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)?

Wi-Fi 5 (802.11ac)

- **Frequency Band:** 5 GHz
- **Max Speed:** Up to ~3.5 Gbps
- **Technology:**
    - MU-MIMO (Multi-User, Multiple Input, Multiple Output) — **only for downloads**
    - 256-QAM (Quadrature Amplitude Modulation)
- **Limitations:**
    - No support for 2.4 GHz improvements
    - Congestion in 5 GHz band

Wi-Fi 6 (802.11ax)

- **Frequency Bands:** 2.4 GHz **and** 5 GHz
- **Max Speed:** Up to 9.6 Gbps
- **Key Features:**
    - **OFDMA (Orthogonal Frequency Division Multiple Access):** better handling of multiple devices
    - **MU-MIMO for both uploads and downloads**
    - **1024-QAM:** improves speed and efficiency
    - **Target Wake Time (TWT):** extends battery life of devices
    - **Better performance in crowded places** (stadiums, airports, etc.)

Wi-Fi 6E

- **Frequency Bands:** 2.4 GHz, 5 GHz, **and new 6 GHz**
- **Max Speed:** Same as Wi-Fi 6, but with **more available channels**
- **Key Features:**
    - **6 GHz band:** super clean, wide-open airspace → **less interference**
    - Supports **up to 14 extra 80 MHz channels** and **7 extra 160 MHz channels**
    - Best for **VR, AR, 8K streaming**

Wi-Fi 7 (802.11be) — Upcoming/Latest

- **Frequency Bands:** 2.4 GHz, 5 GHz, and 6 GHz
- **Max Speed:** Up to ~46 Gbps (theoretical!)

- **Key Features:**
    - **320 MHz channels:** twice the bandwidth of Wi-Fi 6
    - **4096-QAM:** (higher modulation) → faster speeds
    - **Multi-Link Operation (MLO):** can use multiple bands at once → lower latency
    - **Enhanced OFDMA and MU-MIMO**
    - **Very low latency:** ideal for gaming, AR/VR, and real-time apps

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

OFDMA (Orthogonal Frequency Division Multiple Access)

- It divides a Wi-Fi channel into many smaller sub-channels called Resource Units (RUs).
- Each sub-channel can carry data for a different device at the same time.

Before Wi-Fi 6 (no OFDMA):

- One device used the full channel at a time → causing delays and congestion, especially when many devices are connected.

With Wi-Fi 6 (using OFDMA):

- Multiple devices share the same channel simultaneously, each getting a portion of it.
- Small packets from different devices are sent together efficiently.

How OFDMA Improves Network Efficiency:

- **Reduces latency:** devices don't have to "wait in line" to transmit data.
- **Handles more devices:** perfect for crowded places (homes, offices, airports).
- **Increases speed for small-data devices:** like IoT devices, smartwatches, etc.
- **Minimizes wasted bandwidth:** optimizes channel usage.

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

Target Wake Time (TWT) allows a device and router to **negotiate a schedule** for when the device should **wake up to send or receive data**.

Key Benefits for IoT Devices:

- **Longer Battery Life:**
    - Devices sleep when not needed → **less energy consumption** → **extends battery life** (critical for sensors, smartwatches, etc.).
- **Reduced Network Congestion:**

    - Devices wake up at **specific times**, avoiding clashes and reducing **channel contention**.

- **Improved Efficiency:**
    - Scheduling wake times leads to **more predictable, smoother communication** → better performance for IoT networks.
- **Scalability:**
    - Enables **thousands of IoT devices** to coexist without overwhelming the Wi-Fi network.

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

- More Spectrum:
    - The 6 GHz band adds up to 1200 MHz of new, clean spectrum → more channels and wider bandwidths (80 MHz, 160 MHz).
- Less Interference:
    - 6 GHz is only for Wi-Fi 6E devices → no interference from old Wi-Fi 4/5 devices, microwaves, Bluetooth, etc.
- Higher Speeds:
    - Wider channels allow faster data rates → ideal for 4K/8K streaming, VR, gaming, and large file transfers.
- Lower Latency:
    - Cleaner spectrum and wider channels result in much lower network delays.
- Future-Proofing:
    - 6 GHz band ensures Wi-Fi networks can handle future high-demand applications like AR, VR, IoT, and industrial automation.

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

Range:
Wi-Fi 6 operates on the 2.4 GHz and 5 GHz bands, giving it a good balance of range and speed. The 2.4 GHz band especially provides strong coverage over longer distances. Wi-Fi 6E, on the other hand, adds the 6 GHz band, which offers faster speeds but slightly shorter range because higher frequencies (like 6 GHz) cannot travel as far or penetrate walls as well as lower frequencies.

Bandwidth:
Wi-Fi 6 supports high bandwidth with channels up to 160 MHz, but it shares the 2.4 GHz and 5 GHz spectrum with older Wi-Fi generations, which limits the number of wide, clean channels. Wi-Fi 6E greatly improves this by unlocking the 6 GHz band, providing a lot more spectrum space. It allows for

many more 80 MHz and 160 MHz wide channels, resulting in significantly higher bandwidth and faster data transfer.

