IIJ's LPWA Initiatives
—Current State of LoRaWAN® and Outlook for Wi-Fi HaLow™

2.1 Introduction

The term IoT (Internet of Things) has been around for quite some time now, and IoT is undoubtedly one of the key tools we have for addressing contemporary social challenges, including those highlighted by the UN's Sustainable Development Goals. Examples include the use of IoT in smart agriculture and other such efforts to improve productivity amid a declining labor population, and to achieve high energy efficiency in smart cities. As IoT itself is an abstract concept, there are various approaches to deploying it, with one well-known example being the use of sensors and other devices equipped with LPWA (Low Power Wide Area) wireless technology to collect and utilize data.

LPWA, as the name suggests, refers to wireless technologies that provide wide-area coverage with low power consumption. It limits power consumption by reducing communication speed and frequency, and while differences may arise depending on communication methods and operation practices, the sensors and other such devices can run for years even on small batteries. Strategies used to minimize signal degradation over long-distance transmissions include narrowing the wireless frequency band and the use of spread spectrum techniques. LPWA can be broadly categorized into licensed-band LPWA (provided by communication carriers) and unlicensed-band LPWA (freely available to anyone using wireless devices, such Wi-Fi® devices, approved by the Ministry of Internal Affairs and Communications*1). Within these categories, there are several communication methods, each with their own characteristics as shown in Table 1.

	Communication method	User-installed base stations	Approx. range	Approx. speed	Main characteristics
Licensed band (uses mobile phone frequency bands)	LTE-M	Not needed	Within base station area	Up to several 100kbps*3*4	A major protocol in the licensed-band category as it can use existing LTE infrastructure. Higher power consumption vs. other methods, but supports handover, making it suitable for mobile applications.
	NB-IoT	Not needed	Within base station area	Up to 100kbps*3	Reduces power consumption by reducing bandwidth and transmission speed vs. LTE-M. Does not support handover. Limited base station deployment in Japan due to lack of LTE compatibility; only offered by SoftBank at present*5.
Unlicensed band (mainly 920MHz-band specified low-power radio) *2	ELTRES™	Not needed	Up to 100km*6	Several 10bps*7	A proprietary communications standard developed by Sony that supports ultra-long-distance transmission and mobile applications. Uses GNSS time synchronization and is thus designed for outdoor use. Service including base stations provided by Sony Network Communications.
	LoRaWAN®	Required	Up to 10km	Up to ~5kbps	Uses the LoRa® protocol developed by US-based Semtech. Use of chirp spread spectrum modulation makes it robust to noise. The LoRaWAN® specification defines protocols for the physical layer up (excl. application layer), and because the specification is open, it is used on many devices around the globe among unlicensed LPWA systems*8.
	Sigfox	Not needed	95% population coverage*9	100bps*10	Provided by France-based UnaBiz SAS. Uses ultra narrow band (100Hz) technology to minimize radio interference. Speed is limited, but it is cost-effective. In Japan, service including base stations is provided by Kyocera Communication Systems.
	Wi-Fi HaLow™	Required	Up to 2km*11	Up to several Mbps*11	Standardized as IEEE 802.11ah, based on existing Wi-Fi® (IEEE 802.11 series) technology. HaLow is the designation for devices certified by the Wi-Fi Alliance®. Highest speed among unlicensed LPWA systems; also suitable for streaming communications.
	ZETA	Required	Up to 10km*12	Up to 50kbps*12	Developed by China-based ZifiSense. Uses ultra narrow band (2kHz) communication. Supports multi-channel communication and mesh networking.

Table 1: LPWA Types and Main Characteristics

*1 In Japan, this generally refers to devices bearing the Technical Conformity Mark (Giteki Mark).

*2 Most unlicensed-band protocols used in the LPWA space use 920MHz-band specified low-power radio. The 920MHz band is considered suitable for IoT applications because, compared with other specified low-power radio bands, it performs well in the presence of obstacles (readily diffracts around them) and offers both communication speed and transmission range. "Keiso Mamechishiki: 920MHz Band Musen Tsushin ni Tsuite" [Instrumentation Tidbits: About 920MHz-band Wireless Communications], MG Trend (https://www.mgco.jp/magazine/plan/mame/b_network/1510/, in Japanese). "Sub-GHz musen towa" [What is Sub-GHz Wireless], TechWeb (https://techweb.rohm.co.jp/product/wireless/sub-ghz/43/, in Japanese).

At IIJ, we are focusing on LoRaWAN®, which is becoming the global de facto standard in the unlicensed-band arena, and we offer a range of services that use LoRaWAN®. We are also conducting technical research and the like with a focus on Wi-Fi HaLow™, which is based on existing Wi-Fi® technology and thus has the benefit of user familiarity. In this article, we discuss IIJ's current LoRaWAN® initiatives, the technical characteristics of Wi-Fi HaLow™, with reference to our own experimental results, and future prospects.

2.2 IIJ's LoRaWAN® Initiatives

LoRaWAN® has the largest global market share among unlicensed-band LPWA technologies, with the number of connections projected to reach around 500 million in 2024 and 750 million by 2026[*8]. While overseas markets have been quicker to adopt the technology in areas such as service metering (e.g., water supply) and smart buildings, adoption is also expanding in Japan in the areas discussed below, with IIJ taking the lead.

