Interdisciplinary Description of Complex Systems 20(3), 250-256, 2022

THE PERFORMANCE ANALYSES OF IEEE 802.15.4G SUN LOW-POWER WIRELESS NETWORKS AND THEIR APPLICATION

Dalibor Dobrilović*, Milica Mazalica and Goran Gecin

University of Novi Sad, Technical Faculty "Mihajlo Pupin"
Zrenjanin, Serbia

DOI: 10.7906/indecs.20.3.4
Regular article

Received: 14 January 2021.
Accepted: 31 December 2021.

ABSTRACT

In the era of expansion of smart sensing interconnected devices and their growing application in complex systems, the application of wireless communication technology becomes evident. Many wireless technologies are developed to facilitate the growth of systems such as the Internet of Things and Smart Cities. The application of a particular wireless technology in a particular system depends on many factors, such as purpose, requirements, complexity, range, and node deployment. IEEE 802.15.4 is a technical standard that defines the operation of low-rate wireless personal area networks. It is used as the basis for a group of network standards and protocols designed for wireless sensor networks. In this article, the basic features of the emerging IEEE 802.15.4g SUN low-powered wireless network standard, its application scenarios, and performance analyses are presented.

KEYWORDS

smart utility networks, wireless network performance evaluation, indoor propagation, wireless sensor networks, wireless communications

CLASSIFICATION

ACM: 10002951, 10003033, 10003079, 10011704
JEL: L63

---

*Corresponding author, η: dalibor.dobrilovic@uns.ac.rs; ++381 62 8019760;
Technical Faculty "Mihajlo Pupin", Djure Djakovica bb, 23000 Zrenjanin, Serbia

INTRODUCTION

The appliance of a variety of emerging wireless communication technologies grows together with the increase in the numbers of smart sensing interconnected devices and their application in complex systems. All these factors influenced the development of a variety of metering systems applicable in industry and new field services designed to improve the efficiency and productivity of utility sites, especially in the smart-grid infrastructure. These new services, among others, are the Smart Metering Utility Networks (SUN). SUNs enable multiple applications to operate over shared network resources, providing monitoring and control of utility systems. The scenarios of usage of SUNs include very large-scale, low-power wireless applications designed to use the maximum power available under applicable regulations. The technology should provide long-range, point-to-point connections and coverage of geographically widespread areas containing a large number of outdoor devices. Wireless SUN (Wi-SUN) networks are designed to enable wireless connectivity between smart-grid devices. Wi-SUN Alliance [1] is a consortium of global corporations and world leaders in Smart Utility, Smart City, and IoT Markets formed to improve utility networks using narrowband wireless technology.

With the existence of a great number of applicable wireless technologies used to facilitate the growth of these systems, experiments on the usability of emerging technologies in industrial environments continue to have an important role. The IEEE 802.15.4 is a technical standard that defines the operation of Low-Rate Wireless Personal Area Networks (LR-WPANs). This standard is used as the basis for a group of network standards and protocols designed for wireless sensor networks. This standard has a high potential for implementation in smart metering and similar systems. In this article, the basic features of the emerging IEEE 802.15.4g SUN low-powered wireless network, its application scenarios, and performance analyses in the industrial environment are presented.

IEEE 802.15.4g AND SUN NETWORKS

IEEE 802.15.4g [2] and IEEE 802.15.4e [3] are amendments of IEEE 802.15.4-2011 [4]. These amendments give additional enhancement in industrial application features and radio communications mechanism suited for a SUN. The inclusion of various functionalities such as robust multihop, power saving, interference detection/avoidance, and optimized physical layer design are also enabled with these standards [5]. These additions to the physical layer and MAC layer requirements made both standards more effective for applications in SUN. IEEE 802.15.4g targets usage scenarios in Neighbourhood Area Networks (NAN) too, for the environments where utility meters are deployed outdoor and form mesh/ad hoc networks [6]. Compared with the baseline standard, such usage scenarios present more technical challenges due to a harsher environment [7].

