How Wi-Fi HaLow Is Poised to Transform the IoT Market

Andrew Zignani, Senior Research Director

ABIresearch THE TECH INTELLIGENCE EXPERTS™ Morse Micro

CONTENTS

EXECUTIVE SUMMARY

Wi-Fi HaLow, also known as IEEE 802.11ah, is an extension of Wi-Fi technology into the sub-1 Gigahertz (GHz) bands. By offering robust, extended range wireless connectivity, alongside reduced power consumption, high scalability, support for diverse use cases, and simplified installation and management, Wi-Fi HaLow has the potential to transform the Internet of Things (IoT) market. These unique characteristics can help solve several of the current challenges that are inhibiting digital transformation across home, enterprise, and industrial environments alike, while leading to the creation of valuable new use cases and services.

Momentum for Wi-Fi HaLow is growing, and the continued development and growing awareness of Wi-Fi HaLow technology, in addition to the formation of a global Wi-Fi HaLow ecosystem, are crucial next steps in determining the future success of the technology. To achieve this, advocates for Wi-Fi HaLow technology across different regions, as well as the broader Wi-Fi ecosystem, must come together to help ensure the long-term viability of Wi-Fi in the sub-1 GHz band. However, Wi-Fi HaLow can also solve real-world problems today. With the growing availability of Wi-Fi CERTIFIED HaLow chipsets, modules, infrastructure, and client devices from numerous vendors, along with the clear benefits demonstrated by recent Wireless Broadband Alliance (WBA) trials, device manufacturers, service providers, and end users looking to invest in the

IoT should take advantage of Wi-Fi HaLow technology as soon as possible. The ability to enable scalable, easy to deploy, reliable, and extended range connectivity to support multiple different IoT use cases over a streamlined network infrastructure, reduce the overall cost of ownership versus the competition, and enable a unique combination of IoT applications that other wireless technologies are unable to support on their own will create significant opportunities for Wi-Fi HaLow in the years to come.

INTRODUCTION

Over the last 25 years, Wi-Fi technology has transformed the way in which we live and work. Today, most of us rely on it daily, whether for high-speed Internet access, video streaming, online gaming, or interacting with various appliances such as thermostats, smart doorbells, and security cameras in the home. Meanwhile, from an enterprise perspective, Wi-Fi is also at the forefront of innovation, enabling valuable services and digital transformation across commercial buildings, education and healthcare campuses, public venues, and industrial sites, among many other environments. This has resulted in an enormous market opportunity for Wi-Fi technology, **with cumulative shipments of Wi-Fi-enabled devices expected to reach 40 billion in 2024, and a market size that is expected to reach over 5.1 billion annual device shipments by 2029.**

To achieve this success, Wi-Fi technology has continued to evolve across a number of different metrics. This includes throughput, latency, robustness, power consumption, security, and reliability, among many others. What was once a technology capable of supporting just several Megabits per Second (Mbps) on the unlicensed 2.4 GHz band has evolved into a tri-band technology where Wi-Fi client devices can leverage the 2.4 GHz, 5 GHz, and 6 GHz frequency bands to achieve up to 5.8 Gigabits per Second (Gbps) with the latest 802.11be (Wi-Fi 7) standard.

Traditionally, the evolution of Wi-Fi has centered around increasing throughput and lowering latency, with power consumption typically a secondary concern. However, with the arrival of Wi-Fi 6, this shifted somewhat to focus on more efficient performance in dense deployment environments, and improvements in power efficiency and capacity. Meanwhile, the expansion of Wi-Fi 6 into the 6 GHz band with Wi-Fi 6E, Wi-Fi 7, and, in the future, Wi-Fi 8, enabling up to 1.2 GHz of additional spectrum, brings the potential for even higher throughput, greater capacity, lower latency, ultra-high reliability, and improved Quality of Service (QoS). This continued evolution has enabled Wi-Fi to target an increasingly diverse number of applications, ranging from high-performance Extended Reality (XR) clients to resource-constrained sensor devices across consumer, commercial, and Industrial IoT (IIoT) applications.

However, given the diversity of applications within these markets, the new cases that continue to emerge on a regular basis and the demands for greater performance across multiple metrics, it is clear there is no single Wi-Fi (or wireless) connectivity technology that will be able to effectively address all the heterogenous requirements of the IoT. While Wi-Fi's traditional strengths are in its high throughput and lower latency, the technology also suffers from growing congestion on legacy bands, interference with other wireless technologies, a relatively limited range, difficulty in penetrating walls, and comparatively high power consumption compared to the competition. As a result, Wi-Fi, having recently celebrated its 25th anniversary, must continue to evolve if it

is to improve performance within existing market sectors, deliver next-generation services and user experiences, be able to target new IoT applications, and compete more effectively with other technologies outside of its traditional zone of influence.

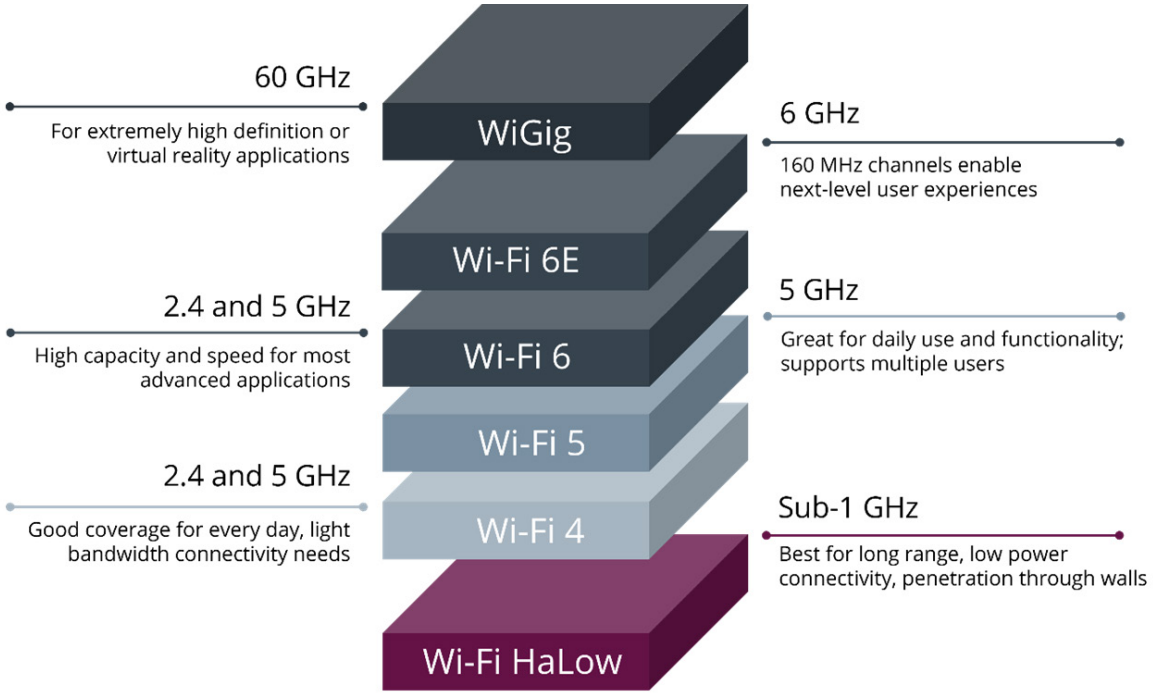
Wi-Fi's expansion into the sub-1 GHz bands via Wi-Fi HaLow, based on the IEEE 802.11ah standard, has the potential to address many of these challenges head on, creating a new value proposition for Wi-Fi technology across a number of consumer, commercial, and IIoT applications. This whitepaper discusses the evolving role and growing opportunities for Wi-Fi HaLow in the IoT ecosystem, highlights innovative use cases that Wi-Fi HaLow can enable, and offers some strategic recommendations on how various parts of the IoT ecosystem can help accelerate Wi-Fi HaLow adoption to bring about valuable digital transformation over the next decade.

Key Benefits and Capabilities of Wi-Fi HaLow

As Figure 1 demonstrates, Wi-Fi technology has evolved to support multiple frequency bands to enable better performance, deliver unique capabilities, and target a greater variety of applications.

Figure 1: Wi-Fi Technology in Different Frequency Bands

(Source: Wi-Fi Alliance)



Development of the IEEE 802.11ah standard began more than decade ago and was finally published in 2017. The main purpose was to enable Wi-Fi technology to leverage the unique capabilities of the unlicensed sub-1 GHz band to better address some of the diverse requirements within smart home, smart building, smart retail, smart city, industrial, and other emerging IoT applications. In November 2021, the Wi-Fi Alliance introduced its Wi-Fi CERTIFIED HaLow™ certification program, ensuring that IEEE 802.11ah solutions will also meet the stringent interoperability, security, and testing requirements required by all Wi-Fi technologies. The key features and benefits of Wi-Fi HaLow technology are discussed in Table 1.