■ Agricultural IoT

In 2017, IIJ was commissioned by Japan's Ministry of Agriculture, Forestry and Fisheries to carry out the management entities strengthening project within the ministry's Innovative Technology Development and Urgent Deployment Program. Under the project, we conducted R&D (including demonstration tests) on the use of IoT technologies to improve water management efficiency in paddy fields[*13*14].

We adopted LoRaWAN®, which has the following advantages as an LPWA wireless standard for agricultural IoT[*15].

- End devices (sensors etc.) can run for years even on small batteries if measurement rate is low.
- Base stations can be placed according to usage patterns, so there are fewer service provider constraints (can be used outside other standards' service areas).
- Communication between end devices and base stations is cost-free, so there are cost advantages to be had from using only a few base stations to cover many devices.
- Supports downlink communication, enabling simple device control.
- As an open standard, it makes it easy to create use cases by combining devices from multiple vendors.

Our R&D efforts demonstrated that by using the paddy field sensors and automatic water valves we developed, it is possible to reduce the total time spent on paddy field water management (including opening/closing water valves and travel time) by around 70%[*14].

*3 "Dai yon-ji sangyo kakumei ni okeru sangyo kozo bunseki to IoT/AI-to no shinten ni kakawaru genjo oyobi kadai ni kansuru chosa kenkyu hokokusho" [Research Report on Industrial Structure Analysis and Current Status of and Challenges Related to the Advance of IoT/AI in the Fourth Industrial Revolution] National Diet Library Search (https://ndlsearch.ndl.go.jp/books/R100000039-I11370285, in Japanese).

*4 "Hodo-happyo-shiryo '(oshirase) IoT service-muke tsushin hoshiki 'LTE-M' wo teikyo kaishi'" [Press Release (Notice) Launch of 'LTE-M' Communication System for IoT Services], NTT Docomo (https://www.docomo.ne.jp/info/news_release/2018/09/26_00.html, in Japanese).

*5 "Kokunai yuiitsu, Softbank no NB-IoT senryaku" [Softbank's NB-IoT Strategy: Unique in Japan", Business Network (https://businessnetwork.jp/article/7505/, in Japanese).

*6 "Gaiyo" [Overview], SONY ELTRES™ (https://eltres-iot.jp/overview/, in Japanese).

*7 "ELTRES™ IoT Network Service", NURO Biz (https://biz.nuro.jp/service/eltres/detail/, in Japanese). "[QA shu] Tokucho, tsushin sokudo, area, shiyo, kakaku nado" [Q&A Collection: Features, Communication Speed, Coverage, Specifications, Pricing, etc.", Sony (https://iot.sonynetwork.co.jp/column/column010/, in Japanese). Transmits a maximum 128-bit payload 4 times every 5 seconds.

*8 "Reiwa 6-nen-ban joho-tsushin-hakusho data-shu" [Information and Communications White Paper, 2024 Data Collection], Ministry of Internal Affairs and Communications (https://www.soumu.go.jp/johotsusintokei/whitepaper/ja/r06/html/datashu.html#f00239, in Japanese).

*9 "Service Area", IoT Network Sigfox, KCCS (https://en.kccs-iot.jp/area/).

*10 "LPWA towa" [What is LPWA], IoT Network Sigfox, KCCS (https://www.kccs.co.jp/sigfox/service/lpwa/, in Japanese).

*11 "802.11ah ni tsuite" [About 802.11ah], 802.11ah Promotion Council (https://www.11ahpc.org/11ah/index.html, in Japanese).

*12 "ZETA LPWA Network" Zeta Alliance (https://japan.zeta-alliance.org/zeta.php, in Japanese).

*13 "Suiden mizu kanri ICT katsuyou consortium wo setsuritsu shi, Norin-suisan-sho no kobo jigyo 'kakushinteki gijutsu kaihatsu / kinkyu tenkai jigyo' wo jutaku" [IIJ Establishes Paddy Field Water Management ICT Utilization Consortium and Wins Commission for Ministry of Agriculture, Forestry and Fisheries' Innovative Technology Development and Urgent Deployment Program" IIJ (https://www.iij.ad.jp/news/pressrelease/2017/0619.html, in Japanese).

*14 "Suiden-saku" [Rice Farming], NARO, Bio-oriented Technology Research Advancement Institution (https://www.naro.go.jp/laboratory/brain/h27kakushin/keiei/result/suidensaku.html, in Japanese).

*15 "Focused Research (1): IIJ's Efforts to Promote LoRaWAN® in Agricultural IoT", Internet Infrastructure Review (IIR) Vol. 47, IIJ (https://www.iij.ad.jp/en/dev/iir/047.html).

Currently, we are using the insight gained to provide services such as the IIJ Water Management System Platform for Paddy Fields and MITSUHA paddy field sensors. Beyond paddy field water management, we are also engaged in a range of initiatives to address regional community challenges centered on agriculture, such as those below[*16]. We currently support around 70 basic municipalities in Japan, with plans to expand this further.

