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A Review of Wi-Fi Evolution from Wi-Fi 4 to Wi-Fi 7 and Its Implications for Internet of Things Connectivity

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Abstract:
Wi-Fi has become one of the most widely used ways to connect Internet of Things (IoT) devices, and each generation of the standard has changed what IoT deployments can do. This review traces the evolution of Wi-Fi from Wi-Fi 4 (IEEE 802.11n) through Wi-Fi 5, Wi-Fi 6 and 6E, and Wi-Fi 7 (IEEE 802.11be), and it explains how the features introduced along the way affect IoT connectivity in practice. The mechanisms that matter most for constrained and dense deployments are examined, including Orthogonal Frequency-Division Multiple Access (OFDMA), Target Wake Time (TWT), the move into the 6 GHz band, and Multi-Link Operation (MLO). Wi-Fi HaLow (IEEE 802.11ah), the sub-1 GHz variant built specifically for long-range, low-power IoT, is also covered, together with the security improvements introduced with WPA3. For each generation the relevant features are summarised, along with the gains they bring for IoT and their limitations. The review closes with the open challenges that remain, including energy, coexistence, and interoperability, and a look ahead to Wi-Fi 8 (IEEE 802.11bn). A clear and current map of how Wi-Fi has evolved, and of what each step means for connecting things, is intended to be provided for practitioners and researchers.

Keywords: IoT Connectivity, Wi-Fi 6, Wi-Fi 7, Wi-Fi HaLow, Target Wake Time, Multi-Link Operation

1. Introduction

Wireless connectivity is the backbone of the Internet of Things (IoT), and among the available options Wi-Fi is one of the most common. It is already present in most homes and buildings, it connects directly to IP networks, and it does not require a separate hub for many device types. As the number of connected devices has grown, the IEEE 802.11 family of standards that underpins Wi-Fi has evolved through several generations, each adding features that change what IoT deployments can realistically support [1].

The early generations were designed mainly for laptops and phones, where peak throughput was the headline goal. More recent generations have paid closer attention to the properties that matter for IoT, namely efficiency in dense environments, predictable latency, and long battery life. Understanding this progression helps explain why some IoT products still use older radios while others depend on the newest features, and it clarifies what can be expected from each standard.

This review follows Wi-Fi from Wi-Fi 4 to Wi-Fi 7, with a focus on IoT. The key features of each generation are described, their effect on IoT use is explained, and Wi-Fi HaLow, the sub-1 GHz variant built for long-range low-power sensing, is covered. Security across generations is also reviewed, and the paper closes with the open challenges and the road toward Wi-Fi 8. The emphasis throughout is practical rather than exhaustive, in that the features which matter for connecting things are prioritised.

2. Scope and Review Approach

This is a narrative review rather than a systematic one. The mainline Wi-Fi generations from Wi-Fi 4 through Wi-Fi 7, plus Wi-Fi HaLow, were selected because these are the standards most relevant to IoT connectivity. Standards documentation, technical white papers, vendor design guides, and recent peer-reviewed and preprint literature were consulted. For each generation the features with the clearest bearing on IoT are reported, namely spectrum and channel use, multiple-access and scheduling mechanisms, power-saving features, and security. Specific products are not benchmarked; instead what the standards and the literature say about capabilities and limits is synthesised.

3. Early Wi-Fi Generations: Wi-Fi 4 and Wi-Fi 5

Wi-Fi 4 (IEEE 802.11n) was the first generation to combine the 2.4 and 5 GHz bands with multiple-input multiple-output (MIMO) antennas and channel bonding, pushing peak rates to a few hundred megabits per second [1]. For IoT, its importance was less about speed and more about establishing dual-band operation and a more robust physical layer that low-cost radios could later build on. Many inexpensive IoT modules still ship with 802.11n radios because they are cheap, well understood, and adequate for light traffic.

Wi-Fi 5 (IEEE 802.11ac) moved to the 5 GHz band, widened channels further, and added downlink multi-user MIMO and higher-order modulation, raising peak throughput into the gigabit range [1]. Wi-Fi 5 improved capacity for media-heavy clients such as cameras and streaming hubs, but it did little specifically for battery-powered sensors. The generation that changed the picture for IoT was the next one.

4. Wi-Fi 6 and Wi-Fi 6E: Efficiency for Dense IoT

Wi-Fi 6 (IEEE 802.11ax), branded High Efficiency, was the first generation designed around dense, many-device environments rather than single high-speed links [2]. Two of its features stand out for IoT. Orthogonal Frequency-Division Multiple Access (OFDMA) splits a channel into smaller resource units so that several devices can be served within one transmission, which suits the small, frequent packets that sensors generate and reduces contention when many devices share an access point [2]. Uplink and downlink multi-user MIMO extend the same idea to the spatial domain [3].

The feature with the largest effect on IoT battery life is Target Wake Time (TWT). TWT allows an access point and a device to negotiate scheduled wake-and-sleep intervals, so the device can stay asleep far longer instead of waking for every beacon, which cuts power consumption substantially [2]. Recent experimental work shows that TWT can also be used to provide deterministic, time-sensitive scheduling, not just power saving, which broadens its value for industrial IoT [4], [5]. Wi-Fi 6E extends Wi-Fi 6 into the newly opened 6 GHz band, adding clean spectrum with far less legacy interference, which helps latency-sensitive and high-density deployments [1]. Together, OFDMA, TWT, and 6 GHz make Wi-Fi 6 and 6E the first Wi-Fi generations whose design goals line up well with IoT needs.

