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TR2024-161 November 28, 2024

Abstract

In addition to conventional internet-connected de- vices such as laptop and smartphones, various IoT/IoE de- vices are now connected to networks. Wireless communication technologies in the Sub-1 GHz frequency bands featuring Low Power Wide Area Network (LPWAN) are used for various IoT/IoE devices. Many different radio systems are operating in the same or overlapping license-exempt Sub-1 GHz bands without coordination. Therefore, performance degradation has been observed on IEEE 802.15.4g in environments where IEEE 802.15.4g devices are densely deployed with other interfer- ing devices. IEEE 802.19.3, published in April 2021, specifies the best recommended practices and coexistence mechanisms which enable IEEE 802.15.4g-FSK PHY and IEEE 802.11ah OFDM PHY based systems to effectively coexist in Sub-1 GHz bands. Subsequently, new functions have been specified in the standards, frequency regulations have been updated and new market requirements have emerged. Accordingly, new coexistence mechanisms are needed. This paper describes the status and future prospects of the IEEE 802.19.3a Task Group which was formed in March 2024 and is working towards developing an amendment of the IEEE 802.19.3-2021 standard for higher spectrum resource efficiency and improved network performance. Simulation results under new conditions between IEEE 802.15.4g- OFDM PHY and IEEE 802.11ah-OFDM PHY are presented with simulation parameters discussed in IEEE 802.19.3a Task Group.

IEEE Conference on Standards for Communications and Networking (CSCN) 2024

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***Abstract*—In addition to conventional internet-connected devices such as laptop and smartphones, various IoT/IoE devices are now connected to networks. Wireless communication technologies in the Sub-1 GHz frequency bands featuring Low Power Wide Area Network (LPWAN) are used for various IoT/IoE devices. Many different radio systems are operating in the same or overlapping license-exempt Sub-1 GHz bands without coordination. Therefore, performance degradation has been observed on IEEE 802.15.4g in environments where IEEE 802.15.4g devices are densely deployed with other interfering devices. IEEE 802.19.3, published in April 2021, specifies the best recommended practices and coexistence mechanisms which enable IEEE 802.15.4g-FSK PHY and IEEE 802.11ah OFDM PHY based systems to effectively coexist in Sub-1 GHz bands. Subsequently, new functions have been specified in the standards, frequency regulations have been updated and new market requirements have emerged. Accordingly, new coexistence mechanisms are needed. This paper describes the status and future prospects of the IEEE 802.19.3a Task Group which was formed in March 2024 and is working towards developing an amendment of the IEEE 802.19.3-2021 standard for higher spectrum resource efficiency and improved network performance. Simulation results under new conditions between IEEE 802.15.4g-OFDM PHY and IEEE 802.11ah-OFDM PHY are presented with simulation parameters discussed in IEEE 802.19.3a Task Group.**

***Index Terms*—Wireless Coexistence, IEEE 802.19.3a, IEEE 802.15.4g, IEEE 802.11ah, CSMA/CA, Spectrum Efficiency, IoT.**

I. Introduction

In addition to cellular based NB-IoT (Narrow Band-Internet of Things) and IoE (Internet of Everything) on 6G, LPWAN on Sub-1 GHz (S1G) frequency bands is getting attraction due to the prevalence of IoT/IoE devices. Standardized communication technologies such as IEEE 802.15.4g/Wi-SUN and IEEE 802.11ah/Wi-Fi HaLow and proprietary communication technologies such as SigFox, LoRaWAN and ELTRES have been introduced to the LPWAN market. These technologies have features of low data rate, long communication distance, flexible network topology and low power consumption. Therefore, these technologies are used for critical infrastructures such as smart metering and industrial IoT applications in addition to IoT applications such as sensor data collection, environmental monitoring and surveillance application with security sensors. Traditionally, many IoT applications have been insensitive to missing packets, but QoS-aware applications are increasing. Therefore, the dramatic increase in the number of IoT devices and the coexistence performance of different technologies cause concerns for communication quality. There are also issues arising from limited international harmonization of frequency regulations. Many different radio systems are operating in the same or overlapping frequency bands without coordination in the licensed exempt Sub-1 GHz bands. Accordingly, the IEEE 802.19.3a Task Group (TG) was formed in February 2024 to update and expand coexistence recommendations specified in IEEE 802.19.3 standard to address new standard features, updated frequency regulations, new market requirements, increasing data traffic, greater device density, and increased potential for congestion based on both IEEE 802.11ah and IEEE 802.15.4g-OFDM PHY mode.

