Wi-Fi CERTIFIED HaLow™

Technology Overview

November 2021

Introduction

Wi-Fi® connectivity has accelerated the rise in Internet of Things (IoT) applications, from sensors that help track device location in a warehouse, to health monitors, to climate control sensors. Wi-Fi CERTIFIED HaLow™ meets the growing IoT market's unique requirements. Wi-Fi 4, based on the IEEE 802.11n standard, is a mature technology offering the data rates and range needed for email, internet shopping, and streaming to a smart TV. Wi-Fi CERTIFIED 6™ is the latest generation of foundational Wi-Fi connectivity, providing improved device power savings to support IoT capability for some environments, while also handling applications with intensive bandwidth requirements. However, many IoT environments require longer range connections, the ability to penetrate multiple walls, and the ability for a device to operate on a single battery charge for months or years.

Wi-Fi CERTIFIED HaLow, based on the IEEE 802.11ah standard, offers the range, data rates, penetration, and low power consumption profiles expected in IoT settings. These include products for industrial, agricultural, and smart city environments, as well as home and building automation. Operating in the sub-1 gigahertz (GHz) frequency spectrum band, Wi-Fi HaLow™ increases Wi-Fi ubiquity and security to address more IoT environments. Its native IP support facilitates streamlined access to internet and cloud-based applications without the burden of extra costly infrastructure such as extra hubs, repeaters, or gateways.

This technology overview document expands on key points made in the paper "Wi-Fi CERTIFIED HaLow™: Wi-Fi® for IoT applications" and provides further background on what makes Wi-Fi HaLow a good solution for the growing IoT market, including:

- Underlying wireless technology characteristics such as sub-1 GHz frequencies, network bandwidths, modulation and coding schemes
- Innovative new power savings features defined for Wi-Fi HaLow, such as Target Wake Time (TWT), Restricted Access Window (RAW) and extended max idle periods
- Wi-Fi HaLow security methods

In addition, this overview identifies comparisons between Wi-Fi HaLow and other unlicensed Low Power Wide Area Network (LPWAN), Licensed WAN, Wireless Personal Area Networks (PAN), and Local Area Network (LAN) technologies on important characteristics such as battery life, range, data rate, and scalability. The reader will gain an understanding as to why Wi-Fi HaLow should be considered a preferred choice for many diverse IoT environments.

Technology overview

Sub-1 GHz and narrow band

The laws of electromagnetics and communication theory dictate the relative trade-offs between power, distance and radio frequency (RF) signal reliability. Generally, reaching a longer distance at any particular frequency requires using a higher signal transmission power or using lower data rates. For any given transmit amplification power, radio waves transmitted in the 2.4 GHz and 5 GHz bands do not travel as far as radio waves in lower frequencies, such as 915 megahertz (MHz). For this reason, Wi-Fi HaLow focuses on operation in the frequencies referred to as the sub-1 GHz spectrum.

Another factor in predicting successful long-distance RF signal transmission is the channel width in which the energy is concentrated. Narrower band channels at a given frequency range can carry focused transmissions that reach farther than wider channels in the same frequency. As shown in Figure 1, narrower channel modes of operation in sub-1 GHz frequencies provide broadened reach beyond the wider channels in 2.4 GHz frequencies.

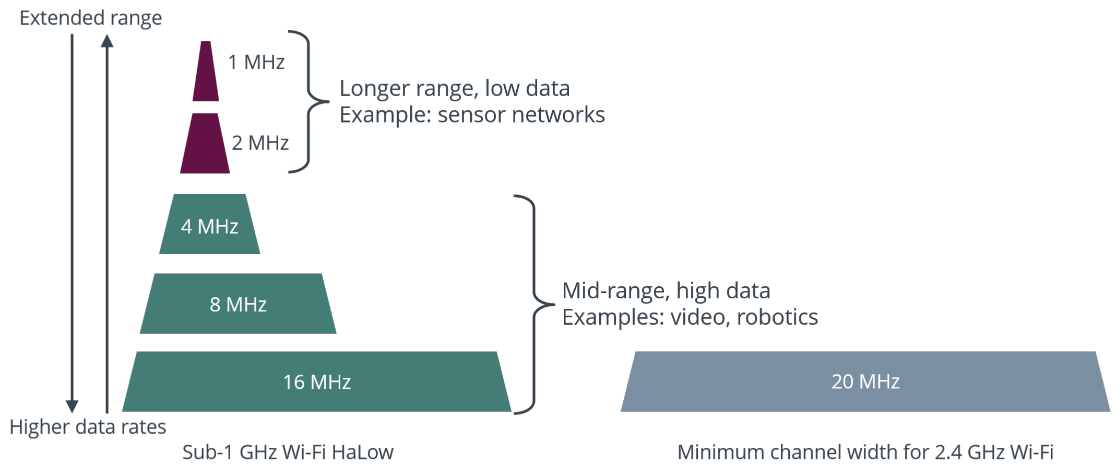

Figure 1. Wi-Fi HaLow operates in sub-1 GHz in channels ranging from 1 to 16 MHz.

Precisely which part of the sub-1 GHz band used by Wi-Fi HaLow varies by market according to regulatory requirements. The United States currently uses 902 MHz to 928 MHz. Australia and New Zealand use 915 MHz to 928 MHz. Europe provides 7 MHz of spectrum split among the 800 MHz band and 900 MHz bands. Device makers should consult their local regulatory entity to determine which portion of the sub-1 GHz band is approved for use. To support product development for worldwide deployment, Wi-Fi Alliance actively advocates for globally harmonized access to spectrum for Wi-Fi HaLow in the 915 MHz to 925 MHz range.

