Multihop Vehicle-to-Infrastructure Routing Based on the Prediction of Valid Vertices for Vehicular Ad Hoc Networks

Raj K. Shrestha, Sangman Moh[*], Ilyong Chung, and Heewook Shin

Abstract: Multihop data delivery in *vehicular ad hoc networks* (*VANETs*) suffers from the fact that vehicles are highly mobile and inter-vehicle links are frequently disconnected. In such networks, for efficient multihop routing of road safety information (e.g. road accident and emergency message) to the area of interest, reliable communication and fast delivery with minimum delay are mandatory. In this paper, we propose a multihop vehicle-to-infrastructure routing protocol named *Vertex-Based Predictive Greedy Routing* (*VPGR*), which predicts a sequence of valid vertices (or junctions) from a source vehicle to fixed infrastructure (or a roadside unit) in the area of interest and, then, forwards data to the fixed infrastructure through the sequence of vertices in urban environments. The well known predictive directional greedy routing mechanism is used for data forwarding phase in VPGR. The proposed VPGR leverages the geographic position, velocity, direction and acceleration of vehicles for both the calculation of a sequence of valid vertices and the predictive directional greedy routing. Simulation results show significant performance improvement compared to conventional routing protocols in terms of packet delivery ratio, end-to-end delay and routing overhead.

Keywords: Vehicular ad hoc network, Multihop communication, Routing algorithm, Vehicle-to-infrastructure routing, Greedy forwarding

1. Introduction

Vehicular ad hoc networks (*VANETs*) are a practical application class of mobile ad hoc

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networks (MANETs), where multihop ad hoc paradigm is successfully applied in pragmatic way to extend the internet and/or to support well defined requirements [1, 15]. They are a distributed and self-organizing communication system which is composed of moving vehicles equipped with computing and radio communication devices to form temporary communication networks with or without help of any infrastructure (or roadside unit). Vehicles can exchange road safety and comfort information with other vehicles (so-called vehicle-to-vehicle or V2V communication) as well as with infrastructure (so-called vehicle-to-infrastructure or V2I communication) with in their communication range. In addition, individual vehicles are responsible for routing the packets with allowable delay.

Automotive industries and research institutions are envisioning the large application

areas running upon the VANETs, extending from cooperative driver assistance systems for collision avoidance to notification of traffic condition on the road, parking availability and infotainment services. In [2], VANET applications are classified into two categories: (i) those that require broadcasting of information from one vehicle to many nearby vehicles, e.g., for collision avoidance, and (ii) those that require the propagation of information hop-by-hop to a single destination point or area, e.g., for sending an emergency messages from an accident site to the closest roadside unit or fixed infrastructure that is connected to a fixed network, or for sending an advertisement from an attraction site to a busy intersection. The proposed routing protocol for VANETs focuses on the latter applications. We can assume that every vehicle is equipped with sensing, computing and radio communication devices. The sensing devices or sensors detect road conditions e.g., accident and traffic congestion. On detection of such events, vehicles can notify to the centralized unit or access point (AP) by sending the sensed data regarding to the road events.

VANETs are characterized mainly by highly mobile vehicles, resulting in frequent topology changes and short connection time in multihop paths. Furthermore, wireless communication is unreliable in V2V communications due to multi-path fading, shadowing, and Doppler shifts caused by the high mobility of vehicles. Such effects make routing quite difficult. As an inherent characteristic, vehicles do not move randomly but they are restricted to move in the roads with the roadside unit at certain speed. This makes the prediction of the future network state including geographic position, speed and direction of vehicles relatively easier in VANETs compared to the random mobility in general ad hoc networks. In city environments, high-rise buildings are the radio obstacles. In Fig. 1, vehicle S forwards a packet to vehicle D, where vehicle D is within the communication range of vehicle S but

