations in Wi-Fi 7 (802.11be)

Innovation	Description
320 MHz Channel Width	Doubles the maximum channel width from 160 MHz (Wi-Fi 6) to 320 MHz, enabling huge throughput.
4096-QAM (4K-QAM)	Higher-order modulation increases data rate by ~20% over 1024-QAM (Wi-Fi 6).
Multi-Link Operation (MLO)	Devices can use multiple bands simultaneously (e.g., 5 + 6 GHz), improving speed, reliability, and latency.
Multi-RU Allocation	Allows a single device to use multiple Resource Units (RUs) at once, improving efficiency and speed.
Preamble Puncturing	Allows use of partially available channels by skipping over interfered parts—less wasted spectrum.
Deterministic Latency / Time-Sensitive Networking (TSN)	Ensures guaranteed latency and jitter performance for industrial IoT, AR/VR, and gaming.
Enhanced MU-MIMO	More spatial streams (up to 16) = better parallel data handling for many users.
Peak Throughput	Theoretical speeds of up to 46 Gbps, compared to 9.6 Gbps in Wi-Fi 6.

- Speed: Up to 4x faster than Wi-Fi 6
- Latency: Ultra-low, ideal for real-time applications
- Reliability: Seamless, robust connections in congested and mission-critical environments
- Capacity: Handles more devices more efficiently than any previous standard

7. Explain the concept of Multi-Link Operation (MLO) and its impact on throughput and latency.

Multi-Link Operation (MLO)

- Multi-Link Operation (MLO) allows a Wi-Fi 7 device to connect to an access point (AP) on multiple frequency bands simultaneously (e.g., 5 GHz + 6 GHz), treating them as one logical link.

Types of MLO:

- Simultaneous MLO: Uses all connected links concurrently for data transmission.
- Alternate MLO: Switches between links dynamically depending on congestion or interference.

Metric	Impact
Throughput	Significantly increased aggregate bandwidth from multiple channels.
Latency	Reduced packets can take the faster or less congested path.
Reliability	Improved seamless failover if one link degrades.
Load Balancing	Dynamic scheduling across links avoids bottlenecks.

8. What is the purpose of 802.11k and v, and how does it aid in roaming?

802.11k – Neighbour Reports to Help Clients Find the Best AP Faster

802.11k helps client devices (like smartphones or laptops) make better and faster roaming decisions by providing information about nearby access points (APs).

Working Principle:

- When a client is connected to an AP, it can request a Neighbour Report.
- The AP responds with a list of nearby APs, including details such as:
  - Their channel numbers
  - Signal strengths
  - Supported capabilities
- Without 802.11k, clients scan for nearby APs manually, which takes time and causes delays during roaming.
- With 802.11k, the client already knows which APs are available, so it can prepare to switch in advance.
- This leads to faster roaming and less interruption, especially during real-time applications like VoIP or video streaming.

802.11v – BSS Transition Management to Guide Clients to Better Aps

802.11v allows the network (via APs or a wireless controller) to guide a client device to move to a better AP based on signal quality, AP load, or network policies.

Working Principle:

- The current AP sends a BSS Transition Management Request to the client.
- This message suggests one or more alternative APs that offer better performance.
- The client can then choose to roam to the recommended AP.
- Prevents clients from staying connected to a weak or congested AP (“sticky clients”).
- Enables the network to perform load balancing by steering devices away from overloaded APs.
- Improves overall performance and user experience in environments with many APs and users.

9. Explain the concept of Fast BSS Transition (802.11r) and its benefit in mobile environments.

Fast BSS Transition (802.11r)

- 802.11r, also known as Fast BSS Transition (FT), is a Wi-Fi standard that reduces the time required for a client device to roam from one access point (AP) to another within the same network (ESS – Extended Service Set). It is designed to speed up the handoff process during roaming.
- In traditional Wi-Fi roaming, whenever a client switches APs, it must go through the full WPA2 authentication process, including the 4-way handshake. This takes time and can interrupt services like voice or video calls.
- 802.11r solves this by allowing the client to perform key negotiations in advance, so the handoff becomes seamless and faster.

Working Principle:

- When a client connects to the first AP, it generates a pairwise master key (PMK).
- With 802.11r, the AP and client derive a Fast Transition Key (FTK) from the PMK.
- This FTK is pre-shared with neighbouring APs.
- When the client roams to a new AP, it reuses the FTK and completes the handshake quickly without re-authenticating from scratch.

Benefits in Mobile Environments are Faster handoffs, Seamless user experience and essential for mobile clients and Improved performance

10. How do 802.11k/v/r work together to provide seamless roaming in enterprise networks?

- 802.11k helps clients discover nearby access points (APs) by providing a neighbour report, reducing scan time.
- 802.11v allows the AP or controller to suggest better APs to clients, improving load balancing and connection quality.
- 802.11r speeds up the handoff process by allowing fast re-authentication using pre-shared keys, minimizing latency during transitions.
- Together, these standards enable fast, efficient, and intelligent roaming, ensuring uninterrupted connectivity for mobile users in environments with multiple APs, such as offices, hospitals, or campuses.

Standard	Function	Role in Roaming
802.11k	Neighbour Report	Helps client quickly discover nearby APs
802.11v	BSS Transition Management	Suggests better APs to the client
802.11r	Fast Transition	Enables fast authentication during AP handoff