Quantitative Evaluation of Effectiveness of FramePreemption in IEEE 802.1TSN on QoS over In-Vehicle Ethernet

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***Abstract*—IEEE 802.1TSN, a standard for transmitting time-limited traffic over Ethernet, includes FP as a standard for prioritizing the transmission of periodic, urgent traffic. FP is used in conjunction with scheduling such as CBS, and its effect depends on the environment. Therefore, it is necessary to evaluate the effect of FP on QoS. In this paper, QoS is estimated by multiple regression analysis in an Ethernet-based vehicular network using CBS and FP, and the effect of FP on QoS is quantitatively evaluated by this regression equation.**

***Index Terms*—QoS, In-vehicle network, FP, CBS, TSN**

I. Introduction

Fully automated driving requires high-speed processing of a huge amount of data obtained from a large number of sensors in the car. So the adoption of Ethernet, which enables high-speed data processing, is being considered. Furthermore, the adoption of Ethernet integrates the in-vehicle networks, which were previously divided into multiple networks for different purposes, into a single network. Therefore, QoS (Quality of Service) control, which prioritizes the transmission of safety-related data, is essential. Therefore, the adoption of IEEE 802.1TSN (Time-Sensitive Networking)[1] is being considered as a control method for prioritizing the transmission of time-sensitive data. IEEE 802.1TSN has various priority control methods. Among them, FP is a standard for prioritizing the transmission of urgent periodic traffic. FP is used in conjunction with scheduling such as CBS, and its effect depends on the environment. Therefore, it is necessary to evaluate the effect of FP on QoS. In this paper, we quantitatively evaluate the effect of FP on QoS in an Ethernet-based automotive network.

In the previous literature, an estimation method for network QoS using SPQ has already been proposed in [2]. In this paper, we investigate the quantitative effect of FP based on the estimation method using multiple regression analysis proposed in the previous literature. Experiments are conducted using the simulation software Time Critical Network Analysis [3].

The structure of this paper is shown below. II shows the related references. III provides an overview of Frame preemption. IV provides an overview of Credit-Based Shaper. V and , VI, we present the evaluation experiments and experimental results. VII, we summarize this paper.

II. Related works

[4], an efficient algorithm using FP is proposed. [5], an architecture suitable for implementing multi-level frame preemption is proposed. Thus, research on FP has not yet quantitatively evaluated the effects of FP.

III. Frame Preemption

Frame Preemption (FP) defined in IEEE 802.1TSN is a priority control, also known as interrupt-priority forwarding. The operation of FP is shown in Fig.1. High priority data frames are treated as Express Frames and low priority data frames as Preemptable Frames. When an Express Frame is received during the transmission of a Preemptable Frame in Fig.1, the transmission of the Preemptable Frame is temporarily halted and the Express Frame is transmitted first. After the Express Frame is sent, the pre-empted frame is sent.

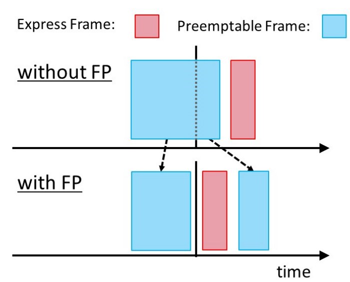

Fig. 1. Behavior of FP

IV. Credit-Based Shaper

In CBS, $Credit$ is allocated to each queue. When a frame is sent from a queue, $Credit$ is decremented. When there are no $Credit$, no frames are sent. The credit is increased according to the $Idleslope1$value set by the administrator. When all stored data frames are sent from the queue, $Credit$ is set to 0.

V. EXPERIMENTS

A. Experimental Environment

In this paper, two experiments are conducted. In Experiment A, we calculate an estimating equation from multiple regression analysis and evaluate the impact of FP on QoS from the coefficients of the equation. In a network environment using CBS, the Idleslope value has a significant impact on QoS. So in Experiment B, we change the value of $idleslope$ in CBS and evaluate the impact of $idleslope$ on FP. Five values of

$idleSlope$ in Experiment B are used: 20, 30, 50, 60, and 70 Mbit/s. In this experiment, QoS evaluation is performed using simulation. As the simulation software, we use TCN[3] from Time Critical Networks.

Since IEEE P802.1DG[6] considers multistage networks with up to 7 hops, this study targets multistage networks with 3 and 5, 7 hops, which is considered the maximum number of hops in automotive networks, as the first step of the study. Based on the IEEE P802.1DG[6], which is in the process of defining a profile for in-vehicle networks, we target a multistage in-vehicle network. The network of this experiment is shown in Fig.2.

