Wi-Fi HaLow for IoT

Overview, Features, Use Cases, Markets

Source: Wireless Broadband Alliance

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About the Wireless Broadband Alliance

Wireless Broadband Alliance (WBA) is the global organization that connects people with the latest Wi-Fi initiatives. Founded in 2003, the vision of the Wireless Broadband Alliance (WBA) is to drive seamless, interoperable service experiences via Wi-Fi within the global wireless ecosystem. WBA's mission is to enable collaboration between service providers, technology companies, cities, regulators and organizations to achieve that vision. WBA's membership is comprised of major operators, identity providers and leading technology companies across the Wi-Fi ecosystem with the shared vision.

WBA undertakes programs and activities to address business and technical issues, as well as opportunities, for member companies. WBA work areas include standards development, industry guidelines, trials, certification and advocacy. Its key programs include NextGen Wi-Fi, OpenRoaming, 5G, IoT, Testing & Interoperability and Policy & Regulatory Affairs, with member-led Work Groups dedicated to resolving standards and technical issues to promote end-to-end services and accelerate business opportunities.

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Table of Contents

Figures

Executive Summary

Implementations compliant with the IEEE 802.11ah (11ah) standard are referred to by the Wi-Fi Alliance (Wi-Fi.org) as Wi-Fi HaLow. The purpose of the standard is to extend the benefits of Wi-Fi into more Internet of Things (IoT) applications by solving certain problems such as limited reach between connections, poor connections through walls, short battery life, and limited number of connections in traditional Wi-Fi. New features include operation in the sub-1 GHz radio band, the use of narrow channel bandwidths, an increased number of supported devices, and new operating modes to accommodate battery-operated devices. Wi-Fi HaLow builds upon the foundations of Wi-Fi, retaining such features as the most up-to-date high levels of security and native-IP support inherent in all internet connectivity. Thus, Wi-Fi HaLow extends the ease-of-installation and management benefits of Wi-Fi-based networks.

WBA's contributing members of the "Wi-Fi HaLow for IoT" project team will deploy 11ah Wi-Fi HaLow solutions in real-world use cases to demonstrate the advantages. Features to be highlighted include Wi-Fi HaLow's longer reach of connections, better penetration through materials, higher density of devices, and lower use of energy by this secure, native-IP technology. The use cases will span a wide variety of venues and types of IoT applications to emphasize the multitude of benefits for service providers, device-makers, and end users. Each scenario will highlight how Wi-Fi HaLow solves connectivity problems, which previously may have required non-standard RF radio technology, or incurred higher costs of ownership.

The resulting report from the WBA will offer a roadmap for deploying Wi-Fi HaLow in ways that continue to leverage the strengths of Wi-Fi technology, without having to resort to proprietary or non-IP technologies to accomplish system goals.

How the Growth of IoT Challenges Traditional Wi-Fi

Increased demand for more and different devices

The estimated number of IoT connected devices worldwide was nearly 10 billion in 2020, with over 7 billion of those devices using short-range wireless technologies like Wi-Fi, Bluetooth and Zigbee. The consumer segment accounted for nearly 60 percent of the applications, where people learned to rely on products that simplified their lives.

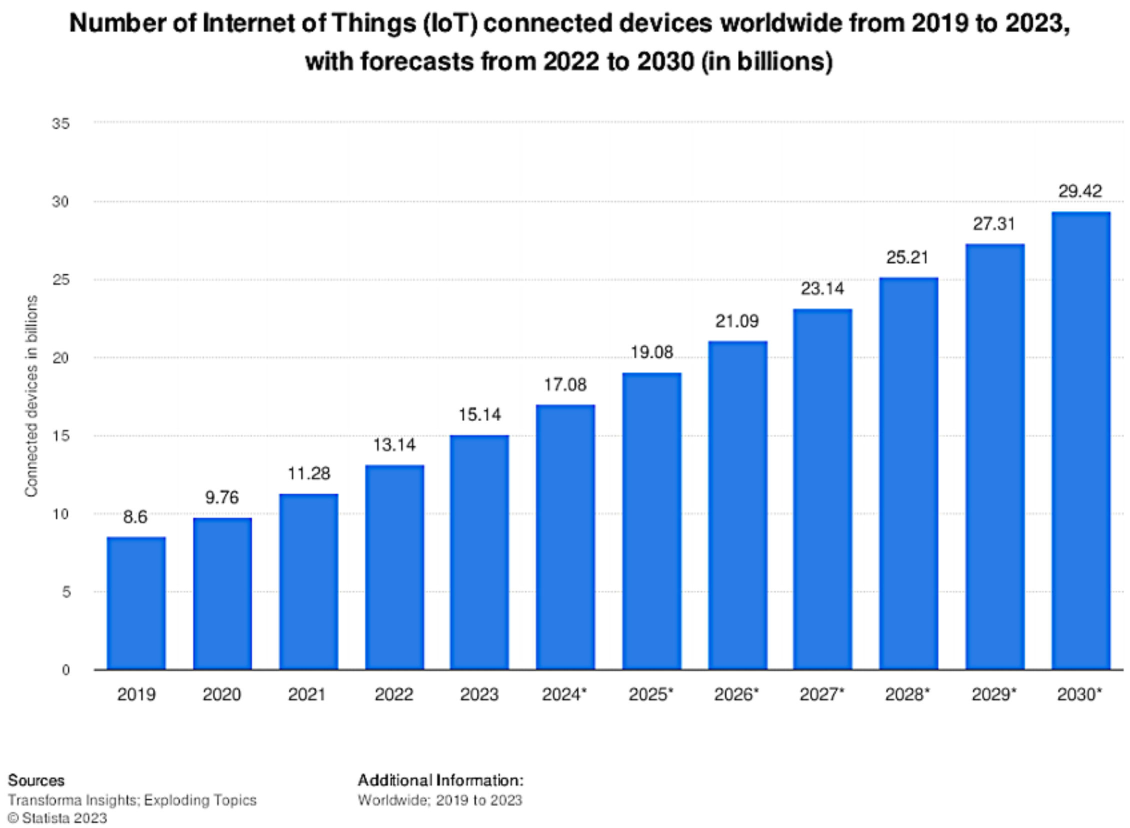


Figure 1 Number of IoT connected devices worldwide 2019-2023, with forecasts to 2030

[Sources: Transforma Insights; Exploding Topics]

Wi-Fi technology, based on the body of IEEE 802.11 Wireless Local Area Network (WLAN) standards established over 25 years ago, has consistently delivered the highest data rates and the most secure connectivity for IP-based IoT devices. The simplicity of setting up and operating a Wi-Fi network makes it a preferred choice versus using proprietary wireless solutions.

