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Study on TSN and EDCA effect on QoS in wired and wireless home networks

Ennouhe Taleb[1]* and Ito Yoshihiro[2]

Nagoya Institute of Technology, Nagoya, Japan.

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ABSTRACT

This paper proposes to adapt IEEE 802.1 Time Sensitive Networking (TSN) standards and EDCA to wired and wireless home networks as a combined QoS control for smart house networks. The authors conducted several experiments under different scenarios with IEEE 802.1TSN standards such as Credit Based Shaper (CBS), and Strict Priority Queuing (SPQ), and EDCA. The results showed TSN's ability to guarantee a much better QoS control by keeping the latency below 0.2 milliseconds across all traffic except one, with baseline latencies where no QoS control was applied, reaching as far as four milliseconds. This difference was considered statistically significant upon performing a t-test between the registered latencies values (With QoS and Without QoS) and finding a p-value of 0.042 (<0.05). The case of the outlier traffic was examined as well. Furthermore, these results were held with the new setup with SPQ, keeping low latency results. However, when combined with EDCA, there was a decline in the performance even though EDCA showed better results for the wireless network registering the lowest latency overall (below 0.1 milliseconds). Thus, concluding TSN and EDCA efficacy for home networks and the conditions under which that can be maintained. Future work will focus on minimizing the impact of SPQ on the wireless network with the application of EDCA. This paper is the first article to offer a complete study on SPQ, CBS, and EDCA as QoS control methods, potentially solving a growing problem in modern smart homes and addressing the dual challenge of QoS in wired and wireless home networks.

Keywords: QoS, TSN, SPQ, CBS, EDCA, home networking.

*Corresponding author. E-mail: cmm14064@ict.nitech.ac.jp.

INTRODUCTION

House automation has been a focus in academia and industrial areas for the last few years due to the widespread of IoT (Internet of Things) devices. As a result, companies are increasingly introducing IoT devices into the market, and smart appliances are connected more and more over what has come to be known as home networks. The COVID-19 pandemic has further established this new reality.

This situation can cause congestion and lead to the degradation of the Quality of Service (QoS) provided by the smart devices within the house. Therefore, a high-speed network for home networking is necessary to guarantee the high QoS provided inside this grid.

Adopting Ethernet ("IEEE 802.3 WG", n.d.) as a high-speed home network is reasonable since Ethernet and its related technologies are already widespread. This is also a decision that will eliminate the concerns of interoperability. However, even if Ethernet is used in home networks, congestion cannot be avoided entirely for a few reasons. The most obvious one is that Ethernet is a best-effort network that cannot guarantee any QoS. Considering the possibility of traffic exceeding Ethernet capacity, we must implement some QoS control at a particular time to reduce the potential congestion.

Here, it should be noted that the importance of traffic depends on the home appliance generating it. This means that there are various types of traffic with different levels of importance. Thus, when important traffic is reduced, the losses or delays of such traffic can degrade the QoS of the home network and, subsequently the Quality of Experience (QoE) of the residents. Therefore, it is necessary to find an appropriate QoS control for suppressing congestion without causing any packet losses or delays in important traffic.

On the other hand, with the different models that exist in home networks and how they differ from the other networks regarding particularities and QoS requirements, it is a distinct type of network with its own QoS challenges, such as limited bandwidth and shared media. Although many technologies have been suggested before to treat these challenges in general and were adopted for home networks, none of these approaches fit the specific needs of home networks. Existing QoS approaches like Prioritized QoS are not optimal as they can accommodate only up to 3 priority levels and Parameterized QoS divides the already limited bandwidth.

To solve the above problem, we propose adapting the IEEE 802.1 Time-Sensitive Networking (TSN) standard ("TSN Task Group", n.d.) to an Ethernet-based home network. IEEE 802.1TSN is a set of standards that treat real-time communication with low latency over IEEE 802 networks; it is being adopted in factory automation (Bello and Steiner, 2019) and automotive networks (Sabry et al., 2020), and so on. Therefore, we consider that it can be applied to home networking. Our study focuses first on evaluating our proposal in an environment with IEEE 802.1TSN standards. The two TSN standards to be treated here are Strict Priority Queuing (SPQ) and Credit-Based Shaper (CBS), which are defined in the IEEE 802.1Q standard ("802.1Q", n.d.). Secondly, since additional devices that monitor security, such as cameras and smoke detectors, are needed in home networks, there is a need for a more inclusive home network that consists of two parts: a wired network and a wireless one. Moreover, it is important to ensure that this wireless traffic is prioritized for the most part for the following reasons. In an emergency, it is also necessary to ensure a QoS for these safety-critical data as well. Thus, Enhanced Distributed Channel Access (EDCA) (Gao et al., 2014) was adopted as QoS control over the IEEE 802.11 wireless part of our home networks. EDCA is an extension of the Distributed Coordination Function (DCF) and is defined in IEEE 802.11e ("IEEE 802.11e", n.d.). TSN and EDCA are further discussed in section 2-1. CBS is often used to limit bandwidth to frames, while SPQ works for the purpose of traffic prioritizing. For more information about TSN standards refer to the work of Hirano and Ito (2020).

As the first step of this study, the authors evaluated their proposal in an environment with IEEE 802.1TSN standards. Based on the findings, they considered a new environment with wireless and wired networks and different types of traffic. They also apply EDCA to control QoS in the new network's wireless LAN. Consequently, two experiments were performed. For convenience's sake, the authors refer to them as Experiment A and Experiment B. The former showcases the TSN effect on home network QoS. The latter discusses what the combination with EDCA means.

To the best of our knowledge, this study is the first of its kind, as it studies, demonstrates, and discusses the findings of the combined TSN and EDCA approach as QoS control for home networks. We are potentially laying the groundwork for smart cities to operate smoothly while maintaining deterministic communication.

EXPERIMENT A

Purpose

Related studies, such as bandwidth allocation, traffic scheduling, and prioritizing, have been conducted to properly control QoS issues over Ethernet-based home networks (Rahman and Hossen, 2018; Liu et al., 2006). However, no prior research has studied QoS control in home networks by TSN. In addition, the existing studies with TSN do not offer the best solution considering home network particularities. Thus, applying TSN to home networks is necessary for the assumed potential of its effectiveness.

On the other hand, TSN is usually used within industrial (Bello and Steiner, 2019) and automotive networks (Sabry et al., 2020). However, a home network differs from the Internet in scale and topology, and it differs from the automotive or industrial network in the prioritization and criticality of traffic types, as it usually does not require as strict QoS as in-vehicle networks. In Experiment A, we consider the adaptation of TSN to home networks and examine its effect on smart home QoS.

