IEEE 802.11ah (HaLow) Dongle for Simplified IoT Wireless Networking

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Abstract

This demo presents design, implementation, and performance analysis of an IEEE 802.11ah (HaLow) dongle that provides license-exempt sub-1GHz wireless RF channel, and USB (universal serial bus) interface for power supply and wired data link for easy Internet of Things (IoT) wireless networking. The presented HaLow dongle is implemented using TI CC1352P1 sub-1GHz smart RF chipset that can provide 50Kbps ~ 4Mbps in 10m ~ 1Km distance range. It provides merits of i) flexible Tx rate/power adjustments and channel selection with minimized interference to maximize throughput for massive IoT devices, ii) user-friendly API (application programming interface) for raw-socket-based easy application implementations for various IoT services, and iii) simplified installation using USB interface for both data exchange and power supply. This demo presents the details of the IEEE 802.11ah (HaLow) dongle, and its performance analysis results in practical environments.

I. Introduction

The IoT is an essential technology for implementations of smart city/transportation, environmental monitoring and remote control, telemetering for utility, smart health, and smart farm/factory[1-3]. The IoT access networking must support good scalability for up to 8000 IoT devices scattered within 1 Km range, and providing data rates of 50Kbps ~ 4Mbps. The IoT access networking should provide data exchanges for applications of various categories, such as non-periodic real-time event sensing and handling, periodic environmental data monitoring, and remote telemetry [4-8].

As low power wide area (LPWA) IoT communications, several technologies are commercially available, such as LoRa (long range), IEEE 802.11ah (WiFi-HaLow), NB-LTE (narrow-band long term evolution) and NB-IoT [7]. The LoRaWAN [8] is commercial product that can provide long range wireless data exchanges up to 20 Km, but its data rate is limited to 290bps ~ 50Kbps, and it is not programmable for efficient channel configurations /managements and socket-based Internet networking.

NB-LTE support 200Kbps uplink and down link data rates, and NB-IoT supports ultra-low power consumption, wide area coverage and massive connections, up to 250Kbps data rate with 180KHz channel bandwidth. Both NB-LTE and NB-IoT, however, operate in licensed spectrum and they require expensive infrastructure of LTE/5G.

In this demo, we present an IEEE 802.11ah (HaLow) dongle that provides merits of i) flexible Tx rate/power adjustments and channel selection with minimized interference to maximize throughput in environments of massive IoT devices, ii) user-friendly API (application programming interface) for raw-socket-based easy application implementations for various IoT services, and iii) simplified IoT networking with USB interface for both data exchange and power cabling. The demonstrated HaLow dongle is equipped with USB (universal serial bus) 2.0 interface that supports up to 1 Mbps data rates and simplified power cabling [7].

The rest of this demo paper is organized as follows. Section II explains the functional architecture and implementation of HaLow dongle. Section III analyzes the measured throughputs obtained in simple IoT networking with HaLow dongles with 50Kbps ~ 1Mbps in up to 1 Km range. Section IV concludes this demo paper with brief introduction of future work.

II. Functional Architecture and Implementation of IEEE 802.11ah (HaLow) Dongle

2.1 Functional Architecture

Fig. 1 depicts the functional blocks of IEEE 802.11ah HaLow Dongle, which is composed of two major chipsets: TI CC1352P1 [9] and FT4222H [10]. The TI CC1352P1 provides sub-1GHz wireless communication channel, and FT4222H provides USB (universal serial bus) 2.0 interface that greatly simplify power supply cabling. CC1352P1 is using dual cores: Cortex M0 for RF configurations and Cortex M4F for multi-thread processing on TI RTOS (real-time operating system). IEEE 802.11ah MAC protocol is implemented using the basic API of TI RTOS.

SPI (serial peripheral interface) and GPIO (general purpose input output) are used to connect CC1352P1 with outside modules. Control message for CC1352P1 configurations and user data frames are delivered through SPI, while interrupt from CC1352P1 to FT4222H is delivered through GPIO.

