

Research Article

Grid-Based Predictive Geographical Routing for Inter-Vehicle Communication in Urban Areas

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Vehicular ad-hoc networks (VANETs) are highly mobile wireless ad hoc networks for vehicular safety and other commercial applications, whereby vehicles move non-randomly along roads while exchanging information with other vehicles and roadside infrastructures. Inter-vehicle communication (IVC) is achieved wirelessly using multihop communication, without access to fixed infrastructure. Rapid movement and frequent topology changes cause repeated link breakages, increasing the packet loss rate. Geographical routing protocols are suitable for VANETs. However, they select the node nearest to the destination node as a relay node within the transmission range, increasing the possibility of a local maximum and link loss because of high mobility and urban road characteristics. We propose a grid-based predictive geographical routing (GPGR) protocol, which overcomes these problems. GPGR uses map data to generate a road grid and to predict the moving position during the relay node selection process. GPGR divides roads into two-dimensional road grids and considers every possible node movement. By restricting the position prediction in the road grid sequence, GPGR can predict the next position of nodes and select the optimal relay node. Simulation results using ns-2 demonstrated performance improvements in terms of local maximum probability, packet delivery rate, and link breakage rate.

1. Introduction

VANET is a research field that is attracting growing attention. VANET provides both vehicle-to-infrastructure (V2I) communication and vehicle-to-vehicle (V2V) communication. V2I can provide real-time information on the road traffic conditions, weather, and a basic Internet service via communication with backbone networks. V2V can be used for providing information about traffic conditions and/or vehicle accidents based on wireless inter-vehicle communication (IVC). In V2V communication environments, vehicles are wirelessly connected by multihop communication without access to some any fixed infrastructure [1]. Already, automobile manufacturers and research centers are investigating the development of IVC protocols for the establishment of VANETs, which are expected to be useful for road safety and many commercial applications [2]. VANET has unique characteristics compared with MANET such as high node mobility and a rapidly changing network topology compared

to mobile ad hoc network (MANET). Current VANET routing protocols typically use relay nodes to forward data packets to their destination. However, the rapid movement of vehicles and the frequent topology change of vehicles mean that link breakages occur repeatedly, as shown in Figure 1. Frequent link disconnection is also caused due to other characteristics of VANET such as vehicle movements that are constrained by roads and traffic lights that have greatly affected vehicle movement [3]. The frequent link disconnections may increase the possibility of a local maximum. Because of these problems, geographical routing protocols such as GPSR [4] are known to be more suitable and useful for VANET than existing routing protocols designed for MANETs. For instance, Figure 1 shows that geographical forwarding could use node N2 instead of N1 to forward data to D.

Geographical forwarding is one of the best solutions for VANET routing because it maintains only local information of neighbors rather than per-destination routing entries.

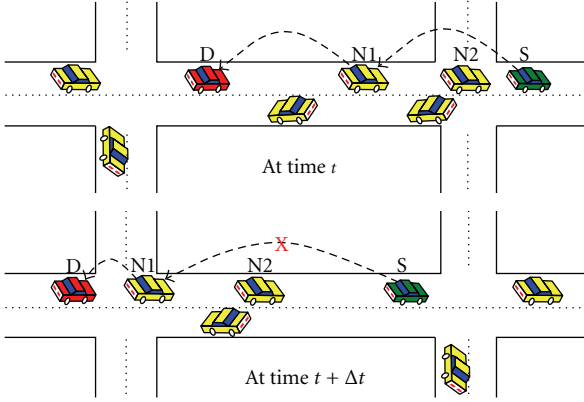


FIGURE 1: Route (S, N1, D) that was established at time t breaks at time $t + \Delta t$ when N1 moves out of the transmission range of S.

