V2X Communication Congestion Control Method based on Vehicle Flow Management

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Vehicle-to-Everything (V2X) communication is a key element in the efforts to realize the Intelligent Transport Systems (ITS) and automated driving society. In the practical application of automated driving, there are high expectations for the use of V2X communication as a method for extending and supplementing the information obtained by sensors, while maintaining autonomous control based on the vehicle's onboard sensors. In order to support this V2X communication, the 3rd Generation Partnership Project (3GPP) has developed specifications for Long Term Evolution (LTE)-V2X and New Radio (NR)-V2X. For NR, data communication with lower latency and higher reliability is expected compared to conventional LTE. The use of V2X communication has advantages such as the acquisition of blind spot information through vehicle information sharing, the provision of signal information, and the facilitation of traffic flow through travel mediation. However, on the other hand, there are some problems such as the communication quality cannot be guaranteed when vehicles are concentrated, such as poor connection and delay, and the coverage area of NR is smaller than that of LTE, making it difficult to cover all the vehicles. In this study, we propose a V2X communication congestion control method based on vehicle flow management to improve the efficiency of V2X communication. In order to confirm the effectiveness of the proposed method, we construct an evaluation environment and implement the distance-based routing method, the previous research method, and the proposed method using the traffic simulation software Vissim, and evaluate the transition of the number of connections in the coverage area and the number of vehicles that received the information during the evaluation period. The results show that when the traffic volume is high or there is not enough room for the number of connections in the coverage area, the system can provide more information to the vehicles with guaranteed communication quality compared to other methods.

Key words: V2X Communication, NR, Travelling Mediation

1. Introduction

V2X communication is one of the key elements in the efforts to realize ITS and an automated driving society[1,2]. Traditionally, narrow range communication called Dedicated Short Range Communication (DERC) has been the mainstream, such as Vehicle-to-Vehicle (V2V) communication, where a vehicle communicates with a vehicle within a range of tens to hundreds of meters, Vehicle-to-Infrastructure (V2I) communication, where a vehicle communicates with a traffic infrastructure, and Vehicle-to-Pedestrian (V2P) communication, where a vehicle communicates with a pedestrian. Recently, however, vehicle-to-network (V2N) communications, which mainly use cellular networks to distribute large amounts of data over a wide area, have been added to these, and are collectively called V2X communications. In the practical application of automated driving, there are high expectations for the use of V2X communication as a method to extend and supplement the information

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obtained by sensors, while maintaining autonomous control based on the vehicle's onboard sensors[3)].

To support this V2X communication, 3rd Generation Partnership Project (3GPP) has developed LTE-V2X specifications based on Long Term Evolution (LTE), a radio access technology specified for 4G, and NR-V2X specifications based on New Radio (NR), a radio access technology specified for 5G. In the case of NR, data communication with lower latency and higher reliability than conventional LTE is expected[4,5)].

In addition, dynamic map has been proposed as an information communication platform to superimpose and manage information collected by V2X communication on maps[6,7)]. A dynamic map is a collection of data that manages each state hierarchically by dividing traffic information into layers according to update frequency. This platform can be used to provide future information compared to DERC, for example, travelling mediation.

The use of V2X communication and dynamic map has the advantage of sharing vehicle information to obtain blind spot information, providing signal information, and facilitating traffic flow by travelling mediation. On the other hand, however, when there is a concentration of vehicles, communication quality cannot be guaranteed due to poor connections and delays, and the coverage area of NR is much smaller than that of LTE, with a maximum radius of 100 m, making it difficult to cover the entire area[8,9)].

Therefore, this research aims to improve the efficiency V2X communication by proposing a V2X communication congestion control method based on vehicle flow management, based on the issues of V2X communication described in the background. We also evaluate the transition of the number of connections to the base station using simulation and compare the proposed method with the distance-based routing method and the previous research method to check the conditions under which the proposed method is effective and the conditions under which the previous research method is effective. We also check how much more information can be obtained by the proposed method compared to the other methods under the effective conditions.

2. Related Research

Based on the problems in the previous chapter, the priority control method and the vehicle guidance method are mentioned as methods to improve the efficiency of V2X communication. In this chapter, these methods are explained.

