Evaluation of TSCH/IEEE 802.15.4e in a Domestic Network Environment

Luis Pacheco[1], Tom Vermeulen[2], Sofie Pollin[2], and Priscila Solis[1(✉)]

[1] Departamento de Ciência da Computação, Universidade de Brasília, Caixa Postal 4466, Brasília, DF 70910-900, Brazil
luisbelem@gmail.com, pris@cic.unb.br

[2] Dept. Elektrotechniek-esat-telemic, KU Leuven, Kasteelpark Arenberg, 10, 2444, 3001 Leuven, Belgium
{tom.vermeulen,sofie.pollin}@esat.kuleuven.be

Abstract. The IEEE 802.15.4e standard was published in 2012 as an amendment to the Medium Access Control (MAC) protocol defined by the IEEE 802.15.4-2011 standard. The purpose of this paper is to evaluate the Timeslotted Channel Hopping (TSCH) mode of IEEE 802.15.4e in the context of IoT (Internet of Things) regarding environment and changes in application requirements. A simulation scenario of a typical domestic sensor network is designed to evaluate the TSCH mode in a dynamic environment with the presence of WiFi devices. Also are explored the upper and lower bounds in performance gain due to self-learning. The relatively recent release of such standard accounts for its lack of support in network simulators and this work implements the TSCH in the well known open-source network simulator ns-3. This work enables the preview analysis of TSCH networks, decreasing necessary resources and therefore facilitating the use of such networks for social goods such as health monitoring, The results clearly show that the presence of WiFi signals greatly degrades the IEEE 802.15.4e network performance, in terms of throughput, delay and energy consumption. When applying self-learning techniques to avoid degraded channels, the network can properly function and achieves better performance. Also, a significant decrease in delay is also achieved when adapting the slotframe size according to the number of active devices.

1 Introduction

Wireless sensor networks are composed by several sensor nodes that link the physical with the digital world by transforming the sensed analog information into digital data.

The IEEE802.15.4e Timeslotted Channel Hopping (TSCH) [1] aims to enhance and add functionality to the 802.15.4 MAC layer for better support the industrial markets. This work evaluates the performance of channel hopping (TSCH) operational mode of IEEE 802.15.4e Amendment. Consequently, this work implements the TSCH mode in the ns-3 [5] network simulator. The implementation is verified by known results and a simulation scenario is designed

B. Mandler et al. (Eds.) IoT 360° 2015, Part I, LNICST 169, pp. 257–262, 2016.
DOI: 10.1007/978-3-319-47063-4_25

to investigate the performance of TSCH under dynamic conditions of channel quality and number of active devices in the network. The paper is organized as follows: Sect. 2 overviews the main features of 802.15.4e, Sect. 3 describes the proposed simulation scenario, Sect. 4 discusses and analyses the results and finally, Sect. 5 concludes this work.

2 IEEE 802.15.4e Amendment

Three new MAC operational modes are defined in this amendment: Low Latency Deterministic Network (LLDN), Deterministic and Synchronous Multi-channel Extension (DSME) and Timeslotted Channel Hopping (TSCH). Channel hopping was introduced to increase network resilience, devices hop among predefined frequency bands, so if there is some interference in a channel, the next one may be in better conditions.

TSCH is a deterministic mode, all communications are previously scheduled during the PAN formation or pre-configured into devices. A slotframe repeats using devices' shared notion of time, each slotframe is composed by timeslots, which contains a link between two devices.

3 Simulation Scenario

The proposed scenario simulates a wireless acoustic sensor network used in a family home. As shown in Fig. 1 the residence dimension's are 8 by 11 m and it has 5 rooms. The sensor network features 16 devices, one as the central sink, which receives and processes all information generated by the other 15 devices.

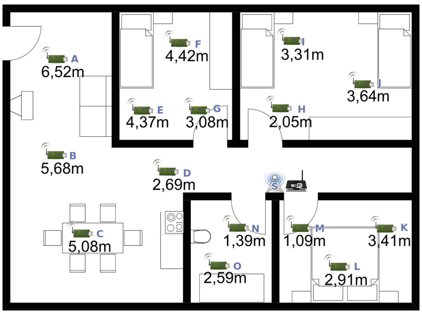

Fig. 1. House schematic used as simulation scenario

The network is configured with one slotframe with 15 timeslots, each timeslot has a length of 10 ms. Sensors produce 114 bytes of data (maximum allowed considering a header of 13 bytes) every 10 ms.

An IEEE 802.11-2007 [6] (WiFi) compliant device is disposed next to the central sink, it is configured with a transmit power of 0.1 W and channel 6 to

Table 1. Activity levels

Activity	Description	Time of the day	Nodes	WiFi activity
Low	Everybody sleeping	23 h to 07 h	3	None
Medium	1 or 2 people present	09 h to 17 h	6	50 %
High	Everybody present	07 h to 09 h and 17 h to 23 h	15	100 %

generate a PSD according to the above mentioned standard. The Friis propagation loss model [15] is used to represent the signal's energy loss during the transmission.