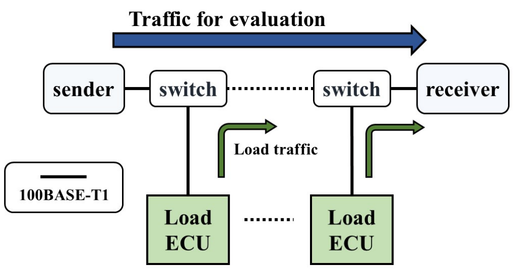

Fig. 2. Experimental Network

The network consists of senders, switches and receivers. The number of switches in this experiment is 3, 5, and 7. The traffic for evaluation is set to priority 7, and the traffic for load is set to priorities 0, 3, and 6. CBS is used on the output port of each switch.
The traffic for evaluation and load traffic are set to priority 7 and priority 0,3,6 for load traffic. The maximum delay is measured by changing the transmission rate and frame size of the evaluation traffic and the load traffic. The traffic used in the experiment is fixed frame size traffic from 64 bytes to 1500 bytes and fixed transmission speed. The QoS parameter for the evaluation is the maximum delay, which is important for time-constrained data in automotive networks.

B. QoS Estimation Formula as the explanatory variables

Using the estimation scheme proposed in the literature[2], we obtain the estimating equations to be used in experiments A and B as follows. In Experiment A, the explanatory variables are the frame size (bit) and transmission rate (Mbit/s) of the evaluation traffic, which are measurable, and the frame size (bit), transmission rate (Mbit/s), number of hops, and FP dummy variables of the load traffic. In Experiment B, the explanatory variables are the frame size (bit) and transmission rate (Mbit/s) of the evaluation traffic, which can be measured, and the frame size (bit), transmission rate (Mbit/s), number of hops, and $idleslope$ value (Mbit/s) of the load traffic. The objective variables for both Experiments A and B are QoS parameters. The estimating equations to be obtained consist only of explanatory variables that are significant.

Each variable is shown below.

TABLE I
VERIFICATION ENVIRONMENT

e_s	frame size for evaluation traffic(bit)
e_v	transmission speed of evaluation traffic(Mbit/s)
l_s	frame size of traffic for load(bit)
l_v	transmission speed of traffic for load(Mbit/s)
h	the number of hops
i	idleslope
k	dummy variable for fp

k is a dummy variable for fp and k=1 when fp is used.

VI. RESULTS

A. Experiment A

First, the estimating equation obtained from the multiple regression analysis is shown in Eq.(1).

$$\begin{aligned}\tilde{L_1} =&7.09 \times 10^{-1} - 1.36 \times 10^{-2} \times i \\ &+ 5.95 \times 10^{-2} \times h + 1.02 \times 10^{-4} \times e_s \\ &- 6.22 \times 10^{-3} \times e_v + 2.17 \times 10^{-5} \times l_s \\ &- 2.56 \times 10^{-3} \times l_v + 4.85 \times 10^{-2} \times k\end{aligned} \tag{1}$$

Each coefficient in the equation indicates the weight of the impact on QoS. Therefore, the impact of FP on the maximum delay can be expressed as 4.85×10^{-2}. Here, the impact of FP on QoS can be quantitatively expressed.

Next, we derive the estimating equations (2) and (3) for the cases with and without FP.

$$\begin{aligned}\tilde{L_1} =&1.30 - 1.46 \times 10^{-2} \times i \\ &+ 1.00 \times 10^{-3} \times h + 9.74 \times 10^{-5} \times e_s \\ &- 7.07 \times 10^{-3} \times e_v + 7.47 \times 10^{-6} \times l_s \\ &- 3.25 \times 10^{-3} \times l_v\end{aligned} \tag{2}$$

$$\begin{aligned}\tilde{L_2} =&1.29 \times 10^{-1} - 1.25 \times 10^{-2} \times i \\ &+ 1.20 \times 10^{-1} \times h + 1.08 \times 10^{-5} \times e_s \\ &- 5.23 \times 10^{-3} \times e_v + 3.55 \times 10^{-5} \times l_s \\ &- 1.77 \times 10^{-2} \times l_v\end{aligned} \tag{3}$$

The coefficients of h in Eq.(2) and (3) are shown in TableII.

TABLE II

Experiment	Coefficient of h
FP	1.00×10^{-3}
no FP	1.20×10^{-1}

This indicates the magnitude of the impact of the number of hops on the maximum delay. Since the coefficient when FP is used is much smaller, the use of FP can reduce the impact of hop count changes on the maximum delay. It has been shown in the literature[7] that the maximum delay is highly dependent on the number of hops. The use of FP can suppress the effect of the number of hops on QoS.

Next, the errors between the estimated and measured values obtained from the estimation equation are shown below. The horizontal axis shows the environment number and the vertical axis shows the error between the estimated and measured values. Fig.3 shows the results when FP is used, and Fig.4 shows the results when FP is not used.

