Replica Distribution Scheme for Location-Dependent Data in Vehicular Ad Hoc Networks using a Small Number of Fixed Nodes

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ABSTRACT

In vehicular ad hoc networks (VANETs), it is difficult for nodes to reliably access data on other nodes due to the mobility of vehicles. To improve the accessibility by certain vehicles to data generated at other vehicles, it is effective to distribute replicas of such data. However, if the density of vehicles is low, it is difficult to distribute an adequate number of replicas. In this paper, we propose the System for Sharing Objects with Location information on Ad hoc Network Fixed Node eXtention (SOLA-FX). SOLA-FX utilizes a small number of fixed nodes that are not connected to the infrastructure network. They are placed at intersections to support the storage and distribution of location-dependent data generated by vehicles, and forwarding of request/reply messages. We conducted simulations to determine suitable positions of the fixed nodes and an effective replica distribution operation between vehicles and the fixed nodes. The results showed that arranging fixed nodes in an area where location-dependent data items are frequently generated improves the accessibility to replicas with a small number of fixed nodes. We also confirmed that making each fixed node broadcast a replica when it has been received by a few vehicles in a previous replica distribution improves the accessibility to the replica with low replica distribution overhead.

Keywords: VANET, replica dissemination, location-dependent data, geocasting, fixed nodes

1 INTRODUCTION

To disseminate location-dependent data on roads, for example, information about traffic jams and traffic accidents to vehicles, researchers have been attracted to Vehicular Ad hoc NETworks (VANETs). VANETs do not rely on network infrastructures since they enable vehicles to communicate with each other without such infrastructures. Moreover, in VANETs, location-dependent data can be exchanged in a local region; hence, it is not necessary to deploy or manage servers for information exchange in a fixed-infrastructure network. To provide ITS services for safety and environment using vehicle-to-vehicle and vehicle-to-infrastructure communication, C2CCC (Car-2-Car Communication Consortium) have been discussing the practical use of V2V communication system. If roadside infrastructures are available, they would support intermittent V2V communication and provide more reliable ITS services. Hence we consider reasonable to support data sharing between vehicles using fixed nodes.

In this paper, we discuss SOLA (System for Sharing Objects with Location information on Ad Hoc network), a system in which vehicles collect and share location-dependent data in vehicular ad hoc networks without any data servers in a fixed-infrastructure network [1]. In SOLA, vehicles near the source area of a location-dependent data item store replicas of that data item. When a vehicle needs a data item related to a location, it sends a request message to the location of interest using Geocast. If a vehicle near the destination location receives the request message, it replies to the request and sends the location data item to the requesting vehicle. However, in VANETs, the network topology changes frequently due to the mobility of vehicles. Thus, inter-vehicle connectivity is not assured. Even if vehicles try to share some data with each other in this environment, it is not always possible to access information that other nodes have because of the lack of connectivity between vehicles. In SOLA, vehicles distribute replicas of location-dependent data so that the replicas remain in the area near the ”birthplace” of the location dependent data.

Generally, it is difficult to disseminate replicas of location-dependent data to other vehicles in a network with low vehicle density because there are fewer chances to exchange replicas between vehicles. In this paper, we propose SOLA-FX (SOLA Fixed nodes eXtention), which improves the access success rate of replicas requested through geocasted messages under conditions of low vehicle density. In SOLA-FX, to make sure the location-dependent data stay near the birthplace, a small number of fixed nodes that hold and distribute replicas of location-dependent data items are implemented. We assume that the fixed nodes have the same capability of vehicle-to-vehicle communication.

The fixed nodes distribute replicas of the location-dependent data stored in their buffer in order to increase the opportunities to distribute replicas when vehicle density is low. To obtain the maximum possible effect by deploying a small number of fixed nodes, we consider the most suitable positions of fixed nodes and effective schemes to distribute replicas to other nodes with a small amount of traffic.

Our contributions are summarized as follows.

- We propose replica distribution schemes using vehicles and a small number of fixed nodes (Section 3), SOLA-FX, to improve the accessibility of location-dependent data items. In SOLA-FX, fixed nodes placed at intersections hold and broadcast replicas of location-dependent data items by taking into consideration local information such as neighboring vehicle density and the traveling direction of neighboring vehicles.

- We propose two methods to reduce replica distribution traffic for fixed nodes (Section 3.3.3). To avoid the increase in replica distribution traffic due to added fixed nodes, the fixed nodes cancel replica distribution so that they send the replicas to many vehicles by one broadcast and avoid sending redundant replicas over a short period of time.

- We present the effects of the layout of fixed nodes on replica distribution by evaluating SOLA-FX with several fixed-node layouts (Section 5). The results showed that SOLA-FX can improve the access performance with low replica distribution traffic by placing fixed nodes at intersections in areas where location-dependent data items are generated frequently.

