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Data Uploading Control Method Based on Exchange of Metadata in VANET for On-demand Onboard Camera Picture Sharing System

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Abstract: Drivers can make driving plans and save traveling time if they can download real-time pictures taken at each driver's point of interest (POI). We designed a system that provides pictures taken by other drivers at a driver's POI. In one naive system design, vehicles send picture data to a central server via a cellular network whenever they take a picture. However, sending all pictures taken by vehicles to the server leads to high processing loads on the server and major amounts of cellular network traffic. In this paper, we propose a scalable data sharing system that uses VANETs and a cellular network for providing a picture taken at POI. For realizing the system, we propose a data upload control method. In this method, all vehicles exchange metadata via VANETs to know the existence of pictures taken by other vehicles and reduce the traffic for uploading pictures taken under a similar condition of other pictures. We evaluate the performance of the proposed method through simulations. The simulation results show that the proposed method reduces the cellular network traffic to 36% in comparison with a system that sends all pictures received by the server to meet all driver POI picture requests.

Keywords: ITS, vehicular ad hoc network, cellular network, data sharing

1. Introduction

Drivers can make driving plans and save traveling time if they can download real-time pictures taken at each driver's point of interest (POI). For example, when a driver knows that a car accident happened at a place by seeing a digital signboard, if he/she can see the real-time picture of the accident site, he/she can roughly estimate the time when the congestion caused by the accident will end and determine whether he/she makes a detour. In another example, when a driver firstly visits a complicated intersection, if he/she can see the real-time picture of the intersection, he/she can choose a suitable lane for smoothly entering the intersection. To realize a real-time visual car navigation system that provides drivers with such location-dependent data, such as onboard camera pictures, degree of congestion, and occurrence of car accidents, we previously proposed data dissemination protocols for vehicular ad-hoc networks (VANETs) [1], [2], [3]. In this system, when a driver inputs the POI to the system by a voice or touch operation, as shown in **Fig. 1**, the system provides the driver with a picture taken in the vicinity of the POI.

In one possible design, vehicles share pictures with other vehicles by using the VANET. In a VANET, vehicles equipped with wireless communication devices communicate with other vehicles without using cellular network infrastructures. The VANET enables vehicles to share local and timely location-dependent data, such as congestion information and pictures of traffic accidents. However, the performance of a VANET is strongly affected by vehicle density and movement. For example, a vehicle in an area with a low vehicle density sometimes cannot communicate with other vehicles because no vehicle is in the vehicle's communication range. In addition, a driver may not be able to obtain location-dependent information, including a picture taken at or near the driver's POI because of the disconnection of network topology due to movement of the vehicle. Okamoto and Ishihara proposed a message routing strategy and data dissemination algorithm so that request messages can be forwarded to vehicles that have copies of the disseminated location-dependent data items [1]. Kusumine and Ishihara proposed an efficient data dissemination algorithm using network coding for quickly and reliably disseminating location-dependent data items in sparse and dense road traffic conditions [2], [3].

The other possible design is sharing pictures across a cellular network. In this approach, whenever vehicles take pictures, they send picture data to a central server via a cellular network. When the driver of a vehicle wants to obtain a picture, the vehicle sends a request message, which includes picture conditions, such as po-

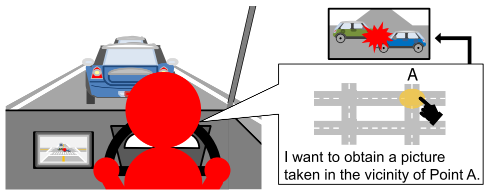

Fig. 1 Overview of real-time car visual navigation system.

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sition and direction, to the server. Once the server has received the request message, it selects an appropriate picture from the pictures sent from vehicles beforehand and sorted at the server, then sends that picture to the driver. Pioneer Corporation provides a similar service, called Smart Loop Eye [4]. In their system, vehicles equipped with the Pioneer car navigation system take pictures when they travel near preset locations, such as major intersections and motorway junctions, and they send pictures to the server via a cellular network. The system can only provide pictures taken at preset locations. Restricting the POIs in this way reduces the server load.

In this paper, we propose a highly scalable data sharing system for providing drivers with pictures recently taken at any POI by using both a VANET and a cellular network. By using a cellular network, the system enables wide service coverage, and by using a VANET, it relaxes the restrictions on available POIs without losing scalability. For realizing the system, we propose a data upload control method to reduce the data upload traffic from vehicles. The key idea of the method is to allow vehicles to upload pictures taken at any place but make them avoid uploading pictures that have been taken under a similar condition of pictures taken by other vehicles according to metadata of the pictures sent via a VANET. In the method, all vehicles broadcast beacon messages that contain the metadata of pictures taken by the vehicle (e.g., position, time, and direction when the picture was taken). Thus, vehicles can know the conditions of pictures taken by other vehicles. When a vehicle takes a new picture, the vehicle compares the conditions of the new picture with the metadata transmitted from other vehicles, and it sends the new picture to the server only if no pictures having a similar condition (position, direction, and time) have been uploaded to the server. The proposed method improves the scalability of the system without increasing the server load. In addition, the proposed method maintains a high probability that the driver can obtain a picture near his or her POI.