With the previous attempts at parameterized and prioritized QoS control methods, TSN has the upper hand regarding home networking characteristics. In a paper that studied applying TSN between layers (Hassani and Cuijpers, 2020) the authors indicate that the control data traffic requiring the highest amount of priority in certain networks is usually treated with CBS and ATS. SPQ is the most basic control method in TSN, and CBS is bound to provide a lower latency. All of the above help with the decision to stick with these QoS controls in this study.

Concerning the TSN standards considered in this study, CBS often limits bandwidth to frames, while SPQ prioritizes traffic. CBS provides an algorithm that can limit the bandwidth for each frame by setting the priorities in the TSN switch ports. It has a controllable parameter called IdleSlope, and its value can affect QoS (Hirano and Ito, 2020). We opt to use CBS because it is bound to assure lower latency. SPQ is used to prioritize frames, so the ones with the highest priority in the queue will always be sent first. We combined it with CBS so that the least prioritized traffic would not get starved.

Configuration

In Experiment A, two different experiments were covered. The first one was conducted without any QoS control. In the second one, both CBS and SPQ are adopted to control QoS.

Figure 1 displays our experimental network. This architecture follows a zonal model suggested by Klaus-Wagenbrenner (2019) for Ethernet-based networks. This paper showed zonal network architecture as a good fit for Ethernet-based networks. This topology was chosen because of the architectural similarities between automotive networks and LAN home networks. The network consists of 6 switches and 28 senders, representing the different smart appliances around the house, such as printers, phones, PCs, sensors, and cameras, which generate various types of traffic, such as media traffic, like video streaming, or audio, or other types such as event traffic, sensory traffic, and control traffic. In our experiment, two types of traffic are generated: Control and media traffic labelled TCP and UDP, respectively, and are given different priority levels, as shown in Table 1. All seven devices are connected to one switch and constitute one VLAN. The VLANs are named VLANs A and B. Here, the seven appliances in VLAN A are named Host1.A through Host7.A, and the ones in VLAN B are referred to as Host1.B through Host7.B. The three switches are connected to the fourth switch, which connects seven receivers.

Table 1. Traffic types.

Traffic	TCP	UDP	UDP	TCP	UDP	UDP	UDP
Priority levels	1	2	3	4	5	6	7
QoS	SPQ	SPQ	SPQ	CBS	CBS	SPQ	SPQ

The receivers are Sinks, referred to as Sink1 through Sink7. They receive data from each room (VLAN). Each Sink receives the same kind of traffic from the correspondent appliances: Traffic1 through Traffic7. The traffic received by Sink1 and Sink7 is TCP. The other five remaining traffics are UDP. This simulation is done with the software OMNET++ (“Omnet++”, n.d.). SPQ is applied to the third, fifth, and fourth traffic within the initialization file within the INET framework (“INET”, n.d.). An OMNET project can have multiple files, such as a NED file (Network Description File) to establish the architecture and an initialization file to configure the QoS. Similarly, CBS is applied to the remaining four traffics. To analyze only essential factors, the authors opted for a simulation. The seven traffics are accorded seven different priority levels according to their weight and criticality. The traffic types and their priority levels are shown in Table 1. Every host in each VLAN transmits data to the correspondent receiver. Accordingly, every Sink receives the same type of traffic from two different senders (smart appliances). The entire network is connected via 100-Mbps Ethernet.

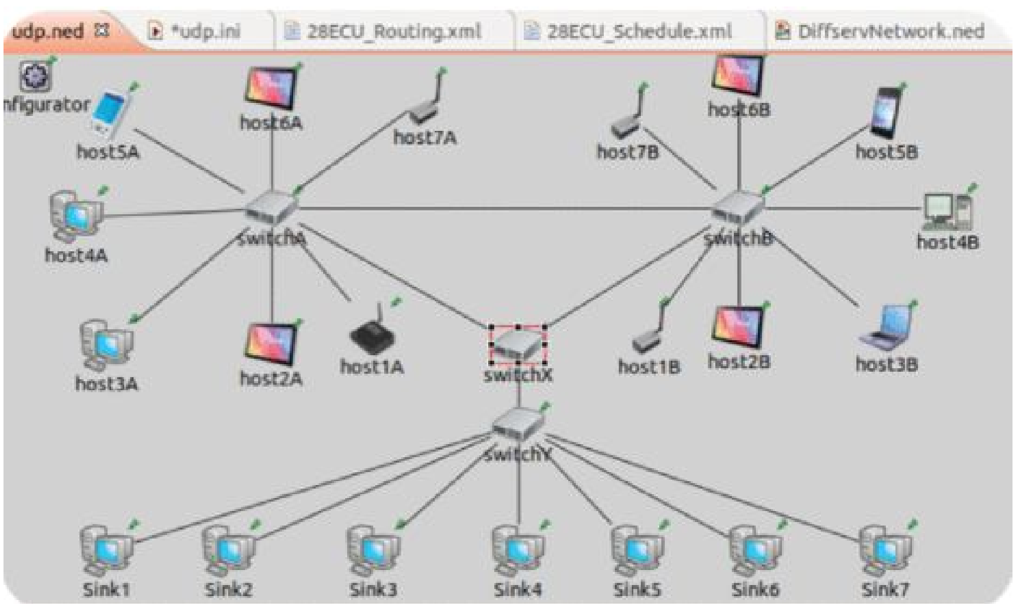


Figure 1. Experimental network.

In the experiments, Latency and packet loss were considered the OoS parameters. Here, the latency is the time data takes to get through the switches to the PCs. We measure both the mean and the maximum latency. The packet loss rate is the percentage of the packets lost from the packets sent.

Results

Figures 2 and 3 depict the experimental results. In Figures 2 and 3, the abscissa stands for traffic arriving at each PC from the two different VLANs. The ordinate in Figure 2 is the mean latency of each traffic with and without QoS control. The ordinate of Figure 3, on the other hand, is the maximum latency with and without QoS control.

Figures 2 and 3 indicate no large difference between the two outcomes. However, two main points can be noted: It can be confirmed that TSN standards helped improve the overall QoS of the network when implemented, as all the QoS-controlled traffic has lower latency except for one (Traffic 2).

