Implementation and Evaluation of Priority Processing by Controlling Transmission Interval Considering Traffic Environment in a Dynamic Map

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***Abstract*—Much attention has been attracted to the research of cooperative automatic driving that focuses on safety and efficiency by sharing the data obtained from sensor information of a vehicle. In addition, dynamic maps, a common information and communication platform for the integrated management of shared sensor information, are under consideration. A vehicle always sends data to a server that manages the dynamic map, and the server runs applications for driving support and control on the basis of the data, so fast information processing is required. However, congestion is a concern when data is continuously sent from vehicles to the server at high transmission intervals and when many vehicles are managed by dynamic maps on the server. In addition, the data transmission interval from the vehicle required by the road characteristics differs in actual traffic environments. Therefore, congestion can be alleviated by adjusting the transmission interval of data from the vehicle in consideration of road characteristics. In this paper, a platform for a dynamic map consisting of a server and a vehicle is constructed. We have also implemented a priority processing function that sets the priority for each section of a lane, and adjusts the transmission interval on the basis of the characteristics of the road around the vehicle.**

Keywords–ITS; Dynamic Map; Connected Vehicle; Automated Driving; Priority Processing; Load Balancing.

I. INTRODUCTION

In recent years, there has been a lot of research and development on automatic driving, where automobiles use sensors to recognize the surrounding environment and automatically control driving by avoiding hazards [1]–[3]. However, in-vehicle sensors are limited to detecting objects in the visible range but not in the inaccessible range. Therefore, cooperative intelligent transport systems (ITSs), which aims to improve safety by using wireless communication technology to exchange information between vehicles and roadside equipment, have attracted attention [4]–[6]. A variety of applications are being considered, including collision warning at intersections, provision of traffic jam and signal information, and support for merging on expressways [7]–[9]. However, the data sent from the vehicle is currently managed separately for each application. Therefore, dynamic maps, which are platforms for managing and processing data in an integrated manner, have been investigated [10]–[12].

A dynamic map is a structure in which dynamic information is layered on top of a static road map in accordance with the update frequency of each data. Figure 1 shows the structure of the dynamic map. The data obtained from the in-vehicle sensors are sent to the server that manages the dynamic map, and the application that achieves cooperative automatic driving runs on the basis of the data [13]. Therefore, dynamic information transmitted from the vehicle must always be sent to the server, and the server must process the information and send it with low latency to the vehicle [14]. In addition, the vehicle generally transmits to the dynamic map at 100-millisecond intervals [15]. However, the number of vehicles handled by the dynamic map is huge, and congestion is a concern if all vehicles continue to transmit data at high frequencies.

Therefore, congestion can be alleviated by adjusting the data transmission interval, considering the traffic environment around the vehicle. Although there is controversy over the arrangement of servers to manage dynamic maps [16]–[19], in this study, we constructed a platform for dynamic maps consisting of vehicles and servers. In addition, we have implemented a priority processing function that divides the lane where a vehicle travels into sections (Lane ID) on the basis of the traffic environment around the vehicle, sets the priority for each Lane ID, adjusts the data transmission interval from the vehicle in accordance with the priority, and evaluate its effectiveness.

In Section 2, we describe the basic structure of the dynamic map. In Section 3, we describe the priority processing function by adjusting the transmission interval. In Section 4, we explain how to determine the transmission interval considering the traffic environment. In Section 6 The effectiveness of the system is evaluated in Section 6. In Section 7, the results of the evaluation are discussed, and Section 8 is a conclusion.

II. COMMUNICATION METHOD FOR DYNAMIC MAP

In the dynamic map developed in this study, the data that a vehicle sends to the server includes vehicle ID, vehicle position, speed, time stamp, etc [20], [21]. The vehicle position is obtained using the vehicle ’ s GPS position and scan matching [22]. A vehicle and a server are called nodes, which