vehicle D cannot receive the packet from vehicle S because of radio obstacles (high-rise buildings) and at the same time the transmitted packet may be lost. As a result, the packet need to be retransmitted which consumes unnecessary channel bandwidth. Furthermore, packet delivery delay is increased as well. Therefore, in the city environments, the prediction of future network state is very important and the packet routing through the predicted vertices or junctions or intersections between source and destination should be a promising approach. Hereafter, vertex or junction or intersection can be used interchangeably.
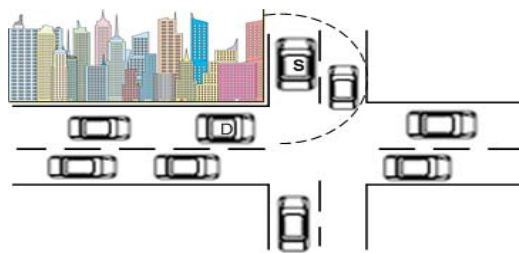

Fig. 1. Effect of high-rise buildings in the inter-vehicle communication in city environment

The focus of this paper is the prediction of sequence of vertices for forwarding data from source vehicle to fixed infrastructure. In this paper, we propose a geographic position based routing for VANETs called *Vertex-Based Predictive Greedy Routing* (*VPGR*). It predicts a sequence of vertices from a source vehicle to a fixed infrastructure (or access point) at the area of interest and, then, forwards data to the destination (fixed infrastructure) using well-known predictive directional greedy forwarding mechanism [3], which will be described in detail in Section IV.2, through the sequence of vertices in city environments. According to the simulation results, the proposed VPGR outperforms the conventional routing protocols in terms of packet delivery ratio, end-to-end delay and routing overhead.

The proposed VPGR protocol takes the

advantage of prediction of sequence of vertices and the predictive directional greedy forwarding technique [3] and results in more efficient and reliable routing. The main contributions of our work are as follows:

• VPGR uses the prediction technique for selecting valid vertices and making forwarding decision. Such a prediction leverages the useful knowledge of future network conditions. (See Section III for the definition of a *valid* vertex.)
• VPGR always forwards packets through a sequence of valid vertices and, thus, there is less risk of packet loss due to wireless medium obstacles at the intersection of city area.
• VPGR saves channel bandwidth, reduces packet re-transmissions, increases reliability of packet delivery, and minimizes end-to-end delay.

The remainder of the paper is organized as follows: In the following section, VANET routing strategies found in the literature are overviewed. Section III outlines the system model, assumptions, and objectives of our work. The proposed vertex-based predictive greedy routing protocol is presented and discussed in detail in Section IV. Section V evaluates the performance of the scheme via extensive computer simulation. Finally, the paper is concluded with possible future work in Section VI.

Ⅱ. Related Work

Routing protocols for mobile ad hoc networks are categorized into topology based ones and location (or position) based ones. Position based routing protocols outperform topology based ones in VANETs even though they have some limitations and drawbacks.

Many routing protocols have been proposed in the literature in order to improve the performance [4-7, 9-10]. GPCR (Greedy Perimeter Coordinator Routing) [4] has been designed to deal with the challenges of the city environment. This employs restricted greedy forwarding strategies along in a predetermined path that selects a coordinator node as its next hop even if it is not the closest node to the destination.

GPSR (Greedy Perimeter Stateless Routing) [5] forwards a packet using so-called planar graph algorithm. But it takes large number of hops to get its destination and the path between source and destination is not optimal.

In GSR (Geographic Source Routing) [6], the shortest path between source and destination is calculated based on the street map. But, while calculating the shortest path, GSR does not consider whether there are enough vehicles or not on a street to provide connectivity between two involved junctions.

A-STAR (Anchor-based Street and Traffic Aware Routing) [7] was designed for inter-vehicle communication in city environment to identify anchor paths with higher connectivity. But, it utilizes the static vehicular traffic information based on the city bus route. Therefore, in GSR [6] and A-STAR [7], the selected path between source and destination might not be optimal. Moreover, they forward the packets using greedy forwarding techniques without consideration of the velocity and direction of vehicles while choosing intermediate nodes.