The rest of the paper is organized as follows. In Section 2, we present related work. In Section 3, we explain the system of interest in this paper. Section 4 details the proposed method. We evaluate the performance of the proposed method through simulations in Section 5 and conclude the paper in Section 6.

2. Related Work

Today, several systems provide drivers with road traffic information by using a cellular network (e.g., Google maps and Waze [5]), DSRC (ITS Spot services in Japan [6]), FM multiplex broadcasting and light beacons (e.g., Ref. [7]). In addition, many distributed methods (e.g., Refs. [8], [9], and [10]) have been proposed for road traffic data dissemination by using VANETs. Moreover, centralized systems collecting road information from vehicles and providing road information have been proposed. For example, Refs. [11] and [12] proposed systems for providing both road traffic information and time-efficient driving paths. In some proposed systems, a server collects road information generated by car-mounted cameras and by car-mounted sensors and distributes the information of parking lots and travel time [13], [14], [15]. However, collecting data from all vehicles in centralized systems leads to a very high server load and very high network traffic, and so strategies to reduce the data from vehicles are indispensable.

Santa et al. proposed a cellular network architecture of unified vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications for data sharing and data dissemination between vehicles and servers [16]. The architecture utilizes two kinds of servers, environment servers and a group server. Environment servers are placed at roadsides and manage the road information of a finely divided area of the road network. The group server manages the environment servers and the available services in each area. When a vehicle passes from one area to another area, the vehicle first sends its position to the group server, and then the vehicle obtains the available services in the current area through V2I communication. The driver sends a request message to the nearest environment server through V2I communication to obtain new road information at his or her current area. If a vehicle generates a new item of road information data, it sends the data item to the nearest environment server through V2I communication and to other vehicles traveling in the same area through V2V communication. This method improves the scalability of the system by layering servers to distribute the load across multiple servers. However, providing services in a wide range requires many environment servers, which increase the monetary cost.

Adachi et al. proposed a central server system for distributing road information at the point where drivers travel based on the prediction of the path of movement of all vehicles [17]. In this system, the central server periodically predicts the moving paths of all vehicles based on their probability of movement between road segments. The probability is predicted according to information of the vehicles' past moving paths. The server instructs all vehicles regarding what they should obtain and how they obtain it (i.e., via VANET or cellular network). This method reduces the traffic on the cellular network by instructing vehicles to use a VANET to obtain pictures if possible. Since this system depends on vehicles' past predictions at the server, many vehicles being in the system would lead to high server processing loads and restrict the system scalability.

Ide et al. proposed a centralized mobile sensor data collection method based on clusters of vehicles [18]. Vehicles form a cluster by vehicle-to-vehicle communication and select a cluster head (CH). Vehicles other than the CH transmit their sensor data to the CH, and only the CHs transmit the sensor data to the server. This method can reduce the load of the cellular network and the central server because only a limited number of CHs can send sensing data to the server via the cellular network. In this method, vehicles select a CH from vehicles belonging to the cluster according to the following scheme. The vehicle having the highest number of vehicles that have connectivity to the vehicle via a vehicle-to-vehicle link and that had belonged to the vehicle's cluster at the previous time step is selected as a CH. Each CH sends sensor data, aggregated from other vehicles belonging to the CH's cluster, via a VANET and then via the cellular network to the server. The vehicles that were CHs in the previous time step are preferentially selected as a new CH. This algorithm improves the lifetime of clusters. It also reduces the traffic of a cellular network by sending compressed sensing data. However, it is difficult to incor-

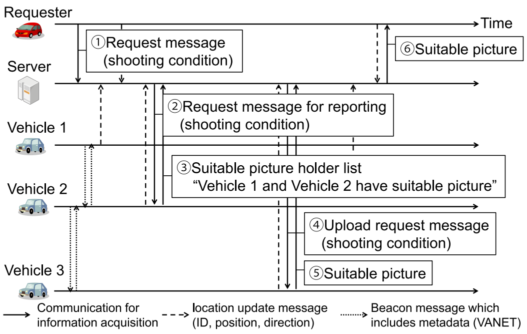


Fig. 2 Basic strategy of the method proposed in Ref. [19].

porate this mechanism in our system because our system assumes that the information sent is large data, such as pictures, and thus sending such data via VANET leads to congestion of the VANET and low reliability of data delivery.

