Controlling Sensor Data Dissemination Method for Collective Perception in VANET

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***Abstract*—Vehicles can expand its own perceptual range about road traffic by collective perception technique for sharing sensor data about objects in vicinity among the neighbors by using Vehicle-to-Vehicle communication. In high vehicle density, however, packet collisions and the hidden terminal problem make it difficult to deliver messages containing the sensor data. To ensure delivering the useful sensor data for avoiding collision accidents, we proposed the strategy of a method to control the transmission frequency of sensor data based on the positional relationship of vehicles and the road structure in order to improve the surrounding awareness of vehicles in previous our work. In this paper, based on the strategy, we propose the detail of the strategy, the scheme for automatically select vehicles with a high probability to broadcast sensor data, method and evaluate the effectiveness of the method through simulations compared with a related work. This method is effective for avoiding collision accidents because vehicles can perceive the presence of other vehicles while reducing radio traffic.**

I. Introduction

Road traffic perception applications in today's Advanced Driver Assistance System (ADAS) applications provide the driver with support for mainly collision avoidance to obstacles such as other vehicles, pedestrians and buildings. The support is based on detecting the presence of a road participant by on-board sensors, e.g. RADAR, LIDAR, camera etc.. If a vehicle detects the presence of an object with a collision risk to the vehicle by the sensors, safety applications of ADAS alert the risk to the driver.

Vehicles with ADAS using the Vehicle-to-Vehicle (V2V) communication function are in service in some regions of Japan. By using V2V communication, the vehicles can expand their perception area for traffic wider than when they use only their own on-board sensors. Vehicles equipped with the V2V communication function (hereinafter referred to V2V-equipped vehicles) periodically broadcast messages (hereinafter referred to beacons) to notice its presence to the surrounding vehicles in Vehicular Ad-hoc Network (VANET) [1]. The beacon contains the status information of the sender such as position, speed and direction. A vehicle that has received beacons can notice the presence of the sender vehicles and use them for safety applications.

However, it remains difficult for V2V-equipped vehicles to know the presence of non-V2V-equipped vehicles that are out of the field-of-view of the sensors. Additionally, the number of V2V communication partners is insufficient for safety applications using V2V communication in the stage of introducing V2V-equipped vehicles. That is a way of making a V2V-equipped vehicle to perceive the presences of other vehicles including non-V2V-equipped vehicles even if the number of V2V-equipped vehicles is low is required.

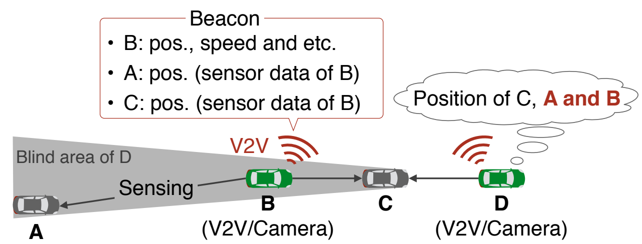

Fig. 1. Perception of the presence of a car being out-of-sight using by collective perception

Collective perception technique enables V2V-equipped vehicles to alleviate these issues. The concept of collective perception envisions sharing of sensor data obtained by perception sensors such as RADAR, camera, LIDAR, etc. among road participants [2]. Vehicles periodically transmit the sensor data including the positions of objects sensed by the on-board sensors. Fig. 1 shows that V2V-equipped vehicles are sharing beacon containing sensor data. By receiving the sensor data, as shown in the figure, vehicles can realize the position of an object in the data. [3] reports that a car can realize the presence of an obstacle installed on a curved road at about three times earlier than without collective perception by real-world testing.

On the other hand, collective perception suffers from scalability issues as the network grows. V2V communication standards in the U.S., Europe and Japan is based on the IEEE 802.11 wireless LAN technology [4]–[6]. The V2V communication uses Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) as the access mechanism [7]. In dense traffic situations, the communication channel may be overloaded because vehicles transmit beacons at a constant interval. As a consequence, the reception rate of beacons deteriorates due to collisions of beacons [8].