The rest of this paper is organized as follows. Section II presents related work for standardization. IEEE 802.19.3a standardization status and difference from IEEE 802.19.3 are provided in Section III. Use case and simulation methodology are described in Section IV. Section V provides simulation results. Finally, we conclude our paper in Section VI.

II. Related Work

Several standardization groups have been established to develop wireless communication standards for Sub-1 GHz bands, their utilization for the market, and to solve issues among standards. IEEE 802.11ah/Wi-Fi Halow, IEEE 802.15.4g/Wi-SUN, and IEEE 802.19.3a are very active for standardization on Sub-1 GHz frequency bands. Their status is presented in this section.

IEEE 802.11ah/Wi-Fi HaLow: IEEE 802.11 Working Group (WG) completed Sub-1 GHz band wireless LAN standard in 2016 as IEEE Standard 802.11ah-2016. Wi-Fi Alliance started Wi-Fi HaLow certification program from 2021 for interoperability of products compliant with the IEEE Standard 802.11ah-2016. 802.11ah Promotion Council (AHPC) has been established in 2018 as voluntary organization to promote IEEE 802.11ah/Wi-Fi Halow.

IEEE 802.15.4me: IEEE 802.15 WG has started Task Group 4me (TG4me) in 2022 to revise IEEE Standard 802.15.4-2020. The TG4me provides to incorporate accumulated maintenance changes and corrigenda into the standard and to include approved amendments. The TG4me also includes additional technical features to resolve existing technical issues. Suspendable CSMA/CA, proposed by authors of this paper, for better wireless coexistence mechanism is adopted in this revision. The WG has finished approving the draft specifications, SA Ballot and comment process are underway for the publication of the standard.

IEEE 802.15.4ad: IEEE 802.15 WG has started Task Group 4ad (TG4ad: IEEE 802.15.4ad) in 2024 amend IEEE Standard 802.15.4-2020. This TG4ad provides data rate extension to IEEE 802.15.4 Smart Utility Network (SUN) Physical Layer (PHY). The PHY enhancement better address the needs of emerging applications and as well as meeting the needs of wider set of applications where additional data rates can expand the usefulness of the SUN-PHYs. Use cases, channel models and interference model have been discussed in the past sessions before making draft standards.

Wi-SUN FAN: Wi-SUN Alliance has been developing new profile named Wi-SUN FAN 1.1 (Wireless Smart Utility Network for Field Area Networks 1.1), which uses both IEEE 802.15.4g-FSK PHY and OFDM PHY as wireless communication standards. This Wi-SUN FAN 1.1 has features of long-distance communication through multi-hop communication, automatic network reconstruction in case of communication path failure, LFN (Limited Function Node) that achieves battery operation by intermittent operation, and coexistence of high-speed OFDM-PHY and conventional FSK-PHY.

IEEE 802.19.3a: IEEE 802.19 WG completed Sub-1 GHz band wireless coexistence recommendation for IEEE 802.15.4g-FSK PHY and IEEE 802.11ah as IEEE Standard 802.19.3-2021 [1]. Authors of this paper had led this standardization as TG officers. In addition to the restrictions of frequency regulations, wireless coexistence schemes between IEEE 802.15.4g-FSK PHY and IEEE 802.11ah have been specified. IEEE 802.19 WG started discussion about amendment to IEEE Standard 802.19.3-2021 from 2023 in consideration of the extension to IEEE 802.15.4g-OFDM PHY and the changes in frequency regulations. IEEE 802.19 WG has started Task Group 3a (TG3a: IEEE 802.19.3) to amend IEEE Standard 802.19.3-2021 from March 2024. This TG3a TG will provide coexistence recommendations to address new market requirements, increasing data traffic, greater device density, and increased potential for congestion based on both IEEE 802.11ah and IEEE 802.15.4 in Sub-1 GHz frequency bands. Authors of this paper are leading this group as TG Chair and Secretary. The status of the TG3a study is presented in the next section.

Regulation Updates: The spectrum allocation is constrained, especially in the Sub-1 GHz frequency bands, where spectrum allocation, transmission power and channel bandwidth (CBW) vary from country to country. Regulation is also updated periodically. For example, channel plans for 902 - 928 MHz are provided in US [2], 920.6 - 928 MHz in Japan [3], and 863 - 868 MHz in Europe [4], respectively. Furthermore, transmit duty cycle is defined in certain regions including Japan and Europe. ARIB STD-T108 deregulated the maximum channel bandwidth from 1 MHz (200 KHz x 5) to 4 MHz (200 KHz x 20) in March 2023 to meet the demand for relatively large capacity data transmission such as video transmission [3]. Therefore, IEEE 802.11ah can operate with the maximum channel bandwidth up to 4 MHz in Japan.

