QoS Evaluation of combination SPQ, FRER and FP for In-Vehicle Networks

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Abstract: This paper evaluates QoS of the next-generation in-vehicle Ethernet-based networks in combination with the following three controls defined in IEEE 802.1TSN by simulation. The authors target Strict Priority Queueing (SPQ), Frame Replication and Elimination for Reliability (FRER) and Frame Preemption (FP). The experimental results indicate the followings. First, traffic of the highest priority should be applied SPQ to guarantee its QoS. Second, it is necessary to adopt an appropriate combination of QoS control for traffics of other priority in order to prevent them from deteriorating too much.

Keywords: IEEE 802.1TSN, QoS, In-Vehicle Network

1 Introduction

Nowadays, it is regarding to use Ethernet technologies to achieve an in-vehicle network for completely autonomous driving. It is expected to transmit a huge amount of data in ultra-low latency without data loss. Moreover, we
can integrate in-vehicle networks with various traffic types into Ethernet networks. However, we have to send safety-relevant data in preference to other data, such as infotainment one. Therefore, a QoS control of prioritizing the safety-relevant data is required.

IEEE802.1TSN\cite{1} standard has been adopted to achieve an in-vehicle network which meets the above-mentioned requirement over Ethernet. IEEE802.1TSN is a series of standards to guarantee the frame transmission with bounded low latency, the low frame delay variation, and the low frame loss rate; it is composed of various standards.

Among the standards, we especially focus on the following three standards. First, we treat SPQ (Strict Priority Queueing) in IEEE802.1Q\cite{2} to control traffic according to the priority. Second, we use FRER (Frame Replication and Elimination for Reliability) in IEEE802.1CB\cite{3} to improve the network reliability by transmitting redundant frames. Third, we handle FP (Frame Preemption) in IEEE802.1Qbu\cite{4} to accomplish the low latency transmission by interruption of transmitting. By using these standards, we can make an in-vehicle network guarantee low latency and keep reliability of the data.

On the other hand, since the above standards work independently and affect each other, the total QoS given by them has not been clarified. To design a safe in-vehicle network, it is indispensable to study QoS provided by the combination of the three standards.

In this paper, we evaluate the QoS over a network with SPQ, FRER, and FP. This paper is organized as follows. Section II and Sect. III describe IEEE802.1TSN and our experiments, respectively. In Sect. IV, we represent our results. Finally, we conclude our paper in Sect. V.

2 IEEE802.1TSN

SPQ is one of the queueing control defined in IEEE802.1Q standard; it has eight queues with different priority levels (0 through 7). In SPQ, every transmitted frame has the Priority Code Point (PCP). When a frame comes to the switch, it is assigned to one of the queues based on its PCP. A frame on a queue with a higher priority level is transmitted in preference to that on a lower one.

FRER is defined in IEEE802.1Qbu; it achieves the seamless redundancy for network reliability. When one frame comes into a replication switch, the frame is replicated completely into the same two frames and the replicated frames are sent to an elimination switch via two different paths. The elimination switch treats the frame received earlier as data and forwards it to the next switch but the other frame is eliminated on the elimination switch. Even if there is some problem with one of the paths, the data will not be lost because the same frame is transmitted via the other path.

FP is defined in the two standards: IEEE802.1Qbu and IEEE802.3br; it has two kinds of frame types: the express frame and the preemptable frame. Express frames are prioritized more than preemptable frames. When
an express frame enters the transmission queue while a preemptable frame is being sent, the express frame divides the preemptable frame and interrupts between the divided preemptable frames. Therefore the express frames do not need to wait for the transmission of the preemptable frame and the latency will be lower.

3 Experiments

3.1 Experimental Environment

Our experimental network is shown in Fig. 1; it is based on a Zonal network[6]. The network consists of four domains (Domain A, Domain B, Domain C, and Domain D), one central switch (Central Switch), and one ECU (Listener) as a receiver. Each domain has seven ECUs (ECU A through ECU G) which are talkers, and one switch (Switch). The central switch and all other switches support SPQ, FRER, and FP. All of the ECUs and switches are connected to each other using 100BASE-T1. The traffic generated in each domain is sent from the talkers to Listener via its switch and the central switch.

In this experiment, ECU F and ECU G have the highest priority while ECU A, ECU B, and ECU C have the lowest one. Specifications of the traffic used in this experiment are defined based on [6] as follows. The frame transmission intervals from ECU A to ECU G are 0.25ms, 12.5ms, 25ms, 6.25ms, 12.5ms, 1.25ms, and 2.5ms, respectively. The frame size is a uniform random value between 64 bytes and 1500 bytes.