We have proposed a strategy to control a frequency of transmission of sensor data based on the positional relationship of

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vehicles and the road structure in order to keep the surrounding awareness of vehicles sufficient high for safety applications even if traffic density is high in our previous work [9]. We have investigated the perception area of a vehicle using collective perception by simulations of two scenarios: i) part of vehicles selected according to the proposed strategy transmit beacons with relatively higher priority than others and ii) all vehicles transmit beacons at a constant frequency, 10Hz. The results showed that vehicles can perceive a wider area while keeping lower communication traffic in (i) scenario than (ii) scenario.

In this paper, based on the proposed strategy, we propose a method for automatically selecting vehicles with a high probability to broadcast sensor data. Additionally, we demonstrate the effectiveness of the method through simulations in a dense highway scenario. In the scenario, each vehicle dynamically calculates beacon transmission priority and beacon transmission frequency based on the priority.

The feature of the proposed method is that vehicles covering the blind area of other vehicles more widely by sensors transmit sensor data with a high priority (blind area means an area which a vehicle cannot detect by sensors). For this feature, the method has two advantages: first, reducing communication traffic and, secondly, disseminating more useful sensor data about vehicles in non-line-of-sight regions for safety applications within allowable latency. The second advantage, as well as the first one increase the safety of a driver because vehicles need to realize positions of other vehicles with a collision risk to the ego within allowable latency to avoid the collision [10].

The remainder of this paper is organized as follows. In Section II, we present work related to the transmission control of beacons in VANET. Section III proposes the data transmission control method based on the positional relationship of vehicles and the road structure. We describe how vehicles calculate the positional relationship in a decentralized manner in our method in Section IV In Section V, we evaluate the effect of surrounding awareness of vehicles by using our proposed method by simulation of a simple highway scenario. Finally, Section VI concludes this paper and presents the future direction of this study.

II. RELATED WORK

Methods for dynamically controlling beaconing in vehicular networks for ADAS have proposed in order to reduce packet collisions and to improve the beacon reception rate in high vehicle density environments. The authors of [11] propose Distributed Fair Power Adjustment for Vehicular Network (D-FPAV) that controls the transmission power of beacons based on the current channel utilization. Vehicles with D-FPAV share its transmission power of beacons among them and calculate the transmission power based on the transmission powers of other vehicles. Vehicles increase the transmission power until the beaconing load exceeds the predefined maximum of network load. As a result, D-FPAV can keep network load below a given constant and vehicles can use channels fairly.

Sommer et al. propose Adaptive traffic beacon (ATB) that controls the transmission frequency of beacon based on channel quality and a message priority [13]. Vehicles estimate the channel quality by means of three metrics which are indicative of network conditions in the past, present and future respectively. To estimate the network conditions in the past, present, and future, vehicles calculate the number of collisions on the channel, the Signal-to-Noise Ratio (SNR) on the channel, the number of neighbors respectively. If a vehicle estimates that the channel is overloaded, the vehicle extends the beaconing interval. On the other hand, if a vehicle estimates that the channel is still underutilized, the vehicle shortens the beaconing interval. Vehicles calculate the message priority that is derived from two metrics: the distance between an event and the position of the vehicles, and the age of a message. ATB allows messages that have been sent by vehicles closer to an event and newer information to spread faster.

European Telecommunications Standards Institute (ETSI) standardizes Decentralized Congestion Control (DCC) algorithm as a part of medium access control (MAC) method of Vehicle-to-X (V2X) in Europe [12]. DCC controls the transmission parameters (e.g., power, frequency, datarate, etc.) of beacons based on a Channel Busy Ratio. Vehicles estimate the current level of channel utilization and control the transmission parameters according to the level. Whenever an average received signal level in a vehicle exceeds a predefined threshold, the vehicle regards the current level of channel utilization as busy. In this case, the vehicle controls the transmission parameters so that vehicles in the vicinity can receive beacons stably. On the other hand, if the vehicle does not regard the current level of channel utilization as busy, vehicles control the transmission parameters to deliver beacons to farther vehicles at a higher frequency.

