

A survey on Wi-Fi HaLow technology for Internet of Things

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Abstract—Wi-Fi HaLow is a wireless networking protocol: IEEE 802.11ah, which was published on May 10th 2017. The technology's low power consumption competes with LoRa, ZigBee, Bluetooth. It uses sub 1 GHz (S1G) license-exempt bands, allowing the creation of large groups of stations or sensors, to provide extended range Wi-Fi networks and support the concept of Internet of Things (IoT). This paper gives an overview of the Wi-Fi HaLow technology, which is able to solve the weakness of Wi-Fi in penetrability and transmission distance up to 1km at the default transmission power of 200mW.

Keywords—ICT; Wi-Fi HaLow; LPWAN; Internet of Things

I. INTRODUCTION

As Information and Communication Technology (ICT) develops, human's desire to automate everything will reshape their lives completely in the aspects of economics, politics and social life. Emerging applications and services of the smart systems will require a large number of smart devices, such as robots, sensors, and controllers. The development of ICT has turned to be aimed at the interconnection between people and people, people and objects, and objects and objects, and finally making all things connected.

Analysts predict, the total number of smart devices will reach 50 billion by 2020. In face of billions of the access requirements of IoT in the future, the excessively high cost of the mobile cellular network technology does not seem to adapt to this connection scenario any longer, and short distance communication technology restrained by its short distance, is unable to meet the needs of wide coverage and long distance of IoT either. Considering this situation, the United States and Europe have begun to develop the low-power wide-area network (LPWAN) Internet access technology^[1] that supports large connections since 2012. Currently, there are several technical camps around the globe, such as NB-IoT (narrow-band Internet of Things), LoRaWAN (Long Range wide-area network), Sigfox, Weightless, Wi-Fi HaLow. As shown in figure 1, although they are different from each other, these technologies are all aimed for suiting the characters of IoT, for example, low cost, low power consumption, long distance and extensive connection^[2].

IoT owns a broad application market, where a lot of IoT technologies emerge nowadays. The booming creates more and more opportunities for new technology access. It is under this background that Wi-Fi HaLow comes into real. It features low power consumption, multiple access nodes and

wide coverage, which can meet the requirements of IoT applications.

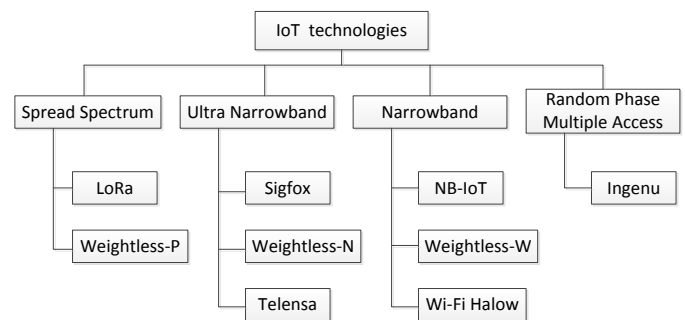


Fig. 1. IoT technologies

II. PROTOCOL OF IOT

A. LoRa

LoRa is a physical layer technology owned by Semtech. Backed by Semtech's patent data and the analysis of LoRa signal spectrum, LoRa adopts a narrowband spread spectrum technology based on the linear frequency modulation signal (Chirp)^[3]. By modulating the Chirp signal, the digital signal spreads the original signal frequency band to the entire linear spectral range of the Chirp signal. This modulation demodulation technology enhances LoRa's performance in low power consumption wide coverage. According to Shannon's theorem,

$$C=B * \log_2(1+S/N) \quad (1)$$

The maximum transmission rate of the channel is determined by B and S/N. In the case of the channel capacity, increasing the signal-to-noise ratio can reduce the requirement for bandwidth, and the increase of bandwidth can also reduce the requirement for noise ratio. Spread-spectrum technology is used to compensate the receiver's demand for SNR by amplifying the signal bandwidth. The receiver can extract signals under very low SNR, which significantly improves the receiving sensitivity, and resists the declining effects on the signal. Spread spectrum technology, therefore, to a certain extent, determines the properties of LoRa long-distance transmission.