The IEEE 802.15.4-2015 [4] standard revision dates from 2015. It includes three new physical layers targeted to SUN applications. The three layers are MR-FSK, MR-OQPSK, and MR-OFDM. MR stands for multi-rate multi-regional. The MR-FSK and MR-OQPSK modulations focus on maintaining backward compatibility with previous standards and commercially available transceivers, whereas the MR-OFDM focuses on adding robustness and improving spectrum efficiency at the physical layer [7]. The IEEE 802.15.4g as revision defines the PHY specifications for outdoor networking environments, e.g. Wi-SUN. The frequency bands for this technology are 868 MHz (Europe), 915 MHz (USA), and 2,4 GHz ISM (global). Combining different parameter values (speed, bandwidth, etc.), this standard offers numerous options for PHY, and achievable speeds ranging from 6.25 kbps to 800 kbps and frames up to 2 047 bytes [2, 8].

Besides the data rates up to 800 kbps, the IEEE 802.15.4g SUN specification supports a long communication range of several hundred meters and a reliable mesh-routing protocol, which is expected to be a promising solution for mesh sensor networks. It has been processed to offer a global standard that facilitates large-scale process control applications, such as smart-grid networks. This standard also provides application mainly to outdoor communications, and mechanisms to coexist with other systems in the same bands, such as the IEEE 802.11, IEEE 802.15, and 802.16. [9]

The Wi-SUN systems for the wide-area of the IoT are composed of two types of wireless stations, i.e. the devices and the coordinators. In the uplink (UL), the devices with sensors or meters transmit acquired data to the coordinators. In the downlink (DL), the coordinators send control signals to the devices. Although Wi-SUN systems support multi-hop transmission, from the viewpoint of running cost, the area in which the coordinators can communicate with the devices directly should be as wide as possible. [10]

APPLICATIONS OF IEEE 802.15.4g Wi-SUN

The usage of the IEEE 802.15.4.g standard for smart metering and SUN as a part of a smart grid is presented in the article [6]. In other research [8], the example of an application of IEEE 802.15.4g standard in healthcare systems, developed for health monitoring and data aggregation is given. The article [11] shows the application of the IEEE 802.15.4.g standard in environmental indoor monitoring systems for sensing temperature, humidity, CO2, and energy control. The article [12] presents the usage of IEEE 802.15.4g for OpenMote open-hardware prototyping ecosystems, which is used for the implementation of the Industrial Internet of Things (IIoT). In the research [13] the evaluation of IEEE 802.15.4g is given for environmental monitoring and it is proved that this standard can be used for outdoor operations with the ability to reduce the number of repeater nodes. In the same research, the usage of the IEEE 802.15.4g standard for monitoring, intrusion and fire detection, elevator monitoring, HVAC, and lighting management in Smart Building application is presented. The article [5] shows the usage of IEEE 802.15.4g in applications in outdoor environments for facilitating communication in SUN, machine-to-machine (M2M) networks, and sensor networks.

In [10] a wide area Wi-SUN system is proposed based on IEEE 802.15.4g composed of a high-performance base station (BS) and terminal devices with sensors and meters. In the proposed system, the high-performance BS is developed as the coordinator, which is rich in power supply and calculation resources. In the DL, transmission power is enlarged, and in the UL, high gain directional antennas are used, e.g. the transmission power of the BS is around 10 dB more compared to other devices. In the same research, a method for measuring the performance of proposed systems during the field experiments in the urban area is presented.

PERFORMANCE ANALYSES OF IEEE 802.15.4g

Considering the potential of the IEEE 802.15.4g, the evaluation and analysis of the performance of standards are presented in this article. For the evaluation, the data set presented in [7] is used. The data set is available at [14]. During the evaluation, the three PHY layers are compared: SUN-FSK, SUN-OQPSK, and SUN-OFDM. The data set is collected during the experiment described in the same source [7] in the industrial indoor environment. Eleven nodes are evaluated. The distances of the nodes from the receiver range from 34 to 273,5 meters. The data set is evaluated in two ways. First, the measured Received Signal Strength Indicator (RSSI) data from each node are compared with the ITU Indoor Propagation model [15]. The estimated signal strength at the receiver side is calculated using the following formula:

$$P_{rx} = P_{tx}+G_{tx}+G_{rx} - L_{pl}. \tag{1}$$

The parameters of the formula (1) are as follows: P_{rx} is received power presented in dBm, P_{tx} is transmitter output power also in dBm, G_{tx} is transmitter antenna gain in dBi, L_{tx} is total transmitter losses in cable, connectors, etc. in dB, and L_{pl} is propagation loss or path loss also in dB, calculated with the formula (2).

