Connectivity-Aware Minimum-Delay Geographic Routing with Vehicle Tracking in VANETs

Kaveh Shafiee and Victor C.M. Leung

Department of Electrical & Computer Engineering
The University of British Columbia
Vancouver, BC, Canada V6T 1Z4
`{kshafiee,vleung}@ece.ubc.ca`

Abstract. In this paper, we propose a novel geographic routing protocol for vehicular ad-hoc networks (VANETs) that adapts well to continuously changing network status in such networks. On one hand, when the network is sparse, the protocol takes the connectivity of routes into consideration in its route selection logic which maximizes the chance of packet reception. On the other hand, in situations with dense network nodes, the routes with adequate connectivity are recognized and among them the route with minimum delay is selected. Also the proposed protocol includes a mechanism for tracking target vehicles when they move away from their initial locations. Finally, the proposed protocol is compared with other successful state-of-the-art routing protocols for VANETs and its effectiveness is verified via simulations.

Keywords: Vehicular ad-hoc network (VANET), geographic routing protocol, connectivity awareness.

1 Introduction

Many applications in vehicular ad-hoc networks (VANETs) require the deployment of an efficient, reliable and robust routing protocol. One of these applications is Internet access in which the vehicle in need of accessing the Internet employs a routing protocol to establish a connection with the most appropriate gateway (GW) in its neighboring area. Discovering GWs in the neighboring area is usually carried out in an anycasting manner. The inherent characteristics of vehicular communications, including highly dynamic network topologies and highly variable vehicle densities make the design of routing protocols in VANETs challenging.

Routing protocols for VANETs in which an *end-to-end* route between the vehicle and the GW is needed to be established before any data packet is sent can be characterized as *topology-based* or *on-demand*. One of these protocols is *multi-hop routing protocol for urban vehicular ad-hoc networks* (MURU) [1], in which each intermediate vehicle estimates the quality of the wireless link between itself and its downlink vehicle and updates the value of a metric called *expected disconnection degree* (EDD) accordingly. Finally, the route with the lowest breakage probability is selected. Another topology-based routing protocol is *movement prediction-based*

J. Zheng et al. (Eds.): ADHOCNETS 2009, LNICST 28, pp. 256–267, 2010.

routing (MOPR) [2, 3], which determines the most stable route in terms of lifetimes of the links in the route by taking the movements of vehicles into account. While in most topology-based protocols new routes are only discovered when existing routes fail, which incurs large delays due to the reconstruction of new routes, in *prediction-based routing* (PBR) [4] the lifetimes of routes are predicted based on the mobility patterns of vehicles and new routes are discovered before the existing ones fail. Another protocol that predicts route failures before they occur based on vehicular mobility patterns is proposed in [5]. In this work, to guarantee the stability of routes, vehicles with similar velocity vectors are given higher priorities in establishing routes.

Since in vehicular networks the network topology can change rapidly, the amount of signaling traffic that is generated in the process of discovering an end-to-end route may be unreasonably large compared to the data traffic that actually uses the route before it fails. Furthermore, when the network is sparse, end-to-end routes may not even exist. Therefore, topology-based protocols have not gained as much popularity as *geographic* or *position-based* protocols. In geographic routing protocols packet forwarding decisions are made based on current neighbors of the packet forwarding vehicle, and the next forwarding vehicles are not initially determined. One of these protocols is *movement-based routing algorithm* (MORA) [6] in which a metric is defined on the basis of the distance between the line connecting the source and the destination nodes and their moving directions, and vehicles forward their data to the neighbors with the best values of the metric. In [7] the authors use the idea of MOPR to develop a geographic routing protocol. In this work, every forwarding vehicle obtains a list of its neighbors that are predicted to stay in its transmission range for at least one second based on their velocity vectors, and selects the one closest to the destination as the next hop. To consider the information on roadmaps, *spatially-aware routing* (SAR) is proposed in [8], in which the streets and junctions on a roadmap are mapped onto the sides and vertices of a graph and Dijkstra's algorithm is used to find the shortest path to the destination.