III. Wireless coexistence Study in IEEE 802.19.3a

A. Standardization Status

Initial discussion to set up IEEE 802.19.3a to update IEEE 802.19.3-2021 started in the IEEE 802.19 WG in July 2023 based on regulation updates, market requirement changes and IEEE 802.15.4 channel access mechanism enhancement [5]. The S1G (920 MHz) regulations in Japan have been updated to support a maximum 4 MHz aggregated channels, increased from the prior maximum of 1 MHz [3] [6]. AMI 2.0 (Next-Gen Advanced Metering Infrastructure) and Demand Response are being expected in US. Activity in IEEE 802.15 WG has resulted in enhancements to the IEEE 802.15.4 channel access options to address new requirements for metering systems in Japan. A new IEEE 802.15.4 channel access option named Suspendable CSMA/CA, proposed by authors of this paper in [7] [8], has been adopted by the IEEE 802.15 WG. Suspendable CSMA/CA allows to IEEE 802.15.4 devices to suspend the backoff timer when channel is detected to be busy. This function can reduce backoff failure incurred by the exceeding the backoff threshold (macMaxCSMABackoffs) and improve coexistence in the presence of interfering devices. It will positively impact coexistence behavior of implementations based on the IEEE 802.15.4 standard. Enhanced S1G band Study Group was formed to create a PAR (Project Authorization Request) and CSD (Criteria for Standards Development) to identify the project scope at IEEE 802.19 WG session in November 2023 [9]. The IEEE New Standards Committee (NesCom) and Standards Board approved the PAR a in February 2024. The 802.19 WG formed the IEEE 802.19.3a TG to develop an amendment to IEEE 802.19.3 standard. Project IEEE 802.19.3a will develop further best practices and strategies to improve coexistence of IEEE 802.11ah and IEEE 802.15.4-OFDM PHY systems in the S1G frequency bands [9]. The IEEE 802.19.3a TG officially started working in IEEE 802 Plenary Meeting in March 2024. The authors of this paper have actively led this standard development. Benjamin A. Rolfe is Task Group Chair, and Yukimasa Nagai is Task Group Secretary / Working Group Secretary.

B. Discussion Items

IEEE 802.19.3a TG will add the best recommended practices for better wireless coexistence between IEEE 802.11ah and IEEE 802.15.4g-OFDM PHY systems. Discussion topics have been agreed at IEEE Plenary Meeting in March 2024 as

- Analysis such as simulations and measurements studies
- Spectrum situation from different locations
- Study and measurement methods
- Regulatory updates for EU/US/JP
- Application and use case information
- Ideas on developing interference models
- Technical requirements and constraints

Several experimental measurement results are also shown in IEEE 802.19.3a sessions. J. Robert introduced interference Spectrum Measurement using Software Defined Radio (SDR) [10]. S. Kitazawa, et al. presented 920 MHz band radio environment in the Tokyo area [11]. K. Yano, et al. compared radio use in the 920 MHz band in Japan between in 2019 and in 2024. These measurements show that radio use is becoming congested due to the proliferation of smart meter systems and other communication systems in the Sub-1 GHz (920 MHz) frequency bands [12].

The use cases and simulation model used in IEEE 802.19.3 can be also used for IEEE 802.19.3a. Details are given in the next section. New conditions to be considered in IEEE 802.19.3a are also described.

IV. Use case and simulation methodology

Fig. 1 shows typical coexistence use case of smart utility networks using IEEE 802.15.4g/Wi-SUN and smart home networks using IEEE 802.11ah/Wi-Fi HaLow in the S1G band [13]. In smart utility use case, the HEMS GW (Home Energy Management System Gateway), as an indoor data hub, connects to the appliances using IEEE 802.15.4g. The Smart Meter installed on the wall outside house uses IEEE 802.15.4g to communicate with the DCU (Data Concentrator Unit) to send messages corresponding to electricity usage and demand response. The smart meters which cannot directly communicate with the DCU, communicate with the DCU via neighboring smart meters by the multi-hop (mesh) communication. IEEE 802.15.4g can also be used for other critical infrastructures such as gas, water and storage battery systems. In the smart home use case, IEEE 802.11ah/Wi-Fi HaLoW operating in S1G bands is promising for home automation, smart appliance, healthcare, and content synchronization between home server and vehicles. In addition, the Wi-Fi Router can communicate with intercoms, surveillance cameras, security sensors and other devices around house. Thus, IEEE 802.15.4g and IEEE 802.11ah are expected to be used in the same area for various IoT/IoE applications and devices. These same use case scenarios can be used for IEEE 802.19.3a TG.

