A Survey of the State of the Art of 802.11ah

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Abstract—**Wireless networking technologies are the best options to connect a large number of devices. The emerging IEEE 802.11ah, aka Wi-Fi HaLow, is a promising communication standard that supports a massive number of heterogeneous devices in the Internet of Things (IoT). It utilizes sub-1 GHz license-exempt bands to provide an extended range to the Wi-Fi networks. This standard seeks to address various limitations of legacy 802.11 Wi-Fi by incorporating enhancements in both the PHY and MAC layers. This work assesses the evolution and the market readiness of this new, low power Wi-Fi standard. It focuses on the technical challenges faced by this standard. This standard is still in its infancy and there is a large spectrum of opportunities for the research community to evaluate its successful deployment. In this paper, we survey the state of the art of 802.11ah and identify how device manufacturers are responding to this new standard and the promising research directions in this area.**

Keywords— IEEE 802.11ah; Wi-Fi HaLow; sub-1GHz; PHY; MAC layer; Internet of Things (IoT)

I. INTRODUCTION

Over the years, Wi-Fi has become a technology of choice as it provides high data rate, easy deployment and low cost. According to ABI Research, the leader in transformative technology market intelligence, it is expected that more than 20 billion Wi-Fi chipsets will be shipped between 2016 and 2021 [4]. Wi-Fi's success story is being built based on a strategy of steady upgrades to its standards. With these advancements, the technology has also started encountering new challenges. Its popularity has resulted in congestion in the unlicensed 2.4 GHz band. As a result, Wi-Fi keeps on expanding its ecosystem, with new standards focused on taking advantage of new spectrum and new use cases [4].

IoT is a major developing area for the wireless industry with applications such as home and industry automation, energy management [21], environmental monitoring and health care [18] [22]. Wi-Fi must satisfy requirements and constraints of different devices to become the technology of choice for IoT applications. Nowadays, wireless sensor networks (WSN) have been the driving force of IoT applications since it covers a significant proportion of deployment. But traditional Wi-Fi is not suitable for a wireless sensor network for the following reasons: [2].

- Devices such as sensors and smart meters are designed to last for several years on a single battery. Long term monitoring of sensors is not possible with the use of higher power consumption of legacy Wi-Fi.
- Most of the wireless sensor networks are being designed to support dense installations. But existing Wi-Fi has been intended for a limited number of nodes with high throughput.
- Traditional Wi-Fi, which is operating in 5 GHz and 2.4 GHz, has a very limited range, which makes it unsuitable for real time monitoring.

Due to these drawbacks of the classical Wi-Fi standard and the increased demand of end users, the IEEE802.11 working group initiated work on a new standard called 802.11ah in 2010. The brand name for 802.11ah is Wi-Fi HaLow and the technology is intended to operate in sub-GHz bands [22] excluding TV whitespaces . It is mainly aimed to provide enhanced connectivity with a longer transmission range and an increased number of stations per access point. Provision for a range of throughput options from 150 Kbps to 40 Mbps is also a special feature targeted by this technology.

The topology for 802.11ah is limited to single hop star and peer to peer networks [22] as shown in Fig. 1. It allows the use of relays with the help of tree based multi hop network which is shown in Fig. 2 [13]. But mesh network functionality at MAC level is not defined by 802.11ah standard and it is expected to come in the future.

Its physical layer is based on the down clocked version of PHY used in IEEE 802.11ac. IEEE 802.11ah can operate in channel bandwidths of 1, 2, 4, 8 and 16 MHz [22]. Among these, 2 MHz and 1 MHz are specifically for IoT applications. The 802.11ah amendment includes a number of MAC layer features for power savings such as short beacon frame, a null data packet, a restricted access window (RAW) mechanism, target wake time (TWT) functionality, extended sleep cycle, etc. Key channel access procedures such as TWT and RAW have been rolled out for implementing the IoT applications [18]. Fig. 3 shows 802.11ah MAC architecture. In this architecture Distributed coordinated function (DCF) is a basic MAC functionality of IEEE 802.11 based networks which uses CSMA/CA with binary exponential back off algorithm. Hybrid coordination function (HCF) is a priority based access mechanism for ensuring the QoS requirements.