All the aforementioned geographic routing protocols fail when the packets are forwarded toward a disconnected street, i.e., a street with no vehicle. The situation in which the packet-forwarding vehicle cannot find any next hop vehicle along the route to forward the packet is called a *local maximum*. To overcome this issue, *connectivity-aware* geographic routing protocols were proposed. One of these protocols is *anchor-based street and traffic aware routing* (A-STAR) [9], in which different static weights are assigned to different streets based on the number of bus lines running along them. The Dijkstra's algorithm is applied to compute the route with the minimum sum of weights. The computed route is stated as a set of consecutive junctions, also called anchors. Another connectivity-aware protocol is *vehicle-assisted data delivery* (VADD) [10]. In VADD the average delays of packets on each street are computed by taking the average vehicle density of the street into account. Then, a stochastic model is used to obtain the packet forwarding direction priorities at junctions aiming for minimizing end-to-end delivery delays.

An effective routing protocol for vehicular networks should have good performance regardless of the status of the network. When the network is sparse the main challenge is to maximize the chance of reception before packets expire, by taking the connectivity of streets into account. On the other hand, when the network is dense and consequently connected in most parts the main challenge in the design of the routing protocol is to minimize the delay by selecting non-congested routes that have a sufficient level of connectivity over time. With these two objectives in our minds, we have developed our proposed Connectivity-aware Minimum-delay Geographic Routing (CMGR) protocol as presented in the next section. Among the existing routing protocols only A-STAR and VADD consider the first challenge, i.e., the connectivity of streets when the network is sparse, in their routing algorithms. Therefore, we only compare our proposal with these protocols in the performance evaluation presented in Section III. Section IV concludes the paper.

2 Connectivity-Aware Minimum-Delay Geographic Routing

2.1 Assumptions and System Model

As in most work on vehicular networks, we assume that vehicles are equipped with global positioning system (GPS) receivers and they periodically send beacons reporting their positions to their neighbors. So, every vehicle can calculate the vehicle density in its immediate area. To make the beaconing more efficient, we may adopt the idea of adapting beaconing period to the vehicle density in the neighboring area [11]. However, for the sake of simplicity we assume a fixed beaconing frequency for now. Also we assume that vehicles are equipped with digital maps with detailed locations of streets and junctions. Such digital maps have already been commercialized [12].

In our system model for vehicular networks every GW is connected to the Internet and any vehicle wishing to access the Internet uses the IP address of the GW to which it has established a route. Although in this paper we focus on the initiation and maintenance of these routes, our future work revolves around vehicle handovers between GWs, and to enable mobility management among GWs, where IPv6 is considered as the network layer protocol.

2.2 CMGR Protocol Operations

Any vehicle that wants to establish a route to any GW generates a *route discovery* (RD) message including its ID, *location*, *velocity vector*, and the *generation time* of the message, and broadcasts it in the network. Any intermediate vehicle that receives the RD attaches its *location* to the RD before rebroadcasting it. The intended recipient of the RD is any one of the GWs in the network (i.e., anycasting is used). To constrain the dissemination of RDs in the network, we define a *message lifetime* field in the RD, which depends on the application that is requesting the route. When any intermediate vehicle receives the RD, it subtracts the generation time of the RD from the current time and drops the packet if the result exceeds the message lifetime.

Among all the RDs that are received for the same request but coming from different routes the GW selects the most appropriate one according to the *route selection logic* which will be described in the next subsection. Then, based on the locations of the intermediate vehicles included in the selected RD, the GW determines all the junctions on the route the RD has come from as the *junction sequence* (JS). Then, the GW generates a *route reply* message (RR) comprising the JS, and the ID, location and velocity vector of the route-requesting vehicle already provided in the RD. The RR is sent back to the route-requesting vehicle along the JS by using a *geographic greedy forwarding algorithm*. In the algorithm any forwarding vehicle forwards the packet to the neighbor closest to the next intended junction in the JS or starts carrying the packet if a local maximum occurs.

2.3 Route Selection Logic

To take the connectivity of routes into consideration in selecting the most appropriate route, a naive approach is to select the route with the maximum value of the minimum vehicle density along the route. For this purpose we have intermediate vehicles include the vehicle densities in their neighboring areas in the RDs they rebroadcast, i.e., ρ_i for vehicle i, and the route with the maximum value of the minimum vehicle density along the route is the most connected route at any point in time. However, vehicle densities are highly variable and this approach does not take their changes over time into account. In other words, at the time of decision-making the density information based on which the route is being selected may be obsolete and consequently not valid. To deal with this issue, we propose the following mechanism.

