IEEE 802.11ah: Advantages in Standards and Further Challenges for Sub 1 GHz Wi-Fi

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Abstract—**The rapid development in Internet-of-Things (IoT) and Machine-to-Machine (M2M) communication make it necessary to design communication systems operating in different wireless spectrum as an alternative to highly congested wireless access systems. In addition, the deployment of wireless smart meter devices is ramping up and it is expected that such devices will flood the market in the near future competing for the same wireless spectrum. The IEEE 802.11ah standardization working group is aiming for a global Wireless LAN (WLAN) standard operating with carrier frequencies below 1GHz in the ISM (Industrial, Scientific, and Medical) band and will help to provide Wi-Fi-enabled devices to get guaranteed access for short-term transmissions in less congested frequency bands. In addition to exploiting the underutilized Sub 1 GHz spectrum the improved coverage range allows new applications to emerge such as wide area based sensor networks, sensor backhaul systems and potential Wi-Fi off-loading functions. This paper summarizes the IEEE 802.11ah standardization activities in progress and discusses advantages and challenges in the design of physical layer (PHY) and media access control (MAC) schemes.**

Keywords: Sub 1GHz, IEEE 802.11ah, long-range Wi-Fi, smart grid, IoT, M2M.

I. INTRODUCTION

It is widely accepted that the dominant indoor (wireless) network is based on the IEEE 802.11 standard including IEEE 802.11 based indoor access points (APs) and stations (STAs) such as laptops, printers, PDAs using wireless LAN (WLAN) interfaces. Operating at 2.4GHz/5GHz this standard and its amendments, such as 802.11a/b/g/n, allow unlicensed wireless access in the ISM band (Industrial, Scientific, and Medical) and thus make it simple for Internet user to build up their own wireless access network.

This widespread deployment of IEEE 802.11-based wireless networks in indoor environments and also for urban city deployments has led to dramatic interference problems and network performance reduction where wireless Internet user suffer from low speed or even network disruption.

Beside in indoor environments, so called Wi-Fi interfaces can be found in various mobile devices such as tablet PCs, and smart phones, thus increasing the competition for unlicensed wireless access in the ISM band. Smart grid application, Internet of Things (IoT) and Machine-to-Machine (M2M) communication will further lead to saturated spectrum when the same frequencies are being used, including Wi-Fi and IEEE 802.15.4-based communication systems.

Beside the successful deployment of IEEE 802.11 devices in the 2.4GHz/5GHz frequency band, the design of RFID and sensor networks operating at lower frequencies such as 900MHz ISM took a niche in the development of wireless systems. With the rapid demand for unlicensed, ubiquitous access in less-interfered frequency bands, the 900MHz ISM bands have kindled new attraction not only in the research domain but also in standardization. The target is to define a global WLAN standard that operates at ISM frequencies below 1GHz. For instance, in the United States, Europe and Japan, such frequencies are available, however a standard has not been available yet that utilizes such frequencies.

The new task group (TG) at the IEEE 802 standardization organization aims to create a WLAN standard for PHY and MAC that operates at frequencies below 1GHz. The so-called Sub 1GHz WLAN system is under current standardization in the IEEE 802.11ah group. In the following, we are going to reflect on the advantages and challenges of a Sub 1GHz WLAN system.

To the best of our knowledge there has been less focus and studies on Sub1GHz WLANs. In [1] the authors argue that the scope of 802.11ah is to enhance the MAC and PHY design to operate in the license-exempt bands below 1 GHz. For smart grid and smart utility communications the authors discuss the advantages of access in TV frequency bands. However the access to the so-called TV white-space is outside of the scope of IEEE 802.11ah (the operation of WLAN in the TV white space is being standardized by the IEEE 802.11af group). We then refer to our earlier work in Sub 1 GHz WLAN in [2] and [3]. Use cases and scenarios for using Sub 1GHz frequency bands has been discussed in [2] and we identified smart grid, surveillance and smart farming as main applications in rural areas. In addition, link budget and outage probabilities have been discussed in [2] In [3] we outlined the required PHY design of Sub 1GHz systems and argued that the proposed IEEE 802.11ah path-loss design for outdoor Sub 1GHz is too optimistic and may require a larger number access points (pico-cells) in an outdoor deployment scenario when using WLANs operating at carrier frequencies around 900MHz. We refer the reader to the official project site of 802.11ah [4] for further information about project description of Sub 1GHz standardization. In the following we will give further insight into the development of a global Sub 1GHz ISM WLAN system and also what lies ahead and enlist many challenges and issue thereof.