2.1 *Priority control method*

Related research that aims to improve the efficiency of V2X communication by controlling the priority of communication is described. In Sugisaka's research, the frequency of information transmission is controlled according to the road environment and vehicle speed to improve the efficiency of communication[10)]. For example, they propose a method to increase the frequency of information transmission at intersections, where there are many dangerous elements and the surrounding information is needed, and to decrease the frequency of information transmission on straight roads, where there are no dangerous elements. In addition, they propose a method to increase the frequency of information transmission when the driving speed is high and decrease it when the driving speed is low. Next, in Kishida's research, the frequency of information transmission is controlled according to driving conditions to improve the efficiency of communication[11)]. This method sends information to vehicles that are moving and does not send information to vehicles that are stopped. Finally, in their research, Furukawa et al. have improved the efficiency of communication by controlling the frequency of information transmission based on the location of the vehicles in addition to the road environment[12)]. For example, depending on the vehicle's location, some vehicles overlap the detection range of the sensor with many other vehicles. On the other hand, some vehicles have less overlap. Therefore, this method prioritizes the collection of information on such vehicles. However, the problem with these studies is that the more vehicles are concentrated, the more information there is that is excluded due to low priority.

2.2 *Vehicle guidance method*

Related research aimed at improving the efficiency of V2X communication through vehicle guidance is described. As mentioned in the previous section, the coverage area of NR-V2X communication is small and it is difficult to cover all of the area. Therefore, for example, if the route is determined so that the distance is as short as possible, depending on the route, there may be a problem where information cannot be obtained along the way as shown in the Distance-based route in Fig. 1. As a solution to this problem, we have proposed a method to manage the coverage area information of base stations and vehicle information (location, route, etc.) on a dynamic map server, and to provide vehicles with routes that pass through many coverage areas based on the managed information[13]. This method increases the chance of passing through the coverage area, as shown in the route of vehicle guidance method in Fig. 1, and allows for efficient information collection.

However, depending on the conditions, such as heavy traffic, this method does not guarantee the quality of communication, such as poor connection and delay, because a large number of vehicles may be concentrated in the coverage area by the provided route[8].

3. Proposed Method

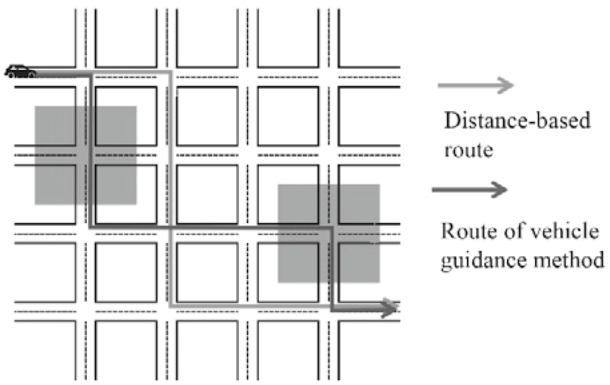

Fig. 1. Problems caused by small coverage area.

In this chapter, we describe the outline and assumptions of the proposed method, the structure of the method, and the flow of route determination in the travelling mediation server used in the method.

3.1 *Outline*

Based on the problems of the related research in the previous chapter, we propose a method to predict the next vehicle location based on the vehicle information collected from the vehicle, such as location and route, and to periodically adjust the vehicle's movement so that the maximum number of connections is not reached, while performing travelling mediation to pass through more coverage areas. The maximum number of connections refers to the maximum number of vehicles that can maintain communication quality in each coverage area. If the number of vehicles in the coverage area exceeds this number, the communication quality will be insecure.

3.2 *Assumptions*

The assumptions for this study are as follows.

- All vehicles are able to communicate with the dynamic map server through cellular lines.
- All vehicles generate the expected route to the destination at the time of departure.
- Each base station has a coverage area and a maximum number of connections where the communication quality is maintained.
- All vehicles follow the requested route.
- All vehicles in the coverage area are connected to the cellular line.

3.3 *Structure of the method*

The structure of the method is shown in Fig. 2. The

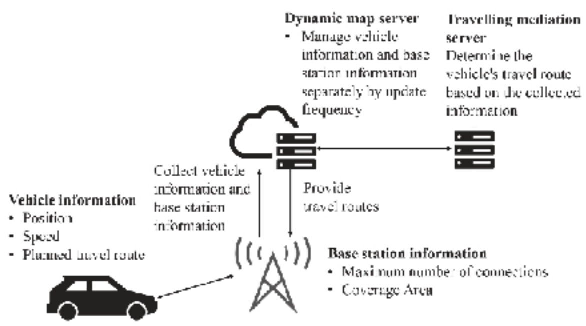

Fig. 2. Structure of the method.