GPSR selects the node closest to the destination as the relay node from neighbor nodes. However, GPSR may lead to a link loss problem in urban environments. GPSR does not take into account road structure or the speed and movement direction of vehicles, so it may select stale nodes as relay nodes. Vehicle movements are constrained by roads, so GPSR that fails to consider urban environment characteristics is not suitable for VANET [3]. To solve this problem, greedy perimeter coordinator routing (GPCR) [5] and greedy perimeter urban routing (GPUR) [6] have been proposed as possible solutions. However, GPCR may cause transmission delays and path selection errors because it identifies nodes on a junction by detecting coordinator nodes when selecting relay nodes. GPUR selects nodes with 2-hop neighbors as relay nodes. This causes serious transmission delays. GPUR cannot resolve the local maximum problem because it does not consider road specifications such as dead end streets.

This paper proposes GPGR, which is a grid-based predictive geographical routing protocol for IVC. The protocol uses map data to generate road grids for the path of moving vehicles, and it predicts the exact movement position along the road grids. To do this, we assume that each vehicle knows its location by GPS, as with most related geographic routing protocols, and it uses a grid-based street map for road information. A grid sequence on a road path is a route where vehicles can move. Vehicles can be located on one space of the grid sequence at a specific time. Our target was to improve the routing protocol for IVC, based on vehicle movement information including the position, direction, and velocity on the grid sequence. Position prediction based on a road grid is more realistic rather than blindly predicting whether roads in a segment of roads contain many curves.

The rest of the paper is organized as follows. Section 2 discusses related work while Section 3 introduces the proposed IVC routing protocol. The performance evaluation is presented in Section 4. Finally, our conclusions and future research are outlined in Section 5.

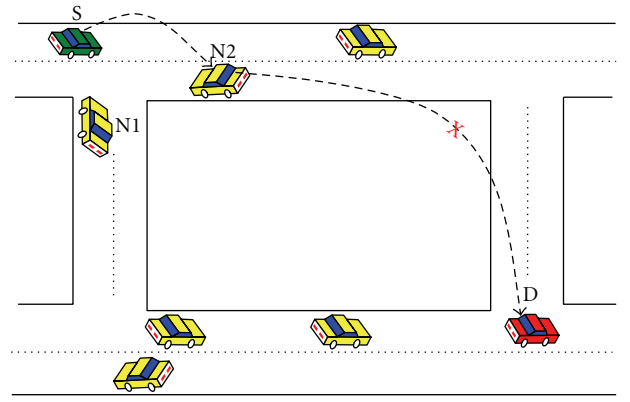


FIGURE 2: GPSR selects N2 rather than N1 for forwarding the packet, because N2 is closer to D and within the transmission range of S.

2. Related Work

Traditional MANET routing protocols, such as AODV [7] and DSR [8], are not suitable for VANET, because VANET has unique characteristics such as high node mobility and a rapidly changing network topology compared with MANET. To deal with the rapidly changing network topology of VANET, greedy forwarding protocols have been proposed that are based on geographic information.

GPSR [3] is a well-known greedy forwarding protocol. GPSR makes greedy forwarding decisions using only information about immediate neighbors in the network topology. GPSR may increase the possibility of a local maximum and link breakage, because of the high mobility of vehicles and the specific characteristics of roads in urban areas. This is because it simply selects the nearest node within the transmission range of the destination as a relay node when making packet forwarding decisions. GPSR may also lead to a link loss problem because it maintains stale nodes as neighbor nodes when selecting a relay node in the greedy mode. These local maximum and link breakage problems can be recovered by perimeter mode forwarding, but packet loss and delay time may result because the number of hops is increased by perimeter mode forwarding. This decreases the reliability of VANET. Figure 2 shows an example. Assume that vehicle S wants to send a packet to D, and S has two neighbors: N1 and N2. GPSR will select N2 to forward the packet because N2 is closer to D. However, common sense dictates that we should choose N1 because vehicle movements are constrained by roads.

