Shadowing Fading based Crossroad Geographic Opportunistic Routing Protocol for Urban VANETs

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***Abstract*—In Vehicular Ad-hoc Networks (VANETs), the presence of many obstacles such as buildings and trees cause shadowing and fading, which interfere with the propagation of radio waves. However, most of the existing opportunistic routing protocols do not take into account shadowing in their simula-tions, which may lead to an overestimation of VANETs performance. To solve this problem, our proposed routing protocol can minimize the effect of shadowing by actively selecting street intersection nodes as relay nodes. In this study, we investigated the effect of shadowing on an existing routing protocol LSGO, using a shad-owing obstacle model implemented ns-3. Additionally, we propose a Shadowing Fading based Crossroad Ge-ographic Opportunistic Routing Protocol (SFCGO). SFCGO determines the priority of a relay node by considering the distance between the relay node and the destination node, the link quality between these nodes, and a street Intersection Relay Index(IRI) in which the best relay node is selected according to the influence of shadowing. Through simulations, we confirmed the improvement of the packet delivery rate and the de-crease of the end-to-end delay and demonstrated the effectiveness of SFCGO's communication performance.**

***Index Terms*—VANET, Routing Protocols, Opportunistic Routing Protocols, Shadowing**

I. Introduction

Intelligent Transportations Systems (ITS) [1] have been actively pursued to improve the safety and convenience of driving and to reduce the environmental impact. Many efforts are being made to improve the safety and convenience of driving and to reduce the environmental impact. Vehicle Ad-Hoc Networks (VANETs), which are formed by inter-vehicle communication, are essential for the realization of various applications in ITS. In VANETs, ad-hoc communication is achieved between vehicles equipped with wireless communication devices, which enables the construction of flexible n etworks. When V ANETs a re d eployed in urban environments, fast node mobility, heterogeneity, and the presence of buildings need to be considered in the performance evaluation. A rich variety of routing protocols have been proposed to meet various needs [2]. The existing routing protocols in VANETs can be classified into two categories: Topology-based routing protocols and Geographic routing protocols. Topology-based routing protocols [3]–[5] which use the network links information to forward packets. Topology-based routing protocols are not suitable for VANETs because they cannot support fast node movement. On the other hand, Geographic routing protocols [6]–[15] can forward packets based on the neighboring nodes location information and the Destination node location. In this kind of routing protocol, nodes do not need to maintain established routes as in conventional mobile ad-hoc network routing protocols. Therefore, the geographic routing protocol can cope with topology changes with a small number of packets. Greedy forwarding is one of the most used packet forwarding methods in geographic rout-ing protocols. However, in an actual urban environment, the drop rate of packets may increase due to shadowing and degradation of signal strength over distance. This increases the possibility of packet retransmission, resulting in increased overhead and end-to-end delay.

In contrast to these methods, opportunistic routing protocols have been attracting attention [16]. The main difference between opportunistic routing protocols and conventional routing schemes is that opportunistic routing proto-cols do not use a fixed route, but allows nodes that receive packets to decide whether or not to forward them. This can increase the chance of receiving packets and consequently achieve better performance than conventional routing schemes. However, most of the existing originally opportunistic routing protocols are not designed for urban environments, therefore their performance evaluation does not take into account the effect of shadowing caused by buildings and may result in an overestimating of the communication performance. In fact, it has been demonstrated that the radio wave of 802.11p channels is attenuated by buildings, and the data trans-mission is limited alongside the road [17].

In this study, we evaluate the Link State aware Geographic Opportunistic routing protocol for VANETs (LSGO) [18], using the obstacle shadowing model [19]. Our evaluations tested LSGO under the obstacle shadowing model [19] using the ns-3 network simulator [20]. We also tested the communication performance when shadowing is not considered. Additionally, we proposed a new routing protocol (SFCGO) to improve the communication performance in the environments where shadowing exists.

In the SFCGO protocol, we consider the distance to the destination node and the expected transmission rate. Furthermore, SFCGO considers whether a node is close to an intersection node when selecting relay nodes. Our evaluations demonstrated the effectiveness of the proposed method in a simulation environment. The rest of this paper is organized as Follows. Section II describes the existing opportunistic routing protocols and shadowing. Section III describes LSGO, one of the most popular opportunistic routing protocols as well as problems with LSGO. Section IV describes the proposed method (SFCGO), and Section V shows the performance evaluation and effectiveness of the proposed method. Finally, Section VI summarizes and discusses future work.

II. RELATED WORK

A. Opportunistic Routing Protocols Backgraund

Recently, opportunistic routing protocols have attracted much attention. Compared with conventional geographic routing protocols [6], opportunistic routing protocols im-prove communication performance by increasing the num-ber of opportunities for relay nodes to receive packets. The basic model of opportunistic routing protocols is shown in Figure 1. Node N_s is the source node and N_d is the destination node. Node N_s selects relay candidate nodes and sends packets from N_1 to N_n specifying their priority. In each packet of the figure, the priority of the relay node is described for the sake of clarity, but the actual packet is broadcast, so the contents of the packet are identical. The nodes received the packet, it sets a relay timer according to its own priority. The higher the priority, the smaller the relay timer is set. The nodes that time out will rebroadcast packets. In addition, each relay node cancels its rebroadcast when it overhears the transmission of the packet from a node with a higher priority than itself before its timer expires, thereby preventing the increase of redundant packets. These results show that in opportunistic routing protocols, the priority determi-nation algorithm has a direct impact on communication performance.