This paper is organized as follows: In Section II the advantages of using Sub 1 GHz frequency band is discussed. IEEE 802.11ah use cases are explained in Section III. IEEE 802.11ah standardization challenges are dealt with in Section IV. We conclude in Section V.

II. Advantages of Standardized Sub 1GHz WLANs

Even though Wi-Fi is standardized for the 2 – 5 GHz frequency range, there is non-standard modified Wi-Fi equipment available that operates in the 900 MHz ISM band. As for now, various vendors take the core technology, e.g., 802.11a, and change the frequency. The demand for a standardized Sub 1GHz WLAN comes, in part, from the smart grid community, who like it for linking to smart meters because of the band's greater range and lower obstruction losses. A problem, though, has been lack of interoperability. Each vendor has its own implementation, and smart grid customers don't want to be tied to one vendor.

The IEEE Standards Association's Standards Board approved a request by IEEE 802 Working Group 802.11 to start a project that will amend the IEEE 802.11 standard to include Sub 1 GHz operation. This project, under new Task Group 802.11ah, does not include TV white space frequencies, which is being handled under Task Group 802.11af. The most important contribution of this amendment is to establish standard RF channel width and center frequencies. Because 802.11 is an international standard, global frequency allocation schemes will be considered.

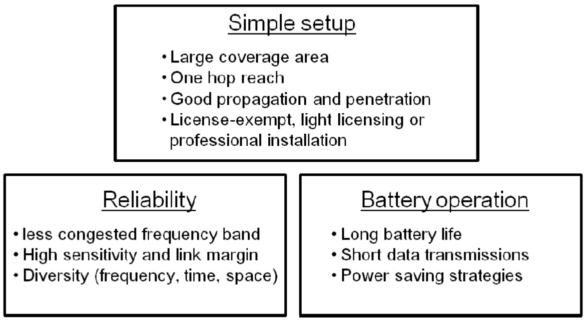

Fig. 1: Advantages of a standardized Sub 1 GHz Wi-Fi system

IEEE 802.11ah offers a variety of advantages, such as simple to use in outdoor environments in addition to excellent propagation characteristics of low frequencies [5] and different levels of installation scenarios (license-exempt, light licensing, professional/interference reduced). High sensitivity and link margin are further characteristics of IEEE 802.11ah. In addition, long battery life and energy saving strategies will be integral part of the IEEE 802.11ah standard. Details are shown in Fig.1. In the following we outline the main advantages of a standardized Sub 1GHz WLAN:

- Optimal propagation characteristic of below 1GHz license-exempt frequency bands.
- Use of ISM frequency bands.
- License-exempt in various different countries.
- Easy to understand, follow and to implement for network device manufacturers.
- Almost clear co-existence issues.
- Longer range and less power consume due to optimal frequency characteristics (below 1GHz).
- No license problems, no regulatory issues.
- Vendors can be sure about their products/markets.
- Enrichment of wireless communication devices, e.g., IEEE 802.11a/b/g/n/ah.

III. IEEE 802.11ah Use Cases

This section provides an overview of the use cases that have been adopted by the IEEE 802.11ah task group. We also refer to additional use cases to further motivate the usability of the future IEEE 802.11ah standard that is not in the standard as yet. The following discussion on use cases provides a comprehensive picture about the advantages of using Sub 1 GHz bands in various domains and scenarios.