Wi-Fi's success has raised expectations along several metrics. IoT designers have pushed traditional 2.4, 5 and 6 GHz Wi-Fi to their operational limits. Customers desire longer reaching connections in houses and buildings without having to purchase repeaters or meshes. Reliable connections through multiple walls and floors are necessary to reach new types of networked equipment. Demand is high for long-battery-life Wi-Fi products which may be outdoors or in hard-to-reach spaces. With the availability of Wi-Fi HaLow technology, new products can be designed to operate beyond the old boundaries of reach and energy consumption, without having to resort to non-Wi-Fi architectures.

Confidence in the consumer market has influenced other industries to adopt reliable, secure Wi-Fi to solve problems in the office, factory and field. The number of unique applications is growing fast, stretching the limits of device count and distances of coverage by traditional Wi-Fi.

Reaching farther and using less energy

By operating in the Sub-1 GHz spectrum, and using narrower bandwidth channels, Wi-Fi HaLow extends the boundaries around the area of service; up to 100 times the area, and up to 1,000 times the volume of a 2.4 GHz Wi-Fi network. Concurrently, the number of stations (STAs) addressable by a single access point (AP) in this larger volume was increased to 8,191.

While increasing range and device counts, 11ah also adds better support for battery-operated STAs. The Target Wake Time (TWT) feature was introduced by 11ah as an optional mode of operation for sleepy sensor devices. TWT STAs that are not required to be immediately responsive to downstream network communications can negotiate long sleep cycles to save power, without getting disassociated. Traditional mode STAs must constantly monitor the AP's frequent beacons—multiple times per second—which contain the traffic indicator map (TIM) telling them whether they must prepare to receive downstream data. This is referred to as TIM-mode of operation. An unresponsive STA in TIM-mode runs the risk of being dissociated by the AP. There is a resulting penalty of restarting the association process anew, which consumes more energy. In contrast, the TWT STA conserves energy and wakes at its target time and only then has to monitor the TIM. Wi-Fi HaLow networks can operate in a mix of TWT STAs and traditional TIM-mode STAs.

The total number of connected IoT devices worldwide is forecasted to grow to nearly 30 billion by 2030. The sheer scale-up of networks will adopt technology that can reach farther, encompass more devices and maintain the security of cloud-connected communications.

Use of Unlicensed Spectrum

Wi-Fi HaLow operates in the industrial, scientific and medical (ISM) frequency band below 1 GHz, as defined by the International Telecommunications Union (ITU). There is some variability in regulations between different countries. In most of ITU Region 2 (North, Central, and South America), the band is within 902 MHz to 928 MHz. Frequencies in Europe, regulated by ETSI, are in bands at 863 MHz and 915 MHz. Multiple different radio technologies may share these bands. Operating wireless devices in the ISM bands, when compliant with the regulator's rule of a given country, generally does not require a license or fee. The economic benefit of operating in unlicensed spectrum is that end consumers can deploy solutions without concerning themselves with ongoing costs of ownership. This has led to the rapid adoption of customer-owned Wi-Fi networks. There is no recurring cost of operating a Wi-Fi or Wi-Fi HaLow network for the end customer, aside from the time it takes to monitor the network's performance.

In contrast, licensed spectrum used by mobile and satellite service operators is reserved for only their products and services. If an IoT device is designed to use cellular modem technology, there is typically a recurring cost of subscription fees for each device which must be added to the total cost of ownership for the implementation. By extending the reach of Wi-Fi HaLow networks to up to 1 kilometer, a Wi-Fi HaLow network can serve many new applications for long reach, outdoor IoT devices with license-free technology, and reduce reliance on cellular network service.

"In addition to its well-known societal benefits, Wi-Fi provides significant benefits to economies worldwide. The global economic value of Wi-Fi is estimated at more than $3.5 trillion USD, according to a study commissioned by Wi-Fi Alliance®. By 2025 that value is expected to grow to nearly $5 trillion." – Wi-Fi Alliance

Wi-Fi HaLow further expands the footprint for new services in an unlicensed spectrum.

Pressure on 2.4 GHz Spectrum

The 2.4 GHz ISM band, used since the earliest days of traditional Wi-Fi, can experience heavy congestion within homes and businesses. A network analyzer in a crowded neighborhood or office will show multiple APs using the same 20 MHz channels in the 2.4 GHz band for transferring data and video, usually centered around channels 1, 6 and 11.

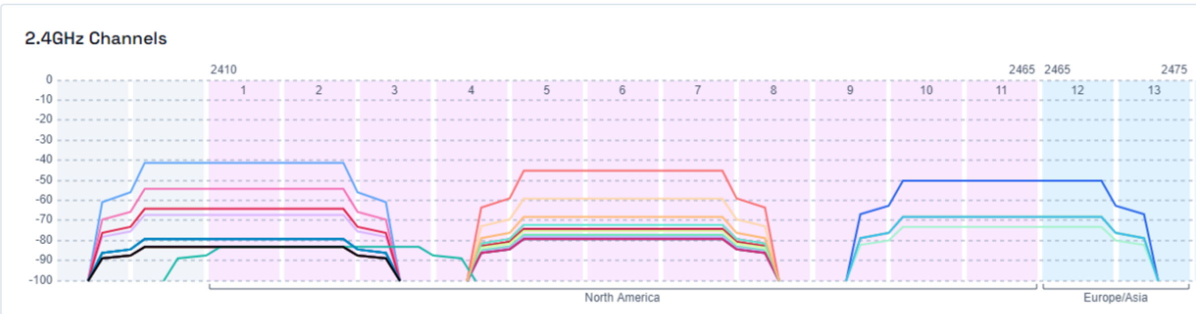


Figure 2 Multiple 2.4 GHz Wi-Fi APs sharing the same channels in a hotel

The most up-to-date Wi-Fi APs continue to support backwards compatibility for older 2.4 GHz devices. Many IoT device-makers continue to produce products using the older, slower 802.11b/g technology to save costs and minimally claim "Wi-Fi connectivity". This further exacerbates the throughput challenges for the shared wireless medium. Additionally, the 2.4 GHz band is used by Bluetooth, Zigbee, Thread as well as other proprietary radio solutions. Products such as baby monitors, audio headsets and speakers, automated light fixtures, HVAC sensors and controls, door locks, and appliances contend for this shared spectrum.

