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Study on the Influence of V2V Communication Noise on AEB System

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Abstract

The conventional V2V-based autonomous emergency braking (AEB) system assumes an ideal communication environment and arbitrary message transmission speed, which does not reflect the real-world communication environment. Accordingly, it is necessary to overcome such a limitation and develop an advanced V2V-based AEB system by considering communication specifications and noise. This study proposes a pattern of the effect that the noise of the physical layer has on the application layer, on the basis of V2V communication architecture. The proposed noise pattern is message transmission delay and successive message loss, and a V2V communication scenario is assumed according to the noise pattern. The collision avoidance performance of the AEB system is analyzed by calculating the time of TTC (Time to Collision) application required for braking based on V2V communication. This study proposes the maximum noise level that does not affect the AEB system in a V2V communication environment. As a result, it turns out that the larger the communication noise becomes, the earlier the braking intervenes, and the faster the message transmission speed becomes, the less the AEB system is affected by communication noise. We expect that the findings of this study will contribute to developing an advanced V2V-based AEB system and improving the performance of the V2V communication module.

Keywords: *V2V (Vehicle to Vehicle), communication noise, delay, AEB (Autonomous Emergency Braking), ADAS (Advanced Driver Assistance System)*

1. Introduction

According to a report from the National Highway Traffic Safety Administration (NHTSA), driver inattention accounts for as much as 80% of total traffic accidents [1]. To deal with this problem, automobile manufacturers and research institutes around the world are actively attempting to develop advanced driver assistance systems (ADAS) that could improve driver safety and convenience. The recent research trend with respect to ADAS is shifting to an active safety system that intends to enhance safety by preventing the accident itself [2]. Such a system includes ABS (anti-block brake system), ACC (adaptive cruise control), BSD (blind spot detection), LDW (lane departure warning), and AEB (autonomous emergency braking).

Among the many types of active safety systems, the AEB system is a representative horizontal collision prevention system [3]. This system recognizes the positions of objects by using various sensors, such as lidar, radar, and camera, and estimates the collision risk on the basis of sensor data. It automatically applies braking when a collision is likely to occur. It is reported that approximately 30% of collision accidents can be prevented by the AEB system [4]. A system using sensors alone has a limited detection range at a curve or crossroad. Such a system also cannot detect blind spots. To overcome those limits, many

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recent active safety systems use V2V (vehicle-to-vehicle) or V2I (vehicle-to-infrastructure) communication. Given that such information as vehicle location and speed can be exchanged via V2V communication, the problems related to the limited detection range of sensors and blind spots can be solved [5].

Until now, research on the existing V2V-based active safety system has assumed the following two ideal communication conditions, which are difficult to be reflected in a real communication environment. First, data are communicated in on/off mode depending on the detection range of the antenna and DSRC (dedicated short-range communication) [6][8]. This does not consider communication noise. To compensate this defect, we will reflect the effect of communication noise in the application layer. Second, V2V message transmission time was arbitrarily set [7]. V2V communication messages for safety service are transmitted at a regular cycle depending on the communication specifications. However, this fact has not been considered by the existing studies. Contents about V2V message transmission speed need to be updated to satisfy the relevant standards. Thus, we configured a V2V communication model that could overcome the above two defects and reflect the real communication environment. We expect that our supplementary work for the communication model will affect the performance of the V2V-based active safety system.

In this study, we analyzed the effect of V2V communication noise on the performance of an AEB system. From this analysis, we aimed to propose the maximum noise level that would not affect the performance of the AEB system. It is expected that our study will contribute to determine a minimum performance criterion for developing a V2V communication module and to improve the performance of V2V-based AEB systems.

2. V2V Communication Noise Model

Recently, system research and development for enhancing vehicle safety and traffic efficiency are being actively conducted by focusing on the application of V2X (vehicle-to-everything) communication, such as of V2V and V2I. Standard institutes and vehicle manufacturers in the US and Europe are actively participating in the development of services and applications using inter-vehicle communication. Different communication standards have been adopted by the US and European standard institutes. The analysis of the defined message set shows that the cooperative awareness message (CAM) and basic safety message (BSM) have the same objective of periodically transmitting the status information, including vehicle speed and position [11-13].

As mentioned in Section 1, the existing studies commonly assume an ideal environment for V2V communication, and thus, could not reflect a real communication. Those limitations were compensated through communication specifications. First, the message transmission time was arbitrarily set. Here, the message transmission condition should be reflected in the communication specification. Accordingly, our next discussion is about message transmission time and speed. In this paper, the CAM and BSM, which is the European standard communication message, were used for vehicle safety message. The transmission time of CAM is between 0.1 s and 1 s. In case one of the following conditions is satisfied, a new vehicle message is transmitted.