A. Sensor networks

The IEEE 802.11 has sensor networks as one of three adopted use cases. Sensing can be executed as short-term data transmissions and includes smart metering such as gas, water and power consumption [6]. Wireless controlled power distribution systems are also covered by this use case. Due to the increased penetration at lower frequencies, a higher number of sensors can be covered in one-hop fashion. Fig. 2 shows a simple smart grid scenario where IEEE 802.11ah is applied (Sub 1 GHz AP and wireless meter stations).

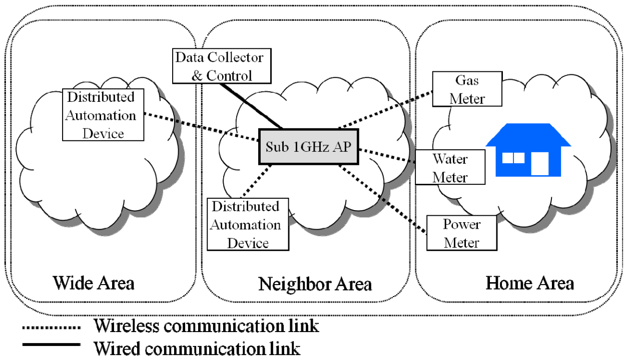

Fig. 2: Smart grid wireless communication network use case for outdoor Sub 1GHz WLANs.

B. Backhaul networks for Sensors

The second use case covers the backhaul connection between sensors and/or data collectors and remote servers. The large coverage of Sub 1 GHz allows a simple network design to link Sub 1GHz APs together, e.g., as wireless mesh networks. Fig. 3 shows a backhaul sensor network, including IEEE

802.11ah APs and router/gateways to connected sensor networks (IEEE 802.15.4g).

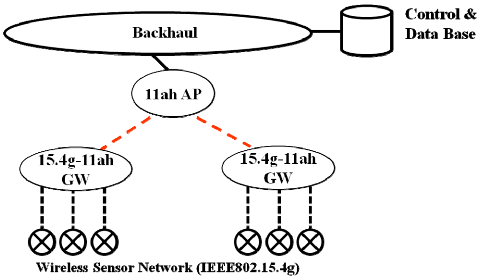

Fig. 3: Backhaul network for sensor networks

C. *Extended Wi-Fi Range for Cellular Traffic Off-loading*

The third use case considers technical requirements for a Wi-Fi based cellular traffic offloading in 802.11ah. It is important that the technology used for off-loading has at least comparable performance to the cellular system being offloaded both from the user as well as the operator perspectives. Therefore, it is essential to consider what kind of spectral efficiency, user throughput, and system load the current and future cellular networks can and will support, and based on that, consider the performance requirements for 802.11ah.

Although it can be easily understood that a large coverage may be utilized for off-loading, some may argue that user expectations can be easily covered by existing wireless standards such as IEEE 802.11n. If the performance is not sufficient or if the 802.11ah offloading provides only marginal gains and no real additional value for the end user, the offloading might not be successful and operators and end users may prefer the existing solutions e.g. 802.11n and 802.11ac at 5GHz or utilization of cellular network.

Next, we outline additional use cases and scenarios for IEEE 802.11ah.

D. *Machine-to-Machine (M2M) Communication*

The future IEEE 802.11ah standard has been found as an optimal candidate as wireless communication system for Machine-to-Machine (M2M) communication. Wireless M2M communication allows data transfer for direct machine to machine communication with little or no human interaction [7]. Whereas current systems are optimized more for human-to-human (H2H) communications, IEEE 802.11ah standard will mainly consider sensing applications.

Due to all the different M2M standards activities happening in various standardization organizations, IEEE 802.11ah could play an important role in providing a base for a global M2M wireless standard, which some entities consider as a precursor of cloud computing [8]. This includes smart metering, fleet management, security sensing, and on-demand business-charging applications. IEEE 802.11ah will address required functions such as low power consumption, large number of devices, long-range and short-burst data transmissions.

