IEEE Wireless Standards for Internet of Things

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Abstract

The IEEE 802 has developed Sub-1 GHz band wireless communication standards such as IEEE 802.11ah and IEEE 802.15.4g for the IoT. This paper introduces various use cases of wireless communications in the Sub-1 GHz band and describes the challenges that arise in an environment where these wireless communication systems coexist. In addition, the standardization activity of IEEE 802, especially the coexistence of multiple systems in the Sub-1 GHz band by the IEEE 802.19 Working Group, the issues and countermeasures in the coexistence environment are introduced as well.

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***Abstract*— The IEEE 802 has developed Sub-1 GHz band wireless communication standards such as IEEE 802.11ah and IEEE 802.15.4g for the IoT. This paper introduces various use cases of wireless communications in the Sub-1 GHz band and describes the challenges that arise in an environment where these wireless communication systems coexist. In addition, the standardization activity of IEEE 802, especially the coexistence of multiple systems in the Sub-1 GHz band by the IEEE 802.19 Working Group, the issues and countermeasures in the coexistence environment are introduced as well.**

Keywords—Wireless coexistence, sub-1 GHz band, IEEE 802.19.3, IEEE 802.15.4g, IEEE 802.11ah, internet of things.

I. Introduction

Advances in the Internet and sensor technology have led to an explosion in the number of not only traditional PCs and smartphones, but also home appliances, automobiles, factories, and many other things around the world connected to the Internet. LPWAN (Low Power Wide Area Network) is attracting attention as a wireless communication network for the Internet of Things (IoT), and wireless communication standards and technologies such as IEEE 802.11ah, IEEE 802.15.4g, Wi-SUN, SigFox, and LoRaWAN have been introduced to the market. These standards and technologies use the Sub-1 GHz band and are used for applications that collect information from a large number of IoT terminals, such as environmental monitoring and smart meters. Although the Sub-1 GHz wireless communication system has lower throughput than conventional cellular phone systems and Wi-Fi systems, it features a wide communication range of tens of meters to several kilometers, multi-terminal connectivity, low cost, and low power consumption for integration into sensor devices and extended use. IEEE 802.11ah was developed by the IEEE 802.11 Working Group as a wireless standard for IoT applications in the Sub-1 GHz band, and is promoted for deployment by the Wi-Fi Alliance, which promotes the spread of wireless LAN terminals, under the brand name Wi-Fi HaLow, and IEEE 802.11ah/Wi-Fi HaLow is expected to be widely used in the future. However, in the Sub-1 GHz band, interference between wireless communication systems will become an issue with the explosive spread of IoT in the future, due to the limited frequency resources available and the disorganization of multiple wireless communication standards and technologies mentioned above. This paper introduces various use cases in the Sub-1 GHz band and the efforts in the IEEE 802.19.3 Task Group on frequency sharing between IEEE 802.11ah and IEEE 802.15.4.

The rest of this paper is organized as follows. Section II presents use cases of Sub-1 GHz band systems. Section III provides IEEE Sub-1 GHz Standards for IoT. Challenges and activities of IEEE 802.19.3 standardization is presented in Section IV. Finally, we conclude our paper in Section V.

II. Use cases of Sub-1 GHz Band Systems

Sub-1 GHz wireless communication technologies are mainly used for IoT applications in smart utility, smart city, field monitoring and building automation. This section describes the use cases of IEEE 802.11ah and IEEE 802.15.4g standardized in the IEEE 802 and the issues in coexistence environments.

A. IEEE 802.11ah Use Cases

The following use cases are considered for IEEE 802.11ah systems[1]-[3].

- Smart home/building: home/building automation, smart appliance, home security network, health, wearable
- Smart power: smart grid, smart meter, smart lighting, power management for office
- Backhaul: bridging and mesh backhaul, wireless sensor network backbone, backup network for cellular drone, hot spot
- Monitoring: efficient field work and inspection at factory, remote monitoring of wildlife, detecting deterioration of infrastructure
- Smart city: surveillance camera system, water pipe management, intelligent transportation system
- Industry industrial sensor, industrial automation

B. IEEE 802.15.4g Use Cases

The following use cases are considered for IEEE 802.15.4g systems[1][4].