In summary, perhaps the best way to think about Wi-Fi HaLow technology is that it is an extension of Wi-Fi into a new, sub-1 GHz band that can provide whole home, building, or neighborhood level coverage, help offload the congested 2.4 GHz band for IoT devices, readily and easily integrate into existing Wi-Fi APs, and take advantage of the inherent interoperability and security benefits of Wi-Fi technology. It offers a unique set of features compared to the competition, including enhanced signal penetration, support for thousands of devices, and scalable throughput, and its role as part of the Wi-Fi landscape means it has the potential to create a compelling ecosystem in the years to come. The next section of this paper discusses how these unique capabilities can address a growing number of use cases and place Wi-Fi HaLow at a competitive advantage over alternative technologies in different market sectors.

Table 1: Key Features and Benefits of Wi-Fi HaLow

(Source: ABI Research)

Key Benefit	Technical Info and Extended Discussion
Extended Range Capabilities	Wi-Fi HaLow devices operate in the unlicensed sub-1 GHz band between 750 Megahertz (MHz) and 928 MHz, depending on the region in which it is deployed. Generally speaking, the lower the frequency band, the farther the signal is able to travel. When combined with the narrow channel bandwidths of 1 MHz, 2 MHz, 4 MHz, 8 MHz, and the optional 16 MHz, compared to the smallest 20 MHz channels of conventional Wi-Fi, Wi-Fi HaLow provides an enormous link-budget improvement over the 2.4 GHz, 5 GHz, and 6 GHz Wi-Fi bands, enabling operation of beyond 1 Kilometer (km) in certain configurations, an up to 10X longer range compared to 2.4 GHz Wi-Fi. This capability can help to reduce deployment, management, and optimization cost and complexity compared to conventional Wi-Fi, requiring fewer Access Points (APs), mesh nodes, gateways, or repeaters to be deployed.
Enhanced Signal Penetration and Robustness	The sub-1 GHz band enables much better signal penetration through building materials compared to conventional Wi-Fi technologies. This means Wi-Fi HaLow devices can operate effectively in difficult environments such as attics, basements, or concrete outbuildings. The use of Orthogonal Frequency Division Multiplexing (OFDM) further helps combat multipath fading and enhances resistance to interference, making Wi-Fi HaLow an extremely robust technology. In addition to improving the reliability, range, and user experience of connected devices, it also reduces the need for Wi-Fi extenders or additional gateways and bridges currently needed to provide coverage in these more challenging environments, reducing the cost and complexity of the deployment.
Higher Throughput Compared to Alternative IoT Technologies	While Wi-Fi HaLow is not targeting the same multi-Gbps applications as Wi-Fi 6 and 7, depending on the channel bandwidth and targeted range, Wi-Fi HaLow can provide adaptable data rates that can support a much wider range of applications compared to alternative IoT connectivity technologies. Depending on the channel bandwidth, Wi-Fi HaLow can support data rates spanning a maximum of 86.7 Megabits per Second (Mbps) at short distances to 150 Kilobits per Second (Kbps) when 1 km from the AP or gateway, with the ability to increase or decrease depending on the proximity to the AP. This means Wi-Fi HaLow is flexible enough to support large-scale sensor networks' more limited throughput requirements, in addition to indoor and outdoor surveillance cameras, video doorbells, and voice applications, which require significantly higher data rates. Alternative technologies such as Bluetooth® and 802.15.4 are much more limited on range and unable to support video applications, while technologies such as Narrowband-IoT (NB-IoT), Sigfox, and LoRa support extended range, but with much lower throughput.
High Scalability	Wi-Fi HaLow can support up to 8,191 client devices from a single Wi-Fi HaLow-enabled AP or gateway, typically 4X higher than conventional Wi-Fi APs. However, in real-world performance scenarios, the number of clients that can effectively be supported by conventional Wi-Fi-APs may be much lower. Wi-Fi HaLow-capable APs deployed in the home, office, enterprise, or industrial environment can support scalable, dense network deployments of client devices. In contrast, alternative technologies may require additional gateways or more complex topology deployments (e.g., mesh), which can have negative impacts in terms of deployment complexity, performance, latency, congestion, and overall cost of the solution. If multiple Wi-Fi HaLow APs points are combined in a mesh network, this could enable even greater coverage, enabling neighborhood area, agricultural, and smart city network deployments.
Network Capacity	The additional throughput of Wi-Fi HaLow versus alternative IoT technologies means that it can offer bidirectional communications, while maintaining network performance. This can allow for more intelligent edge devices, reduce latency and real-time monitoring, enable Over-the-Air (OTA) firmware updates, and support larger capacity networks. In contrast, some competitive Low-Power Wide Area Network (LPWAN) technologies with more limited bandwidth may experience considerable network congestion in dense deployment scenarios, and may require manual firmware updating of field devices, reducing QoS and adding significant labor costs. Due to Wi-Fi HaLow's additional throughput, the technology can enable both client devices and aggregators such as APs and IoT gateways, which can offload the information from sensors to the cloud more readily.
Reduced Total Cost of Ownership (TCO)	In addition to requiring fewer APs than conventional Wi-Fi technologies, unlike other licensed wireless technologies for the IoT, Wi-Fi HaLow is an extension of Wi-Fi into the unlicensed sub-1 GHz bands. This Wi-Fi compatibility means there are no additional subscription or network charges to operate. These additional charges may be cost prohibitive in deployments of thousands of client devices, where the cost does not just extend to the hardware itself, but also to the number of devices or amount of traffic that is running on the network. Wi-Fi HaLow can thus help reduce both the upfront infrastructure costs and longer term TCO of an IoT deployment. This can help maximize device and infrastructure Return on Investment (ROI) and simplify the procurement and deployment cycles.

Key Benefit	Technical Info and Extended Discussion
Avoids Congested Frequency Bands	By leveraging the sub-1 GHz frequency bands for Wi-Fi HaLow-enabled IoT devices, additional 2.4 GHz, 5 GHz, and 6 GHz spectrum can be freed up to allow those bands to deliver better performance within high-throughput applications. The performance and QoS of Wi-Fi technology in the 2.4 GHz and 5 GHz bands is increasingly impacted by the volume of Wi-Fi devices, their growing performance requirements, and greater reliance on the technology. The deployment of alternative 2.4 GHz technologies such as Bluetooth® and 802.15.4 in the same environment can also pose additional congestion and interference challenges. By enabling Wi-Fi HaLow to bear some of the burden, Internet Service Providers (ISPs), enterprise network providers, and Operational Technology (OT) implementers can all benefit from improved network performance in the legacy Wi-Fi bands. This can deliver a higher quality and more reliable and robust experience over Wi-Fi technology, a key theme of future innovation such as Wi-Fi 8. Wi-Fi HaLow infrastructure can also be deployed alongside these alternative technologies without impacting their performance.
Reduced Power Consumption	Wi-Fi HaLow incorporates several features to minimize power consumption. In addition to leveraging the sub-1 GHz band to offer greater range with less transmit power than conventional Wi-Fi, additional features such as Target Wake Time (TWT), Restricted Access Window (RAW) and BSS Coloring, among others, can help Wi-Fi HaLow-enabled devices be as efficient as possible, enabling multi-year battery life for certain device types. This can also help extend the life span of higher throughput devices (several Mbps) compared to conventional Wi-Fi technology, enabling months to years of battery life for smart doorbells or battery-powered video cameras. Offering higher throughput than alternative technologies reduces active transmission, allowing for even further power savings. This can also potentially be combined with energy harvesting capabilities to enable even longer life spans or potentially battery-free implementations of the technology.
Simplified Integration	Wi-Fi HaLow, like conventional Wi-Fi, is a native Internet Protocol (IP) technology. This enables Wi-Fi HaLow-enabled end devices to connect directly to the cloud without the need for intermediary translation protocols or proprietary application layers. Non-IP implementations have historically hindered the scalability of certain markets such as the smart home. With the arrival of Thread and the Matter protocol, the industry is converging around IP to enable seamless communications regardless of device type and technology. By supporting IP natively, Wi-Fi HaLow can reduce any potential network architecture, setup, and device management challenges, enabling consumers, Information Technology (IT) personnel, and OT personnel already familiar with Wi-Fi technology to deploy Wi-Fi HaLow swiftly.
Security, Reliability, and Interoperability	Wi-Fi HaLow supports the latest Wi-Fi CERTIFIED WPA3™ security protocols for both consumer and enterprise applications, enabling the technology to be deployed in mission-critical applications such as industrial automation. Furthermore, the high throughput capabilities ensure that critical security and firmware updates can be swiftly deployed OTA, while leaving additional headroom for additional security protocols. As Wi-Fi HaLow is also a relatively new technology, there are also no legacy devices with inferior security that could compromise the network. As with other Wi-Fi technologies, the Wi-Fi HaLow certification program ensures that all Wi-Fi HaLow products are interoperable regardless of the device Original Equipment Manufacturer (OEM). One of the biggest challenges of the IoT, to date, has been the inability of devices from different vendors and connectivity technologies to work together effectively. Thanks to the native IP support, embedding Wi-Fi HaLow technology into a Wi-Fi AP can allow for easy integration of Wi-Fi HaLow devices into the home network, while not degrading performance or creating additional interference issues for other 2.4 GHz technologies. These benefits can also help ensure that Wi-Fi HaLow technology will remain future-proof and conducive to creating an open ecosystem of interoperable Wi-Fi HaLow devices over time.

