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Harnessing the Power of Wi-Fi 6 in the New Age of IoT

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Introduction

The average household has more IoT devices than ever before, and wireless device manufacturers are tasked with keeping up with demand and setting the rules of engagement for emerging technologies. Their efforts in areas like battery life and device security will influence technology adoption today and long into the future. With rapid technological advancement, the variety of connected devices and application environments is exploding in all directions.

802.11ax, better known as Wi-Fi 6, is the newest standard designed to support Wi-Fi's growing reputation as a core element of infrastructure today. Its release comes with a variety of features to improve throughput, increase network efficiency, and extend battery life, particularly in over-saturated networks. In this paper, we'll cover the rapid evolution of Wi-Fi over the last two decades and dive into the value of Wi-Fi 6 for IoT devices.

The Evolution of Wi-Fi Technology and Today's Deployments

Wi-Fi has seen incredible advancements since the first version, 802.11b. 802.11b was released in 1999 as a product of the Institute of Electrical and Electronics Engineers' (IEEE) efforts to standardize wireless local area network (WLAN) technologies. 802.11b had a maximum data rate of 11 Mbps, and it featured a single 2.4 GHz band. Today's data rates peak at 9607 Mbps with support for multiple bands (i.e., 2.4, 5, and 6 GHz). Wi-Fi really took off when high-speed broadband entered households and it continued to proliferate, making it a household name. "Wi-Fi" even found its way into the Merriam-Webster English Dictionary in 2005.

The Evolution of Wi-Fi

IEEE Protocol	802.11b	802.11a	802.11g	802.11n	802.11ac	802.11ax
WFA Naming	N/A	N/A	N/A	**Wi-Fi (Certified) 4**	**Wi-Fi (Certified) 5**	**Wi-Fi (Certified) 6, Wi-Fi 6E**
Year Introduced	1999	1999	2003	2009	2013	2019, 2021 doe 6E
Band(s) (GHz)	2.4	**5**	**2.4**	**2.4, 5 (SB or DB)**	5	2.4, 5, **6 (SB, DB, TB)**
Channel Bandwidth (MHz)	20	20	20	20, **40**	20, 40, **80, 160**	20, 40, 80, 160
Allowable Streams	1	1	1	**4**	8 (only 4 implemented)	8
Max Data Rates (Mbps)	11	**54**	54	**600** (150 Mbps per stream)	433 (80 MHz, 1 SS) 866 (160 MHz, 1 SS **3467** (160 MHz, 4 SS)	143 (20 MHz, 1 SS) 600 (80 MHz, 1 SS) **9607** (160 MHz, 8 SS)
MIMO	N/A	N/A	N/A	**Single User (SU-MIMO)**	**Downlink Multi-User (DL MU-MIMO)**	Multi-User (DL MU-MIMO)
Subcarrier Spacing (KHz)	N/A	312.5	312.5	312.5	312.5	**78.125**
Symbol Duration (us)	N/A	3.2	3.2	3.2	3.2	**12.8**
Guard Interval (us)	N/A	0.8	0.8	**0.4**, 0.8	**0.4**, 0.8	0.8, **1.6, 3.2**
PHY Modulation	DSSS	OFDM	DSSS, OFDM	**DSS, OFDM, HT-OFDM**	DSS, OFDM, HT-OFDM, **VHT-OFDM**	DSS, OFDM, HT-OFDM, VHT-OFDM, **OFDMA**
Multi-user Operation	No	No	No	No	**Yes (DL MU-MIMO)**	**Uplink and Downlink OFDMA** **Uplink** and Downlink MU MIMO
Highest Order Modulation	CCK	**64-QAM**	64-QAM	256-QAM	256-QAM	**1024-QAM**
Power Saving Mechanisms	PS-POLL	PS-POLL	PS-POLL	PS-POLL	PS-POLL	**Target Wake Time**
Spatial Reuse Mechanisms	No	No	No	No	No	**BSS Coloring**

Features in green represent new additions for that version.