IEEE 802.19.3 TG has defined simulation use cases and scenarios for coexistence evaluation between IEEE 802.11ah and IEEE 802.15.4g [14]. All IEEE 802.11ah STAs and IEEE 802.15.4g nodes are deployed in a 200 m diameter area with density of 500 / km^2. 15 STAs / nodes for each of IEEE 802.11ah network and IEEE 802.15.4g network are accommodated in the area. Figure 2 shows the example of deployment of IEEE 802.11ah and IEEE 802.15.4g for simulation as agreed by the IEEE 802.19.3 Task Group. This same configuration and scenario can be used for IEEE 802.19.3a analysis, with the enhanced PHY modeles.

V. Simulation OFDM PHY

For IEEE 802.15.4g and IEEE 802.11ah coexistence performance evaluation, PHY mode and channel bandwidth can be clarified into 4 combinations in Table I. In addition to conventional parameters discussed in IEEE 802.19.3 (Case 1), new features for IEEE 802.15.4g-OFDM PHY and 4 MHz channel bandwidth for IEEE 802.11ah will be evaluated (Case 2 - 4). Table II shows the candidate simulation parameters for the IEEE 802.19.3a TG [16] [17]. OFDM Option 3 MCS4 (300 kbps) and MCS5 (400 kbps) are added for IEEE 802.15.4g-OFDM PHY by node deployment and transmission range as shown in Figure 2. In consideration of device location, SEAMCAT Extended Hata Model (SUburban) was also added for simulation. For the metering use case, utility pole height to node location level for IEEE 802.15.4, and AP/STA location level for IEEE 802.11ah were referred to [16]. This paper introduces the performance evaluation for Case 2 as the first step compared with Case 1.

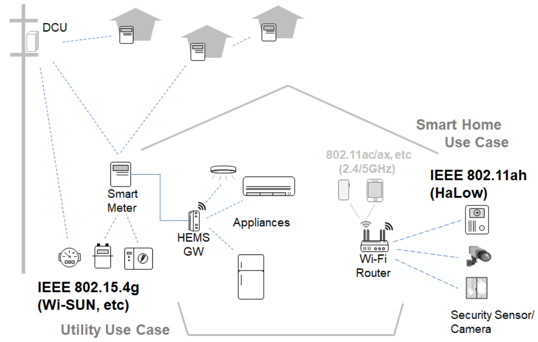

Fig. 1. IoT application coexistence use case of smart utility using IEEE 802.15.4g and smart home using IEEE802.11ah in S1G band [13].

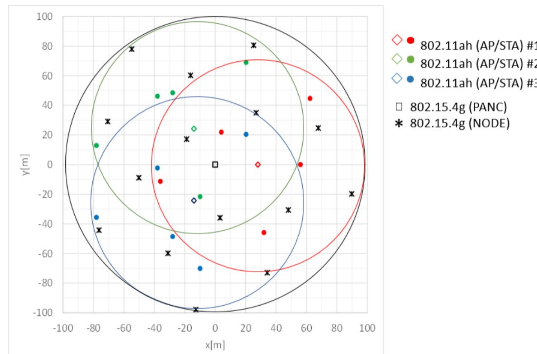

Fig. 2. IEEE 802.11ah and IEEE 802.15.4 node deployment for simulation which discussed in IEEE 802.19.3. [14].

Figure 3 shows Packet Delivery Rate (PDR) curve for Case 2 compared to Case 1, where IEEE 802.15.4g offered load was 20 kbps and IEEE 802.11ah offered load were between 10 kbps to 120 kbps. PDR of IEEE 802.15.4g was dramatically degraded by coexistence between IEEE 802.15.4g and IEEE 802.11ah. Case 2 had same trends with Case 1 where IEEE 802.15.4g packets were discussed by IEEE 802.11ah transmission.

Figure 4 shows Data Packet Latency for Case 2 compared to Case 1, where IEEE 802.15.4g offered load was 20 kbps and IEEE 802.11ah offered load were between 10 Kbps to 120 Kbps. Latency of IEEE 802.11ah was increased by about twofold when offered load was 100 kbps due to traffic saturated. On the other hand, IEEE 802.15.4g PDR was maintained due to IEEE 802.15.4g packet discurd.