The remainder of this paper is structured as follows: Section II explains the evolution of the IEEE 802.11ah standard and section III provides a brief overview of the

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deployment scenarios. The market readiness of the new standard is discussed in Section IV. Section V covers the technical challenges, and finally, the paper concludes with Section VI.

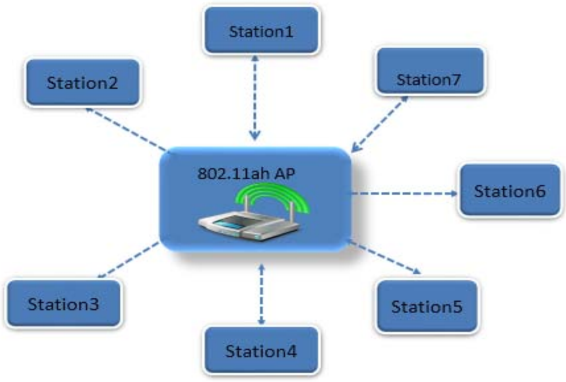

Fig. 1. Star Topology

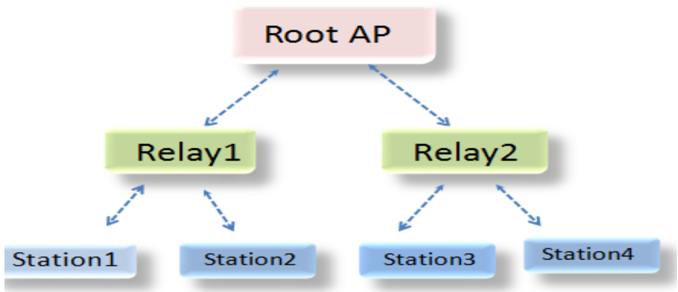

Fig. 2. Tree Topology

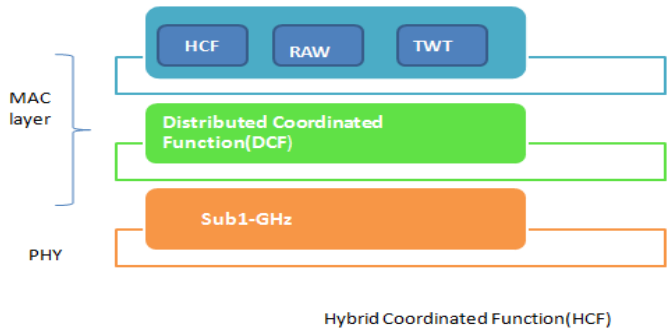

Fig. 3. MAC Architecture

II. EVOLUTION OF STANDARD

As the development of IEEE802.11ac standard progressed and related products became popular, the IEEE 802.11working group initiated a new project referred to as 802.11ah in 2010. It was an amendment to the IEEE standard 802.11-2007 and was sponsored by the IEEE 802 LAN/MAN standard committee which describes both physical layer and medium access control specifications [20]. It enables 802.11 wireless networks operating in the license exempt frequency bands below 1 GHz excluding the TV White space. This 802.11 standard aims for a transmission range of one km with a minimum data rate of at least 100 kbps [2]. At the very beginning of a standardization process, it is necessary that the new standard be sponsored by an IEEE approved organization from inception to completion. Coordination and supervision of the IEEE 802.11ah standard development was performed by the IEEE computer society. Later on, to gain authorization for the standard, a Project Authorization Request (PAR) [5] was submitted by the S1G (Sub 1_GHz) study group in July 2010, which was approved after undergoing the revision process driven by the New Standards Committee (NeSCom) of the IEEE-SA Standards Board. After Sub 1_GHz Study Group completing the principal work of generating a PAR document, the standardization work was undertaken by Task Group AH (TGah) in November 2010 [20]. The PAR document describes the intention and scope of the IEEE 802.11ah project [20].