1. The difference of heading angle between the present and previous message is 4° or more.

2. The difference between the present location and the location contained in the previous message is 4 m or more.

3. The difference between the present speed and the speed contained in the previous message is 0.5 m/s or more.

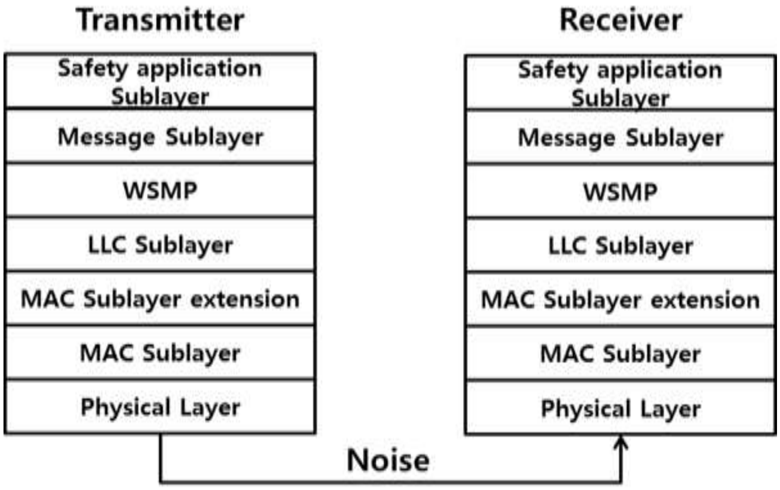


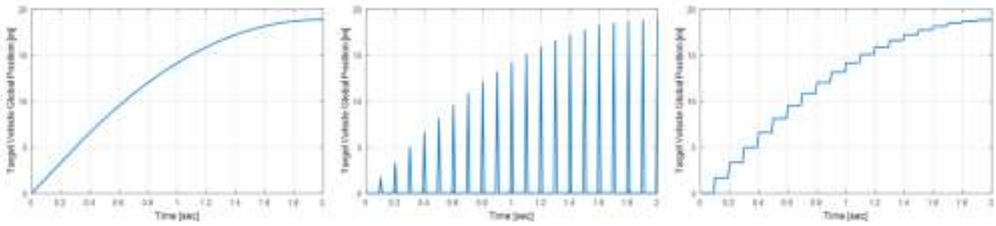
Figure 1. V2X Communication Architecture

As it is clear from the following transmission conditions, the message transmission bandwidth varies between 1–10 Hz depending on the condition of the target vehicle [14]. However, the existing studies conventionally assumed that the communication transmission speed is the same as a simulation sample time. Their system models could not ensure crash prevention performance in real situations. In an active safety system, the issue of safety is determined in a short time. For this reason, we analyzed the effect of the message transmission speed on system performance. Although the CAM transmission bandwidth varied from 1 to 10 Hz, the research on VANET, which had been developed for production, indicated that message transmission frequently occurred at 0.1, 0.2, and 0.3 s [14]. Based on this finding, we set the inter-vehicle message transmission speed to 0.1, 0.2, and 0.3 s. Each speed was expected to have an effect on system performance.

Second, the existing studies assumed that the message is transmitted in on/off mode depending on the detection range of the antenna. However, this does not reflect the communication noise that occurs depending on the radio environment. Accordingly, we examined the V2V communication architecture and improved V2V communication by modeling the effect of communication noise at the physical layer on the message data at the application layer.

Figure 1 shows the V2V communication architecture. When a message is transmitted, most of the noises occur at the physical layer owing to the influence of the radio environment, and thus, we ignored other noises occurring elsewhere. The transmitter sends the hided data by using an encapsulation technique. The receiver gets the data by a decapsulation process, including error detection. Each layer of the receiver conducts error detection and requests retransmission in case of data loss [15].

Now, we can define the phenomenon that the communication noise of the physical layer occurs at the application layer in the following two ways. The first is message transmission delay, and the second is successive message loss. The cause of each case is as follows. When a message is sent on a transmission line, reflection/propagation/diffraction generate many paths. Messages sent through different paths interfere with one another and this leads to delay, distortion, or attenuation of the received signal. Message error is detected at each layer of the receiver, and if data are missed because of distortion or attenuation, retransmission is requested. No message can be received while retransmission is being requested. In case distorted signals are consecutively received, this causes consecutive message loss.