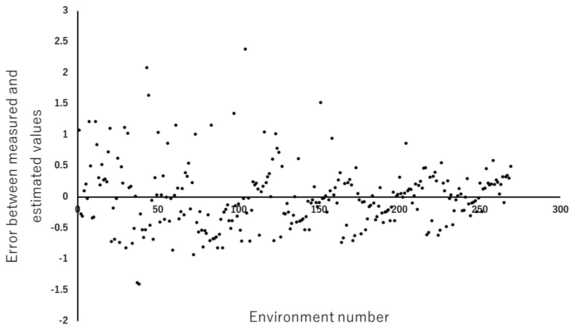

Fig. 3. Error(FP)

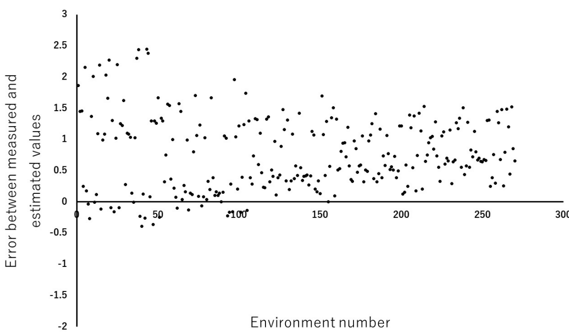

Fig. 4. Error(no FP)

The dispersion values when FP is used and when FP is not used are 0.273 and 0.350, respectively. It can be said that the error between the measured value and the estimated value is smaller in the environment when FP is used. In other words, the estimation equation calculated using multiple regression analysis is more accurate in the environment when FP is used than in the environment when FP is not used.

B. Experiment B

The following is the estimating equation obtained using multiple regression analysis. Only coefficients with valid P-values are employed in the estimation equation. The results when $idleslope$ is set to 20Mbit/s, 30Mbit/s, 50Mbit/s, 60Mbit/s, and 70Mbit/s are shown in Eq. (4), (5), (6), (7), and (8).

$$\begin{aligned} \tilde{L_1} =& -8.58\times10^{-1} + 2.00\times10^{-2}\times k \\ & -1.51\times10^{-4}\times e_s + 1.29\times10^{-3}\times e_v \end{aligned} \tag{4}$$

$$\begin{aligned} \tilde{L_2} =& -5.27\times10^{-1} + 1.30\times10^{-1}\times k \\ & +1.32\times10^{-4}\times e_s + 8.16\times10^{-3}\times e_v \\ & +5.36\times10^{-3}\times l_s \end{aligned} \tag{5}$$

$$\begin{aligned} \tilde{L_3} =& -8.17\times10^{-2} + 1.50\times10^{-1}\times k \\ & +5.89\times10^{-2}\times h + 9.88\times10^{-5}\times e_s \\ & +8.12\times10^{-3}\times e_v + 1.52\times10^{-1}\times l_s \end{aligned} \tag{6}$$

$$\begin{aligned} \tilde{L_4} =& -2.84\times10^{-1} - 4.61\times10^{-2}\times k \\ & +6.14\times10^{-5}\times e_s + 2.51\times10^{-5}\times l_s \\ & +2.17\times10^{-4}\times l_v \end{aligned} \tag{7}$$

$$\begin{aligned} \tilde{L_4} =& -3.46\times10^{-1} - 3.14\times10^{-2}\times k \\ & +9.32\times10^{-2}\times h + 6.68\times10^{-5}\times e_s \\ & +2.65\times10^{-5}\times e_v + 2.15\times10^{-3}\times l_s \\ & +3.14\times10^{-2}\times l_v \end{aligned} \tag{8}$$

The coefficients of k in equations Eq. (4), (5), (6), (7), and (8) are shown in Table III.

TABLE III

idleslope	coefficient of k(ms)
20	2.00×10^{-2}
30	1.30×10^{-1}
50	1.50×10^{-1}
60	-4.61×10^{-2}
70	-3.14×10^{-2}

Each coefficient indicates the magnitude of the effect on the maximum delay. The larger the $idleslope$, the larger the bandwidth, and thus the larger the effect of FP. Conversely, the effect of FP is negative at 60Mbit/s and 70Mbit/s. This is because the bandwidth of the load traffic becomes smaller and the delay of the load traffic becomes larger. The effect of FP is suppressed because the delay of the evaluation traffic becomes smaller. The above equations quantitatively show the effect of FP.

VII. Conclusions

In this paper, the effect of FP on QoS in a network with FP and CBS is evaluated experimentally. The experiments showed the effect of FP on maximum delay quantitatively. Future work includes evaluation using more traffic and in actual in-vehicle networks.

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