Position-based Routing Algorithm for Improving Reliability of Inter-Vehicle Communication

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Abstract

A vehicular ad-hoc network (VANET) consists of vehicles that form a network without any additional infrastructure, thus allowing the vehicles to communicate with each other. VANETs have unique characteristics, including high node mobility and rapidly changing network topology. Because of these characteristics, routing algorithms based on greedy forwarding such as greedy perimeter stateless routing (GPSR) are known to be very suitable for a VANET. However, greedy forwarding just selects the node nearest to the destination node as a relay node within its transmission range. This increases the possibility of a local maximum and link loss because of the high mobility of vehicles and the road characteristics in urban areas. Therefore, this paper proposes a reliability-improving position-based routing (RIPR) algorithm to solve those problems. The RIPR algorithm predicts the positions, velocities, and moving directions of vehicles after receiving beacon messages, and estimates information about road characteristics to select the relay node. Thus, it can reduce the possibility of getting a local maximum and link breakage. Simulation results using ns-2 revealed that the proposed routing protocol performs much better than the existing routing protocols based on greedy forwarding.

Keywords: VANET, position-based routing, greedy forwarding, local maximum, link breakage, stale node

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1. Introduction

Because of the recent growth in intelligent transportation system (ITS) [1] technology, attention has been focused on vehicle and driver safety as well as the necessity of communication technology to improve traffic flow. As a result, many researches for VANET-based vehicular communication technology are now underway [2][3].

VANET is a special kind of mobile ad-hoc network (MANET). It is a network of many highly mobile, wirelessly connected vehicles using multihop communication without access to some fixed infrastructure [4]. VANET has unique characteristics such as high node mobility and a rapidly changing network topology compared to MANETs. Because of the rapid movement of vehicles and frequent changes in the topology of VANET, link breakages occur repeatedly and the packet loss rate increases. Because of these weaknesses, geographical routing protocols are known to be more suitable and useful to VANET than existing MANET protocols such as AODV [5], OSLR [6], and DSR [7].

Recent research has shown that position-based routing (PBR) [8] performs well in vehicular movement scenarios, especially in highway environments [9][10]. PBR uses the geographic position of nodes to determine the direction for forwarding a data packet. Traditional PBR protocols such as greedy perimeter stateless routing (GPSR) [11][12] or face-2 [13] use beacon messages: each node announces its address and geographic position to all of its neighbors via a radio broadcast. Whenever a node receives such a beacon message from a neighbor, it stores the address and position of that node in its neighbor table. When a node has to forward a packet, it uses the table to determine the neighbor the packet should be forwarded to in order to make progress toward the final destination. Usually, this decision is based on a geometric heuristic by selecting the neighbor that minimizes the remaining distance to the destination [14]. This is called greedy forwarding. Routing algorithms based on greedy forwarding [15][16][17][18][19][20][21][22][23] have been used to resolve the characteristics of VANET.

Greedy forwarding is able to solve problems such as high mobility and low transmission delay because it maintains only the local information of neighbors instead of per-destination routing entries in VANET. When the network nodes move, the established paths may break, and the routing protocols must dynamically search for other feasible routes. Therefore, with a rapidly-changing topology, maintaining connectivity is very difficult with the existing routing protocols of MANETs. The topology of a VANET can change rapidly. Such networks require a responsive routing algorithm that finds valid routes quickly as the topology changes and old routes break. GPSR is a typical greedy-forwarding protocol for VANET. It uses greedy forwarding to forward packets to nodes that are always progressively closer to the destination. In regions of the network where such a greedy path does not exist, GPSR recovers by forwarding in perimeter mode, in which a packet traverses successively closer faces of a planar subgraph of the full radio network connectivity graph, until it reaches a node that is closer to the destination, where greedy forwarding resumes [12]. However, GPSR may increase the possibility of getting a local maximum and link breakage because of the high mobility of vehicles and the road specifics in urban areas [11]. GPSR also suffers from link breakage with some stale neighbor nodes in the greedy mode because of the high node mobility and rapidly changing network topology. The local maximum and link breakage can be recovered in perimeter mode forwarding, but packet loss and delay time may occur because the number of hops increases in perimeter mode forwarding. These characteristics of greedy forwarding decrease VANET reliability.

Therefore, this paper proposes a reliability-improving position-based routing (RIPR) algorithm to solve the abovementioned problems by predicting the positions, velocities, and moving directions of vehicles after receiving a beacon message and information about the road characteristics to select the relay node. Thus, it reduces the possibility of getting a local maximum and link breakage. The results of a simulation performed using ns-2 showed that the proposed RIPR protocol performs much better than the existing routing protocols based on greedy forwarding.

The rest of this paper is organized as follows. The existing routing algorithms used in this research field are introduced in Section 2. The proposed RIPR is introduced in Section 3. Section 4 presents a performance evaluation of the proposed algorithm by comparing it with the existing routing algorithms. We conclude this paper with remarks about future work in Section 5.

2. Related Work

In this chapter, we examine and analyze the existing routing algorithms for VANET and describe the need for more advanced routing algorithms.

The contention-based forwarding (CBF) [18] algorithm is a greedy position-based forwarding algorithm that does not require the proactive transmission of beacon messages. In CBF, the next hop is selected through a distributed contention process based on the actual positions of all of the current neighbors. In this contention process, CBF makes use of biased timers. To avoid packet duplication, the first node that is selected suppresses the selection of further nodes by using an area-based suppression algorithm. This algorithm chooses the suppression area such that all nodes within that area are in transmission range of each other, avoiding extra packet duplications. However, this approach can still cause problems with incorrect path setting and routing overhead in a particular area because of the road characteristics.