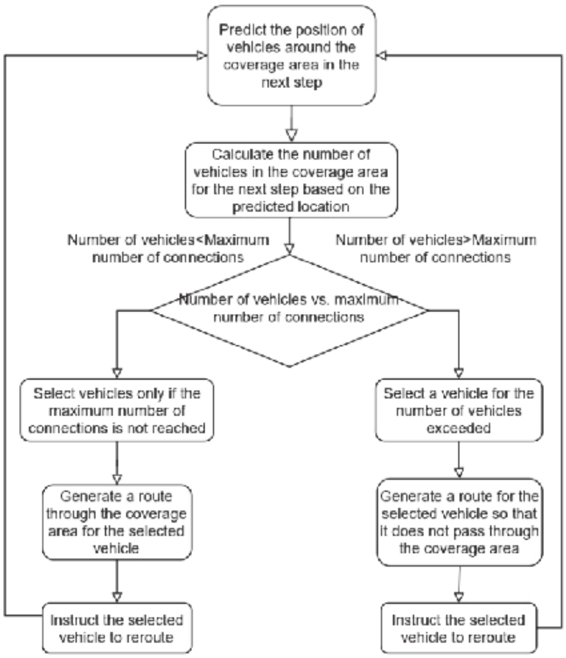

Fig. 3. Flow of route determination for travelling mediation server.

vehicle and infrastructure periodically send vehicle and base station information to the dynamic map server. The collected information is managed by the dynamic map server, and the travelling mediation server uses the information to determine the driving route. The flow of route determination is shown in Fig. 3. Once the route is determined, the route information is provided to the vehicle through a dynamic map server.

4. Evaluation

This chapter provides an overview of the evaluation, the evaluation environment, and the details of each evaluation, followed by an explanation of the implementation details of each method to be compared in the evaluation.

4.1 *Overview*

An evaluation environment was established using the traffic simulation software Vissim, and the transition in the number of connections and the number of vehicles that were able to obtain information during the evaluation time were evaluated by comparing the distance-based

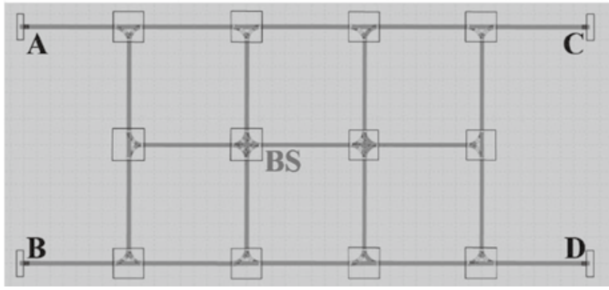

Fig. 4. Road model in evaluation.

routing method, the previous research method, and the proposed method.

4.2 *Evaluation environment*

The traffic simulation software Vissim was used to construct the road model as shown in Fig. 4. The length of each square is 180 m. Vehicles have leftward priority at cross intersections and straight ahead priority at T-intersections. The speed of the vehicle is 60 km/h on straight roads and 10 km/h near intersections. However, when the vehicle is in the coverage area and information is available, the vehicle travels at a speed of 60 km/h, except for curves, because the surrounding information is available. The base station was set up at the intersection of the locations marked BS in Fig. 4, and the coverage area was set to a radius of 100 m around the base station. The maximum number of connections was increased from 20 to 20 in intervals, and it was checked under which conditions the previous research method was effective and under which conditions the proposed method was effective for the inflow volume of vehicles at the origin. In the following sections, each evaluation is explained in detail.

4.3 *Transition of the number of connections*

The first part of the evaluation, the transition of the number of connections, will be explained. The vehicle departs from locations A, B, C, and D in the road model Fig. 4, and has the following destinations.

- Origin : A → Destination : D
- Origin : B → Destination : C
- Origin : D → Destination : A
- Origin : C → Destination : B

The evaluation starts with the vehicle flowing from

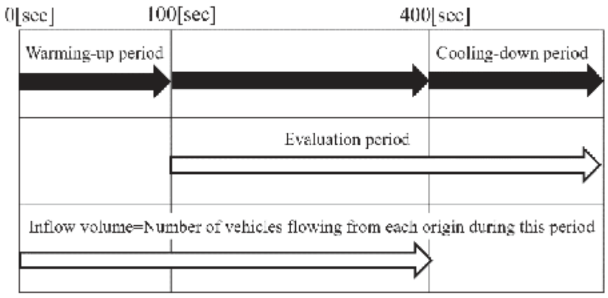

Fig. 5. Breakdown of evaluation period.

each origin for 100 seconds beforehand, and with the vehicle spilling out onto the road. This time is defined as the warming-up period. After the start of the evaluation, he vehicle is allowed to flow for 5 minutes. Then stop the flow of vehicles and continue until all vehicles have reached the destination. This time is defined as the cooling-down period. The evaluation period is defined as the five minutes after the start of the evaluation plus the cooling-down period. The number of vehicles flowing during the warming-up period and the 5-minute period after the start of the evaluation until the inflow of vehicles stops is defined as the inflow volume. The breakdown of the evaluation period is shown in Fig. 5.