Lower frequency and narrower channels lead to link budget improvements

One method to determine which IoT radio technology will best meet an application's requirements is to evaluate the available link budget. At a basic level, link budget uses the transmitted power and transmission gains and losses in decibels (dB) to determine the received power of a transmission at a given distance. The IEEE 802.11ah standard specifies valid channel width options of 1, 2, 4, 8, and 16 MHz. Using the United States as an example in a scenario where Wi-Fi is being considered as an IoT radio option, Wi-Fi HaLow utilizes sub-1 GHz operation and narrow channel widths to achieve an 8 to 12 dB advantage over Wi-Fi operating in the 2.4 GHz band using 20 MHz wide channels.

Wi-Fi HaLow can transfer data at longer distances in the sub-1 GHz bands, effectively addressing a host of IoT and Industrial IoT (IIoT) applications while freeing up capacity in the other frequency bands where Wi-Fi operates. This makes Wi-Fi HaLow an excellent addition to the Wi-Fi portfolio, enabling Wi-Fi in all its forms to handle nearly any use, from the low bandwidth IoT network needs to more bandwidth intensive applications.

Beacons, the packets broadcast by the AP to synchronize the client devices that it serves, set an upper limit to network range. Whereas Wi-Fi HaLow is operating with Modulation Coding Scheme 0 (MCS0)[1] or 300 kilobits per second (kbps) in a 1 MHz channel, Wi-Fi HaLow beacons have a 10 dB advantage over beacons sent in 20 MHz channels at a 6 megabits per second (Mbps) rate. The combination of these effects creates approximately 20 dB in link budget advantage, roughly translating into a 10 times (10X) range advantage over 2.4 GHz Wi-Fi.

At the farthest range limits at around one kilometer, Wi-Fi HaLow can operate in MCS 10 mode, where data is duplicated in a 1 MHz channel at 300 kbps, effectively a 150 kbps data rate. This purposeful redundancy gives the receiving device an extra opportunity to correct data errors and provides another improvement for the Wi-Fi HaLow link budget. This data rate and range combination exceeds that of many alternative wireless IoT technology options.

[1] *Wi-Fi HaLow MCS rates are described later in this document*

Orthogonal frequency division multiplexing (OFDM) modulation and forward error correction (FEC)

Wi-Fi HaLow uses OFDM modulation, which has been used in previous Wi-Fi versions since 802.11g. Data to be transmitted is encoded with a powerful forward error correction (FEC) code that adds valuable redundant check information, and the encoded stream is sent simultaneously on 26 or more subcarriers spread across the operating channel, as indicated in Figure 2. The division across multiple subcarriers enables robust reception in the presence of channel distortion, and the redundancy improves the link budget for the signal being received in the presence of interference and noise. The combination of OFDM and powerful FEC provides a more robust solution than simple frequency shift keying (FSK) types of radios found in Z-Wave or other proprietary IoT devices. Using OFDM, combined with Phase Shift Keying (PSK) or Quadrature Amplitude Modulation (QAM), Wi-Fi HaLow carries much more data in a given time period than alternative radio technologies. This spectral efficiency provided by Wi-Fi HaLow is especially important in countries without wide availability of the sub-1 GHz Industrial, Scientific and Medical (ISM) bands, and where there are some limits on the duty cycle for sensor devices. In many countries, no license is required to use the ISM bands. The data rates that Wi-Fi HaLow is capable of delivering within this spectrum are orders of magnitude higher than competing IoT technology options like Sigfox, LoRaWAN, Zigbee, Z-Wave, Bluetooth Low Energy, NB-IOT, and other proprietary frequency shift keying (FSK) radios systems, shown in the table below.

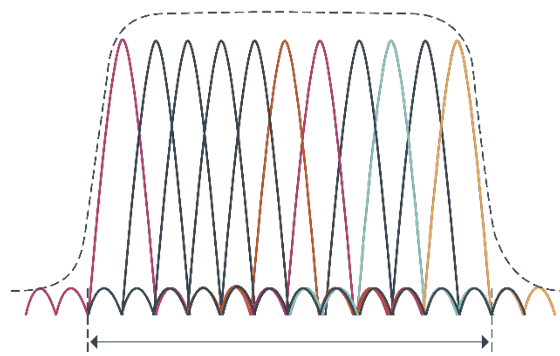

Figure 2. Example of OFDM channel with multiple subcarriers, typically 26 or more.

Attributes	Wi-Fi HaLow	Bluetooth Low Energy	Z-Wave	Zigbee	Wi-SUN	Sigfox	LoRaWAN	NB-IoT
Frequency	Sub-1 GHz	2.4 GHz	Sub-1 GHz	2.4 GHz / Sub-1 GHz	Sub-1 GHz	Sub-1 GHz	Sub-1 GHz	Licensed
Data rate (bps)	150 k - 86.7 M[2]	125 k - 2 M	9.6 k – 100 k	250 k	6.25 k – 800 k (50 k default)	100 or 600	300 – 27 k	20 k – 127 k
Range (m)	> 1 k	< 100	< 30	< 20	< 1 k	< 40 k	< 10 k	< 10 k
Modulation	OFDM over BPSK, QPSK, 16/64/256 QAM	GFSK	GFSK	BPAK/ OQPSK	MR-FSK / MR-OFDM / MR-OQPSK	DBPSK/ GFSK	CSS	QPSK
Battery life	Years	Years	Years	Years	Years	Years	Years	Years
Security	WPA3™	128-bit AES in CCMode	Security 2 (S2)	128-bit AES in CCMode	IEEE 802.1X	Session-level security	128-bit AES in CCMode	3GPP security
OTA firmware updates	Supports	Supports	-	-	-	-	-	-