We have vehicles calculate the *moving average* of the *vehicle density changing rates* in their neighboring areas over a number of beaconing periods and attach them to the RDs they rebroadcast, i.e., r_i in the neighboring area of vehicle i. On the other hand, for any of the received RDs the GW calculates the *trip time* (TT) which is the duration of time between the generation time of the RD and the reception time of the RD at the GW, i.e., TT_j along route j. Therefore, the vehicle density in the neighboring area of vehicle i when the RR gets back, i.e., ρ_{ia}, can be approximated as

$$\rho_{ia} \approx \rho_i + r_i(2TT_j) . \tag{1}$$

The reason we consider a fixed value for r_i over $2TT_j$ is that in urban areas there is a high correlation between the current value of vehicle density changing rate and its value after maximum allowable message lifetime [13]. By adjusting the weights of old values in the calculation of the moving average we can make the approximation more accurate. This weight optimization problem is the subject of our future work. On the other hand, since the time it takes the message to get back to any intermediate vehicle is smaller than $2TT_j$, when r_i has a negative value and consequently the vehicle density is decreasing, $\rho_i + r_i(2TT_j)$ will be a lower bound for ρ_{ia}. Therefore, we define *connectivity* along route j, i.e., C_j, as follows

$$C_j = \min_{\forall \text{ vehicle } i \in \text{ route } j} (\rho_i + r_i(2TT_j)) . \tag{2}$$

We define U = {route 1, route 2, …, route n} as the set of all candidate routes and the GW selects the route with maximum connectivity in U as the most appropriate route, i.e., route k

$$\text{route } k = \arg\max_{\text{route } j \in U} (C_j) . \tag{3}$$

The issue with the aforementioned logic is that in dense situations selecting the route with maximum connectivity leads to the maximum level of congestion as well. To avoid congestion, we improve the route selection logic in (3) as follows

$$\text{route k} = \begin{cases} \underset{\text{route j} \in V}{\arg\min}(TT_j) & \exists \text{route j: } 1/C_j < R \\ \underset{\text{route j} \in U}{\arg\max}(C_j) & \text{otherwise} \end{cases} \tag{4}$$

where R is the transmission range and $V = \{\text{route j} \mid \text{route j} \in U,\ 1/C_j < R\}$. The condition in (4) differentiates the dense enough situations where at least a route with relative distances of vehicles smaller than the transmission range exists from the sparse situations where no such route can be found and therefore the packet needs to be partly carried by the vehicle. In other words, by employing this route selection logic we make sure that in dense situations the route with minimum delay which is dense enough but not congested is selected.

If the RD is received by several GWs, each of them sends back an RR. Upon the reception of these RRs, the route-requesting vehicle computes the connectivities (C_js) and trip-times (TT_js) of each route and selects the most appropriate one according to the same logic in (4) for sending the data packet.

2.4 Vehicle Tracking Mechanism in CMGR

As mentioned earlier, the route-requesting vehicle places its location and velocity vector in the RD it generates, and this information will also be included in the RR the GW generates. By the time the RR is sent back to the route-requesting vehicle, there is the chance that it moves away from its initial location recorded in the packet. Particularly, when the network is sparse and the packet is needed to be partly carried by vehicles, the chance is higher. To resolve this issue, we propose the following mechanism in the design of CMGR.

When the route-requesting vehicle gets to a junction and makes a turn, it attaches its new velocity vector to the next beacon it broadcasts. All the vehicles that hear this beacon keep this information as long as they reside at that junction and rebroadcast it whenever they are about to leave the junction. Therefore, the information remains at the junction until either the returning packet is informed about it or the session expires. When the returning packet arrives at the junction, the corresponding vehicle responsible for forwarding the packet queries the new velocity vector of the route-requesting vehicle and by following the updated velocity vectors the packet is eventually delivered to the route-requesting vehicle.

3 Performance Evaluations

3.1 Simulation Settings

The street layout we use in the simulations is derived from a real street map in TIGER database [14] from US Census Bureau. For simulating the mobility of vehicles, we used the *simulation of urban mobility* (SUMO) [15] which is a microscopic street traffic simulation package. In SUMO, different types of vehicles can be defined. We used this feature to differentiate buses from cars which is of concern in A-STAR. For each line of buses, we defined the route the buses run along and the number of buses in the line at any interval. Every street is assigned a maximum speed, a functionality and a priority of usage used in computing the way-giving rules at junctions. This mobility model is used to generate a mobility trace-file which is immediately employable by *network simulator 2* (NS-2) [16] with the help of *mobility model generator for vehicular networks* (MOVE) [17]. The parameters we used in the mobility model and the wireless communications parameters are listed in TABLE 1.