In order to promote the application of LoRa technology in IoT, along with IBM, Actility and Microchip, Semtech founded LoRa global technology alliance (LoRa) in March 2015 and released LoRaWAN1.0 in June 2015. So far, over 150 cities in 17 countries have already been deployed metro

LoRaWAN^[4], according to LoRa coalition official data. Besides the Netherlands and South Korea, they have completed nationwide network deployment and been put into commercial use.

B. NB-IoT

NB-IoT is standardized by 3GPP. It uses LTE wireless technology based on existing mobile cellular networks, reducing the time which is taken to develop a full range of technical specifications. For operators using licensed spectrum, the technology can be upgraded through existing cellular devices so that operators can enter the IoT market at low cost and with high efficiency^[5].

Compared to LTE network, NB-IoT RF bandwidth (up and down) is only 180kHz, with a 10kHz Guard band on both sides, which is 200kHz in total. The higher the power spectrum density of the narrowband signal, the stronger the anti-jamming capability of the signal, it is widely used in LPWAN technology. In order to reduce the terminal power consumption, the downlink does not support more complicated transmission modes such as beam forming and space division multiplexing. In addition to the conventional 15kHz subcarrier spacing, the physical layer increases the subcarrier interval of 3.75kHz, which supports users to use single carrier so as to increase the power spectrum density of uplink transmission as well as coverage ability.

In terms of commercialization, NB-IoT has earned supports from main operators and communication equipment vendors globally, and has a good user base plus a complete ecological chain base^[6]. In terms of performance, NB-IoT is deployed in operators' licensed spectrum, which is undoubtedly the best working band for any LPWAN technology. IoT possesses various application scenarios. In many industries, it can also provide a stable network service, which is independent to operator networks, so that the non-authorized frequency band can not be restricted by the frequency band attribute.

C. Sigfox

As early as the beginning of 2010, Sigfox launched the low-power wan technology for Sub-GHz unlicensed spectrum, in the purpose of building a dedicated network for IoT at low cost and low power consumption. Sigfox targets short information service business, defining the packet size to 12 bytes, and limiting the transmission rate to 100 b/s, and transmission frequency, for example, 140 pieces of news up, four pieces down every day at most^[7]. This enormously reduces power consumption. On the physical layer, ultra-narrow-band modulation is adopted and the spectrum efficiency is high, which consumes low channel resources. Sigfox covers a distance of 30-50km in the open field, and 3-10km in city, so that the network coverage of a region can be achieved with very few base stations. For example, Sigfox has achieved full coverage of France with just 1,500 base stations. This fundamentally reduces the operating cost of the network, and thus reduces the cost of the network. At present, according to the cost of network deployment, Sigfox's worldwide network cost is about 1 to 12 euros per year.

D. Wi-Fi HaLow

Wi-Fi HaLow is the technology that Wi-Fi Alliance has specially launched for IoT. In fact, in 2010, IEEE launched a WLAN technology standard, 802.11ah, for the IoT, named

Wi-Fi Halow, which was officially released in May 2017. Wi-Fi HaLow application frequency band is sub 1 GHz, with more user accesses, low energy consumption, strong penetration and wide spread range^[8]. The corresponding mechanism is used to avoid interference with IEEE802.15.4, so that Wi-Fi chips can be more widely used in IoT.

Wi-Fi HaLow has redesigned PHY and MAC layers, based on a reduced clock rate of 802.11ac. The physical layer can be divided into two categories: 2MHz, 4MHz, 8MHz, 16MHz transmission mode, and 1MHz transmission mode^[9]. For the first class, it can be considered as 802.11ac declined by 10 times. Because FFT is the same size as 802.11ac; the subcarrier spacing is one tenth of 802.11ac, which is 31.25kHz. Wi-Fi HaLow orthogonal frequency division multiplexing (OFDM) symbol period is 10 times of 802.11ac. For the second type, the 1MHz transmission mode, it also uses 31.25kHz subcarrier intervals, and the FFT size is 32. The target of 1MHz channel is to further extend the transmission distance. Wi-Fi HaLow adds a new modulation encoding mechanism (MCS10) for long-distance transmission. MCS10 and MCS0 use half of the encoding rate, but repeat twice, thus increasing the transmission distance. Wi-Fi HaLow can be used for both star network and point-to-point communication. Large coverage, low power consumption, native IP support, and large number of device support are its main advantages.