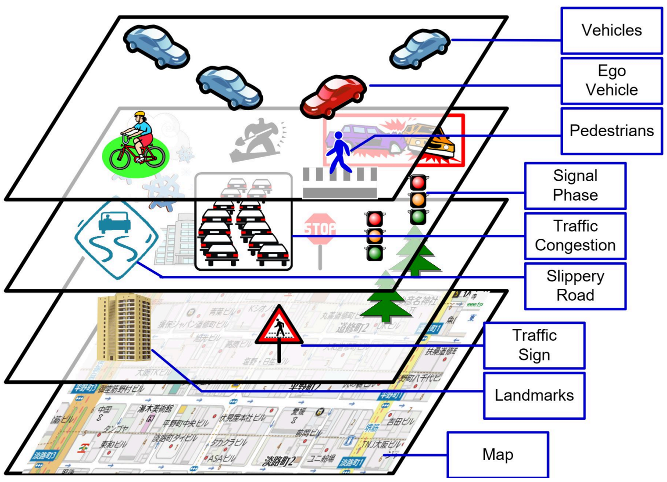

Figure 1. Overview of dynamic map

are composed of four layers: an Operating System (OS), a Communication Unit (Transmission), a Database System (DB), and an Application (APL). Each node communicates through a communication section, and the data sent and received is processed by the application of each node. Figure 2 shows an overview of the constructed dynamic map.

The vehicle and the server need to send and receive data at a high speed, and in this study, UDP is used for communication [23]. However, although UDP has a small header size and can send and receive a lot of application data, there is no guarantee that the packets will reach the user because it is a connectionless protocol [24]. Therefore, it is necessary to guarantee the communication by performing retransmission processing on the application side, or the application must be able to tolerate packet loss. In addition, since the server and the vehicle use wireless communications, which is considered to be less reliable than wired communication, a function to send Acknowledgement (ACK) data was constructed.

As shown in Figure 3, the server sends data to the vehicle. The vehicle will then send an ACK to the server to confirm the received data. During this time, the server will continue to retransmit the data periodically until the ACK has been received. Once received, it will stop the retransmission. This enables the reliability of the communication to be maintained even with UDP.

III. Priority Processing by Adjisting the Transmission Interval

Safe-driving support applications, such as merging and mediation, require the position and speed information of each vehicle [25], [26]. Such applications require the high-frequency acquisition of location information for vehicles approaching or being within an intersection. However, location information for vehicles far from the intersection or moving away from it is not needed as frequently. However, every vehicle sends data to the server at regular intervals, regardless of the application's request. As a result, the processing and communication bandwidth of the server is tight, which may interfere with the services to support safe driving.

Therefore, we developed a function to minimize the impact on traffic and alleviate the processing load and bandwidth congestion on the server by setting the priority in accordance

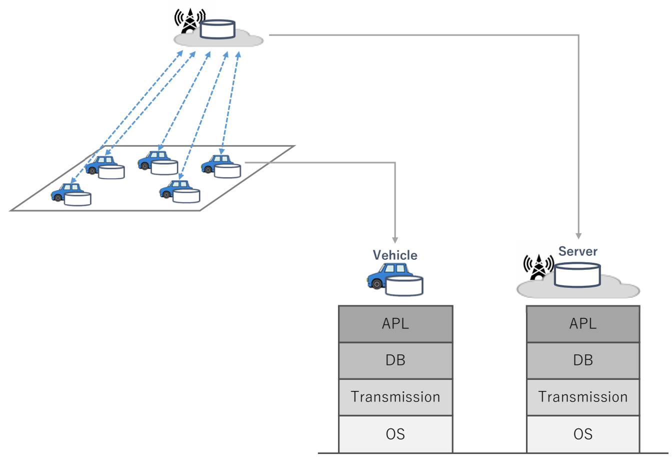

Figure 2. Dynamic map of server and vehicles

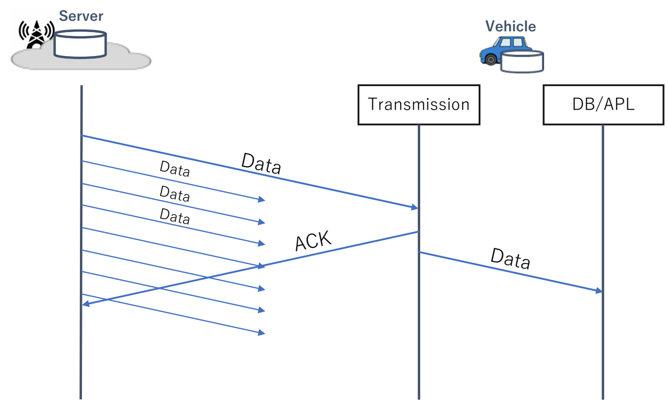

Figure 3. Sequence of resend function

with the position of the vehicle on the road and adjusting the transmission interval from the vehicle by the communication section of the vehicle.

