Evaluation of Effect of Congestion on Time Synchronization Accuracy in IEEE 802.1AS

Yohei Ozawa
Nagoya Institute of Technology
Nagoya, Japan
ozawa@en.nitech.ac.jp

Yoshihiro Ito
Nagoya Institute of Technology
Nagoya, Japan
yoshi@nitech.ac.jp

***Abstract*—This paper studies the effect of congestion of an in-vehicle network on the time synchronization accuracy of IEEE 802.1AS, a time synchronization protocol. It considers using QoS control of IEEE 802.1TSN (Time-Sensitive Networking) to improve the time synchronization accuracy. Since in IEEE 802.1AS, its time synchronization messages are transmitted over Ethernet, the QoS of the transmission will be affected by the network congestion. By experiment, the authors evaluate the time synchronization accuracy over an experimental network that consists of a pair of switches where the line between them is congested while varying the degree of congestion. In addition, the paper assesses the time synchronization accuracy while prioritizing the time synchronization messages over other frames by SPQ of IEEE 802.1TSN. The experimental results show the following. First, the time synchronization accuracy can be degraded over a congested in-vehicle network. Second, the accuracy degradation worsens as the other traffic's frame length is longer. In other words, when the priority of messages for time synchronization is lower than other traffic, the long frame length of other traffic will degrade the time synchronization accuracy even if the degree of congestion is small.**

***Index Terms*—In-vehicle network, time synchronization, IEEE 802.1TSN, IEEE 802.1AS, IEEE 802.1Q**

I. INTRODUCTION

Realizing fully autonomous driving requires processing a large amount of data obtained from many sensors in a vehicle, which is why high-speed Ethernet is being adopted as the in-vehicle network. Moreover, this allows the integration of existing multiple in-vehicle networks separated by purpose into an Ethernet network. However, this results in competition between safety-related data and other data over the Ethernet. Therefore, the adoption of IEEE 802.1TSN (Time-Sensitive Networking), a standard for transmitting time-sensitive data over Ethernet, is also being considered.

On the other hand, in fully autonomous driving, collaborative processing among multiple devices, such as in-vehicle cameras, sensors, and ECUs, is envisioned to recognize pedestrians and others. For this collaborative processing, time synchronization among devices is essential. Consequently, the adoption of IEEE 802.1AS, a standard within IEEE 802.1TSN for time synchronization, into the in-vehicle network is also being considered. IEEE 802.1AS enables time synchronization between devices with internal clocks by exchanging timing information within the network.

What needs to be emphasized at this juncture is that the traffic for the time synchronization is transmitted along with other traffic over the same Ethernet as well in IEEE 802.1AS. Especially in the context of in-vehicle networks, which have limited resources, congestion can occur because of the failure of devices or links. The congestion within the in-vehicle network causes significant variations in delay for the traffic for time synchronization; it can result in the desynchronization among in-vehicle devices. Therefore, it is inevitable to study the impact of network congestion on time synchronization accuracy to design safe in-vehicle networks.

This paper evaluates the effect of network congestion on time synchronization in an in-vehicle network that supports IEEE 802.1AS time synchronization protocol over Ethernet by experimentation. The rest of this paper is as follows. First, Sect. II shows the experiments. Sections III present their results. Finally, we conclude this paper in Sect. IV.

II. EXPERIMENTS

To evaluate the impact of network congestion on the time synchronization accuracy, we perform two different environments, Experiment A and Experiment B, over the same experimental network. This network consists of two ECUs (ECU1 and ECU2), two ECUs that generate traffic for load (Load1 and Load2), two switches (SW1 and SW2), and one Grand Master, which is responsible for providing the network-wide clock. All devices, except the load ECUs, are compatible with IEEE 802.1AS. ECU1 receives the traffic sent from both Load1 and Load2. The lines connecting the ECUs and switches are 100BASE-T1, one of the Ethernet standards for in-vehicle networks. The drift rates for the devices' clocks are 0ppm for the Grand Master and 100ppm for the other devices. Here, we treat the absolute value of the time transition difference between the Grand Master ' s and slave's clock as a Quality of Service (QoS) parameter. Experiments A and B are conducted through simulation with OMNeT++-6.0.1 [3] simulator and the INET 4.4.1 [4] framework.

In Experiment A, the time synchronization accuracy is measured in an environment where the degree of network congestion varies. The traffic used in Experiment A is determined based on use cases discussed in IEEE P802.1DG and consists of fixed-length and fixed-interval traffic. We prepare fifteen types of traffic by varying the frame length and then configure the transmission period to achieve bandwidth utilization between SW2 and ECU1 of 50% to 100%.

In addition to the environment of Experiment A, Experiment B is conducted with SPQ applied to the switches. The traffic priorities are set such that the traffic for load has higher priority than the traffic for time synchronization. The traffic used in Experiment B is the same as in Experiment A.