USE CASES FOR Wi-Fi HaLow

Smart Home

One of the key market verticals that can benefit from adopting Wi-Fi HaLow technology is the smart home. **According to ABI Research, shipments of smart home devices are expected to grow from 846 million in 2023 to over 1.7 billion by 2030.** This includes a diverse range of devices, including door locks, garage door sensors, security cameras, video doorbells, thermostats, lighting, smart speakers and displays, smart appliances, and a variety of sensors, among others. In addition, the expansion of home-connected Electric Vehicle (EV) infrastructure, consumer robotics, energy storage systems, and smart meters will open up new opportunities for wireless solutions in and around the home in the years to come.

Today, a number of technologies serve the smart home market, including Wi-Fi, Zigbee and Thread, Bluetooth® and Bluetooth® Low Energy (LE), Z-Wave, and several other proprietary solutions. Each has several trade-offs when it comes to range, power consumption, throughput, scalability, and other key metrics, meaning that they struggle to meet all the diverse requirements for different smart home devices. In contrast, there are many benefits for leveraging Wi-Fi HaLow technology within a variety of smart home applications, including:

Home Security Cameras and Other Video Applications: The ability to offer tens of Mbps throughput, penetrate walls, operate over longer distances, and minimize power consumption can enable both wired and battered-powered Wi-Fi HaLow security cameras to operate in more remote areas of a property such as basements, outbuildings, and garages. This can help reduce the overall cost of deployment by avoiding the need to purchase an extender or repeater for it to work effectively, or to compromise on the location in which it is deployed due to range limitations. These benefits can also apply to other video applications such as baby monitors or smart doorbells. In 2023, Morse Micro and Primax Electronics announced the Buzz-HaLow smart doorbell to offer longer reach than traditional Wi-Fi, while minimizing power consumption. Earlier this year, Abode Systems and Morse Micro unveiled the Abode Edge Camera, the world's first battery-powered Wi-Fi HaLow smart home security camera, capable of transmission over 1.5 miles with a battery life span of a year. Figure 2 shows some examples of Wi-Fi HaLow security cameras and smart doorbell products on the market.

Figure 2: Wi-Fi HaLow Smart Doorbell and Camera Product Examples

(Source: ABI Research)

Primax Electronics Buzz-HaLow Doorbell

ViewSEC Wi-Fi HaLow Outdoor Bullet & Dome and Indoor Wi-Fi Cameras

Chicony Wi-Fi HaLow Security Camera

Abode Systems Wi-Fi HaLow Edge Camera

Battery Powered Sensors: As more and more sensors and home automation devices are deployed in the home, it will become an enormously tedious and expensive task to continue to charge or replace their batteries every few months. Wi-Fi HaLow's ability to support battery-powered sensors over extended ranges is another key differentiator, enabling more flexible and optimal deployments of various battery-powered home automation devices, including smart locks, window and door sensors, thermostats, and window blinds, among others, while extending their possible life spans.

Consumer Robotics: Wi-Fi HaLow can also enable much more robust outdoor connectivity for consumer robotics devices such as lawn mowers and pool cleaners. Due to the extended range and throughput, Wi-Fi HaLow can ensure these devices always remain connected, even at edges of the property. Thanks to the throughput scaling, the same Wi-Fi HaLow technology can also be leveraged to deliver firmware updates when the robot is closer to the AP. According to ABI Research, annual shipments of consumer robotics devices are expected to reach over 90 million units by 2030.

EV Charging Infrastructure: As demand for home EV charging infrastructure grows over time, Wi-Fi HaLow-equipped connected EV charging units can ensure robust, extended range communication with the home Wi-Fi HaLow infrastructure. This can provide end users with information and notifications on the charging status, enable them to control charging remotely and schedule charging times, and provide them with performance, diagnostics, and even firmware updates. On some properties, the EV charger or garage may be some distance from the main property, requiring either cellular connectivity or Wi-Fi repeaters to operate effectively.

Home Access Control: Wi-Fi HaLow's combination of extended range and low-power consumption can also help enable many different access control devices, including door, garage, gate, barrier, and other entry point locks on the property, bypassing more complex mesh implementations or the need for additional network extenders. The same benefits also apply to motion sensors, exterior lighting, garden sensors, and watering systems, among other outdoor use cases.

Smart Utilities and Neighborhood Network Enablement: Wi-Fi HaLow also has the potential to support neighborhood area networks where alternative sub-1 GHz, LPWAN, and even cellular technologies are used today. For example, Global Navigation Satellite System (GNSS)-enabled child, elderly, and pet tracking devices could leverage Wi-Fi HaLow to offer direct connectivity to a home AP without the need to pay for a cellular subscription. Utility companies could also leverage the extended range capabilities by gathering real-time readings from smart meters or other sensors deployed throughout residential areas, as well as operating as a backhaul technology to aggregate Wi-Fi HaLow or alternative LPWAN solutions to centralize control. This can significantly reduce the setup, maintenance, and cost of neighborhood-level networks.

Smart Building

Incorporating connected technologies within smart buildings, whether they are office spaces, healthcare and educational campuses, hospitality settings, Multi-Dwelling Units (MDUs), or apartment buildings, can lead to numerous benefits. These include reduced energy consumption, reduced operation and maintenance costs, increased life span of commercial equipment, improvements in tenant health and comfort, productivity enhancements, and higher security, resilience, and safety. These benefits are realized through multiple use cases, including Heating, Ventilation, and Air Conditioning (HVAC) control, networked lighting control, access control, video surveillance, and wireless sensor networks, among others.

Wi-Fi HaLow's extended range, better penetration through walls, high scalability, IP support, and strong security are arguably most critical here, given the requirements for campus-level coverage that may span several buildings with dense building materials, outdoor environments, and operation on multiple floors. Wi-Fi HaLow can also help meet the desires of building owners and Building Management System (BMS) operators who require seamless connectivity that can bridge disparate applications into a unified, intelligent smart building network. **With wireless building automation equipment set to reach over 400 million annual shipments by 2027, this represents a significant future opportunity for Wi-Fi HaLow.** Key potential use cases for Wi-Fi HaLow in smart buildings include:

Access Control: Digital access control systems using wireless technology can help reduce the cost of cabling, simplify installation, and enable real-time monitoring and remote operation in times of emergency. They can also enable cabinet, locker, and drawer-level access solutions, and be combined with card, digital key, video, or biometric authentication to provide additional layers of security. Given the large and complex deployment environments of offices, hotels, hospitals, educational campuses, and MDUs, Wi-Fi HaLow's expansive range and enhanced penetration of walls and other obstacles are key benefits for access control solutions. In addition to supporting in-building access control in remote parts of the building, Wi-Fi HaLow can enable access control systems to be deployed in outbuildings, vehicle gates, barriers, garage doors, and other entry points. Support for thousands of clients from a single AP can help simplify room, cabinet, drawer, and locker-level access control deployments without the need to deploy multiple hubs. This also reduces latency by offering direct, centralized control. When this is extended across an entire building, Wi-Fi HaLow can bring enormous potential cost savings in terms of reduced installation costs, deployment complexity, and cost of additional hardware. Recent trials highlighted in the WBA's Wi-Fi HaLow for IoT: Field Trials Report found that just four Wi-Fi HaLow APs could address all building automation services effectively across multiple floors.

Video Surveillance: Security cameras in smart buildings and campus environments typically require wired connections for both power and streaming capabilities. While wireless cameras that leverage Wi-Fi or cellular technologies exist, both can struggle with effective network coverage, penetration though walls, and power consumption, limiting deployment flexibility or requiring the purchase of additional network infrastructure. When this is extended to multiple floors, multiple outbuildings, campus perimeters, or simply over larger-scale sites, the increased costs are significant. Wi-Fi HaLow's ability to support video applications over extended distances, penetrate walls effectively, and reduce power consumption has the potential to enable security cameras with extended battery life and much greater deployment flexibility.

HVAC Control and Wireless Sensor Networks: Smart buildings require the deployment of numerous battery-powered wireless sensors to enable lighting, HVAC, security, access, and fire and safety services across a facility. The diverse deployment environments of smart buildings may require sensors to be deployed over large coverage areas, in outdoor environments, or in more remote areas where equipment is monitored at significant distances away from the nearest AP or IoT gateway. They may also need to be deployed in harsh areas with strong potential for interference, travel through multiple walls, or operate in very high or low temperature environments with difficult signal propagation conditions. Facilities may also want to deploy hundreds or thousands of devices in a single area and require these sensors to have years of battery life. These challenges typically require the use of multiple wireless technologies, which can be complex to integrate into a single intelligent smart building network. Wi-Fi HaLow's inherent benefits can vastly reduce the deployment cost and complexity of smart building wireless sensor network rollouts.

Smart Retail

Retailers continue to face a multitude of challenges, including declining footfall, increased online competition, high energy costs, personnel shortages, the need to deliver new fulfillment methods, and the need to operate more sustainably. To solve these issues, retailers are turning toward wireless smart retail IoT technologies such as smart displays, kiosks and retail robots, Electronic Shelf Labels (ESLs), and automated checkout systems, among several others, to help deliver front end and back end operational efficiencies, increase conversion, and encourage customers to return to stores.