Opportunistic Multi-Hop Routing for Wireless Net-works (EXOR) [16] has been proposed as a typical op-portunistic routing protocol. It determines the priority of relay nodes by using an original expected transmission cost (ETX) [21]. However, this newly devised way to calculate the ETX value has a problem in that it does not take into account the random and fast mobility nature of nodes, which is a characteristic of VANETs nodes.

Therefore, LSGO devised a new ETX value suitable for VANETs. In LSGO, the ETX value is used as a metric to determine the priority, which improved the packet delivery rate (PDR) and reduces the end-to-end delay. In the Collision Aware Opportunistic Routing Protocol (SCAOR) [22], to prevent the problem of packet collision that degrades network performance, node density is added as a metric in the priority determination. As a result, performance is improved compared to LSGO and EXOR in a highway deployment environment. In the Hybrid Oppor-tunistic and Position-based Routing protocol for vehicular ad-hoc networks (OPBR) [23], to solve the problem of delay increases when the packet does not reach the relay node, OPBR infers the link breakage of the neighboring node from the location information gathered from the neighboring nodes.

However, one common issue in all of these protocols is that they do not take shadowing into account. This problem makes these protocols overestimate their com-munication performance. In Section III, we examine the impact of shadowing on the communication performance of LSGO using simulations.

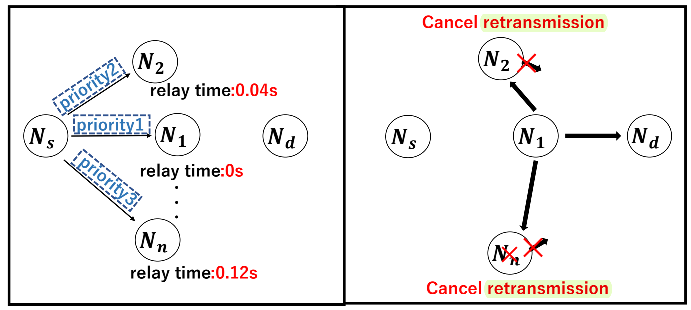

Fig. 1
Basic model of opportunistic routing protocols

B. Shadowing

When designing routing protocols for VANETs, many papers consider fast mobility of nodes, deviating node density, and link instability. However, VANETs are often assumed to be deployed in urban environments, therefore it is very important to design routing protocols that consider the effects of shadowing. As shown in Figure 2, the 802.11p channel commonly used in VANETs has shown to have a lower packet delivery rate (PDR) in real-world measurements in the gray-zone [17] located on the side of the streets due to the influence of buildings.

Intersection-based selection routing protocols [24]–[26] are effective for these shadowing problems. The forwarding strategy of these protocols can be classified i n t o three steps. The first o n e i s i n t ersection s e l ection, t h e second one is road selection at the intersection, and the third one is forwarding on the selected road. In these intersection based routing approaches, the impact of shadowing can be minimized because packets are forwarded along the road. However, when packets are forwarded linearly as shown in Figure 3, extra hop relays are introduced for each intersection in an intersection-based selection routing. These extra hop relays result in unnecessary relays and increasing the overall delay.

III. LSGO

In LSGO, each node periodically broadcasts a *hello* packet consisting of the node ID and its current position coordinate(x,y). To deliver the data packet to the destination