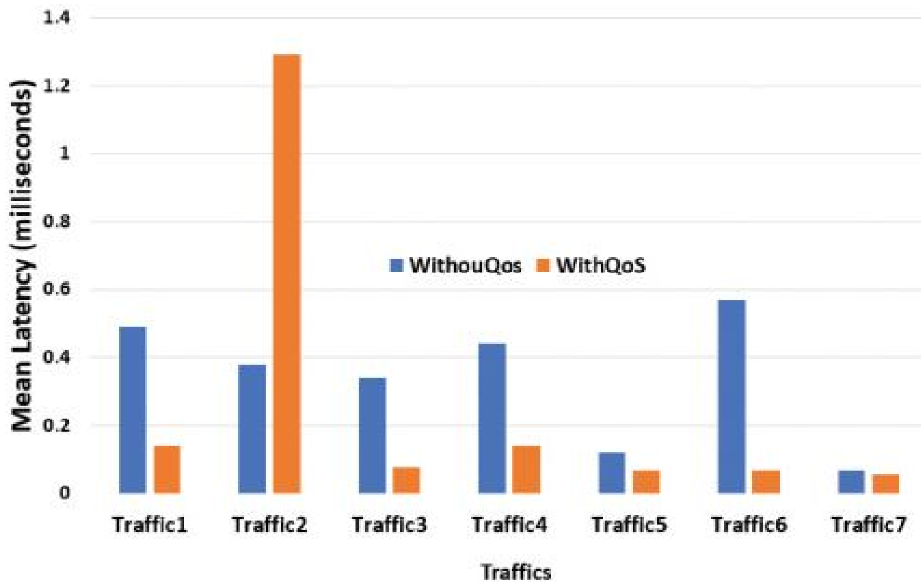


Figure 2. Mean latency.

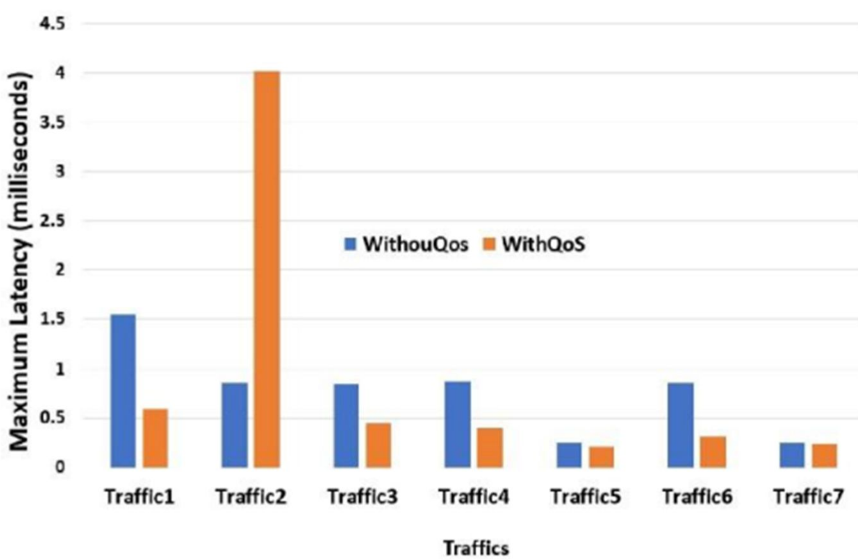


Figure 3. Maximum latency.

However, one UDP sink, Sink2, showed precisely the opposite impact, where the latency increased when TSN was applied.

A lower latency has been registered among almost all hosts except for the second traffic, which represents media traffic. In our experiment, this streaming traffic was labelled as non-critical. TSN could not assure better QoS for low-prioritized media traffic. This suggests that Media traffic should be moderately prioritized in home networks.

To evaluate whether the positive impact of TSN on the home network is significant, the authors performed a t-test (Bevans, 2023) between the registered latencies with and without QoS in the hosts that showed a lower latency with QoS control. As a result of the t-test, the p-value of the latencies becomes 0.042. This indicates that the results are statistically significant. For a t-test, a p-value lower than 0.05 is considered statistically significant (Bevans, 2023). Therefore, we proved that applying TSN as QoS control is not just effective, but the control method is also essential.

As we have confirmed that TSN is effective for wired networks, in Experiment B, we work with different wired topologies while integrating wireless networks and testing the media traffic with different QoS control management.

EXPERIMENT B

Purpose

Experiment B used a different wired topology to test TSN in a different configuration and integrate a wireless connection to ensure a more diverse and inclusive architecture. Since TSN was primarily designed for wired Ethernet networks, we added EDCA for an end-to-end QoS control.

The authors used the traffic type division mentioned in Attia et al. (2019) to compare different traffic types and three different environments. The purpose of the comparison is to study the effect of EDCA on three different types of environments. In each, new traffic was added that follows the work of Attia et al. (2019) as a source for traffic types that can have different impacts on QoS performance in home networks. Their work explains the details and use of streaming traffic, event-triggered sensorial traffic, and periodic sensorial traffic.

Furthermore, a new topology was established to test the effect of EDCA over a wireless network always with OMNET++ simulations. Three scenarios for experimental simulation ensure the network's complexity. The network topology of each scenario is shown in Figures 4 to 6.

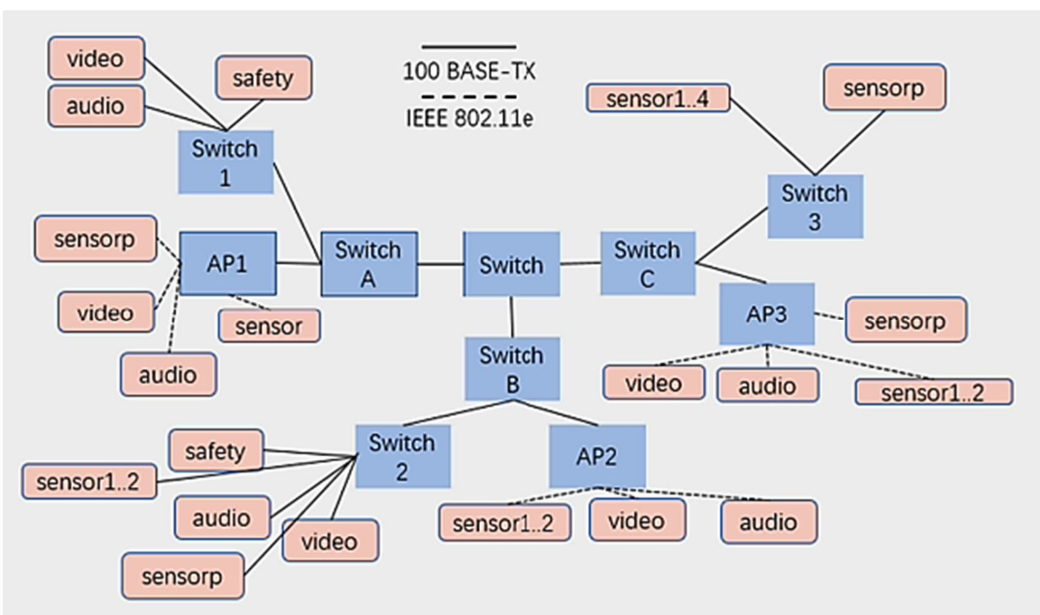


Figure 4. Environment 1.

