SHAHAR FELDMAN, Vice
President of Marketing, Morse Micro
(www.morsemicro.com)

What's the Difference Between Wi-Fi HaLow and Traditional Wi-Fi?

Wi-Fi HaLow is coming soon to a smart door lock, security camera, wearable device, and wireless sensor network near you. What is Wi-Fi HaLow, how is it different from traditional Wi-Fi (4/5/6), and what makes it an ideal protocol for the future of IoT connectivity?

Wi-Fi is like oxygen for our connected world. It's the most pervasive wireless networking protocol used today, carrying more than half of all internet traffic. "Wi-Fi" is a catch-all term for the growing family of 802.11 protocols that have evolved over more than two decades. The Wi-Fi Alliance, the organization that drives Wi-Fi adoption and evolution, has simplified the names of commonly used Wi-Fi generations with a numerical nomenclature, e.g., Wi-Fi 4 = 802.11n, Wi-Fi 5 = 802.11ac, and Wi-Fi 6 = 802.11ax. Chances are you're using one of these flavors of Wi-Fi in your home or workplace.

Despite the ubiquity of Wi-Fi 4/5/6, the rapid growth of the Internet of Things (IoT) has forced a rethinking of traditional Wi-Fi. That reassessment has revealed technological gaps and redefined the roles that 802.11 protocols should play in today's wirelessly connected world of ultra-low-power IoT devices. The higher demands for long-range connectivity and low-power requirements of IoT and machine-to-machine (M2M) applications are driving the need for another type of Wi-Fi optimized for the IoT.

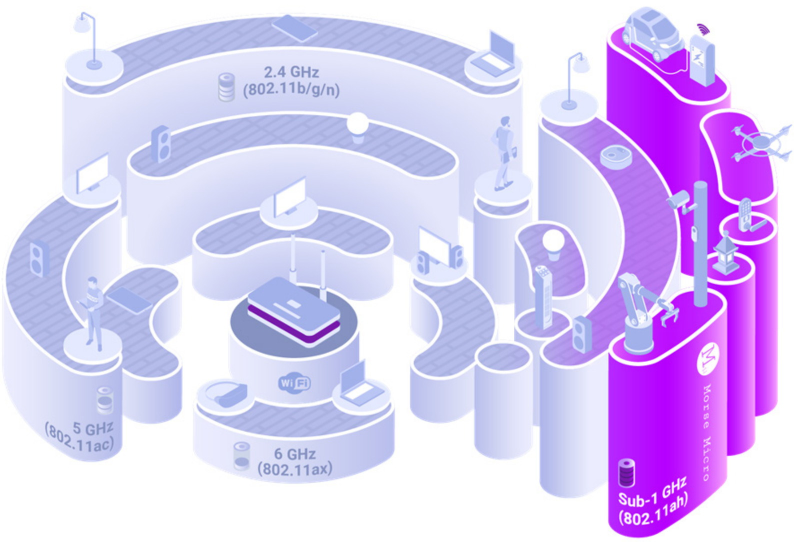
The Wi-Fi HaLow (say "HEY-low") protocol fills these gaps by providing an ultra-low-power wireless solution that connects larger numbers of IoT devices at much longer distances and at much lower power than traditional Wi-Fi. The protocol was ratified by the IEEE 802.11ah task group in 2016 and dubbed Wi-Fi HaLow by the Wi-Fi Alliance.

Wi-Fi HaLow is essentially a lower-power, longer-range, and more versatile version of Wi-Fi operating in the unlicensed sub-1-GHz spectrum. The Wi-Fi HaLow standard's unique combination of energy efficiency, long-range connectivity, low latency, HD video-quality data rates, security features, and native IP support makes it an ideal protocol choice for wirelessly connected, battery-powered IoT devices.

Let's take a closer look at some of the primary differences between Wi-Fi HaLow and traditional Wi-Fi *(see table)* and why the 802.11ah protocol is ideally suited to meet the connectivity requirements of IoT applications.