Retail environments can encompass customer-facing, logistics, and warehouse environments, which can be challenging to wireless networks with extensive building sizes, difficult to penetrate building materials, and obstacles that may impact signal propagation. In addition, some retail environments may require thousands of devices to be supported. Here, the unique combination of characteristics that Wi-Fi HaLow offers can potentially streamline deployment and improve the performance of smart retail use cases, including:

Point of Sale (POS) Terminals and Barcode Scanners: With the acceleration of contactless payments and increase in payment limits post-pandemic, **more than 212 million POS terminals are now expected to ship between 2024 and 2027 according to ABI Research.** Much of this will be addressed by battery-powered portable POS terminals equipped with Short-Range Wireless (SRW) technologies such as Wi-Fi and Bluetooth® to connect with base stations or existing wireless infrastructure. Meanwhile, modern countertop and smart POS terminals and cash registers are also coming equipped with Wi-Fi technology to enable more flexible deployments. Wi-Fi HaLow appears to be an obvious solution to help address common range, robustness, and power challenges. With the potential for a single Wi-Fi HaLow AP to enable whole venue coverage and support all terminals, Wi-Fi HaLow POS solutions will be a significant opportunity going forward. Similarly, wireless barcode scanners deployed to enable customers to scan their items as they shop throughout the store can use Wi-Fi HaLow to provide a more robust experience for consumers while extending the device battery life..

Electronic Shelf Labels: The ESL market has grown tremendously in recent years and this growth is expected to continue with **ABI Research forecasting annual shipments of ESLs to grow from 215 million units in 2023 to over 650 million by 2029.** While several wireless solutions underpin the ESL market, many are proprietary and locked into a single vendor, while others operate on the crowded 2.4 GHz band, and others may require extensive backhaul infrastructure to operate effectively. Given the potential for tens of thousands of battery-powered labels in a single retail space covering vast distances and potential dead spots, Wi-Fi HaLow's unique benefits can help provide a more robust experience, streamline deployment, and take advantage of the open nature and security benefits of the Wi-Fi ecosystem. Wi-Fi HaLow can also be utilized within retail gateways or APs to help extend the coverage of these alternative technologies and enable cloud connectivity by acting as an aggregator.

Digital Signage, Kiosks, Smart Displays, and Retail Robotics: Another advantage of Wi-Fi HaLow in retail environments is that the infrastructure can support multiple different use cases, ranging from higher throughput video applications to extended range, low-power label and sensor

applications. To help increase in-store conversion, retailers are increasingly deploying Wi-Fi-enabled kiosks, digital signage, and smart display devices, enabling customers to access additional information on products, receive personalized offers, customize products in-store, and check stock or pay for items directly. In addition, interactive service and inventory robots with high-throughput Wi-Fi connectivity are also being deployed on the retail floor, enabling use cases such as shelf-scanning for inventory management, price checks, misplaced item handling, cleaning, and customer engagement. Each of these can benefit from the scalable throughput, extended range, robustness, and bidirectional connectivity enabled by Wi-Fi HaLow.

Shelf Cameras and Automated Checkout: Retailers are increasingly deploying miniaturized shelf cameras that take images of shelves, refrigerators, freezers, or other retail storage units to help detect stock levels and notify staff when they need to be replenished. With typical deployments requiring several hundred cameras, Wi-Fi HaLow can help enable comprehensive extended network coverage, low-power consumption, and simplified network management from just a single AP. Meanwhile, other camera-based use cases such as automated checkout systems, people counting, and heatmapping can also benefit from Wi-Fi HaLow. For example, Milesight's VS135 Wi-Fi HaLow Ultra ToF People Counter camera can be used to analyze dwell time, track shopping cart fill levels and people flow, and distinguish between staff, adults, and children for better retail analytics.

Industrial IoT

Industrial, warehouse, and logistics facility managers are turning toward wireless connectivity technologies to help enable digital transformation of their enterprises. This encompasses several incentives, including Condition-Based Monitoring (CBM), machine control, asset tracking, Automated Guided Vehicles (AGVs), Autonomous Mobile Robots (AMRs), connected tools, worker safety applications, and industrial scanners, as well as traditional building automation applications.

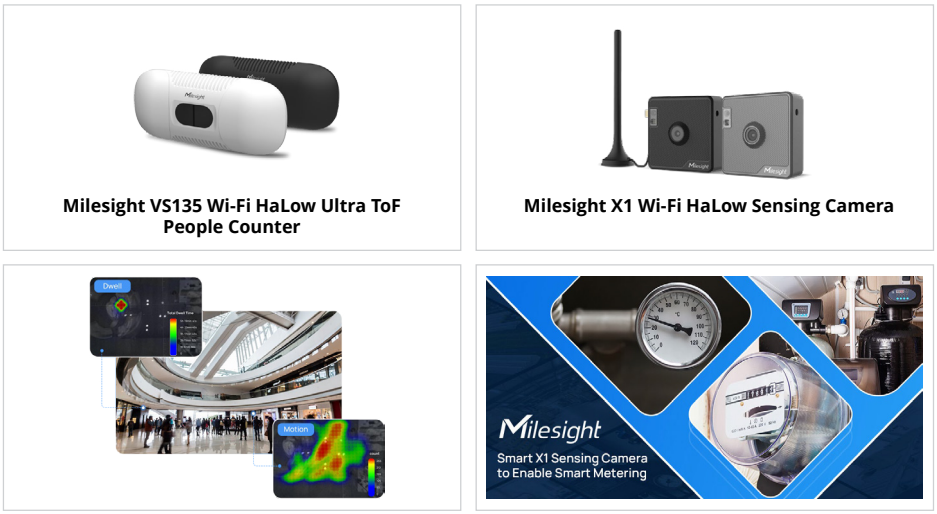
Wireless connectivity solutions are a fundamental pillar of this transformation due to wired solutions being too costly, time consuming, complicated, or hazardous to be deployed. However, many enterprises are still hesitant or find it difficult to deploy wireless technologies effectively. This is due to the harsh Radio Frequency (RF) environment, the need for extremely high reliability, operation in remote areas or over extended ranges, the need to support both low-power and higher-throughput applications, and potentially thousands of clients being deployed in a single facility. Given these limitations, Wi-Fi HaLow can help address some of the existing barriers to the adoption of wireless connectivity in these industrial environments, with key use cases including the following:

Industrial Sensor Networks: Wireless industrial sensors can enable a range of previously unconnected and unmonitored devices to share information and enable predictive and preventative maintenance. This can ensure smoother and safer operations, increase equipment performance, comply with regulations, and reduce the risk of costly downtime. Given the importance of these sensors, reliability is critical. Wi-Fi HaLow's strong coverage and support for thousands of clients from a single AP can significantly reduce deployment complexity, time, and cost, which is typically made more difficult due to the harsh environment, as well as a strong desire to minimize downtime as much as possible. Many sensors may also be deployed in remote or hazardous environments where cabling is too challenging to implement. Here, the combination of Wi-Fi HaLow's range, penetration,

star topology, and low-power consumption will be critical in reducing latency and deployment complexity, and enabling OTA firmware updates. Wi-Fi HaLow can also help to enable unique video sensing applications thanks to its higher throughput. For example, Milesight's X1 Sensing Camera, highlighted in Figure 3, can provide extended range connectivity with multi-year battery life to capture vital information such as meter readings that are critical to the safe and efficient operation of industrial facilities.

Figure 3: Wi-Fi HaLow Sensing and People Counting Camera Product Examples

(Source: ABI Research)



Commercial and Industrial Robotics: Robots such as AGVs, AMRs, and Collaborative Robots (cobots) are increasingly being deployed to enable more flexible production environments. These increasingly require robust wireless connectivity to enable wireless control and remote operation, navigation, diagnostics, and robot-to-robot communication when traveling through large sites. Wi-Fi HaLow's superior penetration through walls, extended range capabilities, and flexible data rates can ensure seamless operation across the entire facility. This can enable remote updates of the robots' tasks or routes simply and at any time, transferring onboard video or sensor information for Simultaneous Location and Mapping (SLAM) purposes, or receiving critical firmware updates. **With annual shipments of commercial and industrial robotics set to grow to nearly 4 million by 2030, this represents another significant opportunity.**

Pickers, Scanners, and Logistics Devices: Various inventory management-related devices such as barcode scanners, Radio Frequency Identification (RFID) readers, and industrial computers are leveraged across warehouse and manufacturing sites. Wi-Fi HaLow can enable more seamless connectivity coverage across an entire facility, allowing greater worker flexibility, while also minimizing the time needed to recharge the device. This can help reduce any potential delays in operations and improve productivity.

