POSTER: Enhanced IoT Network Communications Using Multi-PHY 6TiSCH

Chloe Bae
Computer Science
Dalhousie University
Halifax, Canada
chloe.bae@dal.ca

Lareina Yang
Computer Science
Dalhousie University
Halifax, Canada
lareina.yang@dal.ca

Michael Baddeley
Secure Systems Research Center
Technology Innovation Institute
Abu Dhabi, UAE
michael@ssrc.tii.ae

Israat Haque
Computer Science
Dalhousie University
Halifax, Canada
israat@dal.ca

***Abstract*—Recently, single-radio, multi-protocol wireless chips are introduced to the market. These chips are equipped with multiple physical layer protocols and can switch between different physical layers (PHYs) on demand. Traditionally, IoT devices operate on a single physical layer protocol, IEEE 802.15.4, which have predetermined performance and limitations. Thus, the multi-protocol wireless chips can enable multi-PHY IoT wireless communications, especially in Low-Power and Lossy Networks (LLNs). A device can then switch between the PHYs to use the most suitable one to satisfy the application demand, e.g., offering a high throughput or a long-range. This study will evaluate the detailed performance and potential benefits of multi-PHYs on the 6TiSCH stack in Industrial IoT wireless network communications, so users choose appropriate protocols to meet their application demand.**

I. Introduction

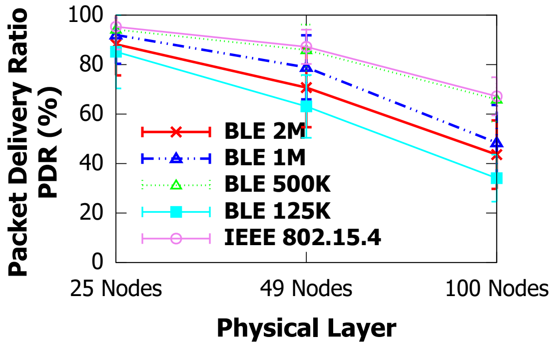
Internet of Things (IoT) has limited resources for energy and computing hardware and often communicates wirelessly via Low Power and Lossy Networks (LLNs). IoT wireless network has a proximity of Personal Area Networks (PANs) and employs RPL routing protocol (Routing Protocol for Low-Power and Lossy Networks). Traditionally, the physical layer of IoT devices is based on the IEEE 802.15.4 standard [1], where the data rate is low and the radio range is not long.

Due to the limited resources of IoT devices and the lack of standardized protocols, IoT wireless network suffers low reliability. To mitigate this problem, Internet Engineering Task Force (IETF) has proposed several enhancements or new protocols. One of them is Time Slotted Channel Hopping (TSCH). TSCH is a protocol stack designed to enhance the reliability of IoT wireless network communications, where the hardware buffer and timeline are divided into slots and the slots of nodes are time-synchronized and managed by a scheduler which oversees all tasks of the nodes in each slot. Because the scheduler organizes tasks efficiently over all different cells (buffers) at the participating nodes, and because the time-synched cells use non-overlapping wireless channels at each time point [2], TSCH can help reduce the number of collisions of packets and some network issues, such as a signal distortion affected by an unexpected interference in the neighbor which has a stronger signal. There has been many research that showed TSCH stack and 6TiSCH stack (a specification for IPv6 over TSCH) improved the performance of IoT communications [3].

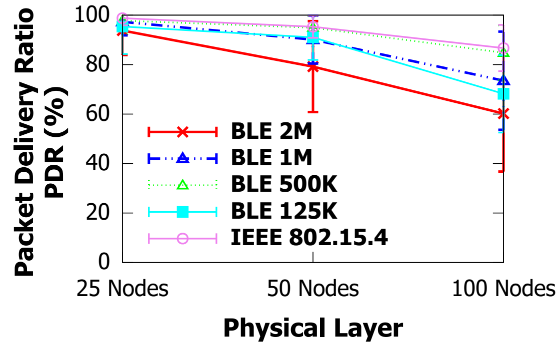
Traditionally, IoT devices mainly operated via IEEE 802.15.4 standard, where the performance of IoT network communication has been predetermined by the IEEE 802.15.4 specification. With the recent introduction of multi-PHY protocol wireless chips [4] [5], there has been increasing interest on harnessing the multi-PHY capability with IoT devices, which may provide solutions to the traditional issues of the wireless low power lossy IoT network (low reliability, low throughput, low range, and low energy efficiency - e.g., frequent collisions and packet loss, slow data rate, weakness to a stronger external interference, limited range, limited re-transmission opportunity). These chips are equipped with multiple physical layers of varying protocols with a programmable software, providing more flexibility to choose better performance for the desired goal.