These methods, however, do not take into account the perception of the presences of vehicles by the collective perception technique. Vehicles using collective perception transmit larger size of beacons than vehicles not using collective perception because the former need to send sensor data regarding to their surrounding environment in addition to its own status information. Such sensor data may not be included in one IEEE 802.11 frame. Therefore, these methods may not work well if the size of messages is large. These methods, additionally, are largely influenced by the vehicle density. If the vehicle density is high, the transmission opportunity of packets even from vehicles at an important location such as at the head of a cluster, where a vehicle can perceive obstacles in front of the cluster, could decrease just as packets from other vehicles. In order to increase the transmission opportunities of such beacons from vehicles at important locations and delivery them with short transmission delay, we propose a method to control the transmission frequency based on the positional relationship of vehicles and the road structure.

III. BEACON TRANSMISSION CONTROL

In this section, we briefly introduce our method for controlling beacon transmission frequency according to the positional relationship of vehicles and road structure. We first present the basic strategy of the method described in our previous work

[9]. Then, we explain how to calculate the beacon transmission frequency.

A. Basic Strategy

We assume that V2V-equipped vehicles and non-V2V-equipped vehicles on a road and the V2V-equipped vehicles recognize the presences of other vehicles by the collective perception technique. We, additionally, assume that each vehicle has a LIDAR to detect the 360-degree view of its surrounding objects.

We designed the proposed method so that sensor data with high importance can be disseminated frequently. Sensor data about the position of an obstacle that a vehicle cannot directly detect the presence is important for ADAS of the vehicle if the obstacle is in the vicinity of the vehicle and in its moving direction of the vehicle. Because ADAS of the vehicle can notice driver the risk of collision to the obstacle if the vehicle has received the sensor data and ADAS of the vehicle detects that the collision risk is high. Hence, in our method, the wider the area not covered by sensors of other vehicles, the higher the importance of the sensor data.

B. Calculation of Beacon Interval

Vehicles with our proposed method calculate beacon transmission interval I derived from two priorities: i) R is the priority derived from the relative positional relationship with other vehicles and ii) S is the priority derived from a position around the road structure. The importance of sensor data is higher, R and S of a vehicle having sensor data are higher. R and S range in the interval (0, 1]. Vehicle continuously adapts the beacon interval between the minimum beacon interval I_{min} and the maximum beacon interval I_{max} according to

$$I = \min\left(\frac{I_{\text{min}}}{R \cdot S}, I_{\text{max}}\right). \tag{1}$$

That is, if the importance of sensor data is higher, the sensor data is transmitted by a vehicle more frequently.

C. Priority Assignment Rules

In order to disseminate important sensor data for ADAS, in our method, vehicles having such sensor data transmit beacons with a high priority than others (i.e, a chance of beacon transmission of the vehicles is more than others). In this subsection, we briefly describe the relative position of vehicles with such important sensor data in a cluster of vehicles and the relative positions of vehicles with such sensor data in a road structure. The detail of the basic ideas of selecting vehicles with a higher beacon transmission priority is described in our previous work [9]. We define a cluster as a group consisting of V2V-equipped and non-V2V-equipped vehicles that are traveling the same direction and keeping the inter-vehicle distances less than a given distance.

The positional relationship of vehicles that can have important sensor data in a cluster and in the vicinity of merging lanes is the positional relationship of colored (red, blue, yellow, and green) cars shown in Fig. 2. We set a constant, OL, the number of lanes that a vehicle observed by a LIDAR with high accuracy. The detection accuracy of a perception sensor such as LIDAR drops when the distance between a sensor and a detection target is long. To share only highly accurate sensor data obtained by an on-board sensor among vehicles, in our method, vehicles on a lane at OL lanes away from a vehicle having high priority also have a high priority. The colored cars in Fig. 2 have important sensor data and transmit beacons with a higher priority than gray cars. Specifically, vehicles satisfying the following condition of position obtain higher priority than other vehicles.

