Channel selection in 2.4 GHz ISM band for IEEE 802.15.4 networks

Slađana Đurašević[1] and Uroš Pešović[2]

Abstract – **IEEE 802.15.4 standard represents one of the most used communication technologies for the Internet of Things. This standard shares 2.4 GHz band with WLAN and Bluetooth devices, which number has been drastically increased in the past decade. This paper presents analysis of usage of IEEE 802.15.4 channels in ISM band.**

Keywords –**IEEE 802.15.4, Channel selection, ISM band, Coexistence**

I. Introduction

License-free bands represent part of the radio spectrum which can be freely used by anyone, where the only constraint is limited transmitting power. With the rapid increase in the number of wireless devices which used license-free bands, these bands almost reached the limits of their capacity in highly urbanized environments [1]. This is especially the case for the 2.4 GHz ISM band which is used by IEEE 802.15.1 Bluetooth devices, IEEE 802.11 Wireless LANs, IEEE 802.15.4 WPAN devices and cordless phones. IEEE 802.15.4 standard represents one of the key wireless transmission technologies for implementation of Internet of Things (IoT). This technology, targeted for smart devices in homes, can be significantly affected by other types of networks in ISM band. Term coexistence, represents the ability of devices to operate under the presence of device which uses different wireless standards in the same frequency band [2]. Coexistence of these wireless standards in the ISM band can be achieved using proactive and reactive techniques. Proactive techniques require cooperative channel sharing and complete control of deployed networks which is usually not the case. Also, most radio standards are not designed to detect other network transmissions and cooperatively share channels. Reactive approaches are typically focused on techniques which are used by the device itself to be able to coexist without need to influence interfering devices.

II. IEEE 802.15.4 standard

IEEE 802.15.4 standard is designed for Low Power Wireless Personal Area Networks (LP-WPAN) and defines Physical (PHY) Layer and Medium Access Control (MAC) Layer. The PHY layer is responsible for wireless transmission and reception of packets and control of radio transceiver, while the MAC layer provides fair and efficient access to the wireless channel. The physical layer of the IEEE 802.15.4 standard defines several radio bands, where the 2.4 GHz ISM band is the most commonly used worldwide. This band is divided into sixteen IEEE 802.15.4 channels, which are separated by 5 MHz and each channel has a bandwidth of 2 MHz and data rate of 250 kbps. The maximum transmitting power is 0 dBm (1mW), which is much lower compared to maximum transmitting power of 100 mW used for IEEE 802.11 networks. In order to improve coexistence IEEE 802.15.4 devices use Direct Sequence Spread Spectrum DSSS which spreads every bit with eight chips which significantly improve immunity on bit errors. As we can observe from Fig.1, IEEE802.15.4 achieves the best BER (Bit Error Rate) performance compared to the other standards which operate in 2.4 GHz band.

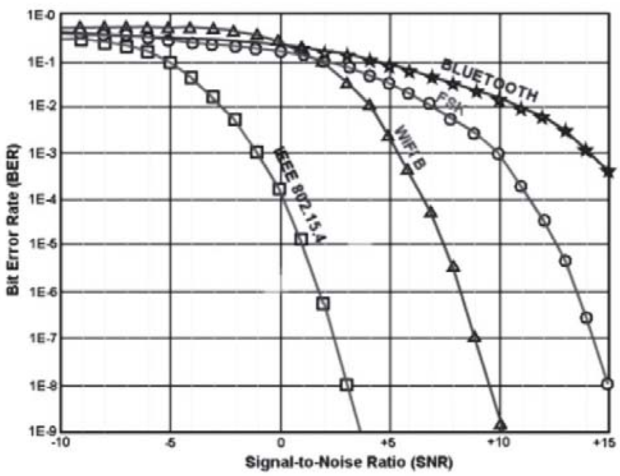

Fig. 1. BER for wireless standards in 2.4 GHz ISM band [3]