Connected Tools: Increasingly, tools that are leveraged in manufacturing or construction sites are being equipped with wireless technologies to monitor their position and usage, check their operational condition, provide enhanced traceability and quality assurance, and enable remote authentication and provisioning. A single Wi-Fi HaLow AP could potentially ensure robust coverage

throughout an entire site, provide real-time monitoring, scale effectively to accommodate potentially thousands of tools on a single network, and free up valuable 2.4 GHz bandwidth for other industrial applications. **As the connected tool market grows to over 14 million annual unit shipments by 2030, more and more devices could benefit from being equipped with Wi-Fi HaLow.**

Asset and Personnel Tracking: Wi-Fi and other short-range technologies such as Bluetooth® and Ultra-Wideband (UWB) are increasingly used to enable Real-Time Location System (RTLS) and asset tracking solutions within commercial and industrial environments. However, these often cover comparatively short distances and require dense networks of anchor points and backhaul infrastructure to track tag positions in large-scale environments, making whole campus coverage difficult and costly to achieve. In contrast, Wi-Fi HaLow APs can support thousands of tags from a single AP, offer better penetration through difficult objects such as shipping containers, and cover both indoor and outdoor environments. The inherently low-power consumption can also extend the battery life of tags, while bidirectional communications enable sensor-enabled tags to provide information on temperature, humidity, and whether a tag has fallen or been impacted. As more and more tags and sensors are deployed, leveraging the less congested sub-1 GHz bands may be desirable to avoid additional 2.4 GHz band congestion. **Toward the end of the decade, hundreds of millions of tags are expected to ship annually across these facilities, representing a large potential opportunity for Wi-Fi HaLow.** Wi-Fi HaLow can also help expand the viability of other RTLS solutions as an extended range backhaul infrastructure.

Other IoT Applications

Given this diversity of applications already discussed, it will come as no surprise that there are many other potential smart city, smart energy, connected agriculture, and other IoT applications that can take advantage of the unique capabilities of Wi-Fi HaLow technology. Some of the more notable include the following:

Smart Cities: The ability to provide extended range connectivity to support smart urban IoT infrastructure use cases places Wi-Fi HaLow in a unique sweet spot compared to alternative connectivity solutions. Wireless smart city sensors connected by Wi-Fi HaLow could help monitor the structural health of buildings, noise and pollution, temperature and humidity, water leaks, and waste levels, as well as control and monitor street lighting or smart parking infrastructure. Here, the deployment of thousands of low-power sensors over extended distances and an ability to penetrate buildings is a critical differentiator. In addition, the ability to mesh Wi-Fi HaLow networks together can also lead to even greater coverage areas being supported. Meanwhile, Wi-Fi HaLow's scalable throughput can also enable video and machine vision-related applications such as Closed-Circuit Television (CCTV), occupancy, crowd and traffic monitoring, and crime detection, among other emerging smart city use cases. TCO can also be reduced through the avoidance of costly cellular or LPWAN subscriptions.

Temporary and Emergency Networks: In emergency response scenarios, disaster zones, or other areas such as construction environments where temporary networks are required, Wi-Fi HaLow could enable extended range connectivity to help protect emergency service personnel and site

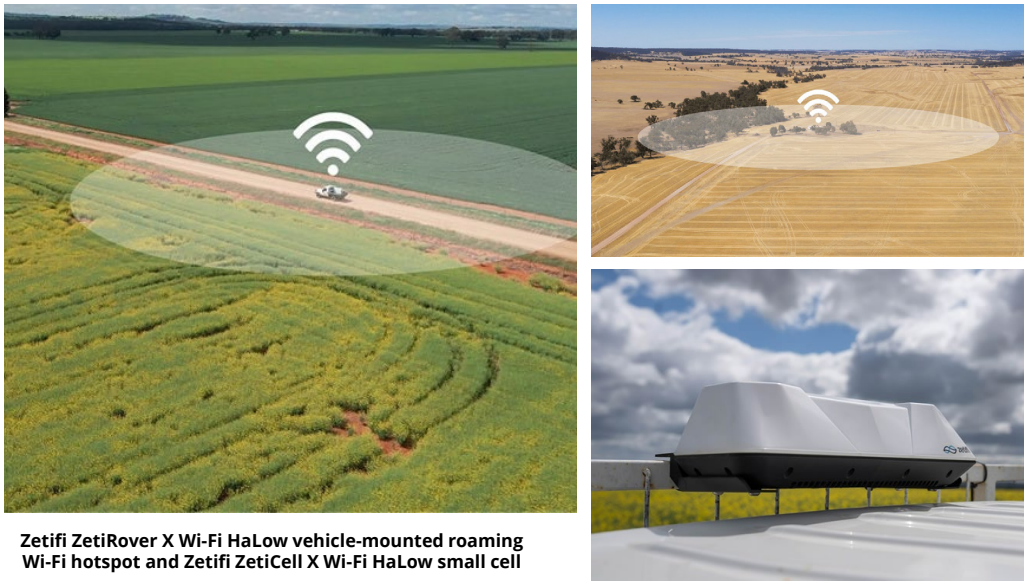
workers, or to provide essential communications when they have been disrupted. For example, a Wi-Fi HaLow AP with cellular backhaul in an ambulance could enable voice and video communication over extended distances, while relaying the location of personnel. Police officers or security personnel can be equipped with body-worn cameras and ensure coverage across large areas. Wi-Fi HaLow could also be used as a backhaul technology in disaster areas.

Smart Energy: Real-time performance monitoring of the energy supply chain is becoming increasingly desired as the transition toward distributed renewable energy generation continues. Wireless sensors and controllers for battery energy storage systems, solar farms, and metering applications can all benefit from the extended range, scalability, and low-power consumption benefits of Wi-Fi HaLow.

Connected Agriculture: Wi-Fi HaLow can also help enable digital transformation across a variety of agricultural environments. A range of wireless sensors and control devices can be deployed across large areas of farmland to deliver increased automation, more effectively monitor soil, plant, and livestock health, and increase yield. This can include weather sensors, moisture sensors, temperature and humidity sensors, asset trackers, pumps, irrigation valves, and many other devices. In addition, the same network could also enable video surveillance and access control applications in outbuildings or entrance points to help protect assets and livestock from theft or predators. As shown in Figure 4, one example of Wi-Fi HaLow's usage in agricultural environments is within Zetifi's next-generation ZetiCell and ZetiRover products, providing stationary and mobile extended range hotspots to enable digital transformation of entire farms without the need for a cellular or LWPAN subscription.

Figure 4: Wi-Fi HaLow Agricultural Hotspot Product Examples

(Source: ABI Research)



Zetifi ZetiRover X Wi-Fi HaLow vehicle-mounted roaming Wi-Fi hotspot and Zetifi ZetiCell X Wi-Fi HaLow small cell

Table 2 provides a visual summary of the key benefits of Wi-Fi HaLow technology across different market verticals and use cases.

Table 2: Benefits of Wi-Fi HaLow Technology Across Different Markets

(Source: ABI Research)

Vertical	Use Case	Extended Range and Enhanced Penetration	Reduced Power Consumption	Support for High Throughput	Security, Reliability, and Interoperability	High Scalability	Deployment Flexibility
Smart Home	Security cameras	●	●	●	●		●
	Video doorbells	●	●	●	●		●
	Door locks and garage sensors	●	●		●		●
	Wireless sensors	●	●		●	●	
	Smart lighting	●			●	●	
	EV chargers	●			●		●
	Consumer robotics	●			●		
Smart Building	Access control	●	●		●	●	●
	Video surveillance cameras	●	●	●	●		●
	HVAC control and wireless sensor networks	●	●		●	●	●
Smart Retail	POS terminals and barcode scanners	●	●		●		●
	Electronic shelf labels	●	●		●	●	●
	Digital signage, kiosks, smart displays and retail robotics	●		●	●		
	Shelf scanners and automated checkout	●	●	●	●		
	Retail building automation	●	●		●	●	
IIoT	Industrial wireless sensors	●	●		●	●	●
	Industrial robotics	●			●		●
	Pickers, scanners, logistics devices	●	●		●		●
	Connected tools	●			●	●	
	Asset and personnel trackers	●	●		●	●	●
Smart Cities	Wireless smart city sensors	●	●		●	●	●
	Video surveillance cameras	●	●	●	●		●
	Smart parking sensors	●	●		●	●	
	Digital signage	●			●	●	
	Smart street lighting	●			●	●	
	Temporary and emergency network infrastructure	●		●	●		
	Battery energy storage systems	●	●		●	●	
	Solar farms	●	●		●	●	
	Smart metering	●			●	●	
Connected Agriculture	Agricultural sensors	●	●		●	●	●
	Livestock trackers	●	●		●	●	
	Video surveillance cameras	●	●	●	●		●
	Access control	●	●		●	●	●

Access Points, Gateways, and Wireless Infrastructure

To deliver on these promises, Wi-Fi HaLow technology needs to be embedded within consumer, enterprise, and industrial Wi-Fi APs, IoT gateways, and other wireless infrastructure if it is to become widely deployed. As Figure 5 shows, there are already many Wi-Fi HaLow APs and gateways on the market, and ABI Research expects many more solutions to emerge soon:

Figure 5: Wi-Fi HaLow Wireless Infrastructure Product Examples

(Source: ABI Research)

Silex AP-150AH-US and EX-150AH Wi-Fi HaLow AP and extender (Silex SX-SDMAH-US module)

AsiaRF Wi-Fi HaLow gateways, routers, and relay devices (AsiaRF MM610X module)

Edgecore Networks EAP112 Wi-Fi 6 and Wi-Fi HaLow router (Morse Micro MM6108 module)

Wireless network infrastructure vendors and service providers are increasingly realizing that there are several benefits from developing Wi-Fi HaLow APs, whether standalone or combined with conventional Wi-Fi and other IoT connectivity technologies, as summarized in Table 3.