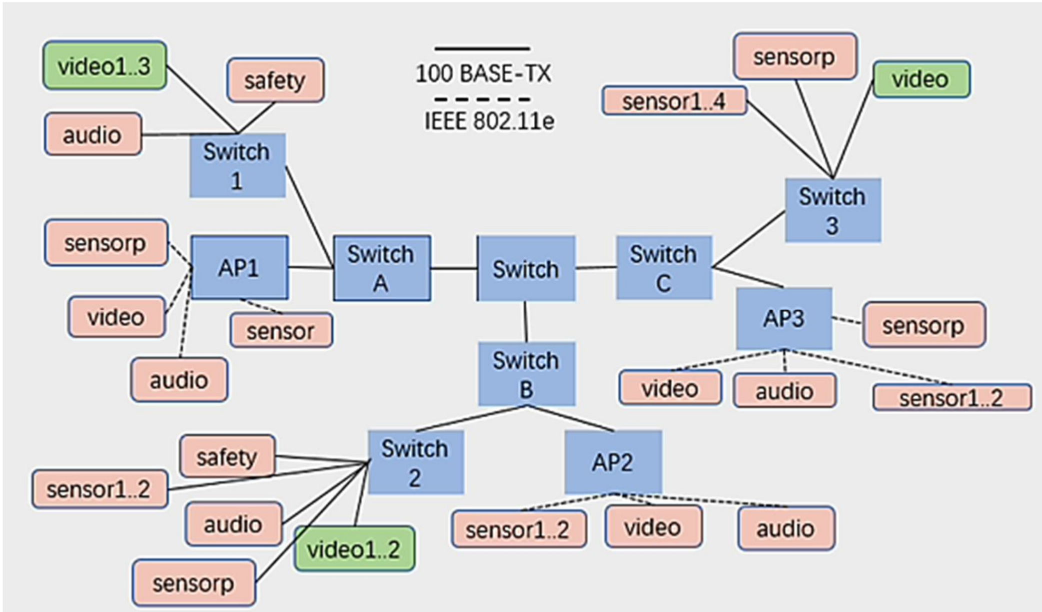


Figure 5. Environment 2.

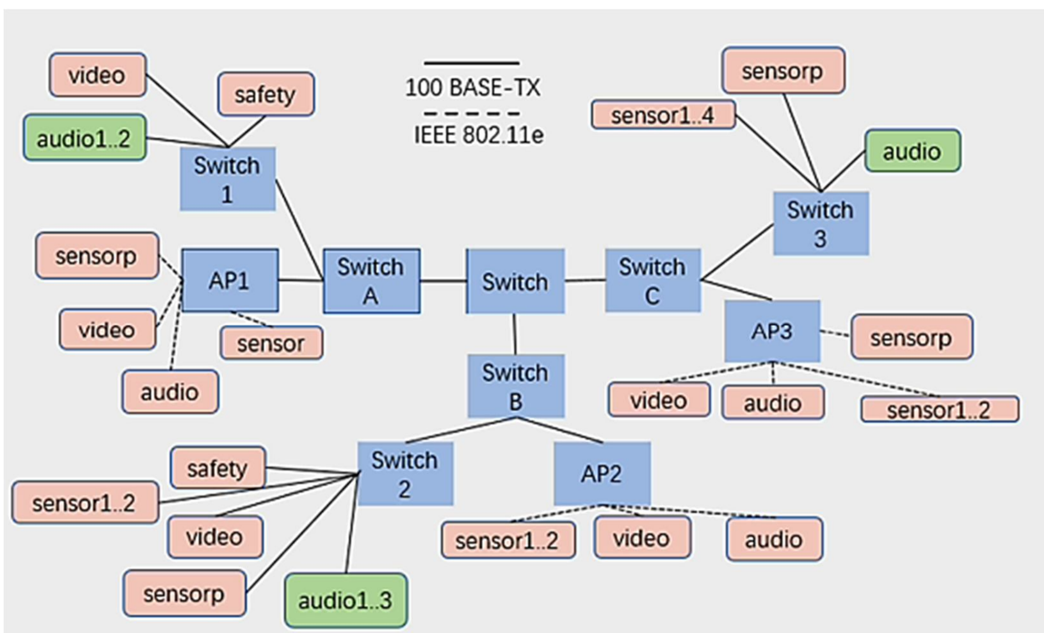


Figure 6. Environment 3.

EDCA is an extension of the Distributed Coordination Function (DCF) as defined in IEEE 802.11e. There are four Access Categories (AC) in EDCA, and each of them has a different priority by using Transmission Opportunities (TXOP), Contention Windows (CW), and Arbitration Inter Frame Spacing Number (AIFSN). The priority levels, from lowest to highest, are accorded to background, best effort, video, and voice. The purpose of prioritization is achieved by assigning a different value of the above contention parameters (TXOP, CW, AIFSN) to each access class (Sheikh et al., 2016).

The number of devices in each scenario in wired and wireless networks is shown in Tables 2 to 4. They are named after the traffic they generate and will be referred to as such. In environment 1, for example, we have two safety traffic, 5 video traffic, five audio traffic, five sensorial traffic, and two periodic sensorial traffic. The number of devices belonging to each grid (wired or wireless) is shown in Tables 2, 3, and 4. The QoS parameters in this experiment are the latency and the jitter. The latency was previously defined, and the jitter is the fluctuation in the latency. In this experiment, the priority assigned to traffic is as follows: Safety: 7, Audio: 6, Video: 5, Sensor: 4, and Periodic Sensor: 3. The periodic sensor traffic will be referred to in the figures by sensorp. The packet sizes are 500, 100, 600, 200, and 300, respectively. The speed is 100 Mbits.

Table 2. Number of Apps under Env1.

Environment 1			
Wired LAN		**Wireless LAN**	
Safety	2	Video	3
Video	2	Audio	3
Audio	2	Sensor	3
Senser	2	Sensorp	2
Sensorp	2		

Table 3. Number of Apps under Env2.

Environment 1			
Wired LAN		**Wireless LAN**	
Safety	2	Video	3
Video	3	Audio	3
Audio	2	Sensor	3
Senser	2	Sensorp	2
Sensorp	2		

Table 4. Number of Apps under Env3.