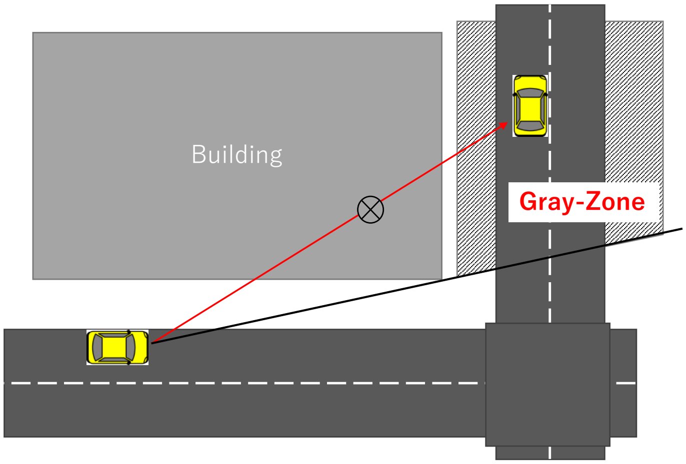

Fig. 2
The gray-zone in an intersection

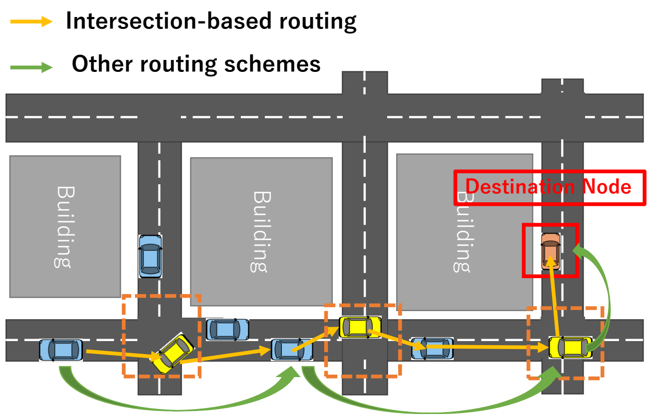

Fig. 3
Cases where intersection-based routing is inefficient

node, the node received the data packet selects some relay candidate nodes based on the information collected from neighboring nodes' hello packet. Then, it assigns a priority to the selected candidate nodes and rebroadcasts the received packet. The priority of the candidate nodes is determined by the transmitting node according to the algorithm described below. In LSGO, the priority of relay candidate nodes is determined based on two metrics: link quality and distance to the destination. Each node that receives the data packet checks whether it contains its own ID, and discards the packet if it does not. If the ID is valid, the node checks its own priority and rebroadcasts the packet according to the priority scheduling algorithm.

A. link quality estimation

In LSGO, each node broadcasts a hello packet periodically, and they use the hello packets to measure the expected transmission rate. The transmitted hello packets consist of the node ID, and the node position coordinates (X,Y). To calculate the ETX of a link, each node should record t_0 which means the time when the first hello packet is received and the number of packets it has received from the neighbor during the last w seconds. Then, according to the interval between t_0 and the current time t and the window w, the expected transmission rate $r(t)$ is calculated by Equation (1)

$$r(t) = \begin{cases} count(t, t_0), & 0 < t - t_0 < 1, \\ \frac{count(t,t_0)}{(t-t_0)/\tau}, & 1 \leq t - t_0 \leq w \\ \frac{count(t-w,t)}{w/\tau}, & t - t_0 \geq w \end{cases} \tag{1}$$

The denominator is the number of Hello packets that should have been received during the window, and τ represents the broadcast interval of the Hello packet. $count(t, t_0)$ is the number of Hello packets received during t-t_0. As can be seen from the formula, there are three situations in terms of the difference between t-t_0 and window time w. (1) $0 < t$-$t_0 < 1$, in this case, the packet delivery rate is the number of Hello packets received from t_0 to t. (2) $1 \leq t$-$t_0 < w$, the packet delivery probability in this condition is the number of Hello packets received from t_0 to t divided by the length of this period. (3) t - t_0 $\geq w$, in this situation, the calculation is the same as the calculation in the ETX metric.

In LSGO, they do not consider the asymmetry of the link and only use the one-way transmission rate to calculate the link ETX. Assuming that the one-way expected transmission rate is $r(t)$, then the link ETX is calculated by Equation (2)

$$ETX = \frac{1}{r(t)^2} \tag{2}$$

B. Priority Scheduling algorithm

LSGO uses a timer-based priority scheduling algorithm, in which the highest priority node sends the packet firstly. For other candidate nodes, if they hear a higher-priority node send a packet, they would not process the packet; if the timer expires and a higher-priority node is not transmitting, they would begin to send the packet. LSGO calculates the priority of node i according to Equation (3) below.

$$\frac{D_{sd} - Did}{ETX_i^2}, Did < D_{sd} \tag{3}$$

D_{sd} is the distance from the transmitting node to the destination node, and D_{id} is the distance from the candidate node i to the destination node. In addition, D_{sd} - D_{id} is distance metric. If the condition Did < D_{sd} is not satisfied, the node is excluded from the relay candidate nodes without calculating its priority. The larger the value calculated in Equation (3), the higher the priority of node i becomes.

C. Influence of shadowing

In this section, we explain the difference between the communication performance of LSGO with and without radio attenuation caused by shadowing.

1) Simulation Settings: The simulation parameters are shown in Table I. The simulation topology scenario was created using SUMO as shown in Figure 4, and the source node and destination node are randomly selected from the source area and destination area in Figure 4 . Traffic signals are placed at each intersection, and buildings are placed as shown in the blue area of Figure 4. The obstacle shadowing model[20] is used as the radio wave propagation model. The obstacle shadowing propagation loss *Ls,o* is calculated based on the loss for each wall and the distance (m) through the building as follows.

$$L_{s,o} = \alpha n + \beta d_0 \tag{4}$$

where α is the attenuation per wall (dB), n is the number of walls penetrated. β is the attenuation per meter (dB), and d_0 is the distance, traveled through obstacles (m). In this simulation experiment, α= 10dB and β= 0.4dB were used for evaluation. Although an optimized algorithm to select the number of candidate nodes was proposed in LSGO, the performance of this algorithm was poor when the shadowing propagation loss was used. This algorithm is constructed using the expected transmission rate (r(t)). Since the expected transmission rate is calculated from the hello packet, the packet arrives with a higher probability than the transmission rate of the data packet with a larger data size. It is assumed that this is the reason for the performance degradation of the algorithm.