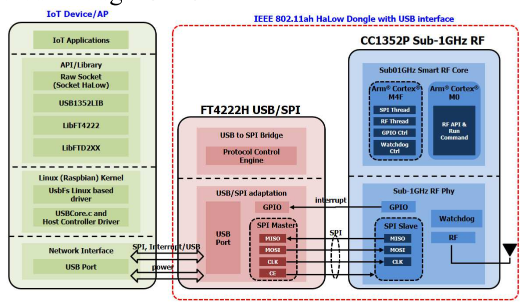

Fig. 1. Functional Block Diagram of IEEE 802.11ah HaLow Dongle

Fig. 2. HaLow Dongle attached to Raspberry Pi 4 with GPS

Fig. 2 shows the prototyped HaLow dongle attached to Raspberry Pi 4 with GPS sensor as IoT device example. In the sample IoT device, Raspberry Pi 4 with Raspbian operating system was used as IoT device platform. For easy implementation of IoT applications, the HaLow dongle provides socket interface (socket_HaLow). The IoT application program can configure and manage sub-1GHz

RF channels d using USB1352LIB API.

2.2 Software Architecture of HaLow Dongle

Fig. 3 depicts the software architecture of IEEE 802.11ah HaLow dongle. In order to simplify data cabling and power supply, the HaLow dongle is equipped with USB interface using FT4222H USB-to-SPI bridge. The USB interface provides both data exchanges and power supply. For incoming frame handling, the HaLow dongle sends interrupt signal to the main processor.

Since the SPI provides bidirectional frame exchanges controlled by the SPI master, HaLow dongle generates interrupt signaling when there is a received RF frame and the SPI master does not initiating frame exchanges. The RxQueue of HaLow dongle generates GPIO interrupt signal which is converted to USB interrupt message by F4222H SPI/USB adaptor. The received interrupt message is immediately handled by the interrupt handling thread that requests the SPI module to initiate bidirectional frame exchange.

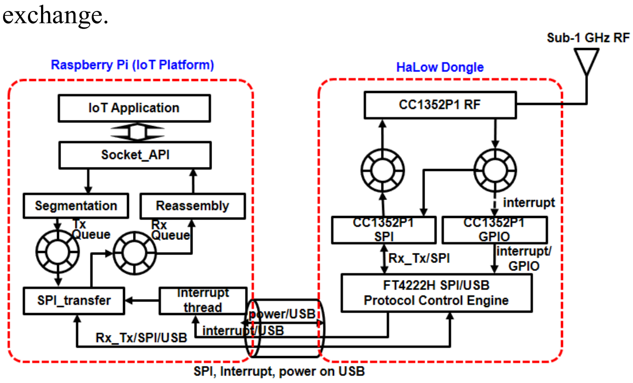

Fig. 3. Software Architecture of IEEE 802.11ah HaLow Dongle

2.3 Socket_Halow API in HaLow Dongle

The HaLow dongle provides socket_halow API for easy IoT networking and power cabling in developments of IoT applications. The IoT application module can directly use socket_halow interface, instead of using API in operating system kernel; thus the same IoT application can be re-used in various environment without Linux operating system.

The Socket_HaLow API includes basic socket related functions, such as socket(), probe(), and ioctl(). IoT application program uses socket() function to create a raw_socket for wireless communication using HaLow dongle. It also uses probe() function to check the connectivity and operational status of HaLow dongle. Using the ioctl() API, the application program can easily (re-)configure operational parameters of sub-1GHz RF channel, such as center frequency of RF channel, data rate, transmission (Tx) power. Also, the IoT application can easily obtain the current operational status information of sub-1GHz RF channels, such as RSSI (Receive Signal Strength Indication) and FER (Frame Error Ratio) of received RF frames. The Socket_HaLow API (i.e., socket(), probe(), and ioctl()) enables easy IoT applications with optimized operations.

In many cases, the IoT devices are mostly positioned at isolated locations where on-site checking and rebooting are not easy. For remote power reset at abnormal condition, the ioctl() API includes one special command (HALOW_IOC_RESET) that makes the IoT device to reboot by itself at watch-dog timer expiration, and (re-)configure itself to the pre-configured operational parameters. This HALOW_IOC_RESET command in ioctl() API provides great flexibility and adaptability for IoT devices located in remote and isolated operational environment.

2.4 Interactions between AP and IoT Devices with HaLow Dongle

Fig. 4 depicts the steps of initial configurations AP and IoT devices with HaLow dongle. The IoT AP/Gateway initially configures the sub-1GHz RF channel for IoT networking, and activates RF channel with periodic beacon broadcasts to IoT devices. The un-registered IoT device makes registration to the IoT AP, using the control channel. In order to mitigate the possible massive collisions by registration requests from IoT devices, the hybrid slotted CSMA/CA-TDMA MAC module of HaLow dongle implements the restricted access window (RAW) and authentication control threshold (ACT) algorithm [5].