Environment 1			
Wired LAN		**Wireless LAN**	
Safety	2	Video	3
Video	2	Audio	3
Audio	3	Sensor	3
Senser	2	Sensorp	2
Sensorp	2		

Related works

Previous works (Aqil and Jarrah, 2022; Rekik and Bourenane, 2020) have discussed the effect of EDCA on QoS. It has been used to enhance the quality of service in various networks, primarily in industrial (Maadani and Motamedi, 2012), but also in UMTS (Burbur et al., 2022) and automotive networks (Sharafkandi et al., 2012).

As mentioned, TSN has been studied alongside QoS control for various networks, including industrial and factory automation networks (Bello and Steiner, 2019) and in-vehicle networks (Sabry et al., 2020). Previous case studies (“802.1Q”, n.d.; Hassani and Cuijpers, 2020; Hirano and Ito, 2020) explored the effects of SPQ, CBS, and TAS on traffic. In particular, Lee and Park (2019) studied the impact of TSN on autonomous driving in automotive networks. Additionally, recent works have evaluated TSN in wireless networks (Satka et al., 2023; Wei and Yang, 2023; Nsiah et al., 2020).

However, no paper studies TSN and EDCA simultaneously on home networks. This paper is the first to study the effect of this control method formula on improving network QoS. This combination is set to ensure end-to-end QoS control and minimize traffic loss, with TSN offering deterministic low-latency communication while EDCA handles Contention and interference.

Configuration

This experiment treats three environments: Environment 1, Environment 2, and Environment 3, depicted in Figure 4, Figure 5, and Figure 6, respectively. Environment 1 has six switches, 21 devices, and three access points. The devices are named after the traffic type they generate, as seen in Figure 4. In Environment 2, one device with video traffic is added, and two other video traffic are modified, as shown in Figure 5. In environment 3, the video traffic is replaced with audio traffic that differs from the existing traffic.

Under these environments, the following four cases are considered: First, no QoS control is applied. Second, only EDCA is applied. Third, only SPQ is applied. Fourth, both SPQ and EDCA are applied.

Results

From the results, we can group the traffic into two different groups: low-priority traffic (priority levels 3 and 4) and high-priority traffic (priority levels 5, 6 and 7). We have four other cases: No QoS was applied, Only SPQ was applied, Only EDCA was applied, and Both SPQ and EDCA were applied. In low-priority traffic, the latency is lower with the EDCA application. However, with high-priority traffic, the introduction of SPQ and EDCA shows a lower latency value (under 0.2 ms for most parts).

This shows us that the application of SPQ can effectively reduce the latency of high-priority traffic. Similarly, the jitter of safety and audio traffic can be reduced after applying SPQ. The jitter of video traffic increases slightly due to the excessive size of packets and the relatively low priority.

Nevertheless, the simultaneous application of SPQ and EDCA leads to increased latency. While TSN proved effective for wired networks and EDCA positively impacted wireless networks, a correlation was observed between the simultaneous use of SPQ and EDCA and the increase in latency in wireless environments. On the other hand, implementing EDCA significantly reduces latency and jitter over wireless networks, particularly for high-priority video and audio traffic. We have also noticed that the “Only SPQ” category in wired networks can show similar results to “both SPQ and EDCA.” This might be because the traffic is similar in priority and behaviour, and therefore, the performance differences may be negligible, resulting in identical results for both QoS mechanisms.

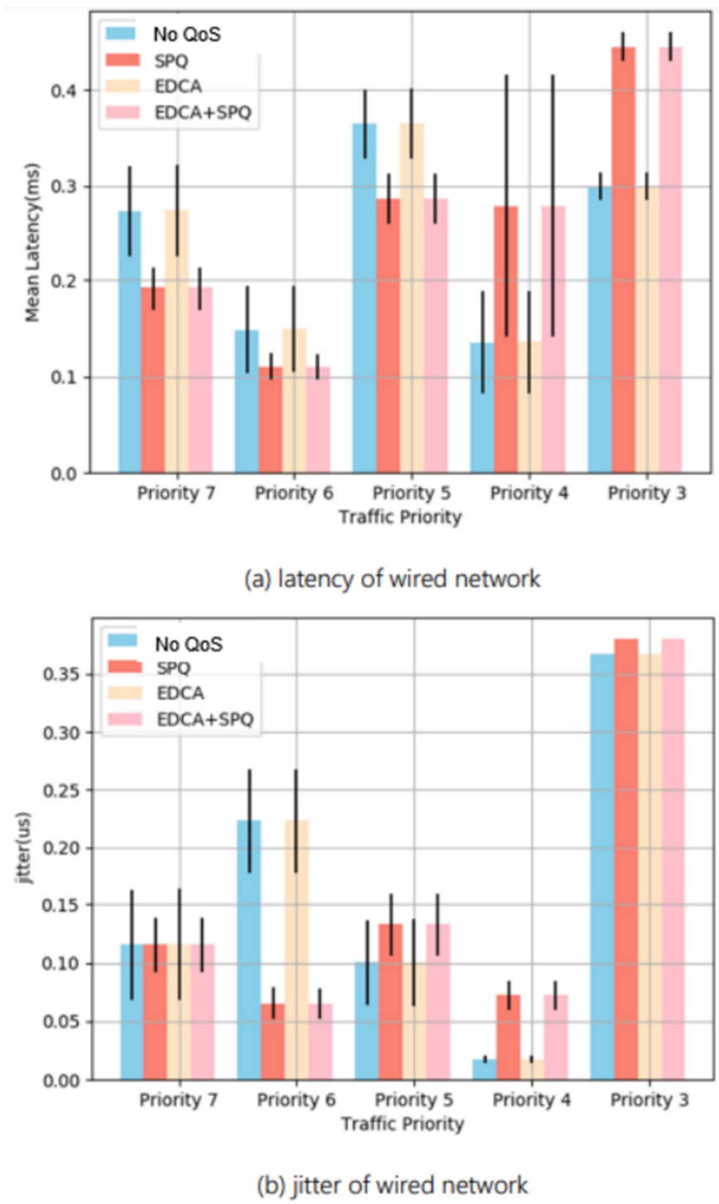
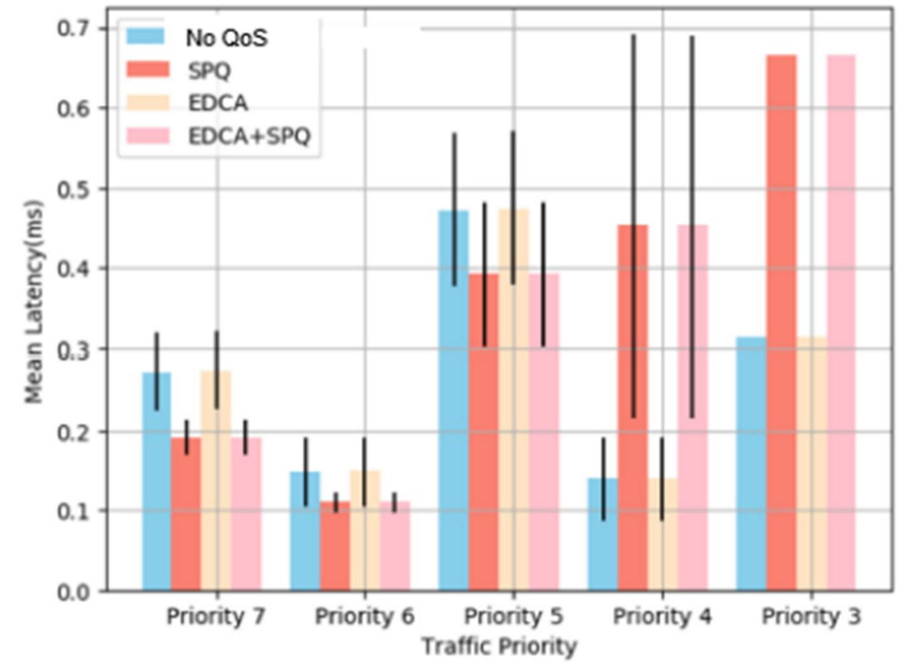