2 RELATED WORK

Many studies have been done on reliably data item sharing between vehicles in VANETs with a small amount of traffic, and various methods utilizing fixed nodes have been proposed.

Lee et al. proposed a data harvesting protocol in mobile sensor platforms which form of content-addressed storage (CAS) [2]. In CAS, 2-D Cartesian space is divided into zones based on the vehicle density. Each zone has an Infostation. Each vehicle senses or detects location-dependent data items, and then sends the data items to the Infostation responsible for the location. To obtain data items, each vehicle sends a request message to the Infostation located in the zone where the data item of interest was generated. In low vehicle density, CAS requires a lot of Infostations because it is difficult for vehicles to send data items to just one of the Infostations. On the contrary, we focus on sharing information mainly using vehicles that do not rely on fixed nodes to share information if there are a sufficient number of vehicles.

Ding et al. proposed a routing protocol called Static-node assisted Adaptive data Distribution protocol in VANETs (SADV) [3], which utilizes fixed nodes to reduce packet delivery delays under low vehicle density conditions by relaying packets via the fixed nodes. In SADV, fixed nodes are placed at all intersections in the network area. The fixed nodes temporally store packets they receive, and forward the packets through paths selected in order to minimize the packet delivery delay. While SADV requires fixed nodes at all intersections, our scheme is designed with a small number of fixed nodes, which reduces the equipment and maintenance costs.

In addition to our work [1], some other schemes for disseminating location-dependent data in VANETs have been proposed. Maihofer et al. proposed Abiding Geocast [4], in which vehicles send packets repeatedly to all vehicles in a certain area for a certain period. Xu et al. proposed a method to keep location-dependent data in a certain area by exchanging the data with encountered vehicles [5]. In this method, each vehicle maintains data that have been generated more recently and nearer to the source area. However, these schemes do not utilize information on the road structure, and the nodes distribute replicas of location-dependent data when vehicles encounter other vehicles. On the other hand, in our scheme nodes utilize knowledge about the road structure, and they send replicas by one-hop broadcasting at intersections.

In this paper, we extend Road-aware Direction based replica distribution scheme (RD method) [1]. In RD method, vehicles distribute replicas of location-dependent data items at intersection in order to distribute the replicas to many vehicles with a small number of broadcasts. However, vehicles are not able to distribute replica at even intersection under low vehicles density conditions. Consequently, we introduce a small number of fixed nodes to RD method to improve the connectivity between nodes. We describe RD method and our new proposed approach in the following section.

3 SOLA-FX

In this section, we describe the design of SOLA-FX. After first listing some assumptions about the system, we briefly present a replica distribution scheme that SOLA-FX is based on. After that, we detail the desighn of SOLA-FX.

3.1 Assumptions

We assume the following conditions, which are the same as in our previous work involving the SOLA and RD methods [1].

- Vehicles move according to traffic regulations.
- Each vehicle can track its location using GPS, etc.
- There is no specific data server. Each host does not know which vehicle has a particular location-dependent data item.
- Each location-dependent data item is associated with the position where it was generated.
- When each vehicle needs to obtain a location-dependent data item, it sends a request message to the relevant position by Geocast.
- When a node receives a request message, if it has the replica of the requested data items, it sends the replica as a reply to the request.
- When a vehicle transmits a request or reply message, if there is no neighbor vehicle that can receive the message, the vehicle processes the message in a carry-and-forward manner. In other words, the vehicle holds the message until it encounters other vehicles, and then transmits the message.
- Each node has sufficiently large storage. Thus, vehicles do not exhaust their storage capacity.

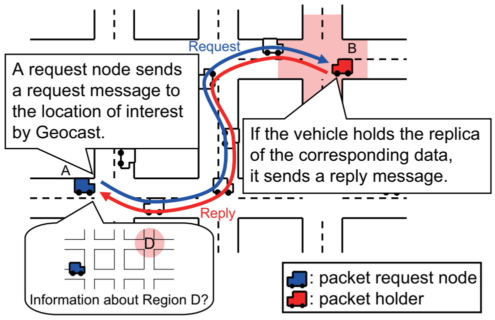


Figure 1: System configuration of Sharing Objects with Location information on Ad-hoc networks (SOLA)

In SOLA, we consider that the nodes near the birthplace of the data item hold location-dependent data by distributing replicas properly. A node that requests a data item (Fig. 1: node A) sends a request message by geocasting to the source area of data (Fig. 1: region D), and a node that has the corresponding data or the replica (Fig. 1: node B) replies.