TABLE I
simulation parameter

Simulator	NS-3 (v3.30)
Simulation area	1000m × 1000m
Mobility model	Random mobility
Transmission range	250m
Number of vehicles	200, 300, 400
Radio Propagation Model	obstacle shadowing model
MAC Layer	802.11p
Packet Size	512 byte
Simulation Time	30 s
hello interval	1 s
Window size w	10 s
Number of relay candidate nodes	5
shadowing parameter α	10db s
shadowing parameter β	0.4db

2) Assessing the influence of shadowing: The attenuation impact caused by the buildings on the communication performance of LSGO is evaluated in three evaluation categories: packet delivery rate, end-to-end delay, and overhead.

Figure 5 shows the packet delivery rate of the network simulator with and without using the obstacle shadowing loss propagation. The packet delivery rate is the ratio of the total num-ber of packets received by the destination node to the total number of packets sent by the source node. In Fig 5, when shadowing is considered in the simulation, the packet delivery rate decreases for all number of nodes. This is presumably due to the decrease in the number of candidate nodes for relaying due to the radio attenuation caused by shadowing.

Figure 6 shows the end-to-end delay (s) of the network simulator with and without shadowing effects. The end-to-end delay is defined as the average time between the transmission of a packet by the source node and its successful reception by the destination node. In Figure 6, when shadowing is considered in the simulation, the end-to-end delay increases for all number of nodes. This is because the attenuation caused by shadowing, makes it difficult for packets to pass through the buildings to reach the destination node, making it difficult to form a linear path between the source and destination node.

Figure 7 shows the overhead of LSGO with and without the shadowing effect. The overhead is the sum of the number of packets sent by each node in the entire network divided by the sum of the number of packets successfully received by each node. In Figure 7, the overhead increases for all number of nodes when shadowing is considered in the simulation. In opportunistic routing protocols, the algorithm works to cancel rebroadcast between relay candidate nodes ac-cording to their priority. However, because the shadowing effect, the possibility of not receiving the rebroadcast packet from high-priority nodes increases, and as a result, the overhead is assumed to have increased.

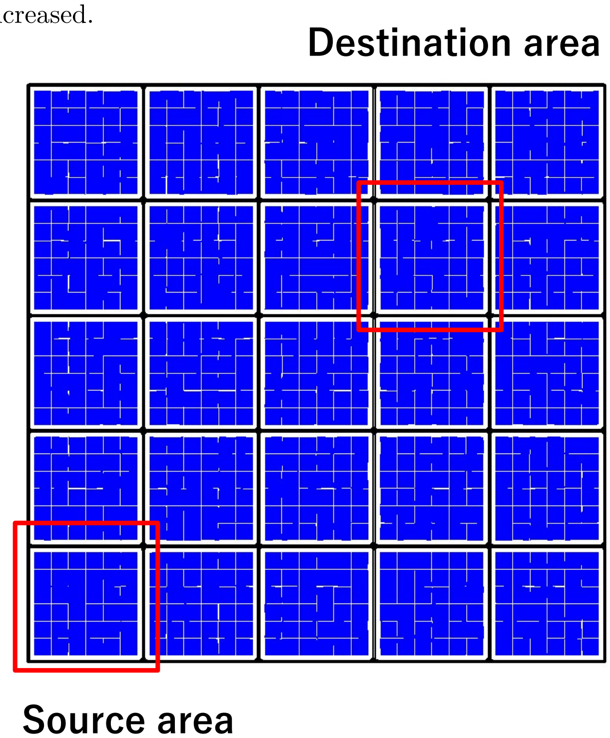

Fig. 4
simulation scenario

D. Problems with LSGO

In this section, we discuss the problems of the LSGO relay strategy. In the forwarding strategy of LSGO, a node which is closer to the destination node and has better