Table 3: Wi-Fi HaLow Key Benefits for Infrastructure Providers

(Source: ABI Research)

Key Benefit	Technical Info and Extended Discussion
Easily Extending the Existing Network	The extension of most Wi-Fi networks typically requires deploying mesh nodes or a significant increase in the number of APs and gateways to provide whole building or campus area coverage, bringing additional hardware and cabling costs. In contrast, deploying just one Wi-Fi HaLow AP can enormously increase network coverage to 1 km or beyond. Being a Wi-Fi technology and IP native, integration and management is as simple as managing the existing infrastructure. Wi-Fi HaLow can penetrate different building materials to ensure robust coverage indoors on multiple floors, outdoors, and within outbuildings. This reduces dead spots, which typically leads to more service calls and frustration with ISPs and network service providers. Meanwhile, outdoor coverage is typically extremely limited or impossible depending on the AP location. By leveraging the sub-1 GHz band, there will be no detrimental impact to technologies deployed in other bands.
A Backhaul Solution for Other IoT Technologies	Multiple technologies are required to address the diverse requirements of the IoT. By embedding Wi-Fi HaLow alongside them, its higher throughput capabilities can be leveraged as a robust, extended range backhaul technology solution. This means end users can maximize the performance of their network and allow each technology to take advantage of its unique benefits, optimizing the overall efficiency, scale, cost, and simplicity of the deployment. Meanwhile, in Wi-Fi mesh networks, Wi-Fi HaLow can be deployed as an additional backhaul or redundancy technology between different mesh APs. While Wi-Fi HaLow will not be able to offer the same high throughput as conventional Wi-Fi, there is likely to be a sweet spot depending on the channel width leveraged that can utilize tens of Mbps at extended range. This can extend network access, video, and audio capabilities to outbuildings and outdoor environments where traditional mesh is incapable of reaching.
Flexible Network Infrastructure	For those looking to support video and audio applications, offer extended range connectivity up to 1 km or beyond, and support low-power consumption devices with years of battery life. Today, this requires combining multiple different technologies as part of the network infrastructure. Wi-Fi HaLow can achieve this on its own, and even when deploying all of these technologies on a single AP, they still cannot provide video capabilities at range and may be inferior in terms of latency, complexity of setup, management, security, and cost.
Future-proof	By integrating Wi-Fi HaLow technology into infrastructure, network service providers can create a future-proof backbone network that can address both current and future use cases. Solution providers can safely bet on future Wi-Fi HaLow devices being backward-compatible with the existing infrastructure, as well as other benefits such as multi-vendor chipset and device availability, interoperability, strong security, and native IP support. The ability to support thousands of clients from a single AP will enable larger-scale IoT deployments, while network providers can also enable valuable new services and applications thanks to the ability to deploy across the entire home or enterprise.
Enhancing Network Capacity	In congested deployment environments, the addition of a fourth Wi-Fi frequency band can open up significant new capacity in which video, audio, and IoT devices can operate. Offloading certain device categories onto this less congested sub-1 GHz band will not only improve the performance of those devices, but also free up valuable capacity in the traditional Wi-Fi bands for more stringent, high-throughput, and low-latency applications. This can be extremely valuable for ISPs and enterprise infrastructure vendors to improve end-user satisfaction and the reliability and robustness of their products, while deploying even more IoT devices.

THE GROWING MOMENTUM FOR Wi-Fi HaLow TECHNOLOGY

Over the last few years, momentum for Wi-Fi HaLow technology has accelerated. The arrival of new Intellectual Property (IP), chipsets, and modules from multiple vendors has led to more and more commercial products hitting the market. This includes a range of device types, including security, sensing, and people counting cameras, smart doorbells, wireless sensors, and a diverse combination of enterprise, industrial, and agricultural APs, extenders, gateways, and bridges, among others. These devices are helping to prove the credentials of Wi-Fi HaLow technology in the real world and helping to forge the pathway to an end-to-end Wi-Fi HaLow ecosystem. The availability of such solutions is expected to grow considerably over the next few years as awareness of the market develops further and the tangible benefits of the technology are increasingly realized.

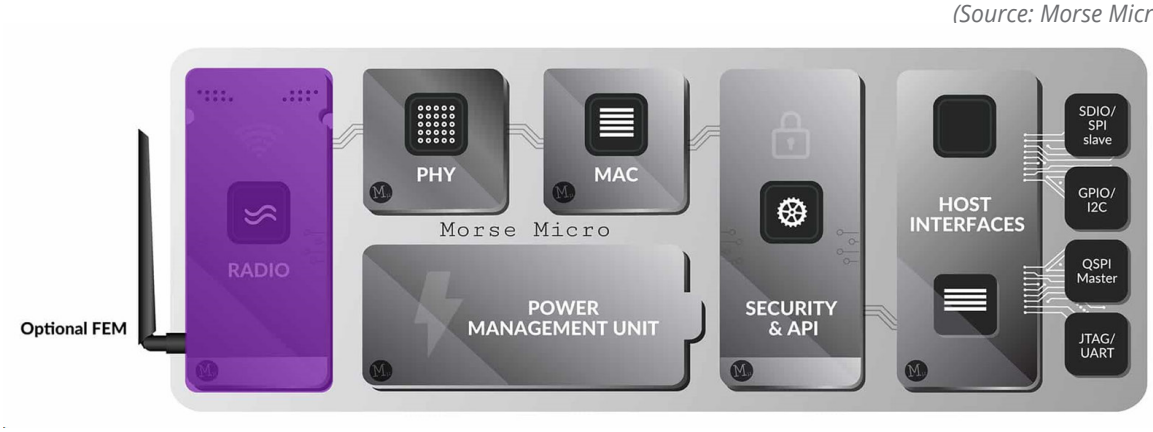
Continued Chipset Innovation

Furthermore, leading Wi-Fi HaLow chipset vendors such as Morse Micro continue to innovate to improve their product offerings, offering smaller, lower-cost, and highly-efficient single-chip solutions that can be more readily deployed across multiple regions. For example, as Figure 6 demonstrates, Morse Micro's latest MM6108 System-on-Chip (SoC) is a single-chip Radio, PHY, and MAC Wi-Fi HaLow solution that operates in the 850 MHz to 950 MHz frequency bands. The solution supports up to 8 MHz wide channels capable of providing up to 32.5 Mbps single-stream throughput.

In addition to an on-chip Power Amplifier (PA) to help speed up deployment and reduce the overall cost, the solution can also be partnered with an external PA, Low-Noise Amplifier (LNA), or Front End Module (FEM) to extend the reach of the technology even further. Combined with high linearity, selectivity, and low out-of-band transmitter noise, the MM6108 can provide extended range and high-throughput connectivity compared to alternative IoT technologies, while minimizing power consumption, offering superior signal penetration, providing strong coexistence, and reducing the TCO by avoiding cellular or LPWAN subscription costs.

Figure 6: Morse Micro's MM6108 SoC Diagram

(Source: Morse Micro)



A Growing Module Ecosystem

Alongside the SoC, Morse Micro also provides an integrated module solution, the MM6108-MF08651-US Wi-Fi HaLow® module, helping to reduce development complexity and shorten the time to market. Meanwhile, growing partnerships between chipset and module vendors are helping to streamline the cost and time required to develop Wi-Fi HaLow devices. In addition to Morse Micro's own module solutions, the company has partnered with several module vendors to integrate it MM6108 SoC, including:

- **AcSip:** AI6108L
- **AsiaRF:** MM610X-001
- **AzureWave Technologies:** AW-HM581 and AW-HM593
- **MegaChips:** MRF61 FI and MRF61 FI MCU
- **Quectel:** FGH100M
- **Silex Technology:** SX-SDMAH
- **Vantron:** VT-MOB-AHs

Figure 7: Wi-Fi HaLow Module Product Examples

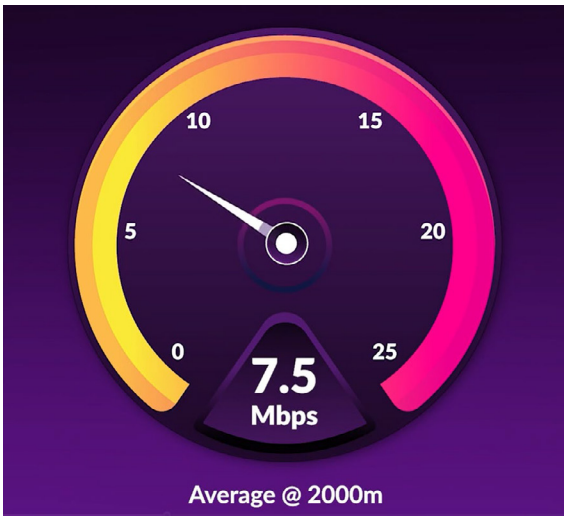
(Source: ABI Research)

Wi-Fi HaLow Field Trials and Case Studies

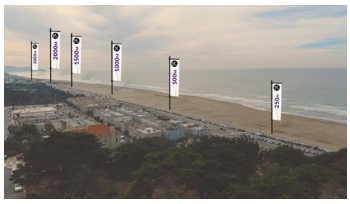
In addition to these real-world products, in July 2024, the WBA made available its Wi-Fi HaLow for IoT: Field Trials Report, demonstrating the effectiveness of Wi-Fi HaLow across a range of environments, including smart home, industrial, warehouse, connected agriculture, smart city, and smart building environments. The findings from these trials validated Wi-Fi HaLow's enhanced range, signal penetration and robustness, high scalability, and reduced power consumption. In early 2024, Morse Micro conducted a live demonstration of a video call over Wi-Fi HaLow at a distance of up to kilometers in San Francisco's Ocean Beach neighborhood. As Figure 8 demonstrates, this was able to achieve an average of 7.5 Mbps at a distance of 2 km. Meanwhile, in September 2024, Morse Micro conducted another field test of Wi-Fi HaLow technology in Joshua Tree National Park. Here, the technology was able to achieve 2 Mbps throughput at a distance of 15.9 km (just under 10 miles).