Figure 7. Environement1 (Wired).



(a) latency of wired network

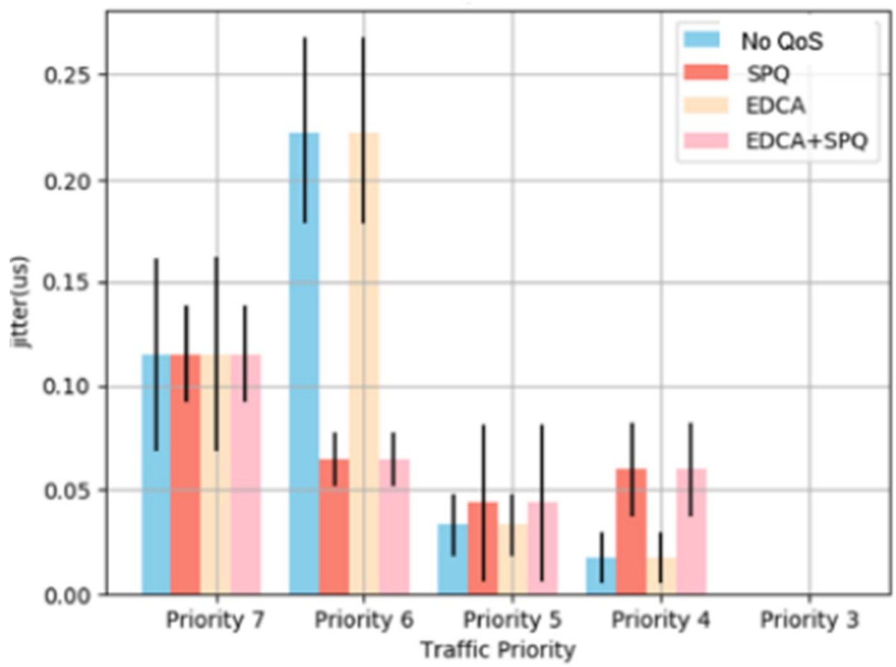
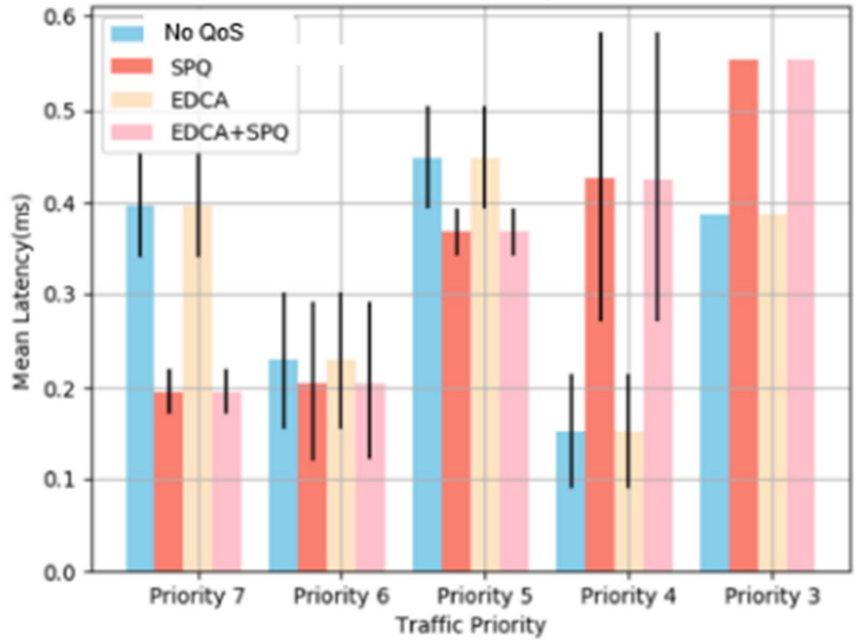


Figure 8. Environement2 (Wired).



(a) latency of wired network

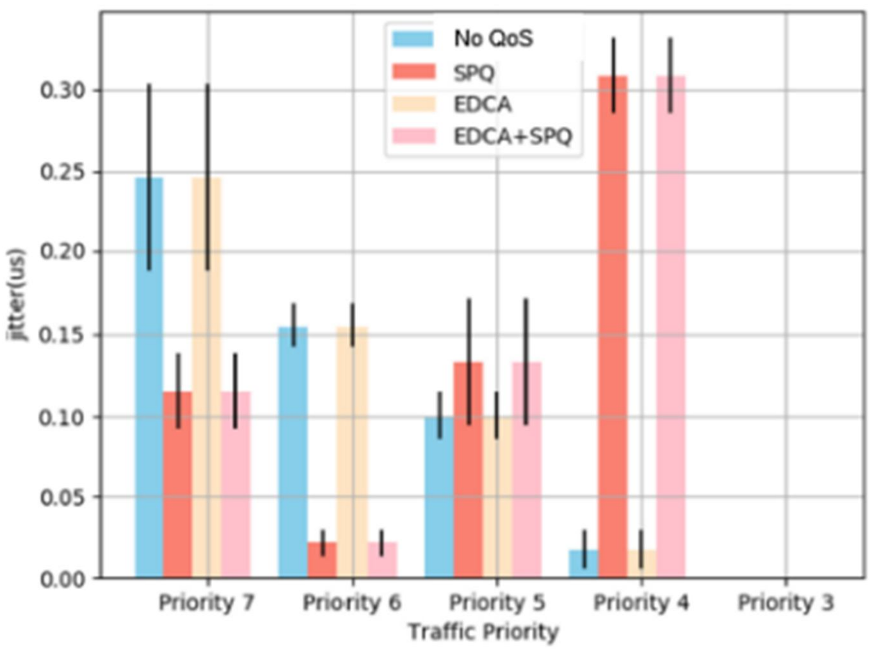


Figure 9. Environement3 (Wired).