(a) (b) (c)

Figure 2. V2V Communication Model

V2V communication and noise were defined as follows for modeling. Figure 2 shows the global position of a vehicle travelling at 40 km/h and decelerating at 0.3 g. If a message is transmitted at the cycle of 0.1 s, the receiver gets the data as shown in Figure 2(b). As the V2V transmission speed is slower than the operation speed of the AEB system, it affects the time-to-collision (TTC) calculation. As shown in Figure 2(c), we assumed that the present data are kept until the next data are transmitted and received. In this way, continuous data were formed to prevent the effect on AEB system. Accordingly, the messages were transmitted at a regular cycle according to transmission speed, and the received messages were continuously modeled.

When the present message is delayed, its delay time needs to be shorter than the receiving time point of the next message. Otherwise, the present message cannot be received. The maximum message delay time was defined based on the maximum message transmission speed. We set the minimum delay time to 0 s and the maximum one to 1 s. Figure 3(a) displays a 0.05 s transmission delay with 0.1 s cycle. The successive message loss occurs during the transmission cycle per each loss. In addition, if there are no data during message loss, the TTC calculation is affected. For this reason, like in V2V modeling, the previous message was used to form a continuous signal. We set the number of missed messages to be between 0 and 10 [16]. Figure 3(b) illustrates one message loss at 0.1 s transmission cycle.

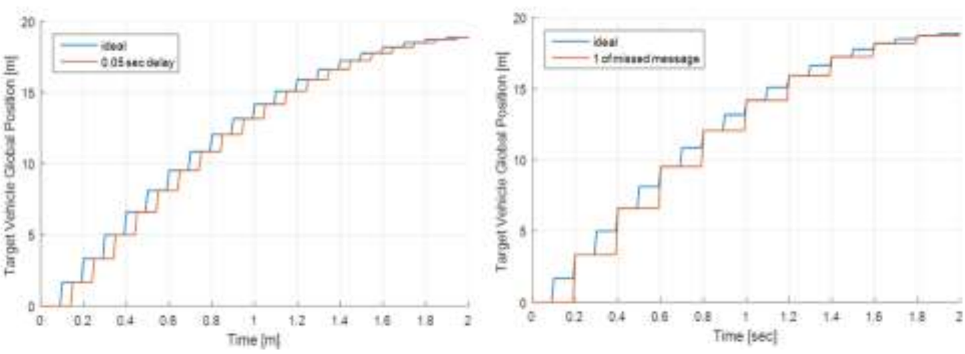


Figure 3. Communication Noise Model

There are numerous noise patterns in the real environment where message transmission delay and successive message loss occur in a complex way. As a standard noise pattern could be hardly obtained, we configured noise patterns by using a single communication noise. As shown in Figure 3, our noise patterns assumed constant repetition of message transmission delay or successive message loss.

3. AEB System Model

Figure 4 shows the overall configuration of a V2V-based AEB system. The data from the speed sensors and GPS, which were mounted on the vehicle, were utilized for operating the AEB system. The AEB system is operated based on the TTC calculation. TTC is calculated from the position and speed data transmitted through V2V communication.

The AEB system automatically applies the brake at a risky situation by deriving brake time based on the relative speed and distance to a target vehicle. To operate the AEB system, the front collision risk needed to be judged, and the TTC, which is the longitudinal collision risk index, was also used [3]. TTC calculation was based on V2V-based information. When data acquisition is based on V2V communication, the limited detection ranges and blind spots of sensors like radar and lidar can be dissolved.

To determine the brake time, we compared TTC, which is the collision risk index for a target vehicle, and TTCmin, which is the minimum brake time for preventing the collision with the vehicle. In other words, we chose the time where TTC became less than as the brake time and applied braking to the host vehicle.