It is difficult to add more 2.4 GHz Wi-Fi devices into these scenarios without carefully determining whether there is adequate capacity to meet desired throughput and reliability. Meanwhile, Wi-Fi HaLow offers IoT connectivity in the less-crowded sub-1 GHz band, and can offload 2.4 GHz for other applications. Both networks can operate without interference from each other. A crowded retail store can add thousands of electronic shelf labels and point-of-sale equipment without impacting their installed base of 2.4 GHz technologies.

Solving the Range, Penetration, Power and Density Problems

Range

Let us look deeper at how 11ah extends the range of Wi-Fi HaLow. In general, the combination of a lower frequency and narrower channel bandwidth of a given modulation scheme, will reach farther distances in free space.

Most traditional Wi-Fi APs deployed today support operation in the 2.4 GHz ISM band. Using orthogonal frequency division multiplexing (OFDM), the Wi-Fi signal is encoded and the energy is spread over a 20 MHz wide channel, as simplified in the above figure. An AP sends beacons on this 20 MHz channel to all the STAs within its reach. If a STA can receive that signal and respond to the AP with enough signal strength, relative to the background noise, it can attempt to associate into that AP's Basic Service Set (BSS).

Wi-Fi HaLow operates in the sub-1 GHz ISM band. In the USA, this is from 902 MHz to 928 MHz. The standard also defines the use of narrower-band channel widths of 1, 2, 4, 8 or 16 MHz.

Applying well-proven physics and principles of RF communications, the effect of reducing the operating frequency and channel bandwidth of a transmitted signal is that it yields direct improvements of that signal's reach. Consider the term "link budget" which takes into account the gains and losses of energy (measured in positive and negative dB, respectively) that a transmitted signal will experience along its path; a net positive signal is required to be received effectively at the maximum range. The lower frequencies suffer less free space loss traveling through the air.

The differences between free-space losses of 2.4 GHz and 900 MHz signals at different distances is shown in the example table below:

Distance	900MHz free-space loss	2.4GHz free-space loss
10 meters	72.5dB	81dB
100 meters	92.5dB	101dB
1000 meters	112.5dB	121dB

Table 1 Indoor Path Loss

[Source: Digi International. "Application Note, XST-AN005a-Indoor. June 2012. Digi.com]

When compared to a 2.4 GHz Wi-Fi signal using 20 MHz channel bandwidth, a 915 MHz Wi-Fi HaLow signal operating in a 1 MHz channel at MCS 10 mode, at the same output power will have a range advantage due to improved link budget:

- Dropping from 2.4 GHz to 915 MHz → 8.4 dB advantage.
- Reducing channel bandwidth from 20 MHz to 1 MHz → 13 dB advantage.
- Applying repeated symbol technique in Wi-Fi HaLow's MCS10 mode → theoretically 3 dB

A total of 24 dB improvement in link budget yields approximately a 10x range improvement for Wi-Fi HaLow in free space (line of sight) for a given output power. If the maximum range from an AP is considered as the maximum radius, consider:

Area covered by Wi-Fi HaLow is approximately 100x (Area=πR^2)

Volume covered by Wi-Fi HaLow is approximately 1000x (Volume = $4/3\ \pi R^3$)

These large difference in coverage between traditional Wi-Fi and Wi-Fi HaLow are demonstrable in warehouses, factories, and outdoor venues like a construction site, smart city or farm.

Penetration

RF signals in frequencies below 1 GHz spectrum such as Wi-Fi HaLow have an additional advantage that they penetrate through objects better than 2.4 GHz or 5 GHz RF signals used by traditional Wi-Fi and other IoT radios. In a study sponsored by UK regulator, Ofcom, the expected attenuation (dB/m) of RF signals that pass through various building materials was calculated and plotted. Refer to the plot below showing 900 MHz has a three-fold advantage when traveling through wood, attenuated at a rate of only 5 dB/m, versus the attenuation of a 2.4 GHz signal at 15 dB/m. For plasterboard, the relative advantage for 900 MHz is 10 dB/m vs. 22 dB/m for 2.4 GHz. For glass, 2.5 dB/m for 900 MHz versus 10 dB/m for 2.4 GHz. The advantages for 900 MHz are even greater compared to frequencies of 5 GHz and higher. (The higher dB/m number represents higher signal loss.)

