Dual-path Method for Enhancing the Performance of IEEE 802.1 AVB with Time-triggered Scheme

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Abstract— **The amount of information traffic is on increase due to the increase of the number of electric components in vehicles. In this situation, IEEE Audio/Video Bridging (AVB) is promising technology in In-Vehicle Network (IVN) since it guarantees high level of Quality of Service (QoS) for real-time applications. Now, new AVB standards that add time-triggered traffic is discussed. Time-triggered traffic uses time division multiplexing access (TDMA) to guarantee the performance of time-critical traffic like control traffic. In other words, time-triggered traffic would be sent when their time window comes. However, it is inevitable that the time performance of AVB traffic is deteriorated by adding time-triggered traffic since the transmission of time-triggered traffic is prior to the transmission of AVB traffic. So, in this paper, a Dual-path method is proposed to improve the time performance of AVB traffic by using Redundancy path, which is presented in IEEE P802.1CB. In Dual-path method, the additional path, which is used as a backup path in IEEE P802.1 CB, is used as an independent path. Therefore, traffic is divided and transmitted through two of independent paths respectively. By distributing traffic, the tiem performance of AVB traffic could be enhanced. To verify the advantage of Dual-path method, three scenarios of traffic allocation are configured. These scenarios are mathematically analyzed. Based on results, the optimal traffic allocation is suggested.**

Keywords—*Ethernet AVB; In-Vehicle Network; Redundancy path; Dual-path method;*

I. INTRODUCTION

From the recent past, the amount of In-Vehicle Network (IVN) traffic is on the increase rapidly. Due to the advancement of network technology, Vehicle-to-X (V2X) which is the communication between vehicles or vehicle and infrastructure has emerged as the core technology in the future. And also, many services like Infortainment, Telematics for enhancing driver's convenience and Advanced Driver Assistance System (ADAS), Line Departure Warning System (LDWS), Line Keeping Assistant System (LKAS) based on sensors for enhancing driver's safety are presented via IVN.

Therefore, IEEE 802.1 Audio/Video Bridging (AVB) which has high speed Ethernet for vehicle has been developing to process increasing IVN traffic. AVB Ethernet guarantees under 2 milliseconds (㎳) latency for traffic class which has a highest priority in 7 hop networks. However, it is not sufficient for driver assistance application data like camera, laser-scanner and sensor. These applications are related to driver's safety, so their latency has to be guaranteed in order of microseconds (μs). To overcome this limitation, AVB with Time-Triggered Ethernet (TT Ethernet) was presented in AVB Generation 2 (AVB Gen 2).

In AVB Gen2, synchronous time-triggered traffic is added for control traffic which is required to have strict timing guarantees. Time-triggered traffic uses Time Division Multiplexing Access (TDMA) multiplexing strategy. So, control traffic could be sent without any interference when their time windows are coming. However, unfortunately, it is inevitable that AVB traffic's latency is increased by adding time-triggered traffic. AVB traffic and best-effort traffic use event-triggered scheme. In other words, AVB traffic and Best-Effort traffic are sent when their frames comes in queue depending on their priority. So AVB messages couldn't be sent in time-triggered traffic's time window. And also, Redundancy path, which is presented in IEEE P802.1 CB, is used as a backup path for seamless redundancy. In this case, bandwidth resources are wasted since additional path is only used as a backup path. And also, by adding additional trailer which is needed to distinguish backup frames and original frames, overhead is increased. Furthermore since IVN is configured in wired network, disconnection or break does not occur much. In this situation, redundancy path dedicated to backup is inefficient.

Therefore, in this paper, we calculate new AVB traffic's worst-case latency in AVB Gen2 environment, and suggest the method to improve AVB traffic's performance using Redundancy path. In order to improve AVB traffic's performance without deteriorating the performance of time-triggered traffic, Redundancy path is used as not backup path, but Dual-path which means that traffic is distributed to original path and redundancy path. We configure many scenarios of traffic allocation, and analyze AVB performance in each scenario mathematically and academically. Finally, we conclude the optimal traffic allocation.

This paper is organized as follows. In Section Ⅱ, overview of AVB Gen2 and IEEE P802.1 CB are introduced. In Section Ⅲ, Dual-path method is presented and it is analyzed mathematically and academically to verify improvement of the time performance of AVB traffic. Finally, Section Ⅳ concludes this paper and suggests our future work.

