Study on Effect of Variable Traffic on QoS of ATS and TAS in IEEE 802.1TSN on In-Vehicle Ethernet

Akari Yoshimura and Yoshihiro Ito
Graduate School of Engineering Nagoya Institute of Technology
Nagoya, 466-8555, Japan
Email: {yosimura@en., yoshi@}nitech.ac.jp

***Abstract*—This paper evaluates the QoS of ATS, one of the QoS controls defined in IEEE 802.1TSN, in an Ethernet-based in-vehicle network by comparing it with TAS by experiment. The experiments consider the maximum delay, the delay jitter, and the frame loss rate as QoS parameters and evaluate the effect of the number of switches on the QoS parameters. In the experiment, the authors use two types of traffic whose transmission intervals are fixed and unfixed. The experimental results indicate that TAS can suppress the maximum delay and the delay jitter more than ATS at fixed transmission intervals. However, ATS is more appropriate in delay than TAS at unfixed transmission intervals. The authors also show that the QoS of TAS deteriorates more at fixed transmission intervals as the number of switches increases. Moreover, the authors mention that a few frame losses can occur in the ATS when the transmission interval becomes large.**

I. INTRODUCTION

Currently, high-speed Ethernet is considered to be adopted in-vehicle networks to transmit enormous amounts of data required to realize fully autonomous driving. Moreover, this enables the integration of multiple in-vehicle networks, which are currently transmitted over different networks according to the applications, to reduce weight and cost. However, the integration can cause congestion at some failure on the in-vehicle network, resulting in the loss or delay of safety-critical data. Therefore, adopting some QoS control to guarantee low latency and low frame loss rate is inevitable. Thus, IEEE 802.1TSN (Time-Sensitive Networking) standard[1] is being considered as such a QoS control.

The IEEE 802.1TSN standard consists of multiple standards and one of them, IEEE 802.1Q[2], has many QoS controls, such as Strict Priority Queueing (SPQ), Credit-Based Shaper (CBS), Time-Aware Shaper (TAS), and so on. SPQ is the most simple QoS control. CBS enables more flexible QoS control than SPQ by using a variable called Credit to limit the maximum bandwidth of traffic with a specific priority. Especially, TAS can perform QoS control accurately by determining the traffic that can be transmitted at each time according to a predefined schedule.

This paper evaluates the QoSs of ATS and TAS, which are defined in IEEE 802.1TSN by experiment and compares them. The rest of this paper is as follows. Section II discusses related research. In Sect III, an overview of TAS is presented; in Sect. IV, an overview of ATS is presented. Sections V and VI describe the experiments and the results, respectively. Finally, we conclude our paper in Sect VII.

II. RELATED WORKS

There are some studies concerning TAS and ATS. For example, [3] evaluates how time synchronization accuracy affects the QoS of TAS. In [4], the analysis and modeling of ATS is discussed. Moreover, [5] compares TAS and ATS. However, [5] evaluates under only one industrial control ring network, not in-vehicle ones, and does not evaluate the maximum delay and the delay jitter while varying the number of switches.

III. TIME-AWARE SHAPER (TAS)

Time-Aware Shaper (TAS) is one of the QoS controls defined in IEEE 802.1Q. TAS has a gate at the egress of a switch and turns outputs on or off from the queue by opening or closing this gate. Figure 1 shows an overview of TAS. As shown in Fig. 1, the state of a gate is changed according to a list Gate Control List (GCL). TAS can transmit a certain amount of traffic without interference from other traffic by isolating the transmission of specific traffic from that of other traffic. However, even if a gate is open, a frame is only picked if the frame can be entirely transmitted before the gate closes.

