Demo Abstract: Towards Interoperability in a Hybrid TSN/6TiSCH Network

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ABSTRACT

There is a growing interest in increasing the flexibility and the mobility of industrial infrastructures to support novel industrial applications. To support this change, industrial networks must provide real-time guarantees while integrating a great variety of traffic over a cohesive network infrastructure. Specifically, there is special interest in the integration of wired and wireless communications in the industrial domain. We present a solution that integrates a Time-Sensitive Networking Ethernet network with a low-power 6TiSCH IoT network and discuss the implementation alternatives and their implications on delay and resource consumption. The main goal is to experimentally identify the research challenges and necessary enhancements for interoperability between constrained battery-driven wireless communication with the time sensitive wired networks.

KEYWORDS

TSN, TSCH, Interoperability, IEEE 802.15.4

ACM Reference Format:

Iliar Rabet, Inés Álvarez, Hossein Fotouhi, and Mohammad Ashjaei. 2023. Demo Abstract: Towards Interoperability in a Hybrid TSN/6TiSCH Network. In *The 21st ACM Conference on Embedded Networked SensorSystems (SenSys '23), November 12–17, 2023, Istanbul,Turkiye.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3625687.3628415

1 INTRODUCTION

Novel industrial applications aim at increasing the flexibility of production systems. One way to increase flexibility is to introduce mobile devices in the infrastructure that allow the system to adapt according to the needs of the application. In this context of increased flexibility and mobility, industrial networks are expected to materialize deterministic behaviors over wired and wireless links alike. The efforts towards determinism and predictable networks, together with the need for interoperability of industrial networks, have led to the wide adoption of standards such as the ones developed by the Time-Sensitive Networking (TSN) Task Group [1] in the wired industrial networks, and the 6TiSCH framework [5] on the wireless side.

TSN aims at providing Ethernet with real-time flexibility, reliability, and (re)configuration capabilities [1]. This makes it an appealing technology to build the network backbone of novel industrial infrastructures. On the other hand, 6TiSCH is a stack of low-power wireless protocols that aims at providing connectivity with predictable and bounded delays. One such protocol is the IEEE 802.15.4-2015 standard Time-Slotted Channel Hopping (TSCH) mode. TSCH offers deterministic networking for low-power wireless networks using a time- and frequency-divided schedule for traffic transmission.

Despite many efforts in the literature to integrate TSN with 5G [3] or WiFi [2], the challenges of incorporating low-power radio with TSN remain unsolved. This technological gap poses a limitation to the use of battery-driven mobile devices in industrial networks. 6TiSCH is tailored for constrained mobile IoT nodes in industrial applications.

The requirements including guaranteed end-to-end latency, and coexistence of traffic flows with different criticalities must be considered across both domains. Unfortunately, the adoption of mobile nodes as one of the inherent advantages of wireless networks introduces new challenges. For instance, closing the TSN gates and buffering traffic on the TSN can help the buffers on the wireless side but incur more delay. For this reason, in this demo, we show an integration of TSN Ethernet and 6TiSCH, which we use to identify the research challenges and necessary enhancements to ensure the correct integration of deterministic wired and wireless networks.

2 DEMO DESCRIPTION

This section describes the network setup, as well as the main contributions of this work. Fig. 1 shows the topology of the employed setup, which includes:

- TSN switch: 1GB Multiport TSN switch implemented on a Zynq Ultrascale+ MPSoC. This switch implements (among others) the IEEE Std 802.1Qbv Time Aware Shaper for scheduled traffic.
- Gateway: This element translates the packets from the wireless network (received over a serial line) to TSN frames and vice versa. We implement the gateway on Raspberry Pi 4b.
- Access-Point: These static nodes are connected to RPIs using a USB cable and to other wireless nodes using an IEEE 802.15.4 radio. The access-points run Contiki-NG's RPL border router on top of Zolertia rev-b motes.
- Mobile node: The mobile node that can connect to any of the access points, depending on its position. Employing Texas Instrument's CC2650 SensorTag, the mobile nodes are programmed with Contiki-NG to run RPL/6LoWPAN/TSCH.