The evaluation target is the transition of the number of connections in the coverage area. If the number of connections is always within the range of less than the maximum number of connections during the evaluation time, the objective of this research, which is to provide more information to the vehicles, can be met. Evaluations were conducted for five different inflow volume: 20, 40, 60, 80, and 100. In addition, as mentioned in the previous section, the maximum number of connections was varied by increasing the number of connections from 20 to every 20 for each inflow volume to confirm the conditions under which the previous research method is effective and the conditions under which the proposed method is effective.

4.4 *Comparison of the number of vehicles that received the information*

This section describes the comparison of the number of vehicles that received the information, the second part of the evaluation. For the conditions where the proposed method is effective, we perform this evaluation to see how many vehicles actually receive the information compared to other methods. The vehicles that passed through the coverage area during the evaluation period with the guaranteed communication quality less than the maximum number of connections are considered as the vehicles that received the information, and the total number of vehicles is compared between the proposed method and other methods. In the next section, we explain the implementation of each method compared in the evaluation.

4.5 *Route information management*

Before explaining the details of the implementation of each method in the next section, we will explain how to manage the routing information used in all the methods in the evaluation. In Vissim, as shown in Fig. 6, each intersection is surrounded by an area called Node, and each section is managed as an Edge, which is divided by the area. When the vehicle departs from the origin, the route information from the origin to the destination is generated in this form. In subsequent explanations of the implementation of each method, we will refer to the Edge in the straight-line section, shown in green in Fig. 6, as the straight-line Edge, and the Edge in the branching section, shown in yellow, as the branching Edge.

4.6 *Distance-based routing method*

The distance-based routing method is a method to select a route based on distance so that the distance is as short as possible. This section describes the implementation of this distance-based routing method.

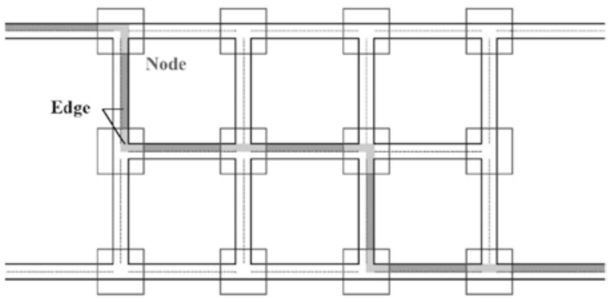

Fig. 6. Manage routes in Vissim.

For this method, we implemented it using Vissim parameters; in Vissim, the path selection depends on the following three things.

- Travel time
- Travel distance
- Economic cost of the route (if toll roads are used)

Since this method selects a route based only on the travel distance, we set the cost parameter to depend only on the travel distance. In this state, only the shortest route is selected, so we set the system to search for alternative routes and avoid selecting a detour route. With these settings, the vehicle randomly decides on a route, excluding detours, to reach the destination when using this method.

4.7 *Previous research methods*

In this method, a route through the coverage area, i.e., Node0, is set and provided to the vehicles in the straight-line Edge that can reach the coverage area depending on the branch (Target Edge) among the straight edges that lead to the surrounding Nodes (Node 1, Node 2, Node 3, Node 4) as shown in Fig. 7. After passing through Node0, the shortest path to the destination was set. For example, as shown in Fig. 7, if a vehicle in the Edge to be rerouted has originally set a dotted line route (Before rerouting), a new straight-line route (After rerouting) will be generated and provided. The vehicle to be rerouted was determined, and the timing and frequency of invoking the rerouting process were adapted to the proposed method described in the next section.

