# Class Notes

**WI-FI TECHNOLOGY**
FUNDAMENTALS COURSE



**Module 1: Introduction and History of Wi-Fi**

**Session 1a:**

# EVOLUTION OF Wi-Fi

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30th Sept 2023

# 20 Years of WiFi Success Story (Source: WiFi Forward)

**1985: JUNK BANDS**

- While computer and wired networking have a long history of many decades, Wi-Fi is relatively new, emerging around 1985.

- The Federal Communications Commission (FCC) in the US plays a crucial role in regulating the use of radio frequency (RF) Spectrum.

- The FCC made an unprecedented move, opening up three spectrum bands for unlicensed use; anyone who follows the rules could use them. This spectrum was previously used for government radar.

- Unlicensed means that people don't need to buy or reserve the Spectrum; it's free for anyone to use, but with certain rules.

- Users must adhere to rules like limiting the transmit power to avoid interference.

- These rules ensure that if you're not transmitting too far, you won't interfere with others using the same frequencies.

- Various wireless devices emerged using this unlicensed Spectrum, including microwave ovens, garage door openers, baby monitors, and cordless phones.

**1988-1989: WIRELESS ROUTERS ARRIVE**

- Even before the wifi standards were introduced the first set of Wi-Fi routers were developed by companies like Proxim Wireless.

- The first wireless routers, the Proxim 900 MHz Range LAN and ARLAN-SST. Were specialty devices to connect computers in warehouses and track retail inventories

**1990: WIRELESS PAYMENTS INTRODUCED**

- WaveLAN, an early version of Wi-Fi, was installed in cash registers, a critical first step for digital payments and the wireless economy.

**1991: CUTTING THE CORD**

- Vtech released the first 900 MHZ cordless phone using the former junk spectrum.

**1994 : Wi-Fi GOES TO COLLEGE**

- Carnegie Mellon University began installing the first campus-wide Wi-Fi network.

**1997 : A NEW STANDARD**

- The first set of standards for Wi-Fi, the IEEE 802.11 protocol, is released. It carries data at 2MB/S.

    (Standards will be discussed in the later sessions)

**1999: LOOK MA, NO WIRES!**

- Steve Jobs unveils Apple's iBook, the first commercial laptop able to surf the web wirelessly.

- This was the first device that was commercially shown as a device that can connect to the internet wirelessly.
- And this kick-started the Wi-Fi to really pick up as a very famous technology and then over a period of time millions of Wi-Fi chipsets were sold.

Reference: https://www.youtube.com/watch?v=HFngngjy4fk

### 2005: MILLIONS SOLD

- More than 120 million Wi-Fi chipsets shipped.

### 2007: BUSINESS ESSENTIAL

- Here on Laptops started replacing Desktops as the go-to work computer, making Wi-Fi a critical business technology

### 2008: SMART PHONES

- Apple's iPhone 3G launched with Wi-Fi, kicking off the smartphone era and a boom in Wi-Fi devices and traffic.

### 2010: TABLETS

- Wi-Fi-only tablets were introduced, setting off the global mobile computing revolution in homes, offices and businesses.

### 2015: BILLION SOLD

- 10 billion Wi-Fi devices have been sold, from cell phones to tablets to sensors at rail yards and wireless airport gates operations to medical telemetry units and point of sale devices in retail stores, Wi-Fi powers our daily lives

### 2017 : NEW REALITIES

- The first self-contained virtual reality headset launches, powered entirely by Wi-Fi.

### 2018 : Wi-Fi SUPERCHARGES THE ECONOMY

- Wi-Fi generated more than $500 billion in economy value in the United States

### 2022: 5G Speeds FOR BILLIONS WITH Wi-Fi

- Wi-Fi 6 global annual chipset shipments will exceed 1 billion.