Protocol translation approach: Our protocol translator uses raw Linux/C sockets based on Raspberry Pi OS with no real-time support. We must note that TSCH nodes are only synchronized

SenSys '23, November 12–17, 2023, Istanbul, Turkiye

ACM ISBN 979-8-4007-0414-7/23/11.
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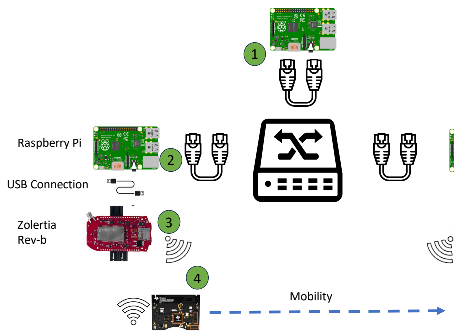

Figure 1: In this network setup, packets transmitted by the end station (1) are relayed by the TSN switch (2) and gateway (3) to reach the mobile node (4)

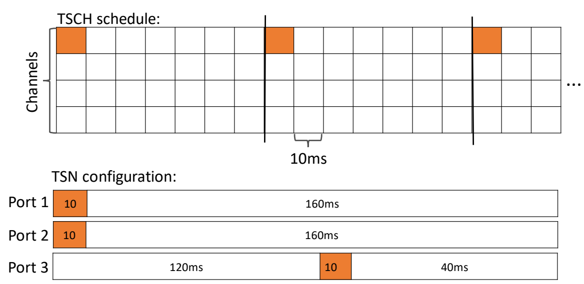

Figure 2: In the TSCH schedule (top), all the nodes use the colored cell for transmitting data/control packets. For the TSN schedule (bottom), the ports 1 and 2 (connected to the gateways) are open during the period [0-10]ms and port 3 (connected to end station) opens 120ms later for 10ms.

within their own domain and not with the TSN network. This is mainly because synchronization in the TSCH nodes is usually in the range of microseconds, rendering the complexities of nano-second synchronization with Precision Time Protocol (PTP) unnecessary. The clock drift in the wireless network may increase in multi-hop networks. Among possible models of integrating TSN with different wireless networks(full synchronization/partial synchronization/no synchronization) [4], this light integration model with two time-synchronized domains is a better match for TSCH. Another important aspect in the translation is the fragmentation of large TSN frames to fit TSN frames with large MTU in the small TSCH frames.

Holistic scheduling approach: Intrinsically, TSCH has plenty of similarities with TSN as its operation is based on a shared schedule among the nodes. The 6TiSCH network is running the Minimal Scheduling Function (MSF) with a 7-cell slotframe. We configured the TSN switch to run a schedule with a longer period (10ms open during a 170ms window) for opening and closing the ports as illustrated in Fig. 2. The schedules are configured in this way **so that the TSN switch buffers the traffic that TSCH cannot relay** thus the constrained devices are not subject to buffer overflow.

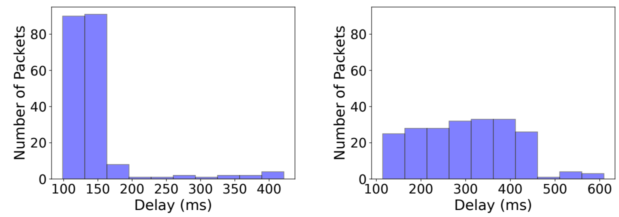

Figure 3: Histogram of delay measured at Gateway (left) which includes only the wireless and End Station (right) for overall delay

3 PRELIMINARY RESULTS AND CONCLUSIONS

We measured the end-to-end delay at the gateway (including only the wireless network delay) and at the End Station to analyze the overall delay. Fig. 3 shows the histogram of the measured values. Specifically, for this demo, the end station initiates the process by transmitting a frame with priority 4 (to be higher than ICMP) to the TSN switch, which will queue it and forward it to the gateway when dictated by the schedule. The gateway reads the information of the frames received from the TSN switch, and it encapsulates such information within a TSCH frame sent toward the mobile node.

We observe that the delays are higher at the wireless side. This was expected due to duty cycling. The clock drift leads to the jitter but the delays are bounded to the periods defined by the two schedules. Needless to say, the measured delays can be improved by reserving a larger bandwidth and different scheduling classes of TSCH (centralized, distributed or autonomous) have implications on the holistic scheduling. The delay on the wired network can be reduced if all the ports are open (assuming no interfering traffic exists). However, on the wireless side, the minimum achievable delay is generally larger and (along with the schedule) depends on the channel quality and the computation load of the operating system when performing the packet translation and transmission over the serial link. Purposeless opening of the gates on the TSN switch precludes the TSCH network from the buffering on the switch and burdens the constrained IoT nodes with extra load. Overall, the results show the necessity for further research on scheduling a hybrid network. Moreover, more accurate synchronization in the wireless mesh is required for a tighter integration.

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