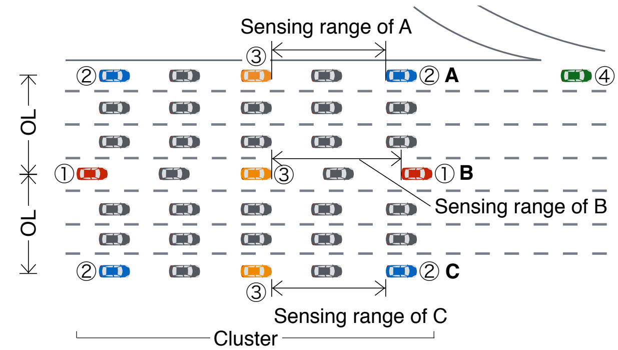

Fig. 2. Positional relationship of cars that can have important sensor data. Colored cars have such sensor data.

1) The head or the tail vehicle of a cluster (red cars in the figure).
2) The head or the tail vehicle on a lane at OL lanes away from the vehicle satisfying (1) (blue cars in the figure).
3) A vehicle located behind at least a sensing distance away from a vehicle having high priority in the front of the vehicle (yellow cars in the figure).
4) A vehicle near a merging point of merging lanes (green cars in the figure).

The reason why vehicles satisfying (1) or (2) obtain a high priority is that their on-board sensor coverage can cover an area in front of the cluster or the behind of the cluster. The reason of that vehicles satisfying (3) obtain a high priority is that they may detect the presence of a vehicle approaching the cluster from out of the sensing range of vehicles satisfying (1) or (2). Vehicles satisfying (4) obtain a high priority since they can directly detect the presence of vehicles on merging lanes even if there is an obstacle between the merging lanes.

IV. Decentralized Calculation of Beacon Transmission Priority

Vehicles, in our proposed method, calculate the beacon interval based on their priorities. In this section, we explain how vehicles calculate their priorities in a decentralized way. Vehicles calculate two priorities: R derived from the relative positional relationship of vehicles and S derived from the position of a vehicle on a road structure.

A. Positional Relationship-based Priority

Vehicles calculate R derived from the relative position among them to calculate the transmission frequency of beacons. In this subsection, we first describe the definitions of the relative position in a cluster. Then, we describe how vehicles identify the relative position in a cluster and calculate R.

1) Definitions of Positional Relationship: We define the relative position of vehicles in a cluster as follows.

- **Cluster head**. A vehicle moving at a position where no vehicles traveling in the same direction of the vehicle on the multiple lanes in front of the vehicle L_{front} [m].
- **Cluster tail**. A vehicle moving at a position where no vehicles traveling in the same direction of the vehicle on the multiple lanes in the behind L_{behind} [m].
- **Line head**. A vehicle moving at a position where no vehicles exist in front of the vehicle L_{front} [m].
- **Line tail**. A vehicle moving at a position where no vehicles exist in the behind of the vehicle L_{behind} [m].
- **Cluster head/tail assistant**. A line head on the lane at OL lanes away from the lane where cluster head/tail exist.
- **Cluster mid**. A vehicle moving at the behind at least a sensing distance away from a vehicle having a high priority in the front of the vehicle.
- **Ordinary vehicle**. A vehicle that does not apply to the above.

2) Identifying of Relative Position of Vehicles: Each vehicle identifies its relative position in a cluster by using its own on-board sensor data and data containing beacons it has received. We assume that vehicles transmit a beacon containing sensor data, the sensing range of LIDAR and its own relative position. We, furthermore, assume that vehicles know the ID of their current lane and moving direction.

Vehicle i identifies its positional relationship as follows.