We previously proposed a location-dependent data sharing system that suppresses the processing load of a server by using a VANET to reduce the cellular network traffic [19]. With this method, in order to reduce the cellular network traffic, each vehicle does not automatically upload a picture it has taken. Instead, each vehicle periodically sends location information to the server via the cellular network and shares the existence of pictures taken by other vehicles through the exchange of beacon messages that include the metadata of pictures from neighbor vehicles. **Figure 2** shows the basic strategy of the method proposed in Ref. [19]. When the driver wants to obtain a picture, it sends a request message including the condition when the picture was taken. After a central server has received a request message from a driver, it first asks vehicles traveling in the vicinity of the requester's POI to report the ID of a vehicle having a suitable picture when it has received the location information from the vehicle, and then asks one of the vehicles having a suitable picture to upload the picture. Finally, the server receives the picture and sends it to the requester when it has received the location information from the requester. In this method, the server can provide pictures to drivers without continually collecting pictures. This reduces the traffic on the cellular network and the processing load on the server. However, if no vehicle is traveling near the requester's POI when the server asks for a picture, the server is not able to provide the image to the requester. Furthermore, selecting suitable pictures after the server has received request messages lengthens the response time.

3. Cellular Network Based Real-time Car Navigation System

In this study, our goal is to design a scalable cellular-based system for providing drivers with pictures recently taken at any POI. We aim to reduce the cellular traffic and shorten the response time because the method used in Ref. [19] is potentially unable to achieve a short response time. In this section, we first show the prerequisites of the system proposed in this paper, then we offer strategies to realize the system. Finally, we describe the challenges of developing the system.

In this system, all vehicles are assumed to take pictures with car-mounted cameras. In addition, when the driver of a vehicle wants to obtain a picture taken at or near his or her POI, the vehicle sends a request message for a picture, including the conditions when the picture was taken, to the server. If the server receives the request message, it provides the driver with an appropriate picture selected from pictures sent from other vehicles to the server.

3.1 Prerequisites of the System

3.1.1 Model of Taking Pictures

We assume that each vehicle takes a picture with a car-mounted camera either regularly or each time the vehicle travels to a location assigned by the system. The vehicle that has taken a picture appends the metadata of the picture (e.g., position, time, and direction when the picture was taken) to the picture data and stores the metadata in its local database.

3.1.2 Definition of a Request

The vehicle that wants a picture taken at a POI sends a request message, which is sent to the server via a cellular network. A request message includes the conditions when the picture was taken, the time that the vehicle generated the request message, and the ID of the vehicle. The condition when the picture was taken consists of a position and a direction.

3.1.3 Operation of the Server When Receiving a Request Message

The server that has received a request message has several possible options:

i) The server somehow collects all pictures taken by all vehicles on a regular basis. When the server receives a request message from a driver, it provides the driver with a picture that meets the condition when the picture was taken described in the request message.

ii) The server collects a suitable picture after receiving a request message from a driver without regularly collecting pictures. The server somehow obtains the metadata including the condition when the picture was taken for each picture. When the server receives a request message from a driver, it asks a vehicle that has a suitable picture to upload the picture to the server. Then, the server sends the picture to the driver.

iii) The server looks for a vehicle that has a suitable picture after receiving a request message from a driver, and the server asks the vehicle to upload the picture to the server. The server does not regularly collect pictures and the conditions when they were taken. When the server receives a request message from a driver, the server first requests cars near the position described in the request message to select a picture that satisfies the request message. After the server has received information describing the existence of a suitable picture, the server requests a vehicle having a suitable picture to upload the picture to the server. Then, the server provides the picture to the driver.

It is desirable for the system to provide pictures to drivers with low latency. Strategies ii) and iii) cannot provide suitable pictures to drivers immediately. Thus, we adopt strategy i).

3.2 Simple Strategies

To design a data sharing method for a cellular network based on a real-time car navigation system, we first show two simple strategies of the system. Then, we discuss the problems of these simple strategies.

3.2.1 All Pictures Transmission Method

The simplest strategy is that the server collects all pictures from all vehicles whenever a vehicle takes a picture. If the server receives a request message from a driver, the server immediately returns a picture that meets the condition when a requested picture was taken described in the request message. We call this method the *all pictures transmission method*. **Figure 3** shows an overview of the *all pictures transmission method*. In this method, the server always provides pictures because all vehicles send all pictures taken on the road to the server.

However, sending all pictures from the vehicles to the server leads to a high processing load on the server and major amounts of cellular network traffic, including redundant information. For example, if some vehicles travel on the same road in the same direction, each vehicle will send pictures taken under a condition similar to pictures taken by neighbor vehicles. This wastes the communication resources of the cellular network and increases the server processing load. As shown in Fig. 3, if vehicle 1 and vehicle 2 have taken pictures at point A, vehicle 2 would transmit its picture taken at point A to the server, even though the server already has pictures taken by vehicle 1 at point A.