Table 1. Mobility-related and wireless communications-related parameters

Simulation area	2500m * 2500m
Average length of streets	500m
Segment size	100m
Number of vehicles	100 ~ 400
Average velocity	15 ~ 105 km/h
Simulation time	20000 sec
R (Transmission range)	250 m
Radio model	Two Ray Ground
Traffic model	CBR over 20 random vehicles
CBR rate	4 packets/sec.
Data packet size	1 KB
Beacon size	512 bit
Beaconing frequency	2 beacons/sec
Data rate	1 Mbps
MAC layer	IEEE 802.11 DCF
Max. Contention Window	32

3.2 Simulation Results

The performance metrics that we consider in our evaluations are *packet delivery ratio*, which is the number of delivered packets to the number of generated packets and *packet delivery delay*. Note that packet time-out is the reason of packet dropping and occurs due to a variety of reasons ranging from high bit error rates and collisions in the medium access control layer to disconnections and inability in finding route-requesting vehicles. Since as investigated in [18], the *maximum allowable one-way transmission delays* for a relatively large number of multimedia services is either 10 seconds or 1 minute, we set the *message lifetime* parameter in our simulations accordingly. Furthermore, we run the simulations with both one and two GWs. As stated before, since A-STAR and VADD are the only existing routing protocols that take connectivity into account, we only simulated these two protocols for performance comparisons. That A-STAR prioritizes the streets with more bus lines in selecting the routes may incur packet traffic congestions on those streets. Besides, the number of bus lines on a street is not an accurate criterion for assessing the connectivity on that street. On the other hand, VADD uses the average vehicle densities and average velocities to compute the routes with minimum end-to-end delay. However, due to a highly dynamic topology, real-time average values are very different from initial average values that are used in the computations.