We expect that SOLA will provide the following services; when drivers would like to get location-dependent data items such as traffic information and stored information on their location of interest, they initiate a request to the location by touching the screen of their car navigation system or by using a voice command.

3.2 RD method

In this section, we briefly describe the Road-aware Direction-based replica distribution scheme (RD method), which is the basis of SOLA-FX. Then we present some problems with this method.

3.2.1 Outline of RD method

The RD method allows nodes to distribute replicas to many other nodes in one broadcast by making nodes broadcast the replicas at intersections. In this method, we assume that vehicles periodically exchange Hello messages with each other. Based on the received Hello message, they create and maintain a list of neighboring vehicles, which includes the IDs of the location-dependent data that the neighbors have (Fig. 2).

Vehicles broadcast replicas at intersections where vehicle density is high due to vehicles waiting at stoplights. A vehicle that generates location-dependent data or a vehicle that is directed to redistribute the replica when it receives a replica, which is called the next-distribution vehicle, distributes the replica at intersections in areas near the birthplace of the data items. When a next-distribution vehicle broadcasts a replica of data item at an intersection, it groups its neighboring vehicles based on the vehicles' traveling direction. Then it selects a vehicle which is headed to another intersection as the next-distribution vehicle from the group (Fig. 3). The ID of the next-distribution vehicle is attached to the broadcast replica. After receiving the replica, the selected vehicle redistributes the replica at the next intersection. All nodes that have received replicas maintain them until the deadlines of the data

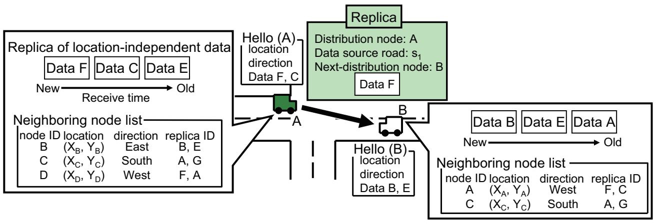


Figure 2: RD method: Neighboring node list and Hello Message

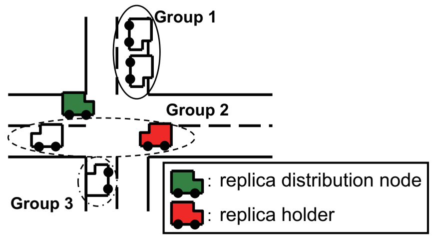


Figure 3: RD method: Grouping vehicles based on their traveling directions

items.

3.2.2 Problem with RD method

One problem with the RD method is that the access success rate of location-dependent data is low under low vehicle density conditions because the replicas are only distributed by vehicles. This is because there are very few or no vehicles at intersections when the next-distribution vehicle arrives if the vehicle density is low. Thus, it is hard to keep the replicas close to the birthplace of the data items.

3.3 The design of SOLA-FX

To solve the previously mentioned problem, we propose a method to improve the probability that request messages reach replicas by using a small number of fixed nodes at intersections. Fixed nodes hold replicas of location dependent data and distribute the replicas to vehicles. We refer to SOLA using the fixed nodes as SOLA-FX. In this section, we describe the design of SOLA-FX in terms of the following points.

- Layout of fixed nodes
- Replica distribution scheme of vehicles and fixed nodes

We assume that fixed nodes have a large storage device and sufficient energy to operate such a device as well as vehicles do. Their communication range is also identical to that of vehicles. They do not have connectivity to a fixed network infrastructure such as the Internet.

3.3.1 Layout of fixed nodes

Deploying many fixed nodes increases the cost of deploying and managing them. To solve this problem, we focus on us-

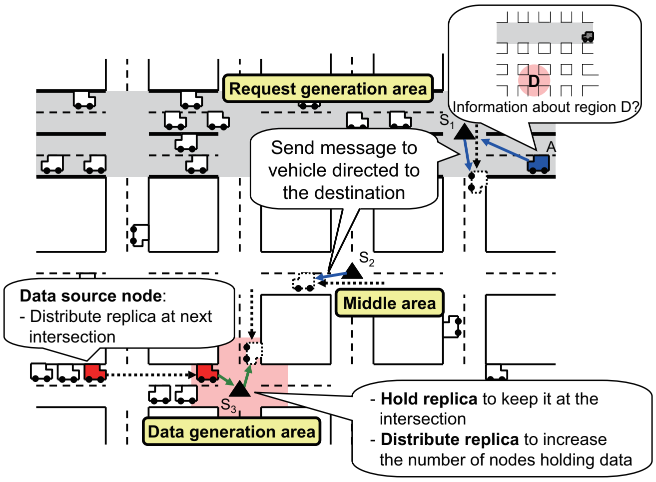


Figure 4: Deployment of fixed nodes

ing a small number of nodes and placing them in suitable positions. In the RD method, because vehicle density at intersections is higher than that on roads between intersections, vehicles distribute replicas of location-dependent data at intersections so that many vehicles can receive replicas from just one broadcast message. We consider that the characteristics of receiving and sending replicas using fixed nodes are the same as when using vehicles. Hence, we limit the locations for deploying fixed nodes to intersections in the SOLA-FX method.