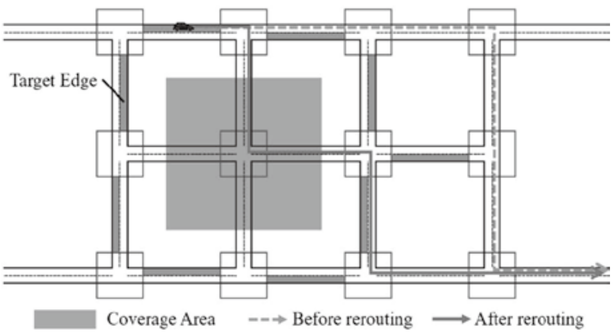

Fig. 7. Rerouting Edge and example of route for previous research method.

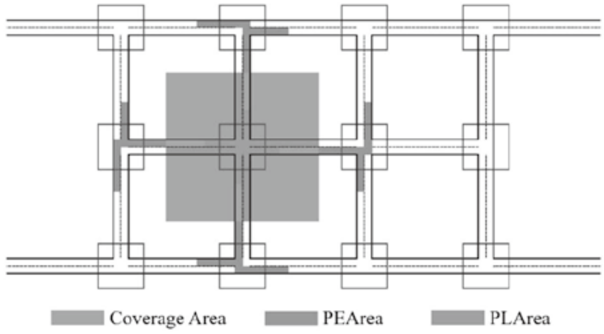

Fig. 8. Areas that may enter (PEArea) and leave (PLArea) the coverage area in the next step.

4.8 *Proposed method*

The implementation of the proposed method is described. First, the method used in this study for vehicle prediction is explained, followed by an explanation of the judgment and the behavior of the vehicle after the judgment.

4.8.1 *Vehicle location prediction*

This section describes the method of vehicle location prediction used in this evaluation. First, we define the areas that may enter the coverage area in the next step and the areas that may leave the coverage area in the next step as shown in Fig. 8. Thereafter, the area that may enter the coverage area in the next step is called PEArea, and the area that may leave the coverage area in the next step is called PLArea. In this case, the step interval is the time when all vehicles currently in the PEArea have entered the coverage area. Therefore, as shown in Fig. 9, we considered that all vehicles would enter the coverage area if the vehicle located at the farthest position from the PEArea coverage area entered the coverage area, and we

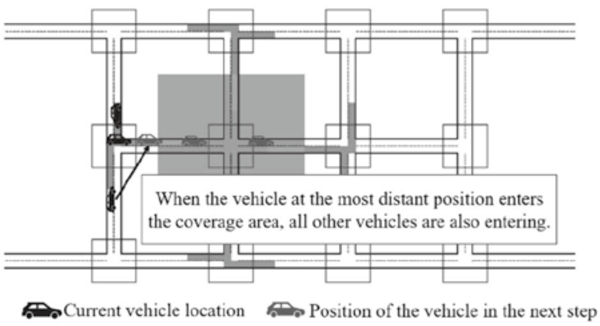

Fig. 9. Defining the set value of the step interval.

set the step interval as the time it takes for a vehicle to travel the longest distance of the PLArea. The PEArea, PLArea, and step intervals were determined by empirical rules based on prior simulations, and have been fixed and used in subsequent evaluations. Using this PEArea and PLArea, the number of connections in the coverage area in the next step is calculated as follows.

$$VN_{n+1} = VN_n - VN_{PEArea} + VN_{PLArea} - W \quad (1)$$

VN_{n+1} refers to the estimated number of connections in the coverage area in the next step, VN_n refers to the number of connections in the current coverage area, and VN_{PEArea} refers to the vehicles in the current PEArea that are expected to enter the coverage area in the next step based on the route information. The VN_{PLArea} refers to the number of vehicles in the current PLArea. If a long queue occurs at the intersection where we are going, we assume that there will be vehicles that do not leave the coverage area in the next step, and perform the following process.

$$VN_{PLArea} = VN_{PLArea} - \left(VN_{QPLArea} + QN - ECN\right) \quad (2)$$

where $QN > 4, ECN < QN + VN_{QPLArea}$.

The QN refers to the number of vehicles in the queue near the intersection, and based on empirical results from prior simulations, it is determined that a long queue is generated when the number of vehicles in the queue is greater than four. For example, as shown in Fig. 10, when a long queue occurs at the Queue Point in the figure, ECN refers to the number of vehicles that can be placed in the ECNArea in the figure. W in Equation (1) is a weight provided to compensate for the difference between the prediction and the actual result that occurred when the simulation was conducted. The numerical value of this parameter was determined by conducting several simulation tests before the evaluation and comparing the predictions with the actual results, and was fixed in subsequent evaluations.