The beacon-less routing (BLR) [19] algorithm was proposed to solve this problem. Unlike other position-based routing protocols, BLR does not require nodes to periodically broadcast beacon messages, and thus avoids drawbacks such as extensive use of scarce battery-power, interference with regular data transmission, and performance degradation. BLR selects a forwarding node in a distributed manner from among all of its neighboring nodes without having information about either their positions or even their existence. Data packets are broadcast and the protocol ensures that just one of the receiving nodes forwards the packet. However, if there is no response from the sending node within a certain time, data packets are forwarded continuously. Thus, the delay of the entire network is increased.

As described previously, GPSR [11][12] is a typical greedy forwarding protocol for VANET. GPSR makes greedy forwarding decisions using only information about the immediate neighbors in the network topology. When a packet reaches a region where greedy forwarding is impossible, the algorithm recovers by routing around the perimeter of the region. However, GPSR may increase the possibility of getting the local maximum and link breakage because of the high mobility of vehicles and the road specifics in urban areas [11]. This is because it just selects the nearest node to the destination as a relay node within its transmission region to make packet forwarding decisions. GPSR may also generate the link loss problem because it maintains stale nodes as neighbor nodes to select a relay node in greedy mode. The local maximum and link breakage problems can be recovered in perimeter mode forwarding, but packet loss and delay time may appear because the number of hops is increased in perimeter mode forwarding. This decreases the reliability of a VANET.

Greedy perimeter coordinator routing (GPCR) [21] was proposed to improve the reliability of GPSR in VANET. The basic behavior of GPCR is similar to GPSR, but it selects a relay node by considering information about the road structure. GPCR makes routing decisions on the basis of streets and junctions instead of 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 there is no connectivity to the destination, then the delay time increase and the local maximum problem are still not resolved.

Wang et al. [24] proposed a GPS based routing algorithm which uses the position data, the moving velocities and directions of nodes. This algorithm consists of four phases which include beacon message, the strategy at straight road, the strategy at intersection, and the strategy for the perimeter mode in case greedy mode fails. Its basic routing algorithm is similar to that of GPSR, which is the reason why it fails to solve the local maximum problem that arises in GPSR. Also its perimeter mode strategy to rectify this problem increases the total delay time due to the limitations in identifying road types.

MOPR [25] takes into account node velocity in order to solve the problem which arises when MORA [26] is used in VANET. However, when compared to existing GPSR, MORP requires equal or more number of hops to reach the destination node. In order to solve this problem, in MOPR, the position data from GPS are requested whenever a node transmits a packet.

RB-MP [27] was proposed in order to increase reliability and efficiency of transmission in VANET through broadcasting. In RB-MP, the positions of neighbors are acquired using GPS and the data are sent to the destination node by broadcasting. In order to resolve the broadcast storm problem in broadcast protocol, only one relay node among the neighbors in transmission range does the rebroadcasting. However, because transmission of data to the destination node is done through broadcasting only, redundant message transmissions cause network overhead. Also, since its transmission method only considers straight roads, data collision problems may arise due to the broadcasting of nodes in proximity to the intersection.

DGRP [28] transmits data to moving nodes using greedy forwarding method and perimeter method. However unlike existing GSPR, DGRP takes into account moving directions and velocities of nodes as well as position data of 1-hop neighbors of the transmitting node. In DGRP, the position data of a node is acquired through periodic beacon messages which predict moving velocities based on beacon message intervals and moving distance of nodes. However in VANET, the actual moving velocity of a vehicular node is not constant, which creates numerous problems for DGRP to be applied.

It is important to forward data packets to the destination node with the minimum delay time without the local maximum and link breakage. Therefore, we should attempt to reduce the possibility of link breakage and the local maximum using routing based on both an estimation of the road conditions and the prediction of the velocities and moving directions of vehicles.

3. RIPR Algorithm

RIPR is a PBR-based routing algorithm for VANETs. It aims at solving the main problems of PBR algorithms for VANETs by predicting the velocities and moving directions of vehicles and estimating the road characteristics for urban environments. **Table 1** lists the symbols used in the proposed RIPR algorithm.

Table 1. Symbols used for defining RIPR.

Symbols	**Definitions**
$\vec{S}$	Location vector of a sender
S_{TxR}	Transmission range of a sender
n_{iCLo}	Current position of a node
n_{iPLo}	Predicted location of a node
n_{iMLo}	Moving distance of a node after receiving beacon messages
N_i^S	Set of neighbors within the radio range of a sender
n_i^S	Neighbor within the radio range of a sender
N_k^i	Set of neighbors within the radio range of n_i^S
n_k^i	A neighbor within the radio range of n_i^S
ΔV_i	Amount of change in the relative velocity of two nodes
RCn_i	Relay candidate node
B	Beacon message

3.1 Mobility Prediction

In VANET, a sender can include some stale neighbor nodes that are out of transmission range. Such stale nodes are prone to get high priorities to become the next relay node in the greedy mode, which will cause the link breakage problem. Therefore, in this section, we describe how to predict the moving velocities and moving directions of vehicles to resolve this problem caused by stale nodes that are out of radio range of N_i^S.