Considering various RF communication environment between IoT device and the IoT AP, the IoT application program on IoT AP/gateway continuously monitors the RF channel condition, selects/recommends the most appropriate RF channel for each registered IoT device, using CHRC (channel re-configuration) and CHRC_ACK frames. The IoT AP and IoT device make handshaking for synchronization of the selected RF channel using Poll_RR and RR frame exchanges. When the channel configuration and synchronization are successfully finished, the IoT device exchanges application data to/from IoT AP. The IoT AP continuously checks the available RF channel(s) and schedules the channel usages considering the amount of IoT application data exchanges from each IoT device.

Based on the continuous monitoring, the IoT AP and IoT devices adjust Tx rate and Tx power for energy efficient and reliable IoT communications. Piggyback scheme is used in the bidirectional full-duplex bulk data transfer between IoT AP and devices for maximized performance.

Since the license-exempt sub-1GHz IoT frequency range is shared by multiple IoT applications, interferences may occur. The interferences are detected by three consecutive frame losses while the RSSI is at good level. If RF channel interference is determined on the currently utilized channel, the AP reselects RF channel for the IoT device, and re-configuration procedure is performed.

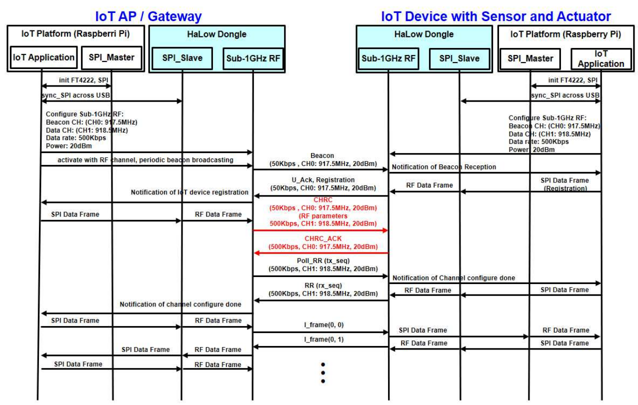

Fig. 4. Initial Configuration of IoT AP/Gateway and IoT Devices

III. Performance Analysis of IEEE 802.11ah HaLow Dongle

3.1 Available Throughput of HaLow Dongle

Table 1 depicts the practically available maximum throughput with HaLow dongle. The available throughput were measured for an IoT AP and IoT devices positioned in 5 ~ 700 meter distances with Tx rate 5 Kbps ~ 1 Mbps, Tx power 20 dBm, RF frame size 200 bytes, antenna gain 2.5 dBi, while the measured RSSI were in the range of -75 ~ -95 dBm.

From Table 1, we can find that HaLow dongle provides practically available throughputs which are around 80 % of the Tx rate (50Kbps ~ 500Kbps) at RSSI of -80dBm ~ -95dBm. The available communication ranges are different for each Tx rate, as explained in next subsection.

Table 1. Available Throughput at each Tx Rate

Tx Rate	Full-duplex (RSSI: -25dBm)	Half-duplex (RSSI: -25dBm)	Minimum RSSI
50Kbps	28.87Kbps	27.07Kbps	-95dBm
100Kbps	67.95Kbps	60.82Kbps	-94dBm
200Kbps	159.93Kbps	141.41Kbps	-92dBm
300Kbps	239.22Kbps	202.05Kbps	-88dBm
400Kbps	321.48Kbps	269.55Kbps	-88dBm
500Kbps	401.90Kbps	314.45Kbps	-80dBm
1Mbps	746.38Kbps	566.15Kbps	-75dBm

3.2 Available Communication Range with HaLow Dongle

Table 2 depicts the available communication range of sub-1GHz RF channels provided by HaLow dongle, based on the measured frame error ratio (FER) in open space with distance 100 ~ 700 meter. For Tx rate of 50Kbps ~ 500Kbps, there was no error when the RSSI is more than -70dBm, while the FER increased when the RSSI is less than -75dBm. For 1 Mbps Tx rate, higher FERs were monitored when the distance is more than 100 m.

From Table 2, we can find that smart adjustments of Tx rate and Tx power are essential for energy-efficient in IoT communications where the IoT devices are mostly operated by limited energy of battery.