[2] *86.7 Mbps is possible using MCS 9, with 16 MHz channels and short guard intervals; results vary based on regulatory requirements and vendor implementation*

Subscription required	No	No	No	No	No	Yes	Yes	Yes
TCP/IP (internet)	Supports	-	-	-	-	-	-	-
Network topology	Star / Relays	P2P* / Mesh	Mesh	Mesh	Mesh	Star	Star	Star
Open standard	IEEE 802.11ah	Bluetooth SIG	Proprietary	IEEE 802.15.4	IEEE 802.15.4g	Proprietary	Proprietary	3GPP LTE Cat-NB1/NB2

** Peer-to-peer*

Source information used for this table is publicly available

Modulation and coding schemes (MCS)

The MCS table for Wi-Fi HaLow is derived from the IEEE 802.11ah specification. This describes the allowed modulation type permutations, channel widths, inter-symbol guard intervals (GI), and the resultant data throughputs that can be used to communicate. The access point (AP) and client device automatically adjust to the optimal MCS they both support to maximize data throughput for the current channel conditions. Such MCS tables exist for Wi-Fi 4, Wi-Fi 5, and Wi-Fi 6. The IEEE 802.11ah table's data rates were generally specified at one tenth the rates of the IEEE 802.11ac MCS table, and for up to four spatial streams. While initial Wi-Fi HaLow implementations will likely be for single stream devices, there is a path to four-stream multiple input multiple output (4x4 MIMO) Wi-Fi HaLow solutions in the future.

The MCS options take into consideration that distances and RF conditions between two devices can vary. As with other Wi-Fi technologies, Wi-Fi HaLow can adapt to changing conditions. The AP and client devices advertise their capabilities when they join the network. They can automatically adjust to the optimal MCS as necessary. For instance, if an AP has an associated client running at MCS 0 on a 1 MHz channel at a 300 kbps rate, and both devices determine RF channel conditions between them are suitable to support MCS 4 on a 4 MHz channel, they can agree to change their MCS and channel bandwidth in order to transfer data at 9 Mbps.

The benefit of a wide variety of MCS options is that administrators can tune the data rate to the particular application and choose to allow a mix of device types to automatically optimize for improved conditions. For instance, a sensor that only needs 150 kbps data rate at a long distance can be served by the same AP that supports a nearby video camera that requires 10 Mbps. A device that moves closer to the AP will typically benefit from operating at the faster MCS rates to transfer its data and conserve energy.

The table shows the MCS for single stream connections. Note that MCS 10 supports the slowest effective rate for long-distance connections, and then MCS 0 through MCS 9 have sequentially higher data rates.

MCS Index	Spatial Streams	Modulation Type	Data Rate (Mbps)									
			1 MHz Channels		2 MHz Channels		4 MHz Channels		8 MHz Channels		16 MHz Channels	
			Long GI[3]	Short GI	Long GI	Short GI	Long GI	Short GI	Long GI	Short GI	Long GI	Short GI
0	1	BPSK	0.30	0.33	0.65	0.72	1.4	1.5	2.9	3.3	5.9	6.5
1	1	QPSK	0.60	0.67	1.3	1.4	2.7	3.0	5.9	6.5	11.7	13.0
2	1	QPSK	0.90	1.00	2.0	2.2	4.1	4.5	8.8	9.8	17.6	19.5

[3] Guard intervals (GI) refer to the time delay inserted between symbols (characters) being transmitted to avoid interference. A long GI assures transmission accuracy, while a short GI increases throughput.

3	1	16-QAM	1.2	1.3	2.6	2.9	5.4	6.0	17.6	19.5	35.1	39.0
4	1	16-QAM	1.8	2.0	3.9	4.3	8.1	9.0	17.6	19.5	35.1	39.0
5	1	64-QAM	2.4	2.7	5.2	5.8	10.8	12.0	22.3	23.6	48.6	52.0
6	1	64-QAM	2.7	3.0	5.9	6.5	12.2	13.5	26.3	29.3	52.7	58.5
7	1	64-QAM	3.0	3.3	6.5	7.2	13.5	15.0	29.3	32.5	58.5	65.0
8	1	256-QAM	3.6	4.0	7.8	8.7	16.2	18.0	35.0	39.0	70.2	78.0
9	1	256-QAM	4.0	4.4	N/A	N/A	18.0	20.0	43.3	43.3	78.0	86.7[4]
10	1	BPSK	0.15	0.17	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Medium access control (MAC) efficiency and energy savings

One of the key design criteria for Wi-Fi HaLow technology is low power consumption to enable battery powered IoT devices to operate for multiple years. New MAC functionality enables devices in a Wi-Fi HaLow network to save energy, reduce congestion, and increase both capacity and device density. Transmitting a radio signal typically consumes more power than receiving a signal. Any reduction in transmissions for a device will usually save energy. The key factor for low power consumption is to ensure that the radio can reliably stay asleep for long time periods, without being dropped or disassociated by the AP. By allowing Wi-Fi devices to spend more time sleeping, the average energy consumption for such devices is greatly reduced. Devices that are asleep or passively listening will free up the available spectrum for active client devices to transmit their data. Key Wi-Fi HaLow features that enable efficiency and energy savings are listed below.