- **Cluster head/tail:** Vehicle i knows other vehicle j's position P_j and direction D_j based on data in a received beacon from j. Vehicle i, furthermore, obtains its current position P_i and driving lane ID L_i. If $D_i = D_j$, then i calculates the distance between P_i and P_j. If $\forall_j$ s.t. $|\vec{P_i} - \vec{P_j}| \cdot \vec{v} > 0, |\vec{P_i} - \vec{P_j}| > L_{\text{front}}$, then vehicle i identifies its relative position as the cluster head. If $\forall_j$ s.t. $|\vec{P_i} - \vec{P_j}| \cdot \vec{v} < 0, |\vec{P_i} - \vec{P_j}| > L_{\text{behind}}$, then vehicle i identifies its relative position as the cluster tail.
- **Cluster head/tail assistant:** If vehicle i is not a cluster head/tail, vehicle i checks vehicle j's lane ID L_j. If $\forall_j$ s.t. $L_i = L_j \wedge |\vec{P_i} - \vec{P_j}| \cdot \vec{v} > 0, |\vec{P_i} - \vec{P_j}| > L_{\text{front}}$, then vehicle i checks the gap between L_i and L_x. Here, L_x is the driving lane of the cluster head and OL is the number of lanes that a vehicle observed by a LIDAR with high accuracy. If $L_i = L_x \pm k\text{OL}$ $(k = 0, 1, 2, ...)$, then vehicle i identifies its relative position as a cluster head assistant. On the other hand, if $\forall_j$ s.t. $L_i = L_j \wedge |\vec{P_i} - \vec{P_j}| \cdot \vec{v} > 0, |\vec{P_i} - \vec{P_j}| > L_{\text{behind}}$, then vehicle i checks the gap between L_i and L_x as above. If $L_i = L_x \pm k\text{OL}$ $(k = 0, 1, 2, ...)$, then vehicle i identifies its relative position as a cluster tail assistant. Here, L_x is the driving lane of the cluster tail.
- **Cluster mid:** If i is not a cluster head/tail assistant, i calculates Y_i and Y_j as follows,

$$Y_i = ||\vec{P_x} - \vec{P_i}| - \text{SD}_x| \tag{2}$$

  where x is the vehicle closest to i among the cluster head, a cluster head assistant and a cluster mid, P_x is the position of x, and SD is the distance that x can sense by its sensor. If $\forall_j$ s.t. $L_i = L_j, Y_i < Y_j$, then i identifies its positional relationship is a cluster mid.

3) Decision of Priority R: Vehicles calculate R based on their relative positions. We introduce three constants R_{min}, R_{mid} and R_{max} that satisfy $0 < R_{\text{max}} < R_{\text{mid}} < R_{\text{max}} \leq 1$. Vehicle i calculates R_i as follows.

1) $R_i = R_{\text{max}}$ if it is a cluster head or a cluster tail.
2) $R_i = R_{\text{mid}}$ if it is a cluster head assistant, cluster tail assistant or a cluster mid.
3) $R_i = R_{\text{min}}$ if it is an ordinary vehicle.

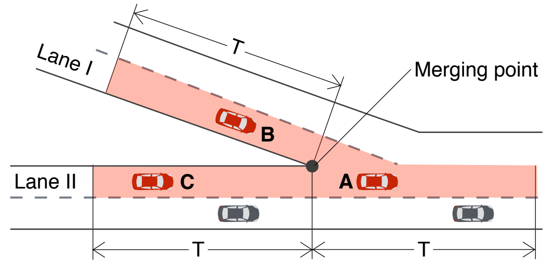

Fig. 3. Merging point and cars to calculate S. Red cars calculate S.

B. Road Structure-based Priority

S is calculated based on the relative position of a vehicle in the road structure (e.g. near merging lanes, intersection etc.). In this paper, we describe the calculation of S at a vicinity of merging lanes.

In the vicinity of merging lanes, only vehicles on a merging lane, e.g. vehicles on the lane I and the lane II in Fig. 3, will calculate S. The other vehicles (gray cars in Fig. 3) set S to the minimum of S, S_{min} $(0 < S_{\text{min}} < 1)$. Vehicle i calculate S_i as follows.

$$S_i = \max\left(1 - \frac{|\vec{P_i} - \vec{P_m}|}{D_{\text{th}}}, S_{\text{min}}\right), \tag{3}$$

where P_m is the position of the merging point and D_{th} is the threshold of distance between the merging point and vehicle i. The closer a vehicle to the merging point, the higher S of the vehicle is. Therefore, if the order of closeness of three cars to the merging point in Fig. 3 is A, B, C, the magnitude relationship of S of the vehicles becomes $S_A > S_B > S_C$.