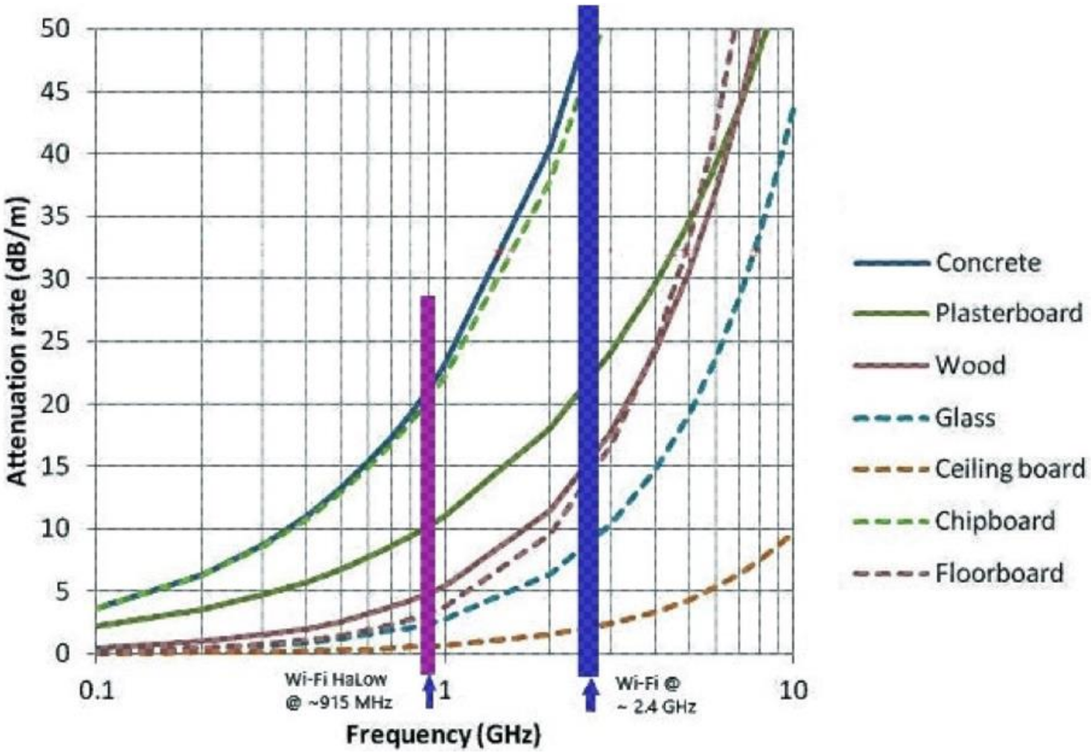


Figure 3 Calculated attenuation rates of building materials.

[Source: Ofcom, "Building Materials and Propagation Final Report". Dr Richard Rudd, Dr Ken Craig, Dr Martin Ganley, Richard Hartless. September 14, 2014.]

Power Consumption

As mentioned above, power advantages of using Wi-Fi HaLow are achieved via new radio, physical layer (PHY), and media access control (MAC) layer changes.

The sub-1 GHz, narrow-band radio waves travel much farther than 2.4 GHz, at the same or less transmit power. Conversely, Wi-Fi HaLow battery-powered sensors do not require as much transmit power as 2.4 GHz needs to cover large areas and penetrate walls and obstructions more reliably.

As mentioned above, Wi-Fi HaLow can use power saving features found between TIM and Non-TIM modes of operation, supporting a blend of streaming and sleeping devices. In traditional TIM mode, the AP sets the frequency of beacons and the frequency of delivery traffic indication map (DTIM) which includes indicators of broadcast and multicast downstream traffic. A typical DTIM set to favor fast responsiveness of STAs to network commands is DTIM=1 (STAs have 100ms listening intervals). DTIM can be set at longer intervals to allow devices to sleep and save power between beacons. For example, extending the period using DTIM=10 (STAs have 1 second listening intervals) can yield large power savings. Non-TIM modes of operation can take advantage of features like TWT and RAW.

TWT provides STAs with the ability to negotiate with an AP to sleep longer than traditional Wi-Fi. Sleep periods can range from seconds, hours, days, weeks or months.

Restricted Access Window (RAW) is both a capacity planning feature and a power saver. RAW slots can be assigned as reserved for certain groups to minimize their contention on the medium when they need to send their data, thereby reducing collisions and the power consumption associated with transmission retries.

Extended BSS Max Idle is a feature whereby the AP tolerates longer idle times from a STA before disassociating it from the BSS. The STA does not have to stay awake to send keep-alive frames. While this feature is offered in other Wi-Fi technologies, 11ah included a new scaling factor that can honor idle STAs for as long as 5 years.

Short MAC headers feature can be used to reduce power consumption and increase network capacity by reducing the amount of information required to be transmitted in a packet's header. For small packets of approximately 100 bytes, a reduction of 8% on-air time can be saved.

Short Beaconing can be applied by an AP in which it sends shorter, more frequent beacons to keep STAs synchronized. The STAs can spend less time listening, and more time sleeping to save power.

Density

As mentioned above, the 11ah standard expanded the Wi-Fi address field of unique STA identifiers. Wi-Fi HaLow APs can address up to 8,191 STAs. This four-fold increase is helpful to include the greater number of potential IoT devices in the volume covered by the Wi-Fi HaLow AP. Wi-Fi HaLow is also a listen-before-talk (LBT) protocol, which helps prevent network contention from overwhelming the network's capacity. Other IoT protocols that do not enforce the MAC-layer functions incur frequent collisions, which can be exacerbated by congestion through mesh nodes. IEEE 802.11ah Wi-Fi HaLow can consistently outperform meshes of IEEE 802.15.4 devices in terms of effective density of devices, peak throughput, and reduced end-to-end delay.

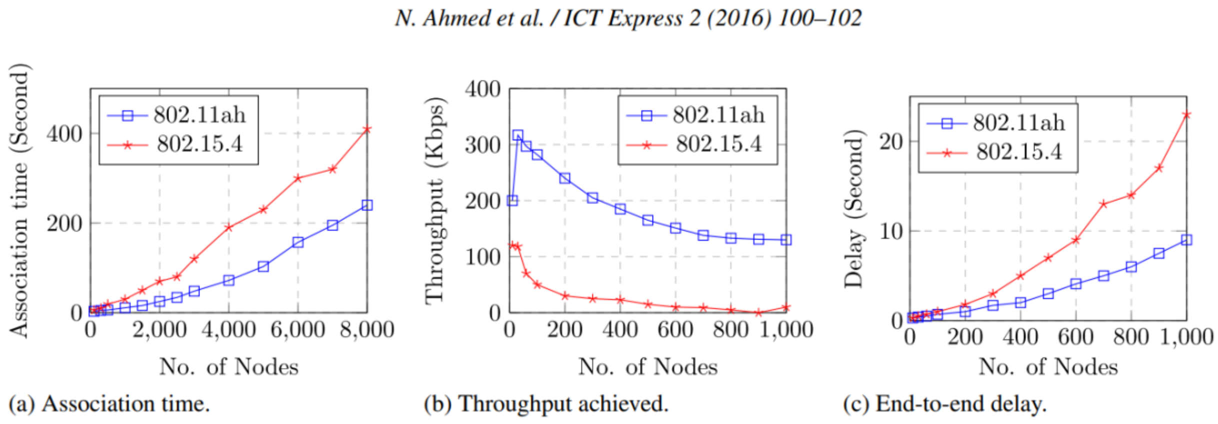


Figure 4 Performance of 802.11ah and 802.15.4 with different network sizes

[Source: "A comparison of 802.11ah and 802.15.4 for IoT", N. Ahmed, H. Rahman, Md.I. Hussain. August 6, 2016. https://www.sciencedirect.com/science/article/pii/S2405959516300650]

Groups of devices can be organized by TWT and RAW features to improve the efficient use of the available network capacity. Streaming devices can be served by the same AP as sleeping devices. Wi-Fi HaLow includes support for up to 4 quality of service (QOS) queues, with the ability to give preference to voice and video traffic.