3.2.2 Probability Based Picture Transmission Method

For improving the scalability of the system, it is desirable to reduce the number of vehicles transmitting pictures similar to other pictures that have been taken. Therefore, we consider an approach in which vehicles upload pictures according to a certain probability P_{upload} after taking a picture. This method can reduce the number of operations of uploading pictures taken by vehicles in high vehicle density areas, as compared to the all pictures transmission method. We call this method the *probability based picture transmission method*. However, this system may not provide pictures taken by vehicles in low density areas because the number of uploads of pictures taken by vehicles in such areas tends to be small.

3.3 Problem Description

In the *all pictures transmission method*, a central server knows all of the pictures taken by all vehicles, since all vehicles upload pictures to the server every time they take a picture. This wastes the communication resources of the cellular network and increases the server processing load. In the *probability based picture transmission method*, vehicles that take pictures decide whether to upload the picture to the server according to a certain probability. This method can improve the scalability of the system, because it reduces the number of operations of uploading pictures as compared with the *all pictures transmission method*. However, this system might not provide pictures taken by vehicles in low density areas because the number of uploaded pictures taken by vehicles in low density areas tends to be small. The cellular network based real-time car navigation system should be designed to be not only scalable but also capable of providing pictures that meet the request messages sent from drivers.

The problem we solve in this paper is striking a balance between scalability and capability. An approach that reduces the number of operations of uploading pictures having a similar condition when they were taken to those uploaded by neighbor vehicles is desirable. Therefore, we propose an upload control method that exchanges the metadata between neighbor vehicles via VANETs for realizing a scalable cellular-based system for providing drivers with pictures recently taken at any POI.

4. Upload Control Method Using Information Exchange With Neighboring Vehicles

4.1 Basic Strategy of the Proposed Method

In our proposed method, all vehicles broadcast beacon messages that contain the metadata of pictures (e.g., position, time, and direction when they were taken) to reduce the number of operations for uploading pictures that are similar to pictures uploaded by neighbor vehicles. Vehicles can know the conditions when those pictures were taken by other vehicles. Thus, vehicles can upload only pictures that were taken under a condition different from pictures taken by neighbor vehicles.

In the proposed method, all vehicles broadcast beacon messages that contain the metadata of pictures recently uploaded to the server. If a vehicle receives a beacon message, it stores the metadata included in the beacon message in its local database. Every time a vehicle takes a new picture, each vehicle decides whether to upload the picture to the server according to its local database. Vehicles do not send a picture to the server only when other vehicles have already sent pictures taken under a condition similar to the picture. Therefore, the proposed method does not decrease the probability that the driver can obtain a picture taken at a position near his or her POI compared to the probability based picture transmission method because the probability based picture transmission method may not upload pictures taken udner a condition different from uploaded pictures. As shown in **Fig. 4**, vehicle 2 does not transmit the picture taken at point A to the server because it knows that vehicle 1 has already uploaded a picture taken at Point A. The vehicle transmits the picture to the server only when the the condition when the picture was taken is

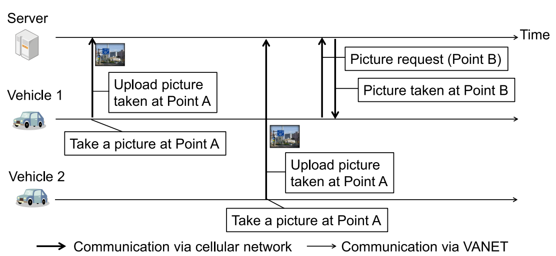


Fig. 3 All pictures transmission method.

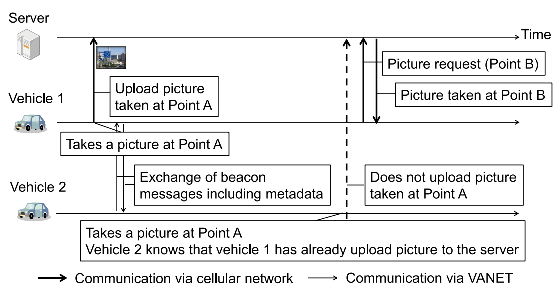


Fig. 4 Proposed method.

not similar to pictures that have been transmitted to the server by other vehicles.

4.2 Exchange of Metadata

Each vehicle regularly broadcasts beacon messages that include the metadata of pictures that are selected from pictures that have been already transmitted to the server by the vehicle itself or by other vehicles. The selection criteria of the metadata to be added to a beacon message are described later. When a vehicle receives a beacon message from another vehicle, the vehicle stores the metadata (e.g., position, time, and direction when picture were taken) included in the beacon message in its local database. The vehicle can know the existence of pictures taken by vehicles a few hops away by including the metadata of pictures taken by neighboring vehicles as well as the metadata of pictures taken by the beacon sending vehicle itself.

