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Paris, 19 August 2020,

Dear Editor, dear Reviewers,

We would like to thank for the efficient handling of our paper “No Free Lunch: Characterizing the Performance of 6TiSCH when using Different Physical Layers”, and the very constructive and encouraging suggestions from the reviewers. We have taken these into account and have revised the manuscript accordingly. We indicate in the remainder of this letter how we have taken your suggestions into account. For clarity, we submit two versions of the manuscript, with one clearly highlighting the changes to the paper.

We thank you for raising the detailed comments concerning the style of figures and tables and their placement for easy readership. Tables and Figures have been updated to meet your comments. Subfigures are arranged in invisible column format. Furthermore, the detailed review of the references and abbreviations allowed us to fix the errors in the bibliography and to ensure consistent and sufficient clarification of abbreviations. We thank you for highlighting the need to merge sections 5 and 6. We merged both *OpentTesbed* and *Methodology* sections into one section on *Experiment Setup and Methodology*. Finally, we adapted the related work section to highlight the part that addresses the experiments testing the physical layers of IEEE802.15.4g without the 6TiSCH stack.

We believe to have addressed all of your comments and suggestions, and hope that the manuscript now warrants publication.

Remaining with kind regards,

For the co-authors, Thomas Watteyne

Response to Reviewer 1

In this paper, the authors have contributed that they have analyzed the implementation of 6TiSCH with different PHY layers. It is interested; however, the paper may be improved if the following suggestions are revised:

(1) The section 5 or 6 are very short. If possible, please combine them.

We thank you for the kind words and for your suggestions

In response to the first comment of the reviewer, we agree that both section seemed too short. We decided to merge both sections into one section titled “Experiment Setup and Methodology”. It contains subsection 5.1 about the OpenTestbed and subsection 5.2 about the methodology

The remainder of this article is organized as follows. Section 2 surveys the most relevant related work. Section 3 clearly states the problems and lists the contributions of this article. Section 4 introduces the agile extension to the OpenWSN PHY-layer that enabled this research. Section 5 introduces the testbed used for the experimental campaigns of this paper and the methodology of the experiments including the used metrics and KPIs. Section 6 demonstrates the experiment results and KPI evaluations. Finally, section 7 provides insights and conclusions based on the results.

5. Experiment Setup and Methodology

We use the OpenTestbed [29] to extract the performance of the OpenWSN stack with the extensions detailed in Section 4. This section demonstrates the architecture of the OpenTestbed experimental setup (Sub-section 5.1) and the methodology for the experiment design and performance evaluation (Sub-section 5.2).

5.1. The OpenTestbed

The OpenTestbed is composed of 42 OpenMote B boards deployed across an office floor at the Inria research center in Paris in groups of 4 (see floorplan on Fig. 2). The distribution of the motes happens in clusters of 4-18 motes, mimicking nodes clustered around machines in an industrial setting [8]. The OpenTestbed is built from off-the-shelf components, networked together using the building’s 5 GHz Wi-Fi network (i.e. no dedicated Ethernet network), without requiring back-end servers, and with an

5.2. Methodology

We run the OpenWSN network once for each of the three PHYs. During the experiments, the floor is mostly unoccupied, so we don’t expect WiFi interference beyond the regular 100 ms beaconing interval of the 8 WiFi access points on that floor [1]. Each time, we load the firmware onto the testbed, then switch on the OpenVisualizer software, which connects to all motes over their serial port (over MQTT). In the OpenVisualizer, we then select the mote that we want to play the role of DAG root. We always select the same mote, shown in Fig. 2, which is positioned at the center of the floor in room A. We then let the network run for 90 min, recording all the data generated by the motes.

(2) In the experimental results, why are no there any results compared without the 6TiSCH over different PHY layers? Currently, there are only results with the 6TiSCH over different PHY. Readers may want to know the results with/without considering the 6TiSCH stack. This mean that the readers could understand the benefits using the 6TiSCH stack.

