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The Evolution of Wi-Fi Technology and Standards

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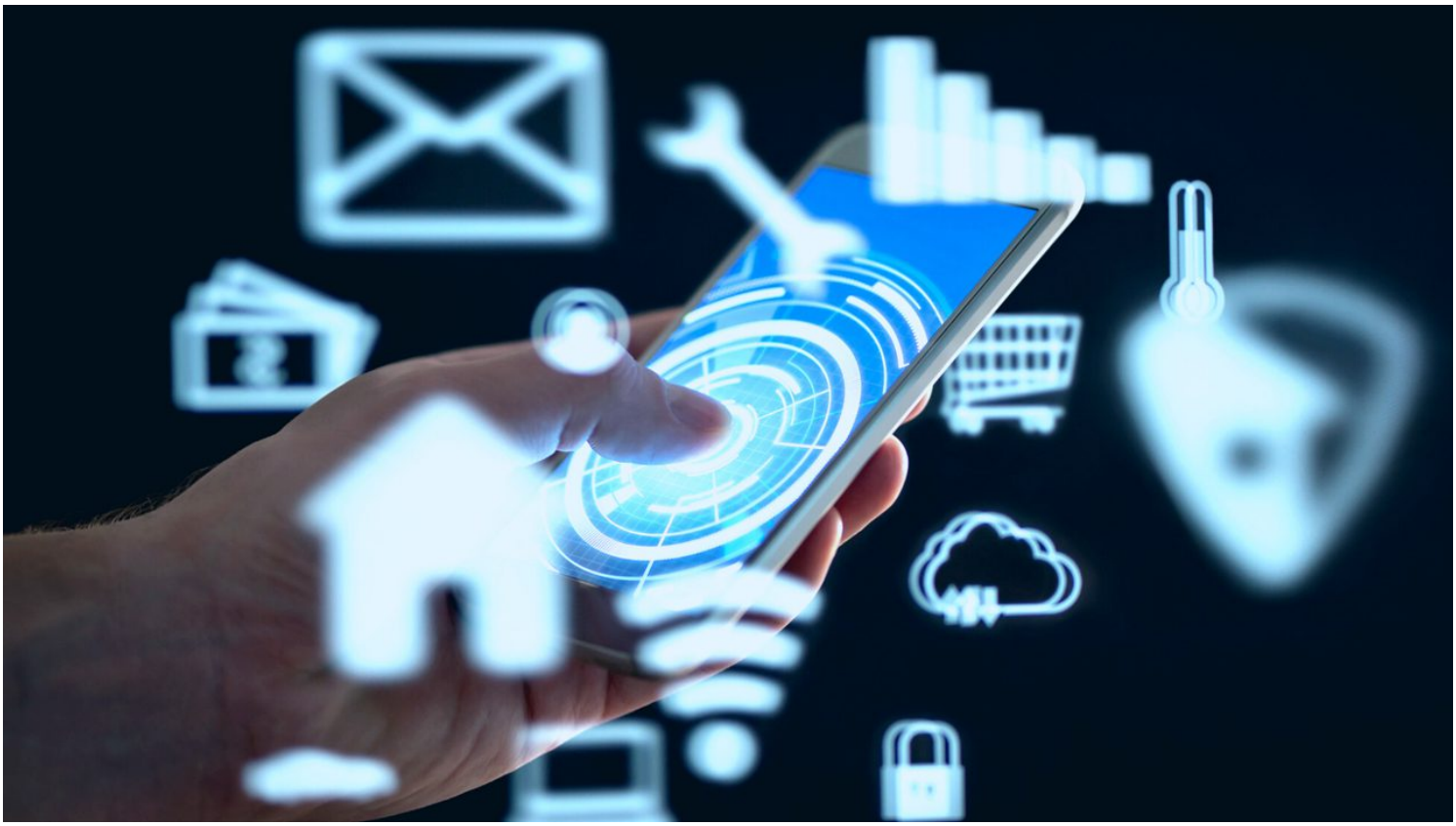

IEEE Standards Association (IEEE SA) | 16 May 2023 | 8 minute read

Highlights:

- Since its introduction in 1997, the ongoing evolution of IEEE 802.11 Wi-Fi standards has led to much faster data transmission rates, longer ranges, and more reliable and secure connections.
- IEEE 802.11ax™, or Wi-Fi 6, is the most recent standard in the IEEE 802.11 series published in 2021. It supports the increasing use of Wi-Fi in data-heavy and new applications such as video and cloud access.
- IEEE P802.11be™, or Wi-Fi 7, is under development with an estimated completion in 2024. This standard represents a major evolutionary milestone with 4x faster data rates and twice the bandwidth.
- The IEEE 802.11 Working Group has formed special-interest groups to support many

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next-generation Wi-Fi applications, such as AI, AR/VR, and battery-free IoT.