Wi-Fi Alliance officially released Wi-Fi HaLow on May 10, 2017. There are no commercially available chips yet. The core members of Wi-Fi Alliance include some of the world's largest chip manufacturers, including Broadcom, Qualcomm, Mediatek and Intel. There should be no problems for future IoT chips to be accommodated in Wi-Fi HaLow technology. It is very important for Wi-Fi Alliance to complete promotion before the IoT market boosting.

E. Others

Weightless technology is a set of IoT communication standards released earlier, which is dominated and managed by Weightless SIG (Special Interest Group). Since its release in December 2012, Weightless has released three criteria: Weightless-N, Weightless-P and Weightless-W. Britain's Telensa is a private technology of Plextek. It originates from and makes achievements in remote street lamp control. Telensa technology and Sigfox technology drive low throughput IoT, supporting the descending rate of 500b/s and the upward rate of 62.5b/s. America's Ingenu also use spread-spectrum modulation--- RPMA (Random Phase Multiple Access). Ingenu technology works in the global 2.4GHz non-authorized frequency band, with the system bandwidth of 1MHz. Using star topology, the base station adjusts the network capacity by controlling the transmitting power of the nodes.

III. WI-FI HALOW OVERVIEW

Wi-Fi HaLow includes three use cases. The first is smart meters and sensors. This one is expected to be largely employed in IoT. The major devices embraces smart meters, smart grids, environmental and agricultural monitoring, automation of industrial process, indoor healthcare/fitness system, elderly care system. In these applications, an access point (AP) covers hundreds or even thousands of devices—sensors or actors—that periodically transmit short packets. A great number of stations contending for the channel results in

collisions, long transmission range lead to high interframe spaces, and short packets increase overhead caused by headers. Even though the required aggregate throughput in the given use cases is not over 1 Mbps, all these issues manifold degrade network performance and the standard developers have to pay a lot of attention to them. Another issue is the energy consumption, since sensors are usually battery powered. The second use case is backhaul aggregation. In this use case, the Wi-Fi HaLow is used primarily as a return link. It connects to the underlying network of 802.15.4g, and then transfers obtained data to the application platform. The third use case is extended range hotspot and cellular offloading, where Wi-Fi HaLow mainly expands the coverage of Wi-Fi hotspots, and provides business shunt for cellular network. Table 1 summarizes requirements for the adopted use cases.

TABLE I. REQUIREMENTS FOR USE CASES

Scenario	Location	Data rate	AP/STA capacity
Sensors and meters	Indoor/Outdoor	100kbps	1:6000
Backhaul aggregation	Outdoor	<1Mbps	10:500
Extended Range and cellular offloading	Outdoor	<20Mbps	1:50

TABLE II. DATA RATES (Mbps)

MCS	1MHz	2MHz	4MHz	8MHz	16MHz
MCS0	0.3	0.65	1.35	2.925	5.85
MCS1	0.6	1.30	2.70	5.850	11.70
MCS2	0.9	1.95	4.05	8.775	17.55
MCS3	1.2	2.60	5.40	11.700	23.40
MCS4	1.8	3.90	8.10	17.550	35.10
MCS5	2.4	5.20	10.80	23.400	46.80
MCS6	2.7	5.85	12.15	26.325	52.65
MCS7	3.0	6.50	13.50	29.250	58.50
MCS8	3.6	7.80	16.20	35.100	70.20
MCS9	4.0	-	18.00	39.000	78.00
MCS10	0.15	-	-	-	-

The Wi-Fi HaLow PHY layer is inherited from IEEE 802.11ac and adopted to available sub 1 GHz bandwidth. The Table II shows data rates of the Wi-Fi HaLow PHY layer for various MCSs in Mbps, single spatial stream and normal OFDM symbol. They can be improved by reducing the duration of OFDM symbol and using several spatial streams. The Wi-Fi HaLow stations can use up to 4 spatial streams.