GPCR [9] was proposed to improve the reliability of GPSR with VANET. The basic behavior of GPCR is similar to GPSR, but it selects a relay node by considering information related to the road structure. GPCR makes routing decisions on the basis of streets and junctions rather than individual nodes and their connectivity. However, GPCR forwards data packets based on the node density of adjacent roads and the connectivity to the destination. Thus, if the density of nodes is low or if there is no connectivity to the destination, the delay time increases and the local maximum problem

is still unresolved. GPUR [5] selects a relay node based on information about the road characteristics, which is similar to GPCR. However, unlike GPCR, GPUR selects a relay node from nodes with 2-hop neighbors. It transmits periodic beacon messages to estimate the presence of 2-hop neighbors among all the relay candidates. The periodic beacon messages that are used to evaluate the presence of 2-hop neighbors lead to serious transmission delays. GPUR also fails to resolve the local maximum problem because it does not consider road specifications such as dead ends.

GSR [10] uses a map and a position-based addressing scheme when sending packets to destinations. The source node evaluates the shortest path between itself and the destination. GVGrid [11] is a source-routing protocol that is similar to GSR. GVGrid finds a network route by route discovery that is expected to provide the best stability, based on a digital map and the positional information of each vehicle. HarpiaGrid [2] is a geography-aware grid-based routing protocol, which uses map data to generate the shortest transmission grid route. This method effectively trades off route discovery communication overheads with insignificant computation time. By restricting the packets in grid sequences rather than a blind greedy search and by making use of a route cache approach, HarpiaGrid reduces many unnecessary transmissions. However, GSR, GVGrid, and HarpiaGrid are all proactive routing protocols. In proactive routing protocols, all vehicles need to maintain a consistent view of the network topology. When a network topology change occurs, the respective updates must be propagated throughout the network to notify the change. Using proactive routing algorithms, vehicles proactively update the network state and maintain a route, regardless of whether data traffic exists, and the overheads of maintaining up-to-date network topology information is high. Thus, they are not suitable for VANETs.

3. Grid-Based Predictive Geographical Routing (GPGR)

GPGR employs road segments based on a routing approach with street awareness, and it uses knowledge of the road topology provided by a static street map. Therefore, data packets will be routed between vehicles, following the road topology and the road segments in the real area. This method aims to improve the routing protocol for IVC based on vehicle movement information such as position, direction, and velocity, as well as the road topology. To do this, we assume that each vehicle knows its location by GPS, as with most related geographic routing protocols, and has a digital street map for road information. Table 1 lists the symbols used in the proposed GPGR algorithm.

The geographic area of VANET is partitioned into a two-dimensional logical grid. Grids are numbered (x, y) following conventional x, y coordinates. Each grid is a sequence area of size $d \times d$ as shown in Figure 3.

Given any physical location, there should be a predefined mapping from the location to its grid coordinates. Where each vehicle has a radio range of r , each grid size d is

TABLE 1: Symbols used for defining GPGR.

Symbols	Definitions
r	Radio range of each vehicle
d	Each grid size
$G(x_i, y_i)$	A grid coordinate for position (x_i, y_i)
V_S	A source vehicle
V_D	A destination vehicle
V_R	A relay vehicle
V_N	A set of neighbor vehicles within a sender's r
$D(V_S, V_N)$	Distance between V_S and V_D
G	A grid sequence of a vehicle
V	Velocity of a vehicle
θ	Moving direction of a vehicle
t	Current time
Δt	Difference in time measurement

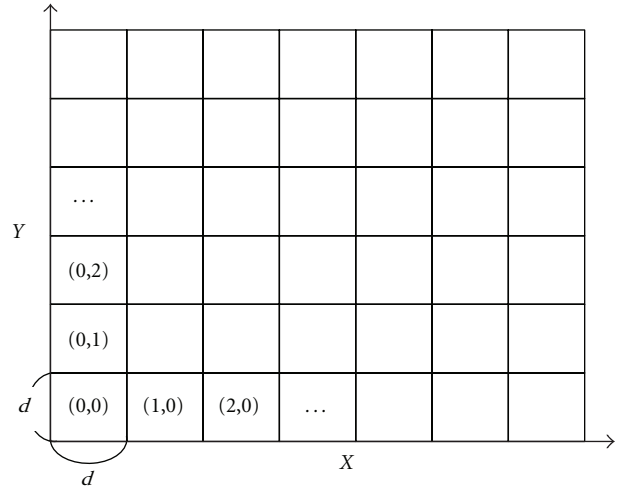


FIGURE 3: GPGR uses logical grids to partition a physical space.

determined by $d = r/2\sqrt{2}$ to represent the maximum value of d such that a vehicle located at a position in a grid is capable of transmitting data to any vehicle in its eight neighboring grids, as shown in Figure 4.