- Smart utilities: advanced metering infrastructure, peak load management, distribution automation, electric vehicle charging stations, gas and water metering, leak detection

- Smart cities: street lighting, smart parking, traffic and transport systems, environmental sensing, infrastructure management
- Smart home: smart thermostats, air conditioning, heating, energy usage displays and health and well-being applications
- Machine to machine: agriculture, structural health monitoring (e.g. bridges, buildings, etc.), monitoring and asset management
- Industrial plant monitoring

C. *Issues in Coexistence Environments of IEEE 802.11ah and IEEE 802.15.4g*

As mentioned above, similar use cases are being considered in IEEE 802.11ah and IEEE 802.15.4g. For example, in the smart home use case, the router is connected to devices with relatively long communication distances, such as security sensors and surveillance cameras, using IEEE 802.11ah in the Wi-Fi router, as shown in Fig. 1. The HEMS (Home Energy Management System) Controller connects to the Appliance, Light device, etc., using IEEE 802.15.4g. In addition, smart meters installed on the outdoor walls of houses communicate using IEEE 802.15.4g. Thus, IEEE 802.11ah system and IEEE 802.15.4g system operate in close proximity and coexist in the environment. However, although IEEE 802.15.4g and IEEE 802.11ah use the same Sub-1 GHz band, they have different modulation schemes and frame structures, and considering that they are used in the same house, mutual interference is considered to be an issue.

III. IEEE Sub-1 GHz Standards for IoT

This section presents an overview of the standardization of Sub-1 GHz systems in IEEE 802. In IEEE 802, there are several Working Groups and Technical Advisory Groups as shown in Fig. 2. Working Groups develop standards. For example, The IEEE 802.11 Working Group and the IEEE 802.15 Working Group developed IEEE 802.11ah and IEEE 802.15.4g standards, respectively. There is also the IEEE 802.19 Working Group that considers the coexistence of multiple wireless communication standards. In the Sub-1 GHz band, interference between IEEE 802.11ah and IEEE 802.15.4g has been an issue as described above. The IEEE 802.19 Working Group established the IEEE 802.19.3 Task Group in January 2019 to study coexistence in the Sub-1 GHz band and develop a recommended practice document. Standardization in the IEEE 802.19.3 Task Group has been completed and released the recommended practice document as IEEE 802.19.3-2021 in April 2021[1].

IV. IEEE 802.19.3 Standardization

This section introduces the study on the coexistence of wireless communication standards for IoT in the Sub-1 GHz band in the IEEE 802.19.3 Task Group.

A. *Coexistence Evaluation of IEEE 802.11ah and IEEE 802.15.4g*

IEEE 802.11ah and IEEE 802.15.4g cannot recognize each other's wireless communication signals due to their different communication methods employed (access method, frame format, modulation method, etc.) as well as their different communication bandwidths and receiver sensitivity. Therefore, the IEEE 802.19.3 Task Group decided to quantitatively evaluate the mutual effects of these two wireless systems in a coexistence environment and studied the evaluation method and parameters. As an evaluation method, a network simulator was developed to evaluate the mutual interference between IEEE 802.15.4g and IEEE 802.11ah. As shown in Fig. 3, the developed simulator enables the transmission signal information to be shared between the IEEE 802.15.4g module and the IEEE 802.11ah module of ns-3, an OSS network simulator, to evaluate mutual interference. The simulator was used to quantitatively evaluate the impact of mutual interference under the evaluation parameters (TABLE I.) [5]-[7] agreed in the IEEE 802.19.3 Task Group. The terminal location for IEEE 802.11ah and IEEE 802.15.4g is shown in Figure 4, with 15 terminals each placed within a 100 m circle. The results of the evaluation are shown in TABLE II[7]. In an environment where IEEE 802.11ah and IEEE 802.15.4g coexist, the packet delivery rate of IEEE 802.15.4g degraded significantly and will be a serious issue in the future. On the hand, 802.11ah packet latency can be a significant issue for devices such as security sensors.