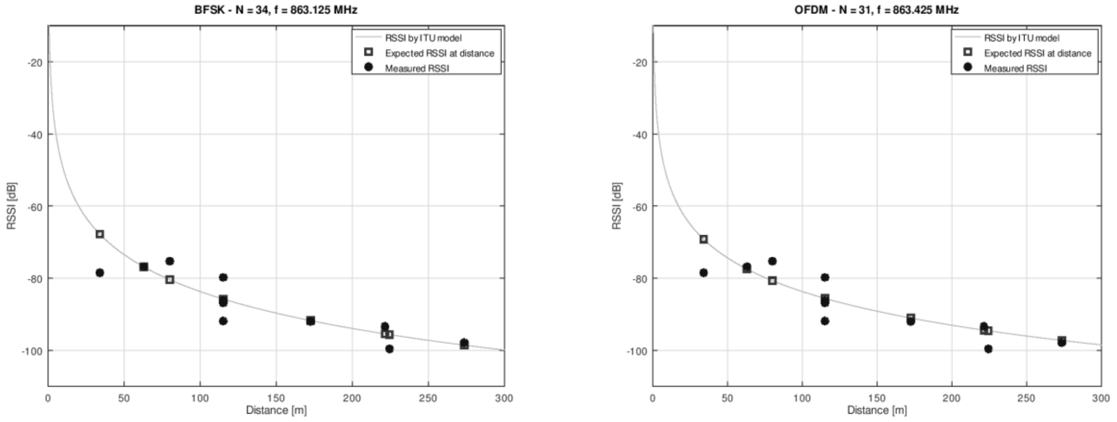
The ITU indoor propagation model uses the following formula [15] for calculating indoor propagation path loss L_{pl} in decibels [dB]:

$$L_{pl} = 20\cdot\log_{10}(f) + N\cdot\log_{10}(d) + L_f(n) - 28, \tag{2}$$

with the following parameters: N is the distance power loss coefficient, f is the frequency in MHz, d is the distance in meters, $L_f(n)$ is the floor penetration loss factor in decibels, n is the number of floors between the transmitter and the receiver. The $L_f(n)$ is omitted from the calculation because all nodes in the experiments were deployed at the same level. In [15] the recommended values for N are 22, 28, and 30. For the best fitting of the model, the range of values from 22 to 38 are used for N to achieve the highest accuracy in estimating signal strength. The best-fitting is determined with the use of the Root Mean Square Error (RMSE) value.

RESULTS

The results of the analyses are displayed in Fig. 1. The SUN-FSK is shown in Fig. 1 a) with the best fitting for the value of N = 34, and the SUN-OFDM is shown in Fig. 1 b) with the best fitting for the value of N = 31.



a) b)

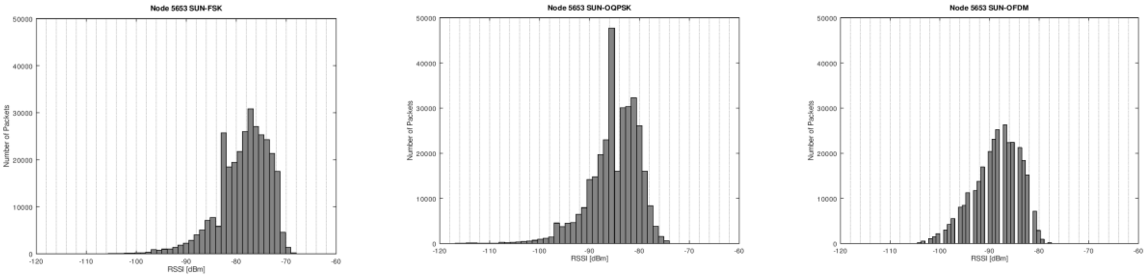
Figure 1. The accuracy of the ITU model with a) SUN-FSK and b) SUN-OFDM modulation.

The fitting of the ITU indoor model with the different values for N and with resulting RSME in decibels is shown in Table 1. The SUN-FSK and SUN-OQPSK have similar results with the lowest RMSE with N = 34 when RMSE is around 4,6 dB. SUN-OFDM has the best fitting with N = 31 when the RMSE is 4,46 dB.

Table 1. The architecture of the learning system.