- Monitoring of soil moisture to improve fruit and other crop yields
- Automatic tractor steering in areas without cellular coverage
- Monitoring of rivers etc. for disaster prevention
- Detection of trap sensor activation for wildlife damage control

■ Temperature Control for Cold Storage Items

With the 2018 revision of Japan's Food Sanitation Act, which systematized food hygiene management in line with HACCP principles, the practice of temperature control is spreading to a variety of industries. Drawing on the expertise gained from agricultural IoT, IIJ has been offering a LoRaWAN®-based solution for food temperature control since 2020[*17]. This solution helps reduce the workload associated with temperature control in refrigerators and freezers in fresh food markets, seafood processing plants, and the like as well as in food preparation and processing workplaces such as restaurant central kitchens.

Beyond hygiene management, there is also a growing trend of late toward the monitoring of storage temperatures in an effort to properly manage the disposal cycle in order to reduce food waste.

The need for temperature control is also expanding beyond food to the following applications.

- Pharmaceutical quality control in the medical industry
- Cold-storage item quality control in logistics warehouses

Something common to all these use cases is that it is not always possible to run power to the location where sensors are to be installed inside refrigerators, pharmaceutical storage systems, and logistics warehouses. It is also crucial that communications between the inside and outside of such storage systems be maintained even when the doors are closed.

With LoRaWAN®, temperature control sensors can run for years even on small batteries, making it easy to install them in places where power is unavailable. As it is regarded within Japan as being for private LPWA systems, LoRaWAN® makes it easy to create wireless environments tailored to the use case, even inside of buildings or storage units. And because it is designed for long-distance communication, connectivity can be maintained even when the doors, which act as obstructions, are closed, provided the distance is short. With these features being utilized, we can expect to see an increasing number of LoRaWAN® temperature control applications being deployed in the IoT/LPWA market.

■ Monitoring at Construction and Civil Engineering Sites

Japan's construction industry faces a number of challenges—chronic labor shortages, workplace accidents, and the stagnation of efforts to increase efficiency. In addressing these issues, sensors can be useful in understanding the current state of affairs and taking action accordingly. Yet the environment at construction sites changes daily as work progresses, and this means collecting wireless sensor data is no easy task. LoRaWAN® is suitable even in such environments. Indeed, proof-of-concept (PoC) testing we performed in collaboration with a construction company showed it was possible to reliably collect sensor data throughout the construction period at a roughly 30,000m^2 logistics facility[*18].

The PoC work also demonstrated that remote monitoring of the following items led to improved efficiency during the construction period.

---

*16 "Smart nogyo setsumeikai" [Smart Agriculture Briefing', IIJ (https://www.iij.ad.jp/news/pressrelease/2024/pdf/handout_20240917.pdf, in Japanese).

*17 "IIJ LoRaWAN(R) Solution for HACCP Temperature Management", IIJ (https://www.iij.ad.jp/en/biz/haccp/).

*18 "Zenitaka-gumi to kensetsu genba ni okeru LoRaWAN® wo katsuyo shita genba kankyo data no shushu/bunseki shisutemu no jissho jikken wo jisshi" [Conducting demonstration testing with Zenitaka Corporation on a system for collecting and analyzing data on construction site environments using LoRaWAN®], IIJ (https://www.iij.ad.jp/news/pressrelease/2024/1106.html, in Japanese).

- Heat stress index (WBGT)
- Worker safety management via monitoring of security guard skin temperature and heart rate
- Images showing construction progress
- Construction machinery operation status
- Construction machinery location (work zone)
- Location of construction machinery keys

Recently, we have also been receiving requests about monitoring factors such as lights being left on, windows left unclosed, and amount of rainfall, and we can thus expect LoRaWAN® to be widely used in construction site monitoring applications ahead.

Beyond construction, there is also demand for worker safety management on civil engineering sites where LTE connectivity is unavailable, such as tunnels. Such locations are another field in which LoRaWAN® can help thanks to its long-range communication capabilities and battery-powered operation.

■ Building LoRaWAN® communication Environments

As mentioned earlier, LoRaWAN® is regarded within Japan as being for private LPWA systems, so base stations must be installed to receive data from the end devices. Because LoRaWAN® radio uses spread spectrum technology, communication can be transmitted even when the received signal strength is below the noise level (even when SNR is negative, as discussed later)[*19]. This is a major advantage of LoRaWAN®, in many cases making it possible to set up a communications system fairly effortlessly simply by placing devices wherever users want them. That said, when there is a need for signals to propagate over several kilometers outdoors, for instance, or when end devices need to be located in complex building interiors, we may conduct some preliminary environmental assessment before considering base station placement. Below, we offer a technical perspective on the factors to consider when assessing the communications environment in such situations, based on our experience working with LoRaWAN®.

The main points to check when assessing communication conditions are as follows.