V. Simulation Study

To demonstrate the effectiveness of our proposed method, we evaluate the surrounding awareness of vehicles applied the proposed method through simulations using Scenargie wireless network simulator [14].

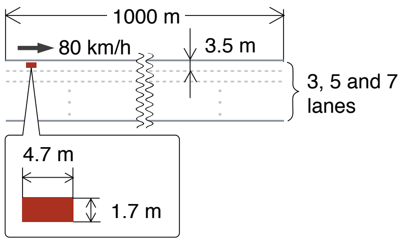

Fig. 4. Road layout in the simulation

A. Simulation Scenario

Vehicles were generated for each lane following a Poisson distribution. They moved on a 1000m straight highway as shown in Fig. 4 keeping the velocity at 80km/h and the distance between vehicles at 20m or more. To change the network traffic in the simulation, the number of lanes of the road was set to 3, 5 and 7. To duplicate a high vehicle density environment, the vehicle arrival rate was set to 1200 vehicle/h. The size of each car is 4.7m $\times$ 1.7m. To remove the initialization biases of the simulation, we use a warm-up period of the 20s of the simulation time to measure the results. We assume that all cars are equipped with a LIDAR sensor. They can detect objects on the road in 100m range unless their line-of-sight is not blocked by bodies of other cars. Table I summarizes other simulation parameters. All cars have the V2V communication function and they transmit beacons including LIDAR sensor data at a given frequency. Additionally, all cars applied the proposed method contain the relative position in a cluster to beacons.

We evaluated the effectiveness of our proposed method by comparing performances of the proposed methods, ATB and the vanilla V2V manner (i.e. constant beaconing frequency 10Hz). In order to evaluate the performance by using Scenargie, we implemented our method and ATB to the Scenargie. Table II summarizes the parameters of our proposed method and ATB. Most of these parameter values of ATB are values described in [13], [15]. However, part of the parameters, interval weight and message priority are changed. We set them to 1 because we did not place RSUs in the simulation scenario. On the other hand, we set S, a parameter of our proposed method, to 1 because we use a straight highway scenario.

B. Performance Metric

We introduce a metric of awareness ratio k_{rel} described in [2] in order to evaluate the performance of methods. The awareness ratio describes the number of vehicles known to a vehicle relative to the number of vehicles within the communication range of the vehicle:

$$k_{\mathrm{rel}} = \frac{\Sigma \text{ unique vehicles known to the a vehicle}}{\Sigma \text{ unique vehicles within the comm. range}} \quad (4)$$

Fig. 5 schematically shows how a vehicle calculates the awareness ratio. Let δt is the maximum time to live available for ADAS of data included in a beacon. The awareness ratio of car A at t_2 is calculated by dividing (i) the number of vehicles derived from received beacons and its own sensing data, by (ii) the number of vehicles within the communication range of car A. To obtain the number of vehicles of (i) at t_2, data included in the beacon received by A from B is used but data included in the beacon received by A from C is not used. Because the transmission time of the beacon from C is before t_1 that is time before δt seconds. On the other hand, to obtain the number of vehicles of (i) at t_2, sensing data obtained by the sensor of A at t_2 is used but ones obtained by the sensor of A at t_0 and t_2 are not used for the same reason as above. We sat the communication range in this metric to 600m. We confirmed that two vehicles capable of line-of-sight communication can communicate at a distance of 600m with the given parameter values.

TABLE I
SIMULATION PARAMETERS

Radio	IEEE 802.11p at 5.9 GHz
Bandwidth	10 MHz
Data bitrate	6 Mbps
Propagation model	Free space
Transmission power	20 dBm
Receiver sensitivity threshold	-85 dBm
Carrier sense level	-65 dBm
Packet size	1500 Bytes
LIDAR sensor range	100 m
LIDAR sensor horizontal FoV	360°
Sensing interval	0.1 s
Beacon data expired time	1 s
Simulation time	50 s
Number of runs	10