No.	Modulation	TX frequency	N value	RMSE
1	FSK	863.125	22	26,0868
2	FSK	863.125	28	13,9049
3	FSK	863.125	30	10,0506
4	FSK	863.125	34	4,6304
5	OQPSK	868.3	22	26,0357
6	OQPSK	868.3	28	13,8555
7	OQPSK	868.3	30	10,0037
8	OQPSK	868.3	34	4,6219
9	OFDM	863.425	22	20,199
10	OFDM	863.425	28	8,3934
11	OFDM	863.425	30	5,2909
12	OFDM	863.425	31	4,4611

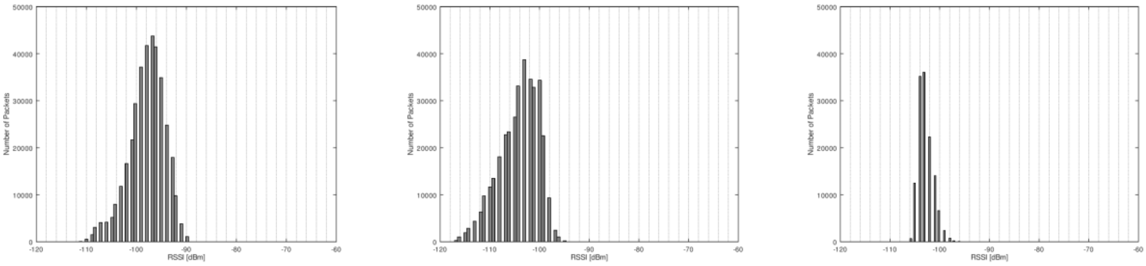
The second approach in comparison of three different PHY layers is the analysis of the variations of signal strength of nodes 5 653 and 630a. Two nodes are selected as the closest (5 653) and furthest (630a) nodes from the receiver. The distribution of RSSI per packet of those two nodes is shown in Fig. 2 for node 5 663 and in Fig. 3 for node 630a, for FSK, OQPSK and OFDM respectively.



a) b) c)

Figure 2. The RSSI of packets of node 5 653 a) SUN-FSK b) SUN-OQPSK c) SUN-OFDM.

In Fig. 2 and Fig. 3 it can be seen that the packet RSSI distribution differs for all three modulations. The standard deviation of RSSI for node 5 653 is 5,0187 dB for SUN-FSK, 5,0663 dB for SUN-OQPSK, and 4,7193 dB for SUN-OFDM. Node 5653 is deployed at a distance of 34 m from the receiver. The difference between the maximal and minimal RSSI values is 43 dB for SUN-FSK, 44 dB for SUN-OQPSK, and 30 dB for SUN-OFDM.



a) b) c)

Figure 3. The RSSI of packets of node 630a a) SUN-FSK b) SUN-OQPSK c) SUN-OFDM.

The distance between the node 630a and the receiver is 273,5m. The standard deviation of RSSI is 3,5661 dB for SUN-FSK, 3,9341 dB for SUN-OQPSK, and 1,5061 dB for SUN-OFDM. The difference between the maximal and minimal RSSI values is 23 dB for SUN-FSK, 25 dB for SUN-OQPSK, and 15 dB for SUN-OFDM.

CONCLUSION

This article deals with the performance analyses of the IEEE 802.15.4g Wi-SUN and its behavior in industrial applications. The third-party dataset is used for the analyses. The analyzed data contain the RSSI of received packets and the distance between transmitter and receiver. For the analyses, the comparison of collected data with the ITU indoor propagation model is made. The ITU model shows great accuracy in the estimation of the received signal strength (RSSI) for given locations and experimental environments. The distribution of received packet strengths, as well as the values of standard deviation, indicate that the IEEE 802.15.4g Wi-SUN technology is highly applicable for industrial scenarios. This research and its results will be used as a motivation for authors to make further analyses and experimentation with the IEEE 802.15.4g technology.

ACKNOWLEDGMENT

This research is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia under the project number TR32044 “The development of software tools for business process analysis and improvement,” 2011-2020.