The Wi-Fi HaLow PHY gives high data rates, but the aggregate throughput could be very low due to the large overhead inherent to short packet transmission for sensor networks. In the Wi-Fi HaLow networks, the issue is worsened by quite long time characteristics of the PHY layer showed in Table III. Besides declining throughput, the overhead degrades power efficiency. Aggregation, Block Ack and a few other IEEE 802.11 solutions are sometimes inapplicable to sensor networks: used in uplink (from sensor stations to the AP), they lead to a high latency, not acceptable in a lot of use cases.

TABLE III. TIME CHARACTERISTICS

Characteristics	Value
Backoff slot	52 us
SIFS	160 us
CCA Time	< 40 us
Air Propagation Time	6 us
PHY-RX-START-Delay	1 MHz: 600 us 2/4/8/16MHz: 280 us
PPDU Max Time	27.84ms (511 bytes at 1 MHz using MCS0 and 1 spatial stream)
PSDU Max Length	797,160 octets (511 symbols (limited by PPDU Max Time) at 16MHz using MCS9 and 4 spatial streams)

The Wi-Fi HaLow technology optimization is mainly embodied in enabling it to reduce power consumption, to expand coverage and to increase the number of nodes. Some technical optimizations need to take multiple features into account, such as TIM, which supports more than 6,000 users while reducing the power of the terminals.

In some application scenarios, nodes are powered by batteries. In order to save power, these nodes will enter an energy saving mode when operation is not conducted. For nodes in this mode, the AP notifies them whether there is buffer data to be issued by sending the business indicator (TIM) information element in Beacon.

In order to support many users, and to make nodes save electricity as much as possible, and the system work more efficient, 802.11ah introduces the RAW technology. Its basic idea is to divide the nodes into different groups and allow them to be transmitted over a given period of time, which on one hand enables each node to obtain data transmission opportunity and on the other hand reduces access conflicts and improves the efficiency of the system. In the uplink channel access process, the node STA wakes up at a predetermined time and starts sensing Beacon frames, which carry RAW information, such as RAW start time, RAW period, the number of slots in RAW, and how the nodes will be assigned. When the node STA receives this information, it will know the access time allocated to it by the AP. Before the access time comes, STA sleeps, which can save power to the largest extent. When the access time comes, the node STA wakes up and accesses the channel based on the EDCA.

IV. SIMULATION

The Wi-Fi HaLow is required to support over 6000 stations. In smart grid (e.g. power meter), large number of STA may try to authenticate/associate with AP simultaneously after power outage. AP is required to handle a sudden burst of authentication/association requests from many STA within a short period^[10] (see figure 2).

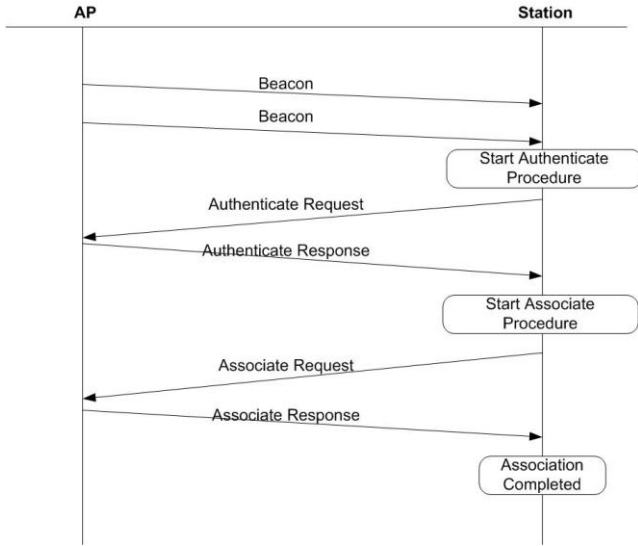


Fig. 2. Authentication/Association Procedure

This paper uses Qualnet network simulators. The first simulation parameter set here is DCF mode, with 1 MHz bandwidth as specified by the Wi-Fi HaLow frame work. The second is with implemented power saving protocols. The third is PHY modulation: MCS0-REP2 and the last one is transmission range: 1 km (see figure 3).