4.3 Taking Pictures and Uploading Picture Data

Vehicles take a picture and upload the picture data as follows. Each vehicle takes a picture with an onboard camera either regularly or each time the vehicle travels to locations assigned by the system beforehand. When a vehicle takes a new picture, it attaches the metadata (e.g., position, time, and direction when it was taken) of the pictures to the data file. In addition, it stores the metadata in its local database. The vehicle decides whether pictures that have been taken under a similar condition of the new picture have already been uploaded to the server by comparing the metadata of the new picture and the metadata stored in its local database. Note that the local database stores the metadata of pictures taken by the vehicle as well as pictures taken by other vehicles. If no pictures that were taken under a similar condition when the new picture was taken have been uploaded to the server, the vehicle uploads the picture to the server because it is beneficial to satisfy requests from other vehicles. Otherwise, the vehicle does not upload the picture. When the server receives a picture from the vehicle, it stores the picture in its database.

Figure 5 shows an example of the data flow in the proposed method. Two vehicles travel on the same road. Vehicle 1 has already taken a picture at point A and has uploaded the picture to the server. Vehicle 2 can know that the picture taken at point A has already been uploaded to the server, if vehicle 1 broadcasts a beacon message that includes the metadata of the picture taken at point A and vehicle 2 receives the beacon message before it takes a picture at point A.

In the following, we discuss the effect of the proposed method under the following assumptions. Each vehicle takes a picture every time it travels to locations assigned by the system. We consider a scenario in which vehicles are traveling on a single lane with a one-way road. Let us assume that vehicle α is traveling near point A, and vehicle β is traveling ahead of vehicle α.

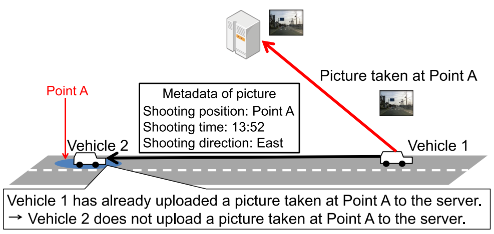


Fig. 5 Example of the proposed method.

If vehicle α has received the metadata of a picture taken at point a by vehicle β, vehicle α does not upload pictures taken near point A. If the distance between vehicle α and vehicle β is within the communication range of the vehicle-to-vehicle communication r, the vehicles can completely share the metadata of pictures that have been uploaded to the server by 1-hop vehicle-to-vehicle communication. The probability P that vehicle α uploads the picture taken at Point A is given by

$$P = 1 - F(r) \tag{1}$$

where $F(r)$ is the probability that the distance between vehicle α and vehicle β is less than or equal to r. Therefore, the traffic of the cellular network of the proposed method is P times the traffic of the all pictures transmission method because vehicles using the all pictures transmission method upload all pictures. In the proposed method, vehicle α can receive the metadata of pictures taken by vehicles traveling ahead by more than one hop because vehicles append the metadata of its own pictures as well as the metadata of pictures taken by other vehicles to beacon messages. Thus, vehicles can know the existence of pictures uploaded by more than one hop away, and the load of the cellular network can be less than P times the load of the all pictures transmission method.

4.4 Selection Criteria for Metadata Appended to Beacons

Because packet size is limited, it is not realistic to include all the metadata of pictures included in the local database of each vehicle. Thus, in order to reduce the load of the cellular network, selection criteria are needed for metadata that can both reduce the number of uploading operations of pictures and maintains a high probability that a driver can obtain pictures taken in the vicinity of his or her POI. We can easily come up with the following selection criteria for metadata appended to the beacon message:

i) Vehicles give higher priority to the metadata of pictures taken recently.
ii) Vehicles give higher priority to the metadata of pictures taken in the vicinity of neighbor vehicles.
iii) Vehicles give higher priority to the metadata of pictures taken on the neighbor vehicle's planned driving route. To make other vehicles know the existence of pictures taken on their proposed route, each vehicle exchanges the vehicle's proposed route information with other vehicles.

We excluded selection criterion iii) in the consideration of privacy. We use a selection criterion based on the other two selection criteria, i) and ii).

4.5 Procedure to Obtain a Picture via the Cellular Network

In the proposed method, when a driver wants to obtain a picture, the vehicle sends a request message including the conditions when the picture was taken to the server via the cellular network, and the server selects and sends back a suitable picture. When the server has received a request message, it selects the best image satisfying the condition when the requested picture was taken from all the pictures that have been uploaded from vehicles. The server does not send any request to other vehicles, unlike the method proposed in Ref. [19]. This makes it possible to provide pictures to the driver quickly.

5. Performance Evaluation

We evaluated the effectiveness of the proposed method by using the discrete event simulator Scenargie [20]. In this section, we describe the simulation conditions and results.