Our beacon messages contain grid coordinates rather than the positions of vehicles. Vehicles know their own position (x_i, y_i) , so each vehicle can calculate its current grid coordinates $G(x_i, y_i)$ based on the floor function given in (1)

$$G(x_i, y_i) = \left[\left\lfloor \frac{x_i}{d} \right\rfloor, \left\lfloor \frac{y_i}{d} \right\rfloor \right]. \quad (1)$$

The procedure for selecting a relay vehicle among all relay candidates is shown in Algorithm 1. It is assumed that sender V_S is sending message MSG to the destination vehicle V_D .

In GPGR, when a source vehicle, V_S , wants to send a message to a destination vehicle, V_D , V_S should first inspect all relay candidates that are similar to GPUR. From these relay candidates, it then selects the node nearest to the destination as a relay node within its transmission range r

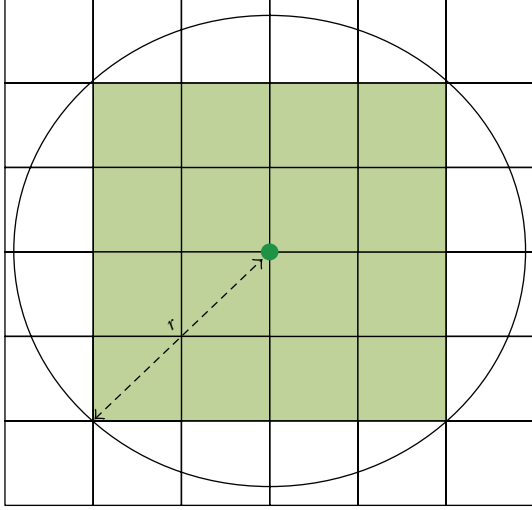


FIGURE 4: The side length of grids d is determined by $d = r/2\sqrt{2}$ where each vehicle has a radio range of r .

based on the future vehicle position using the road grid. V_S finds all neighbor vehicles $V_N = \{V_j, V_k, \dots, V_l\}$ in its r and calculates the distance $D(V_S, V_N)$ to find a relay vehicle V_R whose distance is maximal based on the road grid.

For the distance between two grids, GPGR calculates the Euclidean distance between the two centers of the grid cells according to (2)

$$\overline{G(x_i, y_i)G(x_j, y_j)} = \sqrt{(x_i - y_i)^2 + (x_j - y_j)^2} \times d. \quad (2)$$

An advantage of RPGR is that the predicted positions based on the road grid are more realistic. If a vehicle is on a curved road with no road grid, its position prediction will be incorrect.

Let there be N vehicles present in a road segment space. The location of each vehicle at time t is given by $G(x_i(t), y_i(t))$, where $i = 1$ to N . The next location of each object at time $(t + \Delta t)$ is predicted to be $G(x_i(t + \Delta t), y_i(t + \Delta t))$. Therefore, based on the previous position $G(x_i(t - \Delta t), y_i(t - \Delta t))$ and the current position $G(x_i(t), y_i(t))$, GPGR can predict the next position of the relay candidate at $t + \Delta t$ as $G(x_i(t + \Delta t), y_i(t + \Delta t))$ by using the velocity and direction of the relay candidate.

The velocity and the direction of the relay candidate are given by (3) and (4), respectively

$$V = \frac{\sqrt{(x_i(t) - x_i(t - \Delta t))^2 + (y_i(t) - y_i(t - \Delta t))^2}}{t - (t - \Delta t)}, \quad (3)$$

$$\theta = \tan^{-1} \left(\frac{y_i(t) - y_i(t - \Delta t)}{x_i(t) - x_i(t - \Delta t)} \right). \quad (4)$$

TABLE 2: Simulation parameters.