Since we target time-constrained data, we consider the mean delay and the maximum delay as QoS parameters for evaluation. Here, we define the delay as the difference between the time when a talker sent a frame and that when the corresponding listener received it. In this experiment, we...
use OMNet++[7] as the simulation; we also utilize two OMNet++ moduels: INET[8], which is a network architecture framework, and NeSTiNg[9], which realizes a TSN network.

### 3.2 Configuration of QoS Controls

The experiment assumes the following three experimental scenarios. In the first scenario (Scenario 1), SPQ is not utilized to assign the same priority to all ECUs, and FRER is applied to ECU F and ECU G to prioritize them over the others. In the second scenario (Scenario 2), SPQ is used to prioritize ECU F and ECU G, and FRER is used for ECU D and ECU E. In the third scenario (Scenario 3), SPQ is applied according to the values of PCP of ECU D, ECU E, ECU F, and ECU G. Moreover, either FRER or FP, or both of them are applied to ECU D and ECU E. The combinations of the QoS controls and the priorities used in this experiments are shown in Table I.

In Table I, the number in each column represents the PCP value, and the columns marked as FRER and FP indicate that they are applied FRER and FP, respectively. There are 8 combinations and we refer to them as env1 through env8.

#### Table I. Network Environment

| Scenario | env  | ECU A | ECU B | ECU C | ECU D | ECU E | ECU F | ECU G |
|----------|------|-------|-------|-------|-------|-------|-------|-------|
| Scenario 1 | env1 | 7 | 7 | 7 | 7 | 7 | 7 | 7 |
| Scenario 1 | env2 | 7 | 7 | 7 | 7 | 7 | 7 | FRER | FRER |
| Scenario 2 | env3 | 5 | 5 | 5 | 5 | 6 | 7 |
| Scenario 2 | env4 | 5 | 5 | 5 | 5 | FRER | FRER | 6 | 7 |
| Scenario 3 | env5 | 4 | 4 | 4 | 4 | 6 | 7 |
| Scenario 3 | env6 | 4 | 4 | 4 | 4 | FRER | FRER | 6 | 7 |
| Scenario 3 | env7 | 3 | 3 | 3 | 4 | FRER | FRER | 6 | 7 |
| Scenario 3 | env8 | 3 | 3 | 3 | 4 | FRER | FRER | 6 | 7 |

### 4 Results

Figure 2 shows the results of the maximum delay. In Fig. 2, the abscissa is the environment and the ordinate means the maximum delay. From Fig. 2, we see that the maximum delay of env2 is larger than that of env1 for all ECUs. This is because the numbers of frames of ECU F and ECU G increased by applying FRER to ECU F and ECU G. Moreover, since the priorities of all ECUs are the same with each other under env1 and env2, there is no difference in the maximum delay.

On the other hand, under env3 and env4, the delay of ECU F and that of ECU G are small. In addition, the delay of ECU G is lower than that of ECU F. According to the results of the mean delay, there is no difference between the mean delay of env3 and that of env4 while the maximum delay of env4 is slightly higher than that of env3 except for ECU D and ECU E. This is because the traffic of ECU D and ECU E increased due to the redundant traffic generated by FRER.
Finally, considering the results under env5 to env8, we see that the delays of ECU D, ECU E, ECU F, and ECU G are suppressed more than other ECUs. This is because SPQ prioritized them over ECU A, ECU B, and ECU C, whose priority are 3. Since priority 4 was assigned to ECU D and priority 5 was assigned to ECU E under env5 and env6, these delays became larger than those of ECU F and ECU G. However we cannot confirm any difference in the delay between ECU D and ECU E. Although FRER is applied to ECU D and ECU E under env6, the effect of the increase in traffic is not recognized. On the other hand, FP is applied to ECU D and ECU E under env7 and env8, and the frames of ECU D and ECU E are Express frames, and those of other ECUs are Preemptable frames, the delays of ECU D and ECU E are smaller than that of ECU F and ECU G, which have higher priority in SPQ.

From the above results, we conclude that when using these three standards at the same time, we must at first give priority to the traffic with the highest priority by SPQ. Then, for other traffic, we have to consider carefully the combination of controls according to the required QoS. In addition, the adoption of FP is effective in reducing the delay of non-priority frames, and the adoption of FRER is effective in terms of network fault tolerance, it must be taken into account that the overall delay will increase as the number of frames increases.

![Fig. 2. Maximum Delay](image)

5 Conclusion

In this paper, we evaluated QoS in an in-vehicle network using the three IEEE 802.1 TSN standards of SPQ, FRER, and FP. From the experimental results, we clarified that it necessary to fully consider the control selection and its combination depending on the required QoS.

we show our future works as follows. First, we will treat other standards. Second, we evaluate QoS using different experimental networks.