4.8.2 *Judgment and the behavior of the vehicle after the judgment.*

This section describes the judgment after the prediction of the number of connections for the next step and the behavior of the vehicle after the judgment. If the number of connections in the coverage area at the next step (VN_{n+1}), which is calculated by the vehicle location prediction, is less than the maximum number of connections, select vehicles from the vehicles in front of the branch that can be rerouted (Rerouting Area in Fig. 11) only to the extent that the number of connections does not exceed the maximum number of connections. However, all vehicles to be selected are on routes where the next route does not connect to the coverage area. We then provide the selected vehicle with a route that passes through the coverage area as in the previous research method. If the number of connections in the coverage area in the next step (VN_{n+1}) is greater than the maximum number of connections, select only the excess number of vehicles from those in front of the branch that can be rerouted (Rerouting Area in Fig. 11). However, all vehicles to be selected are on routes where the next route connects to the coverage area. And provide the selected vehicle with a route that does not pass through the

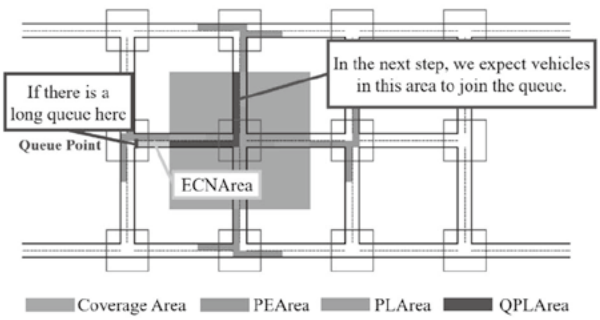

Fig. 10. Handling of long queues.

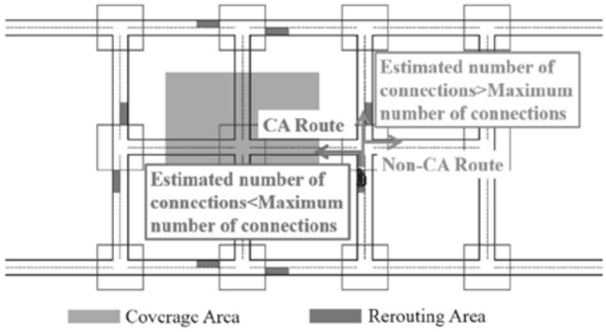

Fig. 11. Behavior of the vehicle after the judgment.

coverage area. In other words, if a vehicle is in the location shown in Fig. 11, if the predicted number of connections is less than the maximum number of connections, the route will be changed to go in the direction of CA Route for vehicles that were scheduled to go in one of the directions of Non-CA Route next, and if the predicted number of vehicles is greater than the maximum number of connections, the route will be changed to go in one of the directions of Non-CA Route for vehicles that were scheduled to go in the direction of CA Route next. This process is called every 4 seconds, which is the shortest interval that does not cause leaks in the rerouted vehicles. However, when the vehicle location is near the destination, this process is not performed because a large detour may occur. For example, as shown in Fig. 12, if a vehicle has been on the dotted line route and a reroute occurs in an area where a reroute may occur (red area) toward the coverage area, a detour will occur as shown by the straight line. Therefore, in order to avoid this event, this process is not triggered when the current vehicle is within five Edges of the destination, including straight branches.

5. Results and Discussion

In this chapter, we review the results of the evaluation and discuss the proposed method based on the results.

5.1 *Transition of the number of connections*

As shown in the graph in Fig. 13, when the inflow volume is less than 60 and the maximum number of connections is 20 or more, when the inflow volume is 80 and the maximum number of connections is 40 or less, or when the inflow volume is 100 and the maximum number of connections is 60 or more, the previous research method is effective without exceeding the maximum number of connections. However, when the inflow volume is less than 80 and the maximum number of connections is 20, or when the inflow volume is 100 and the maximum number of connections is 20 or 40, there are times when the maximum number of connections is exceeded, as shown in Fig. 14. Therefore, in this case, the proposed method is effective because the

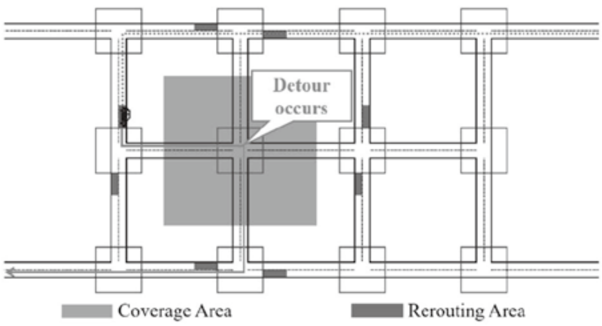

Fig. 12. Example of detour occurrence.