VADD (Vehicle Assisted Data Delivery) [9] implemented predicable mobility by taking the traffic pattern and road layout into account. It is based on idea of carry and forward. It performs well even in sparse road conditions.

Epidemic routing [10] performs well even in the harsh connectivity of sparse and rarely connected networks. Both of the routing protocols VADD and Epidemic routing increase packet delivery ratio but consumes more bandwidth as well as increase end-to-end delay.

III. System Model

We assume that each vehicle has a GPS receiver and is aware of its geographic position. Each vehicle knows the position of neighbors by hearing beacon messages that are periodically exchanged by vehicles. The road map is abstracted as a directed graph G (V, E) where V is set of vertices and E is set of edges. The position of destination is obtained with the help of map information provided by the navigation system. The proliferation of applications that may be running on VANETs in the near future suggests that vehicles will be equipped with wireless transceiver devices and sensing devices. Using such devices, vehicles can communicate with neighboring vehicles or fixed infrastructures within the radio range. The infrastructures are fixed roadside units whose absolute location is known to all vehicles.

VANETs consist of hundreds or thousands of highly mobile vehicles, and a few number of fixed infrastructures or access points (APs). Upon sensing any event on the road, vehicles communicate in ad hoc manner among themselves to forward data from the source vehicle to the nearest AP. When a vehicle senses an event, it produces a message containing the event description and all the event-specific information such as message generation time (Tg) and a time-to-live (TTL) value. The message is considered to be successfully delivered if it is arrives at the nearest AP from the source vehicle before time (Tg + TTL) without any transmission error.

For the prediction of a sequence of vertices or junctions, a source vehicle identifies the number of involved junctions between the source vehicle and nearest AP from it. The remaining time RT(i, j) of vehicle i at vertex j is the time duration during which vehicle i remains within the threshold range T of vertex j. The vertex j is said to be valid if RT(i, j) ≥

τ, where τ is the minimum duration required for forwarding a packet from vehicle i to vertex j and depends on the underlying wireless technology. The calculation of RT(i, j) of vehicle i within the threshold range T of vertex j plays a significant role to make routing decision. Note here that the threshold range T of vertex j is set to the radio transmission range R_i of vehicle i for high-performance routing in this paper even though it can be dynamically set within R_i. That is, RT(i, j) can be effectively used to indicate whether the particular junction may provide connectivity for routing of data towards destination or not. If one of the vertices in its selected path is invalid, VPGR considers the next shortest path and follows the same procedure as discussed above. Note here that the prediction of a sequence of vertices will be presented in following section. If all the vertices in a path are valid, the source vehicle forwards data through the sequence of vertices up to the destined fixed infrastructure in multihop fashion. For data forwarding, the conventional predictive directional greedy routing mechanism [3] is used.

IV. Vertex-Based Multihop Routing

In this section, the proposed *Vertex-Based Predictive Greedy Routing* (*VPGR*) protocol is presented in detail. VPGR performs two key operations: (i) predicting a sequence of vertices and (ii) forwarding data through the sequence of vertices by using well-known predictive directional greedy routing mechanism [3]. For the prediction of a sequence of vertices, a source vehicle identifies the number of involved junctions between itself and the nearest AP.

1. Prediction of a Sequence of Vertices

For the prediction of a sequence of valid

vertices, a source vehicle calculates the shortest path between itself and its nearest AP with the help of city map information provided by the navigation system. $RT(i, j)$ is calculated only for the vehicles within the threshold range T from the center of vertex j and identifies whether a vertex is valid or not as presented in Section III. Note that T is set to the radio transmission range of vehicle i as described in Section III.
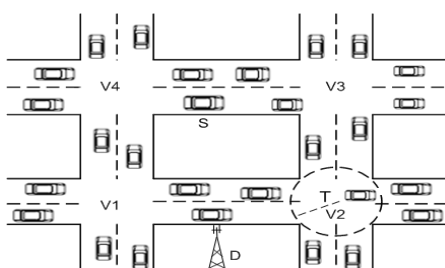

Fig. 2. Selection of a sequence of vertices between a source vehicle and a fixed infrastructure

Calculation of $RT(i, j)$

Notations :

  $RT(i, j)$: Remaining time of vehicle i within threshold range T from the center of vertex j

  T: Threshold range of vertex j.

