

Lecture 41: Wi-Fi (IEEE 802.11): Basic concept and overview of modern standards

Wireless Technologies

DI05011011: Mobile Communication

Agenda for Today

- 1. Introduction to Wi-Fi
- 2. What is IEEE 802.11?
- 3. Wi-Fi Architecture (BSS and ESS)
- 4. Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)
- 5. Evolution of Wi-Fi Standards
- 6. Modern Standards (Wi-Fi 4 to Wi-Fi 7)
- 7. Wi-Fi Security Basics
- 8. Summary and Next Steps

Introduction to Wi-Fi

- **Wi-Fi** stands for Wireless Fidelity.
- It is a family of wireless networking technologies used for Local Area Networking of devices and Internet access.
- Wi-Fi allows smartphones, computers, and IoT devices to connect to the network without physical cables.
- Typically operates in the **2.4 GHz, 5 GHz, and recently 6 GHz** ISM (Industrial, Scientific, and Medical) radio bands.

What is IEEE 802.11?

- **IEEE 802.11** is part of the IEEE 802 set of LAN protocols.
- Specifies the set of media access control (MAC) and physical layer (PHY) protocols for implementing WLAN computer communication.
- Created and maintained by the IEEE LAN/MAN Standards Committee (IEEE 802).
- The Wi-Fi Alliance tests and certifies that equipment complies with the 802.11 standards.

Wi-Fi Architecture: Basic Service Set (BSS)

- The fundamental building block of an 802.11 architecture is the **Basic Service Set (BSS)**.
- **Infrastructure BSS:** Contains an Access Point (AP) and one or more wireless clients (stations or STAs). All traffic flows through the AP.
- **Independent BSS (IBSS):** Also known as an ad-hoc network. STAs communicate directly with each other without an AP.
- Each BSS has a unique ID called the **BSSID** (usually the MAC address of the AP).

Wi-Fi Architecture: Extended Service Set (ESS)

- An **Extended Service Set (ESS)** connects two or more BSSs together.
- Connected via a Distribution System (DS), typically a wired Ethernet network.
- All APs in an ESS share the same **SSID (Service Set Identifier)**, which is the network name users see.
- Allows for **Roaming**: Users can move from one BSS to another without losing network connectivity.

- Wi-Fi uses **Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)**.
- Unlike wired Ethernet (which uses Collision Detection - CSMA/CD), wireless radios cannot send and receive simultaneously to detect collisions.
- **Mechanism:**
 1. Station listens to the channel (Carrier Sense).
 2. If idle, it waits a random backoff time.
 3. If still idle, it transmits the data.
 4. Waits for an ACK (Acknowledgment) from the receiver.

Evolution of Wi-Fi Standards

- The IEEE 802.11 standard has evolved continuously to provide higher speeds, better range, and more capacity.
- To make it easier for consumers, the Wi-Fi Alliance introduced generational naming (Wi-Fi 4, 5, 6, etc.).
- **Legacy Standards:**
 - - **802.11b (1999):** 11 Mbps, 2.4 GHz
 - - **802.11g (2003):** 54 Mbps, 2.4 GHz
 - - **802.11a (1999):** 54 Mbps, 5 GHz

Modern Standards: Wi-Fi 4 (802.11n)

- **Introduced:** 2009
- **Bands:** 2.4 GHz and 5 GHz (Dual-band)
- **Max Data Rate:** Up to 600 Mbps
- **Key Innovation: MIMO (Multiple Input Multiple Output)**
 - - Uses multiple antennas to send and receive multiple spatial streams of data simultaneously.
 - - Significantly improved range and throughput over 802.11g.

Modern Standards: Wi-Fi 5 (802.11ac)

- **Introduced:** 2014
- **Bands:** 5 GHz only
- **Max Data Rate:** Up to 3.5 Gbps (Wave 2) or 6.9 Gbps theoretically
- **Key Innovations:**
 - - Wider channel bandwidths (up to 160 MHz).
 - - **Downlink MU-MIMO** (Multi-User MIMO): AP can talk to multiple clients simultaneously.
 - - Higher order modulation (256-QAM).

Modern Standards: Wi-Fi 6 and 6E (802.11ax)

- **Introduced:** 2019 (Wi-Fi 6), 2020 (Wi-Fi 6E)
- **Bands:** 2.4 GHz, 5 GHz, and **6 GHz (Wi-Fi 6E only)**
- **Max Data Rate:** Up to 9.6 Gbps
- **Key Innovations:**
 - - **OFDMA:** Divides channels into sub-carriers, allowing simultaneous transmission to multiple users.
 - - **BSS Coloring:** Reduces interference in dense environments (like apartment buildings).
 - - **Target Wake Time (TWT):** Improves battery life for IoT devices.

Modern Standards: Wi-Fi 7 (802.11be)

- **Introduced:** Expected finalization in 2024
- **Goal:** Extremely High Throughput (EHT)
- **Bands:** 2.4, 5, and 6 GHz
- **Max Data Rate:** Up to 46 Gbps
- **Key Innovations:**
 - - **320 MHz channels:** Double the width of Wi-Fi 6.
 - - **Multi-Link Operation (MLO):** Devices can connect and transmit on multiple bands (e.g., 5GHz and 6GHz) simultaneously to reduce latency.
 - - **4K-QAM:** Packing more data into each signal.

- Since wireless signals travel through the air, security and encryption are critical.
- **WEP (Wired Equivalent Privacy)**: The original security, now easily broken and obsolete.
- **WPA (Wi-Fi Protected Access)**: A temporary patch over WEP.
- **WPA2**: The standard for over a decade, uses strong AES encryption.
- **WPA3**: The latest standard (mandatory for Wi-Fi 6 certified devices). It provides robust protection against dictionary attacks and better security on public open networks (via OWE).

- Wi-Fi operates in unlicensed ISM bands using the IEEE 802.11 standard.
- Networks are structured into BSS (single AP) and ESS (multiple APs).
- CSMA/CA is used to avoid collisions in the half-duplex wireless medium.
- Standards have evolved rapidly: Wi-Fi 4 (MIMO), Wi-Fi 5 (Gigabit/5GHz), Wi-Fi 6/6E (Efficiency/6GHz), to Wi-Fi 7 (MLO/46 Gbps).
- Security has evolved from WEP to the highly secure WPA3.

Next Lecture Preview

- In the next lecture, we will explore short-range identification technologies:
- **RFID (Radio Frequency Identification):** Used for inventory, toll tags, and logistics.
- **NFC (Near Field Communication):** Used for contactless payments (Apple Pay, Google Pay) and fast pairing.
- We will understand their working principles and how they differ from Wi-Fi and Bluetooth.