### *EVEN MORE WIFI!*

- 57% of internet traffic will run over Wi-Fi,

### 2023: SPOILER: THIS WILL BE BIG

- Wi-Fi is expected to generate nearly $1 trillion for the U.S economy in 2023

# WiFi Technology Evolution (Hardware to Software)

## Residential Wi-Fi Evolution:

### 1.1990s: Inception

- Introduction of 802.11 standard with 11 Mbps data rates.

- Early Wi-Fi routers relied on phone lines, using DSL or dialup technology.

- Predominantly used for basic email communication due to low data rates, and routers were cost-effective, priced around $20-$30 in the US.

### 2. 2000s: Speed and Broad Deployment

- Technological advancements led to routers achieving speeds of up to 1 Gbps.

- Telecom operators embraced Wi-Fi at a larger scale, bundling it with voice and video services.

- Wi-Fi became integral as Over-The-Top (OTT) streaming emerged, demanding faster and more reliable connection.

### 3.Connected Devices Boom

- Homes witnessed a surge in connected devices, with an average US household having 20-30 devices.

- This shift was fueled by the increasing prevalence of high-definition video streaming, making robust Wi-Fi connectivity imperative.

### 4.Addressing Coverage Challenges

- Larger homes encountered Wi-Fi coverage limitations.

- Innovative solutions emerged, including larger, more powerful routers and the introduction of mesh networks.

- Mesh networks extended wireless coverage without the need for wired connections, enhancing accessibility.

### 5.Present Decade: Wi-Fi 7 and Beyond

- Wi-Fi technology continued to evolve, with speeds reaching up to 50 Gbps.

- Wi-Fi's scope expanded to accommodate augmented reality (AR), virtual reality (VR), home automation, and the increasing number of connected devices in households.

# Enterprise Wi-Fi Transformation:

**1.1990s: Initial Stages**

- Enterprises adopted Wi-Fi with 11 Mbps standalone access points (APs).

- Early implementations faced security concerns.

**2. Deployment and Centralized Management**

- Enterprises deployed multiple APs and routers.

- Centralized controllers emerged to efficiently manage these access points.

- The complexity of management led to the need for IT teams dedicated to network maintenance.

**3.Shift to Cloud-Based Solutions**

- Cloud technology revolutionized Wi-Fi management, allowing controllers to migrate to cloud platforms.

- This shift streamlined centralized management across multiple locations.

- Physical access points and routers remained in place but were controlled through cloud-based systems.

**4.Integration of AI and ML**

- In the current decade, artificial intelligence (AI) and machine learning (ML) have been integrated into Wi-Fi networks.

- These technologies have enabled networks to self-organize and self-heal, reducing the dependency on highly skilled IT personnel.

**5.Transition from Hardware to Software Focus:**

- Initially, the focus was on hardware features, including antenna design and processing power.

- Over time, software became the primary differentiator among Wi-Fi providers.

- Companies now compete based on the capabilities and features of their software solutions.

# WiFi in Key Industries

- Wi-Fi technology has transcended its early applications and is now prevalent in numerous industries.

- It plays a pivotal role in sectors such as healthcare, education, transportation, and more.

- Wi-Fi has become an indispensable part of modern society, enabling connectivity and communication across various domains.

# WiFi Technology Life Cycle / Industry Ecosystem:



**Use Cases**
PAR, Basic concepts submitted to Standards Bodies based on business case.

**Pre-Silicon Design Verification**
Verify designs through simulations, IDE tools. Companies: Synopsis, Cadence, Mentor Graphics etc..

**Develop WiFi APs/Routers**
Develop and Test WiFi Routers/AP Companies: Cisco, Aruba, Netgear, Asus, TPlink, Ubiquiti etc...

**Certifications**
Various certifications for compliance Companies: FCC, TUV, UL, WiFi Alliance

**Deployment**
Operators, Service Providers, System Integrators Companies: Airtel, Comcast, Telefonica etc..

**Standards/ Pre-Standards**
IEEE and all Member Companies

**Develop WiFi Chipsets**
Develop WiFi Chipset and SoCs Companies: Qualcomm, Broadcom, Intel, Mediatek etc.

**Proof of Concept/Plug fests**
Initial trails and testing of Beta hardware and standard implementation Companies: WiFi Alliance, WBA, BBF etc..