In **Fig. 1**, node A should select the next relay node to send the data packet to node D based on the location of N_i^S. At this point, node A selects node B as a relay node because node B is the nearest node to node D among the N_i^S of node A. Thus, node A sends a beacon message to node B to forward data. Assuming that the current time is *T*, node B informs node A of its location, and moves to the location on B' after $T + 1$ s. However, node A attempts to forward data to node B because node A assumes that node B is still within its transmission range. Thus, the link breakage problem arises.

The link breakage problem arises from two factors. The first factor is the distance between the sender and its neighbors. If the sender is away from its neighbors (i.e., neighbors are at the edge of the sender's maximum transmission range), prediction errors will generate the link breakage problem. The second factor is the elapsed time since the sender received the last beacon from a neighbor. That is, the link breakage problem will occur because of the location of the neighbor at $T + n(B)$ s after the last beacon is received. Therefore, to solve the problem, we should consider the sender's maximum transmission range, the distances between the sender and its neighbors, and the elapsed time after receiving beacon messages. We can predict the sender's distance to each neighbor and the moving position of the relay node by sending beacon messages for forwarding data.

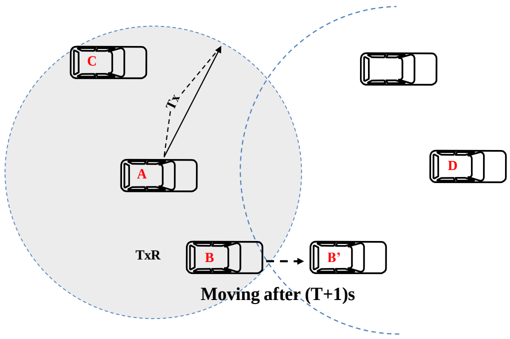


Fig.1. Link breakage problem caused by high mobility.

Thus, assuming that the maximum transmission distance of the sender is Tx, the maximum transmission range of the sender, TxR, can be obtained using formula (1).

$$TxR = Tx^2 \prod \tag{1}$$

The sender therefore can predict the locations of its neighbors within its TxR. The positions of its neighbors can be predicted using formula (2).

$$\vec{n}_{iPLo} = \vec{n}_{iCLo} + \Delta V_i \times T \times \{\frac{(\vec{S} - \vec{n}_{iCLo})}{\vec{S} - |\vec{n}_{iCLo}|}\} \tag{2}$$

$$\{\vec{n}_{iPLo} - \vec{n}_{iCLo} \geq \frac{Tx}{T + n(B)}\} \tag{3}$$

where $\vec{n}_{iPLo}$ and $\vec{n}_{iCLo}$ are the predicted position vector and the current position of the node, respectively. ΔV_i is the relative velocity variation and $n(B)$ is the position vector of the sender. T is the elapsed time since the sender received the beacon message from the candidate relay node and is the number of beacon messages. Therefore, if the position of $\vec{n}_{iPLo}$ satisfies formula (3) after receiving beacon messages, the node is assumed to be unstale. This is because if the elapsed time to send a beacon message is 1 s, the total elapsed time after receiving all of the beacon messages is $T+2$ s. Thus, the distance covered by the node during $T+1$ s is less than $\frac{Tx}{2}$, and the node will be within the sender's transmission range after $T+2$ s. If there are any candidate relay nodes within the sender's transmission range, as shown in **Fig. 2**, the variation in velocity can be estimated using the relative velocity between the sender and candidate relay nodes by formula (4).

$$\Delta V_i = \frac{V \times n_i(x_j - x_i, y_j - y_i)}{S(x_i, y_i)}(\cos\theta + \sin\theta) \tag{4}$$

where V is the velocity of the relay node, and n_i and S are the relay candidate and sender, respectively. If there are one or more relay nodes and formula (4) is not satisfied, the sender should select one relay node. That is, if $n_i \Delta V_i \neq n_j \Delta V_i$ and $\vec{n}_{i_{PLo}}, \vec{n}_{j_{PLo}} \leq \frac{Tx}{2}$ is true, the sender selects the node that has the largest relative velocity as the ultimate relay node and predicts the position of this node.

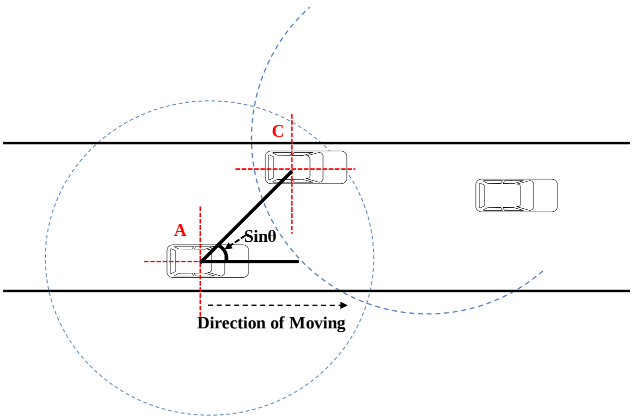


Fig. 2. Relative velocity between sender and relay candidates.

3.2 Relay Node Selection

In this section, we describe the method used to select the relay node for reliable data forwarding based on the mobility prediction described in the previous section. In RIPR, the sender selects the next relay node by determining the existence (or nonexistence) of neighbors and using the position list of neighbors within its transmission range, as shown in **Fig. 3**.