Today, the Wi-Fi Alliance assists in expanding Wi-Fi's uses and availability; with each new release, there are new challenges. Today, for instance, most smart phone users have access to high-resolution video on the go. This is one of many examples in the high-bandwidth application space. Bandwidth refers to the maximum amount of data transmitted over an internet connection in a measured amount of time. Because they're transmitting large amounts of data, high-bandwidth technologies place a heavy burden on networks, and in dense areas, like cities, there are many devices vying for limited network resources. That's not the only challenge. The sheer volume of devices on Wi-Fi today increases network latency and decreases throughput, resulting in connectivity issues and slow network speeds for consumers.

Access points are devices that create a WLAN so Wi-Fi devices can connect to a wired network. Along with this, consumer expectations for speed and battery life continue to increase. Instead of improving Wi-Fi on an individual device level, for its newest version release, IEEE and the Wi-Fi Alliance focused their attention on network-level and access point improvements.

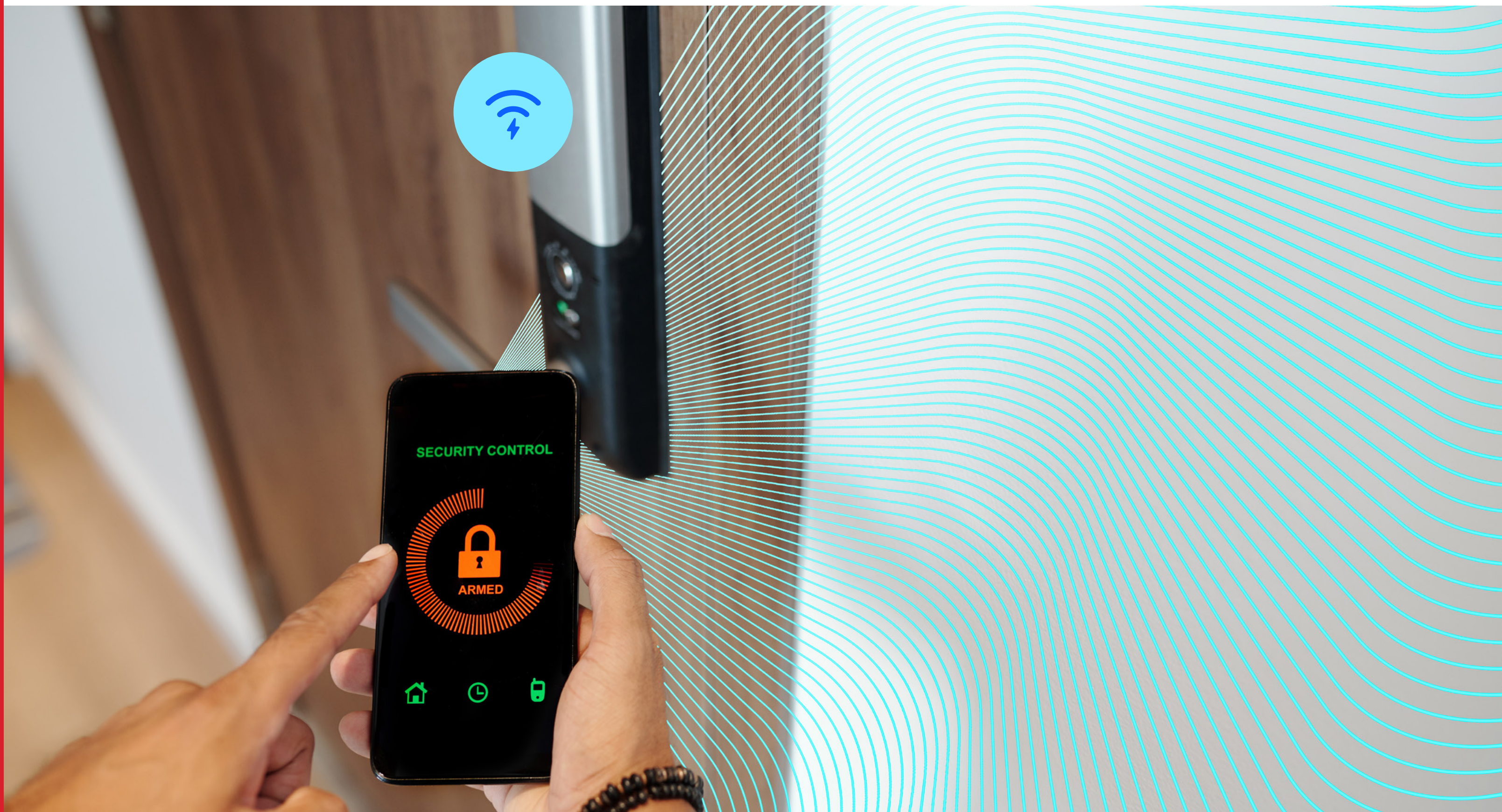
With the explosion of smart home IoT devices from different providers, the CSA alliance launched the release of Matter 1.0, its first iteration to reduce fragmentation and improve interoperability and end user experience. Wi-Fi's ubiquitous presence in the smart home means that bridging Matter devices to Wi-Fi networks is going to be important for device manufacturers and consumers to integrate new technologies.