Our contribution. Multi-PHYs and 6TiSCH can build a communication foundation in Industrial IoT. However, there is no detailed performance evaluations of these protocols together in their packet delivery ratio (PDR) and radio duty cycles and more. In this work, we present performance evaluation of multi-PHY in 6TiSCH stack over varying number of nodes in varying topology in industrial IoT network, so users can choose the most appropriate protocols to meet their application's demands.

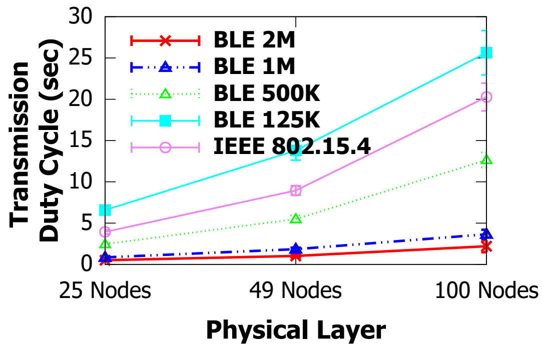
Related work. Though rare by far, there were several studies that suggested to incorporate both 6TiSCH and multi-PHYs in IoT devices network. The authors in [6] studied the use cases of multi-PHYs approach on concurrent transmissions flooding to enhance 6TiSCH standard. The work in [7] showed the performance of concurrent transmission based solutions with varying RF interference had high reliance on the type of the used physical layer. The research in [8] built multi-PHY g6TiSCH stack, which utilize all 3 PHYs at once per node and treat each PHY as a distinct entity. g6TiSCH has an ability to determine and switch to the best PHY for a given task, which proved its effectiveness improving performances. However, these papers only focused on the metrics that proved the efficacy of their end products. They lack comprehensive evaluations of performance of multi-PHY's in 6TiSCH stack with varying number of nodes in varying topology in the industrial IoT network.



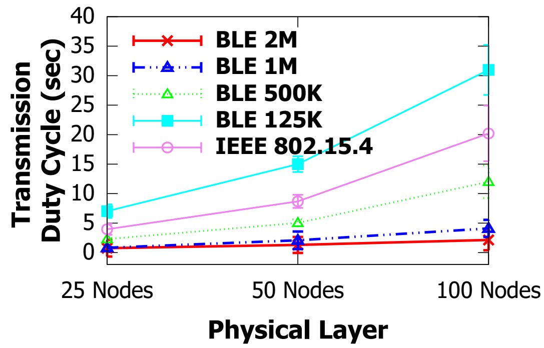
(a) PDR in a grid mesh.



(b) PDR in a random mesh.



(c) TDC in a grid mesh.



(d) TDC in a random mesh.

Fig. 1: Packet Deliver Ratio (PDR) and Transmission Duty Cycle (TDC) (in seconds) in Grid Mesh and Random Mesh.

II. Methodology

To simulate the TSCH based architecture, TSCH-SIM simulator [9] was used with modification along with the necessary configuration changes. Orchestra 6TiSCH scheduler was used to assign different roles (e.g., advertising, dedicated, shared cells) and different tasks (e.g., sleep, packet transmission, packet reception) to individual 6TiSCH cells at each time slot. A multi-PHY node network environment was simulated by setting the simulation parameters at a time accordingly to represent each of the physical layer conditions (see Table I; the data rate of IEEE 802.15.4 is 250 Kbps, while BLE 125K, 500K, 1M, and 2M has data rate 125Kbps, 500Kbps, 1Mbps, and 2Mbps respectively). At each simulation, IoT network was designed to have one of the increasing number of nodes (from 25, 50, and 100 nodes) implementing one of the 5 PHYs, where the nodes together form either Grid Topology (17 meters distance between the horizontally/vertically adjacent nodes) or Random Topology (randomly dispersed nodes in the same sized total area for the same number of nodes as in the Grid Topology such that each node has at least 5 valid UDGM links with its immediate adjacent nodes).

The indoor maximum radio ranges (home/office) of each PHY for simulation was determined following NIST PAP02-Task 6 model [10]. As shown in Table I, the indoor ranges of BLE 125K, 500K, 1M, and 2M were respectivey set to be 38, 35.5, 30.5, and 26.5 meters [10], where the corresponding range for IEEE 802.15.4 was 36 meters. TSCH slot duration was chosen for the time amount needed to transmit (or receive) exactly one data packet through the physical layer at each PHY. Unit Disk Graph Medium (UDGM) distance loss radio medium link model was used to simulate the realistic signal loss depending on the distance between nodes. With varying number of nodes implementing each of the 5 different physical layers at a time, 40% sender/receiver random pairs of nodes were chosen to generate/receive packets every 160 seconds. 100 repetitions of network simulations (each 5 minutes) were conducted for different topologies (Grid Mesh and Random Mesh), where the network performance - Packet Delivery Ratio (PDR) and Transmission Duty Cycles (Transmission Energy) were measured.