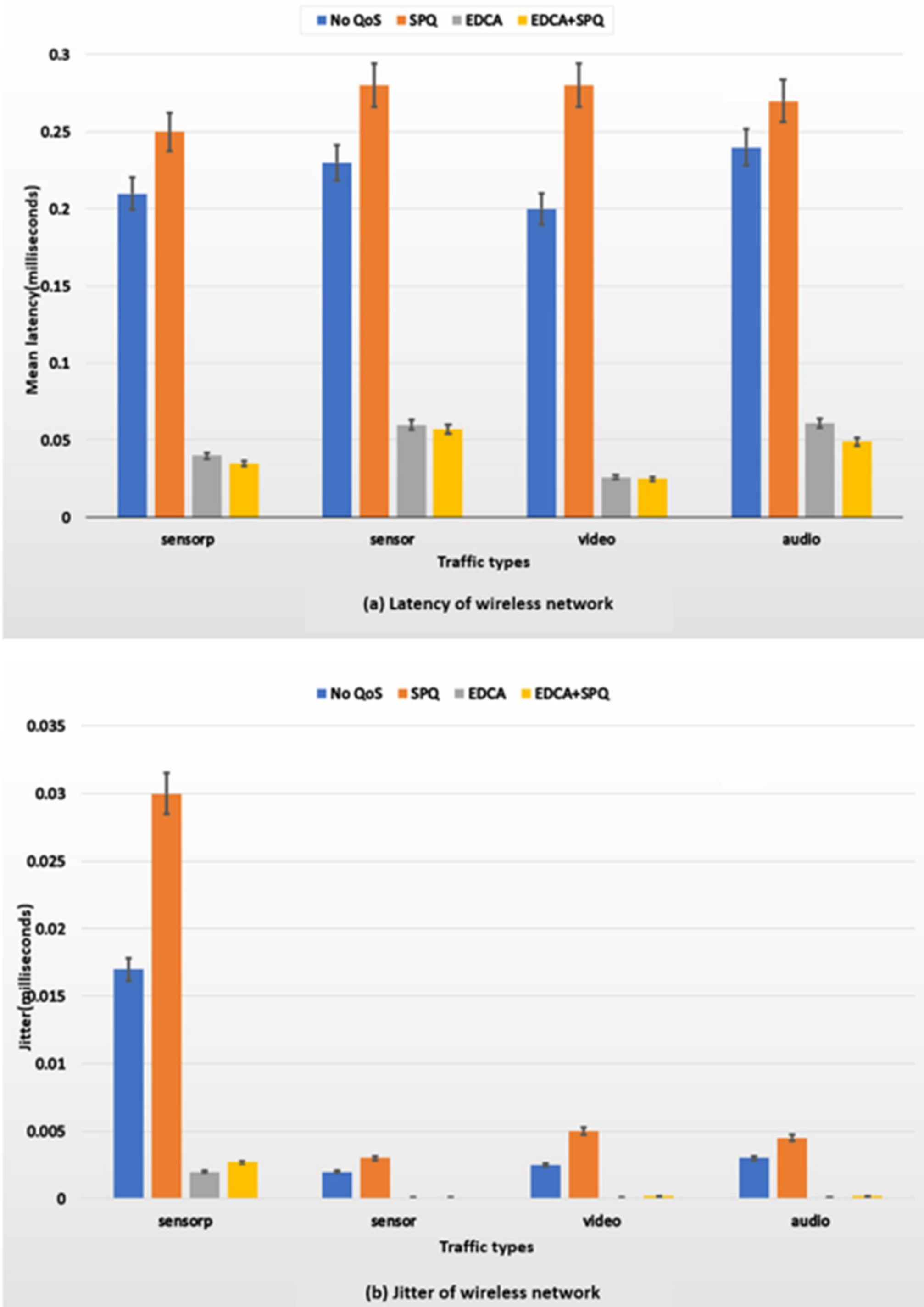


Figure 10. Environement1 (Wireless).