This task group was enriched by a host of companies, interested in the development of this technology. As a first step in drafting the amendment, a selection procedure document [6] was developed in March 2011 and was being followed by the TGah until the 802.11ah draft 1.0 specification was completed. The task group also defined a usage model document [7], a channel model document [8], a functional requirements document [9], and a specification framework [10] in the selection procedure document. The usage model was comprised of important use cases of the upcoming standard. The channel model document consisted of both outdoor and indoor channel models which are based on the 3GPP/3GPP2 spatial channel models (SCM) [2] and the MIMO channel models respectively. Both models provided a detailed representation of the multi-antenna propagation channel for both indoor and outdoor cases. Proposed specification, system level performance targets and simulation scenarios for those targets were addressed in the functional requirements document. In addition, the task group created a specification framework that outlines the main functional blocks and the document was accepted by the task group with 75% approval. For functional blocks outlined in the specification framework, two Ad Hoc subgroups were created: the PHY Ad Hoc Sub Group [20] and the MAC Ad Hoc Sub Group [20]. Draft specification of the two main functional blocks, called PHY layer and MAC layer were developed by these Ad Hoc Sub Groups.

Finally, 802.11ah Draft 1.0 was approved for first Letter Ballot in September 2013. Similarly, after nine more revised draft versions, the final Draft 10.0 was forwarded to RevCom and approved in 2016.

III. DEPLOYMENT SCENARIOS

Currently, a large numbers of applications are proposed for 802.11ah which can be generally classified into three areas.

- Smart meters and sensors
- Backhaul aggregation
- Cellular offloading and Extended range

The following discussions cover two major use cases, namely, smart sensors and meters and extended range hotspot and cellular offloading.

A. Smart Meters and Sensors

Since 802.11ah is specifically designed for applications that involve thousands of devices per access point, following sensing applications are considered as appropriate for this particular use case category [20].

- Smart grid: It monitor usage status (gas, water, power consumption) of end users in real time. Proposed scenario involves an 802.11ah access point and a number of smart meters (gas meter, power meter, water meter) for monitoring
- Environmental and agricultural monitoring with sensors for monitoring temperature, humidity, wind speed, water level, moisture, forest fire detection, etc., [21].
- Wearable devices supporting 802.11ah for enabling indoor healthcare/fitness system (blood pressure, heart rate, weight) [21].
- Wearable devices for multimedia/infotainment: Wearable devices that offer information regarding nearby stores, optimal routes to get from one location to another.
- Lightning control in large offices for industrial automation

B. Cellular offloading and Extended range

Both long transmission range and high throughput are necessary for effective cellular offloading. Although 802.11n and 802.11ac have high throughput, because of the short transmission range, they can hardly be used for offloading [20]. In contrast, 802.11ah can be used for this application because of its extended range.

IV. MARKET READINESS

IEEE802.11ah has come up with a very different set of enhancements than its earlier well-known siblings. Many new features including both the PHY and the MAC layer improvements launched by the IEEE802.11ah are mainly for achieving more efficient transmissions [13]. At this point, the most relevant question that should be answered will be - where are the HaLow products? For the previous version 802.11ac, shipping products had started to appear 18 months before its final draft got approved. But in the case of 802.11ah, no official product announcements are made by the manufactures yet. One of the reasons for this delay could be the strong competition from the existing IoT friendly technologies. This section covers some ongoing research and developmet activities on HaLow products.

The first demonstration based on the new standard was made by Antcore S.A, a leading innovator of Wi-Fi IP in 2014. Its applications included battery controlled devices such as sensors and wearables. These devices were also scalable up to 4*4 MIMO to support industrial automation, Smart Home Gateways, etc., [12].

NRC6101 is the first test chipset rolled out by NEWRACOM, a leading developer and one of the participants in the development of 802.11ah specification. The following are the special features of this 802.11ah chip.

- Single stream up to 2.167 Mbps data rate.
- Supports 1 MHz channel bandwidth.
- Support TWT functionality for power savings.

A. Target Applications

- Smart Grid.
- Extending Wi-Fi coverage.
- It can also be used for remote controls, home/office automation devices or industrial automation.

Commercial sample chipsets made by NEWRACOM are waiting for the upcoming WFA ERah [15] certification. Features of these products [3] are listed in Table I.

V. TECHNICAL CHALLENGES

According to Analysts at ABI research, by the year 2020, 802.11ah devices are scheduled to arrive that are capable of shipping about 11 million devices annually [19]. This slow growth indicates, the challenges need to be faced by the manufactures.