5.1 Simulation Model

We set up a 1,250 × 1,250 m simulation field that included four east-west roads and four north-south roads (**Fig. 6**). The roads were arranged in 250 m intervals. All roads had one lane in each direction. All vehicle-to-vehicle communications were broadcast at 6 Mbps (QPSK r = 1/2), as defined in the IEEE 802.11p standard, and the transmission power was set to 10 dBm. Every second, each vehicle broadcasts a beacon message including the vehicle ID, position, direction of travel and timestamps of the message. Each beacon message is 1,024 bytes long. The propagation model is ITU-R P.1411.

5.1.1 Vehicle Mobility

We obtained mobility traces by using the open-source traffic simulator SUMO [21]. In our scenario, 10–100 vehicles enter the simulation field from the ends of all roads in one hour, and each travels at a varying speed between 0 and 50 km/h. All intersections have traffic lights, which change in 60-second cycles (green, yellow, red = 26 s, 3 s, 31 s). Each vehicle turns right or left at any intersection with a 15% probability. When a vehicle arrives at the ends of a road, it exits from the simulation area. In this paper, we show the results of 50 and 100 [vehicles/lane/hour]. The simulation area has 36.7 and 74.9 vehicles on average.

5.1.2 Generating Picture Data

Each vehicle checks the ID of the current road segment, where it is traveling every second. If the ID of the current segment is different from the previous ID, the vehicle takes a new picture. Then, it appends the metadata of the picture (e.g., position, time, and direction then the picture was taken) to the picture data and stores the metadata in its local database. We assume the data size of the metadata of each picture is 100 bytes, and the data size of each picture is 1 Mbytes.

5.1.3 Generating Request

Each vehicle generates a request message as follows. Each vehicle knows its planned driving route. It requests a picture taken at the next road segment where it will visit with a shooting direction that is equal to its planned moving direction. In this simulation, we assume that any pictures taken at the next road segment in the same direction as the vehicle's planned route satisfy the driver's requirement. Every time it enters a different road segment, each vehicle sends a request message to the server via the cellular network. All communication via the cellular network is assumed to be successful. The communication speed is 5 Mbps and the propagation delay is 5 msec.

5.2 Selection Criteria for Metadata Appended to the Beacon

As stated in Section 4, we adopt the selection criterion based on i) and ii). In this evaluation, we refer the senders of beacons that a vehicle has received in the last 1 second as *neighbor vehicles* of the vehicle. When a vehicle sends a beacon message, it contains the metadata of up to N pictures taken in the last t_e seconds on the road segments where its neighbor vehicles exist and/or where neighboring road segments connect directly to them. For example, if a neighbor vehicle of a beacon sender vehicle is on the road segment indicated by the black circle in **Fig. 7** (a), the beacon sender appends the metadata of pictures taken inside the red frame to the beacon message. If two neighbor vehicles are on the road segment indicated by the black circle in Fig. 7 (b), the beacon sender appends the metadata of pictures taken inside the red frame to the beacon message. In this evaluation, we used $t_e = 100$ seconds.

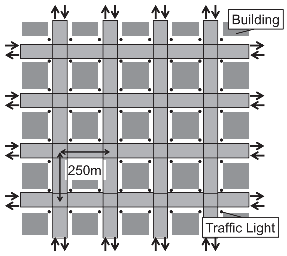
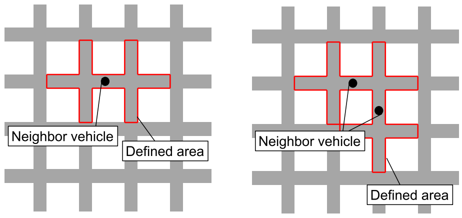


Fig. 6 Simulation area.



(a) 1 neighbor vehicle (b) 2 neighbor vehicles

Fig. 7 Example of selection criteria metadata included in a beacon message.

5.3 Comparative Approach

To evaluate the performance of the proposed method, we simulated the following two data dissemination methods.

- The proposed method: The maximum number of metadata items attached to a beacon message is 1 or 10.
- Probability based picture transmission method (Section 3.2.2): The probability of uploading images P_{upload} changes between 0.1 to 1.0 at 0.1 intervals. When P_{upload} = 1.0, this method is the same as the all pictures transmission method (Section 3.2.1).

5.4 Performance Indices

We use these performance indices.

- Traffic of the cellular network: This is the number of pictures uploaded from vehicles via the cellular network.
- The age of pictures delivered to requesting vehicles: This is the length of time from when the image was taken to when a vehicle obtains the image.

5.5 Simulation Results

Figure 8 and **Fig. 9** show the relation of the traffic of the cellular network and the age of pictures that drivers obtained when the

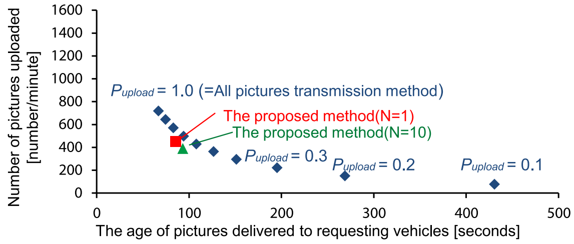


Fig. 8 Relation of traffic of the cellular network and the age of pictures that drivers obtained (50 [vehicles/lane/hour]).