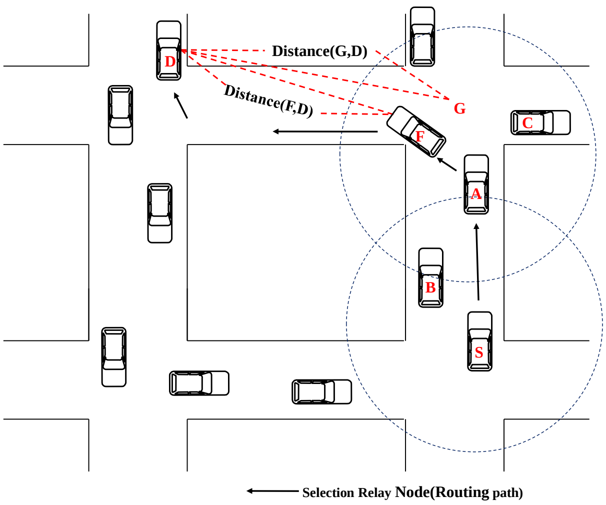


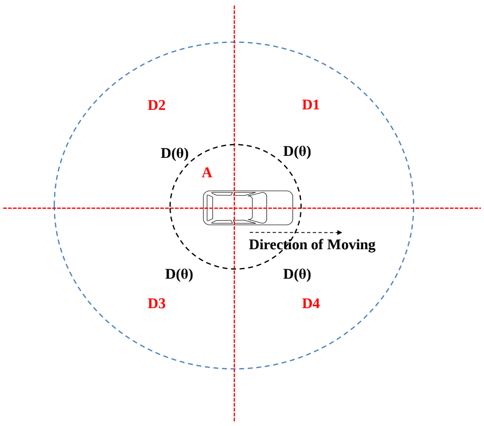
Fig. 3. Example of procedures for selection of relay candidate.

The sender constructs a position list that consists of the current position and moving velocity of each node, and selects the relay node using the road characteristics and this position list after receiving the beacon messages. For example, in **Fig. 3**, node S, to transmit data to destination node D, requests a position data list of neighboring nodes to node A and node B. Then node B transmits a position data list of itself and node A nearby. In the same manner, node A also transmits to node S a position data list of neighbors. Node S compares the position data sent by both node A and node B, and selects node A as the relay node. This is because node A is closer to the destination node than node B and has more neighbors. Node A then also selects the next relay node using the same principle and transmits data to the destination node. RIPR determines the existence of neighbors for the relay candidate. This is to avoid falling into the local maximum in a case where a candidate that does not have any neighbors is selected as the relay node because it is close to the destination. In addition, if the relay candidate is within the sender's radio range, has one or more neighbors, and is not at an intersection, the candidate nearest to the destination is selected as the relay node. However, if a relay candidate moving in the direction of the destination is at an intersection, this candidate is selected as the relay node. Moreover, if there are two or more relay candidates moving in the direction of the destination at an intersection, the nearest candidate to the destination is selected as the relay node. The road characteristics can be obtained by using the correlation coefficient, p_{xy}, as shown in formula (5).

$$p_{xy} = \frac{\sum_{i=1}^{n}(x_i - R_n x)(y_i - R_n y)}{\sqrt{(\sum_{i=1}^{n}(x_i - R_n x)^2(\sum_{i=1}^{n}(y_i - R_n y)^2)}} \tag{5}$$

where $R_n x$ and $R_n y$ represent the set of the relay candidate positions, thus $-1 \le p_{xy} \le 1$. In other words, a value close to 1 indicates that the node is on a straight road, whereas a value close to -1 means the node is located on the adjacent road. Therefore, in RIPR, the sender selects the node that has neighbors moving in the direction of the destination as the relay node according to the nodes located on adjacent roads. If there is no node moving in the direction of the destination, the sender selects one of its edge nodes as the relay node.

RIPR defines each θ value of D_1, D_2, D_3, and D_4 to predict the moving directions of the sender's neighbors located on adjacent roads, as shown in **Fig. 4**.



Symbols	Definitions
$D_1(\theta)$	$0 \le D_1(\theta) \le 90$
$D_2(\theta)$	$91 \le D_2(\theta) \le 180$
$D_3(\theta)$	$181 \le D_3(\theta) \le 270$
$D_4(\theta)$	$271 \le D_4(\theta) \le 360$

Fig. 4. Value of $D(\theta)$ used to predict moving direction of node.

In **Fig. 5**, B is the neighbor of relay candidate A, and B' is the moved position of B after T seconds. θ is the angle between A and B, and θ' is the angle between A and B'. Therefore, we can estimate the value of the angle, $D(\theta)$, using formula (6).

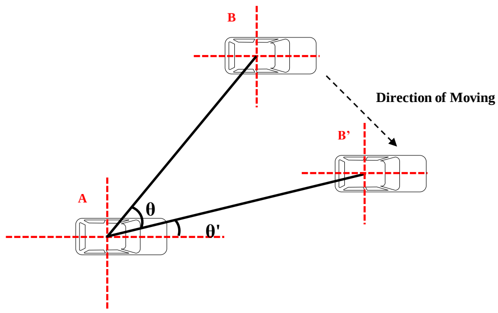


Fig. 5. Parameters used in calculating value of $D(\theta)$.

$$D(\theta) = \frac{(n_{iPLo}Sin\theta - n_{iCLo}Sin\theta) \times \Delta V_i \times (T + n(B))}{(T + n(B))^2} \tag{6}$$

where $n_{iCLo}Sin\theta$ is the current position of the node, and $n_{iPLo}Sin\theta$ is the new position after $T + n(B)$, the total elapsed time after receiving the beacon message. ΔV_i is the relative velocity variation between the sender and receiver. Therefore, RIPR can predict the moving directions of the nodes within the sender's transmission range on an adjacent road through the value of $D(\theta)$.