In Figure 4, the server receives data at regular intervals from vehicles over all the areas in the figure. Under this condition, it is not possible to filter out the vehicles because it is unclear which vehicles are placed in which traffic environment. Therefore, as shown in Figure 5, when vehicle location information is linked to road map information, it is possible to understand the traffic situation such as vehicles heading towards or away from an intersection. As a result, it is possible to prioritize each vehicle in consideration of the traffic environment. When the server receives data from the vehicle, it grasps the location information of the vehicle and notifies the vehicle of the transmission interval of the data in accordance with the priority in the response data. The vehicle transmits subsequent data at the transmission interval indicated by the server. By adjusting the transmission interval in accordance with the position of the vehicle, a priority processing function based on the data transmission interval from the vehicle in consideration of the traffic environment is achieved.

Figure 6 shows the sequence of the priority processing function by adjusting the data transmission interval of a vehicle. The vehicle sends data to the server through the communication section. The server creates ACK data from the received data and transmits it to the vehicle with the delay time for each Lane ID to control the transmission interval. The

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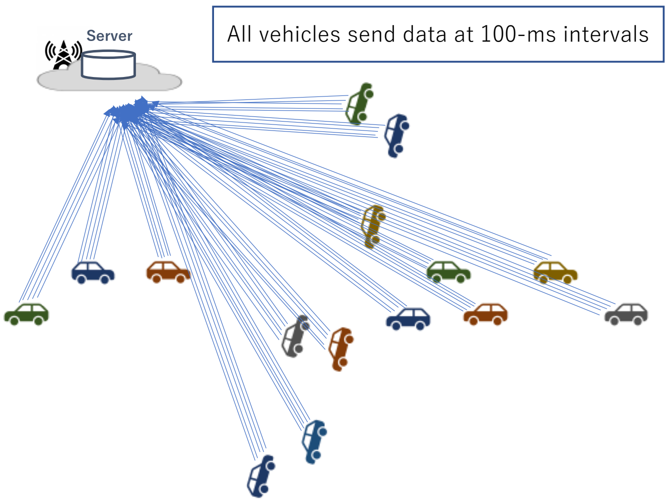

Figure 4. Communication traffic when transmission interval is constant

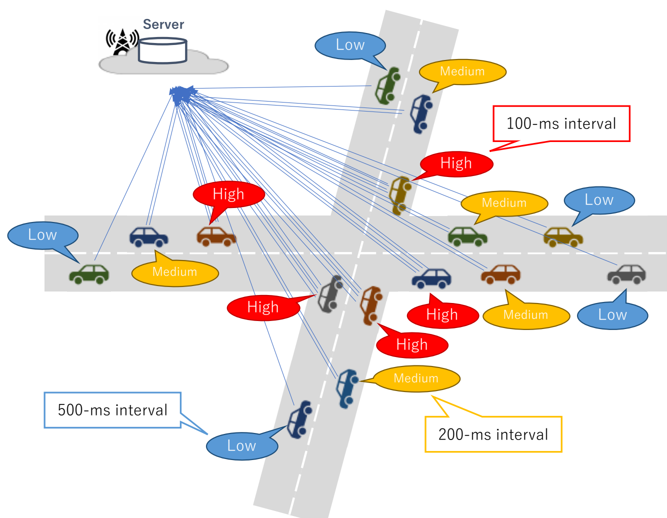

Figure 5. Adjustment of transmission interval in accordance with priority

vehicle adjusts its transmission interval in accordance with the delay time.

Figure 7 shows a flowchart of the priority processing function to adjust the data transmission interval of the vehicle. If the destination of the ACK data sent from the server is the vehicle, the transmission interval of the vehicle is adjusted in accordance with that in the ACK data.

IV. Prioritization in Consideration of the Traffic Environment

We determined the priority of the transmission interval on the road where a vehicle is traveling on the basis of the traffic environment around it. For example, suppose there was a road like the one shown in Figure 8. Since applications on dynamic maps process data from vehicles in real time, they need to transmit data at a high frequency in and around intersections. However, it is not necessary to transmit data at such a high frequency on roads that are far from intersections. Therefore, the lane is divided into sections (Lane ID) in accordance with the characteristics of the road on which the vehicle is traveling, and the transmission interval is determined for each Lane ID.