VI. Conclusion

This paper provides the status and future prospects of IEEE 802.19.3a which started in March 2024 and is working towards

TABLE I
PERFORMANCE EVALUATION METRIX

		IEEE 802.11ah-OFDM PHY	
		1 MHz CBW	4 MHz CBW
IEEE 802.15.4g (400 KHz CBW)	FSK PHY	Case 1	Case 3
	OFDM PHY	Case 2	Case 4

TABLE II
CANDIDATE SIMULATION PARAMETERS FOR IEEE 802.19.3A

Parameter	Value	Note
Network parameters		
Network offered load	20 - 120 [kbps] @ 1 [MHz] CBW 80 - 480 [kbps] @ 4 [MHz] CBW	11ah
	20 - 100 [kbps]	15.4
Data packet payload Size	100 [byte]	Both
PHY parameters		
Frequency	920 [MHz]	Both
Tx Power	20 [mW]	Both
Modulation, Data Rate	BPSK 1/2, N_{ss} = 1, 300 kbps @ 1 [MHz] CBW 1350 kbps @ 4 [MHz] CBW	11ah
	2-FSK, 100 kbps OFDM Option 3 MCS4, 300 kbps OFDM Option 3 MCS5, 400 kbps	15.4
Channel bandwidth (CBW)	1 and 4 [MHz]	11ah
	400 [KHz]	15.4
MAC parameters (IEEE 802.11ah)		
aSlotTime	52 [us]	11ah
aSIFSTime	160 [us]	11ah
aCCATime	$<$ 40 [us]	11ah
aRxTxTurnaroundTime	Less than 5 [us]	11ah
CW (min, max)	15, 1023	11ah
MAC parameters (IEEE 802.15.4g)		
AIFS	1000 [us]	15.4
phyCCADuration	140 [us]	15.4
aTurnaroundTime	1000 [us]	15.4
Rx-to-Tx Turnaround time	300 (300 us or more, 1000 us or less) [us]	15.4
Tx-to-Rx Turnaround time	300 (Less than 300 us) [us]	15.4
macMinBE, macMaxBE	3, 5	15.4

developing an amendment of the IEEE Standard 802.19.3-2021 for higher spectrum resource efficiency and improved network performance. Simulation results for new condition between IEEE 802.15.4g-OFDM PHY and IEEE 802.11ah-OFDM PHY are presented with simulation parameters discussed in IEEE 802.19.3a Task Group. From the coexistence performance evaluation for Case 2, PDR for IEEE 802.15.4g-OFDM is dramatically degraded without coexistence mechanisms with the same trend as Case 1 (IEEE 802.19.3 condition). The results of these studies will be used in future IEEE 802.19.3a standardization meetings to specify recommended best practices and coexistence mechanisms including Suspendable CSMA/CA. Coexistence performance evaluation for 4 MHz bandwidth of IEEE 802.11ah-OFDM PHY (Case 3, 4) are also future work.

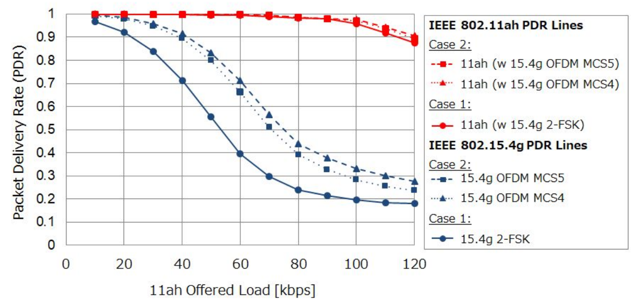

Fig. 3. Packet Delivery Rate (PDR) - 15.4g offered load 20 kbps

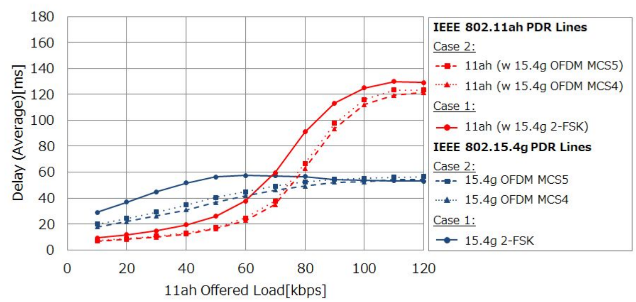

Fig. 4. Data Packet Latency - 15.4g offered load 20 kbps

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