- Received Signal Strength Indicator (RSSI)
- Signal-to-Noise Ratio (SNR)
- Interference from other wireless systems in the 920MHz band

In the case of RSSI, differences across products due to the performance of device antennas, signal processing circuitry, and the like make it difficult to set universal standards for this metric, but based on our operational experience, as long as we can keep it at -100dBm or above, even when packet losses occur, the packets can generally be recovered via end device automatic retransmission functionality. For extra assurance, it is ideal to have a margin for error and ensure around -80dBm. Incidentally, and this is not limited to LoRaWAN®, in open outdoor environments (no buildings or other obstacles), RSSI can be roughly estimated using a two-ray model. As Figure 1 shows, the two-ray model takes into account both free space path loss and the interference between the direct ray and the ground-reflected ray[*20]. While the model itself

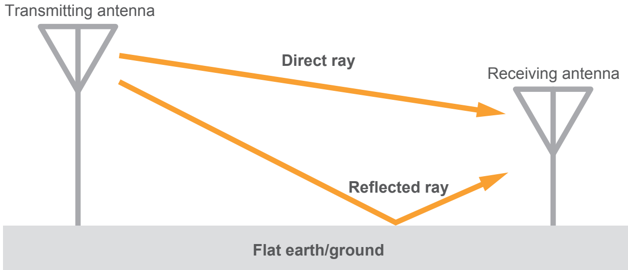


Figure 1: Conceptual Diagram of Two-ray Model

*19 "RSSI and SNR," The Things Network (https://www.thethingsnetwork.org/docs/lorawan/rssi-and-snr/).

*20 "Jun-ichi Takada, "Fundamentals of Radiowave Propagation", Journal of the Institute of Image Information and Television Engineers, vol. 70, no. 1, pp. 142–148 (2016) (https://www.jstage.jst.go.jp/article/itej/70/1/70_142/_article/-char/en).

is too simple to fully simulate real-world environments, it is suitable for getting a rough idea of signal behavior as it only uses a few parameters (radio frequency, transmission power, antenna height and gain, and distance) and is easy to calculate. Figure 2 shows the computed results for a two-ray model. The lower the antenna height, the more susceptible it is to flat earth effects, so if you want to transmit LoRaWAN® signals over 1km, for example, an antenna height of 2m or more should enable good signal transmission. Once antenna height reaches around 8m, it exceeds the (first) Fresnel zone radius, reducing the impact of flat earth effects, such that signal attenuation can be expressed almost entirely by free space path loss alone. The Fresnel zone, incidentally, is the area that determines line-of-sight between antennas, and any obstacles within this zone can significantly affect propagation characteristics through reflection, diffraction, and the like.

Turning to SNR, as shown in Figure 2, LoRaWAN® specifies threshold values for each data rate (DR)[*19*21]. DR2 is often used for very small amounts of data such as sensor data[*22], so theoretically even an SNR of -15dB would be acceptable[*23], but as with RSSI, it is ideal to maintain a margin for error (5–10dB). From experience, when the RSSI is good, SNR is also usually not a problem, but because SNR values can vary depending on the environment, examining both RSSI and SNR together makes quantitative assessments easier.

Since 920MHz-band specified low-power radio is used not only for the LPWA standards in Table 1 but also for other systems such as RFID, the LoRaWAN® communication specifications state that, before transmitting, devices must check that the frequency channel they are about to transmit on is not being used by other systems in

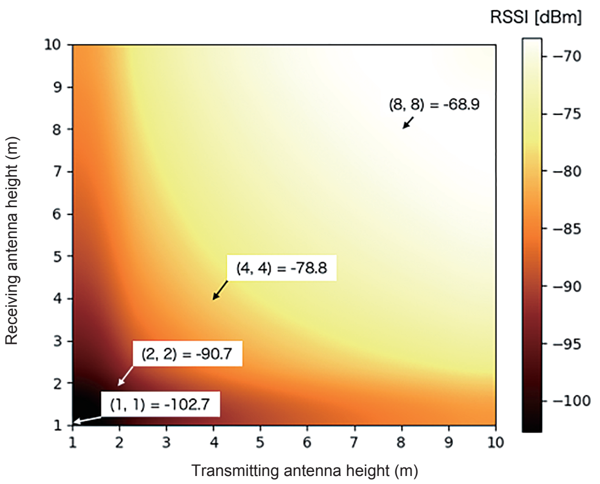


Figure 2: Two-ray Model Computation Example (Frequency: 920MHz, Transmission Power: 13dBm, Antenna Gain: 2.14dBi, Antenna Distance: 1km)

DR	Communication speed [bps]	Required SNR [dB]
DR0	250	-20
DR1	440	-17.5
DR2	980	-15
DR3	1760	-12.5
DR4	3125	-10
DR5	5470	-7.5

Table 2: Communication Speeds and Required SNR Values by LoRaWAN® Data Rate (DR) (125kHz Bandwidth in All Cases)

*21 "RP002-1.0.4 Regional Parameters", LoRa Alliance (https://resources.lora-alliance.org/home/rp002-1-0-4-regional-parameters).

*22 As radio transmission time exceeds 400ms, DR0 and DR1 are rarely used in practice due to the complexity of operating in accordance with Japan's Radio Act.

*23 LoRaWAN® uses spread spectrum technology, so communication is possible even when SNR is negative.

accordance with the ARIB STD-T108 regulation, based on Japan's Radio Act[*21][*24]. Thus, if communication is not established as expected even in the absence of obstacles, there may be radio congestion, so we sometimes check whether other 920MHz-band wireless systems are in use nearby.