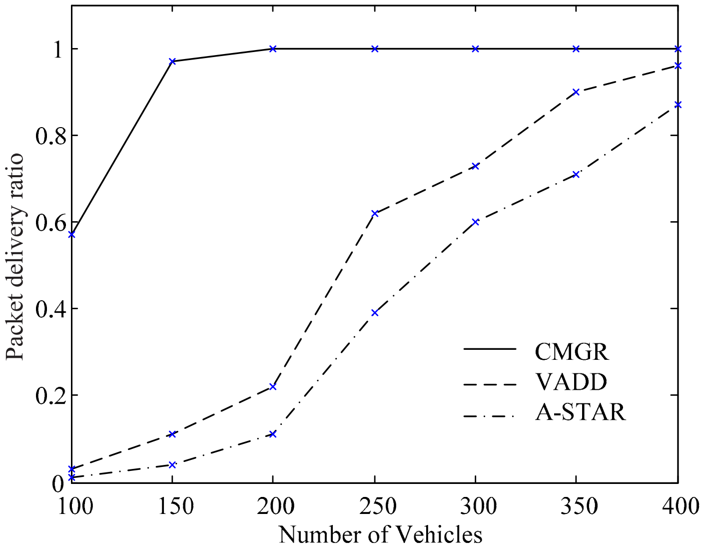

Fig. 1a. Packet delivery ratio for maximum delay of 1min. and 1 GW

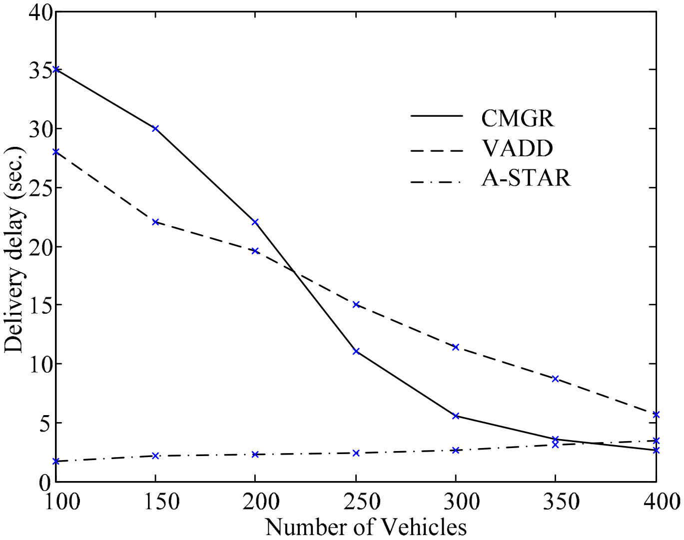

Fig. 1b. Packet delivery delay ratio for maximum delay of 1min. and 1 GW

In the first round of simulations only one GW exists in the network and is placed at the bottom rightmost junction of the network. The packet delivery ratios and the packet delivery delays for maximum allowable one-way delays of 1 minute and 10 seconds are depicted in Figs. 1 and 2, respectively. Any given result is the average value of 20 simulation runs. When a local maximum occurs, A-STAR computes another route as a recovery route. However, the packet is dropped in case no recovery route is found or after a limited number of recoveries. This best explains its low packet delivery delays and low delivery ratios compared to VADD and CMGR. Much higher packet delivery ratios of CMGR in lower vehicle densities in Fig. 1a, compared to those of VADD and A-STAR can be attributed to the vehicle tracking

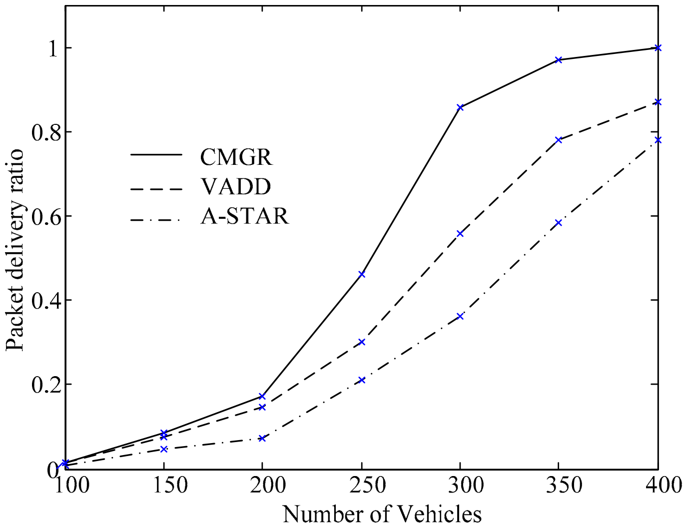

Fig. 2a. Packet delivery ratio for maximum delay of 10sec. and 1 GW

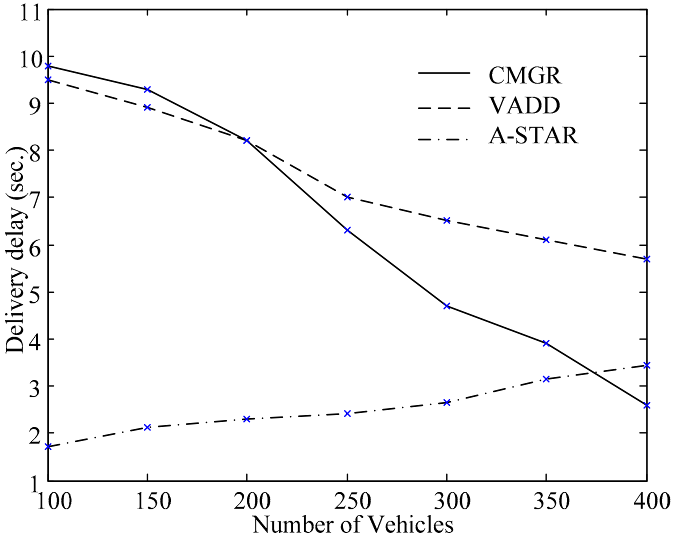

Fig. 2b. Packet delivery delay ratio for maximum delay of 10sec. and 1 GW

mechanism in CMGR. The reason the improvement that the vehicle tracking mechanism makes becomes less noticeable when the maximum allowable delay is 10 seconds (Figs. 2a) is that corresponding packet delivery delays are smaller and the route-requesting vehicles do not get the chance to go far from their initial locations. Also higher delivery delays of CMGR are a direct result of its higher delivery ratios. This is because the packets that cannot be delivered by A-STAR or VADD but are delivered by CMGR mostly undergo longer delays and therefore increase the average packet delivery delays.