The Case for Wi-Fi 6 for IoT Devices

With some already achieving Wi-Fi 6 certification today, most devices will support Wi-Fi 6 by 2025 or 2026. It's expected to proliferate in response to market demands for IoT and other evolving technologies. Beyond wearables and smart speakers, now doorbells, thermostats, alarms, coffee makers, lightbulbs, and many other household staples are getting connected. The number of devices trying to talk to any given access point will only increase, and performance expectations remain high. Homeowners expect sensors, like those deployed in smart home security systems, to operate for long periods of time, even years, without a direct line of power. Consumers want to "set it and forget it" and still feel safe.

Improving network efficiency and increasing bandwidth are some of the ways Wi-Fi 6 seeks to address this pain point, and perhaps encourage connected device adoption by improving consumer trust. Consider another high-stakes application — the smart lock. Wi-Fi smart locks can be a reliable and convenient option for those looking for remote access to their homes, but like any other battery-powered device, power only lasts as long as the batteries. If they aren't replaced in time, residents could be locked out of their homes. Improving network efficiency — and increasing bandwidth increases throughput and reduces reduces the amount of battery power used for achieving and maintaining connectivity.

As part of the Wi-Fi 6 release, the Wi-Fi Alliance assessed existing pain points, considered current and emerging applications, and evaluated environments with the hope of supporting higher throughput per device at any given data rate.



Wi-Fi 6 Enhancements

The Wi-Fi Alliance established the following value-adds to guide the design of Wi-Fi 6: better performance, longer battery life, outdoor / longer range, support for denser environments, and, consistently, backwards compatibility.

Performance Improvements

The Wi-Fi Alliance sees a future where Wi-Fi 6 delivers 40 percent higher peak data rates for single client devices and a four-fold increase in network efficiency.

Wi-Fi 6 makes several adjustments to overcome inefficiencies and increase throughput. Full Duplex OFDMA and Multi-User Multiple-Input Multiple-Output (MIMO) allows an access point to communicate with multiple devices simultaneously.
With Wi-Fi 4, access points and communicated one at a time with different devices. New in Wi-Fi 6, multiple client devices can send data back to an access point at the same time, opening up the opportunity for more information exchange. With MU-MIMO, an access point receives information from antennas and sets it up in a single, efficient packet. To accomplish this, packets are subdivided into smaller packets, and data for different devices are included in a single transmission. Also notable, beamforming capabilities help access points and clients target transmission to a particular device, increasing range and improving throughput and efficiency.

Longer Battery Life

Target Wake Times (TWT) for low-power applications allows a client to negotiate with the access point how long it can be asleep. This prevents the client from constantly looking for beacons to determine when to pull a data packet. A key benefit of Wi-Fi 6 is the ability to set up schedules that reflect the unique needs of any given client device. When each client can set up their own schedule by communicating directly with an access point, it increases network efficiency and allows client devices to sleep longer, better utilizing the network.

In high-density areas, network congestion causes latency and decreases throughput; these negative impacts are felt most by battery-powered devices because they end up wasting power trying to get on the network and processing slower throughput. When a client can sleep for longer periods, the average power consumption decreases thus significantly increasing battery life. With the improved network efficiency and higher data rates of Wi-Fi 6, along with enabling a client to sleep for longer periods, the average power consumption decreases and significantly increases battery life.

Extended Range Indoors and Outdoors

Adopting an extended-range packet structure and longer guard intervals helps with range and coverage, particularly for indoor/outdoor applications like doorbells and video cameras that can sometimes lose connection because they're farther from an access point.

