Beacon-Based Wireless TSN Association

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***Abstract*—Time-sensitive networking (TSN) is utilized in industrial environments to support reliable low-latency communications. Bringing TSN features to wireless networks is getting traction recently by achieving time synchronization and traffic scheduling over wireless links. Besides these basic features, impact-less and network transparent association of prospective clients is paramount for wireless TSN. This demo presents an impactless TSN association procedure, where beacons are used to provide time synchronization and scheduling to prospective clients, where association procedure is done in reserved time slots. The presented demo is designed, implemented, and tested on top of a wireless Software Defined Radio platform using the IEEE802.11 standard. By utilizing a dashboard, this demo will demonstrate real-time control over association as well as high accuracy synchronization on client frame transmissions even with challenging scheduling configuration of 128 μS timeslots.**

***Index Terms*—wireless time-sensitive networking, association, time synchronization, scheduling, impactless, IEEE802.11.**

I. Introduction

In many industrial use cases deterministic, low-latency and highly reliable communication is of utmost importance. While wired Ethernet-based TSN networks are used widely in factory environments, they lack offered flexibility by wireless networks considering mobile and portable use cases. As such, introducing TSN features to wireless networks and achieving wired-wireless TSN integration is getting traction at research community.

Time synchronization and traffic scheduling are two basic TSN features to support deterministic communication. For time synchronization Precise Time Protocol (PTP) is widely used in both wired [1] and wireless [2] network segments. Traffic scheduling is achieved based on a time-aware shaper [3] utilizing a gating system that manages medium access of queues. Communication time is divided on time cycles, where each queue will have its portion of time (timeslot). So for each queue a schedule is determined consisting on cycle length, the start and the end of timeslot relative to start of the cycle. Similarly, such gating mechanism is implemented for wireless nodes as well in openwifi SDR platform [4].

Beside time synchronization and traffic scheduling, in wireless TSN other specific features should be considered as well. Due to shared nature of the wireless medium, the client association procedure should be transparent to the network and should not impact traffic from any other operational node. Assuming that the medium is found busy, a connected W-TSN node will be forced to delay its transmission to avoid a collision, increasing the latency and thus, harming the time-sensitive flow. As such, network need to provide means of time synchronization and scheduling even for the prospective clients during the association phase.

II. Design and Implementation

In this work, the pre-synchronization and pre-scheduling for association purposes are achieved utilizing beacons. As beacons are broadcasted in the network they can be used by prospective clients to receive the necessary information. The Time synchronization function (TSF) is a timer that is initialized by the AP for synchronization purposes. Each beacon will include the AP TSF at the time of transmission. Such information is used to synchronize the client TSF to AP TSF, by compensating for the transmission time delay and processing. Besides these delay compensations, due to the nature of CSMA/CA, at AP beacons transmissions might be delayed, affecting pre-synchronization accuracy. To avoid this, at prospect clients, before setting the TSF, beacons are filtered by checking their arrival time and comparing it with the AP beacon rate, which is one of the fields of the beacon itself.

Additionally, beacons will be enhanced with scheduling information that is encapsulated as vendor-specific *Information Element* in beacons as it is shown in Figure 1. Scheduling information of reserved time slot for association purposes include the cycle length, and timeslot start and stop time relative to cycle start. As such, each prospective client can determine the time when it can start transmitting its association packets, without interfering with any other already operational clients. Once pre-synchronized and pre-scheduled, the prospect client finally transmits the authentication and association requests frames to complete the association.

Once associated, the clients will be held by the network to an operation stage where an improved time synchronization mechanism will be used and based on the needs of the new client, a new schedule will be assigned.

In summary, by using beacons, the TSN manager will dynamically adjust the association timeslot of the APs depending on the network requirements. For instance, in a network boot-up scenario, the association timeslot should be long enough to support the high number of associations. Whereas, in an operational mode, the association timeslot should still provide access to new clients, but the priority will be focused on time-sensitive traffic.