In the second round of simulations, we investigate how the deployment of more GWs in the network affects the results. We place the GWs at the farthest possible distances from each other. For instance, in case of two GWs, we place one at the top leftmost junction and the other one at the bottom rightmost junction of the network. As it can be guessed from Fig. 1a, the packet delivery ratios of CMGR with maximum delay of 1 minute turn out to be one or very close to one for all vehicle densities when the number of GWs in the network is greater than one. Therefore, for maximum delay of 1 minute we only present the graph of packet delivery delays (Fig. 3). The packet delivery ratios and delivery delays of CMGR with maximum delay of 10 seconds for different number of GWs are depicted in Figs. 4a and 4b, respectively. As it can be observed from Figs 3 and 4, the performance improvement obtained by using more GWs becomes less considerable when average vehicle density increases. Based on these results, for any required packet delivery ratio and delivery delay, the number of GWs that should be installed in any area of the network could be determined with respect to the average vehicle density in that area.

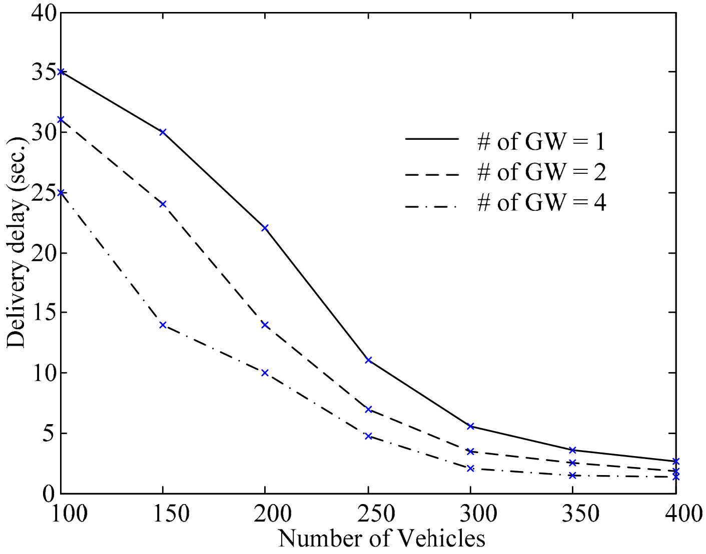

Fig. 3. Packet delivery delay for maximum delay of 1min. and different number of GWs

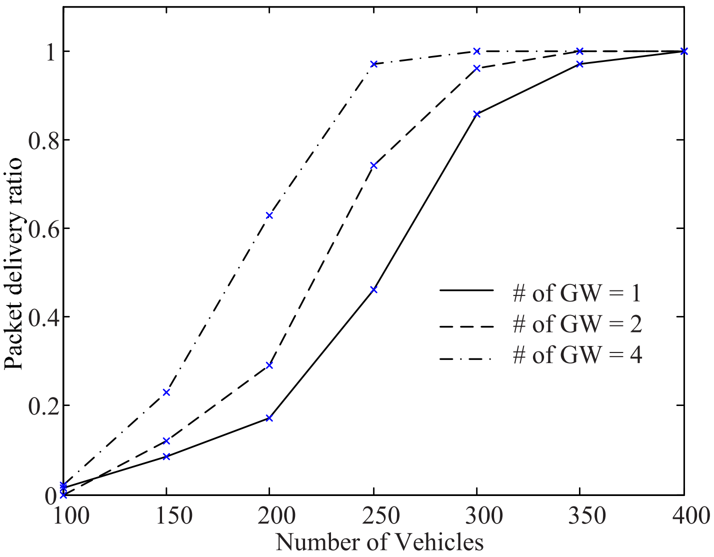

Fig. 4a. Packet delivery ratio for maximum delay of 10sec. and different number of GWs