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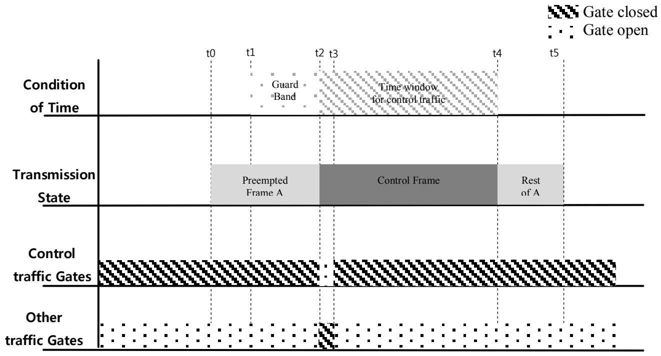


Fig. 1 Transmission procedure in AVB Gen 2

II. Background

A. *Overview of AVB Generation 2*

IEEE Audio/Video Bridging (AVB) is developed to support performance of real-time application like audio and video in IVN. In Ethernet AVB, Stream Reservation (SR) class A and B which has a highest priority is added to guarantee Quality of Service (QoS) of real-time applications. As a result, real-time application has low latency in order of milliseconds. However, control traffic which are based on driver assistance system are needed to have the latency in order of microseconds, so Ethernet AVB has a limitation for these traffic. Therefore, in AVB Gen2, time-triggered traffic has been added to guarantee the performance of control traffic by applying the Time-triggered Ethernet. Time-triggered traffic uses Time Division Multiplexing Access (TDMA) multiplexing strategy. It means that various kinds of control traffic are allocated time window respectively and their frames could be sent immediately without any delays when their time window comes. But, if a frame transmission is not complete until the end of the time window, it could negatively make an impact on next time-triggered frame and other traffic.

Therefore, to send control traffic immediately in their time window, guard band is needed. In guard band, all of frames couldn't be sent to guarantee immediate transmission of time-triggered traffic. But, bandwidth resources are wasted since any frames couldn't be sent in guard band. To reduce waste of bandwidth, transmission of frames could be stopped immediately in the beginning of time window, and the rest of the frame could be sent after transmission of the time-triggered frame. It is called Preemption which is presented in IEEE P802.1Qbu. So, control traffic could be guaranteed the performance of latency in order of microseconds.

Fig. 1 shows transmission procedure in AVB Gen2. At t_0, transmission of preempted frame A is start. As you can see, other traffic gates closed at t_1, which is the starting point of guard band, to guarantee immediately transmission of control traffic. Even if the transmission of preempted frame A is not complete, the transmission is stopped. At the end point of guard band, t_2, control traffic gates open, and then control frame is transmitted. To send other traffic when there is no control frame to send, other traffic gates open at t_3. After sending control frame, the rest of preemptive frame A will be transmitted.

B. *IEEE P802. CB – Frame Replication and Elimination for Reliability*

IEEE P802.1CB is the standard about frame replication and elimination for reliability. In AVB Gen2, two paths are configured for transmission. Additional one path is used for backup path. It means duplicated transmission over each path. When source node sends a frame to destination node, the frame is duplicated and two identical frames are transmitted over each path. To distinguish whether a frame is already received, Sequence number is added in frame's trailer. The trailer is ignored in intermediate bridges, whereas an end bridge which means nearest bridge to destination node look into trailer. When an end bridge receives the frame which has duplicated sequence number, the frame is eliminated immediately in the bridge. So, although one of nodes in networks is failed, destination node could receive a frame through the other path. Furthermore, even if an error occurs, the network operates properly without any additional delays for recovery.

III. The Method to Enhance the AVB Performance

As I said, it is inevitable that AVB traffic's latency is increased by adding time-triggered traffic. So, in part A, we propose Dual-path method for improve AVB latency. And in part B, three scenarios of traffic allocation are configured and analyzed mathematically and academically. Finally, in part B, we find optimal traffic allocation for enhancing the time performance of AVB traffic.

A. *Proposal of Dual-path method*

One of the most distinctive features in AVB Gen 2 is redundancy path. Redundancy path is configured to enhance reliability in IVN. When a node transmits a frame, the edge bridge, which is the closest bridge to the source node, duplicates the frame and sends two same frames via original path and redundancy path each. Even if abnormal situations like congestion or node fail is happened in original path, the frame could be reached to destination node through redundancy path. So, redundancy path can enhance reliability in IVN. And also, additional delay is not needed for network recovery.

However, redundancy path causes waste of network resources in IVN since two identical frames are transmitted through two paths each. And, situations in which network connection is broken are not many, because IVN is connected by wires. Furthermore, the time performance of AVB traffic deteriorates due to time-triggered traffic which has the higher priority than that of AVB traffic.