MAC Layer uses CSMA/CA (Carrier Sense Medium Access with Collision Avoidance) to achieve efficient medium access. This technique requires the device's PHY layer to first check the channel state using Clear Channel Assignment (CCA) before starting transmission of a packet. There are three methods of performing CCA: either by detecting IEEE 802.15.4 carrier signal (Carrier Sense – CS) or by performing Energy Detection (ED) in the channel, or combination of both. CCA reports a busy medium upon detecting a signal with the modulation and spreading

[1]Slađana Đurašević is with the Faculty of Technical Sciences Čačak, University of Kragujevac, Svetog Save 65, Čačak 32000, Serbia, E-mail: sladjana.djurasevic@gmail.com

[2]Uroš Pešović is with the Faculty of Technical Sciences Čačak, University of Kragujevac, Svetog Save 65, Čačak 32000, Serbia, E-mail: uros.pesovic@ftn.kg.ac.rs

characteristics of IEEE 802.15.4 or upon detecting energy level within the bandwidth of an IEEE 802.15.4 channel which is above the Energy Detection (ED) threshold. Carrier sense CCA is intended to prevent collision with IEEE 802.15.4 devices, while ED can be used to prevent collisions with another type of networks which share the same frequency. ED is also used by MAC during the initial formation of the network to estimate the state of all sixteen channels and choose the channel with the lowest energy level.

MAC layer can operate in one of two operating modes: Non-Beacon Enabled and Beacon Enabled mode. Non-Beacon Enabled mode is event-driven medium access mechanism, where device attempts medium access as soon as the transmission is requested. Prior transmission, device performs blind backoff CSMA/CA, where it waits for a random period of time. When this period expires, MAC requests CCA service to ensure that the channel is free in order to start transmission. If CCA reports a busy channel, the device shall wait for another random period before trying to access the channel again. If the number of unsuccessful random backoff exceeds the maximum permissible number of retries, the packet transmission is aborted.

Beacon Enabled mode represents scheduled medium access mechanism in which device can initiate channel access during the appropriate time slot intended for transmission. Using beacon frame, the PAN coordinator announces current channel access timetable, shown in Fig.2.

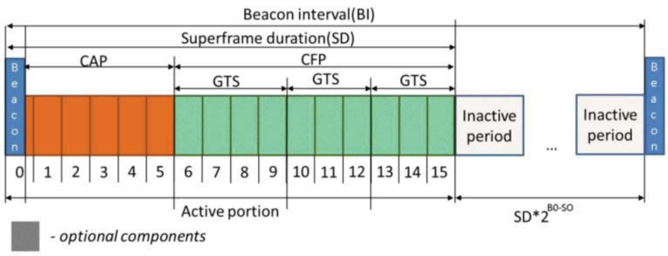

Fig. 2. Superframe structure [4]

Active communication period, called superframe, is divided into 16 slots, which are grouped into Contention Access Period (CAP) and Contention Free Period (CFP). During CAP devices are contenting for medium access using slotted CSMA/CA mechanism. The device, which wants to start transmission, locates a boundary of the time slot, waits for a random period, after which it performs CCA. Backoff time is used to prevent devices from simultaneous channel access, which can lead to a collision of transmitted packets. CFP provides up to seven Guaranteed Time Slots (GTS) troughs which device can transmit time sensitive traffic. GTS is pre-allocated to the specific devices, after device issues GTS reservation request from PAN coordinator. If the device does not use its GTS for the extended period, PAN Coordinator will assign these GTS slots on another device request. Superframe is followed by an optional inactive period in which devices go to low-power sleep mode until the arrival of the next beacon frame.

III. Coexistence techniques

Proactive techniques tend to prevent interference using physical separation of networks, frequency separation and time separation. Physical separation relies on careful network planning in order to achieve spatial separation between different networks. Due reduced signal strength over distance, networks will be less influenced by one another which can improve their coexistence. Physical separation doesn't work well in locations with dense wireless networks. It is only practical, if the user has complete control of networks deployment in certain broader area which is usually not the case.