Parameter	Value
Topology size	700 × 1000 m
Transmission range	125 m
MAC protocol	IEEE 802.11
Node number	100 to 200
Node velocity	0 km/h to 80 km/h
Beacon time	1 s
Bandwidth	2 Mbps
Packet size	1000 bytes

Therefore, GPGR can calculate the next position of the relay candidate using (5).

$$\begin{aligned} &G(x_i(t + \Delta t), y_i(t + \Delta t)) \\ &= \left[\left\lfloor \frac{(x_i(t) + V \times \cos \theta \times \Delta t)}{d} \right\rfloor, \right. \\ &\quad \left. \left\lfloor \frac{(y_i(t) + V \times \sin \theta \times \Delta t)}{d} \right\rfloor \right]. \end{aligned} \quad (5)$$

If $G(x_i(t + \Delta t), y_i(t + \Delta t))$, the predicted next position of the relay candidate is not on the grid sequence of the road grid, so GPGR should select the closest grid to $G(x_i(t + \Delta t), y_i(t + \Delta t))$ instead of the predicted grid. The grid sequence of the road grid $G = \{G(x_1, y_1), G(x_2, y_2), \dots, G(x_k, y_k)\}$ is generated based on the available map information, where $G(x_2, y_2), \dots, G(x_{k-1}, y_{k-1})$ are grids in the road path from $G(x_1, y_1)$ to $G(x_k, y_k)$. For example, the grid sequence of the road for moving the vehicles on the road is $\{G(4, 3), G(4, 4), G(4, 5), \{G(3, 5) \mid G(5, 5)\}\}$, as shown in Figure 5. Therefore, all nodes can move along only one of the following grid sequences: $\{G(4, 3), G(4, 4), G(4, 5), G(3, 5)\}$ or $\{G(4, 3), G(4, 4), G(4, 5), G(5, 5)\}$. As shown in Figure 5, the predicted position of the node will be $G(3, 5)$ instead of $G(4, 5)$ or $G(5, 5)$ at $t + \Delta t$ based on the movement direction of the vehicle given by (5). Therefore, the position of the relay candidate can be predicted. The position prediction based on road grids is more realistic if two roads are superposed with or without different running directions.

4. Performance Evaluation

We analyzed and compared the performance of the proposed GPGR and the existing GPSR, GPCR, and GPUR using the ns-2 simulator. In this performance evaluation, we simply considered the local maximum probability, packet delivery rate, and the link breakage rate at this point. The simulated area was based on a real map of Seoul with a 700 × 1000 m size. Table 2 summarizes our simulation parameters. The simulations were performed for 180 s, and the number of nodes was increased from 100 to 200. The movement velocity of the nodes was increased from 0 km/h to 80 km/h. The experiments were performed three times, and the average values were used. Maximum and minimum values were excluded.

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/* When  $V_S$  sends MSG to  $V_D$  */
(1) All  $V_S$  get their  $G$  to  $V_D$ ,
     $G = \{G(x_1, y_1), G(x_2, y_2), \dots, G(x_k, y_k)\}$ 
(2) For each  $V_S$  do
(3)    $V_S$  finds all  $V_N$ ,
        $V_N = \{V_j, V_k, \dots, V_l\}$  in its  $r$ .
(4)    $V_S$  predicts  $G(x(t + \Delta t), y(t + \Delta t))$  of  $V_N$  at
        $t + \Delta t$ .
(5)   If  $(G(x(t + \Delta t), y(t + \Delta t)) \notin G)$ 
(6)      $V_S$  finds the nearest alternative grid,
        $G(x_i, y_i) \in G$  instead of
        $G(x(t + \Delta t), y(t + \Delta t))$ .
(7)    $V_S$  replaces  $G(x(t + \Delta t), y(t + \Delta t))$  with
        $G(x_i, y_i)$  such that  $V_N$  is on the road.
(8)   End If
(9)    $V_S$  chooses  $V_R$  in  $V_N$  such that  $D(V_R, V_D)$  is minimal.
(10)   $V_S$  forwards packets to  $V_R$ .
(11)   $V_S \leftarrow V_R$ .
(12) End For

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ALGORITHM 1: Relay vehicle selection.