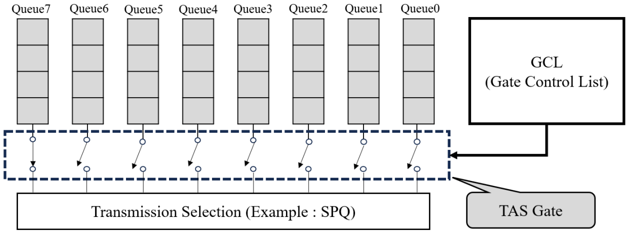


Fig. 1: Overview of Time-Aware Shaper

IV. ASYNCHRONOUS TRAFFIC SHAPING (ATS)

Asynchronous Traffic Shaping (ATS) is one of the IEEE 802.1 TSN standards defined in IEEE 802.1Q. In ATS, each queue is controlled by a scheduler called a shaper, in which the ATS algorithm is implemented and maintains the gates according to its independent clock. The shaper stores frames in the queue when input traffic becomes more than the amount of traffic designated in the traffic specification. As a result, it delays excess traffic to equalize the amount of traffic.

ATS utilizes a scheduler based on Token Bucket Emulation (TBE), shown in Fig. 2. As shown in Fig. 2, TBE maintains priorities using tokens in a memory called a token bucket. A token is a right for the sender to transmit a certain number

979-8-3503-1327-7/23/$31.00 ©2023 IEEE

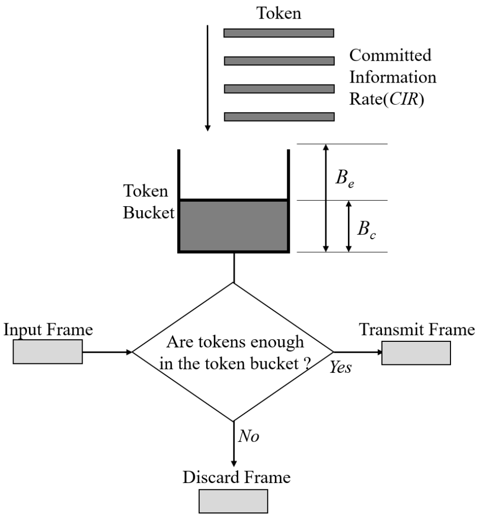


Fig. 2: Overview of Token Bucket Emulation

of bits to the network, and the shaper removes the same number of tokens from the token bucket with the frame size at transmission. The token bucket has a specified capacity, and the newly arriving tokens are discarded at full of the token bucket. If there are not enough tokens in the token bucket to transmit the frame, the frame will either be held for transmission until enough tokens are accumulated, or it will be discarded or transmitted with a lower priority. Consequently, the maximum burst a sender can transmit is proportional to the size of the token bucket. The ATS has the following configurable parameters: *CIR* (Committed Information Rate), *Be* (Burst Exceed), and *Bc* (Burst Committed). *CIR* means the flow rate of tokens, *Be* indicates the maximum amount of tokens that can be stored in the token bucket, and *Bc* is the amount of tokens that can be removed at one time.

V. EXPERIMENTS

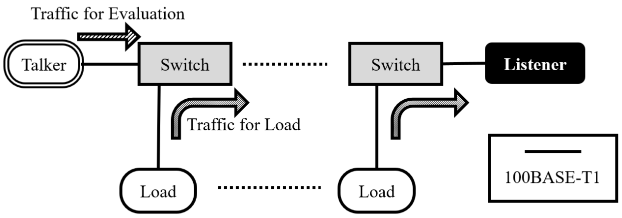


Fig. 3: Experimental environment

Figure 3 depicts our experimental environment. This environment has one transmitting device (Talker), $n (1 \leq n \leq 8)$, n load traffic generators (Load), n switches (Switch), and one receiving device (Listener). The talker and all load generators send traffic to the Listener. The number of switches varies to 1, 2, 4, and 8, and the number of load generators is the same. The priority of the traffic generated by Talker is 5, and all load generators send traffic whose priority is 4.

This paper considers two types of traffic: fixed interval and unfixed interval traffic. The specification of the traffic is shown in Table I. Firstly, as a fixed interval traffic, the talker transmits frames of 1470 bytes at 0.5-millisecond intervals while all load generators send 1470 bytes at 0.125 millisecond intervals. Secondly, in unfixed interval traffic, the transmission interval of Talker is varied so that the mean interval becomes 0.5 milliseconds, which is the same as the fixed interval traffic. In addition, the interval varies from 0.4 to 0.6 milliseconds. We also vary it between 0.0 and 1.0 milliseconds.