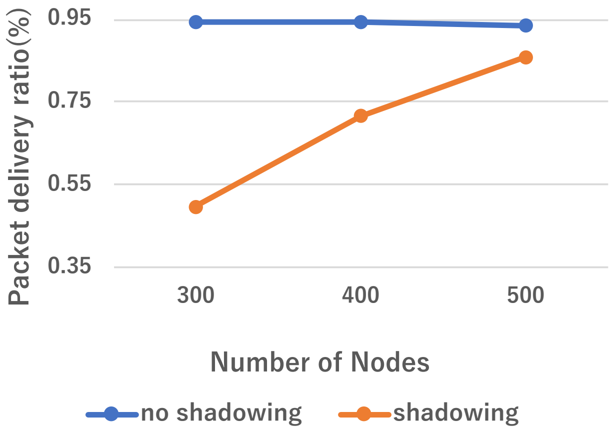

Fig. 5
Impact of shadowing: PDR

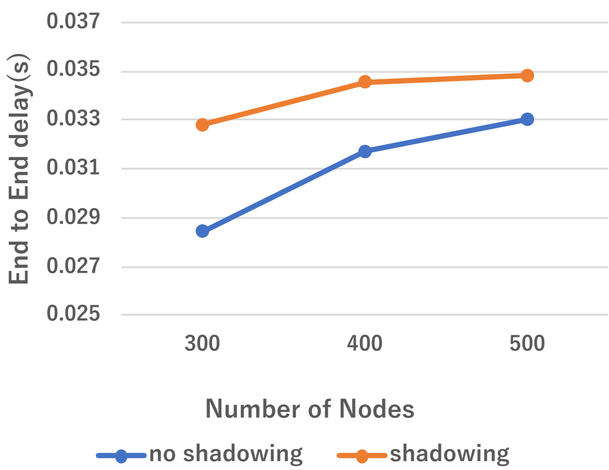

Fig. 6
Impact of shadowing: delay

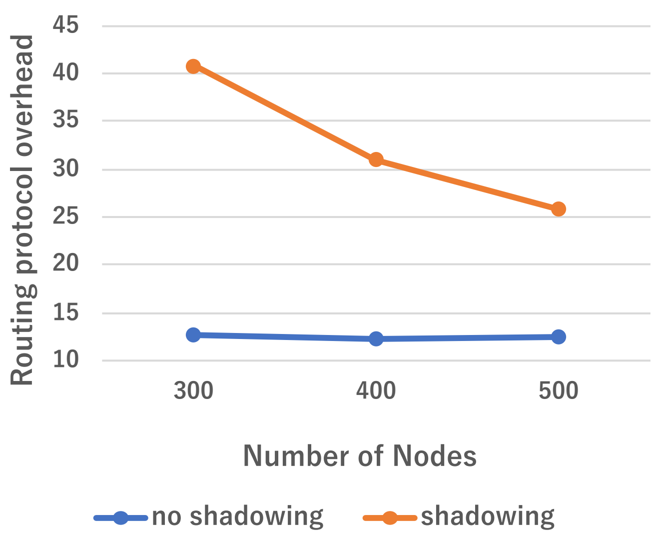

Fig. 7
Impact of shadowing: overhead

link quality is more likely to be selected as a forwarding node. An example is shown in (a) of Figure 8. Consider the situation where node B is selected as a forwarding node. In this case, the next relay nodes after node B (selected from nodes closer to the destination node than node B) are only nodes C and D with poor link quality due to shadowing. We call this problem the local shadowing problem. In addition, there is a case that the link with nodes C and D does not exist completely due to the shadowing. In this case, the problem arises that there is no node closer to the destination than node B. This has long been a problem in the Location based routing protocol, and is called the local optimum problem. From the above, we can see that the LSGO forwarding strategy is likely to fall into the local optimum problem and the local shadowing problem. This problem may be solved by selecting an intersection node, such as node A, as a relay node, as shown in (b) of Figure 8.

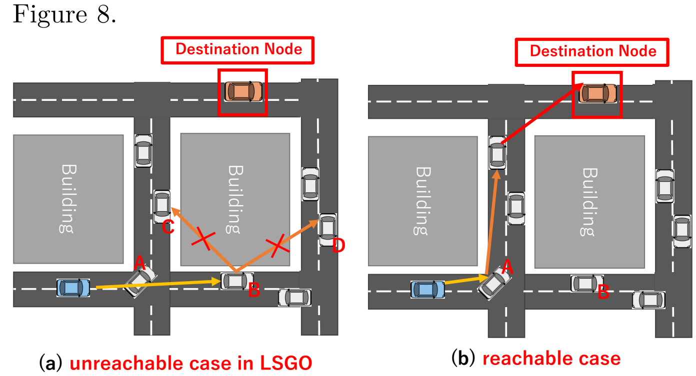

Fig. 8
forwarding node selection problem

IV. The proposed scheme

In this study, we propose a new opportunistic routing protocol named SFCGO, that takes street intersections into account. In SFCGO, the priority of relay nodes is deter-mined based on three metrics: distance to destination, link quality, and a street Intersection Relay Index (IRI) which is used to give priority to nodes in the intersection. The two metrics: distance to destination and link quality are calculated in the same way as in LSGO. In SFCGO, as in LSGO, each node periodically broadcasts a hello packet. To deliver the packets to the destination node, the transmitting node selects several relay candidate nodes among the neighboring nodes based on the information in the hello packet and broadcasts data packets containing the priority information of each relay candidate node.

The priority of the relay candidate nodes is determined by the transmitting node according to the algorithm described below.Each node that receives a data packet checks whether it contains its own ID, and discards the packet if it does not.If the ID is included, the node checks its own priority and decides whether or not to rebroadcast the packet according to the priority scheduling algorithm described in section IV-D below.

A. SFCGO hello and data packet format

In SFCGO, each node periodically broadcasts a hello packet to keep track of the link quality and the location of its neighbors. Some modifications have been made in the hello packet of LSGO protocol. Figure 9 indicates the structure of the hello packet.

- ID: The current Node Id.
- X: The current X coordinate.
- Y: The current Y coordinate.
- v_x: The current X component of velocity.
- v_y: The current Y component of velocity.
- a_x: The current X component of acceleration.
- a_y: The current Y component of acceleration.