In addition, RIPR can estimate whether the sender's neighbors are moving toward the destination using the covariance formula (7).

$$\sigma_{D,n_k^i} = \int_{\infty}^{-\infty}\int_{\infty}^{-\infty}(x-\mu_D)(x-\mu_{n_k^i})f(x,y)dxdy \tag{7}$$

where μ_D is the coordinate of the destination and $\mu_{n_k^i}$ is the coordinate of the middle point of the straight line distance between the sender and the neighbor of the relay candidate. Thus, if the value of σ_{D,n_k^i} is larger then 0, the direction of the node is the same as that of the destination, and if not, the direction of the node is different from that of the destination. Therefore, in RIPR, the node that has a neighbor moving in the direction of the destination within the sender's transmission range on an adjacent road is selected as the relay node.

3.2 RIPR Algorithm Procedure

The RIPR algorithm consists of a greedy mode and perimeter mode, similar to GPSR. It also considers the road characteristics, as well as the node's position through the exchange of periodic beacon messages. Therefore, RIPR can solve the link breakage problem caused by selecting a stale node as the relay node, and reduce the local maximum caused by the road characteristics. Consequently, RIPR can improve the reliability of VANET. The greedy mode of RIPR is the procedure used for selecting the relay node. The greedy mode forwards data packets to the destination through the relay nodes. **Table 2** shows the greedy mode algorithm of RIPR.

Table 2. Greedy mode algorithm of RIPR.

1. S send B to N_i^S
2. **if** $N_i^S \neq \phi \,\&\&\, N_k^i \neq \phi$ **then**
3. n_i^S send $\vec{n}_{iCLo}^S, \vec{n}_{kCLo}^i$ to S
4. **if** $\vec{n}_{iMLo}^S \leq \frac{S_{TxR}}{T+n(B)} \,\&\&\, \vec{n}_{kMLo}^i \leq \frac{S_{TxR}}{T+n(B)}$ **then**
5. **if** $p_{xy} \equiv 1$ **then**
6. $RCn_i = argmin\,(\overline{Dn_i^S}, \overline{Dn_j^S})$
7. **else if** $p_{xy} \equiv -1$ **then**
8. $RCn_i = (n_i^S D(\theta) \equiv DD(\theta)) \,\&\&\, (\sigma_{D,n_k^i} > 0)$
9. **end if**
10. **end if**
11. **else**
12. ***do*** *perimeter mode*
13. **end if**

The method used to get the position of the node and the position of its neighbor within the sender's transmission range is described in line 1 to line 3. Lines 4–10 show the procedure for selecting the relay candidate by considering the nodes within the sender's transmission range and the characteristics of the road where the sender's neighbors are located.

In the greedy mode, if a node with a neighbor moving in the direction of the destination does not exist, RIPR forwards in the perimeter mode. In a case where the perimeter mode is performed continuously, the packet loss and latency problem will occur because of the number of hops used to forward a data packet. To solve this problem, the perimeter mode of RIPR selects the node with the higher density of neighbors, as well as the shortest distance to the destination, as the relay node. At this point, the node means the relay candidate. This is done to reduce the probability that the neighbors are out of the transmission range of the node at the time of receiving the data packet after they receive the beacon message. Therefore, this procedure is repeated until a relay candidate with neighbors moving in the direction of the destination is found. The density of the nodes can be obtained using formula (8).

$$\lambda_i = \frac{\mu}{n_{iTxR}^S} \tag{8}$$

where λ_i is the density of neighbors and μ is the ratio of the number of neighbors within the transmission range of the node. The proximity between the node within the sender's transmission range and the neighbor within the node's transmission range can be estimated using formula (9). Here, the node refers to the relay candidate.

$$V = \sum_{n_k^i \in N_k} \| n_i^k - n_i^S \|^2 \tag{9}$$

where n_k^i and N_k are the neighbor and the set of neighbors within the node's transmission range, respectively. At this point, the node refers to the relay candidate. n_i^s is the node within the sender's transmission range. **Table 3** shows the perimeter mode algorithm of RIPR.

Table 3. Perimeter mode algorithm of RIPR.

1. **if** $N_i^S = \phi \,\|\, N_k^i \neq \phi$ **then**
2. *continue*;
3. **else if** $(N_i^S \neq \phi) \,\&\&\, (\lambda_i > \lambda_j)$ **then**
4. *selection node = argmin* $(n_i^k V, n_j^k)$
5. *break;*
6. **end if**

Lines 1 and 2 describe the procedure for the perimeter mode in the case where the node has no neighbors within its transmission range or the neighbor of the node has no neighbors within its transmission rage. The perimeter mode can escape through the proximity value and the density of neighbors within the sender's transmission range, in accordance with lines 3–6.