Therefore, we propose Dual-path method by using the additional path to improve the time performance of AVB traffic. As I mentioned, it is inefficient that the additional path is used as only Redundancy path. IVN is static network that the amount of transmitting data is not much variable. So, frame loss which is caused by congestion in network is less. In this situation, if the additional path is used as only backup path to enhance reliability, inefficiency occurs by AVB performance degradation. So, the additional path is used as an independent path in Dual-path method. Traffic is distributed to two paths in each, and they are transmitted through their path. Even if one

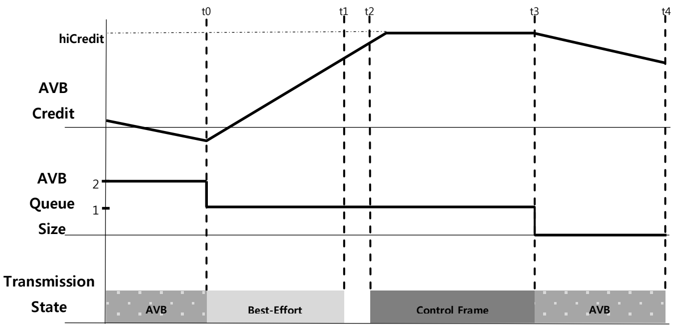
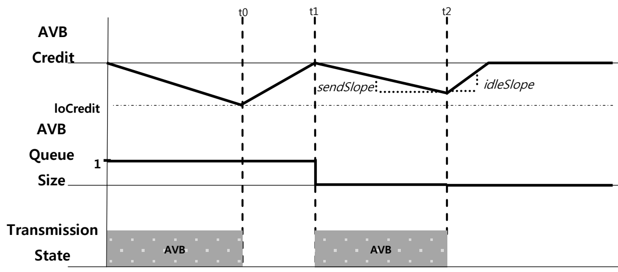
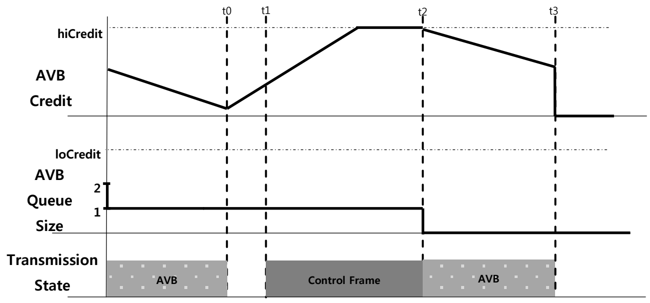


Fig. 2 Worst case of AVB traffic in AVB Gen 2



(a) Worst case of AVB Traffic in Scenario 1



(b) Worst case of AVB traffic in Scenario 2

Fig. 3 Worst case of AVB traffic when Dual-path method is used

of nodes fails, it is not a problem at all since the other path is already configured. Therefore, the time performance of AVB traffic could be improved without any impact on time-triggered traffic, if Dual-path method is used.

B. Verifying the Performance of Dual-path Method.

AVB maximum latency is needed to be recalculated by adding time-triggered traffic in AVB Gen 2. Fig. 2 shows worst case of AVB traffic in AVB Gen 2. At t_0, AVB frame remains in queue, but it couldn't be transmitted since credits have a negative value. So, best-effort frame is sent at that time, and credits start to increase. After transmission of best-effort frame, t_1, credits have a positive value, but AVB frame couldn't be sent since guard band begin at that time. During transmission of time-triggered frame, credits are not increased because it reaches *hiCredit* which is highest value of credits. At t_3, when transmission of time-triggered frame is done, AVB frame could be sent.

To calculate AVB maximum latency, detailed assumption is as follows; Transmit Rate is set to 100Mbps (***R***) and all of frame's sizes set to 1530 bytes that is Ethernet maximum size (***M***). The time gap between frames is set to 1 μs (t_{fg}), and guard band is set to the time span to send 127 bytes which is considering Ethernet minimum frame size (M_{guard}). And also, the percentage of bandwidth reservation (BW_{AVB}) for AVB traffic is 75%. Therefore, AVB maximum latency per each network device (T_{nd}) is as follows in a bridge:

$$T_{nd} = \frac{M_{guard} + 3 \times M}{R} + 2 \times t_{fg}$$
$$= \frac{127\,Byte + 3 \times 1530\,Byte}{100\,Mbit/\sec} + 2 \times 1\mu s = 379.36\mu s \quad (1)$$