Id	***X***	***Y***	v_x	v_y	a_x	a_y

Fig. 9
The format of hello packet

The structure of the relay packet is shown in Figure 10. It is assumed that some location information service is used to obtain the location information of the destination node, which is beyond the scope of this study. Since SFCGO does not use control packets, each relay node assigns a priority to the next-hop relay candidate node Id and broadcasts it in the structure shown in Figure 10.

- $DesId$: The destination node ID.
- $Des_x Cordinates$: The coordinates of the x destination node.
- $Des_y Cordinates$: The coordinates of the y destination node
- Id_i: The relay candidate node with priority i.
- $Data$: The Data payload.

DesId	***DesXpos***	***DesYpos***	ID_1	ID_2	ID_i	...	ID_N	***Data***

header

Fig. 10
The format of data packet

B. Intersection Relay Index IRI

In SFCGO, when the above two points are satisfied, the following procedure is used to calculate the index Ipp(intersection priority point) that gives priority to the intersection node.

- Whether or not there is an intersection node closer to the destination than the source node or the node that received the relay packet.
- The intersection is adjacent to the road where the source node or the node that received the relay packet is located.

When the above two points are satisfied, Ipp is calculated by the following procedure.

Step1: Select the closest road segment. To calculate Ipp, each transmitting nodes (relay node or source node) select one of the road segments that are closest to the destination node among the road segments where relay candidate nodes exists. To calculate the distance between the destination node and the road segment, the center coordinate of each road segment is used. An example is shown in Figure 11. The blue vehicle is the transmitting node, the yellow vehicle is the relay candidate nodes, the red vehicle is the destination node, and the green points are the center coordinates of each road segment. In this example, the road segment closest to the destination node is the road segment enclosed by the blue border in the figure.

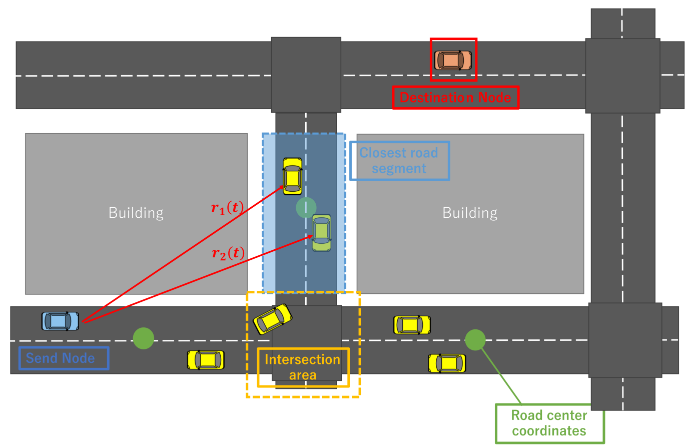

Fig. 11
The closest road

Step 2: Transmission Rate Probability in selected road segment In this step, we calculate the rate R_p that a packet reaches one of the candidate nodes located in the road segment calculated in Step 1, using Equation 5.

$$R_p = 1 - \prod_{p=1}^{N} (1 - r_p(t)) \tag{5}$$

$r_p(t)$ is the expected transmission rate of the relay candidate node $p(1 \leq p \leq N)$ in the road segment closest to the destination node. The expected transmission rate is calculated using the same equation as in Equation 1.

Step3: Calculation of IRI. Using the R_p calculated in Step 2, the street Intersection Relay Index IRI is calculated using Equation 6.

$$Ipp = \alpha \frac{90 \left(\frac{\theta}{90}\right)^{\frac{1}{\gamma}}}{R_p} \tag{6}$$

Where, θ is the angle fared between the lines connecting the transmitting node with the destination node and the line connecting the transmitting node and the intersection node (figure 12). As θ increases and R_p decreases, IRI increases, and the probability that the intersection node is selected by the priority scheduling algorithm described in Section IV-D below increases. We also add a gamma correction to prevent the intersection from being given too much priority when θ is small. γ is the gamma-correction value.

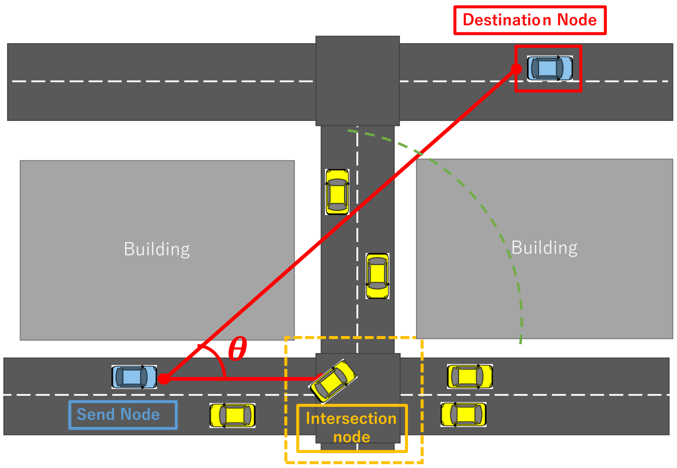

Fig. 12
The Intersection node angle

C. Neighbor status prediction algorithm

In most of the geographic routing protocols, the location information of neighboring nodes is obtained the information of hello packets received from neighboring nodes. However, the information in the hello packet may become outdated if the hello packet cannot be received or the transmission interval becomes too long. Therefore, in SFCGO, the neighbor status prediction algorithm is used to understand more precisely which roads or intersections neighboring vehicles are located on. The neighbor status prediction algorithm improves the accuracy of the SFCGO to calculate the priority of intersection nodes and to remove the expired link nodes from the relay candidate nodes. This algorithm can be divided into two steps.