E. *Rural communication (connecting the unconnected)*

Wireless communication in rural areas such as outback areas has lead to some effort that is also named as "connecting the unconnected". Large potential is given by Sub 1 GHz due to the wider range [9]. E-health and e-learning are main killer applications in such environments and it has been argued that a positive impact on social economics including the GDP (Gross Domestic Product) growth can occur [10].

IV. IEEE 802.11AH STANDARDIZATION CHALLENGES

A. *IEEE 802.11ah project target and time line*

IEEE Standards Board approved the Sub 1 GHz 802.11 (Wi-Fi) Project in November 2010. The sponsor ballot is expected for spring 2013. The project target is specified in the PAR as listed under [4]. Since November 2010 the time line has been extended several times mainly to allow consensus within the standardization group, e.g., for use case identification, optimal PHY channelization, and requirements on the MAC design.

B. *Requirements on IEEE 802.11ah PHY design*

Future IEEE 802.11ah standardized devices will operate as a MIMO-OFDM (Multi Input Multi Output Orthogonal Frequency Division Multiplexing) wireless system at different Sub 1 GHz ISM bands which are available in various countries, including United States, South Korea, China, Europe, Japan, Singapore. In the following we outline the adopted and proposed channelization for IEEE 802.11ah.

The US channelization has been one of the most discussed channelization for IEEE 802.11ah. This is due to the fact that the US allows up to 16MHz bandwidth between 902MHz and 928MHz. Fig. 4 depicts the proposed US bandwidth, including 1, 2, 4, 8, and 16MHz. It is less attractive for vendors having small bandwidth at 1MHz. However, 1 MHz and 2 MHz have been adopted as least channel bandwidth for IEEE 802.11ah. The standardization group thus needs to support 1MHz for US and all other countries which are under discussion in IEEE 802.11ah. A compromise would be a link adaptation scheme which will allow 1MHz/2MHz operation when STAs are outside of AP coverage.

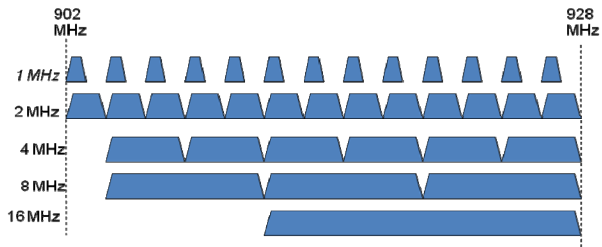

Fig. 4: Proposed (not yet adopted) Sub 1GHz channelization for US

In Fig. 5 the adopted channelization for South Korea is shown, starting from 917.5MHz and 923.5MHz. 6 channels at 1MHz bandwidth are adopted. In addition, 3 channels at 2MHz and 1 channel at 4MHz bandwidth will be available for IEEE 802.11ah in Korea. The reason for the 0.5 MHz frequency off-set is to reduce possible mutual interference with wireless legacy systems at lower frequencies.

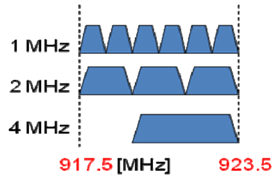

Fig. 5: Adopted Sub 1GHz channelization for Korea

In Fig. 6 the adopted channelization for Japan is presented, starting at 916.5MHz until 927.5MHz. Also the Japanese channelization starts with 0.5MHz off-set [11]. This is due to the fact that the Japanese spectrum regulation specifies center frequencies instead of start/stop bands such as in other countries, e.g., US or Europe.

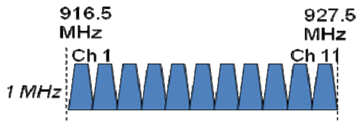

Fig. 6: Adopted Sub 1GHz channelization for Japan

Fig. 7 shows the adopted channelization for Europe, starting at 863MHz and ends at 868MHz. 5 channels with 1MHz bandwidth are available. In addition 2 channels with 2 MHz bandwidth are adopted.