The BSS Coloring feature assigns a small color tag to each AP and the associated STAs in its BSS. In environments with multiple APs on the same channel, STAs and APs can ignore traffic that they sense is from another color, reducing contention and saving energy.

Null Data PHY protocol data units (NDP frames) were specified that can incorporate MAC-layer information in the PHY layer signal field. This reduces the packet size and transmission time relative to legacy management and control frames, saving as much as 60% on-air time for sending acknowledgements.

Security and Ease of Use

Wi-Fi CERTIFIED HaLow networks support the latest, most advanced Wi-Fi security standards specified by Wi-Fi Alliance. The current standard dictates support for Wi-Fi CERTIFIED WPA3™. This is the highest level of encryption which satisfies enterprise and industrial Wi-Fi market segments.

Wi-Fi HaLow's relatively high data rates for IoT devices offer enough headroom to support end-to-end security protocols to protect private data, such as TLS tunnelling to trusted platforms in the cloud. A factory's digital twin in the cloud requires more sensors securely pushing data without exposing proprietary secrets.

Reducing the total down time for executing a firmware over-the-air (OTA) update on IoT devices is an advantage Wi-Fi HaLow offers over competing RF IoT technologies.

Wi-Fi HaLow supports the use of Wi-Fi CERTIFIED Enhanced Open™, based on Opportunistic Wireless Encryption (OWE). Stations which access the internet in public environments can gain access to the cloud without including as much private data in the clear.

For ease of deployment of large numbers of IoT devices, Wi-Fi HaLow supports EasyConnect using the Device Provisioning Protocol (DPP). Not all IoT products have buttons or screens to assist with their initial setup; sometimes referred to as headless devices. DPP uses a secured handshake for STAs that can authenticate their built-in credentials to gain access to the AP. Solution providers can use EasyConnect to on-board such devices in home gateway environments. Large retailers can onboard thousands of electronic shelf labels using the same technique.

Data Throughput

Wi-Fi HaLow offers high rates of symmetric data transfers. Wi-Fi HaLow data rates range from 150 Kbps at very long distances to over 80 Mbps at very short distances. These depend on the MCS rate and channel bandwidth selected to best use the available RF channel. Like traditional Wi-Fi, the farther away from the AP that a STA is located, the lower the negotiated MCS rate. Whole-home coverage for a single Wi-Fi HaLow AP (under FCC regulations) would service most devices at rates in the 10s of Mbps. This is adequate for streaming video while simultaneously serving low bit rate devices.

MCS index	Spatial Streams	Modulation type	Coding rate	Data rate (Mbit/s)									
				1 MHz channels		2 MHz channels		4 MHz channels		8 MHz channels		16 MHz channels	
				8 µs GI	4 µs GI	8 µs GI	4 µs GI	8 µs GI	4 µs GI	8 µs GI	4 µs GI	8 µs GI	4 µs GI
0	1	BPSK	1/2	0.3	0.33	0.65	0.72	1.35	1.5	2.93	3.25	5.85	6.5
1	1	QPSK	1/2	0.6	0.67	1.3	1.44	2.7	3.0	5.85	6.5	11.7	13.0
2	1	QPSK	3/4	0.9	1.0	1.95	2.17	4.05	4.5	8.78	9.75	17.6	19.5
3	1	16-QAM	1/2	1.2	1.33	2.6	2.89	5.4	6.0	11.7	13.0	23.4	26.0
4	1	16-QAM	3/4	1.8	2.0	3.9	4.33	8.1	9.0	17.6	19.5	35.1	39.0
5	1	64-QAM	2/3	2.4	2.67	5.2	5.78	10.8	12.0	23.4	26.0	46.8	52.0
6	1	64-QAM	3/4	2.7	3.0	5.85	6.5	12.2	13.5	26.3	29.3	52.7	58.5
7	1	64-QAM	5/6	3.0	3.34	6.5	7.22	13.5	15.0	29.3	32.5	58.5	65.0
8	1	256-QAM	3/4	3.6	4.0	7.8	8.67	16.2	18.0	35.1	39.0	70.2	78.0
9	1	256-QAM	5/6	4.0	4.44	—	—	18.0	20.0	39.0	43.3	78.0	86.7
10	1	BPSK	1/2 x 2	0.15	0.17	—	—	—	—	—	—	—	—

Table 2 Modulation and Coding Schemes

Key 802.11ah Use Cases and Advantages

Smart Home

Use Cases
Security Cameras and Sensors
HVAC and Air Quality Monitors
Appliances/Lighting
Detached Garage Connections
Solar Power Systems
Power Backup Generators
EV Chargers

Advantages
Long Reach from the AP to outdoors
Penetration through walls to basements, attics and yards
Reliable connections
Battery-operated Devices
Security

Consumer opinions of what constitutes a smart home have evolved over the years. Wi-Fi initially brought connectivity to PCs, laptops, tablets, phones and printers within the home. New products began to take advantage of wireless connectivity solutions for monitoring and controlling equipment such as security cameras, door locks, thermostats, and appliances. With each new product idea, the consumer has been faced with some challenges in terms of distances and reliability of the growing number of connections in the home. They have continuously pushed the limits of reach through interior and exterior walls, floors and ceilings. They also have looked for solutions which might be more conveniently operated using batteries, as opposed to requiring a connection to hard-wired AC power. With some exceptions, such as ultra-high-definition TVs, many of these new devices do not require gigabit per second data. New wireless products which can operate securely and reliably both inside and outside the home in the yard will drive product engineers to use Wi-Fi HaLow, while still taking advantage of the benefits of the Wi-Fi standards. Wi-Fi HaLow is based on the IEEE 802.11ah standard approved to reach farther, improve penetration, increase the density of devices per AP, and reduce power consumption.

Wi-Fi HaLow solves several problems for Smart Home products. Using the sub-1 GHz RF spectrum—902 MHz to 928 MHz in USA—the signals reach much farther and penetrate better through walls, ceilings and floors than the 2.4 GHz, 5 GHz and 6 GHz frequencies used by traditional Wi-Fi. Less energy is required to send these signals across the longer distances. With a single Wi-Fi HaLow AP, very large homes with multiple varieties of building construction materials will be served.