Incidentally, IIJ also provides measurement devices[*25] for assessing LoRaWAN® radio conditions. These devices work as shown in Figure 3, aggregating and displaying measurements (average RSSI/SNR and communication success rate) based on downlink information returned from gateways. Because all the user needs to do is power on the device and check the displayed measurements, these devices are widely used in the field.

2.3 Characteristics and Future Prospects of Wi-Fi HaLow™ (IEEE 802.11ah)

Japan's Radio Act was amended in September 2022, enabling full-scale domestic use of IEEE 802.11ah/ Wi-Fi HaLow™. HaLow is the designation for devices incorporating IEEE 802.11ah ("11ah") technology that have been certified by the Wi-Fi Alliance®. As the name suggests, it is a Wi-Fi® standard, but it is designed specifically for IoT and thus also categorized as an LPWA technology.

11ah as an LPWA Technology

Viewed as an LPWA technology, 11ah has the following characteristics.

- Like other unlicensed-band LPWA technologies, it uses 920MHz-band specified low-power radio.
- 11ah supports communication over IP.
- 11ah uses OFDM for modulation, enabling relatively high speeds for an LPWA technology, ranging from hundreds of kbps to on the order of Mbps depending on communication conditions.
- As an LPWA technology, 11ah uses wide bandwidth (over 1MHz, vs. 125kHz for LoRaWAN®), making ultra-long-distance communication difficult. Relatively careful attention must also be paid to interference.

The characteristics of LoRaWAN® data communications mean it is not well-suited for real-time, bidirectional exchange of relatively large amounts of data. A key distinguishing

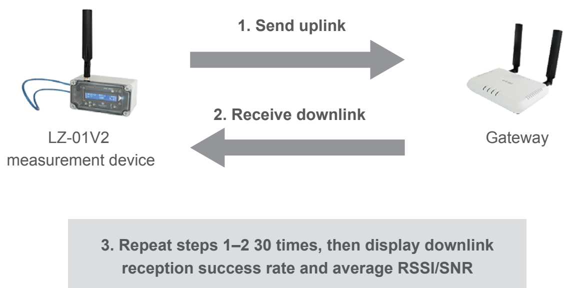


Figure 3: Operation of LoRaWAN® Measurement Device

*24 This is known as carrier sense or LBT (Listen Before Talk).

feature of 11ah is that it supports communication over IP and can achieve transmission speeds suitable for video, making it promising for use cases such as surveillance cameras and remote firmware updates. Conversely, factors such as bandwidth and overhead at the MAC layer and above mean 11ah is likely to be eclipsed by LoRaWAN® from a device power budget perspective, so it seems unlikely that 11ah will be a drop-in replacement for LoRaWAN®. Thus if 11ah-compatible sensor devices do become available, they may primarily be of the type that transmit measurements continuously (non-battery-powered). In any case, it is important to distinguish between LoRaWAN® and 11ah as appropriate to the use case based on their respective characteristics.

Technical Characteristics of 11ah

As mentioned, 11ah is part of the Wi-Fi® series, and the experience from a user's perspective is virtually the same as with conventional Wi-Fi® protocols. Specific examples include the following.

- It uses SSIDs/BSSIDs.
- Client devices (STA) connect to access points (APs).
- Security is provided through WPA2/3.

From a technical standpoint, while 11ah is based on the Wi-Fi® 5 (IEEE 802.11ac) specifications, modifications have been made to enable its use for LPWA in the 920 MHz band. The main modifications are described below*26.

Narrowband Operation

While 11ac specifies bandwidth options of 20, 40, 80, and 160 MHz, available bandwidth in sub-gigahertz bands is limited by country regulations—in Japan's 920MHz band, only 7.6MHz is available. 11ah uses bandwidths of one tenth those of 11ac (2, 4, 8, and 16 MHz) and also supports 1MHz bandwidth. Due to the aforementioned regulations, however, only the 1, 2, and 4 MHz channels are currently permitted in Japan.

Note that using narrower bandwidth in 11ah allows for greater transmission range, as shown in Figure 4. This is primarily because narrower bandwidth helps prevent interference and increases power density per frequency. Narrower bandwidth, however, reduces the number of OFDM subcarriers, which means that for the same Modulation and Coding Scheme (MCS, discussed later), transmission speed will be lower.

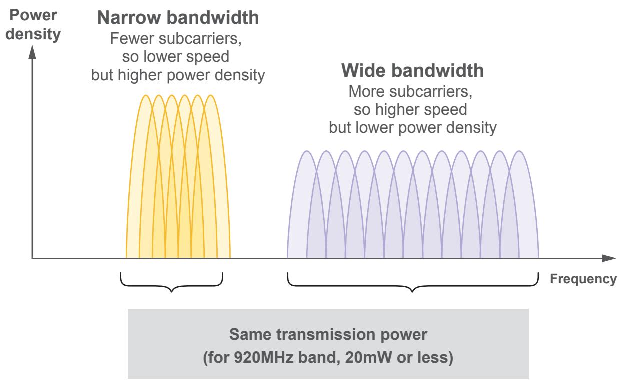


Figure 4: Conceptual Diagram of Bandwidth and Power Density

*25 "LZ-01V2 – IIJ LoRaWAN® Solution", IIJ (https://www.iij.ad.jp/biz/lorawan/device2/sencor_15.html, in Japanese).