Support for Denser Environments

Wi-Fi 6 was designed to improve the average throughput per user by at least 4 times in dense or congested environments. There are two main technologies that improve the average throughput: Uplink and Downlink Orthogonal Division Multiple Access (OFDMA) and spatial reuse protocol. OFDMA allows an access point to allocate a whole channel to a single user at a time or opt to partition a channel to serve multiple users simultaneously. For the first time in Wi-Fi history, multiple users with different traffic profiles (i.e., applications) can transmit simultaneously, downlink or uplink, over the same channel. OFDMA results in better frequency reuse, reduced latency, and increased efficiency, which makes it ideal for low-bandwidth applications, like medical and industrial wearables.

Spatial reuse protocol is designed to reduce collisions between multiple device transmissions, thereby allowing more throughput. This is achieved by ignoring transmissions from an Overlap Basic Service Set (OBSS) to accommodate simultaneous transmit.

Backwards Compatibility

IEEE deliberately develops each Wi-Fi iteration to be backwards compatible, making it possible to use legacy clients and access points and maintain existing infrastructure. That's one of the reasons Wi-Fi is so prolific—people can upgrade their devices as they see fit without worrying about connectivity. Wi-Fi 6 was designed to work with Wi-Fi 4 devices and everything in between. While Wi-Fi 6 devices may get special attention from access points depending on the use case, the updates were designed with compatibility in mind. Households likely support at least 20 IoT devices at this point, from phones to smart speakers, and that number is expected to increase. While Wi-Fi 4 access points are still functional, they cannot support an abundance of devices due to practical limitations like memory. With Wi-Fi 6, household access points can better manage more IoT devices because of features like OFDMA, MU-MIMO, BSS Coloring. Since Wi-Fi 6 is backwards compatible, it's specified that an access point can support both OFDMA for Wi-Fi 6 and OFDM for Wi-Fi 4 clients.

Wi-Fi 6 for IoT + SiWx917

There are several features of Wi-Fi 6 that are particularly useful for IoT applications:

- **Individual and broadcast TWT** allow devices to operate on specific sleep schedules that allow them to sleep for longer. Schedules are negotiated with access points, which reduce interoperability issues caused by sleeping devices. This feature reduces power consumption by 20 percent in high density areas. This is critically important for all battery devices including asset trackers, HVAC, thermostats, cameras, power tools, wearables, medical devices, switches, sensors, locks, shades, and blinds.

- **More end devices supported per access point,** approximately 50+ compared to 20 with Wi-Fi 4, means a higher density of IoT devices can be supported overall. Full duplex multi-user, multiple input, multiple output (DL/UL MU-MIMO) makes communication per device significantly faster. Further, Wi-Fi 6 MU-MIMO increases router capability to connect to eight devices concurrently compared to four in previous versions.

- **Uplink and Downlink OFDMA, spatial frequency reuse, UL MU-MIMO, and beamforming** improve throughput, increase efficiency, and reduce latency for better performance and energy efficiency. Allocating bandwidth to different users and leveraging OFDMA-based scheduling reduce overhead, improve overall efficiency, and increase throughput.

- **Long-guard intervals, cyclic prefix, reduced interference, and extended-range packet structures** help improve indoor and outdoor coverage area. Further, co-channel interference mitigation is possible using BSS color codes to help identify transmissions from another network. These features contribute to improved range, robust connectivity, and better coverage per deployment for IoT devices.

- **Backwards Compatibility** with Wi-Fi 4 2.4 GHz enables seamless future upgrades.

- **Matter over Wi-Fi support** with Matter leveraging Wi-Fi security and performance features, and using Bluetooth LE for provisioning.

At Silicon Labs, we've leveraged these benefits in SiWx917, our ultra-low-power, high-performance ultra-low power Wi-Fi 6 plus Bluetooth Low Energy (LE) 5.1 SoC IoT solution.

Considering power, cost, and IoT optimization, we focused on the 2.4 GHz band to help developers leverage the benefits of Wi-Fi 6 in the widest variety of devices (e.g., battery-operated, low-power, etc.). Further, a 20 MHz bandwidth offers the best performance from a power efficiency perspective while maintaining a strong maximum data rate (86 Mbps) to support streaming for IoT devices (e.g., doorbells or smart cameras).