Since sub 1_GHz bands are not globally assigned and regulated [23] adoption of the standard would be slow. Unlike the unlicensed Wi-Fi frequencies, the bands available for Sub 1_GHz ISM (Industrial, Scientific and Medical) communication are different depending upon the country as shown in Table II.

TABLE I. PRODUCT FEATURES

Product Name	IEEE 802.11ah RF/Baseband/CPU40nm LP-CMOS Soc	IEEEE 802.11ah AP Baseband/MAC IP
Product code	NRC 7191	NRC7271
MAC layer features	TWT,RAW	TWT,RAW
Security features	AES-CCMP,IEEE 802.11w	AES-CCMP,IEEE 802.11w
Supported data rates	Support up to 2Mbps	1 MHz BW: 150 Kbps to 3.3 Mbps 2 MHz BW: 650 Kbps to 6.5 Mbps 4 MHz BW: 1350 Kbps to 15 Mbps
Applications	Mobile device, Digital home	Healthcare,Digital Home, Industrial automation, Home automation

Hence it is clear that, there is no one frequency band that can be used throughout the world [16]. So one of the challenges for the device manufactures to explore the long range and low interference benefits of sub 1_GHz would be designing a single module that offers country specific frequency band selection [16].

TABLE II. SUB 1 _GHZ ISM FREQUENCY BANDS

Country	Frequency band
US	902MHz - 928MHz
South Korea	917.5MHz - 923.5MHz
Europe	863- 868MHz
China	755- 787MHz
Japan	916.5- 927.5MHz
Singapore	866- 869MHz & 920- 925MHz

Technical challenges related to compatibility issues also need to be considered. Since previous Wi-Fi standards are backward compatible, it is possible to use devices that support different standards in an interoperable way. But it is not possible to use an 802.11ah product with an 802.11n Wi-Fi router since it is not backward compatible [19].

Along with that, it has a number of competitors such as Bluetooth, ZigBee, Z-Wave, Thread, Sigfox , etc. Sigfox's IoT network operates in the same band as 802.11ah which may cause interference [14]. However after resolving all the technical challenges, chips for the IEEE 802.11ah standard are expected to hit the IoT market.

VI. CONCLUSION

In this paper we have summarized the events that led to the standardization of 802.11ah.We have also provided the current status of HaLow products in the IoT market. It has been noted that, although the final draft of 802.11ah has been completed, its products are not yet available in the market, but will be available in the near future as they are on the verge of certification. This work also highlighted the technical challenges that will be faced by this standard. On the horizon, we expect that 802.11ah will be used for promising applications in the IoT landscape [20].

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REFERENCES

[1] Park, M, "IEEE 802.11ah: sub-1-GHz license-exempt operation for the internet of things", IEEE Communications Magazine, 53(9), pp.145-151, 2015.

[2] Araiza Leon, Julio Cesar, "Evaluation of IEEE 802.11ah Technology for Wireless Sensor Network Applications", Tampere University of Technology, February 2015.

[3] "Newracom products", Google.co.in, 2017. [Online]. Available: https://www.google.co.in/ newracom.com%2Fproducts, [Accessed: 13- Nov- 2017].

[4] "ABI Research Anticipates More Than 20 Billion Cumulative Wi-Fi Chipset Shipments by 2021 While Increased Use of 5GHz Spectrum Raises Coexistence Issues with LTE-U", [Online]. Available:https://www.abiresearch.com/press/abi-research-anticipates-more-20- billion-cumulativ/. [Accessed: 13- Nov- 2017].

[5] "802.11ah PAR document", Google.co.in, 2017. [Online]. Available: https://mentor.ieee.org%2F802.11%2Fdcn%2F10%2F11-10-0949-00-0s1g-s1g-july-2010-minutes.docx, [Accessed: 13- Nov- 2017].

[6] D.Halasz & R.Vegt, "IEEE 802.11ah proposed selection procedure, IEEE802.11-11/0239r2",https://mentor.ieee.org/802.11/dcn/11-11-0239-02-00ah-proposed-selection-procedure.docx, February 2011.

[7] "Potential compromise for 802.11ah use case document", Google.co.in,2017.[Online].Available:https://mentor.ieee.org%2F802.11%2Fdcn%2F11%2F11-11-0457-00-00ah-potential-compromise-of-802-11ah-use-case-document.pptx, [Accessed: 13- Nov- 2017].