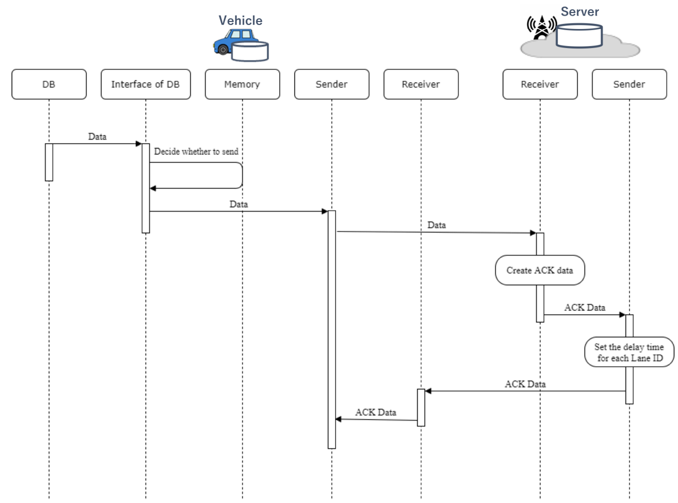

Figure 6. Sequence diagram of priority processing by transmission interval adjustment

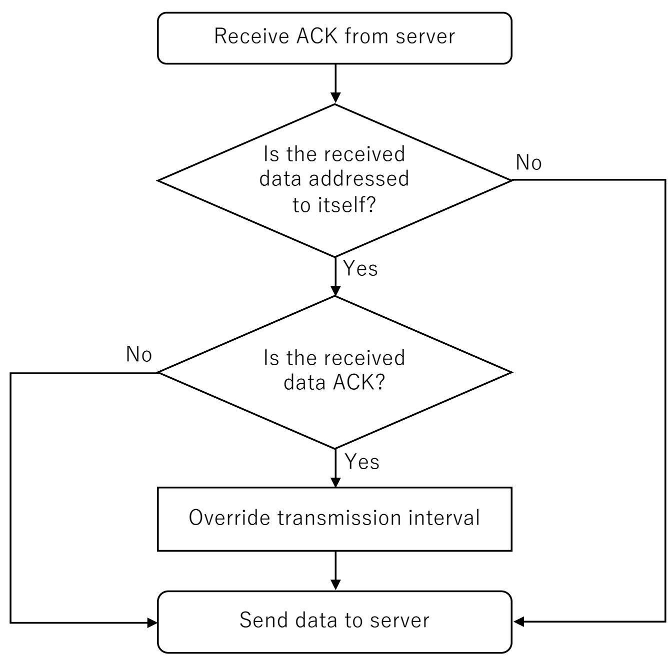

Figure 7. Flowchart of priority processing by transmission interval adjustment

A Lane ID is assigned to one lane of the road in Figure 8 for each road characteristic. The relationship between road characteristics and priority is shown in Table I. For example, if we want to apply a new road in the parking lot to the dynamic map, we can add the data to this database and set it as a Lane ID. The relationship between the priority and the transmission interval is shown in Table II. On the basis of these, the Lane ID is related to the transmission intervals. It is expected that the network will evolve and be able to transmit large amounts of data at higher speeds in the future. Therefore, if we want to communicate data more frequently, we can modify this database to briefly improve the communication interval of the entire dynamic map. The relationship between the Lane ID and the transmission interval is shown in Table III. The server determines the transmission interval to the vehicle based on

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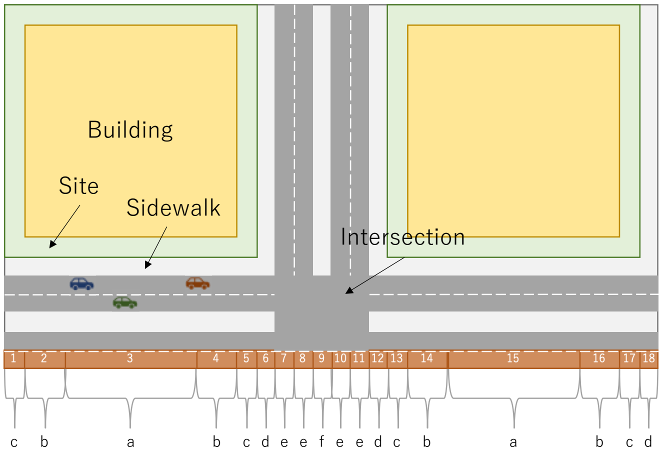