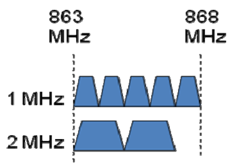

Fig. 7: Adopted Sub 1GHz channelization for Europe

The adopted channelization for China is shown in Fig. 8, starting at 755MHz and ends at 787MHz. Frequencies between 755MHz to 779MHz will allow a max. sending power at 5mW. Between 779MHz and 787MHz, max. 10mW are allowed. In the higher frequency regime 4 channels with 2MHz, 2 channels with 4MHz and 1 channel with 8MHz are approved. It is worth to note that most of the Sub 1GHz frequencies in China are used by TV broadcast stations, thus make it inappropriate to adopted such frequencies for IEEE 802.11ah.

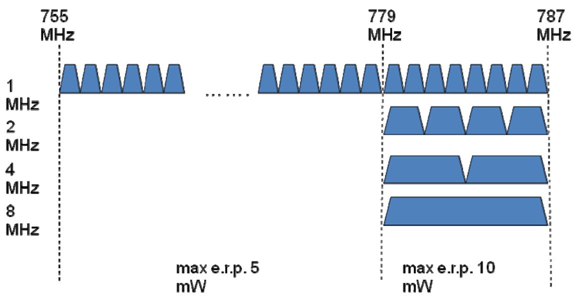

Fig. 8: Adopted 1GHz channelization for China

In Fig. 9 the proposed channelization for Singapore is shown. It starts from 920MHz and ends at 925MHz including 5 channels with 1MHz bandwidth.

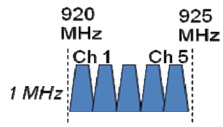

Fig. 9: Proposed (not yet adopted) 1GHz channelization for Singapore

C. *Sub 1GHz related Regulatory Requirements and IEEE 802.15.4d Co-existence in the case of Japan*

The use of the 950 MHz band (950 MHz to 956 MHz) for LR-WPAN (Low Rate Wireless Personal Area Networks) has only been recently allocated by the Japanese Regulatory committee. The Japanese regulation includes requirements to address coexistence for devices operating in the Sub 1GHz band, e.g., Listen Before Talk, Transmission Control and Duty Cycle restrictions. However, two PHYs specified for use in the 950 MHz band, such as IEEE 802.15.4d and IEEE 802.11ah can potentially cause interference to each other. Together with the short duration (burst nature) of 802.15.4 packets and the use of CSMA-CA, coexistence is not considered to be a problem for the two PHYs when they share a common channel [11].

The regulation requires that a device uses listen before talk (LBT) prior to transmission if the duty cycle of transmission exceeds 0.1%. There is also a requirement that a device does not continuously transmit. The maximum continuous transmission time and the duty cycle of transmission are dependent on the LBT duration. The parameters macTxControlActiveDuration & macTxControlPauseDuration permit a higher layer to control both the duration for which a device may transmit and the duration of the pause period, i.e. the time during which the MAC must pause to allow other devices access to the channel. These values are dependent on the transmission power and channel and should be discussed during the IEEE 802.11ah standardization process.

D. *IEEE 802.11ah path loss models*

IEEE 802.11ah path loss models for indoor have been outlined and discussed in [3]. The basic assumption is a path loss model for AP-to-STA communication separated for indoor and outdoor environments [12]. In addition multi-floor and STA-to-STA path loss models are being discussed. Fig. 10 shows a typical STA-to-STA path loss scenario. The two stations operate in AP-to-STA communication, thus mutual interference between the STAs occur when transmitting in same locations.