COMPARING WI-TO WI-FI HALOW

Function	Wi-Fi 4/5/6 (IEEE 802.11n/ac/ax)	Wi-Fi HaLow (IEEE 802.11ah)
Operating frequency bands	2.4 GHz, 5 GHz, 6 GHz	Sub-1-GHz (902 to 928 MHz in U.S.)
Channel-width choices	20, 40, 80, 160 MHz	1, 2, 4, 8, (16 optional) MHz
Maximum addressable stations per access point	2007	8191
Single-stream MCS data-rate range	6.5 to 150 Mb/s (802.11n, Wi-Fi 4)	150 kb/s to 86.7 Mb/s
Typical range	~100 m	Over 1 km 10X longer range 100X greater area 1000X greater volume (compared to 802.11n @ 20 MHz)
Link budget improvement (1-MHz channel)	-	15-24 dBm



1. Traditional Wi-Fi 4/5/6 protocols use higher frequency and wider bandwidth to maximize throughput. Wi-Fi HaLow's sub-1-GHz protocol optimizes penetration, reach, power, and capacity.

A Battery-Friendly Protocol

Wi-Fi HaLow provides exceptional energy efficiency for power-sensitive IoT devices. Various sophisticated sleep modes specified by IEEE 802.11ah enable HaLow devices to stay in very low power states for extended periods of time,conserving battery energy:

- *Target wake time (TWT):* This allows a station (STA) and access point (AP) to pre-arrange a time when a sleeping STA will wake and listen for beacons.
- *Restricted access window (RAW):* An AP can grant privileges to a subset of STAs to transfer their data while others are forced to sleep, buffer non-urgent data, or both.
- *Extended maximum basic service set (BSS) idle:* This extends the allowed idle period of STAs up to five years.
- *Hierarchical traffic indication mapping (TIM):* More efficient coding of TIM by groups conserves the on-air time of beacons.
- *Short MAC headers:* This reduces header overhead, on-air time and power consumption, and frees up spectrum.
- *Null data PHY protocol data units (NPD):* This embeds MAC-like ACKs/NAKs into the PHY layer for time and power reduction.
- *Short beaconing:* Short (limited) beacons are sent frequently to sync STAs while full beacons are sent less frequently.
- *BSS coloring:* Color assignments indicate BSS groups for a specific AP while an STA can ignore other colors.
- *Bidirectional TXOP (BDT) (formerly known as speed frames):* This reduces the number of medium accesses when a STA wakes to find the presence of uplink and downlink frames for transfer. BDT uses response indication in the signal (SIG) field of the physical-layer protocol data unit (PPDU) to increase TXOP duration protection from third-party STA transmissions.

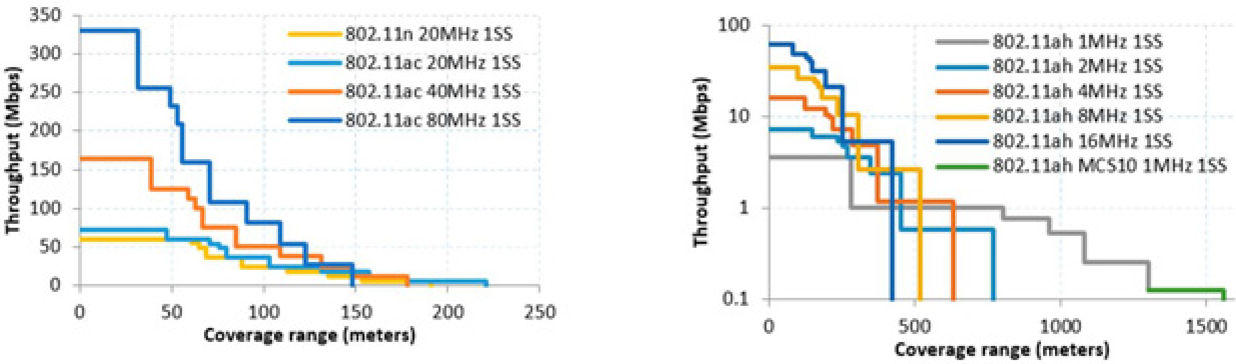
The protocol's efficient sleep and power-management modes enable multi-year battery operation for IoT devices, as well as a wide range of flexible power and battery-size options, from short-reach IoT devices running on coin cells to higher-power, larger-battery applications that extend beyond 1 km. The protocol's sub-GHz narrowband signals travel farther and with less energy, enabling the transfer of more bits per unit of energy than Wi-Fi protocols in the 2.4- and 5-GHz bands.