  $D(i, j)$: Distance between node i and the center of vertex j, where $D(i, j) \leq T$

  V_i: Velocity of vehicle i

  t_1, t_2: Time $(t_1 < t_2)$

Procedure :

  if $D(i, j)_{t2} < D(i, j)_{t1}$

        $RT(i, j) = \{T + D(i, j)\}/V_i$

  else

        $RT(i, j) = \{T - D(i, j)\}/V_i$

  end if

Fig. 3. Calculation of $RT(i, j)$ for vehicle i at vertex j

The prediction of a sequence of vertices is explained with an example: In Fig. 2, let us suppose that the source vehicle S wishes to forward data to the nearest AP. The source vehicle S identifies a sequence of junctions between itself and the nearest AP, with the help of city map information provided by the navigation system. In Fig. 2, the source vehicle S finds two routes to get the destination: S→ $V_4 \to V_1 \to$D and S→$V_3 \to V_2 \to$D. The source vehicle selects the shortest one between possible paths. In case of tie, one of tied paths is randomly selected for simplicity. The source vehicle S identifies the number of involved vertices in the shortest paths and calculate RT(i, j) for each vertex or junction. The formal calculation procedure of RT(i, j) for vehicle i at vertex j is shown in Fig. 3. If a vertex is valid, we can say that the junction can provide connectivity for packet forwarding. In the selected shortest path, if one of the involved vertices is invalid, the source vehicle S chooses the next shortest path.

2. Predictive Directional Greedy Routing

Once the sequence of valid vertices are determined, the existing predictive directional greedy routing (PDGR) mechanism [3] is used to forward data through the sequence of vertices from a source to the nearest AP. In PDGR, a forwarding vehicle calculates the weighted score not only for packet carrier and its current neighbors but also for its possible future neighbors in the very near future [3]. For the knowledge of the possible future neighbors, the packet requires two-hop neighbors' information, which is possible by exchanging beacon messages among them. For this procedure, all data packets are marked with the sequence of vertices in its packet header. Each vehicle maintains a neighbor table, which contains information about node_id, position_of_node, velocity_of_node and direction_of_node of its neighbors. The neighbor table is updated by exchanging hello or beacon packets among neighboring vehicles. With the help of information contained in the neighbor table, a source vehicle calculates the weighted score not only for itself and current

packet carrier but also for possible two-hop neighbors. If a neighbor has the higher score than the current packet carrier, the source vehicle forwards the packet to the neighbor; otherwise, the current packet carrier carries the packet until it finds its neighbor which has higher weighted score than itself. The weighted score is calculated by $W_i = \alpha(1 - D_i/D_c) + \beta\cos(\overrightarrow{V_i}, \overrightarrow{P_{i,d}})$ as in [3]. Here, α and β are the weights for position and direction factors and $\alpha + \beta = 1$, D_i is the shortest distance from vehicle to destination (infrastructure), D_c is the shortest distance from forwarding node to destination; D_i/D_c is the closeness of the next candidate hop, $\overrightarrow{V_i}$ is the velocity vector on node i, $\overrightarrow{P_{i,d}}$ is the vector from the position of vehicle i to the position of destination, and $\cos(\overrightarrow{V_i}, \overrightarrow{P_{i,d}})$ is the cosine value for the angle made by two vectors.