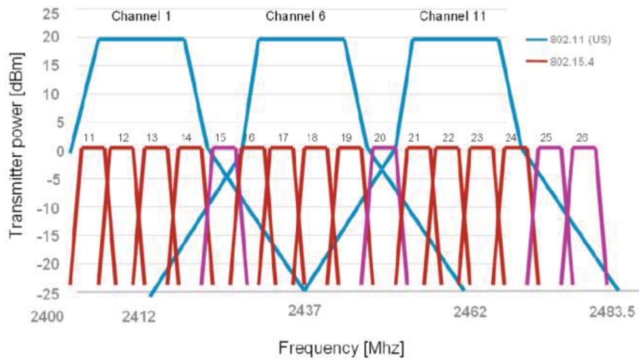

Fig. 3. Channel separation in 2.4 GHz ISM band [5]

Frequency separation reduces interference between two networks by operating on different frequencies. Since ISM band is divided into different channels by different wireless standards, it is necessary to select channels for different types of networks in such manner that their operating frequencies don't overlap. IEEE 802.11 and 802.15.4 devices operate in fixed channels, where transmit power of IEEE 802.11 devices is a hundred times stronger compared to 802.15.4 devices, which can be significantly affected. In order to achieve frequency separation, it's necessary to exploit frequency gaps between non-overlapping IEEE 802.11 channels in which IEEE 802.15.4 devices can operate without interference. These IEEE 802.15.4 channels are 15, 20, 25 and 26 for US and 15, 16, 21 and 22 for Europe as shown by Fig.3.

TABLE I
ISM BAND CHANNELS

Wireless standard	Non-overlapping channels	Channel bandwidth	Channel separation
IEEE 802.11b	4	22	5
IEEE 802.11g	3	20	5
IEEE 802.11n	1	40	5
IEEE 802.15.1	79	1	1
IEEE 802.15.1 BLE	37	2	2
IEEE 802.15.4	16	2	5

IEEE 802.15.1 networks operate in entire bandwidth using the pseudorandom channel-hopping technique. Regular

Bluetooth hops to one of the 79 channels every 625 µs, while newer Bluetooth Low Energy hops to one of 37 channels every 3 ms, with adaptive hopping capability to avoid channels with interference. Due to the unpredictability of channel hopping scheme, frequency separation is not feasible with Bluetooth networks.

Time separation technique enables devices which operate in different standards to send and receive data in different time slots, in order to avoid collisions. This technique exploits low utilization which is common for low power networks, so they can utilize the medium for a small amount of time. In order achieve time separation, it's necessary to implement centralized control of different networks. In case of intense traffic time, separation can increase packet delays and collisions as shown in Fig.4..

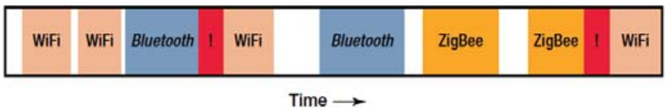

Fig. 4. Time separation in 2.4 GHz ISM band [6]

Proactive techniques require cooperative channel sharing and complete control of deployed networks which is usually not the case. Also, most radio standards aren't designed to detect other network transmissions and cooperatively share channels. Thus, wireless standards need to be upgraded in such a way that they can detect and avoid congested channels. One of the modifications of standard was proposed in 2015. IEEE 802.15.4e implements Time Slotted Channel Hopping. Using this technique all devices operates in one channel during certain time slot, and when that slot expires, all devices switch to another channel where they continue communication. Thus IEEE 802.15.4 devices can avoid using overcrowded channels by adaptive channel hopping as shown in papers [7-11].

IV. Experimental Results

IEEE 802.15.4 channels are observed in 2.4 GHz ISM band with PICDEM Z development board [12]. This board uses MRF24J40MA [13], 2.4 GHz IEEE 802.15.4 compliant transceiver, realized on prefabricated Printed Circuit Board (PCB) with dipole antenna. Board is placed vertically in order achieve omnidirectional radiation pattern of transceiver antenna in the horizontal plane. PICDEM Z is controlled from personal computer using Radio Utility Driver Program [14], which logs ED data from all channels received via RS232 port. Transceiver is put into reception mode in which it performs cyclic ED on each channel. Result of ED is RSSI (Received Signal Strength Indicator) value which is averaged on four received Bytes. When one channel is selected, after expiry of oscillator stabilization time ED is performed 32 times in succession, which is equivalent to duration of transmission of packet of maximum size of 128 Bytes. Maximum detected ED value is then send to console output, after which ED is performed on following channel.