1) Position prediction algorithm: Each transmitting node predicts the position of its neighbor nodes when selecting candidate nodes based on the information in the neighbor node's hello packets. The predicted coordinates x' and y' are calculated by Equation 7.

$$\begin{cases} x' = x + \frac{1}{2}a_x(t - t_l)^2, \\ y' = y + \frac{1}{2}y_x(t - t_l)^2, \end{cases} \tag{7}$$

Each piece of information a_x, a_y, v_x, v_y in the hello packet used for the calculation in Equation 7 is the information at the time t_l when the transmitting node last received the hello packet from each neighbor node. Also, t is the time when the transmitting node transmits.

2) Prediction of expired links: Each transmitting node estimates the distance between each neighbor node at the time of transmission using the predicted position information and predicts the broken link node. If the coordinates of the transmitting node are x_s and y_s, and the predicted positions of neighbor node i are x'_i and y'_i, neighbor node i is removed from the relay candidates when the relationship in Equation 8 holds.

$$\sqrt{(x_s - x'_i)^2 + (y_s - y'_i)} > maxRange \tag{8}$$

The left-hand side is the predicted distance between the transmitting node and the neighboring node at time t, and the right-hand side $maxRange$ is the threshold for determining the link breakage.

D. Priority scheduling algorithm

In SFCGO, a timer-based priority scheduling algorithm is used. In this algorithm, the node with the highest priority sends a packet first. When other relay candidate nodes receive packets from the node with the highest priority, they discard their own packets. When the timer expires and no packet from the node with higher priority than itself has been received, it starts transmission. In SFCGO, the priority of node i is calculated by the following equations (9) and (9).

$$\frac{D_{sd} - Did}{ETX_i^2} \times Ipp, Did < D_{sd} \tag{9}$$

$$\frac{D_{sd} - Did}{ETX_i^2}, Did < D_{sd} \tag{10}$$

D_{sd} is the distance from the transmitting node to the destination node, and D_{id} is the distance from relay candidate node i to the destination node. If the condition $Did < D_{sd}$ is not satisfied, the node is excluded from the relay candidate nodes without calculating the priority. Equation (9) is applied when node i is an intersection node, and equation (10) is applied when node i is located outside of an intersection node. The larger the value calculated by equation (9) or (10), the higher the priority of node i becomes.

V. Performance evaluation

To evaluate the usefulness of the proposed method, we compared it with the LSGO protocol in three evaluation items: packet delivery rate(PDR), End-to-end delay, and routing protocol overhead. The simulation scenario and settings were the same as in section III-C, and the performance was evaluated by varying the number of nodes and the shadowing parameter α in Equation 4. (β=0.4db) Figure 13 shows the PDR of SFCGO and LSGO when the number of nodes and the shadowing parameter are varied. SFCGO(10) shows the PDR of the proposed method when the shadowing parameter α is 10. As Figure 13 shows, as the number of nodes increases and the value of the shadowing parameter increases, the PDR of SFCGO increases compared to that of LSGO. This is presumably since as the value of the shadowing parameter increased, the possibility of forming an inefficient route as shown in Fig. 8 increased in LSGO, while the possibility of forming an efficient route that prioritizes intersection nodes increased in SFCGO.

We can also see that the PDR of SFCGO increases as the number of nodes increases compared to that of LSGO. It is assumed that this is due to the increase in the probability of the existence of nodes in the intersection.

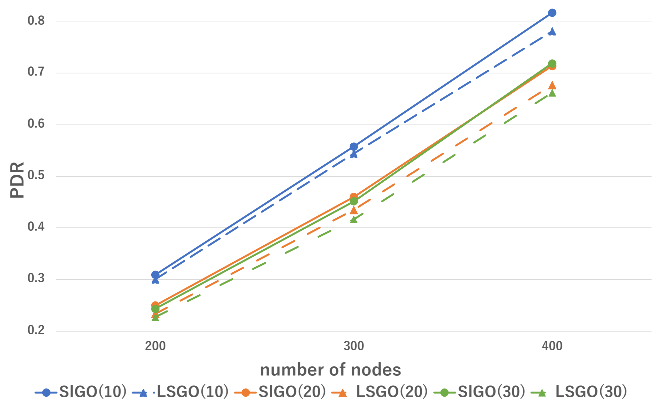

Fig. 13
Packet delivery rate vs. nomber of nodes and shadowing intensity

Figure 14 shows the End-to-end delay of SFCGO and LSGO when the number of nodes and the shadowing parameter are varied. In the simulation scenario and setting of this study, the effect of the proposed algorithm on the delay is very small. We assume that this is due to the following three reasons. (1) Since the simulation scenario has the shape of a grid, the distance does not change regardless of which road the packet is relayed on. (2) In this experiment, we did not implement recovery routing to deal with the local optimum problem such as GPSR recovery mode. (3) Retransmission control is not taken into account in this experiment.