We thank you for this valuable comment. We agree that performance results of the IEEE802.15.4g physical layer alone are necessary first step. We also agree that those results help understand better the performance with the 6TiSCH stack on top of them. Those experiments are, however, previously conducted in dedicated publications. We dedicated subsection 2.2 *IEEE802.15.4g Performance Evaluation* for the sole purpose of reporting those results. This subsection summarizes related work on the performance of the different PHY layers without 6TiSCH stack (as the review suggests). We specifically note paper [3] which runs and exhaustive campaign for the performance evaluation of all the physical layers supported by IEEE802.15.4g without the 6TiSCH stack.

For the reviewer's reference, we quote below the related section that explores the related work on the performance of the physical layers without the 6TiSCH stack. We updated the introduction of this subsection to clarify that this related work does not include the 6TiSCH stack.

2.2. IEEE802.15.4g Performance Evaluation

Some related work evaluate the performance of IEEE802.15.4g PHYs (without the 6TiSCH stack).

Kojima *et al.* [25] examine the impact of interference between MR-FSK mode 2 and MR-OFDM option 4 MCS 3. Authors deploy IEEE802.15.4e MAC with multihop capability on top of each PHY layer and measure the impact of the interference between two networks, each running one PHY. Results are reported in terms of the degradation of throughput of each network in the presence of the other interfering network. Authors demonstrates that since the OFDM modulation scheme uses multiple sub-carriers, it performs better than FSK in the presence of frequency selective interference.

Muñoz *et al.* [1] run an experimental campaign to compare the performance of IEEE802.15.4 O-QPSK 2.4 GHz at 250 kbps, and IEEE802.15.4g OFDM. They show a higher robustness of OFDM, even though it operates as a higher bit rate (800 kbps). They show that, although a radio draws less current when running O-QPSK 2.4 GHz , using OFDM 868 MHz leads to an overall lower power budget as transmission happens much faster.

The same authors also evaluate the performance of all IEEE802.15.4g PHYs [3]. They conduct a complete range-testing campaigns for the 31 PHYs on the four scenarios they consider the most prevalent in outdoor applications: line of sight, smart agriculture, urban canyon, smart metering. Results of the range-tests are reported in terms of PDR measurements, throughput, and electric charge consumption. They demonstrate the longer range of FSK and O-QPSK in the sub-GHz band compared to OFDM options due to their higher receiver sensitivity.

They provide interesting results as to which radio could be better in certain scenarios. This paper goes one step further to address the end-to-end performance of a full 6TiSCH stack using these PHY layers.

Response to Reviewer 2

Dear authors, in my opinion, this article brings significant argument regarding the treated subject. The studies and the experimental results are valuable, correctly defined and properly described. I think that your article will be interesting to readers of Sensors journal and useful for some of them.

We really thank you for the kind words and truly appreciate your support.

Minor problems that I see are related to the fact that the article does not follow the provided template:

Figures:

All figures should be cited in the main text as Figure 1 instead of Fig. 1 - for example - please correct this for all the figures;

If there are multiple panels, in the figures, they should be listed as: (a) Name for the first panel; (b) Name for the second panel and the (a) and (b) must be bold - please see figure 3. (Figures must be placed in an invisible column table. Two or 3 figures must be placed in an invisible columns table - is figure 3 an figure 8 inserted in this way?)

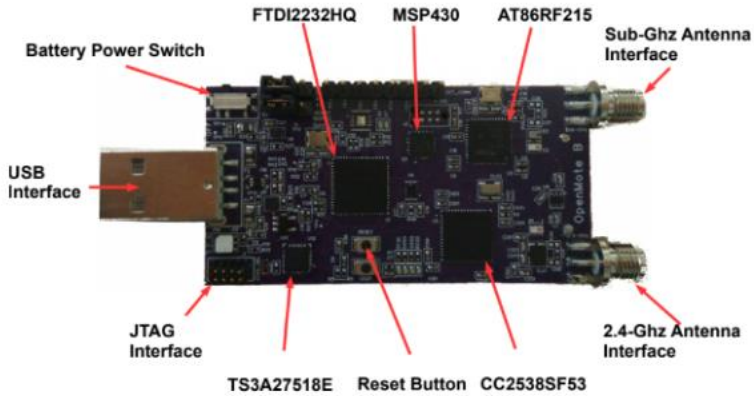
In order to have a better understanding of this work the figures must be placed in the main text near to the first time they are cited and, very important, figure should be placed in the text after it was first quoted (cited) - see figures 2, 4, 7, 8, 9.