In the case of RIPP, the basic principle is in the form of greedy forwarding, and hence shows the exact same time complexity in greedy modes of both GPSR and GPCR. However, when in perimeter mode, RIPR selects the next relay node taking into consideration the data of 2-hop neighbors of the transmitting node. For this reason, the recursive depth can be reduced by at least one, when compared to GPSR or GPCR that only uses 1-hop neighbor's data to search for a node that satisfies the conditions to be converted to greedy mode. Therefore, time complexity of RIPR becomes $O(N^{c-1})$ even in the worst case but becomes $O(N^c)$ in the case of GPSR and GPCR. In this equation, N is the number of neighbors and c is the recursive depth level that searches for nodes until the conditions for the greedy mode conversion are satisfied.

4. Performance Evaluation

In this section, we analyze and compare the performance of the proposed RIPR and the existing GPSR and GPCR using the ns-2 simulator to prove the validity of the RIPR algorithm. In this performance evaluation, we considered the probability of local maximum, the ratio of packet delivery, and the ratio of packet breakage according to the variation in the number of nodes and the velocity of nodes.

Table 4 summarizes our simulation parameters. The simulations were performed for 180 s, and the number of nodes was increased from 10 to 100. The moving velocity of the nodes was increased from 20 km/h to 100 km/h. The experiments were performed thrice and average values were used. Maximum and minimum values were excluded.

Fig. 6 and **Fig. 7** show the probability of the local maximum according to the number of nodes and the probability of the local maximum according to the velocity variation for the nodes, respectively. We observed that a larger number of nodes reduced the probability of the local maximum, as shown in **Fig. 6**. RIPR reduced the probability of the local maximum compared with GPSR and GPCR. This is because GPSR and GPCR only take into account 1-hop neighbor's position when transmitting data. They are not aware of the availability of nodes in the next phase which may be closer to the destintion node than the selected relay node. On the other hand, RIPR not only takes into account 1-hop nodes but also 2-hop nodes, which results in a reduced probability of local maximum.

Fig. 7 shows that a higher velocity for the nodes led to a higher probability of the local maximum in the cases of GPSR and GPCR. RIPR reduced the local maximum rate compared with GPSR and GPCR because RIPR predicts the positions of relay candidates with the positions of the candidate's neighbors after receiving beacon messages, and estimates the moving directions of nodes.

Table 4. Simulation parameters.

Parameter	Value
Topology size	2000 * 2000
Transmission range	250m
MAC protocol	IEEE 802.11
Traffic type	CBR
The number of node	100
Node velocity	20km/h~100km/h
Beacon time	1 sec
Bandwidth	2Mbps
Packet size	1000byte

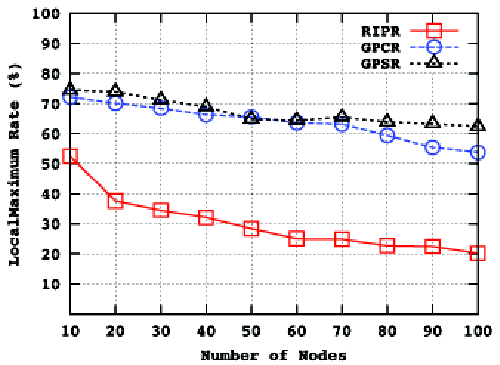


Fig. 6. Local maximum rate according to number of nodes.

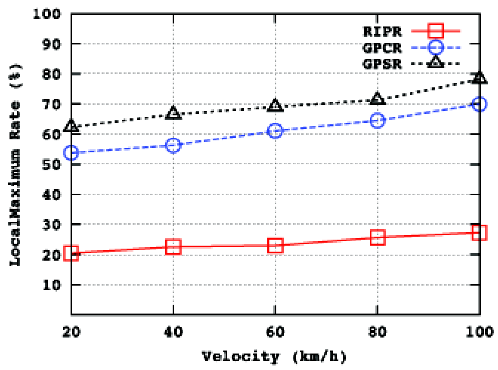


Fig. 7. Local maximum rate according to velocity of nodes.

Fig. 8 and **Fig. 9** show the link breakage rate according to the number of nodes and the link breakage rate according to the velocity variation of the nodes, respectively. **Fig. 8** shows that a larger number of nodes led to lower link breakage rates in all of the routing algorithms. This was because the number of nodes within the sender's transmission range was increased according to the increase in the number of neighbors. However, the link breakage rate of RIPR was lower than those of GPSR and GPCR. In the cases of GPSR and GPCR, link breakage occurs due to selecting stale nodes located outside the transmission range as relay nodes, which is one of the common problems in greedy forwarding. By comparison, RIPR takes into account the velocities of nodes that neighbor the transmitting node. This results in a lower rate of link breakage because selection is based on whether the relay candidate will be within the transmission range after receiving the beacon message. In **Fig. 9**, we can observe that a higher velocity for the nodes results in a higher link breakage in all of the algorithms. This is because as the velocities of nodes become higher, the number of nodes that travel outside the transmission range after receiving the beacon message increases. However, the link breakage rate of RIPR is almost constant compared with GPSR and GPCR. RIPR will not select a node as its next relay node if the predicted moving position falls outside the transmission range, even though it may initially be within proximity to the destination node. RIRP selects relay nodes and transmits data based on the change in relative velocity of the transmitting node and the relay node and transmission range of the transmitting node. These results in a lower rate of link breakage caused by velocity change compared with other routing algorithms.