Non-traffic indication map (TIM) mode options

In some wireless local area networks (WLANs), devices must wake frequently to monitor and respond to the traffic indication map (TIM) sent by the AP in beacon frames multiple times per second. The TIM is used to indicate which client devices should expect inbound data. Wi-Fi HaLow devices can save power by operating in optional non-TIM modes, where they do not have to stay awake to actively monitor the beacon frames. This feature removes the need for a Wi-Fi client device to periodically check beacon messages. Freeing Wi-Fi HaLow from TIM mode allows it to conserve energy, making it competitive with other IoT sensor network technologies.

Note that non-TIM mode is an option that depends upon the desired function of the devices and network. TIM mode is also supported by Wi-Fi HaLow. A Wi-Fi HaLow AP can support both options concurrently for a mix of devices.

Target Wake Time (TWT)

Client devices that expect to sleep for long time periods can negotiate a TWT contract with the AP. The AP stores any traffic destined for the client until the agreed upon wake time is reached. When the client device wakes at the prescribed time, it listens for its beacon and engages the AP to receive and transmit any data required before returning to its sleep state. The interval between wake times, negotiated by the client and AP, can vary from especially short (microseconds) to very long (years).

Restricted Access Window (RAW)

RAW is another planning method when groups of client devices are allowed to communicate. For systems with predictable activity periods, an AP can grant a subset of clients with RAW privileges to transfer their data, while others can be forced to sleep, buffer non-urgent data, or both. The client devices save power and leave more network capacity available for other time-critical traffic.

By combining TWT and RAW functions, a network designer can minimize channel contention and save power throughout the system.

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[4] *86.7 Mbps is possible using MCS 9, with 16 MHz channels and short guard intervals; results vary based on regulatory requirements and vendor implementation*

Extended max idle

The extended max idle feature extends the period during which a client device is permitted to sleep before the AP disassociates the client. This preserved status allows power sensitive sensors to avoid wasting energy having to reauthenticate if they have otherwise been dropped. The feature provides for a maximum idle period greater than five years. In practice, the idle period will depend upon the implementation and application requirements.

Hierarchical traffic indication mapping (TIM)

Hierarchical TIM is a method to more efficiently encode the TIM mentioned above to reduce its on-air time and accommodate a larger number of clients. Different encoding modes are defined to enable large numbers client devices in sleep mode to be managed effectively.

Short MAC headers

Removing unnecessary header fields in the start of a packet will reduce transmit and receive airtime, as well as related power consumption. For example, the overhead for a small 100-byte packet transmission could be reduced by eight percent, from 40 percent to 32 percent.

Null Data PHY protocol data units (NDP frames)

Null Data PHY protocol data units, known as NDP frames, 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. For example, the airtime for NDP acknowledgement is approximately 0.56 milliseconds (ms) at MCS10 on a 1MHz channel, while a legacy acknowledgement would take 1.34 ms.

Short beaconing option

Beacons are usually sent at the lowest MCS rate to reach the farthest away client devices in the coverage area, but they have long transmission times. Wi-Fi HaLow recognizes two types of beacons sent by the AP: full beacons sent less frequently, and short beacons with minimal information to keep the stations synchronized, using less transmission time, yet sent more frequently. Shorter beacons reduce listening device power consumption and free up valuable airtime within the spectrum.

Basic Service Set (BSS) color

BSS coloring assigns a different "color" to each AP or each BSS on an AP. This color coding is a simple indicator that allows a client device to pay attention to transmissions matching its BSS color and to ignore transmissions from adjacent networks not intended for its BSS—those not matching the color of the BSS with which it is associated. This is intended to reduce medium contention overhead and increases overall capacity, especially in dense IoT networks.

Security

Authentication and encryption

Wi-Fi HaLow supports the latest and most advanced Wi-Fi security technology available: Wi-Fi CERTIFIED WPA3™ and Wi-Fi CERTIFIED Enhanced Open™, based on Opportunistic Wireless Encryption (OWE). The latter will provide privacy in public environments where devices require access to servers in the cloud, for example. Wi-Fi HaLow will adopt future Wi-Fi Alliance security improvements as they evolve over time.

High rate symmetric data throughput for over-the-air firmware updates

Wi-Fi HaLow has a minimum effective MCS 10 rate of 150 kbps for use at longer ranges. Higher rates supporting tens of megabits per second are available for nearby devices. If a device needs new firmware to continue operating efficiently and securely, Wi-Fi HaLow can quickly deliver the information and reduce downtime. This has advantages over PANs and wireless WANs, which operate at much lower data rates, as low as 100 bits per second. Such low data rates for those networks do not provide the capacity to react quickly to threats that require security updates to be pushed over the air to thousands of devices in the field. Devices using those technologies might require long downtime periods or incur higher maintenance costs by sending a person to each device to perform manual updates on-site. Wi-Fi HaLow has the security, capacity, range, and data rates to support over-the-air updates with minimal downtime.

IoT technology competitive analysis

Wi-Fi Alliance conducted a comparison between Wi-Fi HaLow and other IoT technology options, which analyzed data rate, range, battery life, ease of IP network integration, efficiency and scalability. These attributes are defined in the following table.