TABLE I: BLE Home Environment PHYs (0 dBm).

PHY Layer	Coded/Uncoded	Range	PHY Rate
IEEE 802.15.4	DSSS	36 meters	250 Kbps
BLE 125K	FEC (S=8)	38 meters	125 Kbps
BLE 500K	FEC (S=2)	35.5 meters	500 Kbps
BLE 1M	Uncoded	30.5 meters	1 Mbps
BLE 2M	Uncoded	26.5 meters	2 Mbps

III. Results

We have obtained the following results. First, in PDR (Figure 1a and 1b), we witnessed that the longer the maximum radio range of the PHY protocol, the higher the PDR. However, the number of collisions may hinder the efficacy of the increased number of effective UDGM links established by a longer radio range. For instance, the low performance of BLE 125K is due to the large number of collisions than others.

Next, the magnitude of transmission duty cycles (transmission energy) (Figure 1c and 1d) is determined by (a) the size of a single packet (which varies for the type of PHY), (b) the unit time to transmit a byte signal via TSCH slot (which varies for the type of PHY), (c) the number of transmitted data packets, and (d) the number of re-transmitted packets and other control packets. Among them, radio range of PHYs strongly affected the number of collisions and re-transmissions, which consequently had a large impact on the amount of transmission duty cycles.

IV. Conclusions

This study showed the detailed performance metrics that can be considered when using multi-PHY approach in 6TiSCH-based industrial IoT networks. Depending on a situation, a proper PHY should be chosen considering all aspects of performance metrics. Overall, BLE 500K appeared to be the best replacement for IEEE 802.15.4, providing great PDR and less energy consumption; however, depending on a specific use case, other PHY might become the best choice. The results of this study can be flexibly used as a reference for designing a high-performance multi-PHY 6TiSCH IoT network protocol for different purposes.

Our research thus far was based on one type of routing protocol (RPL) and scheduler (Orchestra). To further investigate the advantages or drawbacks of using each PHY environment (to see their effect on routing and network performance), the performance under other schedulers and other routing protocols will be examined.

References

[1] *IEEE Std 802.15.4-2020 (Rev. of IEEE Std 802.15.4-2015)*, IEEE 802.15.4 Working Group, 2020.

[2] P. Thubert, “An Architecture for IPv6 over the TSCH mode of IEEE 802.15.4,” IETF, Internet-Draft draft-ietf-6tisch-architecture-24, Jul. 2019.

[3] M. Baddeley, “Software Defined Networking for the Industrial Internet of Things,” Ph.D. dissertation, Dept. of Electrical and Electronic Engineering, Univ. Bristol, UK, 2020.

[4] Nordic Semiconductors, “nRF52840 Product Specification, v1.1.”

[5] Texas Instruments, “CC2652R SimpleLink Multiprotocol 2.4 GHz Wireless MCU datasheet, Rev. H,” Mar. 2021, [Online] https://www.ti.com/product/CC2652R – Last accessed: 2021-06-30.

[6] M. Baddeley, A. Aijaz, U. Raza, A. Stanoev, Y. Jin, M. Schuß, C. A. Boano, and G. Oikonomou, “6TiSCH++ with Bluetooth 5 and Concurrent Transmissions,” Feb. 2021.

[7] M. Baddeley, C. A. Boano, A. Escobar-Molero, Y. Liu, X. Ma, U. Raza, K. Römer, M. Schuß, and A. Stanoev, “The Impact of the Physical Layer on the Performance of Concurrent Transmissions,” in *2020 IEEE International Conference on Network Protocols (ICNP)*, Oct. 2020.

[8] M. Rady, Q. Lampin, D. Barthel, and T. Watteyne, “g6tisch: Generalized 6tisch for agile multi-phy wireless networking,” *IEEE Access*, 2021.

[9] A. Elsts, “Tsch-sim: Scaling up simulations of tsch and 6tisch networks,” *Sensors*, vol. 20, no. 19, p. 5663, 2020.

[10] B. T. Website, “Understanding Bluetooth Range,” 2021, [Online] https://www.bluetooth.com/learn-about-bluetooth/key-attributes/range – Last accessed: 2021-06-17.