Figure 8. Priority corresponding to Lane ID

TABLE I. PRIORITY FOR ROAD CHARACTERISTICS

Symbol in the figure	*Road characteristics*	*Priority*
a	Building site center	1
b	Building site	2
c	Building site edge	3
d	Sidewalk / Side road	4
e	Lane	5
f	Intersection center	6

TABLE II. TRANSMISSION INTERVAL FOR PRIORITY

Priority	*Transmission interval*
1	500 ms
2	300 ms
3	200 ms
4	100 ms

TABLE III. TRANSMISSION INTERVAL FOR LANE ID

Lane ID	*Transmission interval*
1	200 ms
2	300 ms
3	500 ms
4	300 ms
5	200 ms
6	200 ms
...	...

this database. It is expected that the transmission intervals will be adjusted daily while operating a dynamic map, and it will be possible to operate the database concisely by normalizing the database and managing it independently. As the dynamic map utilizes this relationship, when the server receives data from a vehicle, it determines the appropriate transmission interval on the basis of the location information in the data, and transmits this information in the ACK to the vehicle. That way, the vehicle can adjust its transmission interval appropriately.

V. EVALUATION SYSTEM

To evaluate the priority processing function built in this study, a dynamic map system was constructed using two PCs to act as a server and vehicle, respectively. We have developed a dynamic map platform that covers everything from communication to applications, and we used that application to perform simulations in this study as well. However, the effectiveness of the proposed system is not clear due to the large amount of uncertainty in using this application. Also, a discussion of the internal behavior of the application is not the essence of this paper. Therefore, in this simulation, the data sent from the vehicle was assumed to be processed by the same application on the server and return an ACK. The vehicle acquires sensor information by the application and sends it to the server through the communication section. The data is temporarily stored in a queue on the server and processed by the application in turn. Table IV shows the specifications of the PCs used for the server and vehicle. Note that the synchronous method only applies to the vehicle PC. Also, since cars are considered to communicate with the dynamic map wirelessly, we have conducted a demonstration experiment using wireless communication by placing an edge server at a mobile phone base station. However, the proposed system is a dynamic map system, and the use of wireless communication is highly dependent on the communication method and conditions, and the uncertainties are large. Our dynamic map platform can be applied to any communication method, and better communication methods can be adopted as the network evolves. Therefore, in order to evaluate the proposed system in detail, the vehicle and the server were connected by a wired connection, eliminating the uncertainties of wireless communication.

TABLE IV. SERVER AND VEHICLE CONFIGURATION

OS	Ubuntu 16.04
CPU	8-core 16-thread (3.60 GHz)
Memory	16 GB
SSD	256GB
Communication method	Wired (Up to 1 Gbps)
Synchronous method(Vehicle only)	No

TABLE V. SIMULATION CONDITIONS

Number of lanes	56
Maximum number of vehicles per lanes	89
Speed	40 km/h
Vehicle length	4.7 m
Distance between vehicles	20 m
Total number of vehicles	4984

Figure 9 shows the road map used for the evaluation. We used the Manhattan model, which consists of alternating two-lane streets on one side and four-lane streets on the other. There are 56 lanes within a square range of 2205 m per side, with vehicles running at regular intervals in the opposite direction from the end of each lane. The specifications for this simulation are shown in Table V. The length of the vehicle was set to 4.7 m, and the distance between vehicles was set to 20 m.

VI. RESULT

A. Number of vehicle data to be sent and received

Figure 10 shows a comparison of the peak number of the data received by the server. We compared three possible instances. First, there is no retransmission by ACK and the transmission interval from the vehicle remains fixed at 100 ms. Second, there is a retransmission but the transmission interval remains fixed at 100 ms. Third, there is a retransmission and the transmission interval is adjusted by priority processing. By using the priority processing function, we were able to suppress the peak rate of the data received by the server to