TABLE I: Specification of experimental traffic

ECU	PCP	Interval(ms)	Frame Size(byte)
Talker	5	0.5	1470
		0.4 - 0.6	
		0.0 - 1.0	
Load	4	0.125	1470

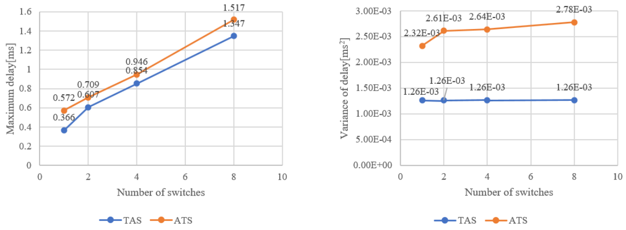
The value of the GCL of TAS is set so that the Talker's frames are not affected by other traffic for the fixed interval traffic. The value of *CIR* is 25 Mbit/s, so the amount of data can be equalized even when a talker sends frames at variable intervals, and the amount of data increases rapidly.

This paper treats the delay as a QoS parameter; it treats the maximum delay and the delay jitter. Here, delay jitter is defined as the variance of delay. The QoS parameters are evaluated when ATS is applied to all switches and when TAS is applied to all switches.

In this experiment, simulation is used for evaluation. OMNeT++[6] will be used as the simulation software.

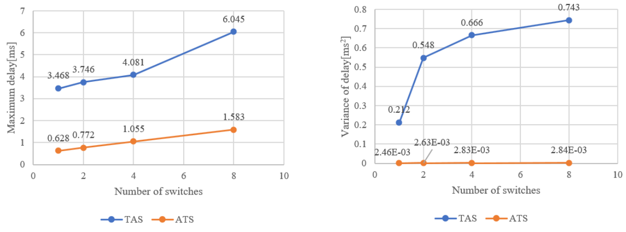
VI. RESULTS

Figures 4 through 6 represent the experimental results and have two subfigures, (a) and (b), which display the maximum delay and the variance delay, respectively. The abscissa of Figs 4 through 6 means the number of switches. The ordinates of Figs 4, 5, and 6 are the results with a fixed transmission interval of 0.5 milliseconds, that unfixed transmission interval of 0.4 through 0.6 milliseconds, and that unfixed transmission interval of 0.0 through 1.0 milliseconds, respectively. From Fig. 4, we find that TAS's maximum delay and delay variance are less than ATS. This is because frames transmitted in a fixed interval are not affected by other traffic when the GCL is appropriately set. However, Figs 5 and 6 indicate that TAS's maximum delay and variance are larger than ATS's. As the number of switches increases, the increase in delay is greater for TAS than ATS. Moreover, we would like to emphasize that the maximum delay



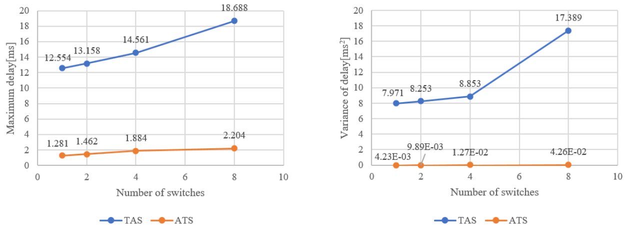
(a) Maximum delay (b) Variance of delay

Fig. 4: Delay (Talker transmission interval is 0.5 ms.)



(a) Maximum delay (b) Variance of delay

Fig. 5: Delay (Talker transmission interval is 0.4 through 0.6 ms.)



(a) Maximum delay (b) Variance of delay

Fig. 6: Delay (Talker transmission interval is 0.0 through 1.0 ms.)

and the delay jitter of TAS become much larger when the transmission interval fluctuates longer by comparing Figs 6 and 7. Especially the delay jitter increases significantly when the number of switches becomes eight.

On the other hand, ATS can significantly achieve a lower maximum delay and delay jitter than TAS, although the difference due to the fluctuation interval occurs a little. This is due to the asynchronous nature of ATS, which is less susceptible to the effects of fluctuating amount of traffic rates.