Devices located in garages, basements, attics, and outside of the house can struggle to communicate with the Access Point. 2.4 Ghz smart devices that have weak connections can slow down the operation of the entire home network. Utilizing the sub-1 Ghz spectrum for these devices benefits the overall network performance for the consumer.

Sub-1 GHz Wi-Fi HaLow also benefits the service providers who cannot predict the size and construction of the homes into which they sell their products. It ensures a smooth out-of-the-box installation experience and reduces product returns and technical support burden. This will benefit the consumer for self-installed security cameras as well benefit the professional installing equipment in difficult to wire outdoor locations.

IP-based protocols are natively supported by Wi-Fi HaLow. This simplifies the installation and management of smart home products. For devices that need to connect to the cloud, the setup can be made as easily as for other Wi-Fi devices from the past. (There is no need for a proprietary hub to convert to the IP network, such as what is needed for Zigbee, BLE or Z-wave network technology.) Wi-Fi

HaLow can support up to 8,191 devices per a single AP. It can support the various smart home ecosystems and products compliant with the CSA Matter specification. Wi-Fi HaLow also leverages the highest level of security defined by the Wi-Fi Alliance (Wi-Fi.org) which is currently WPA3. With data rates in the range of 150 kbps to over 80 Mbps* for single stream devices, Wi-Fi HaLow has additional capacity for extra layers of encryption used for cloud access to trusted platforms.

This study will include testing Wi-Fi HaLow solutions of various types and functionality, in a large home with multiple floors and exterior outdoor locations. Typical Smart Home applications and cloud-based solutions will be demonstrated. Data throughput results will be shared.

[*For channel bandwidth of 16 MHz and MCS9 operation, subject to regulations for country of operation]

Smart City

Use Cases
Infrastructure Monitoring
Smart Utilities
Traffic Management
Safety

Advantages
Wide Coverage Area
High Data Throughput
Device Density
Low Costs Maintenance

With Wi-Fi HaLow, there are new possibilities for supporting existing intelligent systems and creating new ones to better serve a city's residents and keep them safe. Wi-Fi HaLow can connect all types of smart city IoT devices. Examples include bus stops, traffic lights, cameras, utility monitoring, leak detection, temperature measurement, and vibration sensors. Due to Wi-Fi HaLow's high device capacity of over 8,000 devices, multiple smart city systems could be attached to a single AP without having to consider the limits of the access point.

Wi-Fi HaLow has the ability to cover large areas from a single AP. Where more coverage is needed, the area can be expanded with a mesh configuration, making it an ideal connection technology with broad and wide coverage.

With non-licensed spectrum, IP-based connectivity, and low operating costs, Wi-Fi HaLow can enable municipal IoT networks at a lower price than utilizing cellular connections. Where a wired backhaul is not available, Wi-Fi HaLow is a simple and low-cost way to aggregate low power devices while communicating over a cellular backhaul.

Wi-Fi HaLow has far greater data throughput when compared to other LPWAN technologies, allowing for a greater number of devices and a greater number of use cases on a city-wide network solution. The low energy features of Wi-Fi HaLow can help ensure battery operated devices can remain in service without maintenance for months or years at a time, thus lowering overall maintenance costs. This would help use cases in the city in utilizing monitoring devices in areas that may not have access to power such as water meters or safety sensors. Instead of having to use mains power, Wi-Fi HaLow's lower power consumption may be below the threshold such that solar power can be used for IoT devices with long transmit times, such as cameras or digital displays. Lastly, Wi-Fi HaLow has low latency to support emergency services.

All these features in a connectivity standard implemented throughout a city could enable new types of smart city solutions. With low maintenance costs, high data throughput, and ability to support over 8,000 devices per AP, Wi-Fi HaLow has the potential to enable new types of smart city solutions. The fact the Wi-Fi HaLow network is IP-based makes for easy prototyping and deployment and increases the speed of development. We are still at just the infancy of smart city solutions, with more innovations in edge computing, power-saving features, and greater adoption of IoT devices. Wi-Fi HaLow could be at the forefront of innovation for smart cities.

Building Automation

Use Cases
Physical Security and Surveillance
Access Control
Safety Alarms
Water Sensors

Advantages
Signal Penetration
Range
Low Power
Device Density

When it comes to providing full building coverage, Wi-Fi HaLow offers several advantages over traditional building technologies. Its signal penetration can reach through four or more floors, enabling a single access point (AP) to cover most buildings. This simplifies the architecture, avoids issues with existing wireless technologies, and its IP-native technology makes installing Wi-Fi HaLow into an existing building quick and simple.

Wi-Fi HaLow's signal penetration and range also make it suitable for a wide variety of IoT applications, both inside and outside buildings. Whether you need to view a camera to monitor a back gate or control the direction of chilled air in the ventilation ducts, Wi-Fi HaLow can do it. Its range and signal penetration qualities help create ubiquitous coverage over a building more simply than can be achieved using Wi-Fi or Bluetooth Low Energy or Zigbee. By avoiding the need to add additional access points to support IoT devices in a remote part of the building, Wi-Fi HaLow simplifies the network of Smart Building deployments.

Wi-Fi HaLow's trifecta of signal penetration, range, and support for a large number of devices makes it capable of simplifying the deployment of smart devices in new buildings and retrofitting older ones to support a multitude of smart solutions available today. Furthermore, Wi-Fi HaLow boasts great security, using the same WPA3 standard that Wi-Fi uses today.

Finally, Wi-Fi HaLow's ability to avoid interference from the multitude of 2.4 and 5 GHz devices is a significant benefit. This means that cell phones, smartwatches, and Bluetooth wearables won't cause connection issues or disrupt service. The failure of IoT devices to reconnect or interrupt the network association can cause many headaches for users and support staff. By eliminating these headaches, Wi-Fi HaLow could help increase the adoption of smart devices. With all these benefits, Wi-Fi HaLow is future-proof for the mass adoption of smart cameras, devices, and sensors in any given smart building. Wi-Fi HaLow is the perfect upgrade to smart building connectivity.

Smart Retail

Use Cases
Scanners and Readers
Point-of-Sale Equipment
Asset Tracking Security Monitoring
Warehouse Robots and Handlers

Advantages
Wide Coverage Area
Signal Penetration
Native-IP Protocols
Secure Connection

Smart Retail encompasses the IT solutions that help provide a satisfying experience for the consumer, while also improving the productivity of the retailer and its partners. From suppliers of the finished goods traveling through the logistics networks, to store clerks stocking and selling merchandise, to the consumer in the store or restaurant, each stage can benefit from Wi-Fi-HaLow based products.