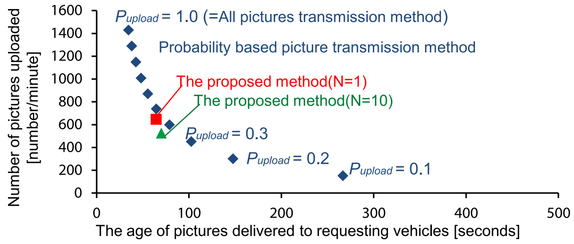


Fig. 9 Relation of traffic of the cellular network and the age of pictures that drivers obtained (100 [vehicles/lane/hour]).

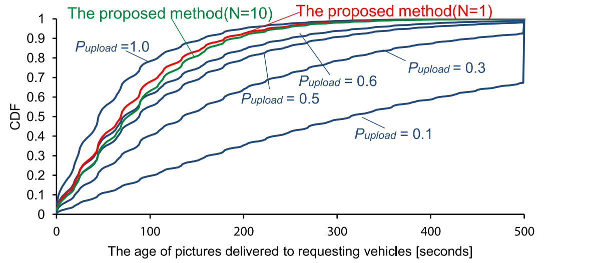


Fig. 10 CDF of the age of pictures that drivers obtained (50 [vehicles/lane/hour]).

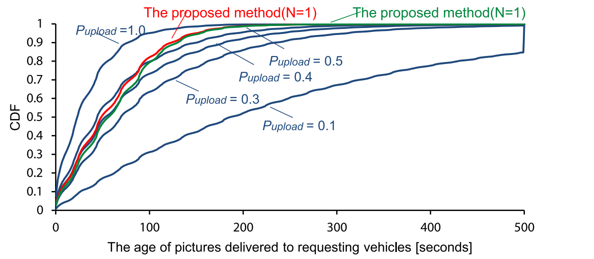


Fig. 11 CDF of the age of pictures that drivers obtained (100 [vehicles/lane/hour]).

incoming road traffic was 50 and 100, respectively. We ran simulations for 3,000 seconds of simulation time and used 10 different mobility traces. The values in the figures are the mean values of 10 simulation times. The points of the graph of the probability based picture transmission method from left to right show the results of $P_{upload} = 0.1, 0.2, 0.3, \ldots, 1.0$.

Figure 8 shows that the proposed method can reduce the number of operations of uploading pictures as compared with the probability based picture transmission method, which has almost the same average age of pictures. This result means that the proposed method can provide more recent pictures. The proposed method reduces only the uploading operation of pictures similar to ones that have been uploaded by other vehicles, whereas the probability based picture transmission method requires more uploading operations for the same age of pictures, because it does not have any information of pictures uploaded by other vehicles. The results showed that the proposed method ($N = 10$) reduces traffic of the cellular network to 55% of that in the all pictures transmission method ($P_{\text{upload}} = 1.0$).

We can see similar characteristics when the incoming road traffic is 100 [vehicles/lane/hour], as shown in Fig. 9. This figure shows that all methods decrease the age of pictures delivered to requesting vehicles with high vehicle density. Because the total number of operations of uploading pictures increases with the number of vehicles, the age of pictures delivered to requesting vehicles decreases with vehicle density. That is, newer pictures are provided to vehicles. Furthermore, by comparing the result of the proposed method in cases where the incoming road traffic is 50 [vehicles/lane/hour] and 100 [vehicles/lane/hour], the case of 100 [vehicles/lane/hour] achieves a smaller number of uploads compared with the probability based picture transmission method. The proposed method ($N = 10$) reduces traffic of the cellular network to 36% of that in the all pictures transmission method ($P_{\text{upload}} = 1.0$) in the case of 100 [vehicles/lane/hour]. This means that many vehicles succeeded in canceling the uploading operations of pictures taken under a condition similar to pictures already uploaded by other vehicles due to the increased chance of knowing the existence of pictures taken by other vehicles. The average distance between vehicles considering both direction lanes is 133.5 m in the 100 vehicles/lane/hour scenario. On real roads, especially on a road with two or more lanes per direction, distances between vehicles can be shorter. Thus, the effectiveness of the proposed method can be more significant in real environments. As the number of metadata appended to the beacon increases, the proposed method reduces the traffic of the cellular network. By comparing the results of the proposed method for $N = 1$ and $N = 10$ cases, $N = 10$ cases achieves a smaller number of uploads with a very small increase in the age of pictures. Vehicles can know the existence of more pictures taken by other vehicles by appending the metadata of more pictures in a beacon message. Thus, vehicles in the proposed method can reduce the number of operations of uploading. However, reducing the uploading operations of pictures increases the age of pictures delivered to drivers. In the comparison of $N = 1$ and $N = 10$ cases, the age of pictures delivered to requesting vehicles of $N = 10$ cases is slightly larger than the $N = 1$ case, whereas the number of uploads of $N = 10$ cases is less than that of the $N = 1$ case. The reason is that the average age of pictures stored at the server becomes longer by not uploading new pictures.