In AVB Gen 1, maximum latency in 7 hop networks is defined as 2 ms for AVB traffic. So, we also have to calculate AVB maximum latency in 7 hop network (T_{max_7hop}) to compare the performance of AVB Gen2 with that of AVB Gen 1. Detailed formula is as follows:

$$T_{\max\_7hop} = T_{nd} \times (1+7) \quad (2)$$
$$= 379.36\mu s \times 8 \approx 3.04ms$$

So, we can know that the performance of AVB gets worse because AVB maximum latency is increased

To solve this deterioration of the AVB performance, we apply Dual-path method. In this paper, three scenarios of traffic allocation are configured to verify the performance of Dual-path method. We assume that there are 5 traffic classes, **time-triggered Class A** and **B**, **AVB Class A** and **B**, as well as **best-effort traffic**. And we consider only the performance of AVB Class A. Since the additional path is used as second path for allocation of traffic, paths are simply distinguished by number, **Path 1** and **Path 2**.

In scenario 1, three kinds of traffic are allocated in Path 1; time-triggered Class A and B, best-effort traffic. And both of AVB Class A and B are allocated in Path 2. In scenario 1, worst case of AVB traffic is shown in Fig. 3, (a). Since there is only AVB traffic in that path, worst case is happened when credits have their minimum value, loCredit that is the lowest value of credits, at t_0. *loCredit* is determined by *sendslope* that is the decreasing rate of credits (You can find each definition of *loCredit* and *sendSlope,* as well as *idleSlope* in [3] IEEE Std. 802.1 Qav). Detailed equation is as follows:

$$loCredit = \frac{M}{R} \times sendSlope = \frac{M}{R} \times \{(1 - BW_{AVB}) \times R\} \quad (3)$$
$$= \frac{1530\,Byte}{100\,Mbit/\sec} \times \{(1-0.75) \times 100\,Mbit/\sec = 3060\,bits$$

AVB frame couldn't be sent until credits have a positive value, at t_1. The time span that credits increase from loCredit to 0 (T_{credit_recov}) is calculated shown in Equation (4). *idleSlope* is the increasing rate of credits.

$$T_{credit\_recov} = \frac{loCredit}{idleSlope} = \frac{loCredit}{BW_{AVB} \times R} \quad (4)$$
$$= \frac{3060\,bits}{0.75 \times 100\,Mbits/\sec} = 40.8\mu s$$

TABLE Ⅰ. Results of all scenarios

Scenario Number	Traffic in Path 1	Traffic in Path 2	AVB Class A Maximum Latency (㎳)	Pros	Cons
1	Time-triggered Class A Time Triggered Class B Best-Effort	AVB Class A AVB Class B	1.52	Improvement of the performance of AVB traffic and best-effort traffic.	Bandwidth is wasted in Path 2. It is hard to send best-effort traffic if the amount of time-triggered traffic is increased.
2	Time-triggered Class A Time-triggered Class B AVB Class A	AVB Class B Best-Effort	1.96	Improvement of the performance of AVB Class A. AVB Class B could have same performance with AVB Class A. best-effort traffic could be sent stably.	The performance of AVB Class A latency is worst among scenarios.
3	AVB Class A AVB Class B Best-Effort	Time-triggered Class A Time-triggered Class B	2.1	The performance of AVB Gen 2 is equal to that of AVB Gen 1, although time-triggered traffic is added.	The opportunities for transmitting best-effort traffic could be decreased. Bandwidth is wasted in Path 2.

Therefore, AVB maximum latency when there is only AVB traffic in a path is shown in Equation (5) and Equation (6):

$$T_{nd} = \frac{M}{R} + T_{credit\_recov}$$
$$= \frac{1530\,Byte}{100\,Mbit/\sec} + 40.8\mu s = 163.2\mu s \quad (5)$$

$$T_{\max\_7hop} = T_{nd} \times (1+6) + T_{Last\_hop}$$
$$= 163.2\mu s \times 7 + 379.36\mu s \approx 1.52ms \quad (6)$$

($T_{Last\text{-}Hop}$, which can be found in Equation (6), means the latency that is measured in last switch before listener. Because all kinds of traffic are transmitted through only one link in last hop, the value of $T_{Last\text{-}Hop}$ is same as T_{nd} in Equation (1))

Of course, the time performance of AVB traffic becomes better than even that of AVB Gen 1 since there is no interference by best-effort traffic. But, bandwidth is wasted in this scenario, because AVB traffic uses only 75 percent of them. And also, if the amount of time-triggered traffic increases in the future by becoming electronic of vehicles, best-effort traffic couldn't be sent.