Channel state is observed in three scenarios: public building (faculty), residential building and downtown house during the peak traffic period: noon at public buildings and evening in

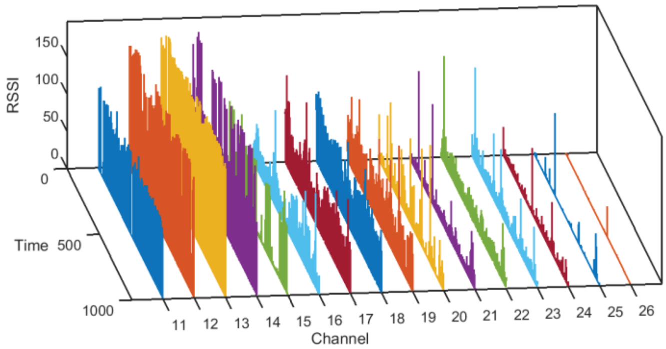

Fig. 5. IEEE 802.15.4 channels in public building

residential buildings. All sixteen channels are monitored for duration of 1000 cycles where each cycle lasts 400ms.

Results for public building, presented in Fig.5, shows one dominant IEEE 802.11 networks which occupies same bandwidth as IEEE 802.15.4 channels 11 to 14. Also we can observe several less influencing IEEE 802.11 networks on other channels. Result shown that, in this case, channel 26 is the least affected by other types of wireless transmission and it can be used for IEEE 802.15.4 operation.

Results for residential building presented in Fig.6, shows several dominant IEEE 802.11 networks which occupies same bandwidth as IEEE 802.15.4 channels 13 to 23. Also we can observe several less influencing IEEE 802.11 networks on other channels. This is the results of number large number of WLANs which are typically used as home LAN infrastructure in apartments in Serbia. Result shown that, in this case, all channels are occupied and it will be challenging task to implement error-free operation of IEEE 802.15.4 network.

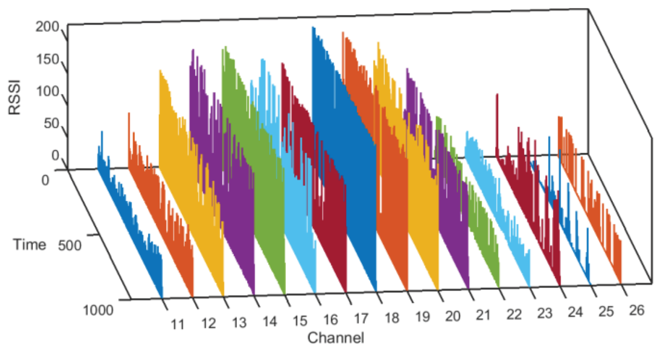

Fig. 6. IEEE 802.15.4 channels in residential building

Results for downtown house presented in Fig.7, shows several IEEE 802.11 networks which occupies same bandwidth as IEEE 802.15.4 channels 22 to 23 and 12 to 15. Interference of these networks is much smaller compared to other two scenarios due physical separation between houses which is dozen meters. In this scenario IEEE 802.15.4 networks can operate without interference on most channels.

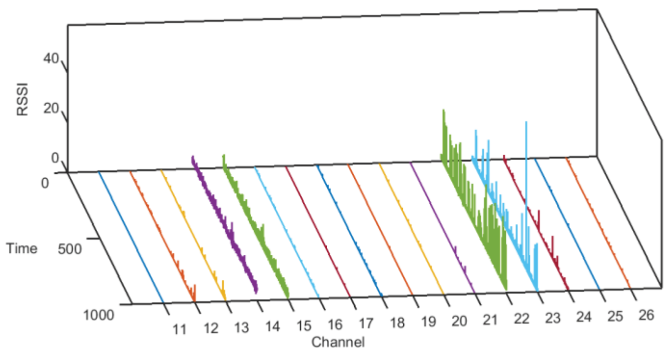

Fig. 7. IEEE 802.15.4 channels in downtown house

V. Conclusion

Results show that IEEE 802.15.4 networks could hardly coexist with other types of networks in highly urbanized environments, such as public and residential buildings. In such scenarios it’s necessary to use advanced mechanisms with adaptive channel hopping.