Attribute	How it is measured
Data rate	Maximum PHY data rate relative comparison
Range	Maximum range comparison in a rural area
Battery life	Battery life in months, assuming a 10-minute transmission interval
Ease of IP network integration	Qualitative comparison based on factors such as protocol conversion requirements, OS support, discovery protocol enablement
Installation and operation efficiency	End user cost for operating a 10,000-device network for two years
Scalability	Capacity per BSS/AP and ability for an AP to support large numbers of devices

The technologies included in the analysis are:

- Unlicensed low power WAN: LoRaWAN, Sigfox, and Wi-SUN
- PAN and LAN: Zigbee, Bluetooth Low Energy, Z-Wave, and 2.4 GHz Wi-Fi
- Licensed WAN: NB-IoT, LTE-M

Before Wi-Fi HaLow, wireless IoT systems were typically designed around meeting a key operating parameter, such as long battery life, at the expense of other parameters, such as longer range, simplicity, or high data throughput. Low power systems implemented with PAN technologies like Bluetooth, Zigbee, Z-Wave, or proprietary radios sacrificed distance, speed, or network simplicity.

The information below shows how Wi-Fi HaLow compares to other IoT technology options using these attributes. For this analysis, the closer to the center the line is, the less effective that aspect of the technology. The farther from the center the attribute line is, the better the result.

Low power WAN systems

Figure 3 reveals that LPWAN systems such as LoRaWAN and Sigfox offer long distance connections, but do not perform well when it comes to data rate, scale, energy efficiency, IP integration ease, or security.

In the analysis, the light blue line representing LoRaWAN reveals that it was the only technology that came close to Wi-Fi HaLow in range, battery life, and scalability; however, it left much to be desired in the data rate and IP network integration categories. Likewise, Sigfox did very well in range, but struggled in all other areas compared to its competition in this scenario.

When compared to other LPWAN technologies, Wi-Fi HaLow outperformed in five of the six attributes. Historically, it has been assumed that Wi-Fi could not be used for IoT because it is not as energy efficient. Wi-Fi HaLow capability renders this assumption obsolete. Wi-Fi HaLow was developed

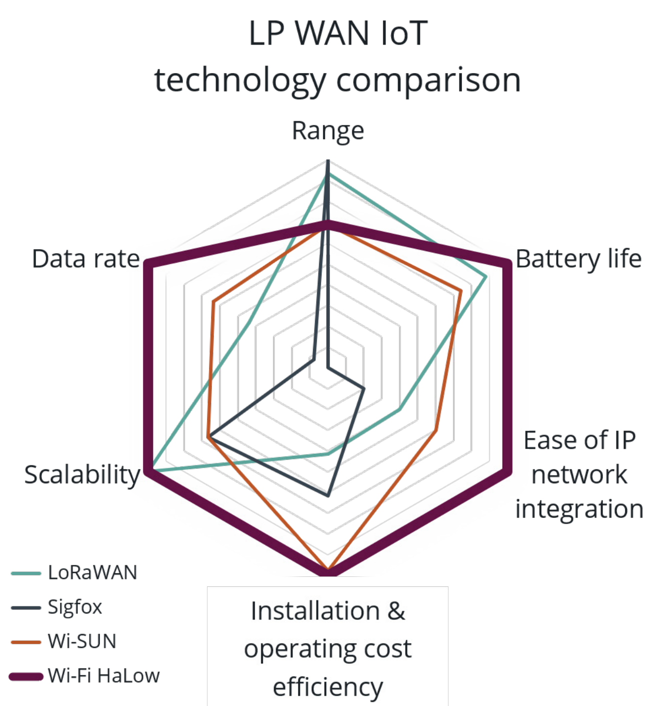

Figure 3. Compared to other low power WANs, Wi-Fi HaLow excels in most measured attributes.

to specifically improve device efficiency with the previously described features dedicated to device energy savings, enabling device batteries—including coin-sized batteries—to last for years.

PAN and LAN networks

Many types of PAN networks are designed for short distance connections. They attempt to reach longer distances with mesh architectures. Mesh architectures[5] involve creating multiple paths between devices for communication. Though mesh architectures can ease initial installation for users, they add extra layers of complexity, latency, and cost in an IoT environment. A Zigbee device within the mesh that relays the traffic of other nodes uses more energy from a battery and is limited to 250 kbps data throughput. Mesh architecture bottlenecks and latencies can prevent these systems from achieving Wi-Fi simplicity. A Z-Wave mesh network is limited to 232 devices at maximum; Wi-Fi HaLow allows 8,191 devices per AP and does not require a proprietary gateway to access IP networks.

Figure 4 shows that while each technology in the PAN/LAN category performed well in the installation and operating efficiency arena, the only technology competitive to Wi-Fi HaLow in the other categories is Wi-Fi operating in 2.4 GHz. This is where an administrator would need to evaluate the IoT environment's main goals. Wi-Fi HaLow is the clear choice when the most important factors are longer range and battery life, penetration through walls, installation ease, and scalability to a higher number of client devices. The IP network integration ease and data throughput within AP range favors 2.4 GHz Wi-Fi, as the technology is mature and already exists in many APs today. Adding Wi-Fi HaLow to Wi-Fi 4, Wi-Fi 5, or Wi-Fi 6 networks enables the user to meet almost any need on the same IT infrastructure, without interference.