Interference:
In Wi-Fi 6, interference is moderate because the 2.4 GHz and 5 GHz bands are already crowded with older devices, Bluetooth, and even microwaves. In contrast, Wi-Fi 6E faces very little interference because the 6 GHz band is brand-new and reserved only for Wi-Fi 6E devices, ensuring a much cleaner and more reliable wireless environment.

6. What are the major innovations introduced in Wi-Fi 7 (802.1 Ibe)?

1. 320 MHz Channel Width:
Wi-Fi 7 doubles the maximum channel width from 160 MHz (in Wi-Fi 6) to **320 MHz**, allowing much faster data speeds.

2. Multi-Link Operation (MLO):
Devices can **connect to multiple bands (2.4 GHz, 5 GHz, 6 GHz) at the same time**, improving speed, reliability, and reducing latency.

3. 4096-QAM (4K-QAM):
Wi-Fi 7 uses **4096 Quadrature Amplitude Modulation** (up from 1024-QAM in Wi-Fi 6), which packs **more data into each transmission**, boosting throughput.

4. Extremely High Throughput (EHT):
Wi-Fi 7 targets **over 30 Gbps** speeds, making it ideal for heavy applications like **8K streaming, AR/VR, and cloud gaming**.

5. Improved OFDMA and MU-MIMO:
It enhances **OFDMA** and **MU-MIMO** technologies to serve **more devices simultaneously** with better efficiency and lower delay.

6. Preamble Puncturing:
It allows routers to **"cut out" small areas of interference** instead of avoiding the whole channel, making better use of available spectrum.

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

- **Multi-Link Operation (MLO)** allows a Wi-Fi 7 device to **use multiple frequency bands (2.4 GHz, 5 GHz, and 6 GHz) at the same time** for a single connection.
- Instead of sticking to one band like in older Wi-Fi versions, devices can now **send and receive data across several links simultaneously**.
  Higher Throughput:
- By combining multiple links, MLO **boosts the total available bandwidth**, leading to **much faster data speeds**.
  Lower Latency:

- MLO can **switch between links** if one becomes congested or faces interference, ensuring **smoother, quicker data delivery** and **less delay**.
  Better Reliability:
- Even if one link has problems, the other links continue working, which **improves connection stability**.

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

802.11k (Neighbor Report):

- Helps devices **quickly find the best nearby access points (APs)** when they need to roam.
- The AP provides a **list of nearby APs** and their signal strengths, so the device can **choose the best one faster**.

802.11v (Network Assisted Roaming):

- Allows the network to **suggest the best AP** for the device to move to.
- The AP can **steer devices** towards a better connection based on network load and signal quality.

- Faster Handoffs:
  Devices don't waste time scanning all channels; they already know where to roam.
- Smoother Connections:
  Devices move between APs without noticeable drops in connection, great for calls, video streaming, or gaming.
- Better Load Balancing:
  Helps distribute devices across APs to avoid overcrowding one access point.

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

- BSS (Basic Service Set) refers to a group of devices connected to an access point (AP).
- Fast BSS Transition (802.11r) is a protocol that speeds up the handoff process when a device roams from one AP to another within the same network.
- This is done by pre-establishing the security keys and other settings in advance, so the device doesn't have to re-authenticate when moving to a new AP.
- **Faster Roaming:**
  - When moving between APs, **802.11r reduces the time it takes to reconnect** by allowing the device to keep its connection alive without full re-authentication.
  - Ideal for applications that require **continuous, uninterrupted service**, such as VoIP calls, video conferencing, or live streaming.
- **Reduced Latency:**

    - **Lower latency** during roaming results in **less lag** and **better user experience**, especially in real-time applications.
- **Improved User Experience:**
    - In environments like airports, stadiums, or offices, where users move between multiple APs, 802.11r ensures that their connection **remains stable** and transitions are seamless.
- **Optimized for Mobility:**
    - It's particularly beneficial in **mobile environments** like cars, warehouses, or hospitals where users are continuously moving and need **consistent connectivity**.

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

1. 802.11k (Neighbor Report):

- **Function:** 802.11k helps devices **discover nearby APs** quickly.
- **How it contributes to roaming:**
    - When a device is moving through the network, it can receive a **list of nearby access points (APs)** from the current AP, along with their signal strengths. This allows the device to **make faster roaming decisions** instead of scanning all available channels.
    - **Result:** Devices can identify the best AP to roam to, minimizing the time it takes to hand off and improving the roaming experience.

2. 802.11v (Network Assisted Roaming):

- **Function:** 802.11v provides **network-assisted steering**, helping the network guide the device towards the best AP.
- **How it contributes to roaming:**
    - The network can suggest or steer the device towards a specific AP based on factors like signal quality, network load, and device location.
    - The AP can communicate with the client, suggesting the best AP to move to, ensuring the device transitions to a better-performing AP.
    - Result: Roaming decisions are made more intelligently, leading to optimal AP selection without requiring device involvement.

3. 802.11r (Fast BSS Transition):

- **Function:** 802.11r speeds up the roaming process by allowing devices to **pre-authenticate** with neighboring APs.
- **How it contributes to roaming:**
    - 802.11r allows devices to store security keys and other relevant connection information before roaming. This eliminates the need for full re-authentication when the device switches to another AP.
    - Result: The roaming process becomes faster and smoother, minimizing connection drop-offs and latency.