WiFi Assessment 5 - Module 5

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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)?**

- WiFi 5 :
  - It is old standard of WiFi
  - It is 802.11ac Wifi Standard
  - Operates only on the 5GHz band.
  - Uses MU-MIMO (Multi-User, Multiple Input Multiple Output) for downlink only.
  - Max speed in WiFi 5 is 3.5 Gbps.
  - No OFDMA as just one device at a time per channel
  - It is less efficient in crowded networks.

- WiFi 6:
  - It is 802.11ax standard which has a major upgrade from WiFi 5.
  - It introduces OFDMA (Orthogonal Frequency Division Multiple Access) - splits channels so multiple users can share the bandwidth at the same time.
  - MU-MIMO supports both uplink and downlink, so it improves multi-device performance.
  - It has Target Wake Time (TWT) - saves battery for IoT/Mobile devices.
  - Improves speed, capacity and efficiency in dense crowded environments.

- WiFi 6E :
  - It is an extension of WiFi 6.
  - It has the same features such as WiFi 6 like OFDMA, MU-MIMO and TWT, but with a cleaner and larger spectrum.

    - It adds 6 GHZ band, which means with more bandwidth comes less interference and faster speed.
    - It gives more congestion free networks in densely crowded environments.

- WiFi 7:
    - The major advantage is it gives next gen speed.
    - It uses 2.4 GHz, 5 GHz, 6 GHz.
    - It supports upto 320 MHz channel which is double than 160 MHz in WiFi 6
    - Multi Link Operation (MLO) : It combines multiple bands at once, which gives higher speed and lower latency.
    - It supports 4096 QAM, which means it gives more speed as more bits are transmitted.
    - Its speed is greater than 30 Gbps which is faster than WiFi 6E.
    - It is ideal for 4K streaming, AR/VR gaming.

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

- OFDMA (Orthogonal Frequency Division Multiple Access) is a multi-user version of OFDM(Orthogonal Frequency Division Multiplexing), which is used in WiFi 5.
- While OFDM transmits data from one user at a time using all available subcarriers, OFDMA divides those subcarriers into groups called Resource Units (RUs) and assigns them to multiple users simultaneously.
- In OFDM (WiFi 5), a 20 MHz channel has 64 subcarriers, but all of them are assigned to one user at a time which gives low efficiency when sending small packets.
- In OFDMA (WiFi 6), the same 20 MHz channel is divided into multiple RUs, such as 26, 52, 106, 242 tone etc… Each RU can be dynamically assigned to different users. Data is transmitted in parallel to multiple clients in one transmission cycle.
- The problem with the Legacy ODFM was that all the subcarriers go to one user, no matter how small the data. If a sensor sends just a few bytes, the entire channel is underutilized. Devices take turns (contention-based), increasing latency.
- OFDMA solves the problems in OFDM by subdividing the channel and assigning RUs based on need, parallel transmission reduces contention and waiting time and by supporting up to 75 clients in 20 MHz channel.
- Downlink OFDMA: Router sends data to multiple clients simultaneously.
- Uplink OFDMA : clients send data at the same time, synchronized via trigger frames from the Access Point (AP).
- Benefits of OFDM are high efficiency, low latency, better QoS, improved battery life and network scalability.
- So OFDMA enables multiple users to transmit and receive data in parallel, minimizing air time contention, reducing latency and improving throughput, especially in high density and low bandwidth device scenarios.

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

- TWT is a power saving feature that allows devices to negotiate specific times with the AP to wake up and exchange data and then go back to sleep.
- AP and client agree on a wake schedule which is either one time or recurring.
- The device sleeps most of the time and wakes up only at its scheduled TWT.
- It sends or receives data, then goes back to sleep immediately.
- Most IoT devices don't need to be always connected as they send only a tiny amount of data, don't need constant updates and run on battery, where TWT is useful.
- But TWT is not only for IOT but also used in smartphones, tablets and laptops to save battery during low activity periods and extend sleep cycles during streaming or file transfers.
- It reduces channel contention in crowded environments as well.
- It makes WiFi 6 ideal for smart cities and industrial IOT.

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

- WiFi 6E is an extension of WiFi 6.
- The E stands for extended meaning it extends WiFi 6 to the 6 GHz band.
- WiFi 6 supports only 2.4 and 5 GHz but WiFi 6E supports 6 GHz along with other two as well.
- By having 6 GHZ, the advantages that we get are :
    - More spectrum is provided. The 6 GHz band adds 1200 MHz of clean spectrum from 5.925 Ghz to 7.125 GHz). It allows for 14 additional 80 MHz channels or 7 extra 160 MHz channels.
    - Less Interference : Unlike 2.4 GHz and 5 GHz, the 6GHz band is not used by older WiFi devices, microwaves or Bluetooth, which mean no legacy congestion, better performance and more reliable connection.
    - Better Performance : Devices can use wider channels without overlap or interference which leads to faster speed, lower latency and higher throughput.
    - Improved Efficiency with WiFi 6 features : WiFi 6E uses the same efficiency features (OFDMA, MU-MIMO, TWT) as WiFi 6, but in a new, interference free band.
    - It is ideal for high density and enterprise use.
- It has few disadvantages like shorter range, as 6 GHz don't penetrate walls, only WiFi 6E capable devices can use 6 GHz and needs a new WiFi 6E router to AP to access this band.