B. *Challenges and Countermeasures in Interference Between IEEE 802.11ah and IEEE 802.15.4g*

The reduction in packet delivery rate of IEEE 802.15.4g due to mutual interference between IEEE 802.11ah and IEEE 802.15.4g is caused by the difference in their wireless access methods[9]-[11]. First, as shown in Fig. 5, the Energy Detection (ED) threshold is different between IEEE 802.11ah and IEEE 802.15.4g, with IEEE 802.11ah having higher ED threshold. Therefore, IEEE 802.11ah may transmit signals even when IEEE 802.15.4g is transmitting and may collide with IEEE 802.15.4g signals. Furthermore, as shown in Fig. 6, the IEEE 802.11ah backoff period may be shorter than the time from the start of IEEE 802.15.4g backoff to data transmission and the IEEE 802.15.4g ACK wait time. As a result, collisions occur between IEEE 802.11ah data frames and IEEE 802.15.4g data and ACK frames. These causes result in packet errors, which lead to a lower packet arrival rate for IEEE 802.15.4g.

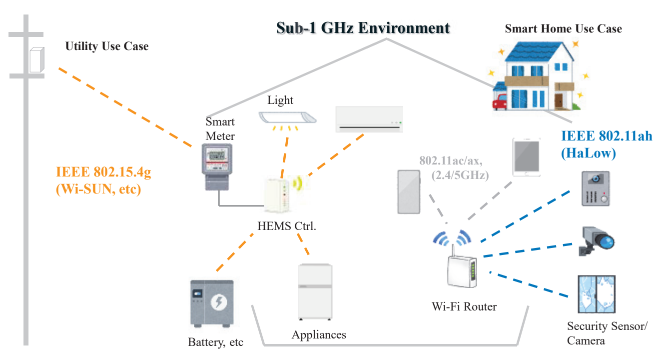

Fig. 1. IoT use cases

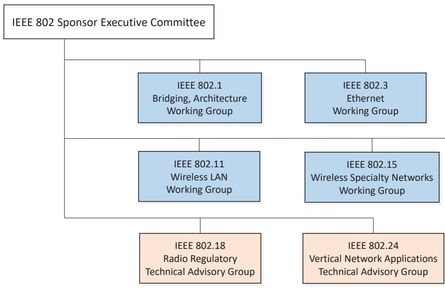

Fig. 2. IEEE 802 organization

In the IEEE 802.19.3 Task Group, frequency sharing schemes based on cooperative control among communication systems[12][13] and frequency sharing schemes based on autonomous decentralized control [14]-[18] where each system proactively detects given and received interference were considered as measures to address these issues. There are several methods for autonomous distributed control, such as α-Fairness Based ED-CCA, Q-Learning Based CSMA/CA, and Hybrid CSMA/CA, which can improve IEEE 802.15.4g packet delivery rate by 15% or more without significantly degrading the packet delivery rate of IEEE 802.11ah [1].

V. Conclusion

This paper introduces various use cases of IEEE 802.11ah and IEEE 802.15.4g, which are Sub-1GHz band wireless communication standards used for IoT, and distributed issues that arise in environments when these wireless communication systems coexist. In addition, we present the issues and countermeasures for coexistence of IEEE 802.11ah and IEEE 802.15.4g discussed by the IEEE 802.19.3 Task Group. The results of the study by the IEEE 802.19.3 Task Group have been released as a recommended practice document, IEEE 802.19.3-2021, which summarizes how to operate each system for coexistence of Sub-1 GHz band wireless communication methods.