Table 2. Available Communication Range and Frame Error Ratio (FER) with HaLow in open space

Tx Rate	Distance between IoT AP and IoT Device						
	100m (-58dBm)	200m (-60dBm)	300m (-62dBm)	400m (-65dBm)	500m (-70dBm)	600m (-75dBm)	700m (-80dBm)
50Kbps	0	0	0	0	0	0	0
100Kbps	0	0	0	0	0	0	0
200Kbps	0	0	0	0	0	0	35.71
300Kbps	0	0	0	0	0	3.33	78.33
400Kbps	0	0	0	0	0	34.05	81.56
500Kbps	0	0	0	0	2.22	48.91	100
1Mbps	42.64	46.75	63.63	74.02	100	100	100

(Remark: Tx Power = 20dBm, RF Frame Size = 254 bytes, Antenna Gain = 2.5dBi)

IV. Conclusion

In this demo paper, we presented a proof-of-concept (PoF) implementation of IEEE 802.11ah (HaLow) dongle that provides sub-1GHz license-exempt wireless channel and USB (universal serial bus) interface for simplified data exchange and power supply cabling. The presented HaLow dongle is implemented using TI CC1352P1 sub-1GHz smart RF chipset that provides 5Kbps ~ 4Mbps in 10m ~ 1Km range. The HaLow dongle uses hybrid slotted CSMA/CA-TDMA MAC mechanism to maximize the utilization of sub-1GHz RF channel among massive number of IoT devices. The software module supports socket_HaLow API to enable easy developments of IoT applications, including basic socket programming APIs (socket(), probe(), and ioctl()). A raw socket connection can be easily established by using socket() function between IoT AP and IoT devices, and the connection and RF channel can be easily (re-)configured by using ioctl () commands. probe() function is used to monitor status for optimizations.

The demonstrated HaLow dongle provides major advantages of i) efficient RF channel usage with flexible Tx rate/power adjustments and channel (re-)selection with mitigated interference and maximized throughput in various environments of massive IoT devices, ii) easy implementations for various IoT application services by using user-friendly API (application programming interface) for raw-socket-based, and iii) simplified IoT device installation using USB interface for both data exchange and simple power supply cabling.

Acknowledgement

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References

[1] Jie Lin et.el, “A Survey on Internet of Things: Architecture, Enabling Technologies, Security and Privacy, and Applications”, IEEE Internet of Things JOURNAL Vol. 3 NO.5, Oct, 2017, pp. 1125-1142.

[2] Stefan Aust, Venkatesha Prasad and Ignas G. M. M. Niemegeers, "Outdoor Long-Range WLANs: A Lesson for IEEE 802.11ah," IEEE COMMUNICATION SURVEYS & TUTORIALS, vol. 17, no. 3, 2015.

[3] T. Adame, A. Bel, B. Bellalta, J. Barcelo, and M. Oliver, “IEEE 802.11AH: The WiFi approach for M2M communications,”IEEE Wireless Communication, vol. 21, no. 6, pp. 144–152, Dec. 2014.

[4] Wireless Equipment Regulation, Ministry of Science and ICT 2016-125, 2016. 11. 30.

[5] Min-Cheol Kim and Young-Tak Kim, “Smart Control of IoT Devices using IEEE 802.11ah/Sub-1GHz Wireless Networking,” in Proc. of KNOM Conference 2019, 2019.

[6] Min-Cheol Kim and Young-Tak Kim, “Smart Control for Energy Efficient Networking of IEEE802.11ah-based IoT,” in Proc. of APNOMS 2019, Matsue, Japan, Sept. 18-20, 2019.

[7] Min-Cheol Kim and Young-Tak Kim, “Design and Implementation of IEEE802.11ah (HaLow) Dongle for IoT wireless networking,” in Proc. of APNOMS 2020, Daegu, Korea, Sept. 22-25, Daegu, Korea, 2020.

[8] LoRa to USB converter (LoryNet – uLory), http://lory.co.kr/kor/LoryNet/view.php?part=1&idx=2.

[9] Texas Instrument (TI) CC1352P1 SimpleLink™ High-Performance Multi-Band Wireless MCU With Integrated Power Amplifier, http://www.ti.com/lit/ds/swrs192d/swrs192d.pdf?ts=1591592716336&ref_url=http://www.ti.com/tool/LAUNCHXL-CC1352P

[10] Future Technology Device International Ltd. FT4222H (USB2.0 to QuadSPI/I^{2}C Bridge IC), https://www.ftdichip.com/Support/Documents/DataSheets/ICs/DS_FT4222H.pdf.