$$TTC < TTC_{min} \tag{1}$$

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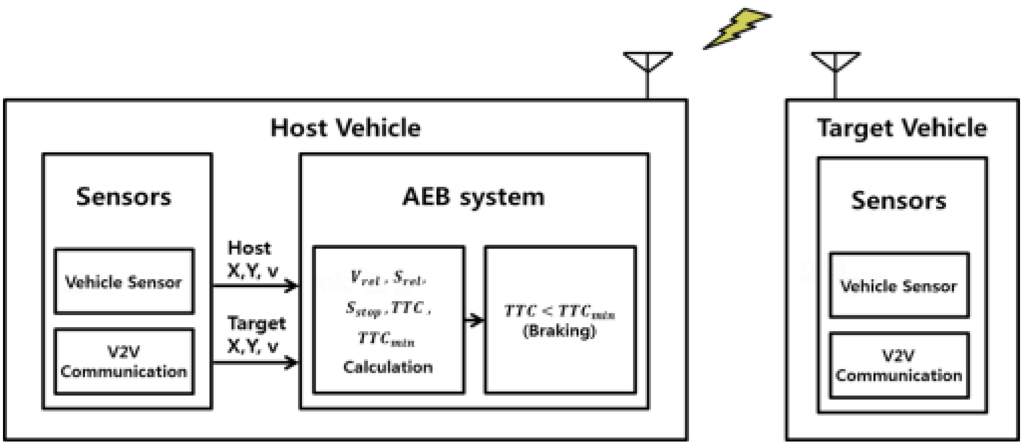


Figure 4. System Configuration Diagram

$$TTC = \frac{S_{rel}}{V_{rel}} [s] \tag{2}$$

$$TTC_{min} = \frac{S_{stop}}{V_{rel}} [s] \tag{3}$$

$$S_{stop} = \frac{V_{rel}^2}{2 \times a_{dec}} [m] \tag{4}$$

Each manufacturer uses a different brake time and braking force for the AEB systems, which are currently mass-produced. We applied the system strategy of Mercedes Benz to analyze the performance of a verified AEB system. Table 1 presents detailed control specifications of the PRE-SAFE brake system that generates brake forces according to the TTC condition [9].

Table 1. PRE-SAFE Brake System

	Warning	Partial Braking	Full Braking
TTC	2.6s	1.6s	0.6s
Deceleration	-	0.4g	0.9 – 1g

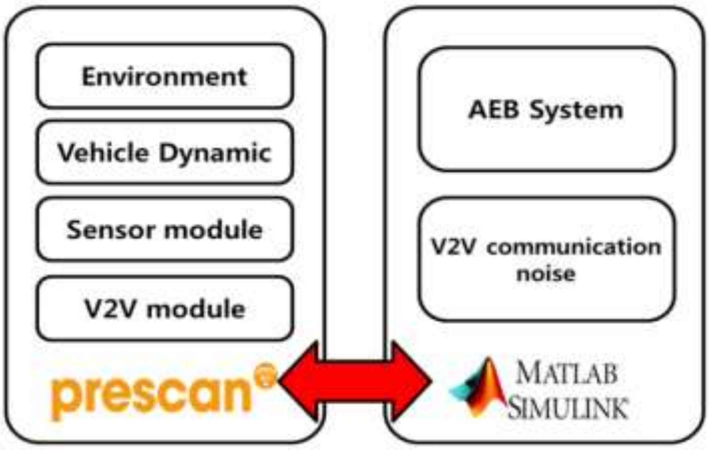


Figure 5. Simulation System Configuration Diagram

4. Simulation Scenario and Results

Figure 5 illustrates the configuration of the simulation system. We used a PreScan tool to model the basic V2V communication and driving environment. A MATLAB/Simulink tool was also implemented to simulate V2V communication noise. The whole system was configured by connecting the PreScan and the MATLAB/Simulink.

4.1. Simulation Scenario

Figure 6 illustrates the simulation scenario. The host vehicle was approaching the target vehicle at 60 km/h on a straight road. The target vehicle traveled at 40 km/h and then decelerated at 0.3 g. We referred to the AEB assessment procedure of ADAC to set the driving scenario and speed. The operation of the AEB system was based on V2V communication, and the initial position of the host vehicle was set to the point where TTC was 4 s, in accordance with the Euro NCAP AEB assessment procedure [17].

Based on the existing studies, the transmission speeds of V2V communication were set to 0.1, 0.2, and 0.3 s, which have a high occurrence frequency. For communication noise, we used the communication noise model of Section 2.