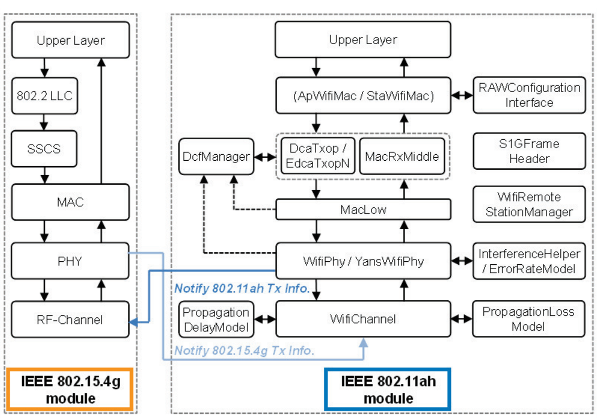

Fig. 3. Network simulator architecture for coexistence evaluation of IEEE 802.15.4g and IEEE 802.11ah

TABLE I. Simulation Parameters for Coexistence Evaluation of IEEE 802.11ah and IEEE 802.15.4g

Parameter	Value
Node density	500 nodes / km^2
Offered load[kb/s]	10, 20 ,40
Packet size[byte]	100
PHY data rate	300 kb/s for IEEE 802.11ah 100kb/s for IEEE 802.15.4g
Propagation model	SEAMCAT Extended Hata Model (Suburban)

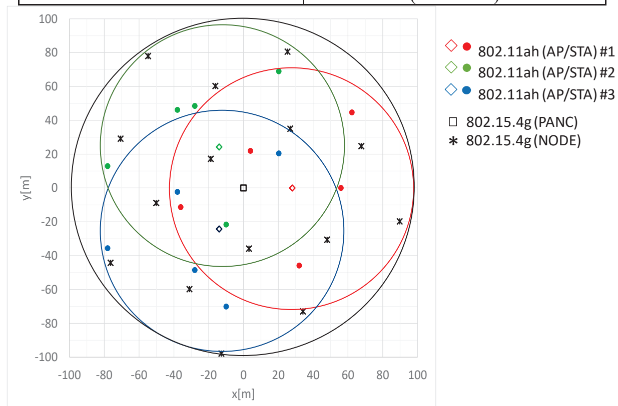

Fig. 4. Wireless terminal locations for coexistence evaluation of IEEE 802.11 and IEEE 802.15.4g agreed in the IEEE 802.19.3 Task Group

TABLE II. Coexistence Evaluation Results

Network Offered Load [kbps]		Packet Delivery Rate [%]		Average Packet Latency [ms]	
802.11ah	802.15.4g	802.11ah	802.15.4g	802.11ah	802.15.4g
10	10	100	96.4	8.7	32.3
20	10	100	91.9	10.0	33.6
40	10	100	75.9	15.2	36.8
20	20	99.9	82.1	15.2	43.6
40	20	99.9	60.7	25.4	46.3

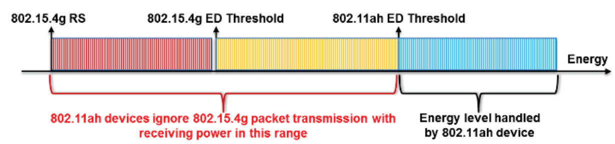

Fig. 5. Interference caused by higher IEEE 802.11ah ED threshold

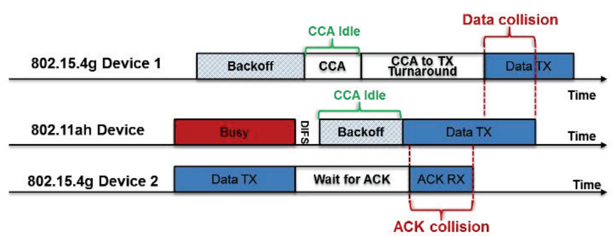

Fig. 6. Interference caused by faster IEEE 802.11ah backoff

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