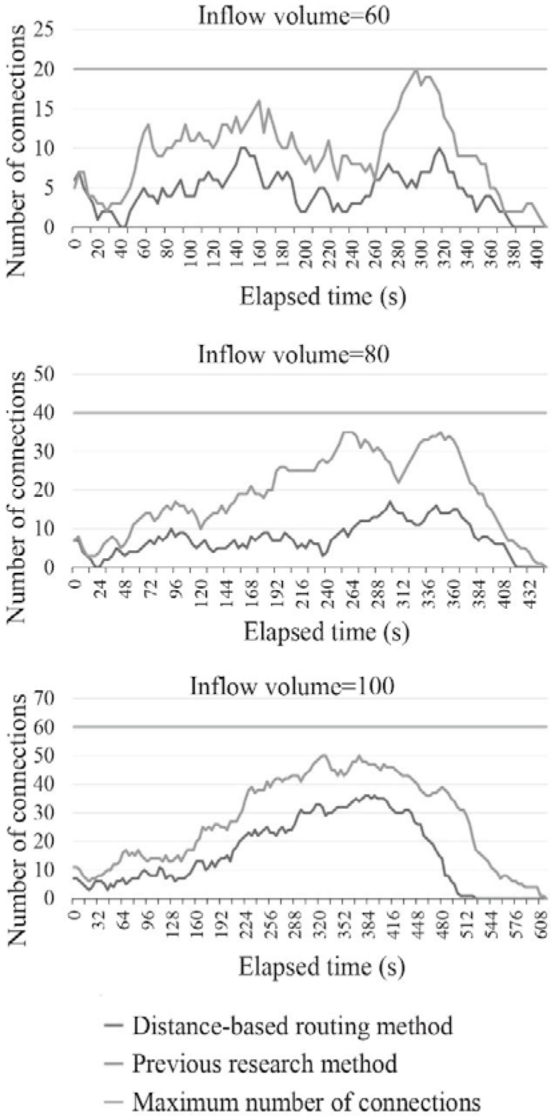

Fig. 13. Transition in the number of connections under conditions where the previous research method is effective.

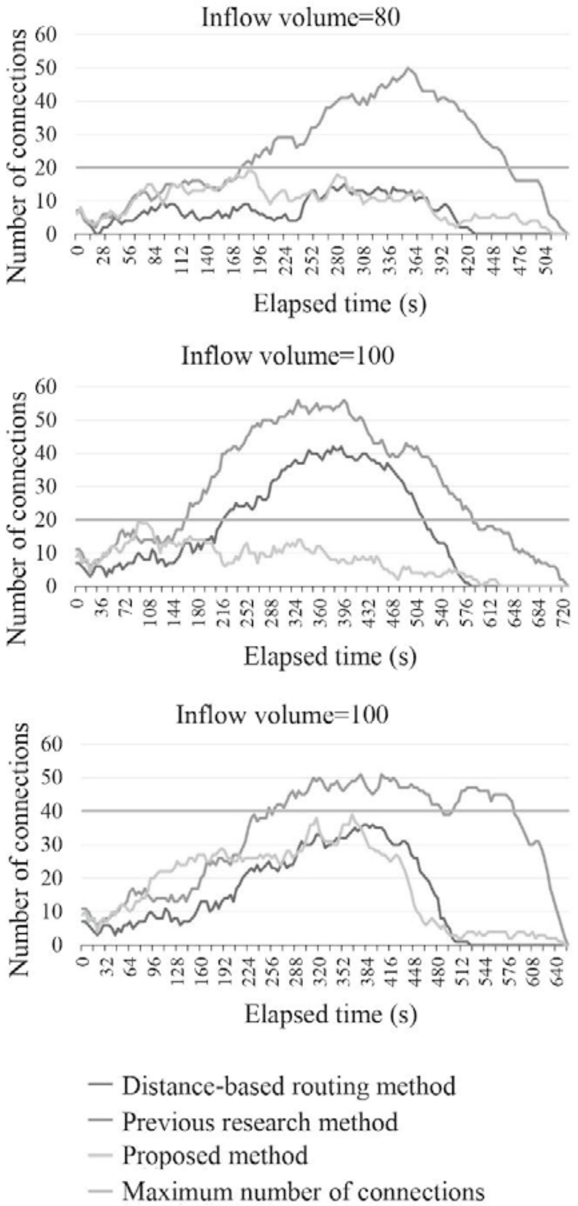

Fig. 14. Transition in the number of connections under conditions where the proposed method is effective.

previous research method will cause problems in terms of communication quality. Looking at the transition of the number of connections of the proposed method in the graph of Fig. 14 again, it can be confirmed that the proposed method does not exceed the maximum number of connections under any condition and obtains information stably compared to other methods. Therefore, under these conditions, our method is able to receive information while guaranteeing the communication quality compared to other methods.