**Manufacturing**
OEMs/ODMs that mass produce WiFi SoCs, Modules and Routers Companies: Askey, Pegatron, VVDN, Arcadyan etc..

**Post Deployment**
Network Management, troubleshooting Companies: Tanaza, SolarWinds, 7Signal, Aprecomm etc..

## 1.Use Cases:

- **Identifying the Need:** It starts with recognizing the need for improvement in existing Wi-Fi technology. For instance, when a generation lacks speed or security, companies and groups outline the issues and propose enhancements.

## 2.Standards/ Pre-Standards:

- **Standardization:** A document detailing these proposed changes is submitted to standards bodies like IEEE. These organizations, comprising numerous member companies, collaborate to develop standards that address the identified problems.

- **Standard Extensions:** Over time, the base standard evolves through extensions to accommodate additional features and improvements. These extensions enhance the capabilities of Wi-Fi technology.

### 3.Pre-Silicon Design Verification:

- **Simulation:** Before implementing the standard concepts into a chip, an intermediate step involves simulation. Much like academic research simulations, companies like Cadence, Mentor Graphics, and Synopsys use their design verification tools to verify if the technology can be realized effectively.

### 4.Develop WiFi Chipsets:

- **Chip Development:** Companies like Qualcomm, Intel, and MediaTek create Wi-Fi chipsets or system-on-chips (SoCs). These chips are the heart of Wi-Fi routers, implementing functions like the physical and MAC layers.

### 5.Develop WiFi APs/Routers:

- **Manufacturers Take Over:** Organizations like TP-Link take these chips and build the actual Wi-Fi routers. They design the components, lay out the boards, and create the physical product.

### 6.Proof of Concept/Plug fests:

Before reaching the final product stage, a proof of concept is conducted to ensure that the Wi-Fi router can connect to Wi-Fi devices and functions as intended.

### 7.Certifications:

Routers undergo certification processes, including FCC certification, to verify compliance with regulations. This ensures that the router operates within specified power, temperature, and emission limits.

### 8.Manufacturing:

Mass Production: Manufacturing units in regions like China, Taiwan, and increasingly in India, produce Wi-Fi routers on a large scale. These routers are then distributed to the market.

### 9.Deployment:

- **Deployment:** Internet service providers like Airtel and Reliance put their branding on these routers and offer them to customers. They manage these devices as part of their network services.

- **Enterprise Deployment:** In enterprise settings, site surveys and network planning are critical. Companies need to determine router placement for optimal coverage.

### 10.Post Deployment:

After deployment, ongoing management, troubleshooting, and monitoring become essential. This includes addressing network issues, managing new devices, and ensuring network security.

# WiFi Devices



- Wi-Fi's widespread adoption can be attributed to its compatibility with a wide range of devices. Initially, it was primarily associated with laptops and smartphones, but over time, it has infiltrated almost every aspect of our daily lives. Today, we can find Wi-Fi connectivity in gaming devices, cameras, printers, set-top boxes, and even household appliances like refrigerators and microwave ovens. Beyond that, Wi-Fi has permeated into more specialized areas, such as sprinkler systems, home robots, blood pressure monitors, patient monitors, and infusion pumps. The ubiquity of Wi-Fi has also made it a vital technology in transportation systems.