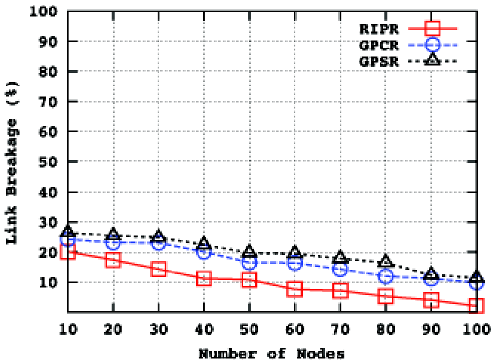


Fig. 8. Link breakage rate according to number of nodes.

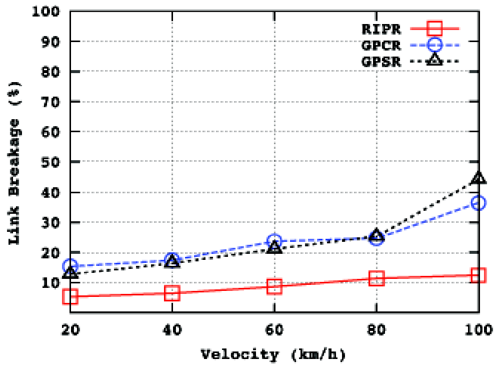


Fig. 9. Link breakage rate according to velocity of nodes.

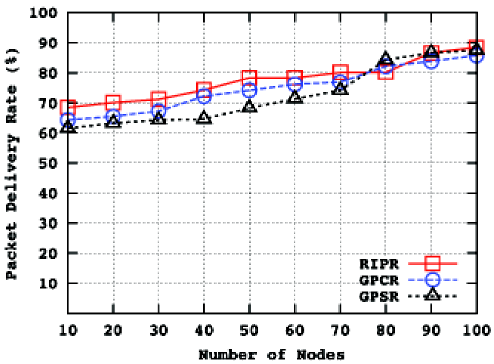


Fig. 10. Packet delivery rate according to number of nodes.

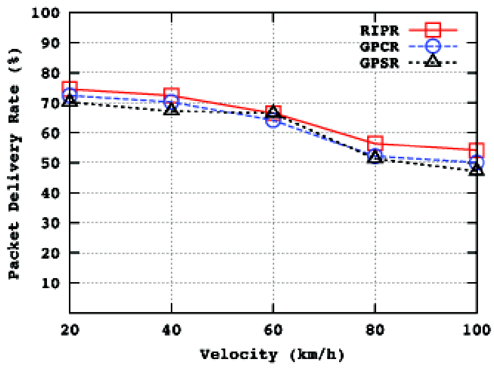


Fig. 11. Packet delivery rate according to velocity of nodes.

Fig. 10 and **Fig. 11** show the packet delivery rate according to the number of nodes and the packet delivery rate according to the velocity variation of the nodes, respectively. The packet delivery rate of RIPR is sensitive to both the velocity and number of nodes, as shown in **Figs. 10** and **11**. However, the packet delivery rate of RIPR is more constant than that of GPSR and GPCR. This is because link breakage can occur as GPSR and GPCR select the nodes nearest to the destination node as relay nodes based on 1-hop neighbor. Link breakage leads to retransmission which results in increased delay time due to changeover to perimeter mode and finally, packet loss. Increased delay time due to changeover to perimeter mode is a problem caused by transmitting data to the final destination via multiple hops in VANET. In VANET identifiable road forms, one of the most important factors, are limited. However in RIPR, packet loss and delay time can be reduced with routing that takes into account particular characteristics of the roads. Data transmission is based on moving velocity and predicted positions of 2-hop neighbors. Therefore, it can be stated that RIPR is more reliable at forwarding data packets than the existing GPSR and GPCR in VANET.

5. Conclusion

In the paper, we proposed the RIPR algorithm to improve the reliability of VANET. RIPR reduces the possibility of getting local maximum and link breakage problems by predicting the positions of relay candidates and selecting the relay node based on the number of neighbors of the node as well as the road characteristics. Simulation results showed that RIPR has very low local maximum and link breakage probabilities, along with a high packet delivery rate compared with GPSR and GPCR for VANETs. Future research will include an improved routing algorithm based on the density of vehicles and a routing method to select efficient paths for vehicle to infrastructure (V2I) communication.

References

[1] ESTL, “Intelligent Transport Systems,” http://www.etsi.org/WebSite/Technologies/Intelligent TransportSystems.aspx.

[2] S. Lawrence, “Wireless on Wheels,” *MIT Technology Review*, Jan. 2005.

[3] J.J. Blum, A. Eskandarian, L.J. Hoffman, “Challenges of Inter-Vehicle Ad hoc Networks,” *IEEE Trans. Intelligent Transportation Systems*, vol. 5, no. 4, pp. 347-351, Dec. 2004. Article (CrossRefLink)

[4] I.Q. Tse, “Improving Message Reception in VANETs,” in *Proc. of International Conference on Mobile Systems, Applications and Services* (*MobiSys*), June 2009.

[5] ETF, “Ad Hoc On-Demand Distance Vector Routing,” RFC3561, Jul. 2003.

[6] IETF, “Optimized Link State Routing,” RFC 3628, Oct. 2003.

[7] IETF, “The Dynamic Source Routing Protocol for Mobile Ad Hoc Network for IPv4,” RFC 4728, Feb. 2007.