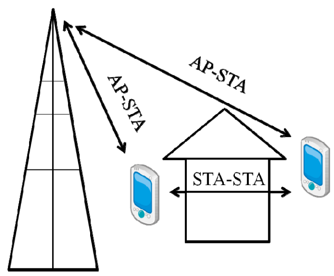

Fig. 10: Path loss model in a STA-to-STA communication scenario

E. Enhanced Coverage Extension through Repetition

IEEE 802.11ah aims to widen the coverage for outdoor WLANs and future Wi-Fi certified devices. Using carrier frequencies in the Sub 1 GHz easily achieve such a goal due to the excellent propagation characteristic of lower frequencies. However, further improvement of coverage and link budget performance can be achieved using *repetition* in addition. IEEE 802.11ah adopted to use repetition as part of the IEEE 802.11 PHY for coverage improvements. Different repetition models have been discussed, e.g., 2-times and 4-times repetition. For instance, different Modulation and Coding Schemes (MCS) are being proposed for IEEE 802.11ah. MCS0-rep (1MHz) is 6 dB higher than MCS0 (2MHz) thus it will provide larger coverage compared to non-repetition based communication. Based on the IEEE 802.11ah path loss model [3], the range covered by MCS0-rep2 (1MHz) would be 1.45 times higher than MCS0 for 2MHz bandwidth. More than half of the coverage area is covered by MCS0-rep2. In the case of remote access with less coverage, the AP will use MCS0-rep2 in significant portion of time to reach stations in the Area 2, as shown in Fig. 11.

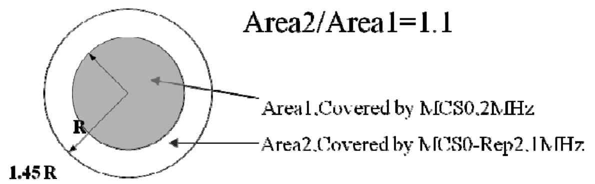

Fig. 11: Impact on coverage range for different replication scenarios

Fig. 11 shows an example for indoor coverage of 1MHz BSS (Basic Service Set) over 2MHz BSS. The assumption is a path loss exponent with 36.7. The sensitivity improvement is given at 6dB. The assumed indoor coverage leads to 1.45 times higher coverage when using MCS0-rep2 at 1MHz.

Fig. 12 shows outdoor coverage of 1MHz BSS over 2MHz BSS. The assumption is a distance exponent path loss at 37.6. The sensitivity improvement is given at 6dB. The assumed outdoor coverage leads to 1.74 times higher coverage when using MCS-rep2 at 1MHz.

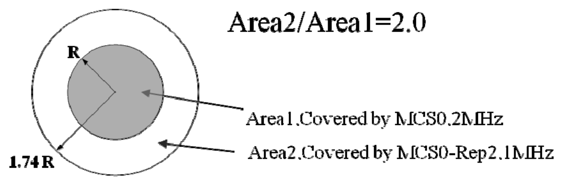

Fig. 12: Impact on coverage range for different replication scenarios

F. Requirements on IEEE 802.11ah MAC design

The IEEE 802.11ah MAC design will support the adopted PHY channelization and repetition modes. Furthermore, the MAC design has to consider a large number of associated STAs and alternative DCF (Distributed Coordination Function) methods for guaranteed media access. In addition, a contention-free MAC design is considered for IEEE 802.11ah for large number of stations, e.g., thousands of STAs, which are essential requirements for M2M and IoT wireless applications.

Due to the adopted use cases, power efficiency for sensor devices will be a required feature that needs to be considered in the IEEE 802.11ah MAC design. Power efficiency proposals include the integration of IEEE 802.11v power saving features and ultra-low power consumption strategies, such as Radio-on-Demand (ROD) for IEEE 802.11ah.

V. Conclusions

With the rapid deployment of smart meter systems, IoT and M2M applications the demand for guaranteed short-term wireless access becomes a challenging task when using current frequency bands. IEEE 802.11ah is an answer to this problem and will define wireless access of Wi-Fi enabled devices in the Sub 1 GHz ISM band in various countries, including US, Europe, Japan, China and Korea. Operating at carrier frequencies below 1 GHz such devices are able to exploit a larger coverage area and high penetration. To this effect, this paper presents the advances of the standardization of Sub 1 GHz WLANs and at the same time it discusses the challenges that need to be addressed so that the emerging IEEE 802.11ah standard will efficiently define an extended PHY and MAC allowing wireless transmission in the Sub 1GHz ISM band.

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