Acknowledgement

The work presented in this paper is part of the research of project TR32043 for the period 2011-2019, funded by the Ministry of Education and Science of the Republic of Serbia.

References

[1] V. Valenta, R. Marsalek, G. Baudoin, M. Villegas, M. Suarez, "Survey on Spectrum Utilization in Europe: Measurements, Analyses and Observations. 5th International ICST Conference on Cognitive Radio Oriented Wireless Networks and Communications, Jun 2010, Cannes, France. pp. ISBN: 978-963-9799-94-3.

[2] "Co-existence of IEEE 802.15.4 at 2.4 GHz", NXP Application Note JN-AN-1079, Revision 1.1, 8-Nov-2013

[3] J.T. Adams, "An introduction to IEEE STD 802.15.4", IEEE Aerospace Conference, 4-11 March 2006,Big Sky, MT, USA, ISSN: 1095-323X

[4] K. Mikhaylov, N. Plevritakis, J. Tervonen, "Performance Analysis and Comparison of Bluetooth Low Energy with IEEE 802.15.4 and SimpliciTI", Journal of Sensor and Actuator Networks 2(3) pp.589-613, September 2013

[5] White Paper: "Integrating an Industrial Wireless Sensor Network with Your Plant’s Switched Ethernet and IP Network", Cisco Systems, Inc. 2009

[6] White paper: "How to Ensure IoT Devices Work in Their Intended Environment - Locate And Identify Interference", Keysight Technologies, 2019

[7] S. Grimaldi, A. Mahmood, M. Gidlund, "Real-Time Interference Identification via Supervised Learning: Embedding Coexistence Awareness in IoT Devices", IEEE Access (Volume: 7) 2018, pp: 835 - 850, ISSN: 2169-3536

[8] H. Dakdouk, E. Tarazona, R. Alami, R. Feraud, G. Z. Papadopoulos, P. Maille, "Reinforcement Learning Techniques for Optimized Channel Hopping in IEEE 802.15.4-TSCH Networks", MSWIM '18 Proceedings of the 21st ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems, pp. 99-107, Montreal, Canada, 28.10 - 02.11, 2018

[9] S. Hammoudi, S. Harous, Z. Aliouat and L. Louail, "Time slotted channel hopping with collision avoidance", Int. Journal Ad Hoc and Ubiquitous Computing, Vol. 29, Nos. 1/2, 2018 85

[10] A. Elsts, X. Fafoutis, R. Piechocki, and I. Craddock, Adaptive Channel Selection in IEEE 802.15.4 TSCH Networks, 2017 Global Internet of Things Summit (GIoTS), 6-9 June 2017 Geneva, Switzerland, ISBN: 978-1-5090-5873-0

[11] N. H. Mahalin, H. S. Sharifah , S.K. Syed Yusof, N. Fisal, R.A Rashid, "RSSI Measurements for Enabling IEEE 802.15.4 Coexistence with IEEE 802.11b/g", TENCON 2009 - 2009 IEEE Region 10 Conference, 23-26 Jan. 2009, Singapore, ISSN: 2159-3450

[12] PICDEM Z Demonstration Kit User’s Guide, Microchip Technology Incorporated,2008,

[13] Microchip, "MRF24J40MA Datasheet, 2.4 GHz IEEE Std. 802.15.4™RF Transceiver Module”, Microchip Technology Incorporated,2008,

[14] MRF24J40 Radio Utility Driver Program, Application Note AN1192, Microchip Technology Incorporated,2009,