We have lined up the following candidates for locations to place fixed nodes.

- Areas where request messages are created frequently (request generation areas)
- Areas where location-dependent data are created frequently (data generation areas)
- Areas between request generation areas and data generation areas (middle areas)

To clarify the description we show some examples. We consider an area that has arterial roads with high traffic density (Fig. 4). Suppose when a vehicle drives along an arterial road (Fig. 4: node A) and it is near an intersection, it wants to obtain data items related to region D. It geocasts a request message to that area. A fixed node deployed at an interesection in the request generation area (Fig. 4: node S_1) or the middle area (Fig. 4: node S_2) relays the message so that the message can reach the destination. If there are no vehicles around an intersection where a fixed node is placed when vehicles send a request message, the fixed node stores the message and forwards it to vehicle the fixed node encounters later. Moreover, because fixed nodes deployed in the data generation area (Fig. 4: node S_3) hold the replica of location-dependent data until the expiration time of the data item, the replicas are kept in this area. Thus, the fixed nodes that have data items that have been requested can reply as long as the request messages arrive at the intersections.

3.3.2 Replica distribution scheme using small number of fixed nodes

In SOLA-FX, when a vehicle has been designated to distribute replicas of location-dependent data items (a next-distribution vehicle) arrives at an intersection, it broadcasts the replica if there are one or more neighboring nodes (a fixed node and a vehicle) as well as in the RD method. Then, the vehicle designates some nodes as next-distribution vehicles according to the RD method. These IDs of nodes that have been designated to distribute replicas are attached to the replica. When a fixed node receives a replica, it is instructed to just hold the replicas or to hold and distribute the replicas. Concretely speaking, when replica distribution vehicles arrive at an intersection where a fixed node is placed, the vehicles broadcast the replica with a *fixed node distribution flag* F enabled, which controls the fixed node that receives the replica, ensuring that the fixed node broadcasts the replica only when it meets certain conditions. Fixed nodes that have received a replica with the enabled fixed node distribution flag distribute the replica according to one of the following rules.

FewReceivers(T_r): fixed nodes distribute replicas that have been received only by a small number of vehicles.

When a vehicle arrives at an intersection where a fixed node is placed, if the number of neighboring nodes in its neighboring node list is less than the threshold value, T_r, it enables the fixed node distribution flag F and broadcasts the replica. If the number of neighbor nodes is equal to or more than T_r, the vehicle broadcasts the replicas turning off F. In the both cases, the fixed node continues to hold the received replica.

When a fixed node detects neighboring vehicles by receiving Hello messages, if F is enabled, it broadcasts the replica and designates all the neighboring nodes in its neighboring node list to distribute the replica. In this scheme, fixed nodes distribute replicas frequently when vehicle density is low.

OmniDist: fixed nodes distribute replicas to enable their distribution at all adjacent intersections.

Generally, the density of vehicles on each road segment connected to an intersection is different. For example, at intersections near arterial roads, traffic going towards arterial roads is busy, while others are not busy. To distribute replicas evenly considering the amount of vehicle traffic to all directions from an intersection, fixed nodes broadcast replicas only when they encounter vehicles that are destined for the direction where they have not distributed the replica previously. Concretely speaking, we use the following process.

When a replica distribution vehicle broadcasts a replica at an intersection where a fixed node is placed, it generates a *distribution direction list*, which is a list containing the traveling direction of each neighboring vehicle in its communication range . After that, it broadcasts the replica with this list attached and with the fixed node distribution flag F on. When a fixed node detects newly arriving vehicles from Hello packets, it broadcasts the replica and designates vehicles whose traveling directions are not contained in its distribution direction list to redistribute the replica.

Always: fixed nodes distribute all received replicas.

All replica distribution vehicles that arrive at intersections where a fixed node is placed enable the fixed node distribution flag and broadcast the replicas. After that, when the fixed node that received the replica detects neighboring vehicles by receiving Hello messages, the fixed node designates all the neighboring nodes in its neighboring node list to redistribute the replica and broadcasts it. In this scheme, because fixed nodes broadcast all received replicas, the opportunities for replica distribution by fixed nodes increase substantially.