[8] "802.11ah channel model document", Mentor.ieee.org, 2017. [Online]. Available: https://mentor.ieee.org/802.11/dcn/11/11-11-0498-01-00ah-channel-models-for-tgah.doc. [Accessed: 13- Nov- 2017].

[9] "802.11ah functional requirements and evaluation methodology", Mentor.ieee.org,2017.[Online].Available:https://mentor.ieee.org/802.11/dcn/11/11-11-0905-04-00ah-tgah-functional-requirements-and-evaluation-methodology.doc. [Accessed: 13- Nov- 2017].

[10] "Specification framewok of 802.11ah", R.search.yahoo.com, 2017. [Online].Available:https://mentor.ieee.org%2f802.11%2fdcn%2f11%2f11-11-1137-15-00ah-specification-framework-for-tgah.docx,[Accessed: 13- Nov- 2017].

[11] "Newracom NRC6101 802.11ah WiFi SoC Promises up to 1 km Range for Smart Grid and Automation", Cnx-software.com, 2017. [Online]. Available: https://www.cnx-software.com/2015/11/12/newracom-nrc6101-802-11ah-wifi-soc-promises-up-to-1-km-range-for-smart-grid-and-automation/. [Accessed: 13- Nov- 2017].

[12] S. Antcor, "World's First 802.11ah IP Introduced by Antcor", Prnewswire.com,2017.[Online].Available:https://www.prnewswire.com/news-releases/worlds-first-80211ah-ip-introduced-by-antcor 245976221.html.[Accessed: 13- Nov- 2017].

[13] "Draft-delcarpio-6lo-wlanah-01 - IPv6 over 802.11ah", Tools.ietf.org, 2017. [Online]. Available: https://tools.ietf.org/html/draft-delcarpio-6lo-wlanah-01. [Accessed: 13- Nov- 2017].

[14] "The Future Of Wi-Fi", Google.co.in. N.p., 2017. Web. [Accessed: 13- Nov- 2017].

[15] "Certification | Wi-Fi Alliance", Wi-fi.org, 2017. [Online]. Available: https://www.wi-fi.org/certification. [Accessed: 13- Nov- 2017].

[16] "Sub-1GHz Radio The Best Solution for the Internet of Things?", Mouser.com,2017.[Online].Available:https://www.mouser.com/pdfDocs/thebestsolutionfortheinternetofthings.pdf. [Accessed: 14- Nov- 2017].

[17] "IEEE 802.11ah (Wi-Fi in 900 MHz License-exempt Band) for IoT Application | IEEE Standards University", IEEE Standards University, 2017. [Online]. Available: https://www.standardsuniversity.org/e-magazine/august-2016-volume- 6/ieee-802-11ah-wi-fi-900-mhz-license-exempt-band-iot-application/. [Accessed: 13- Nov- 2017].

[18] "IoT's sub-GHz 802.11ah Wi-Fi will be dead on arrival, warn analysts", Theregister.co.uk,2017.[Online].Available:https://www.theregister.co.u. [Accessed: 13- Nov- 2017].

[19] Weiping. Sun, "IEEE 802.11ah: A Long Range 802.11 WLAN at Sub 1 GHz", Journal of ICT Standardization, vol. 1, pp. 83–108, 2017.

[20] Khorov,"Asurvey on IEEE 802.11ah: An enabling networkingtechnology for smartcities", Computer communications Volume 58, Pages 53-69, March 2015.

[21] L. F. Del Carpio, P. Di Marco, "Comparison of 802.11ah and BLE for a home automation use case," 2016 IEEE 27th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC),pp.1-6.doi: 10.1109/PIMRC.2016.7794554, 2016.

[22] A. R. Devidas and M. V. Ramesh, "Wireless Smart Grid Design for Monitoring and Optimizing Electric Transmission in India", Fourth International Conference on Sensor Technologies and Applications, Venice, pp. 637-640, 2010.

[23] Dilraj N, Rakesh K, Rahul Krishnan and Maneesha V Ramesh, "A low cost remote cardiac monitoring framework for rural regions", MOBIHEALTH, London, Great Britain, 2015.