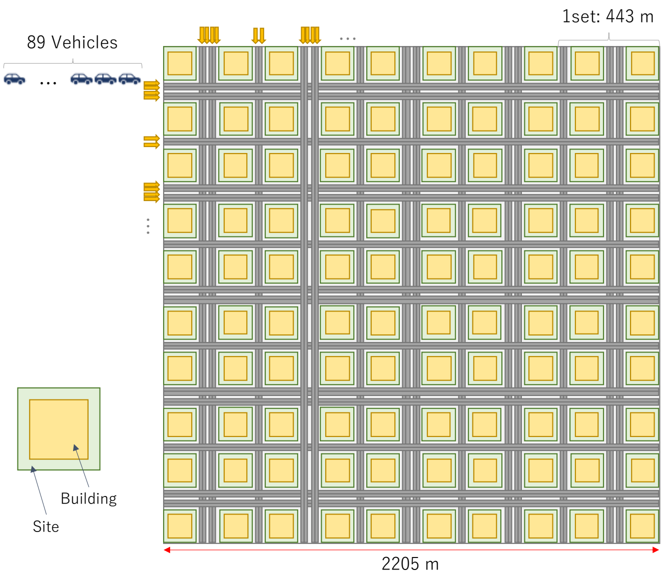

Figure 9. Road map used in the simulation

TABLE VI. PACKET LOSS RATIO

System	*Packet loss ratio*
No Resend & No Priority	0.006 %
Resend & No Priority	0 %
Resend & Priority	0 %

about 70 vehicles. Also, the number of data received by the system with resend is higher than the system without resend. In the case of no resend, this is because the vehicle is sending data at a high frequency and part of it is causing packet loss. Therefore, a resend function is used, and the number of data received is slightly increased. The packet loss rate for each system is shown in Table VI.

We also evaluated the rate at which the server sends and receives data. Figure 11 shows the reception and transmission rates when there is a retransmission with and without priority processing, respectively. The horizontal axis shows the elapsed time from when the first vehicle entered the road in the evaluation range. The vertical axis shows the rate of how much data the server is receiving and sending per second. In the absence of priority processing, the server cannot keep up with the data received from the vehicle, resulting in a processing delay. Therefore, the retransmission is not finished even after 400 seconds of transmission from the vehicle, and the convergence takes a long time. However, by using priority processing, we were able to reduce the rate of data transmission and reception in the server, in which both ended as soon as the transmission from the vehicle was completed without any processing delay.

B. Processing Latency and Scalability

The scalability of the three systems was evaluated by varying the number of lanes and the number of vehicles. In the Manhattan model presented in Section V, the total number of vehicles running during the simulation is 4984. In this case, no processing delay occurred in the system with priority processing, but processing delay occurred in the system without priority processing. Therefore, by varying the