Greedy forwarding reduces end-to-end delay and the number of hops, but in some cases, it may suffer from topology hole [8]; it is a situation when a data packet reaches a host that does not have any neighbor closer than itself to the destination. These problems in greedy routing in position-first forwarding and direction-first forwarding can be solved by taking both position and direction into account when choosing the next-hop neighbor. The weighted score (W_i) described above includes a tradeoff between position-first and direction-first forwarding schemes.

3. Maintenance of Neighbor and Routing Tables

Every node in the network periodically broadcasts a routing information (*RI*) packet to its neighbors. *RI* packet consists of the following fields: *node_id, position, velocity, direction and acceleration of a node*. With the exchange of *RI* packets, each node maintains a neighbor table of its neighbors. VPGR maintains routing table only for the involved vertices between the source vehicle and

nearest AP. In other words, the routing tables in the vehicles existing within the threshold range (T) of the involved vertices are maintained.

Ⅴ. Performance Evaluation

In this section, we evaluate the performance of VPGR using ns-2 simulator (version 2.33) [12]. We compare the performance of VPGR with existing routing protocols of AODV [11] and GPSR [5]. Note here that AODV (which is based on DSDV [16]) is the representative routing protocol standardized by the IETF MANET working group and GPSR is one of the typical geographic routing protocols referenced in many studies, respectively. As described earlier, PDGR [3], a subset of the proposed VPGR, is used for data forwarding in our VPGR implementation.

1. Simulation Setup

The experiment is based on a network area of 1000 × 1000 m^2, which represents a grid layout of city roads. The area consists of 6 two-way roads and associated 9 vertices or intersections. This street layout is derived and normalized into a realistic mobility traces from a Manhattan mobility model [13]. These map data are transformed into the data format that can be used by the ns-2 simulator.

Table 1. Simulation parameters

Simulation setup/Scenario		MAC/Routing	
Network area	1000×1000 m^2	Channel capacity	2 Mbps
Simulation time	900 seconds	Transmission range	$250m$
Number of intersections	9 (on 6 two-way roads)	Traffic model	6 CBR connections
Number of vehicles	100-500 (default: 200)	Packet sending rate	4 packets/sec
Vehicle speed	20-80 km/hr (default: 40)	Data packet size	128 bytes
Mobility model	Manhattan mobility [13]	Weighting factors (*a, β*)	(0.9, 0.1)

The node density is varied from 100 to 500

vehicles deployed on the map, the default value of which is 200. Each vehicle has radio transmission range of 250m. The speed of vehicles is chosen between 20-80 km/hr, the default value of which is 40 km/hr. For the performance evaluation, 6 random connections were established using the CBR traffic of 4 packets/second with a packet size of 128 bytes. IEEE 802.11 DCF is used for the network interface with channel capacity of 2 Mbps. The simulation results are averaged over repetitive runs. Each simulation run takes 900 seconds (15 minutes) of simulation time.

2. Simulation Results and Discussion

The performance metrics used to evaluate the simulation results in this paper are as follows:

• Packet delivery ratio: the ratio of the number of data packets successfully delivered to the destination over the number of data packets sent by the source.
• Average end-to-end delay: the average time it takes for a packet to transverse the network from source to destination.
• Routing overhead: the ratio of the number of bytes of total control packets to those of total data packets delivered to the destination during the entire simulation.

The three algorithms of AODV, GPSR and the proposed VPGR are compared under various values of node (vehicle) density and node speed.
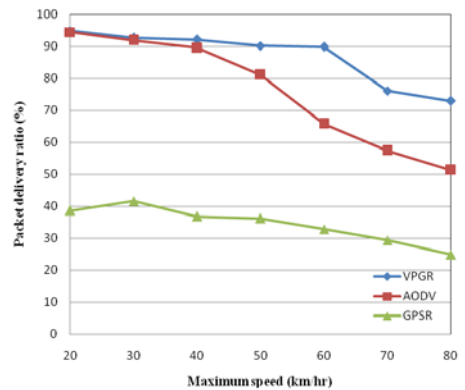
2.1 Packet Delivery Ratio

In this section, we will show how the performance of packet delivery is affected under the different node density and speed for AODV, GPSR and VPGR.