REFERENCES

[1] –: *Wi-SUN Alliance.*
http://wi-sun.org/, accessed 10th January 2020,

[2] IEEE Standard for Local and metropolitan area networks--Part 15.4: *Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 3: Physical Layer (PHY) Specifications for Low-Data-Rate, Wireless, Smart Metering Utility Networks.*
IEEE Std 802.15.4g-2012 (Amendment to IEEE Std 802.15.4-2011), pp.1-252, 2012,
http://dx.doi.org/110.1109/IEEESTD.2012.6190698,

[3] IEEE Standard for Local and metropolitan area networks--Part 15.4: *Low-Rate Wireless Personal Area Networks (LR-WPANs) Amendment 1: MAC sublayer.*
IEEE Std 802.15.4e-2012 (Amendment to IEEE Std 802.15.4-2011), pp.1-225, 2012,
http://dx.doi.org/110.1109/IEEESTD.2012.6185525,

[4] IEEE Standard for Local and metropolitan area networks--Part 15.4*: Low-Rate Wireless Personal Area Networks (LR-WPANs).*
IEEE Std 802.15.4-2011 (Revision of IEEE Std 802.15.4-2006), pp.1-314, 2011,
http://dx.doi.org/110.1109/IEEESTD.2011.6012487,

[5] Chin-Sean, S.; Ming-Tuo, Z.; Fumihide, K. and Hiroshi, H.: *Experimental Performance Evaluation of Multihop IEEE 802.15.4/4g/4e Smart Utility Networks in Outdoor* Environment-Wireless Communications and Mobile Computing, 2017,
http://dx.doi.org/10.1155/2017/7137406,

[6] Kuor-Hsin, C. and Mason, B.: *The IEEE 802.15.4g standard for smart metering utility networks.*
IEEE 3rd International Conference on Smart Grid Communications, Tainan, pp.476-480, 2012,
http://dx.doi.org/10.1109/SmartGridComm.2012.6486030,

[7] Tuset-Peiró, P.: *Dataset to Evaluate IEEE 802.15.4g SUN for Dependable Low-Power Wireless Communications in Industrial Scenarios.*
Data **5**, 64, 2020,

[8] Gardašević, G.; Katzis, K.; Bajić, D. and Berbakov, L.: *Emerging Wireless Sensor Networks and Internet of Things Technologies — Foundations of Smart Healthcare*.
Sensors **20**(13), No. 3619, 2020,
http://dx.doi.org/10.3390/s20133619,

[9] Nguyen, H.; Le, N.T.; Hoan, N.C. and Jang, Y.M.: *Real-Time Mitigation of the Mobility Effect for IEEE 802.15.4g SUN MR-OFDM.*
Applied Sciences **9**(16), No. 3289, 2019,
http://dx.doi.org/10.3390/app9163289,

[10] Mochizuki, K.; Obata, K.; Mizutani, K. and Harada, H.: *Development and field experiment of wide area Wi-SUN system based on IEEE 802.15.4g.*
IEEE 3rd World Forum on Internet of Things (WF-IoT), Reston, pp.76-81, 2016,
http://dx.doi.org/10.1109/WF-IoT.2016.7845425,

[11] Dong Sik, K.; Beom Jin, C. and Sung-Yong,S.: *Implementation of a Low-Cost Energy and Environment Monitoring System Based on a Hybrid Wireless Sensor Network.*
Journal of Sensors **2017**, No. 5957082, 2017,
http://dx.doi.org/10.1155/2017/5957082,

[12] Vilajosana, X.; Tuset, P.; Watteyne, T. and Pister, K.: *OpenMote: Open-Source Prototyping Platform for the Industrial IoT*.
In: Mitton, N.; Kantarci, M.; Gallais, A. and Papavassiliou S., eds.: *Ad Hoc Networks. ADHOCNETS 2015.* Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering **155**, Springer, Cham, 2015,
http://dx.doi.org/10.1007/978-3-319-25067-0_17,

[13] Muñoz, J.; Riou, E.; Vilajosana, X.; Muhlethaler, P. and Tatteyne, T.: *Overview of IEEE802.15.4g OFDM and its applicability to smart building applications*.
Wireless Days (WD), Dubai, pp.123-130, 2018,
http://dx.doi.org/10.1109/WD.2018.8361707,

[14] –: *GitHub repository*.
http://github.com/wine-uoc/wisun_traces, accessed 10th January 2020,

[15] Seybold, J.S.: *Introduction to RF propagation*.
John Wiley & Sons, 2005.