Figure 8: Wi-Fi HaLow Extended Range Trial Examples

(Source: Morse Micro)



An average of 7.5 Mbps over a distance of 2 km was achieved at the Wi-Fi HaLow Extended Range Video Call Trial in the San Francisco Ocean Beach neighborhood



Wi-Fi HaLow Extended Range Video Call Trial in the San Francisco Ocean Beach Neighborhood

Wi-Fi HaLow Extended Range Trial at Joshua Tree National Park

While these were in optimal test conditions, this, as well as the WBA field trials demonstrate the potential for Wi-Fi HaLow technology to support a wide range of indoor and outdoor environments and applications where extended range, robustness, reliability, and scalability are key differentiators from alternative technologies. While there is still undoubtedly work to be done, these trials and the development of a growing Wi-Fi HaLow ecosystem, represent critical steps on the pathway to success for the technology.

WI-FI HALOW MARKET OPPORTUNITIES AND FORECASTS

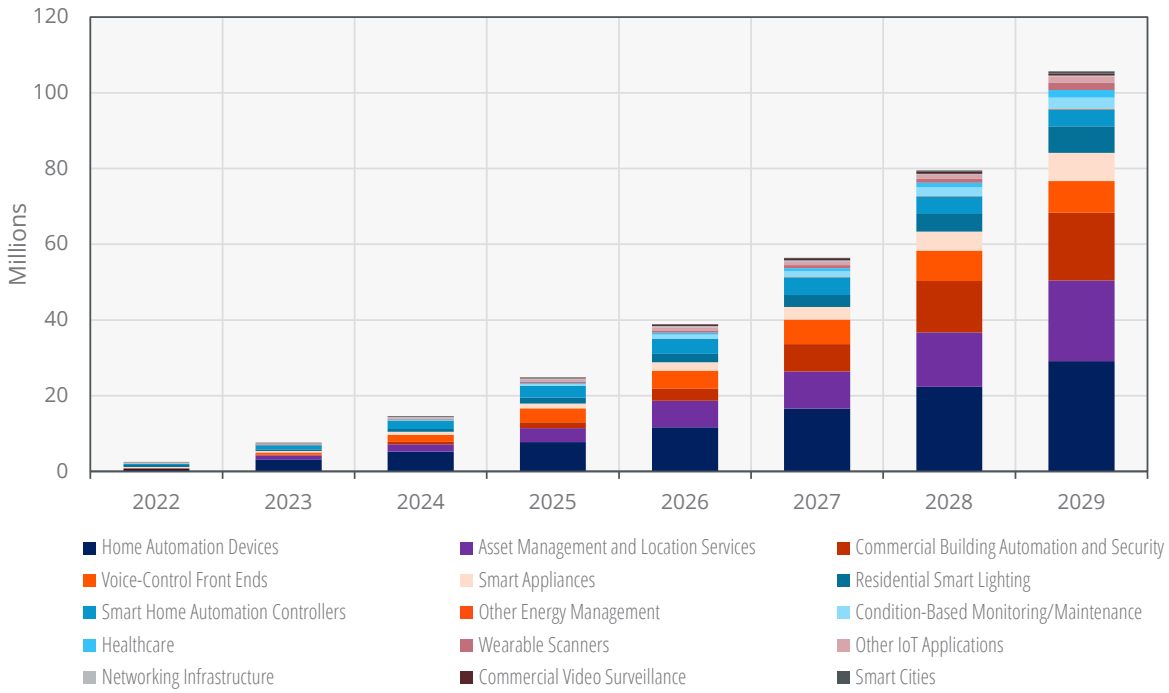
Despite the many benefits of Wi-Fi HaLow, device shipments are currently several orders of magnitude lower than conventional Wi-Fi, Bluetooth® LE, and 802.15.4. However, over the next 5 years, ABI Research expects Wi-Fi HaLow to be one of the fastest growing wireless connectivity technologies on the market as more chipsets and modules emerge, the regulatory landscape improves, industry awareness grows, and the availability of Wi-Fi HaLow-compatible devices and infrastructure continues to accelerate.

Due to the ability to address indoor, outdoor, remote, high-throughput, low-data, and battery-sensitive use cases alike, the Total Addressable Market (TAM) for Wi-Fi HaLow is very large. While Wi-Fi HaLow will not replace existing technologies such as Wi-Fi, Bluetooth®, and 802.15.4 across the IoT, the technology is likely to capture a growing portion of the IoT market over time as device OEMs realize the unique benefits of the technology. **With a connected device installed base of nearly 88 billion by 2028,** capturing even a small percentage of the IoT market would yield high shipment volumes. With key Wi-Fi HaLow target areas such as the smart home, smart building, smart city, and IIoT combining to reach billions of annual device shipments in the coming years, this represents a sizable opportunity.

There are also many potential new use cases that could be enabled thanks to this differentiation from existing technologies. While some of these may be smaller scale or even still to be developed today, Wi-Fi HaLow could create sizable opportunities within extended range applications where proprietary, LPWAN, or cellular technologies are deployed today. This could lead to more open ecosystems, reduce TCO through the avoidance of subscription costs, require less infrastructure to be deployed, and bring swifter and simplified deployments.

Chart 1: Total Wi-Fi HaLow-Enabled Device Shipments World Markets: 2023 to 2029

(Source: ABI Research)



As Chart 1 shows, annual shipments of Wi-Fi HaLow-enabled devices are expected to grow from several million in 2023 to nearly 108 million by 2029. ABI Research expects this to be driven by significant adoption within smart home, smart building, asset tracking, and inventory management applications, as well as a whole host of other IoT applications, including video surveillance, industrial sensors, POS terminals, connected agriculture, smart metering, smart street lighting, smart parking, and healthcare patient monitoring. However, much will also depend on the timeline of integration of Wi-Fi HaLow within residential and enterprise WLAN infrastructure. If the adoption of Wi-Fi HaLow technology within Wi-Fi APs, mesh nodes, and enterprise APs and IoT gateways is swifter, then ABI Research expects wider Wi-Fi HaLow client device adoption to be much more rapid. Similarly, new entrants to the chipset and module ecosystem, adoption from leading consumer device manufacturers, and integration into other potential hub devices such as smart speakers could also further accelerate Wi-Fi HaLow's adoption.

ENABLING A SUCCESSFUL Wi-Fi HaLow ECOSYSTEM

Wi-Fi HaLow's unique characteristics set it apart from existing connectivity technologies on the market. These attributes hold the potential to enhance the performance of existing IoT use cases, while enabling the creation of valuable new consumer, enterprise, and IIoT applications. However, the realization of this potential will hinge on the ability of Wi-Fi HaLow to overcome several challenges and to create a compelling value proposition, ecosystem, and regulatory environment for the technology. This section discusses how the Wi-Fi HaLow ecosystem can flourish in the years to come.

Regulatory Challenges

- Arguably the biggest challenge for Wi-Fi HaLow technology is the regional divergence in sub-1 GHz spectrum availability, transmit power, and duty cycle restrictions. While some regions, such as the United States, can support up to 16 MHz channels, others may be limited to 2 MHz channels, and certain countries like China have no spectrum available for Wi-Fi HaLow at all. This not only potentially adds complexity to product design, but also means that some of the major higher throughput benefits and use cases for Wi-Fi HaLow may not apply to all regions, limiting the utility of the technology.

- However, work is ongoing to increase the spectrum availability for Wi-Fi HaLow around the world, and various regions are currently exploring options for additional sub-1 GHz spectrum. In addition, to help combat any potential additional complexity of developing multiple Stock-Keeping Units (SKUs) per region, solution providers such as Morse Micro have developed modules that can offer flexible operation depending on the region where they are deployed.

- Furthermore, as awareness of the unique benefits of Wi-Fi HaLow grows, additional trials of the technology are conducted, and more and more devices arrive in market, there will be additional incentive to open up additional spectrum for the technology. Given the potential to help ease congestion in other Wi-Fi bands, additional spectrum for Wi-Fi HaLow could also help contribute to solving the broader spectrum challenge for Wi-Fi technology in other unlicensed bands. As a result, in addition to existing standards organizations pushing for global spectrum alignment, regional- or vertical-oriented representative organizations must also come together to push for greater regulatory convergence to help ensure the Wi-Fi HaLow ecosystem can scale effectively and deliver on its promises of performance scaling to different applications.