In Fig. 4(a), VPGR achieves the highest packet delivery ratio for the different number of nodes. It is also observed that more packets are delivered as the node density increases.
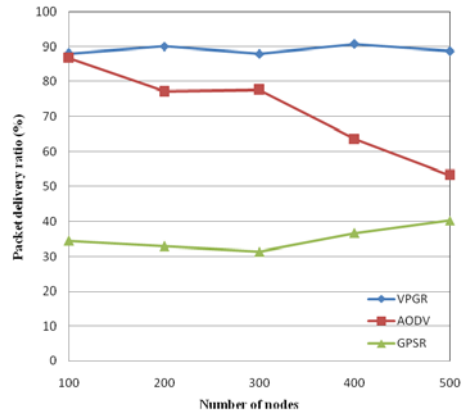
(a)

(b)

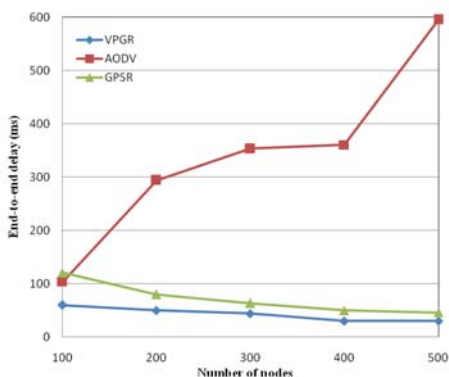Fig. 4. Packet delivery ratio vs. (a) number of nodes and (b) maximum node speed

In GPSR, the packet delivery ratio is slightly decreased up to 300 nodes but, after that point, the packet delivery ratio is linearly increased. In AODV, the packet delivery ratio is linearly decreased with the increasing number of nodes. With the prediction technique, VPGR shows the best performance because it can select the best vertex to route and the best next hop, both of which enhance the reliability in packet delivery. At high node density, VPGR delivers almost 50% more packets than GPSR.

Fig. 4(b) shows the packet delivery ratio with respect to varying node speed. The delivery ratio of GPSR is worst among three routing protocols (almost less than 40%). This is because GPSR suffers from frequent routing

holes at the node placement only in perimeter mode [5]. The delivery ratio of AODV is linearly decreased as the speed increases. Since AODV is a reactive routing protocol, it performs route recovery whenever the packet is dropped due to route breakage. VPGR shows higher delivery performance in all the speed level because the source node always finds the predefined route (through the predefined valid vertices) to the destination AP. In VPGR, the packet delivery ratio is rapidly decreased beyond 60 km/hr, but still maintains almost 80% of packet delivery.

2.2 End-to-End Delay

In this section, we compare the performance of AODV, GPSR and VPGR in terms of end-to-end delay.

(a)
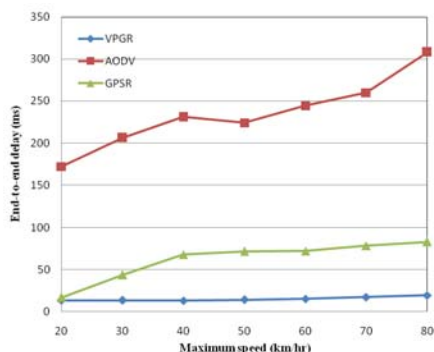
(b)

Fig. 5. End-to-end delay vs. (a) number of nodes and (b) maximum node speed

As shown in the Fig. 5 (a), VPGR achieves a much lower end-to-end delay than AODV and GPSR in all the configurations. This is because (i) the number of hops involved to deliver a packet in VPGR is reduced due to predictive directional greedy routing and (ii) VPGR does not need to keep track of an end-to-end route before sending packets from source to the destination AP. In contrast, the reactive routing protocols like AODV use an on-demand route discovery mechanism which causes longer delay. At very high node density (500 nodes), the end-to-end delay is drastically increased.