*26 Tadao Kobayashi, "Private wireless network nyumon: Wi-Fi® 6, 802.11ah, local 5G tettei kaisetsu" [Introduction to Private Wireless Networks: Comprehensive Guide to Wi-Fi® 6, 802.11ah, and Local 5G], RIC Telecom, 2021

■ **Improved Multipath Resistance**

To narrow the bandwidth, 11ah specifies an OFDM subcarrier spacing of 31.25kHz, one tenth that in 11ac. This choice was made with the idea that the spacing would be achieved by lowering the clock speeds of 11ac wireless chips to one tenth. Thus, as Figure 5 shows, the OFDM symbol time is 32μs, which is 10 times longer than for 11ac. The guard interval (GI) can also be set to be more than 10 times longer than for 11ac, enabling stable transmission even in outdoor and long-distance scenarios. This is because, as illustrated in Figure 6, when the delay time of multipath delayed waves falls within the GI length, the effects of inter-symbol interference can be eliminated when demodulating the OFDM signall[*27].

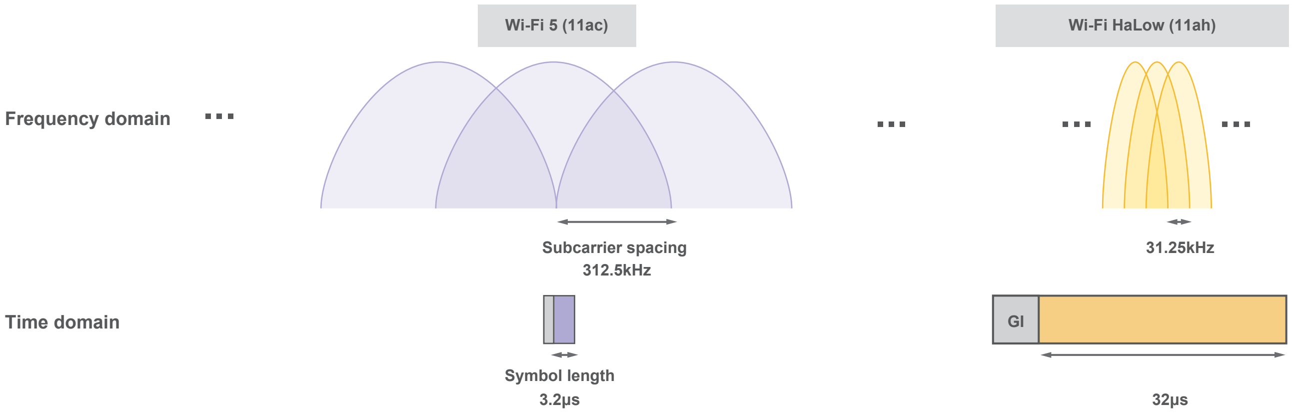


Figure 5: Conceptual Diagram of OFDM Subcarrier Spacing and Symbol Length

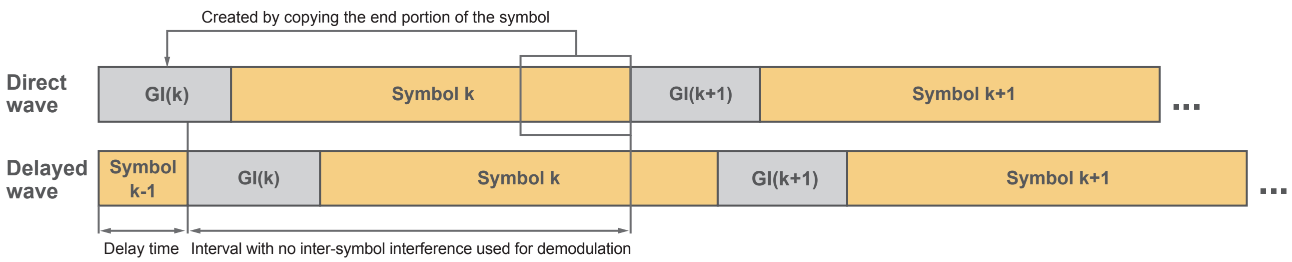


Figure 6: Effect of Guard Interval

*27 Makoto Itami, "OFDM no kiso to oyo-gijutsu" [Fundamentals and Application Technologies of OFDM], IEICE Fundamentals Review, vol. 1, no. 2, pp. 35–43, 2007 (https://www.jstage.jst.go.jp/article/essfr/1/2/1_2_2_35/_article/-char/ja/, in Japanese).

Modulation and Coding Scheme (MCS)

Table 3 shows the Modulation and Coding Scheme and physical layer data rates for 11ah. The MCS in 11ah is based on 11ac, with modulation methods and coding rates for MCS Index 0–9 being identical to those in 11ac. So within MCS Index 0–9, higher indices allow for more bits to be modulated at once, resulting in faster data rates. But as bandwidth is, as mentioned, one tenth that for 11ac, data rates are also one tenth compared with 11ac. MCS10 was created specifically for 11ah and is only supported in 1MHz mode. MCS10 is essentially MCS0 with 2× repetition, which, while reducing speed, ensures communication stability.

Incidentally, many devices have the ability to automatically switch MCS, and it seems that in many cases they check wireless RSSI and SNR values to do this.