Here, we would like to focus attention on frame losses. The experimental results also indicate slight frame losses occurred when the transmission interval was unfixed at 0.0 through 1.0 milliseconds in the experiments for ATS only. Figure 7 shows the results. The abscissa and the ordinate in Fig. 7 are the number of switches and the frame loss rate, respectively. From Fig. 7, we see that as the transmission interval fluctuates, no frame is lost in TAS, but some frames are lost in ATS. This is because frames were discarded when there were not enough tokens, as explained for TBE above.

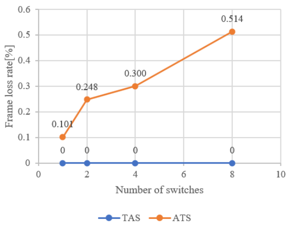


Fig. 7: Frame loss rate (Talker transmission interval is 0.0 through 1.0 ms.)

Let us consider the frame losses of ATS in detail. Making a minute investigation of frame losses at each switch in ATS, all lost frames were found in the first switch. Therefore, we considered applying TAS to only the first switch and ATS to the rest switches and re-evaluated QoS parameters at the transmission interval between 0.0 and 1.0 milliseconds. The maximum delay and the variance of delay become 15.249 milliseconds^2 and 13.383 milliseconds^2, respectively. These values are less than that of all switches adopted only TAS. In addition, the frame loss rate did not occur. This is because TAS can eliminate the rapid increase in frames at the first switch, and the frame flow rate never exceeds *CIR* at the rest switches.

To sum up the above, TAS is suitable for in-vehicle networks when traffic for evaluation is transmitted at fixed intervals. At the same time, ATS is appropriate when traffic is sent at unfixed intervals. Especially the more the transmission interval fluctuates, the worse QoS TAS provides. On the other hand, only when the transmission interval varies between 0.0 and 1.0 milliseconds little frame losses occur in ATS. Indeed, ATS is appropriate for an unfix transmission interval, but the frame losses must be paid attention to.

VII. CONCLUSIONS

This paper studied the QoS of ATS by comparing TAS by experiment. The experiments evaluated the maximum delay, the delay jitter, and the frame loss rate under the environment with multiple switches for fixed and unfixed traffic. The results show that TAS can suppress the maximum delay and the delay jitter more than ATS at fixed transmission intervals, while ATS is more appropriate than TAS when the transmission interval fluctuates. The results also indicate that the delay jitter of TAS becomes larger as the number of switches increases. Furthermore, the paper shows that a few frame losses occur in ATS when the transmission interval fluctuates. The authors concluded that TAS is suitable when the transmission interval is fixed, and ATS is appropriate when the transmission interval fluctuates. However, when ATS is used, the in-vehicle network designer must take care of the frame losses.

Our future works are as follows. First, we want to evaluate QoS for combinations of ATS with various QoS controls. Second, we will evaluate QoS over actual in-vehicle networks with devices.

REFERENCES

[1] "IEEE 802.1 Time-Sensitive Networking (TSN) Task Group," https://1.ieee802.org/tsn/

[2] "IEEE 802.1Q-2018 IEEE Standard for Local and Metropolitan Area Networks–Bridges and Bridged Networks," https://standards.ieee.org/ieee/802.1Q/6844/

[3] C. Kobayashi and Y. Ito, "Study on Effect of Time Synchronization Precision on QoS with Time-Aware Shaper," Proc. the 10th Global Conference on Consumer Electronics (GCCE), Oct. 2021.

[4] Z. Zhou, Y. Yan, M. Berger, S. Ruepp, "Analysis and Modeling of Asynchronous Traffic Shaping in Time Sensitive Networks," Proc. the 14th IEEE International Workshop on Factory Communication Systems (WFCS), Jun. 2018.

[5] A. Nasrallah, A. S. Thyagaturu, Z. Alharbi, C. Wang, X. Shao, M. Reisslein, and H. Elbakoury, "Performance Comparison of IEEE 802.1 TSN Time Aware Shaper (TAS) and Asynchronous Traffic Shaper (ATS)," IEEE Access, Volume 7, pp. 44165 - 44181, 2019.

[6] "OMNeT++ Discrete Event Simulator," https://omnetpp.org/