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Flexible Wired/Wi-Fi TSN Networking through SDN and Soft Traffic Control

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***Abstract*—Industrial-grade applications demand reliable, deterministic performance. Time-Sensitive Networking (TSN) caters to this by enabling precise traffic control, primarily in wired setups. Recent Wi-Fi technologies are moving forward to support TSN features. Seamless multi-domain Wired/Wi-Fi communication requires solutions for synchronization, interoperability, scheduling, and monitoring. Current Software-Defined Networking (SDN) controllers for TSN fall short of this support. In this demo, we showcase our modular SDN TSN Controller architecture and its components for traffic scheduling and fine-grained network telemetry. The controller allows us to control a TSN network comprising Wired and Wi-Fi nodes, with real-time per-flow monitoring and schedule reconfiguration.**

***Index Terms*—TSN, Network Programmability, SDN**

I. Introduction

Modern industrial processes demand robust communication for monitoring and control [1]. To meet such critical requirements, the IEEE Time-Sensitive Networking (TSN) Work Group is enhancing Ethernet network standards [2]. TSN standards offer various features like precise time synchronization, scheduled frame transmission, and advanced methods for network management [3]. To support a broader set of use cases and increase flexibility, extending TSN features to Wi-Fi has been evaluated [4].

TSN standards enable a single Ethernet network for both IT and OT traffic, reducing infrastructure costs. However, properly configuring the network for the strict requirements of time-sensitive traffic, including Wired and Wi-Fi, is challenging and requires new sets of Application Programming Interfaces (APIs) from the Software Defined Networking (SDN) controllers. Supporting seamless operation and interoperability between wired and wireless domains is crucial for leveraging the capabilities of TSN standards [5].

In this work, we demonstrate a modular SDN TSN controller for networks comprising Ethernet and Wi-Fi devices. We implement components for traffic scheduling on Commercial-Off-The-Shelf (COTS) Wi-Fi devices following the IEEE 802.1Qbv standard [6], supporting a homogeneous scheduling scheme between the wired and Wi-Fi domains. We show the use of In-band Network Telemetry (INT) for fine-grained per-flow, and per-hop monitoring, providing the basis for taking reconfiguration and scheduling decisions. The demonstration is carried out over a setup comprising Ethernet and Wi-Fi segments, as described in Section III, running multiple flows, and with schedules and management actions being taken via the controller Graphical User Interface (GUI).

II. TSN Controller Architecture

For this demonstration, we use the TSN Controller Architecture from our previous work [7], which operates in a Controller/Agent model. Figure 1 shows the internal components of the TSN Controller (TSNC) and the TSN Agent (TSNA), focusing on the TSNA version for a Wi-Fi Access Point (AP), and the communication flow between TSNC/TSNA. The TSNC loads the network configuration file and opens a socket, listening for agents to connect. The TSNAs start by scanning node resources, associating with the AP (in the case of Wi-Fi clients), and announcing themselves to the TSNC. The TSNC replies with configuration instructions for the node, including Precision Time Protocol (PTP), scheduling, INT, IP addresses, and interface bridging.

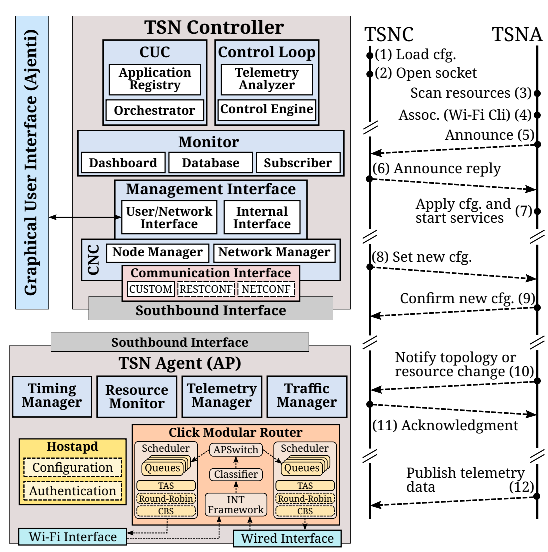

Figure 1: TSN Controller components

For the AP we use *hostapd* (*https://w1.fi/*) for configuration and station authentication. Traffic shaping and INT are implemented using the Click modular router [8]. Click gives the flexibility to dynamically change traffic shaping mechanisms and their configuration, handle more packet queues, and add useful features such as INT. This way we can customize the network for specific needs, at the cost of slightly higher packet processing times. This trade-off between flexibility and raw performance must be taken into account during network planning and vary according to use cases.

The TSNC has an API for node configuration (e.g., set IPs, schedules, telemetry). These actions can also be taken through a GUI that interacts with the Management Interface of the TSNC. The GUI is implemented using *Ajenti* framework (*https://ajenti.org/*) and is the interface used in the execution of this demo. On top of network management, the TSNC and TSNA offer APIs for executing traffic generators (e.g., Iperf (*https://iperf.fr/*), MGEN (*https://github.com/USNavalResearchLaboratory/mgen*)) for network troubleshooting. The generators can be configured and executed via a plugin in the GUI. Telemetry reports are sent by the nodes to the Monitor element of the TSNC, stored in the database, and can be visualized on a Dashboard implemented using Grafana.

III. Demonstration Scenario

Figure 2 illustrates the scenario for this demonstration, composed of one wired client (PC), one switch (SW1), one Wi-Fi AP, one Wi-Fi client (STA), and the TSNC. All nodes are synchronized via PTP and run the TSNA. As the Wi-Fi client does not have hardware support for PTP, we use the wired interface of the node for PTP synchronization. This allows us to precisely analyze the schedule compliance and measure packet delays between the PC and the Wi-Fi client.

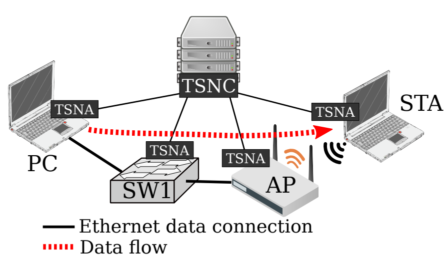

Figure 2: Demonstration setup

The setup starts with the execution of the TSNC (specifically the CNC component), the GUI, and the Monitor services. Then, the TSNA is executed on each node. The TSNAs associate with the TSNC and receive their configuration instructions. Details about the network can be visualized with the TSNC Manager GUI such as the status of TSNC services, TSNAs associated, node resources, status of important services (PTP, INT, hostapd). Under steady operation, the nodes report the PTP synchronization accuracy to the TSNC. This allows schedules to be properly configured using the Time-Aware Shaper (TAS). The TAS schedules follow the format from the IEEE 802.1Qbv standard [6].

We generate flows from the PC to the STA using two applications. A UDP App generates packets from wired client to Wi-Fi client on one slice. Packets are timestamped and one-way delays are calculated and reported so we can analyze the effect of scheduling on end-to-end latency. Iperf is used to flood the network and saturate the links. During the execution of the demonstration, we apply different schedules to the nodes. The TSNC processes, validates and propagates the schedules to the nodes. The allocation of time slots and their duration influence the performance of each flow. The applications report metrics to the Monitor element, and the user can visualize the metrics through the Grafana Dashboard.

IV. Conclusion

This demo showcases the proof-of-concept of our TSN Controller for mixed Wired/Wi-Fi TSN networks. We demonstrate the use of software-based elements for flexible deployments, explore the capabilities of TSN standards for deterministic communication, and monitor network flows using INT.

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