The proposed scenario has a 24 h duration, through the day the number of people in the house changes, as well as the activity of the sensor network and of the WiFi interferer. Table 1 describes the 3 possible activity levels.

4 Results

The presence of a WiFi device in the simulated scenario causes a heavy influence on the sensor network behaviour. Such variance happens due to the attenuation that the WiFi signal suffers along the path to the devices antenna. The graph in Fig. 2 shows the BER observed by the sink node of a transmission performed for each device of the sensor network. As can be seen, the WiFi interferer influences all devices of the network, even the signal from the closer devices are too low compared to the WiFi signal. A BER of 10^{-9} is often considered the threshold as an acceptable condition, Fig. 2 shows that this is only achieved in channels 24, 25 and 26, where there is no WiFi interference, considering that all transmissions in the affected channels would fail or not pass the CCA scheme, only 18,75 % of those transmissions would succeed.

In this study three aspects of the network are analysed: throughput, delay and energy consumption. In order to validate the obtained data a mathematical analysis is performed and compared with the simulation results. Each activity level is analysed for its throughput and then compared with simulated results. Since the slotframe configuration remains the same through all activity levels (with 15 timeslots), there is a different optimal throughput for each one (Table 2).

In Fig. 3 shows the simulated results with and without interference. The results without interference are, as expected, equal to the calculated through-

Table 2. Maximum throughput for each activity level

Activity level	Nodes active	Maximum throughput
Low activity	3	20.32 kbps
Medium activity	6	40.64 kbps
High activity	15	101.60 kbps

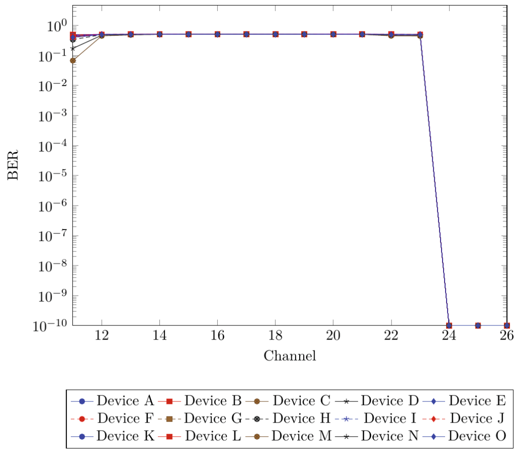

Fig. 2. BER of each channel for each device

puts, this validates the implementation in an ideal scenario where there is no packet loss due to interference.

The first region is relative to a low activity level, which has no WiFi interference, and the maximum throughput of 20.32 kbps is reached. The second region, relative to a high activity level, reaches 18.9 % (19.202 kbps) of the throughput required by the application, this result corresponds to the 18.75 % success rate previously obtained, with transmissions only being successful in 3 of the 16 channels. The third region, relative to a medium activity level, reaches 60 % (24.384 kbps) of the throughput required by the application in this level, considering the WiFi interferer is active during 50 % of the time, in half of this region's

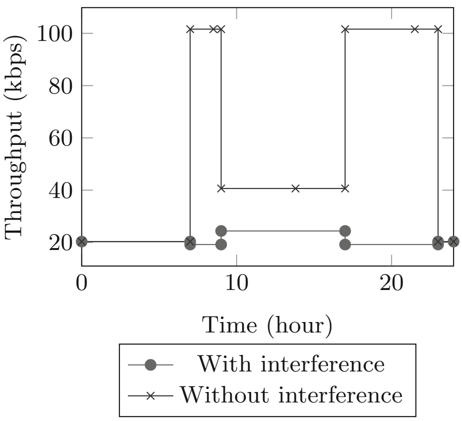

Fig. 3. Simulated throughput with and without interference

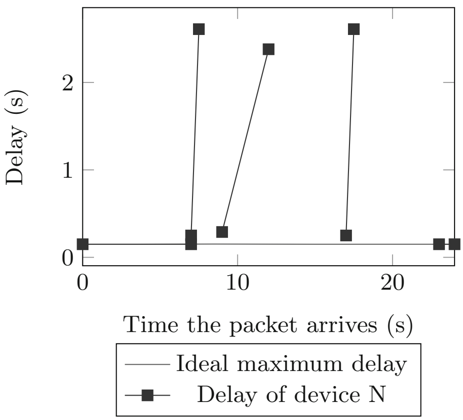

Fig. 4. Delay in device N

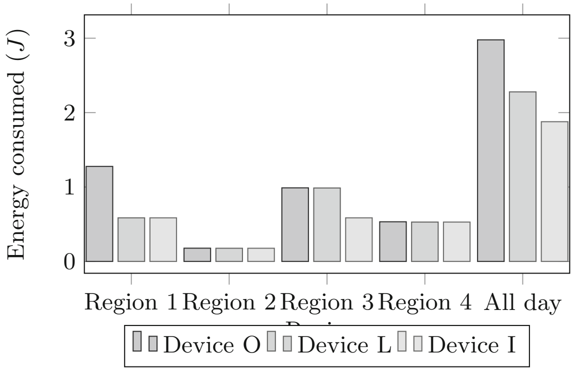

Fig. 5. Energy consumption, in J, of devices O, L and I in each region and throughout the entire simulation

duration the throughput should be as required by the application, in the other half it should be only 18.75 % of the required value, this scheme corresponds to 59.375 % of the required throughput which validates the value obtained by the simulation.