3.3.3 Replica distribution traffic reduction method

Replica distribution traffic will increase in the increase of the number of vehicles at every intersection as fixed nodes distribute replicas when they encounter newly arriving vehicles. To avoid this problem, we designed two methods to cancel broadcasts of replicas.

Number limitation method

Fixed nodes cancel replica distribution if the number of vehicles in their neighboring node list is less than the threshold T_r to ensure that many nodes receive a replica from one broadcast.

Time limitation method

If fixed nodes distribute replicas repeatedly over a short period of time, vehicles in their communication range receive the same replicas many times. To avoid this, we set a threshold for the distribution interval. Each fixed node cancels the replica distribution if a period of time greater than T_p has not passed since the replica was last distributed.

4 SIMULATION MODEL

We evaluated the effects of the layout of fixed nodes and replica distribution schemes of vehicles and fixed nodes using JiST/SWANS simulator[6].

We set up a simulation field 3000 m $\times$ 3000 m in size that included 14 roads directed to four cardinal points every 500 m (Fig. 5). The simulation field contains arterial roads where the vehicle density is high (represented by heavy lines in Fig: 5). Arterial roads have two lanes for each direction, and ordinary roads have only one lane. All communication is broadcast as defined in the 802.11b standard with an 11-Mbps data rate, and the communication range is set to 100 m. Each vehicle broadcasts a Hello message every 1 second. Each Hello message is 100 bytes including UDP and IP headers. The time-to-live (TTL) of a Hello message is 1 second, and it is deleted from their neighboring node list if the TTL has elapsed. We define the area that includes both intersections of the road where location-dependent data items were generated and four adjacent intersections of the orthogonal roads of the birthplace road of the data items, as the replica distribution area (Fig: 6).

4.1 Vehicle mobility models

We obtained mobility traces using the vehicle traffic stream simulator NETSIM. Vehicles enter the simulation field from the edges of all roads, and they move at speeds between 0-60 km/h. Traffic lights changing in 60-second cycles (blue: 26 seconds, yellow: 3 seconds, red: 31 seconds) are placed at all intersections. Vehicles move according to the branching fractions in Table 1.

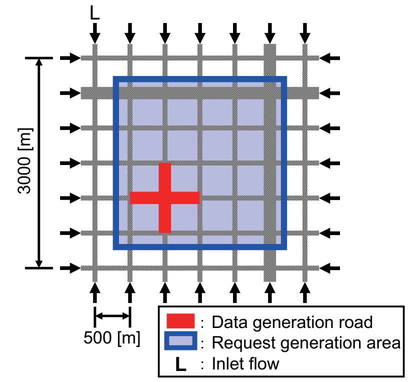


Figure 5: Simulation field

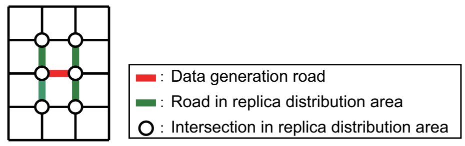


Figure 6: Replica distribution range

4.2 Data generation model

Each vehicle that moves in the data generation area (Fig. 5) generates a new location-dependent data item related to its current road segment. About 40 location-dependent data items are generated regardless of the number of vehicles in the inlet flow. Each generated data item includes the ID of the road segment where the data item was generated. The packet size for each data item (replica distributed, reply message) is 1000 bytes including UDP and IP headers. The TTL of each data item is set to 300 seconds.

4.3 Request generation model

Vehicles that move in the request generation area (Fig. 5) generate request messages for location-dependent data every 200 seconds. Then the destination road ID of the request messages is selected randomly from all roads in the simulation field. Each request message includes its destination road ID and the size is 128 bytes including UDP and IP headers. The TTL of the request messages is 120 seconds.

4.4 Data request model

Request messages are transmitted according to a routing control which uses both greedy forwarding and carry and forward techniques.

Vehicles that generate a request message (Fig. 7: node A) select a vehicle that is closest to the destination (the next hop, Fig. 7: node B) from vehicles included in its neighboring node list created by exchanging Hello messages. When a vehicle is outside of an intersection (Fig. 7: node C) and there are

	straight (%)	turns(%)
ordinary + ordinary	20	40
arterial → arterial	90	5
ordinary + ordinary arterial + arterial	70	15

Table 1: Probability of vehicle mobility at intersection

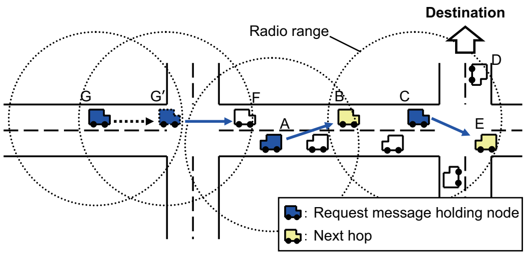


Figure 7: Selection of next hop

neighboring vehicles at the intersection, a vehicle at the intersection (Fig. 7: node E) is selected even though there are other vehicles which are closer to the destination (Fig. 7: node D). If vehicles that have received request messages have the corresponding data, they do not send the request messages to the next hop. On the other hand, if a vehicle does not have the corresponding data item and it is indicated as the next hop, it selects the next hop based on its neighboring node list and broadcasts the request message.