TABLE II
METHODS SETTING PARAMETERS

ATB	Channel quality weighting w_C	2
	Interval weighting w_I	1
	Number of neighbors for $N = 1$	50
	SNR for $S = 1$	50 dB
	Message priority P	1
Proposed method	OL	3
	$L_{\mathrm{front}}/L_{\mathrm{behind}}$	100 m
	R_{max}	1.00
	R_{mid}	0.75
	R_{min}	0.50
	S	1
Common	I_{min}	100 ms
	I_{max}	1 s

C. Simulation Results

Fig. 6 shows that the distribution of the awareness ratios of all vehicles and the amount of communication traffic for various beacon transmission method. The name above each box corresponds to the abbreviation of a method and the number of lanes. "Ours3" means that all vehicles use our method proposed in this paper and the number of lanes is three, "ATB3" means that all vehicles use ATB and the number of lanes is three, and "Vanilla3" means that all vehicles use the vanilla V2V method and the number of lanes is three. Ideally,

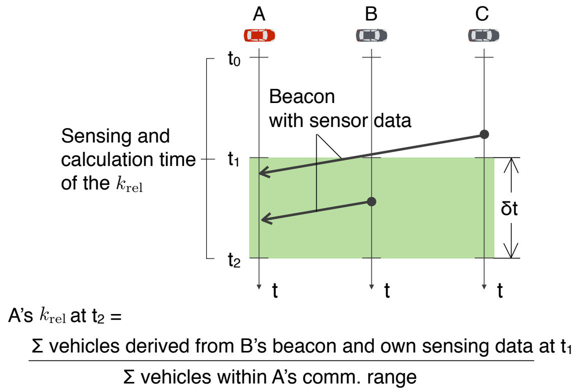

Fig. 5. Calculation of the awareness ratio

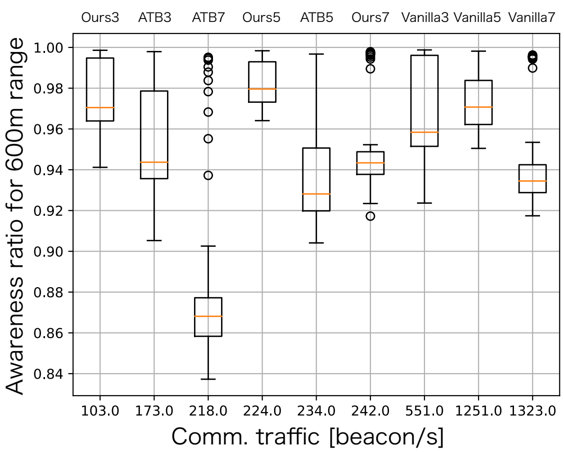

Fig. 6. The awareness ratio and the amount of the communication traffic.

the communication traffic should be smaller and the awareness ratio should be larger. If the distribution of the awareness ratios of vehicles using a beacon transmission method is plotted closer to the top left of the graph, the result indicates the method is more effective.

In the highest traffic density case, i.e. the number of lanes is 7, we can see that the distribution of awareness ratio of vehicles using our method is higher than vanilla and ATB. When vehicles use ATB method, the communication traffic is the lowest but the awareness ratio is lower than ours. These results show that vehicles using our method can perceive the presence of other vehicles more with less communication traffic than vehicles using other methods.

VI. Conclusions

In this paper, we proposed the method for controlling the transmission frequency of sensor data based on the positional relationship of vehicles and road structure in order to keep the surrounding awareness of vehicles sufficient high for safety applications even if traffic density is high. In VANET, collective perception technique helps vehicles to perceive the presence of the surrounding vehicles and increases the safety of their drivers. Our method helps vehicles using the collective perception technique to exchange the sensor data transmitted vehicles at an important location such as at the head of a cluster, where a vehicle can perceive obstacles in front of the cluster, for ADAS because our method has two advantages: i) reducing communication traffic and, ii) disseminating more useful sensor data about vehicles in non-line-of-sight regions for safety applications within allowable latency.

In order to demonstrate the effectiveness of the proposed method, we presented simulation results compared with other beacon transmission control methods. We showed that vehicles using our method can perceive the presence of other vehicles more with less communication traffic than vehicles using other methods.

For our future work, we plan to further evaluate the performance of our method through simulations of realistic traffic scenarios.

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