TABLE IV. SIMULATION PARAMETER

Parameter	Value	Parameter	Value
Data Rate	150 Kbps	Backoff Win	15-1023
Number of Nodes	50-3000	Maximum Short Retry	7
DIFS	250 us	Maximum long Retry	4
SIFS	160 us	Time slot	45 us
Beacon Interval	200 ms	DTIM Period	25(5 seconds)
PS Mode Listen Interval	25 (5 seconds)		

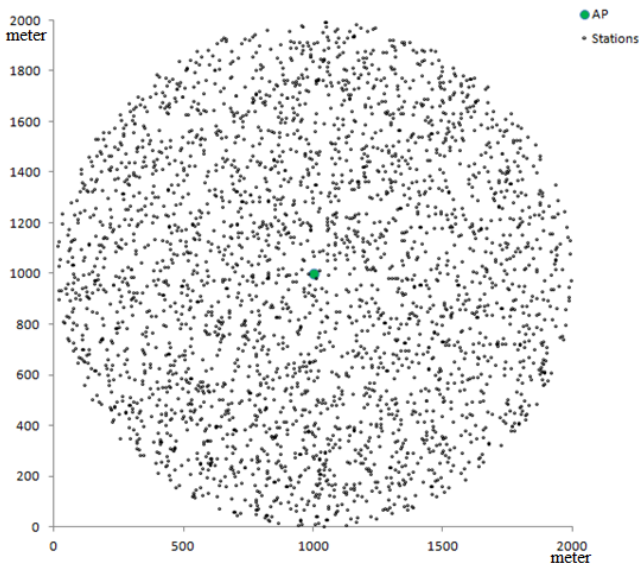


Fig. 3. Simulation Topology

Making use of random number to limit the number of stations that can authenticate/associate with AP at the same time (see figure 4). The simulation results show that, it is necessary to control the number of stations performing authentication/association at the same time to improve the performance in scenario with large number of stations.

The Wi-Fi HaLow uses sub 1 GHz (S1G) license-exempt bands, allowing the creation of large groups of stations or sensors, to provide extended range Wi-Fi networks and support the concept of Internet of Things (IoT). which is able to solve the weakness of Wi-Fi in penetrability and transmission distance up to 1km at the default transmission power of 200mW.

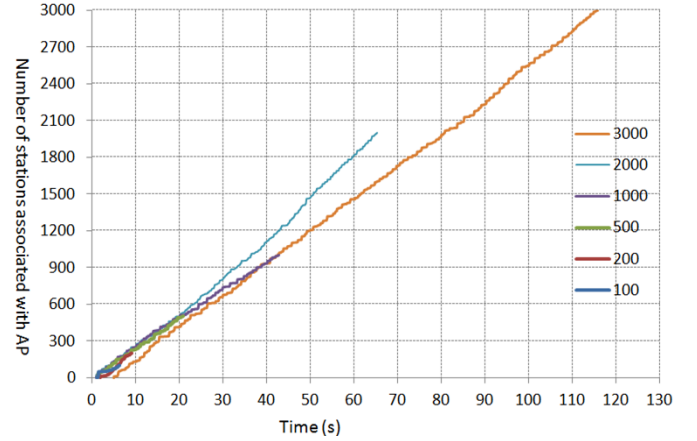


Fig. 4. Authentication & association process for various number of stations

V. CONCLUSION

IoT market shows a trend of sustainably rapid growth, which will promote the development of a variety of wireless technologies. IoT has a broad range of applications, which asks for different demands for network transmission. Therefore, the technologies are not exclusive but complementary. This paper focuses on the discussion of Wi-Fi HaLow new technology, which, supported by its technical advantages and the strong industrial chain of WLAN, is expected to be to play an increasingly important role in the future of IoT.

ACKNOWLEDGMENT

This work was supported by the project of development on wireless communication chip of electric power system based on 802.11ah under grant No. SGRIXTMXXS [2015]1128.

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