If there is no node that can receive the request message around a vehicle even when the message is transmitted by greedy forwarding, the message will be lost. To avoid this, vehicles transmit messages using the following carry and forward technique.

1. If there is no vehicle to transmit a request message to in its communication range, a vehicle holds the packet until it detects a new vehicle from a Hello message (*Carry*, Fig. 7: node G).

2. The vehicle holding a request message selects the next hop from its neighboring node list when it receives a request message or a Hello message while it carries the messages (Fig. 7: node G').

3. The vehicle broadcasts the request message with the next hop ID if its neighboring node list includes vehicles that it can transmit the request message to (Fig. 7: node G', F); otherwise, it continues to carry the message.

5 RESULTS AND DISCUSSION

In this section, we present the simulation results of SOLA-FX. We use the following performance metrics to evaluate SOLA-FX.

- **Access success rate:** the ratio of the number of request messages received by nodes holding replicas of the requested data items to the number of request messages sent from requesting vehicles.

- **Replica distribution traffic:** the number of broadcasts of replicas per generated data item.

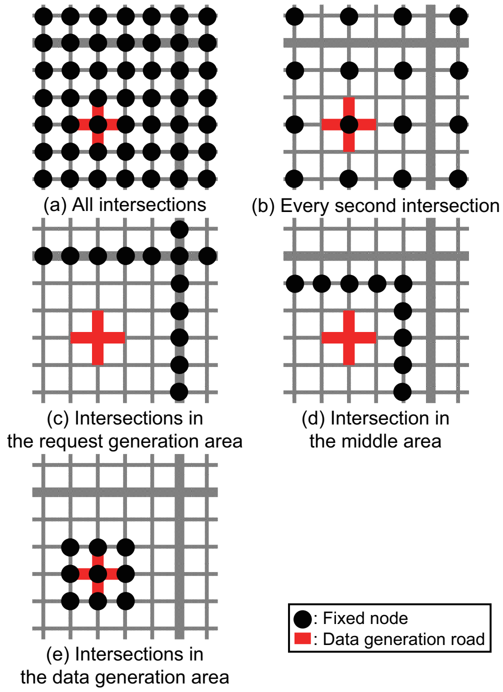


Figure 8: Layout of fixed nodes

In this paper, we do not evaluate whether reply messages were delivered to the requesting vehicles. This is because some challenges arise in delivering reply messages, for example, finding a route to a mobile requesting node even if the request was *carried*. Thus, we focus on request messages.

We ran the simulations for 3600 seconds in the simulation time. Data collected in the first 600 seconds of the simulation were neglected in order to avoid the effects of the initial state. Each data point plotted on the graphs was averaged over 10 runs.

5.1 Effect of layout of fixed nodes

To evaluate how the effect of layout of fixed nodes affected the system, we placed fixed nodes in the arrangements shown in Fig. 8. Fig. 9 shows the access success rate of SOLA-FX. To verify what effects the placement of fixed nodes had on the access success rate, we compare SOLA-FX with the RD method identified as NoFixedNode . In this evaluation, we do not use the replica distribution traffic reduction methods described in section 3.3.3.

When fixed nodes are placed at (a) all intersections and (e) intersections in the data generation area, SOLA-FX, using FewReceivers(3) and Always, improves the access success rate in low vehicle density conditions compared with NoFixedNode. The common point of both layouts of fixed nodes is that there are fixed nodes around the data generation area. The access success rate when fixed nodes are placed