As a result, a Wi-Fi HaLow chip requires a fraction of the power of a conventional Wi-Fi chip. While the higher data rates of traditional Wi-Fi enable users to stream HD video content and download massive files quickly using wide channels in the 2.4-, 5-, and 6-GHz bands, the effective distance for these Wi-Fi connections is short, and they drain batteries quickly. Thus, the need for frequent charging or battery replacements, or ideally a mains power connection. For these reasons, Wi-Fi HaLow is a better choice for power-constrained IoT devices that need to reach longer distances and run on battery power for years while still offering many megabits per second of data throughput.

Longer Range

The 802.11 standard covers an unusually wide range of frequencies, from sub-GHz to millimeter wave (mmWave). HaLow is the first Wi-Fi standard to operate in the unlicensed sub-GHz band. It offers data rates varying from hundreds of kilobits per second to tens of megabits per second and across distances of tens of meters to more than a kilometer.

The sub-1-GHz signals of Wi-Fi HaLow use narrower channels from 1 MHz and up compared to the narrowest 20-MHz channels utilized by traditional Wi-Fi *(Fig. 1)*. This 20X factor in bandwidth translates into 13 dB of link-budget improvement thanks to the lower thermal noise in the channel. RF frequencies between 750 and 950 MHz versus traditional 2.4-GHz Wi-Fi account for an additional 8 to 9 dB of link budget, saving free-space propagation loss. In addition, the Wi-Fi HaLow protocol added a range-optimized modulation and coding scheme (MCS10), which provides an additional 3-dB link budget boost.



2. A comparison of 802.11n/ac (left) and 802.11ah (right) throughput vs. range. (Source: Sensors (Basel). 2016 Nov, [IEEE 802.11ah: A Technology to Face the IoT Challenge] by Victor Baños-

Altogether, Wi-Fi HaLow provides up to 24 dB of link-budget improvement versus traditional 2.4-GHz IEEE 802.11n (Wi-Fi 4). The HaLow link-budget advantage is further enhanced when compared to the even higher-frequency, higher-bandwidth 802.11ac (Wi-Fi 5) and 802.11ax (Wi-Fi 6/6E) protocols, which use 5-GHz and 6-GHz spectrum with wider bandwidths.

That explains why Wi-Fi HaLow signals travel 10X farther than traditional Wi-Fi without the need for network extenders. Battery-powered cameras, for example, can be placed in more convenient locations outside the walls of a home or garage. Lighting systems are able to be controlled from a single AP, regardless of whether the fixture is indoors or outside in a garden.

Providing end users with a wireless IoT solution that reaches hundreds of meters—without additional extenders or costly cellular data plans—is a key competitive advantage for the 802.11ah protocol. With its long-distance reach, the benefits of Wi-Fi HaLow extend the range of smart homes and smart-city networks, enabling users to control IoT devices farther than 1 km, well beyond the reach of traditional Wi-Fi protocols.

Better Signal Penetration

A general rule: The lower the frequency, the longer the reach and the better the penetration through barriers. Sub-GHz Wi-Fi HaLow signals can pass through walls and other obstacles more easily than possible with traditional Wi-Fi.

The variability of construction materials and layouts of homes and commercial buildings have less effect on sub-GHz HaLow signals than Wi-Fi protocols in the 2.4- and 5-GHz bands. The superior reach of Wi-Fi HaLow through walls and buildings can help reduce customer service calls and product returns that sometimes plague products using conventional Wi-Fi *(Fig. 2)*.

Wi-Fi HaLow leverages orthogonal frequency-division multiplexing (OFDM) modulation to correct for reflections and multi-path environments. Device manufacturers can be assured of robust HaLow connections to an AP, whether their products are located inside or outside, or whether in a basement or attic of a home. This flexibility eliminates the added cost and complexity of supplying proprietary hub or bridge devices to compensate for varied home architectures.

A Highly Scalable Solution

A single Wi-Fi HaLow AP can address up to 8,191 devices, more than four times as many devices as a traditional Wi-Fi AP. That's ample capacity to connect every LED bulb, light switch, smart door lock, motorized window shade, thermostat, smoke detector, solar panel, security camera, or any imaginable smart-home device for the foreseeable future.

Typical Wi-Fi routers for the home generally support tens of devices. When deployed in a home by a broadband service provider, a single Wi-Fi HaLow AP can become a scalable platform for delivering additional security- and utility-management devices and services.

Multiple signaling options reduce the overhead required to manage and control large numbers of HaLow devices. This minimizes signal collisions and frees up airwaves for active devices to transfer more data at the fastest MCS rates possible.