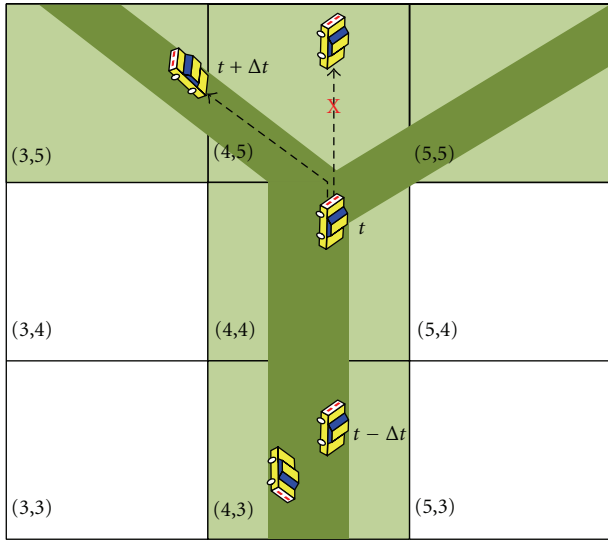


FIGURE 5: GPGR can predict the next position of nodes and select the optimal relay node by restricting position prediction to the sequence of the road grid.

Figures 6 and 7 show the probability of the local maximum based on the number of nodes and the probability of the local maximum relative to the velocity variation of the nodes, respectively. We observed that a larger number of nodes reduced the probability of the local maximum with all the routing algorithms, as shown in Figure 6. GPGR reduced the probability of the local maximum compared with GPSR, GPCR, and GPUR. This was because GPGR predicted the position of nodes and selected the relay node using a grid map based on the road topology. Therefore, GPGR significantly reduced the probability of a local maximum even when the road topology was changed. GPSR had

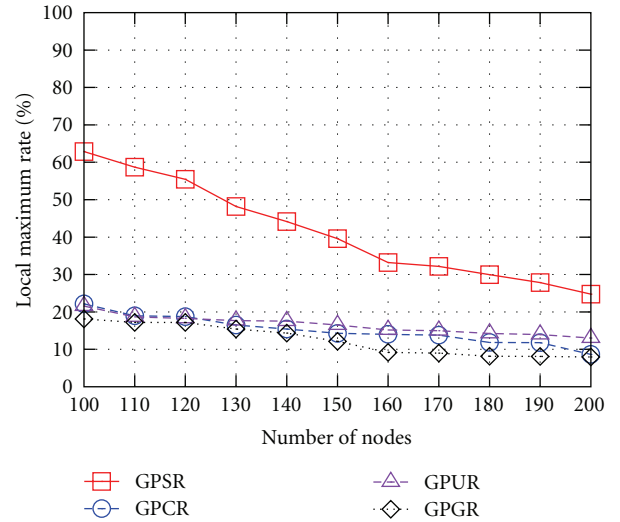


FIGURE 6: Local maximum rate according to number of nodes.

the highest probability of a local maximum because it selected the nearest node to the destination node as the relay node. GPCR and GPUR had a lower probability of a local maximum compared with GPSR. However, because they selected the relay node based only on the intersection and whether the next relay candidate's neighbor nodes were present or not, they had a higher probability of a local maximum than GPGR. Figure 7 shows that a higher velocity for the nodes led to a higher probability of a local maximum with GPSR, GPCR, and GPUR. However, the probability of a local maximum with GPGR was almost constant, regardless of the velocity of nodes. GPGR reduced the local maximum rate compared with GPSR, GPCR, and GPUR because GPGR can reduce errors by selecting a stale node as a relay node even if the velocity of nodes is increased. GPGR predicts the