As shown in Fig. 5(b), VPGR has much lower end-to-end delay than AODV and GPSR. AODV performs a route discovery process in reactive way whenever the current path or route is broken. That is why the end-to-end delay of AODV is the worst and it is linearly increased with the increased speed. As the increased node speed results in a link breakage, GPSR also encounters longer delay than VPGR.
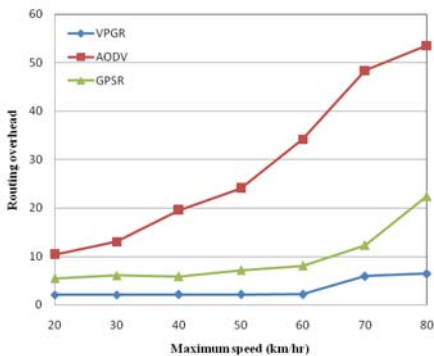
2.3 Routing Overhead

In Fig. 6(a), we evaluate the routing overhead of the three routing protocols with different node densities. VPGR outperforms the other two routing protocols. In all the routing protocols, it is observed that the increase in vehicle density leads to the increase in routing overhead since the rate of control messages depends on the number of nodes. In VPGR, only the routing information (RI) packet is used as a control message. It is a contrast to the three types of control messages (i.e., RREQ, RREP and RERR) used for route discovery and route maintenance in AODV. In GPSR, HELLO packets are used. This is why VPGR and GPSR have lower overhead compared to AODV.

In Fig. 6(b), we evaluate the routing overhead of the three routing protocols with varying vehicle speed. VPGR outperforms the other two routing protocols as well. As shown in Fig. 6(a), it is also observed that the increase in vehicle speed leads to the increase in routing

overhead since the rate of control messages is increased with the number of broken links. Note here that the increased node speed results in more link breakages and, thus, more control packets should be transmitted. As a result, the routing overhead is linearly increased with the increased node speed. In VPGR and GPSR, the overhead is remarkably increased beyond 60 km/hr compared to the lower speed.
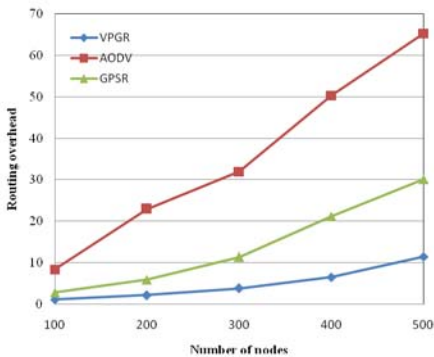
(a)

(b)

Fig. 6. Routing overhead vs. (a) number of nodes and (b) maximum node speed

Ⅵ. Conclusions

In this paper, the geographic prediction based routing protocol so-called vertex-based predictive greedy routing (VPGR) protocol has been proposed for vehicular ad hoc networks in city environment. VPGR leverages the geographic position, velocity, direction and acceleration of vehicles and performs the two key operations of (i) the prediction of a sequence of vertices and (ii) the use of the predictive directional greedy routing to forward the data from source vehicle to destination infrastructure through the sequence of vertices. The proposed routing protocol has been evaluated using the network simulator ns-2 and compared with GPSR and AODV for different conditions. The simulation results show that the proposed VPGR outperforms GPSR and AODV in terms of packet delivery ratio, end-to-end delay and routing overhead. That is, VPGR achieves higher performance and more reliable routing than GPSR and AODV.

Our proposed routing protocol selects vertices and intermediate vehicles in the city environment where sufficient vehicles are on the roads. As a future work, we are investigating the scenarios with relatively low vehicle density to extend VPGR, in which the so-called store-carry-and-forward technique might be useful and can be exploited. To extend VPGR for vehicle-to-vehicle routing is also our future work.

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