III. Demo Setup

For this Demo, the openwifi IEEE802.11/Wi-Fi baseband chip/FPGA design was used, implemented in the Software De-

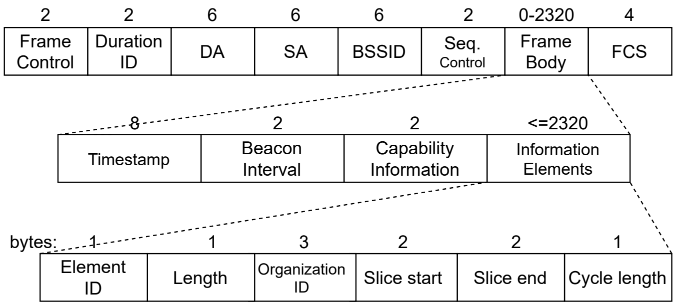

Figure 1. Beacon stuffing using the vendor specific element

fined Radio (SDR) ADRV9361-Z7035 that combines the Analog Devices AD9361 integrated RF Agile Transceiver™ with the Xilinx Z7035 Zynq®-7000. The carrier card ADRV1CRR-BOB/FMC is used for Ethernet interface addition [4]. The demo setup consist of three nodes wireless nodes one access point (AP) and two clients that will be associating with the AP. All the nodes are connected to a PC that acts as a MQTT broker (for real-time measurement collection) and a dashboard to display the results as it can be seen in Figure 2.

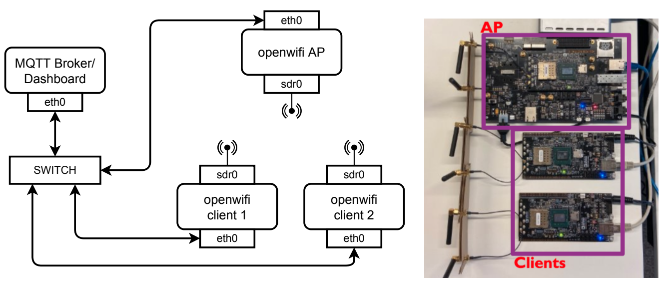

Figure 2. Demo Hardware Architecture

IV. Measuring Procedure and Results

To monitor the schedule changes and the packet arrivals in real-time, a MQTT broker is used and data are visualized in real-time in a dashboard. In addition to association packets we use also ping requests packets to have a continuous flow of packets in order to validate the time synchronization and schedule alignment.

Both already pre-synchronized and pre-scheduled clients transmit ping request packets to the AP. Then, AP acts as an MQTT client and sends every arrival TSF of ping packets to the MQTT broker. Further, such arrival TSFs are converted to time arrival offset inside the schedule cycle, T_{Of}, following Equation 1.

$$T_{Of} = mod(T_{Ar}, C_L) \tag{1}$$

where, T_{Ar} is the arrival TSF at the AP, C_L is the AP schedule cycle length and $mod()$ is the modulo operation. Finally, T_{Of} is plotted as shown in Figure 3.

Hence, for Figure 3 the AP is changing the association pre-schedule, delimited by red lines, which in turn makes the

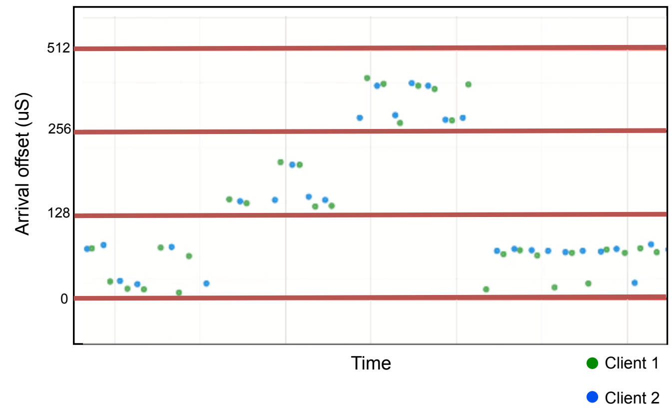

Figure 3. Dashboard - Ping Request arrivals

clients to move their transmissions to the reserved association timeslot. As it is seen in Figure 3 the arrival offset of packets at the AP is well-aligned inside the assigned association timeslot. As such, any other traffic being transmitted by other already operational devices in other timeslots will not be impacted by the traffic during association phase.

V. Conclusion

In this work, we demonstrate a novel association design feasible for next-generation wireless TSN networks. This method allows the network to dynamically assign an association timeslot to prospect clients and ensure a good enough synchronization which avoids transmissions collision, improving the general determinism of the network. This novel association design was developed and tested in real-world conditions on openwifi SDR platform. The performed demo reveals that all packets are received inside the required timeslot, even when the timeslot location is changed by the AP.

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