# WiFi Technology Generations

| | Wi-Fi 4 (IEEE 802.11n) | Wi-Fi 5 (IEEE 802.11ac) | Wi-Fi 6 (IEEE 802.11ax) | Wi-Fi 6E (IEEE 802.11ax) | Wi-Fi 7 (IEEE 802.11be) |
|---|---|---|---|---|---|
| Frequency bands operations | 2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990) | 5GHz (5.030 - 5.990) | 2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990) | 2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990) 6GHz (5.925 7.125) | 2.4GHz (2.402 - 2.494) 5GHz (5.030 - 5.990) 6GHz (5.925 7.125) |
| Maximum bandwidth per channel | 2.4GHz: 40MHz 5GHz: 40MHz | 2.4GHz: 40MHz 5GHz: 80MHz | 2.4GHz: 40MHz 5GHz: 160MHz | 2.4GHz: 40MHz 5GHz: 160MHz 6GHz: 160MHz | 2.4GHz: 40MHz 5GHz: 160MHz 6GHz: 320MHz |
| Maximum number of non-overlapping channels | 2.4GHz: 3 Channel:1,6,11 | 5GHz: Channels:36,52 (80MHz) | 2.4GHz: 2 (40MHz) Channel:1,11 5GHz: Channel 36: 5.180 GHz to 5.340 GHz (160 MHz width) or Channel:36,52,100,116,132 (80 MHz) | 2.4GHz: 2 (40MHz) Channel:1,5,9,13 5GHz: Channel 36: 5.180 GHz to 5.340 GHz (160 MHz width) Channel 36,52,100,116,132 (80MHz) 6GHz: 7 (160MHz) | 2.4GHz: Channel 1,5,9,13 (40MHz) 5GHz: 2 (160MHz) or Channel 36,149 (80MHz) 6GHz: Channel 31, 63, 95, 127, 159, 191 (320MHz) |
| Maximum MIMO configuration | 4x4 | 4x4 | 8x8 | 8x8 | 16x16 |
| Highest modulation | 64 QAM | 256 QAM | 1024 QAM (1K QAM) | 1024 QAM (1K QAM) | 4096 QAM (4K QAM) |
| Maximum PHY datarate | 600 Mbps | 1.73 Gbps | 9.6 Gbps | 9.6 Gbps | 46.1 Gbps |
| Multi user MIMO (MU-MIMO) | N/A | Downlink (Wave 2 only) | Downlink Uplink | Downlink Uplink | Downlink Uplink |
| Multi user OFDMA (bandwidth sharing) | N/A | N/A | Yes | Yes | Yes |
| Target Wake Time (TWT) | N/A | N/A | Yes | Yes | Yes (improved) |
| Multi Link Operation / Multi Resource Unit | N/A | N/A | N/A | N/A | Yes |

# Evolution of Wi-Fi Generations:

- The history of Wi-Fi can be traced through its various generations. It all began even before what we now call Wi-Fi 4, which was the designation given by the Wi-Fi Alliance when they started categorizing the technology. Subsequent generations, namely Wi-Fi 5, 6, and the most recent, Wi-Fi 7, have each seen significant advancements. A noteworthy characteristic of these generations is their relatively short lifespans, typically spanning three to five years, as technology evolves rapidly.

# Technological Advancements:

- With each Wi-Fi generation, several key improvements have been introduced. One of the most noticeable enhancements has been the increase in the allocation of frequencies, resulting in a wider spectrum for Wi-Fi communication. This expanded frequency range has paved the way for faster and more reliable connections.

- Additionally, the number of antennas has multiplied over the years. In the early days, Wi-Fi devices had just a few antennas, but now, the spec have devices with upto 16 antennas. This increase in antenna count directly correlates with improved throughput and data transfer speeds.

- Furthermore, advances in modulation techniques have allowed for more complex data encoding and decoding. This has significantly contributed to the improved throughput of Wi-Fi networks. For instance, Wi-Fi started with speeds around 600 Mbps in the 802.11n standard and has progressed to nearly 50 gigabits per second in Wi-Fi 7.

- Lastly, Wi-Fi's security features have continuously evolved to meet the growing demands for data protection and network security. These improvements ensure that Wi-Fi remains a reliable and secure wireless communication technology for various applications.

# Important terms:

1. **Uplink and Downlink:**

   - **Downlink:** Refers to data transmitted from a Wi-Fi access point (like a router) to connected devices, typically from the internet to your device.