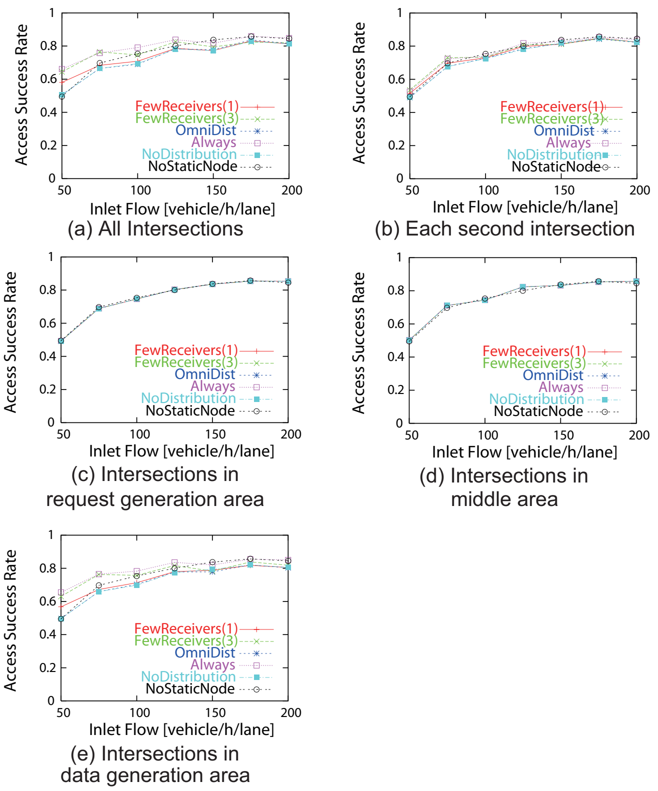


Figure 9: Effect of layout of fixed nodes: access success rate

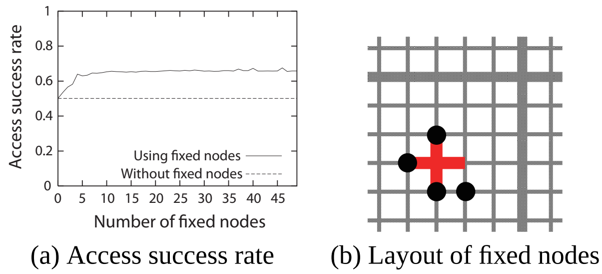


Figure 10: The Relationship between the layout and the number of fixed nodes

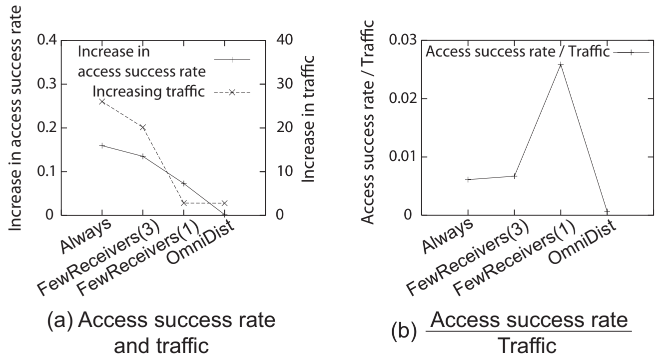


Figure 11: Effect of replica distribution schemes

in 9 intersections around the data generation area (Fig. 9(e)) is equal to that when they are placed at all 49 intersections (Fig. 9(a)), although there is a significant difference in the number of fixed nodes between the two layouts. On the other hand, when fixed nodes are deployed at (c) intersections in the request generation area and (d) intersections in the middle area, the access success rate of SOLA-FX using any distribution scheme is equal to that of NoFixedNode. This is because it is possible to transmit request messages to the vehicles heading to the destination without fixed nodes since there are many vehicles on the arterial road.

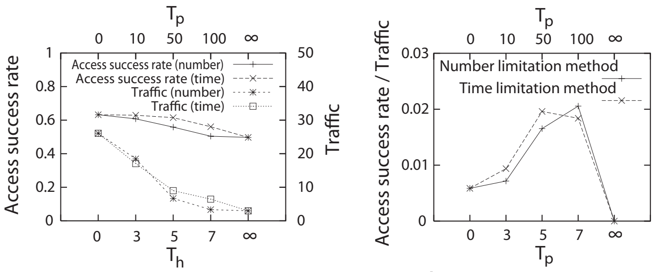
Then, we investigate the minimum number of fixed nodes to improve accessibility. In this evaluation, fixed nodes distribute replicas based on FewReceivers(3), and the number of vehicles in the inlet flow is 50. We placed 49 fixed nodes at all intersections preliminarily. After that, we tested all layouts which have 48 fixed nodes. According to the simulation results of these layouts, we selected a layout with the best access success rate. After that, we tested 47 layouts obtained by removing one fixed node from the last best layout with 48 fixed nodes. We repeated this operation until all fixed nodes are taken away from the field. Fig. 10(a) plots the access success rate of the best layouts for each number of fixed nodes. From this results, we can say that 4 fixed nodes are enough for increasing the access success rate in our scenario. Fig. 10(b) presents the best layout with 4 fixed nodes.

Thus, it is effective to place fixed nodes at intersections around data generation area.