Note that the data rates in Table 3 represent theoretical maximum values at the physical layer, so actual speeds will be lower. In particular, since 11ah often involves use cases with (for an LPWA system) relatively high-capacity continuous communication, such as camera video streaming, more attention must be paid to the 920MHz-band 10% duty cycle rule specified in the Radio Act than with other LPWA standards. The 10% duty cycle rule, in simple terms, ensures that everyone can make efficient use of limited available frequency bands by restricting each device's transmission time to no more than 360 seconds (10%) per hour. So to ensure continuity of communications, transmissions must be broken into smaller segments (keeping speed at one tenth)[*28]. As a result, when 11ah is used for continuous communication, actual speeds fall to less than one tenth (or 1/100 compared with 11ac) of the data rates shown in Table 3.

Other Features

Due to space limitations, we cannot cover all aspects of 11ah here, but below are some of its other features. Incidentally, the power-saving functionality and BSS Coloring were also adopted in the subsequent Wi-Fi® 6 (IEEE 802.11ax) standard.

- Power-saving (sleep function using Target Wake Time, or TWT)
- Reduction of inter-channel interference using BSS Coloring
- Relay function at APs (optional)

MCS Index	Modulation	Coding rate	Data rate (1MHz bandwidth) [Mbps	Data rate (2MHz) [Mbps]	Data rate (4MHz) [Mbps]
0	BPSK	1/2	0.3	0.65	1.35
1	QPSK	1/2	0.6	1.3	2.7
2	QPSK	3/4	0.9	1.95	4.05
3	16-QAM	1/2	1.2	2.6	5.4
4	16-QAM	3/4	1.8	3.9	8.1
5	64-QAM	2/3	2.4	5.2	10.8
6	64-QAM	3/4	2.7	5.85	12.15
7	64-QAM	5/6	3.0	6.5	13.5
8	256-QAM	3/4	3.6	7.8	16.2
9	256-QAM	5/6	4.0	N/A	18.0
10	BPSK x 2	1/2 x 2	0.15	N/A	N/A

Table 3: MCS and Physical Layer Data Rates in 11ah (Number of Spatial Streams = 1, GI Length = 8μs)

*28 In many cases, devices include configuration settings that allow for continuous communication at reduced speeds. If continuous communication is not required, speed restrictions can be dispensed with as long as communications comply with the rule limiting transmission time to 360 seconds per hour.

Establishing 11ah Communications

When building 11ah systems, in addition to what it has in common with LoRaWAN®, you also need to take into account factors such as bandwidth and MCS. RSSI and SNR are crucial, as with LoRaWAN®, and while it depends on the equipment used, you should generally aim for at least -85dBm and 15–20dB or higher. When it comes to RSSI, based on Figure 2, you need antenna heights of 3–4m or more to achieve outdoor communications with a range of around 1km in the absence of obstacles.

As for SNR, while you can adjust the acceptable operating parameters to an extent by changing bandwidth or MCS, such adjustments need to be made while monitoring actual communication conditions, taking into account communication speed in line with the aforementioned 10% duty rule.

Since 11ah, as part of the 802.11 series, uses CSMA/CA, it should not interfere with other 920MHz-band systems. But because the 11ah standard uses relatively wide bandwidth, in cases in which channels are congested, the 11ah side may experience increased waiting times, so it is useful to check for channel congestion in advance. Another important point is that in cases such as connecting multiple cameras to communicate continuously with a single AP, the presence of too many devices may cause communications to fail.

Some AP devices support relay functionality, which offers one means of establishing communication area coverage when achieving single-hop transmission distance is difficult or when line-of-sight between antennas is hard to maintain. As for the task of monitoring communication status, some devices, depending on their specifications, come with such functionality as standard.

11ah Performance Evaluation Tests

At IIJ, we conducted performance evaluation tests of 11ah in an outdoor setting (Arakawa riverside area) over 2023–2024[*29*30].

The first test used iPerf to measure speeds with non-continuous communication (no 10% duty cycle speed restriction), while the second test involved both iPerf measurements and continuous video transmission (with the 10% duty cycle speed restriction applied). Table 4 shows a summary of the test results.

#	10% duty cycle speed restriction	Antenna height (dipole equivalent)	4MHz bandwidth	2MHz bandwidth	1MHz bandwidth
1st round (up to 1000m)	No speed restriction (communication stops once duty cycle reached)	Transmitting antenna: 3m Receiving antenna: 1.8m	• ~2.2Mbps at 100m • ~590kbps at 500m • ~80kbps at 800m • Almost no communication at 1,000m	• ~1.7Mbps at 100m • ~420kbps at 500m • ~380kbps at 800m • ~200kbps at 1,000m	• ~1.3Mbps at 100m • ~840kbps at 500m • ~150kbps at 800m • Almost no communication at 1,000m
1st round (1,100m and beyond)	No speed restriction (communication stops once duty cycle reached)	Transmitting antenna: 3m Receiving antenna: ~4m	• ~120kbps at 1,200m	• ~220kbps at 1,300m	• ~230kbps at 1,300m
2nd round	Speed restriction applied	Transmitting antenna: 4m Receiving antenna: 4m	• 913kbps at 200m • 416kbps at 400m • Unmeasurable at 800m	• 436kbps at 200m • 313kbps at 400m • Unstable at 800m, ~100kbps	Not tested