As with traditional Wi-Fi, HaLow can automatically scale bandwidth depending on signal integrity and distance from the AP. Pre-defined MCS levels support bandwidths from 150 kb/s to 40 Mb/s for single-stream, single-antenna products using channel widths ranging from 1 to 8 MHz, and 80-Mb/s capability also is achievable using an optional 16-MHz-wide channel.

Wi-Fi HaLow's star-network topology, superior penetration, broad coverage, and massive capacity frees up connectivity from difficult-to-deploy and bandwidth-constrained mesh networks, simplifies network installation, and minimizes total cost of ownership.

License-Free Spectrum with Noise Immunity

Like traditional Wi-Fi in the 2.4-, 5-, and 6-GHz bands, Wi-Fi HaLow enables end users to own their equipment and use license-free sub-GHz radio spectrum, ranging from 750 to 950 MHz. Available frequency ranges, maximum transmit powers, and duty cycles for Wi-Fi HaLow vary around the world (for example, the available HaLow spectrum for the Americas is 902 to 928 MHz while in Europe it's 863 to 868 MHz).

Operating within the industrial, scientific, and medical (ISM) band, Wi-Fi HaLow can use a variety of channel bandwidths: 1 MHz, 2 MHz, 4 MHz, 8 MHz, and 16 MHz. The narrower the bandwidth, the farther the signals can travel. Data is transmitted in packets spread across multiple subchannels using OFDM, which enhances performance in challenging RF environments, especially when there's strong interference from other radio devices. Forward error-correction (FEC) encoding also provides additional protection for recovering packets, ensuring robust connections.

Secure and Interoperable

Wi-Fi HaLow, like other IEEE 802.11 Wi-Fi versions, is an inherently secure wireless protocol. It supports the latest Wi-Fi requirements for authentication (WPA3) and AES encryption of over-the-air (OTA) traffic, with data rates that enable secure OTA firmware upgrades.

Also just like other types of Wi-Fi, HaLow is a globally recognized standard (IEEE 802.11ah) that defines how connected devices authenticate and communicate securely. Equipment vendors using Wi-Fi HaLow are assured that their products and networks will interoperate by following Wi-Fi Alliance development guidance. Because it's part of the IEEE 802.11 standard, a Wi-Fi HaLow network can coexist with Wi-Fi 4, Wi-Fi 5, and Wi-Fi 6 networks, too, without impacting their RF performance.

Going Native with IP

All IoT networks require internet-protocol (IP) support for cloud connectivity. Because Wi-Fi HaLow is an 802.11 Wi-Fi standard, it provides native TCP/IP support. This built-in IP capability means no proprietary gateways or bridges are needed for IoT connectivity. All client devices connected to a Wi-Fi HaLow-capable router can use IPv4/IPv6 transport protocols for direct access to the internet for cloud-based services and management of IoT data.

The HaLow Effect: Extending Reach, Expanding IoT Possibilities

The network congestion, range limitations, and higher power consumption of traditional Wi-Fi, along with the limited number of devices that can be connected to a single AP, are no longer viable for today's connected world of IoT devices. These limitations impede new IoT-centric business models emerging across industries that require longer range, greater capacity, and more flexible battery- and power-management options while minimizing deployment costs.

As a long-range protocol, Wi-Fi HaLow supports both indoor and outdoor IoT applications beyond the reach of 2.4- and 5-GHz Wi-Fi, such as remote security cameras, access-control networks, and even drones. Other potential use cases include large public venues such as sports arenas, shopping centers, and convention centers, where a single Wi-Fi HaLow AP can substitute for many traditional Wi-Fi APs, obviating the need for complex mesh networks, simplifying installation, and reducing total cost of ownership.

Industrial IoT, process-control sensors, building automation, warehouses, and retail stores also are among the many other applications that stand to benefit from this long-range, low-power protocol, enabling countless devices to remain connected in an increasingly automated world. Indeed, Wi-Fi HaLow stands out among traditional 802.11 protocols for its extended reach, energy efficiency, capacity, and versatility.

Shahar Feldman has more than 20 years of experience in communications industries, identifying and developing markets and emerging technology products. Before joining Morse Micro as vice president of marketing, Shahar held product management, business development, and marketing roles at Microsemi and Microchip Technology.