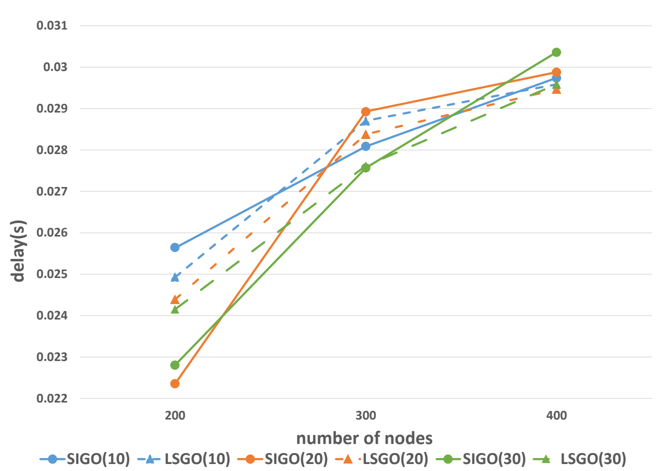

Fig. 14
End-to-end delays vs. nomber of nodes and shadowing intensity

Figure 15 shows the routing protocol overhead of SFCGO and LSGO when the number of nodes and the shadowing parameter are varied. As the figure shows, as the shadowing parameter increases, the overhead of SFCGO decreases compared to LSGO. It is assumed that this is because the number of packets reaching the destination increases in SFCGO compared to LSGO. It can also be seen that SFCGO increases the overhead compared to LSGO when the value of the shadowing parameter is low. This means that if there is a building in the direction of the destination node and an intersection node relays the packet, nodes on two different roads forming the intersection are selected as candidate nodes. In this situation, the possibility that a low-priority candidate node cannot receive packets from a high-priority relay candidate node due to shadowing increases, and redundant packet forwarding increases because re-forwarding is not canceled. An example is shown in Figure 16. The packets relayed by the intersection nodes are received by nodes 1-4, and the priorities of the candidate nodes are set in order starting from node 1. Ideally, only node 1 should relay packets, but even if node 1 sends a packet, nodes 3 and 4 cannot receive it due to the shadowing effect and retransmit it.

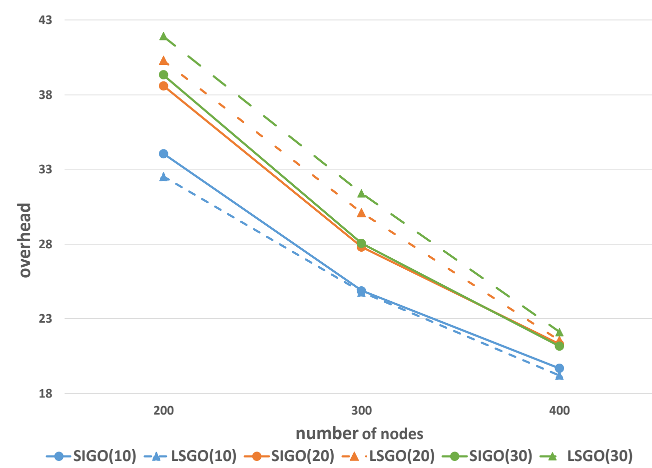

Fig. 15
Routing protocol overhead vs. nomber of nodes and shadowing intensity

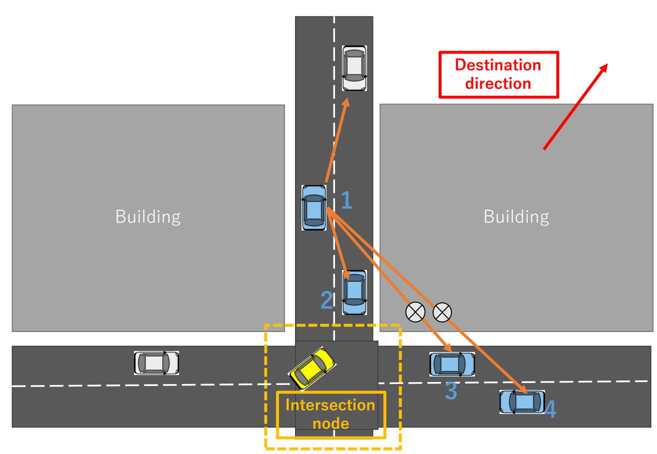

Fig. 16
Causes of increased overhead

VI. Conclusion

In this study, we evaluated an existing opportunistic routing protocols under the impact of shadowing in simulation. We demonstrated that the existing routing protocols degrade the communication performance when the effect of shadowing fading is taken into account by simulation. We also proposed SFCGO, which forms routes that are less susceptible to shadowing, and showed its effectiveness by improving the packet delivery ratio and reducing the overhead. Future work includes the optimization of the number of candidate nodes for relaying, which was set to a fixed value (5) in an experiments. Furthermore, we plan to perform evaluation in more complex simulation scenarios, and redesign the SFCGO routing protocol for various scenarios.

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