Thank you for your detailed feedback on the figure formatting. In response to the comments on the norm for Figure references, we made the following updates to the paper in line with the reviewer's feedback:

1- All figures are referenced as Figure x instead of Fig. x. Updates are highlighted in blue in the paper as in this example:

datarate of the communication or the turn-around time of the radio all influence the timeslot template. Figure 1 illustrates the different timeslot templates when transmitting a 100 B data payload with acknowledgement. Red markers highlight the approximate time for SPI communications from the

2- Figure 3 has been split into two subfigures in invisible columns with separate sub-captions.

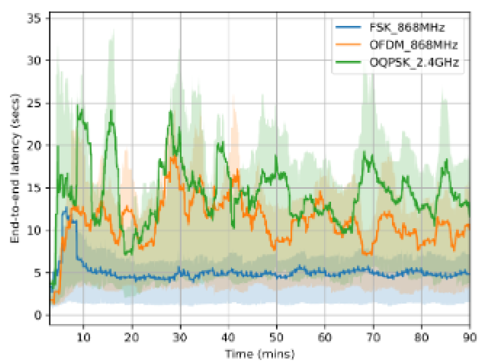


(a) The OpenMote B

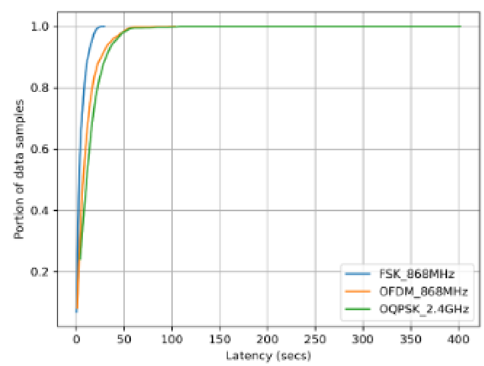
(b) the OpenTestbox, part of the OpenTestbed

Figure 3. Components of the OpenTestbed experiment setup

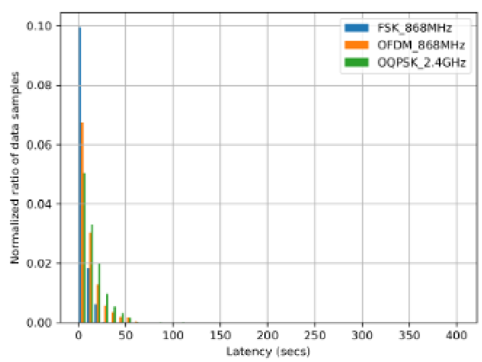
3- Figure 8 was already split into invisible columns. However we aligned it to be in tabular format.



(a) Time series



(b) Cumulative Density Function (CDF)



(c) Probability Density Function (PDF)

Figure 8. End-to-end latency in the network recorded over the entire 90 min experiments. The longer the PHY range, the lower the latency.

4- We did our best in ensuring that figures are displayed as close as possible after their first mention: figures 1, 2, 4, 5, 6, and 7. Unfortunately, some large figures such as 3 and 8 are shifted to different pages by LaTex to optimize space usage (otherwise it leaves large parts of pages empty).

Tables:

Caption of the tables (tables title) should be centered and place in the header of table - see all the tables. Tables may have a footer.

The tables must be placed in the main text near to the first time they are cited and table should be placed in the text after it was first quoted (cited) - see tables 1, 2, 3, 4, 5. - the table is placed in paragraph 8, Conclusion, and the citation is in paragraph 7.4, Battery Lifetime.