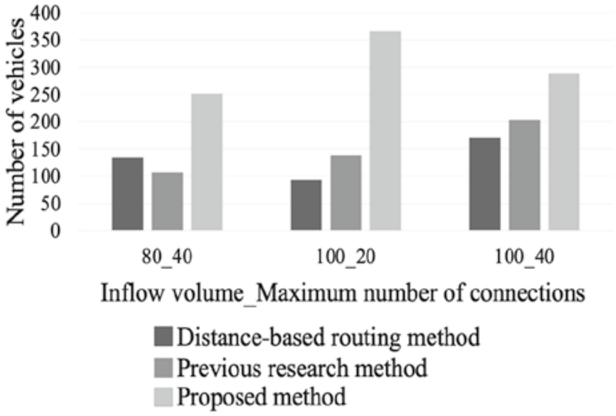

Fig. 15. Comparison of the number of vehicles that received the information.

5.2 *Comparison of the number of vehicles that received the information*

We compared the number of vehicles that received the information during the evaluation period under the condition that the proposed method is effective. The results are shown in Fig. 15. It can be seen that the proposed method can receive the most information in all conditions. Therefore, by considering the congestion situation, the proposed method can receive more information than the previous research method in such a heavy traffic situation.

5.3 *Future work*

Thus, the proposed method was found to be effective in the case where the previous research method does not work effectively, such as when the traffic volume is high. However, as can be seen from the graph of the transition of the number of connections, there are times when there is no problem in the communication quality even if more vehicles are led to the coverage area than the current situation. This is because the proposed method still has room for improvement in predicting the location of vehicles. For example, the PEArea and PLArea are fixed based on the empirical results of prior simulations, but in reality, they change fluidly, so there is still room for improvement in location prediction, such as periodically changing these areas based on the status of surrounding vehicles. If such improvements are made, the effectiveness of the method can be further demonstrated.

6. Conclusion

V2X communication is a key element in the efforts to realize ITS advancement and an automated driving society. V2X communication has the advantage of sharing vehicle information to acquire blind spot information, providing signal information, and facilitating traffic flow through driving mediation. However, on the other hand, there are problems such as the communication quality cannot be guaranteed when there is a concentration of vehicles, such as poor connection or delay, and the coverage area of NR is much smaller than that of LTE, with a maximum radius of 100m, making it difficult to cover everything.

In response to these problems, methods of V2X communication priority control and methods of guiding vehicles to efficiently pass through coverage areas have been proposed, but the former has the problem that the more vehicles are concentrated, the more information exists that is excluded because of its low priority, while the latter does not take into account the problem of communication quality when vehicles are concentrated as a result of being guided to the coverage area. Therefore, based on these problems, this study aims to improve the efficiency of V2X communication by using vehicle information such as location and route collected by V2X communication to guide vehicles so that they do not concentrate in order to avoid vehicle congestion in order to guarantee communication quality while efficiently collecting information as in the vehicle guidance method.

In this method, the maximum number of vehicles that can guarantee the communication quality in the coverage area is defined as the maximum number of connections, and we proposed a method to control the number of vehicles in the coverage area (i.e., the number of vehicles connected to the communication) by using the location prediction of vehicles so that the number of vehicles in the coverage area does not become larger than the maximum number of connections.

In order to confirm the effectiveness of the proposed method, we built an evaluation environment and implemented the distance-based routing method, the previous research method and the proposed method using the traffic simulation software Vissim, and evaluated the transition of the number of connections in the coverage area and the number of vehicles that received the information during the evaluation period.

As a result, it is found that the previous method is effective when the traffic volume is low or the number of connections in the coverage area is sufficient. However, in the opposite case, where the number of connections in the coverage area exceeds the maximum number of connections that can maintain the communication quality, the proposed method is the most effective. The number of vehicles that received the information was also found to be the highest for the proposed method. In other words, it is shown that our proposed method can provide a route that can provide more information to the vehicle with guaranteed communication quality compared to other methods.

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