Table 2. Set of Simulation Variables

Parameter	Value
Speed of host vehicle	60km/h
Speed of target vehicle	40km/h
Deceleration of target vehicle	-0.3g
Message upgrade rate	0.1s
Delay time	0 - 1s
No. of missed message	0 – 10

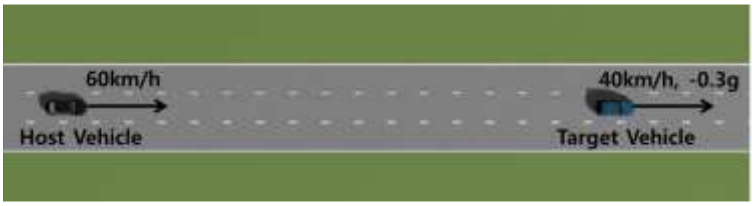
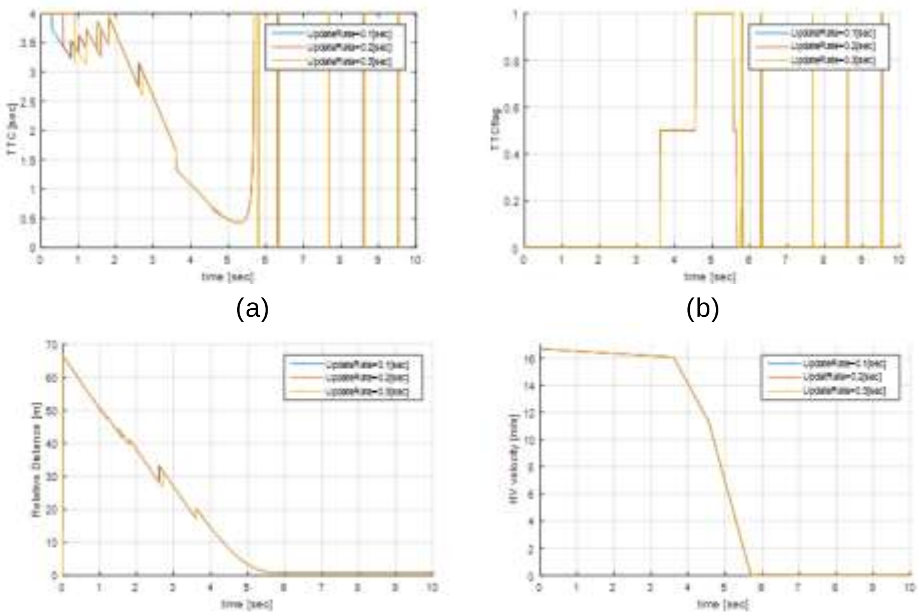


Figure 6. Simulation System Configuration Diagram

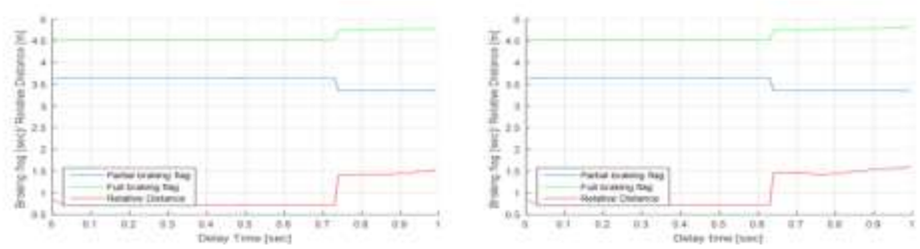
4.1. Simulation Results

To analyze the effect of V2V communication noise on the AEB system performance, we compared the simulation results by applying different message transmission speeds and communication noise patterns. Figure 7 presents the AEB system performance with transmission speeds of 0.1, 0.2, and 0.3 s, under an ideal communication environment. As shown in Figure 7(b) and (c), the TTC flag generation time and inter-vehicle distance at complete stop are 3.61 s and 0.89 m, respectively, and these values are the same for the three transfer speeds. Further, the vehicles did not collide with each other because of the relative distance. The message transfer speed used in the simulation has the highest frequency in a real driving environment and is the fastest one. Thus, the message transfer speeds of 0.1, 0.2, and 0.3 s under ideal communication did not affect the AEB system performance.



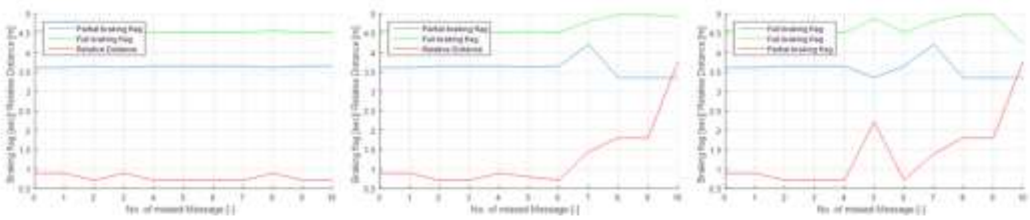
(a) (b) (c) (d)

Figure 7. AEB System Performance Based on Transfer Speed under Ideal Communication



(a) (b)