Figure 10 and **Fig. 11** show the cumulative distribution functions (CDFs) of the age of pictures delivered to vehicles. The points on the graph are plotted every second. These graphs show that the proposed method can provide newer pictures as compared with the probability based picture transmission method that has a comparable uploading load. For example, Fig. 10 shows that the proposed method can reduce the age of pictures delivered to drivers as compared with the probability based picture transmission method that has almost the same cellular network traffic ($P_{upload} = 0.5, 0.6$). Similar results can be seen in Fig. 11. In particular, the proposed method has a lower ratio of providing pictures taken 120 seconds before than the probability based picture transmission method. The reason is that the probability based picture transmission method reduces the uploading operations of pictures regardless of the existence of pictures taken under a similar conditions by neighboring vehicles. Thus, even if a vehicle takes a new picture when no vehicles have taken pictures recently in the vicinity, the vehicle may not upload a picture to the server.

To evaluate the effect of the proposed method on the traffic of a VANET, we examine the traffic generated by the metadata appended to beacon messages. The average number of operations of sending beacon messages through one simulation is 183,570.9 for the simulation of 100 [vehicles/lane/hour]. Since the simulation time duration is 3,000 sec., 61.2 (= 183,570.9/3,000) beacons per second are transmitted in the whole network. By assuming the radius of the coverage of vehicle-to-vehicle communication is 200 m, the number of vehicles in the 1-hop communication range is $61.2 \times \frac{200\times200\times\pi}{1{,}250\times1{,}250} = 4.92$. Since the size of the metadata per picture is 100 bytes, the traffic of vehicle-to-vehicle communication that is generated by vehicles in the proposed method ($N = 10$) in the vicinity of a certain vehicle is only $100\times10\times4.92 = 4{,}920$ bytes/sec. Thus, the time required to send metadata from 4.92 vehicles in the 1-hop vicinity in a second is 4,920 [bytes/sec] × 8 [bits/byte] / 6 [Mbit/s] = 6.56 msec. Compared with 1 second, this value is sufficiently small, and even if the density of vehicles is tenfold of this scenario, the value, 65.6 msec., is still small. From these results, we can conclude that the effect of the additional traffic for sending metadata in the proposed method is sufficiently small. When the density of vehicles is high, sending metadata of many pictures consumes large part of the available bandwidth of the VANET. By reducing the number metadata appended to a beacon (= N) according to the density of vehicles, the traffic on the VANET can be reduced. Even in such a case, if the density of vehicles is high, the estimated number of pictures taken at a place will be high. Thus, the probability that a vehicle can know there is another vehicle that has uploaded a picture taken under a condition similar to a picture taken by the vehicle can be kept sufficiently high. Thus, the cellular traffic for ending pictures from vehicles can be still reduced with reduced number of metadata of pictures sent via the VANET.

6. Conclusions

We proposed a highly scalable data sharing method for providing drivers with pictures taken recently *any* POIs by using both VANETs and a cellular network, and proposed a data upload control method for realizing the system. In this method, all vehicles broadcast beacon messages that contain the metadata of pictures taken by the vehicles (e.g., position, time, and direction when the pictures were taken) to avoid uploading pictures taken under a condition similar to ones uploaded by a neighbor vehicle. Vehicles can know the existence of pictures that have been taken and uploaded by other vehicles. Thus, vehicles upload only pictures taken under a condition not similar to pictures taken by the neighbor vehicles. As a result, this method reduces the number of operations of uploading pictures as compared to the all pictures transmission method and the probability based picture transmission method without imposing new loads on the server, and this method delivers newer pictures to vehicles.

We evaluated the effectiveness of the proposed method by using a discrete event simulator. The results showed that the proposed method reduces traffic of the cellular network to 36% of that in the all pictures transmission method. In comparison with the probability based picture transmission method, the proposed method achieves lower uploading traffic while it delivers newer pictures to drivers. The simulation result also shows that if more metadata of pictures are included in beacon messages, fewer pictures are uploaded to the server with a small cost of the newness of the pictures provided to drivers.

In future work, we plan to evaluate the proposed method in an environment with the bias on vehicle density and positions that drivers request in order to confirm the effectiveness of the method in more realistic environments. We also plan to design more sophisticated criteria for selecting the metadata included in beacon messages, such as using the driving directions of neighboring vehicles.

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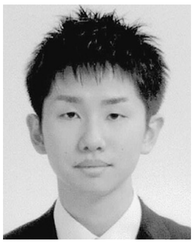

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