Wi-Fi technology is based on the IEEE 802.11™ series of wireless connectivity standards which have revolutionized how we communicate and access information. Billions of Wi-Fi devices are in use worldwide today, dramatically impacting how individuals, businesses, governments, and societies interact. It is no exaggeration to say that the IEEE 802.11 series of standards has helped bring about inexpensive, equitable internet access globally.

In recognition of the Internet's 40th anniversary, we take a look at how the IEEE 802.11 series has driven the evolution of Wi-Fi technology and how new additions to the series will enable greater Wi-Fi capabilities, making innovative new applications possible.

How Has Wi-Fi Evolved?

Wi-Fi, a wireless local area network (WLAN) technology that enables digital devices within a certain area to communicate via radio waves, is so often and universally used today that it's hard to remember a time when it didn't exist. But in reality, that wasn't so long ago.

Wi-Fi first came onto the market in 1997 when the pioneering IEEE 802.11 technical standard was published, enabling wireless data transmission at up to 2 Mbit/s using an unlicensed 2.4 GHz radio spectrum. Its major commercial breakthrough came in 1999 when Apple introduced the first mass-marketed consumer products with Wi-Fi connectivity, its AirPort

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wireless base station, and iBook. Thanks to the then-new IEEE 802.11b™ amendment to the original Wi-Fi standard, theoretical data rates up to 11 Mbit/s became possible.

Soon thereafter, Apple launched AirPort based on IEEE 802.11b, which **kick started the wireless revolution**. While that was true, what made that revolution possible in the first place was the IEEE 802.11 standards family.

Since then, the ongoing evolution of **IEEE 802.11** Wi-Fi standards has led to much faster data transmission rates, longer ranges, and more reliable and secure connections. All IEEE 802.11 standard amendments are constructed in a manner such that devices which operate according to their specifications will be backward compatible with earlier versions so that any modern IEEE 802.11-based device can communicate with older products.

IEEE Standards for Wi-Fi

Along the way, a naming convention was developed by the Wi-Fi Alliance ("Wi-Fi #") to help the general public better distinguish between various IEEE 802.11 implementations:

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- **IEEE 802.11™** is the pioneering 2.4 GHz Wi-Fi standard mentioned above from 1997, and it is still referred to by that nomenclature. This standard and its subsequent amendments are the basis for Wi-Fi wireless networks and represent the world's most widely used wireless computer networking protocols.
- **IEEE 802.11b™, or Wi-Fi 1**, was introduced to the market in 1999 with Apple's announcement. It also operated at 2.4 GHz, but to reduce interference from microwave ovens, cordless phones, baby monitors, and other sources, and to achieve higher data rates, it incorporated modulation schemes called direct-sequence spread spectrum/complementary code keying (DSSS/CCK). Wi-Fi 1 enabled wireless communications at distances of ~38m indoors and ~140m outdoors.
- **IEEE 802.11a™, or Wi-Fi 2**, also introduced in 1999, was the successor to IEEE 802.11b. It was the first Wi-Fi specification to feature a multi-carrier modulation scheme (OFDM) to support high data rates, unlike Wi-Fi 1's single-carrier design. It supported 5 GHz operation and its 20 MHz bandwidth supported multiple data rates.
- **IEEE 802.11g™, or Wi-Fi 3**, was introduced in 2003. It allowed for faster data rates of up to 54 Mbit/s in the same 2.4 GHz frequency band as IEEE 802.11b, thanks to an OFDM multi-carrier modulation scheme and other enhancements. This was appealing to mass market users, as 2.4 GHz devices were less expensive than 5 GHz devices.
- **IEEE 802.11n™, or Wi-Fi 4**, was introduced in 2009 to support the 2.4 GHz and 5GHz frequency bands, with up to 600 Mbit/s data rates, multiple channels within each frequency band, and other features. IEEE 802.11n data throughputs enabled the use of WLAN networks in place of wired networks, a significant feature enabling new use cases and reduced operational costs for end users and IT organizations.
- **IEEE 802.11ac™, or Wi-Fi 5**, was introduced in 2013 to support data rates at up to 3.5 Gbit/s, with still-greater bandwidth, additional channels, better modulation, and other features. It was the first Wi-Fi standard to enable the use of multiple input/multiple output (MIMO) technology so that multiple antennas could be used on both sending and receiving devices to reduce errors and boost speed.