In scenario 2, time-triggered Class A, time-triggered Class B, and AVB Class A are allocated in Path 1, and others are allocated in Path 2. Worst case in this scenario is shown in Fig. 3, (b). We do not consider time-triggered Class B in worst case, because we assumed that AVB Class A frame could be sent between time window of time-triggered Class A and that of time-triggered Class B. At t_0, an AVB frame remains to be sent in queue, but guard band starts for time-triggered traffic Class A. So, the AVB frame must wait until the transmission of time-triggered frame is done, at t_2. In this scenario, AVB maximum latency per network device is decided by adding interference time that is caused by time-triggered frame and guard band, and transmission time of AVB frame, as well as the time gap between frames:

$$T_{nd} = \frac{M_{guard} + 2 \times M}{R} + t_{fg}$$
$$= \frac{127\,Byte + 2 \times 1530\,Byte}{100\,Mbit/\sec} + 1\mu s = 225.96\mu s \quad (7)$$

Therefore, AVB maximum latency in this scenario is as follows:

$$T_{\max\_7hop} = T_{nd} \times (1+6) + T_{Last\_hop} \quad (8)$$
$$= 225.96\mu s \times 7 + 379.63\mu s \approx 1.96ms$$

In this scenario, we can know that the time performance of AVB traffic gets better since AVB maximum latency is almost same with that of AVB Gen 1. And also, the performance of AVB Class B could be improved since AVB Class B can use all the reserved bandwidth by being separated with AVB Class A. Furthermore, the performance of best-effort traffic could be enhanced too, and best-effort traffic could be sent stably if AVB traffic is increased in the future. But, the performance of AVB Class A is worst among scenarios.

In last scenario, AVB Class A, B and best effort traffic are allocated in Path 1, and time-triggered traffic is allocated in Path 2. The combination of traffic is equal to AVB Gen 1, so we can know that AVB maximum latency can be calculated by adding additional delay in last hop. So, the value of AVB maximum latency in last scenario is 2.1ms. Therefore, the time performance of AVB traffic is also improved in this scenario. However, bandwidth is wasted in Path 2 since the amount of time-triggered traffic is generally too small to use all the bandwidth. And also, if multimedia data increase in the future, the opportunities for transmitting best-effort traffic could be decreased. Table Ⅰ shows results of all the scenarios.

C. Discussion

We examined three scenarios of traffic allocation in previous part. The traffic allocation of scenario 1 has the best performance of AVB latency, but it is inefficient that only

AVB traffic is used in path 2, because 25% of bandwidth is not used. In case of third scenario, AVB maximum latency is equal to that of AVB Gen1. However, only time-triggered traffic, which has relatively not many data, is used in Path 2, so bandwidth is wasted. And also, by increasing multimedia data for providing high quality of services in the future, the performance of best-effort traffic could be deteriorated. Though traffic allocation of third scenario has highest AVB latency among scenarios, it also has almost same performance with AVB Gen 1. Furthermore, the performance of overall traffic could be enhanced, even if the amount of multimedia traffic is increased.

IV. Conclusion & Future Work

IEEE 802.1 Audio/Video Bridging (AVB) is promising technology in IVN. Now, for time critical traffic like control traffic, time-triggered traffic which is using time division multiplexing access (TDMA) has been discussed in AVB Gen 2. But, it is inevitable that the time performance of AVB traffic is deteriorated since time-triggered traffic is added.

Therefore, we suggested Dual-path method by using Redundancy path, which is presented in IEEE P 802.1 CB, to improve the time performance of AVB traffic. In IEEE P802.1 CB, Redundancy path is used as backup path to provide seamless redundancy. However, redundancy path causes waste of network resources in IVN since two identical frames are transmitted through two paths each. In Dual-path method, Redundancy path is used as an independent path, so traffic is divided and transmitted via two paths.

To verify the performance of Dual-path method, three scenarios of traffic allocation are configured. These scenarios are analyzed mathematically and academically. As a result, we concluded that third scenario of traffic allocation, in which time-triggered traffic A, time-triggered Class B, and AVB traffic A are distributed in Path 1 and others are distributed in path 2, is the optimal traffic allocation.

In future work, we are planned to analyze the actual performance of AVB latency in lots of scenarios by using network simulator, maybe OMNET++. And also, to find out the impact of the amount of multimedia data, various simulation scenarios would be implemented. Furthermore, we will suggest many problems by using Dual-Path Method such as node fail detection, reservation bandwidth for each path. Of course, we also must present solutions for them. Therefore, we would demonstrate the advantage of Dual-Path method.

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