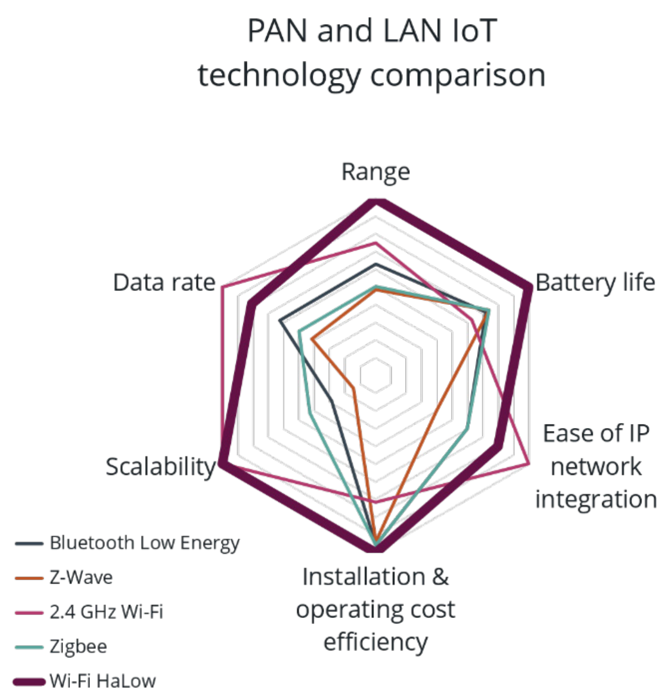

Figure 4. Wi-Fi HaLow meets key requirements when compared to other IoT technology options.

[5] Reference to mesh architecture in this section is not the same as multiple AP systems referred to as mesh Wi-Fi systems in the consumer market today.

Licensed WAN technology

WAN technologies such as NB-IoT or LTE-M use licensed spectrum owned by a carrier or mobile phone service provider. Despite the promise of ubiquitous network coverage areas, these systems add a recurring cost burden to IoT network implementations by requiring data plan subscriptions to use the mobile cellular infrastructure.

Wi-Fi HaLow achieved significantly higher data rates for clients within AP range when compared to LTE-M, reaching 4 Mbps maximum downlink data rates using 5 MHz of bandwidth, and NB-IoT, reaching 127 kbps data rates using 180 kHz of bandwidth. Wi-Fi HaLow outperformed the technologies in this analysis in every area except range (see Figure 5). With a one kilometer range, it is likely that Wi-Fi HaLow will meet the requirements for many IoT use cases within an enterprise.

Wi-Fi HaLow offers a lower cost solution for applications where the devices are within AP reach, as well as advantages in longer battery life, IP network integration ease, and higher data rates. Wi-Fi HaLow is a better choice for aggregating traffic in a dense population of low-power client devices, which can then be routed to the internet. Wi-Fi HaLow networks can continue operating as a LAN if a carrier network becomes unavailable.

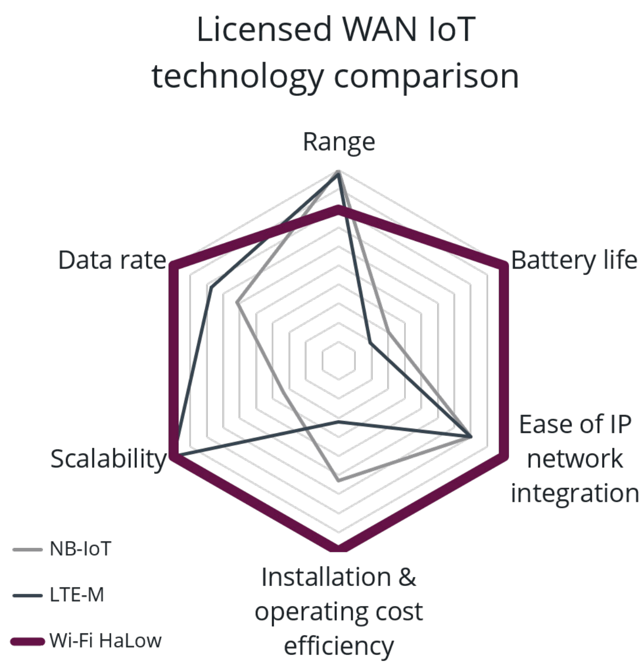

Figure 5. Wi-Fi HaLow cost efficiency, scalability, and native IP support in make it a great alternative to expensive licensed or proprietary IoT technologies.

IoT device energy efficiency comparison

IMEC Research Group conducted a study[6] to compare sub-1 GHz wireless technology energy consumption. The group ran two different scenarios. One scenario compared long range technologies NB-IoT, LoRaWAN, and Sigfox, while the other compared Wi-SUN based on IEEE 802.15.4 Zigbee technology and Wi-Fi HaLow.

To provide a fair and objective comparison across the five solutions, the study assumes a 12-byte packet is transmitted every 10 minutes. Power consumption was measured during operation of each system. Note that the 12-byte packet, which is extremely small for Wi-Fi HaLow, was chosen for this study to include Sigfox in the comparison[7]. In real-world applications, Wi-Fi HaLow can transfer packets as large as 1,500 bytes at rates 15 times faster than Sigfox.

IMEC study assumptions

The following table lists the assumptions used to calculate the battery life shown in the simulation results from IMEC. They are based on the energy consumption for a 10-minute transmission interval: one message every 600 seconds using their chosen example Radio + Microcontroller (MCU) semiconductor solutions. Note that other Wi-Fi HaLow technology vendors may exhibit varying results.