One of the first benefits to the retailer is an overall reduction of infrastructure costs to invest in adding new capabilities to a building. Longer-reaching Wi-Fi HaLow requires only one or two access points to provide coverage in warehouses and distribution centers of 250,000 square feet (roughly the size of a city block) in area. Adding a Wi-Fi HaLow AP to a building can be as easy as connecting to a PoE Passthrough or USB connector on an existing Wi-Fi AP in the building. Managing the connectivity is accomplished via traditional wireless switches and servers. In a restaurant environment, where staff might have to serve customers outside in a patio area, electronic point-of-sale equipment such as tablets and printers have a more reliable connection to a single indoor HaLow AP. A large retailer installing electronic shelf labels (ESLs), active shelf edge video displays and security cameras can be serviced on the 915 MHz band channel, which is not affected by the overburdened 2.4 GHz spectrum being used for other high-speed devices.

Industrial IoT

Use Cases
Asset Tracking
Infrastructure Monitoring
Remote Equipment Control
Safety Automation
Security Monitoring

Advantages
Wide Coverage Area
Signal Penetration
High Data Throughput
Device Density
Low Power

Nothing blocks Wi-Fi and Bluetooth signals quite like metal machinery and structures in odd places, and sometimes you need a sensor in a remote location that simply cannot receive a signal. Instead of running wire to install an additional access point, Wi-Fi HaLow operates at a lower frequency than most wireless technologies, allowing for better signal propagation throughout a factory, mining operation, or concrete building. The Wi-Fi HaLow signal covers a wide area, and one AP has the potential to cover an entire large building or outdoor industrial site.

Wi-Fi HaLow connectivity is simple to implement since it is a sub-1 GHz iteration of Wi-Fi, and it can add a bandwidth layer dedicated to IoT devices that won't disrupt common 2.4 and 5 GHz signals. Wi-Fi HaLow could be used to cover mining or lumber operations, connecting through and around natural objects at longer ranges than traditional Wi-Fi. The ability of an AP to handle over 8,000 client devices means never having to worry about having too many connected objects out in the field, in the warehouse, or in the factory and being able to support multiple "smart" IoT-enabled solutions.

The low power capabilities of Wi-Fi HaLow allow for battery-operated devices in the field to have a lifespan of years. One can deploy temperature sensors, asset trackers, and other battery-operated devices in hard-to-reach places without having to replace them frequently. The high data rate of Wi-Fi HaLow does allow for more data-intensive applications such as security cameras on a Wi-Fi HaLow network.

The use cases for Wi-Fi HaLow to run Industrial IoT smart solutions are practically endless. The features of Wi-Fi HaLow are the right mix of data rate, distance, and low power for many IoT use cases in industrial areas. Wi-Fi HaLow's robust feature set can standardize connectivity for a wide variety of types of IoT devices. This single standard can displace many different connectivity technologies, potentially reducing overall IoT infrastructure costs and simplifying the network structure. On top of that, the features of Wi-Fi HaLow could solve the connectivity portion of new and better IoT solutions for Industrial IoT.

Agriculture Technology

Use Cases
Environmental monitoring
Soil monitoring
Plant health monitoring
Actuator control
Data collection for predictive breeding

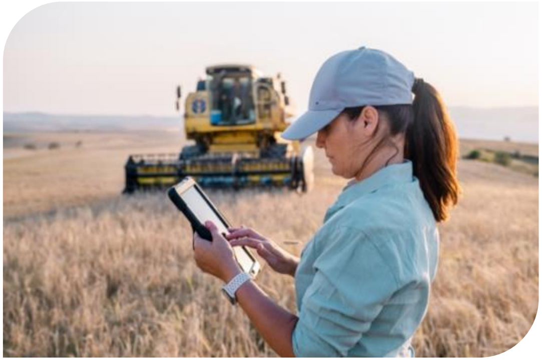
Advantages
Real-time monitoring
Improved breeding outcomes
Reduced resource consumption
Remote control and automation
Data-driven decision making

A specific use case where Wi-Fi HaLow would outperform other protocols is in a smart agriculture or precision farming system. In this scenario, a large farm has multiple sensor nodes and actuators spread over a vast area to monitor and control various aspects of farming operations.

These sensor nodes might include:

1. Soil moisture sensors for measuring the water content in the soil and ensuring optimal irrigation.
2. Temperature and humidity sensors for monitoring the microclimate conditions and assisting with decisions related to planting, pest control, and harvesting.
3. Nutrient sensors for measuring soil nutrient levels and informing decisions about fertilization.
4. Water level sensors for monitoring water reservoirs, wells, or waterways.
5. Cameras and location/biometrics sensors devices to monitor crops and livestock.

Actuators in the system might include:



1. Irrigation valves to control the water supply to specific sections of the farm.
2. Nutrient dispensers to release fertilizers based on soil nutrient data.
3. Pumps and gates to manage water levels in reservoirs, wells, or waterways.

In this use case, Wi-Fi HaLow's extended range, low power consumption, and scalability make it an ideal choice for communication between the sensor nodes, actuators, and a central control hub:

1. Extended range: A large farm can span several kilometers, and the long-range capabilities of Wi-Fi HaLow ensure that even the most distant sensor nodes and actuators can maintain a reliable connection to the central hub.
2. Improved penetration: Wi-Fi HaLow's ability to penetrate obstacles like trees, vegetation, and even small structures ensures that wireless connectivity remains stable throughout the farm.
3. Low power consumption: Many of the sensor nodes and actuators in this scenario are likely to be battery-powered or use energy harvesting techniques, so the low power consumption of Wi-Fi HaLow is crucial for maintaining long battery life and reducing maintenance requirements.
4. Scalability: A smart agriculture system might have hundreds or even thousands of sensor nodes and actuators. Wi-Fi HaLow's ability to support a large number of devices in a network ensures that the system can scale up as needed.

While other wireless communication protocols like Zigbee, LoRaWAN, or NB-IoT could also be used in this scenario, Wi-Fi HaLow's combination of long-range capabilities, low power consumption, and compatibility with existing Wi-Fi infrastructure makes it a compelling choice for smart agriculture applications.