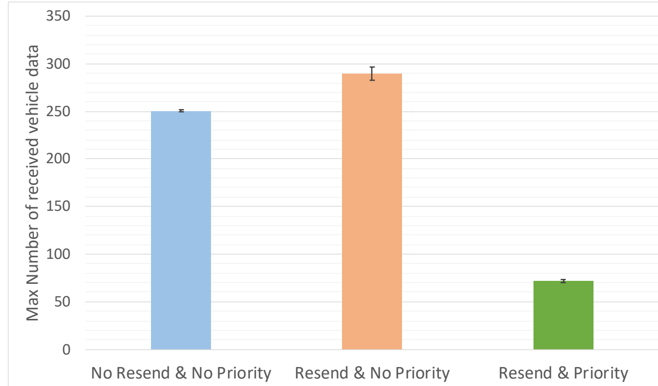

Figure 10. Maximum rate received by server

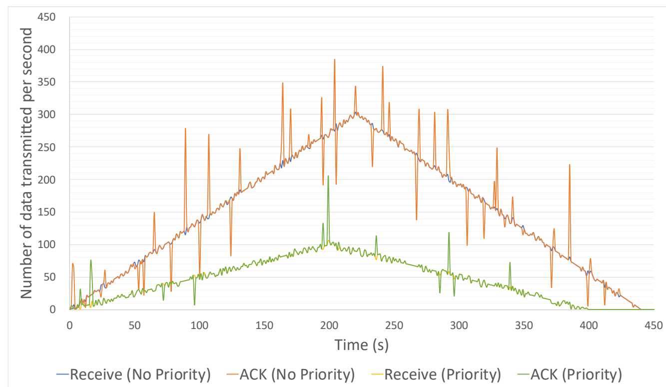

Figure 11. Processing delay time

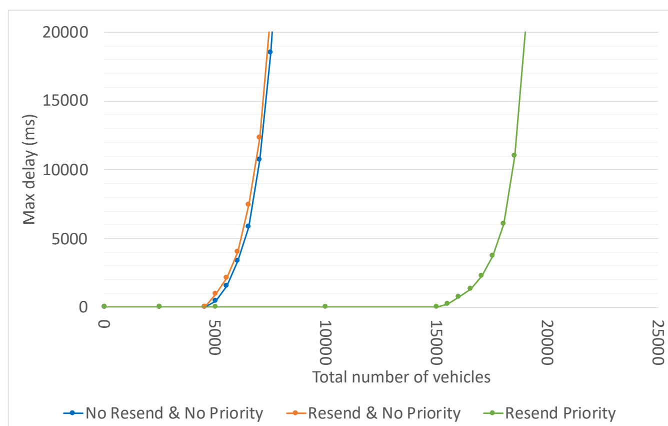

Figure 12. Impact of the number of vehicles on processing delay time

number of vehicles and the number of lanes, we adjusted the total number of vehicles in the simulation and evaluated the maximum processing delay for each. The evaluation results are shown in Figure 12. Scalability was greatly improved by using the priority processing function, which enabled us to process about 15,000 vehicles with low latency. The reason why the scalability is almost the same with respect to systems without the priority processing function, regardless of the presence or absence of resend, is that the packet loss rate remains very low even in systems without resend.

VII. Discussion

As shown in Figure 10, the amount of data transmitted by the vehicle is higher with retransmissions than without retransmissions. However, even if there is a retransmission process, the data volume can be significantly reduced by using priority processing, because the data can be reduced by adjusting the transmission interval on the basis of the Lane ID.

In addition, as shown in Figure 11, due to the processing delay and lack of priority processing, the server continues to receive data from the vehicle after about 400 s when transmissions other than retransmissions have completed. This is because the transmission interval of data from the vehicle is fixed at 100 ms, and the processing delay is caused by receiving data that exceeds the processing performance of the server. However, in the case of priority processing, the transmission and reception of the server ended at the same timing as the data transmission from the vehicle was completed, and no processing delay occurred. In Figure 12, the amount of data that the server needs to process is greatly reduced by using the priority processing function, which greatly improves the scalability of the dynamic map.

Dynamic maps for safe-driving support and automatic driving need to be communicated and processed with low latency. In addition, the server must be able to reliably receive data from a vehicle. Furthermore, the number of vehicles communicating with the server is expected to increase in the future. By using the retransmission function to ensure the reliability of the communication between a vehicle and server, and by using the priority processing function by adjusting the transmission interval, the amount of data received by the server can be reduced to about one-fifth of that of a system with a fixed transmission interval. This will also reduce processing delays and lead to smoother traffic flow.

VIII. Conclusion

In recent years, research and development for automatic driving has attracted much attention, but the range of recognition is limited due to the limitations of in-vehicle sensors. Therefore, research has begun on cooperative automatic driving, in which automatic vehicles share data obtained from sensors, etc., with the aim of improving safety and efficiency. In addition, dynamic maps, a common information and communication platform for the integrated management of shared sensor information, are under consideration. A vehicle always sends data to a server that manages the dynamic map, and the server runs applications for driving support and control on the basis of the data, so fast information processing is required. However, if data is continuously sent from vehicles to the server at high transmission intervals and many vehicles are managed by the dynamic maps on the server, communication congestion and processing load becomes a concern. In addition, the transmission interval of data from a vehicle required by the road characteristics varies in actual traffic environments. Therefore, congestion can be alleviated by adjusting the transmission interval of data from the vehicle in consideration of road characteristics. In this paper, a platform for a dynamic map consisting of a server and a vehicle is constructed. By implementing the retransmission function, we have achieved highly reliable communication even for UDP. In addition, a priority processing function that adjusts the transmission interval is implemented by setting the priority for each section of the lane (lane ID) where a vehicle is traveling on the basis of the road characteristics around the vehicle. We evaluated the amount of data sent and received by the server when there were no retransmissions, when there were resend and no priority processing by adjusting the transmission interval, and when there were resend and priority processing by adjusting the transmission interval. As a result, the maximum reception rate could be reduced by about 80%. We also measured the processing delay of the server and showed that it can be processed with low latency. These results show that the function built in this paper is effective in improving the efficiency of communication between vehicles and servers in dynamic maps.

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