[8] M. Mauve, J. Widmer, H. Hartenstein, “A Survey on Position-based Routing in Mobile Ad-hoc Networks,” *IEEE Network Magazine*, Nov./Dec. 2001. Article (CrossRefLink)

[9] H. Füßler, M. Mauve, H. Hartenstein, M. Käsemann, D. Vollmer, “A Comparison of Routing Strategies for Vehicular Ad Hoc Networks,” *Tech. Rep. TR-02-003*, Dept. of Computer Science, University of Mannheim, July 2002.

[10] C. Lochert, H. Hartenstein, J. Tian, H. Füßler, D. Herrmann, M. Mauve, “A Routing Strategy for Vehicular Ad Hoc Networks in City Environments,” in *Proc. of IEEE Intelligent Vehicles Symposium*, pp. 156-161, June 2003. Article (CrossRefLink)

[11] F. Kuhn, R. Wattenhofer, et al., “Asymptotically Optimal Geometric Mobile Ad-hoc Routing,” in *Proc. of Discrete Algoritms and Methods for Mobile Computing and Communications*, pp.24-33, 2002.

[12] B. Karp, H.T. Kung, “GPSR: Greedy Perimeter Stateless Routing for Wireless Networks,” in *Proc. International Conference on Mobile Computing and Networking* (*MobiCom*), pp. 243-254, 2000.

[13] GPSR, http://www.icir.org/bkarp/gpsr/gpsr.html.

[14] H. Füßler, H. Hartenstein, J. Widmer, M. Mauve, W. Effelsberg, “Contention-Based Forwarding for Street Scenarios,” in *Proc. of 1st International Workshop in Intelligent Transportation* (*WIT*), 2004.

[15] P. Bose, P. Morin, I. Stojmenovic, J. Urrutia, “Routing with Guaranteed Delivery in Ad hoc Wireless Networks,” in *Proc. of International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications* (*DIALM’99*), pp. 48-55, Aug. 1999.

[16] M. Kasemann, H. Füßler, H. Hartenstein, “A Reactive Location Service for Mobile Ad hoc Networks,” *Tech. Rep. TR-14-2002*, Dept. of Computer Science, University of Mannheim, Nov.

2002.
[17] G. Liu, B.-S. Lee, B.-C. Seet, C.H. Foh, K.J. Wong, K.-K. Lee, "A Routing Strategy for Metropolis Vehicular Communications," in *Proc. International Conference on Information Networking* (*ICOIN*), pp. 134-143, 2004.
[18] H. Füßler, J. Widmer, M. Käsemann, M. Mauve, H. Hartenstein, "Contention-Based Forwarding for Mobile Ad-Hoc Networks," *Ad Hoc Networks*, Elsevier, vol. 1, no. 4, pp. 351-369, 2003. Article (CrossRefLink)
[19] M. Heissenbuttel, T. Braun, "BLR: A Beacon-Less Routing Algorithm for Mobile Ad hoc Networks", *Tech. Rep. IAM-03-001*, Institute of Computer Science and Applied Mathematics, University of Bern, Switzerland, Mar. 2003.
[20] F. Kuhn, R. Wattenhofer, et al., "Asymptotically Optimal Geometric Mobile Ad-hoc Routing," in *Proc. of International Workshop on Discrete Algorithms and Methods for Mobile Computing and Communications* (*DIALM'02*), pp.24-33, 2002.
[21] C. Lochert, M. Mauve, H. Fler, H. Hartenstein. "Geographic Routing in City Scenarios," *ACM Mobile Computing and Communications Review*, vol. 9, no. 1, pp. 69-72, 2005. Article (CrossRefLink)
[22] S. Jung, S. Lee, H, Oh, "Improving the Performance of AODV(-PGB) based on Position-based Routing Repair Algorithm in VANET," *KSII Transactions on Internet and Information Systems* (*TIIS*), vol. 4, no. 6, pp. 1063-1079, Dec. 2010. Article (CrossRefLink)
[23] M.-W. Ryu, S.-H. Cha, K.-H. Cho, "A Routing Prediction Algorithm for Increasing Reliability in VANET," in *Proc. of The International Conference on Information Networking* (*ICONI*), Dec. 2010.
[24] Y.-B. Wang, T.-Y. Wu, W.-T. Lee, C.-H. Ke, "A Novel Geographic Routing Strategy over VANET," in *Proc. of IEEE 24th International Conference On*, Apr. 2010. Article (CrossRefLink)
[25] H. Menouar, M. Lenardi, F. Filali, "Movement Prediction-Based Routing (MOPR) Concept for Position-Based Routing in Vehicular Networks," in *Proc. of IEEE Vehicular Technology Conference* (*VTC*), 2007. Article (CrossRefLink)
[26] F. Granelli, G. Boato, D. Kliazovich, "MORA: A Movement-Based Routing Algorithm for Vehicle Ad Hoc Networks," in *Proc. of IEEE Workshop on Automotive Networking and Applications* (*AutoNet 2006*), Dec. 2006.
[27] P. Lai, X. Wang, N. Lu, F. Liu, "A Reliable Broadcast Routing Scheme based on Mobility Prediction for VANET," in *Proc. of IEEE Intelligent Vehicles Symposium*, 2009. Article (CrossRefLink)
[28] R. Kumar, S. V. Rao, "Directional Greedy Routing Protocol (DGRP) in Mobile Ad-Hoc Networks," in *Proc. of IEEE Information Technology* (*ICIT 2008*), 2008. Article (CrossRefLink)

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