The impact of interference in the network's delay is shown in Fig. 4. The maximum delay without interference is 0.15 s, relative to the length of the slotframe. In the presence of the WiFi signal, the delay quickly increases going to impractical values. The slope of the line relates with the success rate, in the high activity level the slope is around 77.6° and in the medium activity level the slope is 34.9°.

Using the realistic energy model for TSCH [16], Fig. 5 shows the energy consumption by devices O, L and I in each region of the simulated scenario. Device O represents nodes active through the entire simulation, device L represents nodes active only in regions 2, 3 and 4, and device I represents nodes active only in regions 2 and 4. Since regions 1 and 3 have the same duration, the impact of the WiFi interferer (with a duty cycle of 50 %) in energy consumption can be observed, in region 1 is which device O consumes 1.277 J while in region 3 it consumes 0.989 J.

5 Conclusion

This work analysed the performance of a TSCH network. The results show that in an environment with interference it is indispensable to deploy self-learning techniques. These techniques mainly restrict the channels used by the channel hopping scheme to only the ones with a minimum quality. It was also observed that changing the slotframe size to bear only active devices can bring a huge improvement in the network's delay. This work's analysis was enabled by the TSCH model developed under the ns-3 network simulator, which, for the best of our knowledge, is the first simulator to implement the IEEE 802.15.4e standard.

As a result of the implementation several additions and corrections were also made for the IEEE 802.15.4 model, with the main addition being the interference support.

As future work, certain enhancements can be implemented in the features of TSCH, such as shared timeslots and the synchronization scheme. A full IEEE 802.15.4e model implementation, including other MAC schemes, would provide a tool to assist the evaluation of the entire standard and the development of new proposals made by the academic community. Part of this research was funded under the IWT SBO project Sound INterfacing through the Swarm (SINS).

References

1. I. S. 802.15.4e 2012. Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs) Amendment 1: MAC sublayer, IEEE Standard for Information Technology (2012)
2. T. I. E. T. F. (IETF). IPv6 over the TSCH mode of IEEE 802.15.4e, The Internet Engineering Task Force (IETF) (2014)
3. Du, P., Roussos, D.G.: Adaptive time slotted channel hopping for wireless sensor networks. In: Computer Science and Electronic Engineering Conference (CEEC) (2012)
4. Sha, M., Dor, R., Hackmann, G., Lu, C., Kim, T.-S., Park, T.: Self-adapting MAC layer for wireless sensor networks. In: Real-Time Systems Symposium (RTSS) (2013)
5. ns 3 project. ns-3 network simulator. http://www.nsnam.org/
6. I. S. 802.11-2007. Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications. IEEE Standard for Information Technology (2007)
7. IEEE, IEEE 802.15 WPANTM Task Group 4 (TG4). http://www.ieee802.org/15/pub/TG4.html. Accessed 09 Apr 2014
8. Information technology - Open Systems Interconnection - Basic Reference Model: The Basic Model (1994)
9. I. S. 802.15.4-2006. Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs), IEEE Standard for Information Technology (2006)
10. I. S. 802.15.4-2011. Wireless Medium Access Control (MAC) and Physical Layer (PHY)Specifications for Low-Rate Wireless Personal Area Networks (WPANs), IEEE Standard for Information Technology (2011)
11. Goldsmith, A.: Wireless Communications. Cambridge University Press (2005). ISBN: 0521837162, 9780521837163
12. DARPA. Transmission control protocol, Defense Advanced Research Projects Agency, RFC 793 (1981). http://www.ietf.org/rfc/rfc793.txt
13. Baldo, N., Miozzo, M.: Spectrum-aware channel and phy layer modeling for ns3. In: Spectrum-Aware Channel and PHY Layer Modeling for ns3 (2009)
14. Crecraft, D., Gorham, D..: Electronics. CRC Press (2003). ISBN: 0748770364
15. Kraus, J.D.: Antennas. McGraw-Hill, New York (1950)
16. Vilajosana, X., Wang, Q., Chraim, F., Watteyne, T., Chang, T., Pister, K.S.J.: A realistic energy consumption model for TSCH networks. IEEE Sens. J. **14**(2), 482–489 (2014)