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[6] *Famaey, Jeroen. (2018). The Long Life of IoT Devices: Comparing the Energy Consumption of Sub-1GHz Wireless Technologies*

[7] *Sigfox restricts packet sizes to a maximum of 12 bytes*

Technology	Radio Module	MCU	Power Consumption (mA) Rx/Tx/Idle/Sleep	Payload Size	TxPower (dBm)
Sigfox	Atmel ATA8520E	ARM Cortex M3*	10.4 / 32.2 / 0.05 / 0.00015	12 bytes	14
NB-IoT (MCS9)	uBlox SARA N210	ARM Cortex M3*	46 / 220 / 6 / 0-.003	12 bytes	20
LoRaWAN (SF7)	SEMTECH SX1272	ARM Cortex M3*	11.2 / 125 / 1.4 / 0.0001	12 bytes	23
Wi-SUN IEEE 802.15.4g	Atmel AT86RF215	ARM Cortex M3*	28 / 62 / 6,28 / 0.03	12 bytes	14
Wi-Fi HaLow IEE 802.11ah	Atmel AT86RF215	ARM Cortex M3*	28 / 62 / 6.28 / 0.03	12 bytes	14
* ARM Cortex MCU @ 32 MHz (3.88 mA power consumption Due to duty cycle restrictions in EU (2.8% for a STA, LoRaWAN and SigFox cannot achieve ten min Tx interval.					
Battery Examples: AA Coin cell Lithium	2850 mAh @ 1.5 vdc, 4.2 Wh 200 mAh @ 2 v dc, 0.45 Wh 500 mAh @ 3.6 v dc, 1.8 Wh				

Energy efficiency (bits per Joule)

This study defined energy efficiency by how many bits can be sent or received using 1 Joule of energy. Figure 6 shows that when comparing key IoT technology options and assuming a 10-minute transmission interval, Wi-Fi HaLow was far more energy efficient in terms of bits per Joule, because its transmission time was relatively very short. In the study, other technologies took much longer to transmit the same length packets. For example, Wi-Fi HaLow sent 22.4 kilobits per Joule, versus NB-IoT's 3.7 kilobits per Joule. This six-fold (6X) advantage for Wi-Fi HaLow translates into much longer device battery life.

The study also showed that Wi-Fi HaLow was four times (4X) more efficient than LoRaWAN and Wi-SUN for simple networks. Wi-SUN efficiency dropped slightly as more nodes were added to the mesh network, while Wi-Fi HaLow efficiency remained relatively unchanged.

Wi-Fi HaLow proved to be much more energy efficient than other options considered in this study.

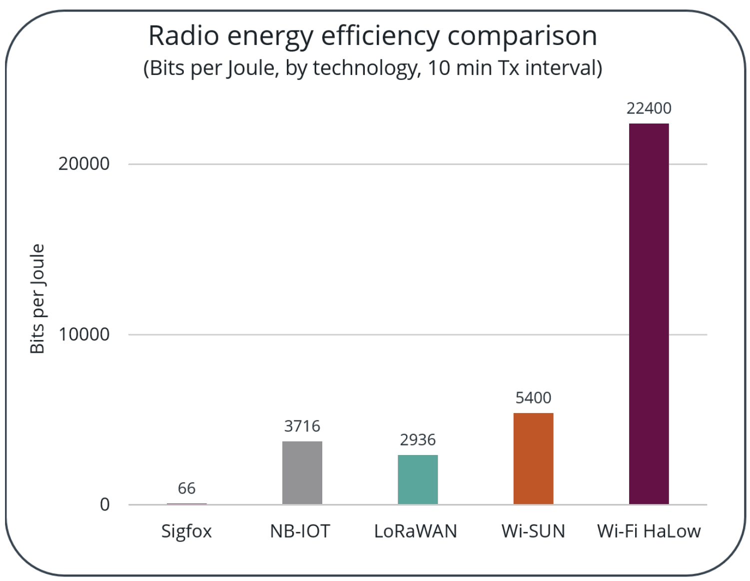

Figure 6. Wi-Fi HaLow demonstrates at least four times (4X) more energy efficiency than several other well-known IoT technology options.

Battery life

Based on battery capacity

The battery life of different sized battery capacities for each IoT technology can be predicted by understanding the energy consumption for each technology. The Joules of energy stored in a battery are relative to their capacity ratings, which are typically stated in milliamp hours (mAh).

The chart on the left in Figure 7 shows a projected Wi-Fi HaLow battery life for various battery capacities. Many common 3-volt coin cell batteries have a 250 mAh capacity. Typical AA 1.5-volt alkaline batteries, which can be used in larger form factor devices, are rated at a 2,000 mAh average. The study results suggest Wi-Fi HaLow would enable operation for over one and one half years on a coin cell battery under this challenging IoT use case, with transmissions every 10 minutes. Regardless of battery size, the study showed that Wi-Fi HaLow can support small, coin cell battery operated IoT devices, and outperform the other technologies for many applications.