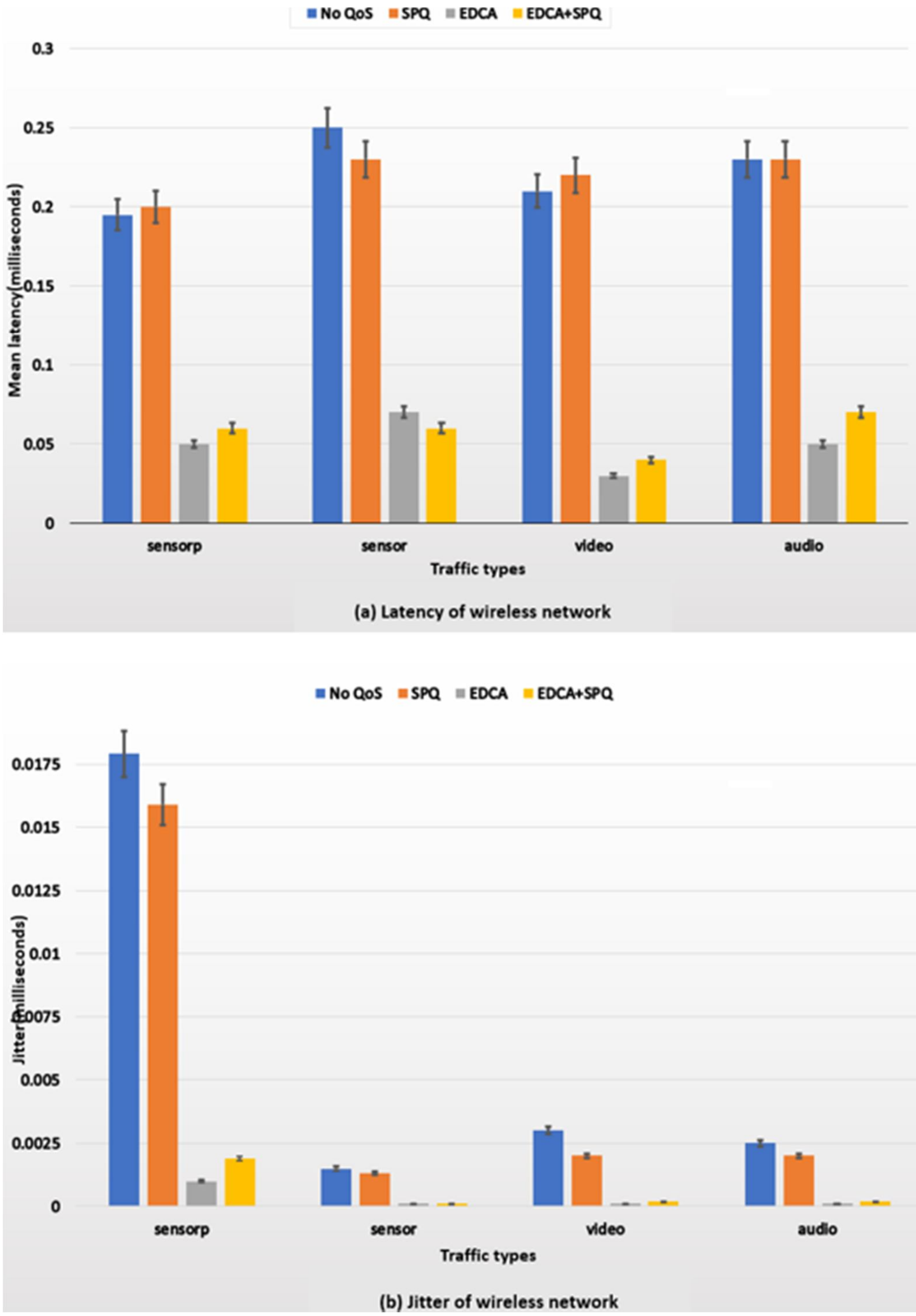


Figure 11. Environement2 (Wireless).

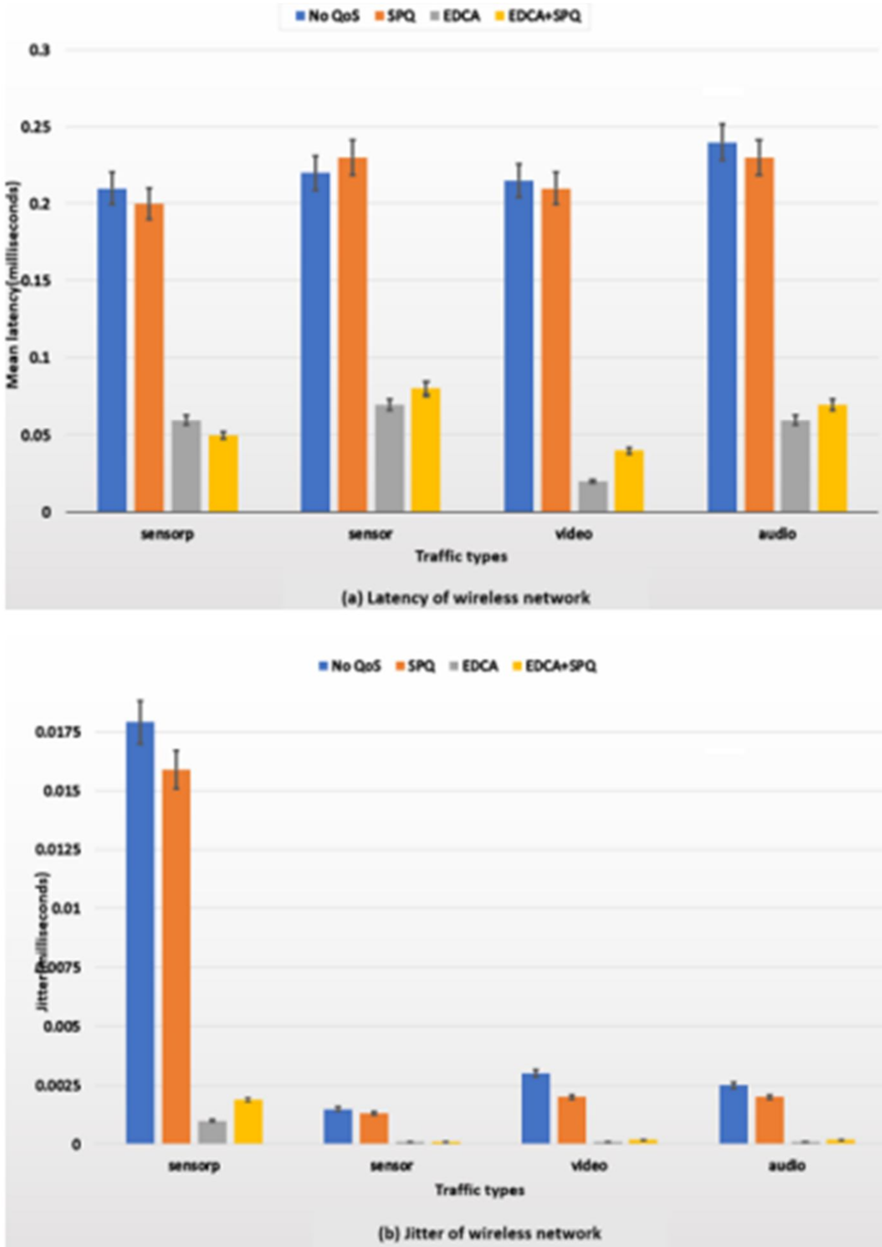


Figure 12. Environement3 (Wireless).

CONCLUSIONS

This paper studied the improvement of the QoS of home networks by TSN and EDCA. The authors first showed TSN effectiveness for QoS improvement in home networks.

The authors then explored different home network architectures to test the TSN effect further and add a wireless model. They then used EDCA to control the Quality of Service over the wireless LAN. They tested its effect while applying it with and without TSN. This new approach confirmed TSN effectiveness and how that effect can be maintained under more severe conditions. On the other hand, it confirmed that while EDCA proved effective for wireless home networks, the simultaneous use of both control methods can lead to negative results.

Future work will focus on minimizing the impact of SPQ on the wireless network with the application of EDCA. One way to do so is to examine the method (Sheikh et al., 2016) proposed for changing the TXOP (Transmission Opportunity) parameters in EDCA to improve transmission efficiency. The authors plan to rely on the author's methodology to examine whether modifying the TXOP values can determine the appropriate balance needed in our future experiments.

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