Ecosystem Formation

- To date, the availability of chipsets, modules, infrastructure equipment, and end devices that support Wi-Fi HaLow has been very limited. This chicken-and-egg challenge has impacted many new technologies, inhibiting speed of adoption, awareness, innovation from competition, product maturity, and willingness to invest in the technology. Critical to the success of Wi-Fi HaLow is embedding the technology in Wi-Fi infrastructure, including APs and IoT gateways, whether through embedded solutions or aftermarket dongles and adapters that can be integrated to enable Wi-Fi HaLow functionality.

- Combining these approaches and forming strategic partnerships with ISPs and Managed Service Providers (MSPs) will be vital in creating an installed base of Wi-Fi HaLow infrastructure from which awareness and device adoption can accelerate. However, over the last couple of years, the

availability of Wi-Fi HaLow equipment and devices has grown significantly. There is a clear renewed interest in Wi-Fi HaLow technology, and while it has taken some time to reach this point, greater availability of chipsets, devices, and infrastructure could lead to accelerated adoption over the next few years.

Market Education, Awareness, and Positioning

- Given its relative immaturity, Wi-Fi HaLow is not yet a household name. Significant work still needs to be done to increase awareness of the technology and the benefits it can provide in relation to the competition. More effort also needs to go into showing how Wi-Fi HaLow is an extension of Wi-Fi technology into the sub-1 GHz band and not just another IoT technology adding complexity to an already crowded ecosystem.
- Thankfully, with the arrival of the Wi-Fi Alliance's Wi-Fi HaLow certification program, recent field trial tests from the WBA mentioned throughput this paper, and other regional consortia such as the 802.11ah Promotion Council (AHPC), which seeks to help accelerate the commercialization of Wi-Fi HaLow in Japan, awareness of and belief in the real-world benefits the technology can bring are starting to be realized.
- The Wi-Fi HaLow ecosystem should also look to foster additional vertical-level partnerships to help accelerate adoption of the technology within the smart home, commercial building, industrial, and other key sectors that can benefit from the technology.

Competitive Landscape

- Wi-Fi HaLow has also entered a hugely competitive landscape of IoT wireless connectivity technologies. This includes Bluetooth® LE, Zigbee and Thread, Z-Wave, proprietary 2.4 GHz and sub-1 GHz, NB-IoT, LoRa, and Sigfox, and 5G Reduced Capability (RedCap), among others. With the continued proliferation of low-cost Wi-Fi 4 and low-power innovation from Wi-Fi 6, some of the greatest competition is coming from within the Wi-Fi ecosystem itself. This has the advantage of a huge installed base of infrastructure to connect to, the ability to support video applications, huge awareness and market familiarity, low-cost solutions, global availability, and a strong ecosystem of chipsets, modules, and device manufacturers that are already established within many IoT sectors. These solutions, regardless of the development of Wi-Fi HaLow, will continue to exist in the years to come.
- Advocates should, therefore, continue to emphasize and promote the unique differentiators of Wi-Fi HaLow such as extended range, superior robustness, and scalability both in terms of the number of client devices and the number of use cases that can be supported.
- Furthermore, while Wi-Fi HaLow may not be as cost-effective as some alternatives, the TCO of deploying Wi-Fi HaLow technology can be considerably lower due to the ease of deployment through reduced installation and maintenance costs, the use of subscription-free unlicensed spectrum, simplified integration into existing buildings, and the extended range star topology, which requires less additional costly infrastructure to be deployed compared to the alternatives.
- Wi-Fi HaLow solution providers should also focus on these core strengths and try to stand out in these areas, rather than try to be another one-size-fits-all technology that can attempt to address every single application. This will also require targeted partnerships with key players and market leaders within those application segments.

Technology Innovation and Maturity

- Wi-Fi HaLow is currently less mature in terms of chipset, module, infrastructure, and device development compared to other technologies. Continued enhancement of key metrics such as robustness, form factors, pricing, and reduced power consumption will be vital in ensuring the long-term success of the technology over the competition.
- Also important in the IoT space is collaboration and interoperability with alternative connectivity solutions. This can enable enhanced performance, reduce power consumption, deliver smaller device form factors, speed up time to market, enhance user experiences, and enable compelling and valuable new features such as positioning and sensing to differentiate from the competition.
- Therefore, developing Wi-Fi HaLow chipsets, modules, infrastructure, and devices that may integrate with other technologies such as Bluetooth® LE for provisioning or low-power sensors, UWB, or GNSS for positioning, or conventional Wi-Fi for higher throughput applications will likely be needed over time and can also help strengthen Wi-Fi HaLow's unique value proposition within different IoT applications.

FINAL RECOMMENDATIONS

Wi-Fi HaLow technology offers a unique value proposition compared to alternative IoT connectivity technologies. As a non-proprietary sub-1 GHz extension of Wi-Fi designed specifically for extended range, highly scalable, and low-power consumption IoT applications, its ability to be deployed more easily in challenging indoor and outdoor environments without the need for additional subscription costs, as well as its support for comparatively high data rates, high security, and higher capacity networks, make it increasingly compelling. Different parts of the IoT ecosystem should, therefore, look toward Wi-Fi HaLow to enable use cases, help create valuable new services and experiences, and accelerate digital transformation of their enterprises. This includes:

- **Module Vendors:** For module vendors, incorporating Wi-Fi HaLow into their portfolio can enable them to stand out from the crowd and add more flexibility to their product offerings. For those already targeting LPWAN and cellular IoT applications, this could be a natural extension and enable solutions with a lower TCO, which could entice new device OEMs. Solution providers without an extended range solution can leverage Wi-Fi HaLow to enable their customers to target new applications.
- **Device Manufacturers:** For device OEMs, there will be opportunities to create new products deployed outside of the home that can benefit from extended battery life spans or support higher throughput, creating unique value and services for end users. Wi-Fi HaLow can also enable vendors to differentiate their product offering in an already crowded IoT market and solve today's key deployment challenges. Meanwhile, for enterprise use cases, new product categories or expansion into new verticals that were previously too challenging to support can be enabled.
- **Infrastructure Vendors:** Embedding Wi-Fi HaLow can also enable Wi-Fi equipment vendors to differentiate their infrastructure solutions from the competition, offering their customers a compelling value proposition of simplified whole-home and enterprise coverage, enhancing brand loyalty, while reducing technical support challenges. For residential AP vendors, outdoor coverage and neighborhood area networks could be enabled to create valuable new home security, metering, and location tracking use cases to create new monetization opportunities. Meanwhile, with certain enterprise and industrial environments hesitant to adopt 2.4 GHz technology

altogether, Wi-Fi HaLow could also allow Wi-Fi vendors to break into new markets and expand their revenue streams to new sectors. Wi-Fi HaLow has the potential to be another tool in the arsenal of Wi-Fi infrastructure to improve coverage, QoS, and reliability, which is becoming increasingly critical across various IoT markets.

- **Smart Building Owners:** Building owners should investigate the potential of Wi-Fi HaLow to enable campus-wide coverage to enable valuable new safety, security, HVAC, retail, asset tracking, and other related applications that can be simple to deploy and future-proof, and that have a lower TCO. Proprietary solutions that may be locked into single vendors can be avoided and the native IP capabilities will make it easier to integrate and manage alongside existing deployments.
- **Governments, Municipalities, and Utility Companies:** Wi-Fi HaLow can provide extended range and high throughput coverage to support a wide range of smart city sensor, metering, tracking, and surveillance applications without the need to invest heavily in a cellular network or pay recurring LPWAN subscription fees. Wi-Fi HaLow can help simplify deployment with reduced infrastructure and compete in areas where LPWAN and cellular currently have distinct advantages.
- **End Users:** Consumers and other end users of the technology should look at how Wi-Fi HaLow can enable better user experiences in their home or enterprise environment, including more flexible deployment of devices, extended battery life, greater reliability, support for outdoor applications, and simplified connectivity and management.

Now, with the growing availability of Wi-Fi CERTIFIED HaLow chipsets, modules, infrastructure, and client devices from numerous vendors, combined with the clear benefits demonstrated by the recent WBA trials, device manufacturers and end users looking to digitally transform their home, enterprise, campus, facility, municipality, or agricultural site should investigate the potential of Wi-Fi HaLow technology as soon as possible. This can enable scalable, easy to deploy, and reliable extended range connectivity to support multiple different IoT use cases over a streamlined network infrastructure, reduce the overall TCO compared to the competition, and enable a unique combination of IoT applications that other technologies are unable to support on their own.

Morse Micro

Published October 2024
157 Columbus Avenue
New York, NY 10023
Tel: +1 516-624-2500
www.abiresearch.com

We Empower Technology Innovation and Strategic Implementation.

ABI Research is uniquely positioned at the intersection of end-market companies and technology solution providers, serving as the bridge that seamlessly connects these two segments by driving successful technology implementations and delivering strategies that are proven to attract and retain customers.