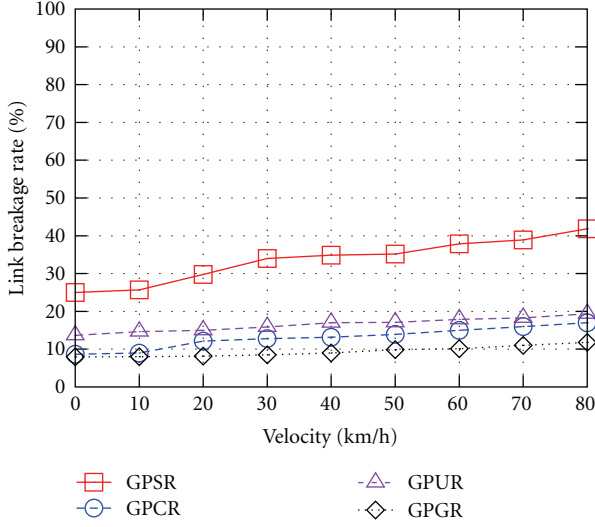


FIGURE 7: Local maximum rate according to velocity of nodes.

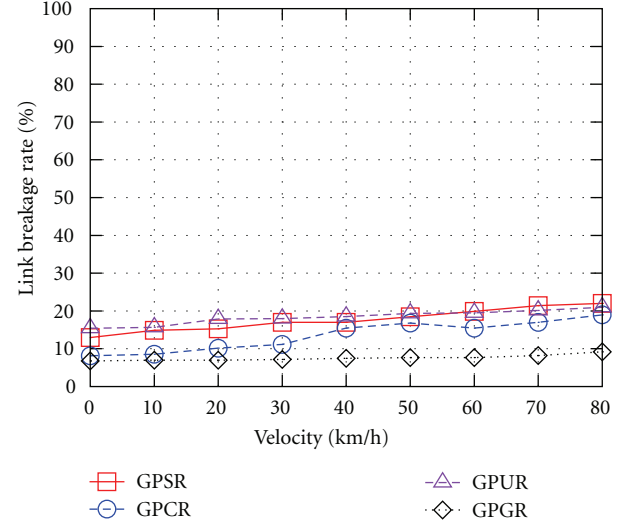


FIGURE 9: Link breakage rate according to the velocity of nodes.

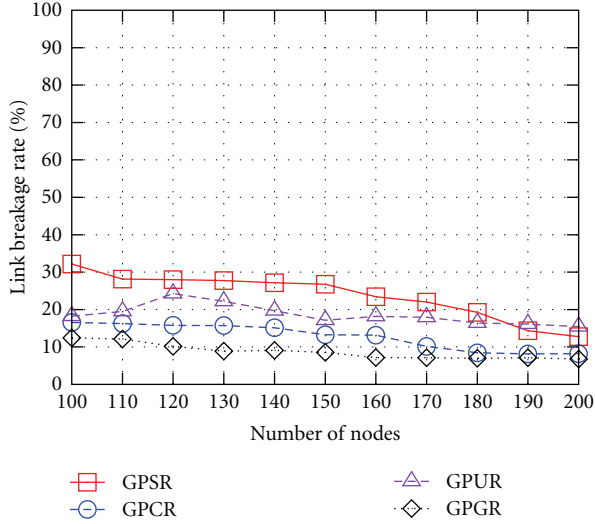


FIGURE 8: Link breakage rate according to the number of nodes.

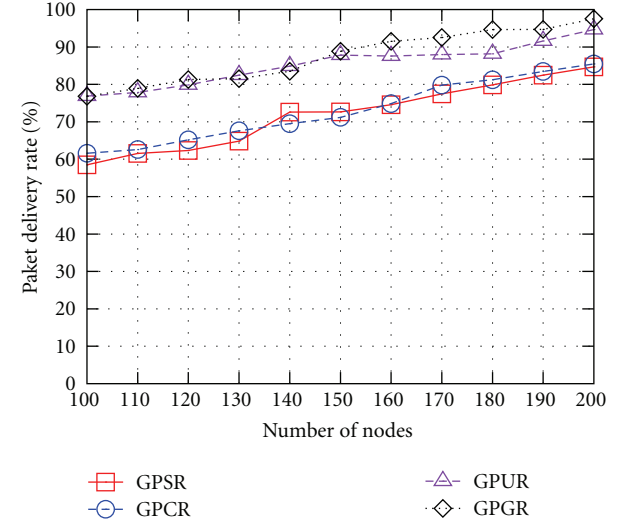


FIGURE 10: Packet delivery rate based on the number of nodes.

positions of relay candidates in grid sequences of roads, and it estimates the movement directions of nodes.