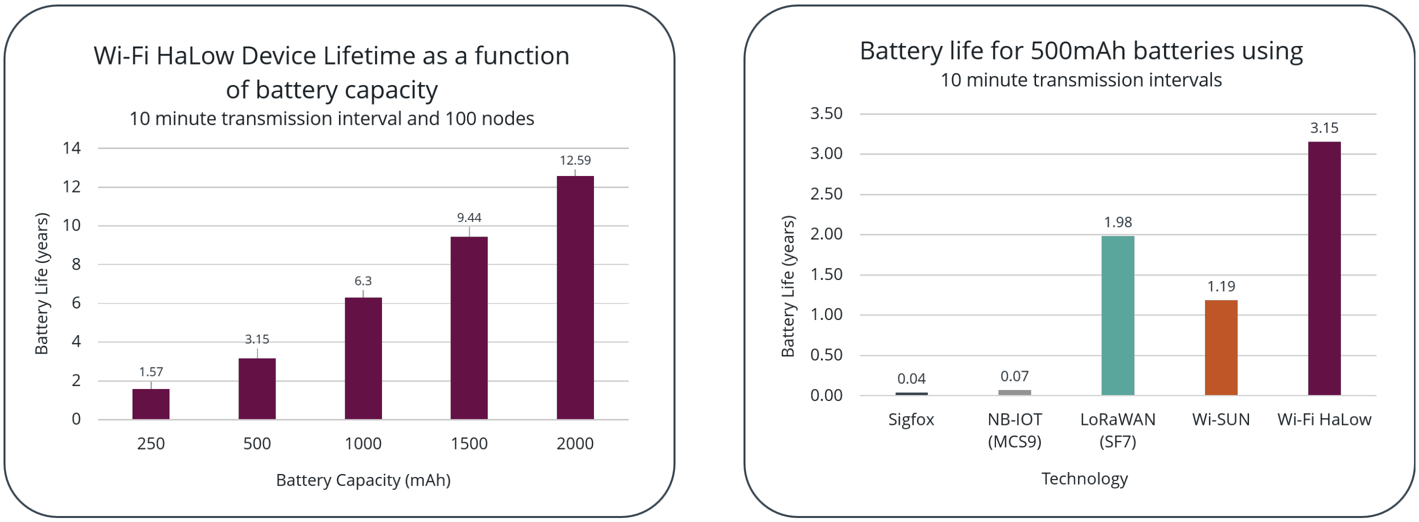

Figure 7. Charts demonstrating Wi-Fi HaLow battery life based on battery capacity (left) and transmission frequency (right).

Based on transmission frequency

This study focused on comparing technologies with a 10-minute interval between transmissions. Technologies that require more frequent communications between data transmissions will suffer from reduced battery life. Wi-Fi HaLow showed it can extend sleep times to much longer durations. Features such as TWT and BSS Extended Max Idle allow Wi-Fi HaLow devices to sleep for hours, days, months, or even years between wakeful operation.

Simulation conclusions

When comparing bandwidth, data rate, and topology, Wi-Fi HaLow demonstrated clear advantages over Sigfox, NB-IoT, LoRaWAN, and Wi-SUN. Against these other technologies in a similar use case, Wi-Fi HaLow was the most energy efficient. IMEC Research Group's assessment determined that not only is Wi-Fi HaLow greater than **four times** more energy efficient than other technologies widely considered as long range, it also provides higher data throughput than other IoT technology options. The group also determined that Wi-Fi HaLow devices using typical alkaline AA batteries could last more than 10 years—longer than typical battery shelf life.

Summary

Wi-Fi HaLow clearly meets, and in many cases exceeds, the key requirements for IoT connectivity and applications. The ability to accommodate a massive number of IoT use cases spanning in range, data rate, and energy efficiency is paramount for IoT technology to succeed. Wi-Fi HaLow sub-1 GHz operation and narrow channels enable a longer range, approximately one kilometer, as well as improved penetration through walls and obstructions. A unique power saving feature suite enables lower device energy consumption yielding increased energy efficiency, multi-year battery operation, and support for coin cell batteries. It supports a wide variety of data rates that accommodate use cases from low data sensor networks to high data rate video systems. New Wi-Fi HaLow PHY and MAC capabilities support thousands of devices per AP while improving radio spectrum use.

Because it is a part of the IEEE 802.11 and Wi-Fi portfolio, Wi-Fi HaLow is an open standard, providing for more efficient installation and operating cost without the need for proprietary controllers, hubs, or gateways. A Wi-Fi HaLow network can be deployed in the presence of existing Wi-Fi 4, Wi-Fi 5, and Wi-Fi 6 networks without interfering with their RF performance. Native IP support and the advanced security of WPA3™ make accessing cloud-based applications and over-the-air updates more streamlined and secure.

Relevant comparison studies show Wi-Fi HaLow to be many times more energy efficient than other wireless technologies. More data can be transferred per Joule of energy, ensuring longer device battery lifetimes. Its star-oriented architecture with long distance connections removes the data bottlenecks and latencies imposed by mesh networks. As part of the complete Wi-Fi portfolio, Wi-Fi HaLow delivers a more comprehensive approach to connectivity, and broadens current Wi-Fi coverage to hard-to-reach places such as garages, basements, attics, warehouses, factories, and large outdoor areas. Wi-Fi HaLow enables network designers to deploy IoT networks using a single, standards-based, IP-ready, reliable architecture without having to sacrifice simplicity and efficiency.

For more information about Wi-Fi HaLow visit https://www.wi-fi.org/discover-wi-fi/wi-fi-certified-halow.

About Wi-Fi Alliance®

www.wi-fi.org

Wi-Fi Alliance® is the worldwide network of companies that brings you Wi-Fi®. Members of our collaboration forum come together from across the Wi-Fi ecosystem with the shared vision to connect everyone and everything, everywhere, while providing the best possible user experience. Since 2000, Wi-Fi Alliance has completed more than 65,000 Wi-Fi certifications. The Wi-Fi CERTIFIED™ seal of approval designates products with proven interoperability, backward compatibility, and the highest industry-standard security protections in place. Today, Wi-Fi carries more than half the internet's traffic in a growing variety of applications. Wi-Fi Alliance continues to drive Wi-Fi adoption and evolution, which billions of people rely on every day.