   - **Uplink:** Involves data transmitted from your device back to the access point or router, such as when you send a request or upload data.

## 2. MIMO (Multiple-Input, Multiple-Output):

MIMO is a technology that uses multiple antennas on both the transmitter (router) and receiver (device) to improve wireless communication by sending and receiving multiple data streams simultaneously, increasing speed and reliability.

## 3. MU-MIMO (Multi-User MIMO):

MU-MIMO enables a Wi-Fi router to communicate with multiple devices at the same time, enhancing network efficiency by serving multiple users or devices simultaneously.

## 4. Multi-user OFDMA (Orthogonal Frequency Division Multiple Access):

OFDMA is a technique that divides the Wi-Fi channel into smaller sub-channels, allowing multiple devices to transmit data simultaneously without interference, optimizing bandwidth sharing.

**5. Target Wake Time (TWT):**

TWT is a feature that allows Wi-Fi devices to schedule when they wake up to transmit data, reducing power consumption and improving battery life for devices like smartphones and IoT devices.

**6. Multi-Link Operation/Multi-Resource Unit:**

It refers to advanced techniques that enable efficient data transmission and resource allocation in modern Wi-Fi standards, ensuring optimal performance in crowded networks.

**7.Modulation:**

It refers to how data is encoded into radio waves for wireless transmission, affecting the data rate and reliability of a Wi-Fi connection.

- **64 QAM:** Stands for 64 Quadrature Amplitude Modulation. It encodes data by varying the amplitude and phase of the signal, allowing 6 bits to be transmitted per symbol, providing a higher data rate compared to lower modulation schemes.
- **256 QAM:** Uses a more complex modulation scheme, transmitting 8 bits per symbol, resulting in higher data rates and improved performance.
- **1024 QAM (1K QAM):** Further increases data transmission by encoding10 bits per symbol, delivering faster speeds, but it may require a stronger signal for reliable communication.
- **4096 QAM (4K QAM):** The most advanced modulation scheme, encoding 12 bits per symbol, offering the highest data rates but requiring a very robust signal for effective use.

**8.Maximum MIMO Configuration:**

It Indicates the number of antennas used for both transmitting and receiving data. For example, "4x4" means there are four antennas for transmitting and four for receiving, enabling multiple data streams and enhancing wireless performance. Higher numbers, like "8x8" or "16x16," represent even greater antenna configurations for faster and more reliable connections.

# Why is Wi-Fi Technology so successful?

1. **Low Cost:** Wi-Fi is a cost-effective choice compared to cellular networks. Cellular networks involve high installation and maintenance costs, requiring infrastructure like base stations and towers. In contrast, setting up Wi-Fi is affordable, with the simple purchase and installation of routers.
2. **IP Network Compatible:** Wi-Fi seamlessly integrates with IP-based internet infrastructure. It acts as the final hop in the network, connecting devices to wired ports and making the last hop wireless. This compatibility with TCP/IP technology simplifies connectivity.

3. **Uses Unlicensed Spectrum:** Wi-Fi operates on unlicensed frequencies, allowing anyone to use them without the need for expensive spectrum licenses. This openness contributes to its widespread availability.

4. **High Data Rates:** Wi-Fi technology offers fast data transfer rates, facilitating efficient communication and data exchange between devices.

5. **Enterprise-Grade Security:** Wi-Fi implements robust security measures, including multiple security protocols, to protect data and ensure safe and secure wireless connections.

6. **Easy to Deploy:** Setting up Wi-Fi is straightforward and user-friendly. It doesn't require the creation of complex network elements, making it easy to deploy and adapt for various needs.

7. **Scalability:** Wi-Fi networks can easily scale to accommodate large venues, stadiums, shopping malls, and more. This scalability enhances its usability in diverse environments.

8. **Open Technology:** Wi-Fi's open nature allows for versatile applications beyond internet browsing. It serves as the foundation for various technologies and services across different industries, making it highly adaptable and open to innovation.