III. Results

A. Experiment A

The results of Experiment A are presented in Figs. 1 through 4. In these figures, the abscissa means the transmission rate of traffic for load, and the ordinate indicates the mean difference in time between the Grand Master and each device. Figure 1 plots the difference in time between the Grand Master and ECU1, while Fig 2 displays that between the Grand Master and SW1. Figure 3 shows the difference in time between the Grand Master and ECU2, and Fig 4 indicates that between the Grand Master and SW2.

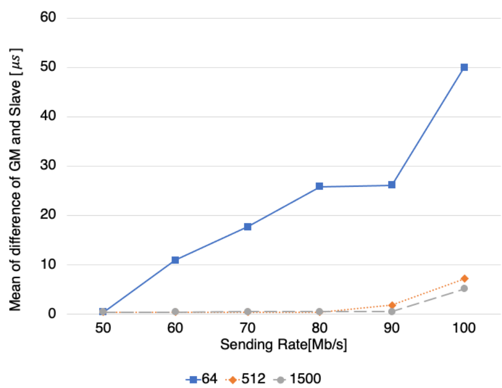

Fig. 1. Difference in time between GM and ECU1

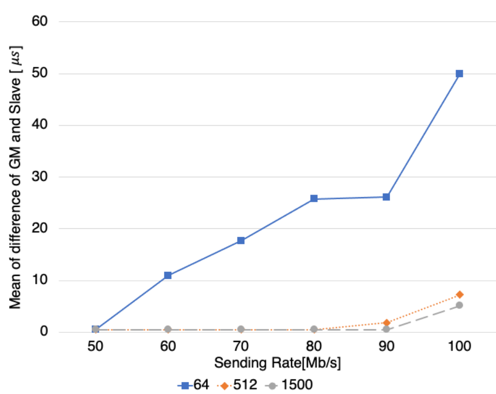

Fig. 2. Difference in time between GM and SW1

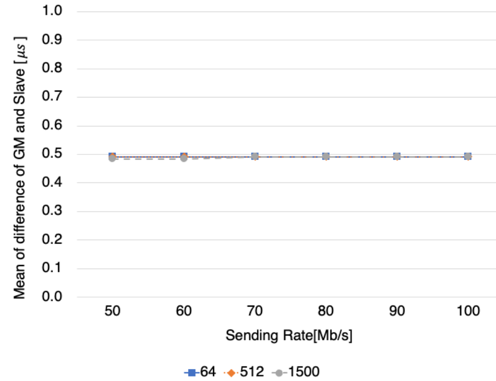

Fig. 3. Difference in time between GM and ECU2

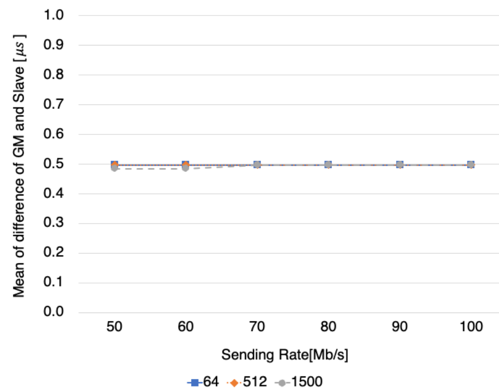

Fig. 4. Difference in time between GM and SW2

From Figs 1 and 2, it is evident that as the transmission rate of traffic for load increases, the difference in time between the Grand Master and two devices (ECU1 and SW1) connected via the congested line significantly increases. On the other hand, Figs 3 and 4 indicate that the difference in time remains relatively unchanged for the two devices (ECU2 and SW2), which are not connected via congested lines. This reason is the following. As the transmission rate of traffic for load increases, the sum of the bandwidth of the input traffic exceeds the line speed of the egress port of the switch. As a result, the number of frames that accumulate in the switch increases, leading to a rise in the time taken for the Pdelay Follow_Up messages, sent from the Master, to reach the Slaves.

To sum up the abovementioned results, the congestion over an in-vehicle network significantly impacts the time synchronization accuracy, especially for the devices that experience congestion, as their difference in time with the Grand Master increases. However, The non-congested devices are unaffected as their time differences remain relatively stable.

This is attributed to the frame length of the gPTP messages. With smaller frame lengths in the traffic for load, there is less waiting time when the frames enter the switch. Conversely, with longer frame lengths, the switch must take longer to read the frames, resulting in increased waiting time for the gPTP messages. As a result, when the frame length is 64 bytes, the switch can output frames at a rate of up to 5.12 microseconds, and the incoming gPTP messages also wait for this amount of time. However, when the frame is 1500 bytes, the switch takes 120 microseconds to output frames, leading to an extended waiting time for the gPTP messages.

To summarize the results of Experiment A, the frame length of the traffic for load significantly affects the waiting time for gPTP messages, which in turn influences the variation in time difference between the Grand Master and ECU1 and SW1. Smaller frame lengths result in shorter waiting times, whereas more considerable frame lengths cause longer waiting times for gPTP messages, leading to increased variation in time difference.