Wi-Fi 6 Addresses Network Density Deeds and Provides Spectral Efficiency

IEEE 802.11ax™, or Wi-Fi 6, is the most recent standard in the series, published in 2021, and devices based on it are now being deployed in billions of devices per year.

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Although its theoretical data rate is 9.6 Gbit/s, this standard isn't primarily about boosting Wi-Fi speeds per se. Rather, it addresses the fact that Wi-Fi usage is now so pervasive that network performance can be degraded in areas of dense Wi-Fi traffic, such as sports stadiums, concert halls, and public transportation hubs, and more and more even in our homes where routers must communicate with a growing number of digital gadgets simultaneously.

IEEE 802.11ax offers many enhancements. It employs a multi-user mechanism that allows the 9.6 Gbit/s data rate to be split among various devices. It also supports routers sending data to multiple devices in one broadcast frame over the air, and it lets Wi-Fi devices schedule transmissions to the router. Mechanisms to support longer-range outdoor operations are also added.

Collectively, these features improve aggregate throughput and support the increasing use of Wi-Fi in data-heavy situations and in applications such as video and cloud access, where real-time performance and low power consumption for battery-powered devices are required. In particular, high-definition video is expected to be the dominant type of traffic in many forthcoming Wi-Fi deployments.

Wi-Fi 7: The Next Evolutionary Step for Wi-Fi

IEEE P802.11be™, or Wi-Fi 7, is now under development at the IEEE Standards Association (IEEE SA) by a group of technical and industry experts, with an estimated completion sometime in 2024.

This standard represents a major evolutionary milestone in Wi-Fi technology, with 4x faster data rates (~40 Gbit/s) and twice the bandwidth (320 MHz channels vs. 160 MHz channels for Wi-Fi 6). It also supports more efficient and reliable use of available and contiguous spectrum through multi-band/multi-channel aggregation and other means. The standard features numerous enhancements to MIMO protocols and many other advancements and refinements of existing Wi-Fi capabilities.

The result of all these technical improvements is that to the user, Wi-Fi 7 technology will be much faster, have much lower latency, will support many more devices, and will perform much better in congested Wi-Fi spaces and where Wi-Fi networks overlap.

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But that's not all.

Evolving IEEE 802.11 Standards for New and Emerging Wi-Fi Use Cases

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power refers to energy harvested from the environment – such as heat – that is converted to electricity. It could be used to power distributed IoT devices, leading to battery-free, more environmentally friendly IoT systems with less need for maintenance. Battery-free IoT networks could benefit multiple industries, including agriculture, smart grid, mining, manufacturing, logistics, smart home, transportation, and more. Studies are underway to examine the use cases, functional requirements, and technical feasibility of adding features to the IEEE 802.11 series to support ambient power-enabled IoT devices.

- **Augmented/Virtual Reality (AR/VR) and the Metaverse** – These are real-time applications that require extremely high data throughput and ultra-low latency. Users of these fast-growing consumer technologies are now in much greater need of faster, smoother, and more reliable Wi-Fi networks. The IEEE 802.11 Extremely High Throughput Study Group has been established to explore new IEEE 802.11 features for bands between 1 and 7.125 GHz that would increase peak throughput to support these demanding applications.
- **Artificial Intelligence/Machine Learning (AI/ML)** – The use of AI/ML techniques has exploded in recent years, and they touch virtually every area of human endeavor. AI/ML algorithms require a large amount of data to move between distributed data sources such as cameras, smartphones, and gaming devices, and a centralized server, where the data is analyzed. To address this need, new AI/ML algorithms have been developed that allow more analysis at the source, reducing the amount of data a network needs to carry. IEEE 802.11-based Wi-Fi networks carry an extensive and growing amount of data, making it possible to leverage new AI/ML algorithms, such as federated learning, to improve Wi-Fi performance and user experiences. A special interest group within the IEEE 802.11 WG is now investigating this idea.

Feedback

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Help Keep the World Connected

Technology has become much more complex in the decades since the initial IEEE 802.11 standard was published, and the enduring value of that series of standards is a tribute to the global innovators who have contributed to it over the years.

As Wi-Fi networks continue to progress on multiple fronts, so will IEEE Standards, to help to bring out the full potential of Wi-Fi technology and serve the future industry and human needs.

Learn more **and join our efforts to continue the evolution of this groundbreaking technology, which has given the gift of connectivity to the world.**

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