Figures 8 and 9 show the link breakage rate depending on the number of nodes and the link breakage rate depending on the velocity variation of the nodes, respectively. Figure 8 shows that a larger number of nodes led to lower link breakage rates in all of the routing algorithms. However, the link breakage rate was lower with GPGR compared with GPSR, GPCR, and GPUR. This is because GPGR selects the relay node based on the grid sequence of roads and the movement direction of nodes. With GPSR, GPCR, and GPUR, link breakage occurred because they selected stale nodes as relay nodes that were outside the transmission range, which is a common problem in greedy forwarding. Figure 9 shows that a higher velocity of nodes results in a higher link breakage with all algorithms except GPGR. The link breakage rate when using GPGR was almost constant

compared with GPSR, GPCR, and GPUR. This is because GPGR more accurately predicts the position of nodes when selecting the relay node on the grid sequences, even if the velocity of nodes is increased. Thus, there was a lower rate of link breakage due to velocity changes compared with other routing algorithms. With GPSR, GPCR, and GPUR, link breakage occurred with rapid changes in the movement direction of nodes, depending on the increase in node velocity.

Figures 10 and 11 show the packet delivery rate depending on the number of nodes and the packet delivery rate depending on the velocity variation of the nodes, respectively. The packet delivery rate with GPGR was higher compared with GPSR, GPCR, and GPUR. Figure 10 shows that the performance of GPGR was similar to that of GPUR. However, GPGR had better performance than GPUR with an increasing number of nodes. This was because GPUR only

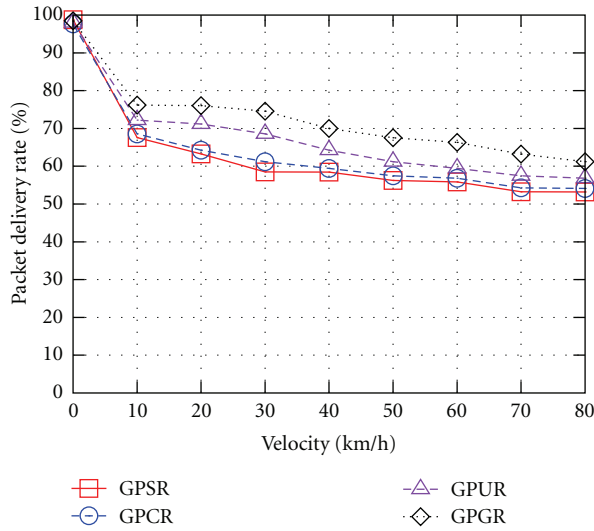


FIGURE 11: Packet delivery rate based on the velocity of nodes.

considers the location of 2-hop nodes when selecting relay nodes, and it does not consider the road topology. However, GPGR provides a high delivery rate when selecting relay nodes based on the grid sequences of roads. Figure 11 shows that all protocols exhibited falls in the packet delivery rate with increasing node speed. However, GPGR had a lower rate of decrease than the other protocols. This is because GPGR knows the exact position of nodes, so it is expected that the delay time when determining the position of nodes will be lower than other protocols.

5. Conclusion

This paper presented a grid-based predictive geographical routing (GPGR) protocol for urban VANETs. GPGR is an inter-vehicle routing protocol that is based on mobility information from vehicles and a digital urban map, which improves the performance of IVC in VANETs. The GPGR protocol reduces the possibility of link breakage and a local maximum by selecting relay nodes based on mobility information and road topology. Simulation results showed that GPGR produces a very low likelihood of a local maximum, low link break probabilities, and a high packet delivery rate compared with GPSR, GPCR, and GPUR for VANETs. In the future, we will consider the probability of a local maximum and the packet breakage rate in simulations. We will also incorporate more realistic factors into our routing protocol, such as the density of vehicles and delay tolerant characteristics.

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