B. Experiment B

The results of Experiment B are depicted in Figs. 5 to 7. In these figures, the abscissa represents the transmission rate o traffic for load, and the ordinate indicates the mean difference in time between the Grand Master and each device; the dashed lines represent the requirement for time synchronization that should be met for in-vehicle networks. Figure 5 plots the result when the traffic for load sent from Load1 and Load2 has a frame length of 64 bytes. Figures 6 and 7 illustrate when the frame length of the traffic for load is 512 bytes, and that is 1500 bytes, respectively. From Figs. 5 to 7, we see

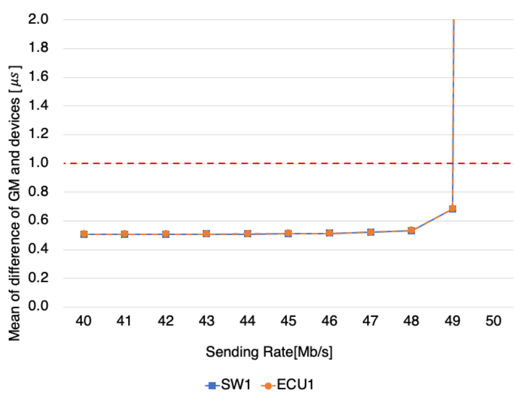

Fig. 5. Difference in time between GM and devices (Flame length is 64 bytes)

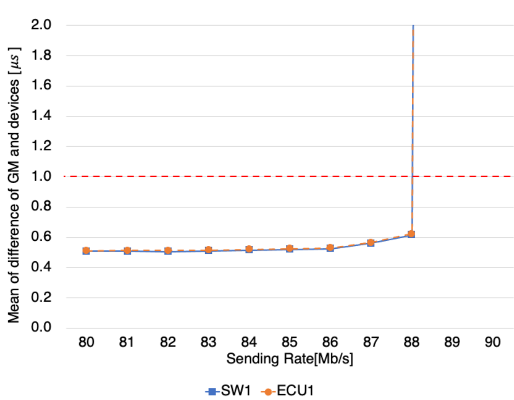

Fig. 6. Difference in time between GM and devices (Flame length is 512 bytes)

that as the frame length of the traffic for load sent from the load ECU increases, the degradation of time synchronization worsens at higher transmission rates. Notably, for the case of

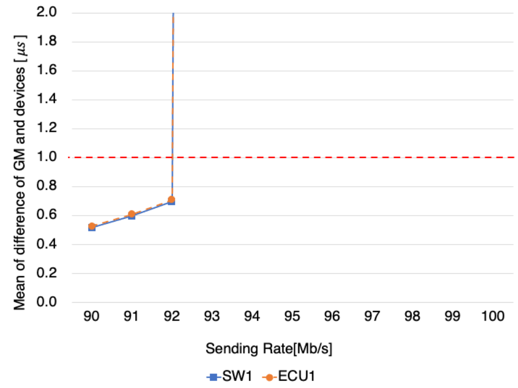

Fig. 7. Difference in time between GM and devices (Flame length is 1500 bytes)

a frame of 64 bytes, the requirement for time synchronization requirements only meets when the transmission rate exceeds 50% of the line speed. The behavior causes this is exhibited when the frame length of the traffic for load is small. In this case, the frame transmission period is short, causing a continuous influx of high-priority frames into the switch. As a result, time-sensitive traffic is subject to priority control and not transmitted effectively, leading to degradation of the time synchronization. In contrast, when the frame length of the traffic for load is more significant, the frame transmission rate increases, and the high-priority queue in the switch is less congested. Consequently, time-sensitive traffic can be transmitted more stably under such conditions.

IV. Conclusions

In this paper, we evaluated the effect of congestion over an in-vehicle network on IEEE 802.1AS time synchronization; we considered the improvement of the degradation of the time synchronization accuracy with SQP by experiment. The experimental results indicated that the time synchronization accuracy degrades as the transmission rate increases. Moreover, the degradation becomes more significant for longer frame lengths. Additionally, the experiments showed that even if SPQ is applied, time synchronization accuracy deteriorates for high-priority frames with smaller frame lengths.

Our future works are as follows. Firstly, we tackle to perform our experiments in the actual environment. Secondly, we will utilize QoS controls other than SPQ to improve time synchronization accuracy.

References

[1] "IEEE 802.1 Time-Sensitive Networking Standard". http://www.ieee802.org/1/pages/TSN.html
[2] "IEEE 802.1AS". https://www.ieee802.org/1/pages/802.1as.html Synchronization of Real-World IEEE 1588-2008 Devices" Proc. IEEE International Symposium on Precision Clock Synchronization for Measurement, Control and Communication, 2010
[3] "OMNeT++ Discrete Event Simulator," https://omnetpp.org/
[4] "INET Framework - INET Framework," https://inet.omnetpp.org/
[5] "P802.1DG – TSN Profile for Automotive In-Vehicle Ethernet Communications," https://1.ieee802.org/tsn/802-1dg/