Figure 8. Simulation Results for Message Transmission Delay



(a) (b) (c)

Figure 9. Simulation Results for Successive Message Loss

Based on the communication noise modeling in Section 2, we conducted the simulation by applying a message transmission delay changing from 0 to 1 s, at 0.01 s interval. Figure 8 shows the simulation results of message delay. Figure 8(a) assumed the transmission speed to be 0.1 and 0.2 s, while Figure 8 (b) applied 0.3 s. The cases of 0.1 and 0.2 s in transmission speed had the same braking flag time and the inter-vehicle distance after complete stop for each delay time. When the delay was shorter than 0.74 s, the braking flag time and the inter-vehicle distance had errors of about 0.05 s and 0.2 m, respectively. This performance was similar to that under ideal communication. When the delay time was 0.75 s or longer, the baking flag time and the inter-vehicle distance had errors of about 0.3 s and 0.8 m, respectively. Besides, the partial braking flag occurred rapidly, while the full braking flag occurred slowly. When the vehicle was stopped by rapid brake intervention, the inter-vehicle distance became longer. Because of the delay, the TTC was calculated by using the present information of the host vehicle and the past information of the target vehicle. In the case of 0.75 s delay or longer, the change rate of relative speed exceeded that of relative distance, which made the TTC shorter than in the ideal environment. Consequently, the brake time was advanced. In addition, because rapid partial braking occurred, thus the speed of the host vehicle and the relative speed decreased, and it took a longer time to reach full braking after TTC was on.

When the message transmission speed was 0.3 s, the transmission delay time was 0.64 s, which was the same result as when the speeds were 0.1 and 0.2 s. If the message delay time becomes longer, TTC calculation is affected and thus the partial braking flag occurs earlier. When the vehicles stopped, the distance between them had an error of about 0.8 m.

It turned out that message delays of 0.74, 0.74, and 0.64 s could guarantee the AEB system performance at each message transmission speed. The longer the message delay time became, the earlier the AEB system intervened. Besides, when the message transmission accelerated, the system performance was less affected by message transmission delay.

The successive message loss was simulated from 0 and 10 messages with an interval of one message. Figure 9 shows the results of successive message loss. Figure 9(a), (b), and (c) assumed transmission speeds of 0.1, 0.2, and 0.3 s, respectively.

In the case of 0.1 s, the AEB system was little affected by successive message loss. The occurrence times of partial and full braking flags had an error of approximately 0.05 s, and the relative distance between vehicles had an error of approximately 0.2 m. This result was similar to the performance of the AEB system in an ideal communication environment. Such similarity seems to be because 0.1 s was the fastest transmission speed.

When 7 and 5 messages were successively lost at the transmission speeds of 0.2 and 0.3 s, respectively, the partial braking flag and inter-vehicle distance after the vehicles stopped showed a drastic change. As the message transmission speed was slower than that in the previous scenario, the message loss time became longer. Because the previous message was used during the transmission of lost data, the relative speed became slower and the relative distance got longer, which resulted in the decrease of TTC value. This again caused earlier braking. Consequently, the more the messages were lost successively, the earlier the intervention of the AEB system occurred. Thus, research for minimizing the effect of successive message loss is required by estimating the message data.

We found that the AEB system performance for message transmission delay and successive message loss varied according to message transmission speed. We also could confirm that, as the message transmission speed became faster, the system performance was less affected by V2V communication noise.

4. Conclusions and Further Study

In this paper, we analyzed the effect of V2V communication noise on the AEB system performance, and proposed the maximum noise levels that would not affect the system performance at each message transmission speed. Because the existing V2V-based AEB systems assume the V2V communication to be ideal, the AEB system has some limitations in real situations. Accordingly, we defined and modeled the pattern where the communication noise generated from the physical layer appeared in the application layer in accordance with the V2V communication architecture.

The AEB system strategy of Mercedes Benz was used to analyze the effect of V2V communication noise. The AEB system performance for message transmission delay and successive message loss varied according to the message transmission speed. As the message transmission delay became longer and the number of successive message losses increased, the intervention time of the AEB system became earlier. In other words, as the message transmission speed increased, the system was less affected by the communication noise. Thus, we expect that the effect of message delay and loss will be reduced by estimating message data.

Because there is no standard V2V communication noise pattern, we examined the AEB system performance in terms of periodically repeated communication noise. For a further study, we will investigate a method utilizing a standard V2V noise pattern based on actual data to analyze and improve the performance of the V2V communication system in an almost real-world environment.

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