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

Feature	WiFi 6 (802.11ax)	WiFi 6E (802.11ax Extended)
Frequency Bands	2.4 Ghz & 5 GHz	2.4 Ghz, 5 GHz & 6 GHz
Range	Better range	Shorter Range
Bandwidth	Moderate (up to 160 MHz, limited availability)	High (more 80 MHz & 160 MHz channels in 6 GHz band)
Interference	More interference as shared with old devices.	Very low interference (mainly new devices use it).
Device Support	Compatible with both old and new devices	Only works with WiFi 6E capable devices.
Use case	General use in mixed device environments	High performance apps.

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

- Multi Link Operation (MLO) : Devices can use multiple bands (2.4 GHz, 5 GHz, 6 GHz) at once. It combines speed, avoids congestion and reduces latency. It is like riding on multiple roads at once.
- 320 MHz Channel Bandwidth : Doubles the max channel width from 160 MHz to 320 MHz. So, more data can travel through provided bandwidth at a time.It is like doubling the size of the highway.
- 4096 QAM (Higher QAM) : Uses more bits per signal. It uses up to 20-25 % of more data transferred at the same time. Which means higher the data density then faster is the speed in short range with strong signal.
- Preamble puncturing : Lets device use only clean part of a frequency if interference exists. It gives better spectrum usage even in noisy environments.
- Deterministic Low Latency : Enhancements to deliver guaranteed low latency communication. It is great for real time apps.
- Improved MU-MIMO and OFDMA :
    - MU-MIMO : it supports 16 simultaneous streams.
    - OFDMA : enhanced to better handle more users and traffic at once.

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

- MLO allows a device to use multiple wireless links across different frequency bands (2.4, 5 and 6 GHZ) simultaneously.
- In previous generations, devices can only connect to one band at a time but with MLO in WiFi 7, a device can establish and use multiple links at once, like using multiple WiFi lanes for a single data stream.
- Types of MLO usage :
    - Simultaneous Transmit and Receive (STR) :
        - Transmit and receive on multiple bands at the same time.
        - Maximize throughput which is great for performance.
    - Non Simultaneous Transmit and Receive (Non-STR):
        - Switches between links, but optimizes based on traffic or congestion.
- Impact on Throughput : Parallel data streams across multiple bands means more bandwidth (up to 320 MHz combined) and faster downloads with smoother high resolution streaming.
- Impact on Latency : MLO can avoid congested or noisy bands, reducing delay. If one link is busy or slow, another link instantly takes over. This means more reliable low latency.

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

- 802.11 k and v are WiFi standards designed to optimize and speed up roaming between APs, especially in environments with multiple APs.
- 802.11k :
    - Helps the client discover nearby APs faster.
    - The current AP provides a list of nearby APs with signal strength, channels, and load.
    - Instead of scanning all channels (which takes time), the client just checks those suggested APs.
    - It provides faster handoff, reduced latency, and less battery drain.
- 802.11v :
    - Let the network tell the client when to roam.
    - APs can suggest the best AP to switch to, based on signal strength, traffic, and client behavior.
    - Helps balance load between APs and prevent sticky clients (client staying too long with a weak AP).
    - Its benefits are smarter roaming, better performance and improved battery life.
- When used with 802.11r (fast handoff), clients roam almost instantly, great for VoIP, voice calls and real time apps.

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

- Fast BSS transition 802.11r is a WiFi standard that allows faster handoffs between APs, especially when a device is moving.
- BSS consists of one AP and its connected devices.
- When a client moves out of range, it must disconnect from one AP and connect to another (called a “roam” or “handoff”).
- This requires a full reauthentication, which can take hundreds of milliseconds which is long enough to drop or freeze video and calls.
- 802.11r introduces fast roaming by pre-negotiating security keys (palled PMK-R0 and PMK-R1) with nearby APs before roaming happens).
- It uses a method called Fast Basic Service Set Transition (FT).
- This allows the device to skip the full authentication process during a handoff.
- The transition is reduced to just a few milliseconds.

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

- 802.11k - Uses AP discovery (know where to go)
    - It helps the client discover neighboring APs more efficiently.
    - The AP provides a neighbor list (signal strength, channel, etc.)
    - Instead of scanning all channels, the client can quickly decide the best candidate to roam to.
    - It speeds up roaming decisions.
- 802.11v - Network Assisted Roaming (gets hints about AP)
    - The network can suggest the best AP to roam using a BSS transition Management Request.
    - It considers network conditions, AP load, signal qualification, etc.
    - The client remains in control but uses this data to make smarter roaming choices.
    - It also enables client steering and optional load balancing.
- 802.11r - Fast Transition (Roam Fast)
    - It handles the actual handoff process between APs.
    - It uses pre-authentication and key caching so roaming can happen in less than 50 ms.
    - It eliminates full authentication during roaming (no delay or dropped sessions).
- 802.11k : client knows which APs are nearby via neighbor report.
- 802.11v : network tells the client which AP is best to roam to (based on signal/AP load).
- 802.11r : when the client roams, it does so quickly using fast authentication.