Thank you for the observation on the table formatting. We made the following changes according to your suggestions:

1- All table captions are places in the header of the table such as this table:

Table 1. The PHY layers tested.

	Radio chip	Data rate	TX power	Sensitivity	Link budget
FSK 868 MHz	AT86RF215	50 kbps	+14.5 dBm	-114 dBm	128.5 dB
OFDM 868 MHz	AT86RF215	800 kbps	+10.0 dBm	-104 dBm	114.0 dB
O-QPSK 2.4 GHz	CC2538	250 kbps	+07.0 dBm	-97 dBm	104.0 dB

2- We ensured that tables are displayed as close as possible to their first reference. This was applied to tables 1, 2, 3,4, and 5

Equations:

The text following an equation need not be a new paragraph.

Equations must be followed by a comma.

We thank you for this detailed observation about comma formatting. The following has been refelected in the paper based on your comments:

Equation 2 : added commas after equations and ensured continuity of paragraph at line 359.

Given T_{TX} and T_{on}, we use (2) to compute reception time T_{RX}, the transmit duty cycle DC_{TX} and the receive duty cycle DC_{RX}.

$$\begin{cases} T_{RX} & = & T_{on} - T_{TX}\,, \\ DC_{TX} & = & \frac{T_{TX}}{T_{total}}\,, \\ DC_{RX} & = & \frac{T_{RX}}{T_{total}} \end{cases} \tag{2}$$

Table 4 details the calculation of battery lifetime, assuming a mote is powered by a pair of AA batteries holding 8.2 Wh of energy. O-QPSK 2.4 GHz exhibits a battery lifetime 5 times larger than OFDM 868 MHz and 10 times larger than FSK 868 MHz. Despite the advantages of FSK 868 MHz and OFDM 868 MHz in range, reliability and latency, their utilization leads to more frequent battery replacement.

Equation 1 is kept as is since it is a single line equation and the paragraphs before and after it are already separate paragraphs.

References:

The format of paragraph is correctly defined? Please verify.

Thank you for this detailed observation. You are correct, there was a glitch in Conference references that lead to consecutive commas. They were fixed in all Conference reference entries.

Example before

References

1. Muñoz, J.; Riou, E.; Vilajosana, X.; Muhlethaler, P.; Watteyne, T. Overview of IEEE802.15.4g OFDM and Its Applicability to Smart Building Applications. Wireless Days (WD); IEEE, , 2018; pp. 123–130.

After

References

1. Muñoz, J.; Riou, E.; Vilajosana, X.; Muhlethaler, P.; Watteyne, T. Overview of IEEE802.15.4g OFDM and Its Applicability to Smart Building Applications. Wireless Days (WD); IEEE: Dubai, UAE, 2018; pp. 123–130.

Text:

The terms must be defined after which the abbreviations can be used. See TSCH from line 32. The definition of term is at line 44. - please correct for all similar situations.

We thank you for this detailed observation. We have reflected on the paper the changes for several abbreviations in line with your comment. The changes have been highlighted in the paper as in this example:

A traditional approach to having this array of choices is to characterize each PHY, select the one that best corresponds to the application, and build a network solution using that PHY. Two elements allow for a more dynamic approach: technology-agile radio chips and Time Synchronized Channel Hopping (TSCH).

changing the PHY layer, the object of our future research. Specifically, we augment the OpenWSN reference 6TiSCH implementation to support the following three PHYs: O-QPSK 2.4 GHz at 250 kbps, FSK 868 MHz option 1 at 50 kbps, OFDM 868 MHz option 1 Modulation and Coding Scheme (MCS) 3 at 800 kbps. The literature indicates that these three PHYs cover the range of possibilities of IEEE802.15.4g:

of shared slots for alarm events. They report end-to-end latency and Packet Delivery Ratio (PDR) under various schedule management strategies, including using uniformly distributed shared cells instead of contiguous (adjacent) shared cells in the slot-frame.