Business Advantages of 802.11ah Wi-Fi HaLow Technology

There are significant advantages to deploying Wi-Fi HaLow networks across these multiple use cases and market segments. Common themes include reduced infrastructure costs, ease of installation, increased reliability, simplified management, and growth of potential new revenue streams for service providers.

Reduction of Network Infrastructure Costs

Reach & penetration of Sub-1 GHz Wi-Fi HaLow technology means that fewer APs are needed to serve a larger number of IoT devices over a larger area or volume. While a 250,000 square feet warehouse may use 40 to 50 APs for Wi-Fi 6 coverage, only a handful of Wi-Fi HaLow APs need to be added into the same space to serve the lower data rate devices. Wi-Fi HaLow is complementary to existing networks in that it does not interfere with the frequencies of the original coverage plans for the higher data rate users. A Wi-Fi HaLow AP can be connected via the USB or ethernet port of an installed Wi-Fi 6 AP already installed in the ceiling. For residential applications, a single Wi-Fi HaLow AP can cover the IoT connections for the whole home and outdoor devices, while maximizing the battery life of the device.

Native IP Traffic to the Cloud & Fewer Proprietary Hubs

Where Zigbee or BLE devices are being considered, one must take into account that these are not native-IP solutions. They typically use a mesh architecture of low-power battery-powered devices, where one node can become a congestion point responsible for relaying all of their neighbors' traffic. Said node is forced to stay active and will likely consume more energy than anticipated. Meshes also introduce congestion into the network, potentially halving the throughput at every shared juncture. They ultimately connect to a proprietary controller hub which must translate all of the traffic into IP frames when destined for the cloud. A simple Wi-Fi HaLow AP in a star-oriented architecture offers a lower infrastructure cost, and serves low-power, high-throughput devices without the congestion and delays of mesh solutions. Wi-Fi HaLow supports native IPv4/v6 networks, minimizing latency and streamlining secure local and cloud connections. Wi-Fi HaLow can be embedded as an additional internal band in APs, or can be added to existing networks as a dongle router.

Ease of Installation

The steps to install a Wi-Fi based network are well known for both consumer and enterprise applications. Plug the AP into an ethernet port in the switch or router, install approved client devices. The Wi-Fi HaLow experience can be the same. Features such as EasyConnect using DPP can automate the task of adding Wi-Fi HaLow IoT devices that do not have buttons or screens. Preconfigured devices can ship to the customer with embedded credentials to simplify the onboarding process.

Increased Reliability of Connected IoT Devices

Wi-Fi HaLow can improve the out-of-the-box experience for end users across a wider variety of environmental conditions. In a business-to-consumer (B2C) relationship, a product shipped to the customer without any knowledge of their home or office conditions carries significant risks of returns or added costs. The Wi-Fi security camera mounted on the garage might not reach back to the home router or gateway. Or it may initially connect and then suffer multiple signal drops. Applying Wi-Fi HaLow solutions improves the reliability of a connection, accommodating a wider variety of construction materials and layouts of the home. Using Wi-Fi HaLow helps avoid the costs of technical support calls and returned materials. For dealer-installed solutions, Wi-Fi HaLow increases the first-pass success and avoids call-backs.

Wi-Fi HaLow also supports EasyMesh. This Wi-Fi Alliance product ensures that multiple APs from different vendors can interconnect with each other via the different RF bands to improve coverage, and find a route back to the internet. In this regard, Wi-Fi HaLow can extend the reach between the APs.

Simplified Management of Native-IP Connections

Since Wi-Fi HaLow is built on the foundations of Wi-Fi, most of the established and trusted tools for managing, securing and monitoring the Wi-Fi HaLow network are already in place, whether managing an enterprise or home gateway, or industrial network. For digital twin industrial networks, the flexibility to quickly add Wi-Fi HaLow sensors and monitors into the network offers closer ties to the data needed for accurate measurement and predictions.

WPA3 security used by Wi-Fi HaLow is common to all new Wi-Fi generations. It is rigorously tested and will be maintained to adapt to new network threats. WPA3 protocols and profiles can be applied across all IOT, regardless of radio. This high level of security exceeds what is applied in other IOT technologies like BLE and LoRa. With Wi-Fi HaLow's higher data rates than these other solutions, it is capable of supporting safe and secure OTA updates to IoT devices, minimizing downtime.

Expansion of Local Services for Homes and Businesses

By improving reach and reliability for devices using Wi-Fi HaLow, services that may have suffered from poor connectivity can be improved. Service providers that offer video surveillance can reach farther out into a property with Wi-Fi HaLow cameras which stay connected across longer distances and through more walls. Utility companies can use Wi-Fi HaLow sensors, meters and monitors in large outdoor configurations and backhaul important data about their service. For example, smart electric grid monitors can feed their data over collocated broadband networks. Broadband service providers could overlay a neighborhood with Wi-Fi HaLow service to improve safety monitoring of inhabitants, as well as monetize the service backhauling electric meter data.

Summary

The Project: Wi-Fi HaLow for IoT Applications

This WBA project will deliver results of testing Wi-Fi HaLow devices in real-world field trials in a variety of industries, applications and use cases. The data gathered in each venue will include coverage areas, data rates, throughput, and reliability of signals. The data will be shared in the final report. The reader will be able to draw clear conclusions from the study about Wi-Fi HaLow's advantages. New IoT products and services can be planned with greater confidence in the Wi-Fi HaLow technology.

Acronyms and Abbreviations

Acronym / Abbreviation	Definition
WBA	Wireless Broadband Alliance
NGH	Next Generation Wi-Fi
AP	Access Point
TWT	Time Wake Time
ISM	Industrial, Scientific, and Medical
ITU	International Telecommunications Union
OFDM	Orthogonal Frequency Division Multiplexing
Traditional Wi-Fi	Wi-Fi standard in earlier day such as Wi-Fi 4, 5 and 6
BSS	Basic Service Set
PHY	Physical Layer
MAC	Media Access Control
DTIM	Delivery Traffic Indication Map
RAW	Restricted Access Window
LBT	Listen Before Talk
QOS	Quality Of Service
NDP	Null Data Protocol
OTA	Over The Air
OWE	Opportunistic Wireless Encryption
DPP	Device Provisioning Protocol
MCS	Modulation Coding Scheme
LPWAN	Low Power, Wide Area Networks

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