5.2 Effect of replica distribution schemes of vehicles and fixed nodes

It is ideal to improve the access success rate with a small volume of replica distribution traffic. In this section, we show simulation results when fixed nodes placed at 9 intersections in the data generation area (Fig: 8(e)) distribute replicas according to FewReceivers(1), FewReceivers(3), OmniDist, and Always as replica distribution schemes. In the Always scheme, fixed nodes broadcast all received replicas when they encounter new vehicles. As follows, we use the following two metrics, increase in access success rate and increase in traffic. The former is the difference in the access success rate of each scheme and that of NoDistribution, in which fixed nodes do not distribute replicas, and the latter is the difference in the replica distribution traffic of each scheme and that of NoDistribution.

Fig. 11(a) plots the increase in the access success rate and that of replica distribution traffic, and Fig. 11(b) plots the increase in the access success rate divided by the increase in the replica distribution traffic. In Fig. 11(a), we can see that SOLA-FX using FewReceivers(1), FewReceivers(3), and Always has a positive increase in the access success rate. In Addition, FewReceivers(1) and FewReceivers(3) reduce the number of replicas distributed under high vehicle density conditions, although Always increases the replica distribution traffic with an increase in the number of vehicles. This is because fixed nodes using FewReceivers(1) and FewReceivers(3) distribute replicas frequently when there are a few vehicles around them under low vehicle density. Fig. 11(b) shows that FewReceivers(1) improves the access success rate with less traffic.



(a) Access success rate and traffic

(b) $\frac{\text{Access success rate}}{\text{Traffic}}$

Figure 12: Effect of replica distribution reduction methods

5.3 Effect of replica distribution traffic reduction methods

We verified the effect of our proposed schemes described in section 3.3.3 on access success rate. In this evaluation, fixed nodes placed at 9 intersections in the data generation area (Fig: 8(e)) distribute replicas according to FewReceivers(3) as the replica distribution scheme. To focus on the effect of SOLA-FX under low vehicle density, we show the results when there were 50 vehicles in the inlet flow.

Fig. 12(a) shows the access success rate and the replica distribution traffic when fixed nodes cancel replica distribution according to each limitation method. The value of T_h=0 and T_p=0 represent the result of SOLA-FX in which the limitation method is not used, and the T_h=∞ and T_p=∞ represent that of NoDistribution. Fig. 12(b) shows the rate of the increase in access success rate compared with that of NoDistribution to the replica distribution traffic. We describe the results of each limitation method as follows.

Number limitation method

In number limitation method, fixed nodes cancel replica distribution when the number of their neighboring nodes is less than the threshold number, T_h. According to Fig. 12(a), the replica distribution traffic is reduced by canceling the replica distribution of fixed nodes when there are few vehicles at the intersection where fixed nodes are placed. In Fig. 12(b), we can see that fixed nodes improve the access success rate with less traffic when we set T_h to 5.

Time limitation method

In time limitation method, if the time that has passed since the previous distribution of the same replica is not above the threshold interval, T_p, the fixed nodes cancel replica distribution. According to Fig. 12(a), we can see that it is possible to reduce the replica distribution traffic and avoid decrease in the access success rate by setting T_p to 50 seconds. Moreover, we can see that the effect of replica distribution using fixed nodes is enhanced by setting T_p to 50 seconds.

These results indicate that the replica distribution traffic reduction methods not only reduce the redundant replica distribution traffic but also improve the access success rate compared to NoDistribution. As both traffic reduction methods are independent of each other, it is effective to distribute replicas of location-dependent data using both methods under low vehicle density conditions where fixed nodes placed at intersections in data generation areas distribute replicas frequently.

6 Conclusion

We proposed SOLA-FX, a replica distribution scheme using vehicles and a small number of fixed nodes to improve the accessibility of location-dependent data in VANETs under low vehicle density conditions. We also verified a suitable layout of fixed nodes and replica distribution schemes for vehicles and fixed nodes in order to increase the access success rate with less replica distribution traffic.

Simulation results of several layouts of fixed nodes and replica distribution schemes for fixed nodes showed that deploying fixed nodes at intersections around the birthplace of data items was effective to improve the access success rate. The access success rate of such a case was almost equal to a case with fixed nodes at all intersections in the simulation area. In particular, we confirmed that the SOLA-FX system increases the opportunity for nodes to distribute replicas with less traffic by making fixed nodes distribute replicas for vehicles only when there is a small number of vehicles selected as the next-distribution vehicle at previous replica distribution, *FewReceivers*. We also confirmed that the replica distribution traffic caused by using fixed nodes can be reduced by canceling replica distribution by taking into consideration the number of their neighboring nodes and the elapsed time since the previous replica distribution.

In this simulation, we assumed that location-dependent data items were generated at a certain location. In general, however, location-dependent data items are generated on any road. We will evaluate SOLA-FX in this environment and discuss a suitable layout and replica distribution schemes of fixed nodes.

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