5. Wi-Fi 7: Multi-Link Operation and Time-Critical IoT

Wi-Fi 7 (IEEE 802.11be), finalised in 2025, targets extremely high throughput and, more importantly for IoT, lower and more predictable latency [6]. Its defining feature is Multi-Link Operation (MLO), which allows a device to use the 2.4, 5, and 6 GHz bands at the same time. MLO aggregates bandwidth, but its real benefit for many IoT scenarios is reliability, because traffic can be moved to a cleaner band or duplicated across links, which reduces dropouts and tail latency [6], [7]. Wi-Fi 7 also widens channels to 320 MHz and raises modulation to 4096-QAM.

These capabilities matter for the emerging class of IoT applications that need real-time responsiveness, such as augmented-reality tools, industrial control, and edge-AI inference at the network edge [8]. The trade-off is complexity and cost. MLO enlarges the configuration space that operators must manage, and exploiting it well increasingly calls for automated, load-aware control rather than manual planning. This coupling of advancing Wi-Fi capability with harder management is a recurring theme, and it has motivated frameworks that treat Wi-Fi evolution and IoT together and apply automated or agentic control to the resulting complexity [9].

6. Wi-Fi HaLow (IEEE 802.11ah): Long-Range, Low-Power IoT

Not every IoT device needs gigabit speed, and many need range and battery life instead. Wi-Fi HaLow (IEEE 802.11ah) was built for exactly this case. It operates in sub-1 GHz spectrum, typically around 900 MHz, which propagates farther and penetrates walls better than the 2.4 and 5 GHz bands [10]. HaLow can reach roughly a kilometre in open conditions and support large numbers of endpoints per access point, at the cost of much lower peak throughput than mainstream Wi-Fi [11].

This profile suits smart agriculture, industrial and utility monitoring, logistics, and extended-coverage smart-home and campus deployments, where the workload is mostly low-rate telemetry with occasional heavier uploads such as images [11]. Field measurements confirm that HaLow can hold reliable long-range links, including non-line-of-sight paths, in realistic monitoring settings [12]. HaLow does not replace mainstream Wi-Fi; it fills the gap between short-range high-rate Wi-Fi and low-power wide-area technologies, and it keeps IoT connectivity within the same IP-based Wi-Fi family.

7. Security Across Generations

Security has advanced alongside throughput. The move from WPA2 to WPA3 strengthened authentication and encryption, replacing the pre-shared-key handshake with Simultaneous Authentication of Equals, which resists offline password guessing, and adding protections for open networks [13]. For IoT, WPA3 also introduced Easy Connect, a provisioning method aimed at devices without screens or keyboards, which addresses a long-standing pain point in onboarding constrained devices. Security remains a weak spot in practice, however, because many low-cost IoT products lag in adopting the latest modes, and a network is only as strong as its least-capable device.

8. Open Challenges and the Road to Wi-Fi 8

Several challenges cut across generations. Energy is still the binding constraint for battery devices, and while TWT helps, always-connected operation remains expensive. Coexistence is a growing problem as the 2.4 GHz band stays crowded with Wi-Fi, Bluetooth, Zigbee, and Thread traffic, and independent measurements show that protocol and band choices have real performance consequences [14]. Interoperability across the wider IoT ecosystem is a related and persistent issue, since Wi-Fi devices must coexist and often cooperate with non-Wi-Fi radios. Looking ahead, Wi-Fi 8 (IEEE 802.11bn), described as Ultra High Reliability, shifts the headline goal from peak speed to dependable, low-variance performance, which is precisely what time-critical IoT needs [15]. If that focus holds, the next generation may matter more for IoT than any single throughput number.

Table 1: Summary of Wi-Fi Generations and Their IoT-Relevant Characteristics

Generation	IEEE Standard	Bands	Key IoT-Relevant Features	Max PHY Rate
Wi-Fi 4	802.11n	2.4 / 5 GHz	MIMO, channel bonding	600 Mbps
Wi-Fi 5	802.11ac	5 GHz	Downlink MU-MIMO, 256-QAM	3.5 Gbps
Wi-Fi 6	802.11ax	2.4 / 5 GHz	OFDMA, UL/DL MU-MIMO, TWT	9.6 Gbps
Wi-Fi 6E	802.11ax	6 GHz added	Clean 6 GHz spectrum	9.6 Gbps
Wi-Fi 7	802.11be	2.4 / 5 / 6 GHz	MLO, 320 MHz, 4096-QAM	46 Gbps
Wi-Fi HaLow	802.11ah	Sub-1 GHz	Long range, low power, dense	150 kbps to 78 Mbps
Wi-Fi 8	802.11bn	2.4 / 5 / 6 GHz	Ultra High Reliability	In development

9. Conclusion

Across its generations, Wi-Fi has moved from a technology built for fast laptop links to one increasingly shaped by the needs of connected things. Wi-Fi 6 brought efficiency and real power savings through OFDMA and TWT, Wi-Fi 6E added clean 6 GHz spectrum, and Wi-Fi 7 added multi-link reliability for time-critical use. Wi-Fi HaLow covers the long-range low-power case that mainstream Wi-Fi cannot, and WPA3 has strengthened the security baseline. Challenges remain in energy, coexistence, and interoperability, and Wi-Fi 8 signals a shift toward reliability that fits IoT well. For anyone deploying IoT over Wi-Fi, the practical lesson is to match the generation and variant to the workload rather than chase peak throughput, and to plan for the management complexity that newer features bring.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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