Table 4: Performance Evaluation Test Results Summary

*29 "Wi-Fi HaLow™ no seino hyoka jikken wo okonaimashita" [We Conducted Performance Evaluation Tests of Wi-Fi HaLow™], IIJ Engineers Blog (https://eng-blog.iij.ad.jp/archives/21601, in Japanese)

*30 "Wi-Fi HaLow™ no seino hyoka jikken dai-ni-dan—dokomade ikeru!? Douga check shitemita!!" [Wi-Fi HaLow™ Performance Evaluation Test Round 2—How Far Can It Go!? We Tested Video Transmission!!", IIJ Engineers Blog (https://eng-blog.iij.ad.jp/archives/25458, in Japanese)

The first test results showed that signal speed did not necessarily decrease inversely with distance, partly due to reflections from roads. With a 4MHz bandwidth, speeds exceeded 2Mbps at 100m but fell below 100kbps at 800m, indicating difficulties with long-distance transmissions. Also, because the devices were set to select MCS automatically, communication tended to become unstable when RSSI and SNR fluctuated. For distances up to 1,000m, we used a receiving antenna height of 1.8m, and with this setup, estimated RSSI in the two-ray model drops below -85dBm at around 800m. So the finding that communication quality deteriorates around this distance made sense. Note that when receiving antenna height was manually adjusted to around 4m, we were able to achieve connectivity at 1km or more.

The second set of test results show that at the 200m point, reasonable speeds were achieved even with the 10% duty cycle restriction, as the system was using MCS7. But because MCS was set to automatic, as in the first test, MCS tended to become unstable with distance, making communication difficult beyond 800m. Given that the average RSSI measurement at this point was around -82dBm, and considering the two-ray model estimates, this distance threshold seems reasonable.

As for video transmissions, frame drops occurred when, for example, vehicles passed through the Fresnel zone, but the system would likely be sufficient for surveillance applications not requiring high image quality (e.g., river water level monitoring) even at 800m. Higher speeds at greater distances could potentially be achieved depending on the selection of antenna, bandwidth, and MCS.

■ Challenges and Future Outlook

Potential use cases for 11ah beyond video transmission include those below. Generally, 11ah lends itself to situations in which conventional methods would be challenging for reasons to do with communication specs or because communication line installation and running costs are infeasible.

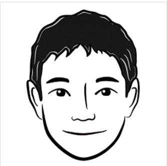
- Extension of in-building communications (wired / existing Wi-Fi®) in factories and similar facilities
- Replacement of LTE to reduce communication line running costs
- Multicast communication for municipal disaster preparedness and related applications
- Long-distance voice communication in tunnels and underground facilities

While price is a key factor for adoption in social infrastructure, 11ah-capable products (devices, communication modules, chips, etc.) are still not widely available in the market. They thus remain relatively expensive compared with existing Wi-Fi® products. In Japan, the 802.11ah Promotion Council, of which IIJ is a regular member, is leading market stimulus efforts, and with the cooperation of overseas vendors as well, the product lineup is gradually expanding. Interoperability of different vendors' devices remains a challenge, however. This issue is also being addressed within the 802.11ah Promotion Council framework, and so usability can be expected to improve ahead.

The use of the 850MHz band will also bear watching ahead[*31]. Currently, this band is allocated to digital MCA in Japan but will become available when that service ends in 2029. If this band is allocated to 11ah, this would enable broader bandwidth communications and likely make it possible to operate without the 10% duty cycle rule, further expanding the range of potential use cases. Using the 850MHz band would also help in avoiding conflicts with other systems, making it easier to use 11ah alongside other LPWA technologies like LoRaWAN®, and possibly enabling it to function as their backbone network. While this is still five years away, there apparently are plans to make portions of the band available in stages. According to the Ministry of Internal Affairs and Communications' schedule, technical requirements were to be compiled by around autumn 2024, so more specific information may already be available by the time this article is published.

2.4 Conclusion

This article has discussed IIJ's LPWA initiatives in the areas of LoRaWAN® and Wi-Fi HaLow™ (IEEE 802.11ah). LoRaWAN® is already used worldwide, and as an open standard offering ease of connectivity, we can expect it to make further inroads in Japan as well. While it is still early days for HaLow, it does offer advantages such as support for communication over IP and easy migration from existing LAN and Wi-Fi systems, so while keeping an eye on developments in this area, we will continue to work toward incorporating these technologies into new services.



Nobuaki Miyake
Sales Department, IoT Business Division, IIJ

Shota Saito
Sensing Services Section, Technology Department, IoT Business Division, IIJ

*31 "802.11ah no riyou shuhasu no kakudai ni muketa, Soumushou '900MHz-tai jieiyou musen system kodoka sagyohan' ga kaishi" [Ministry of Internal Affairs and Communications 'Working Group on Enhancement of 900MHz Band Private Radio Systems' Begins, Aiming to Expand Frequency Range for 802.11ah], 802.11ah Promotion Council (https://www.11ahpc.org/news/20240412/index.html, in Japanese).