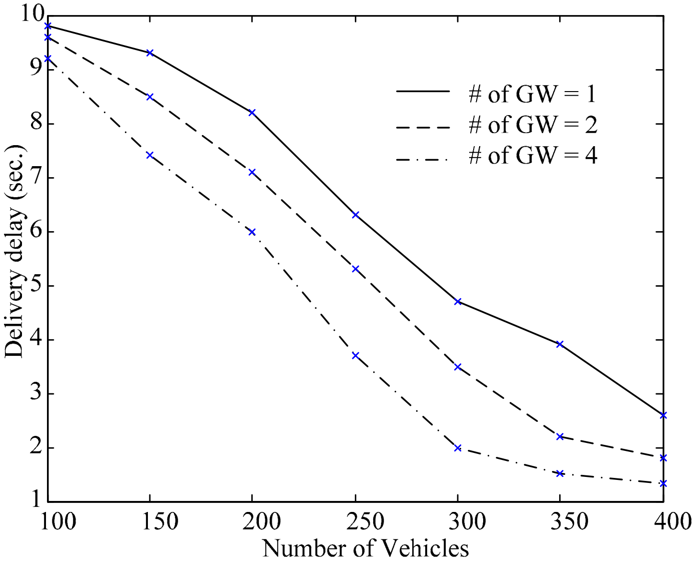

Fig. 4b. Packet delivery delay for maximum delay of 10sec. and different number of GWs

4 Conclusion

In this paper, we have presented a connectivity-aware minimum-delay routing protocol (CMGR) for vehicular ad-hoc networks that employs a novel route selection logic adaptable to the population of vehicles in the network. In order to deal with network disconnections in sparse situations, the routes with higher vehicle densities are prioritized and when the network is dense, less congested routes with minimum delays among routes with enough connectivity level are favored. A target tracking mechanism is included in the protocol to deal with the movement of target vehicles. We have presented simulation results, which show that the proposed routing protocol improves the performance compared to comparable existing protocols.

Acknowledgments. This work was supported in part by grants from the Nokia University Relations Program, from AUTO21 under Canadian Network of Centers of Excellence Program, and from the BC-China ICSD program.

References

1. Mo, Z., Zhu, H., Makki, K., Pissinou, N.: MURU: A Multi-Hop Routing Protocol for Urban Vehicular Ad Hoc Networks. In: 3rd Annual International Conference on Mobile and Ubiquitous Systems: Networks and Services, MOBIQUITOUS (2006)
2. Menouar, H., Lenardi, M., Filali, F.: A Movement Prediction-based Routing Protocol for Vehicle-to-Vehicle Communications. In: V2VCOM 2005, 1st International Vehicle-to-Vehicle Communications Workshop (2005)
3. Menouar, H., Lenardi, M., Filali, F.: An Intelligent Movement-based Routing for VANETs. In: ITS World Congress (2006)
4. Namboordiri, V., Gao, L.: Prediction-based routing for vehicular ad hoc networks. IEEE Trans. on Vehicular Technology 56(4), 2332–2345 (2007)
5. Taleb, T., Sakhaee, E., Jamalipour, A., Hashimoto, K., Kato, N., Nemoto, Y.: A stable routing protocol to support ITS services in VANET Networks. IEEE Trans. on Vehicular Technology 56(6), 3337–3347 (2007)
6. Granelli, F., Boato, G., Kliazovich, D.: MORA: a Movement-Based Routing Algorithm for Vehicle Ad Hoc Networks. In: Proc. of IEEE Workshop on Automotive Networking and Applications (2006)
7. Menouar, H., Lenardi, M., Filali, F.: Movement Prediction-Based Routing (MOPR) Concept for Position-Based Routing in Vehicular Networks. In: Vehicular Technology Conference (VTC) (Fall 2007)
8. Tian, J., Han, L., Rothermel, K., Cseh, C.: Spatially aware packet routing for mobile ad hoc inter-vehicle radio networks. In: Proc. ITS 2003, Shanghai, China, October 2003, pp. 1546–1551 (2003)
9. Seet, B., Liu, G., Lee, B., Foh, C., Wong, K., Lee, K.: A-STAR: A mobile ad hoc routing strategy for metropolis vehicular communications. In: Mitrou, N.M., Kontovasilis, K., Rouskas, G.N., Iliadis, I., Merakos, L. (eds.) NETWORKING 2004. LNCS, vol. 3042, pp. 989–999. Springer, Heidelberg (2004)
10. Zhao, J., Cao, G.: VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks. IEEE Trans. on Vehicular Technology 57(3), 1910–1922 (2008)
11. Naumov, V., Gross, T.R.: Connectivity-aware routing (CAR) in vehicular ad hoc networks. In: Proc. of IEEE Infocom, Anchorage, Alaska (May 2007)
12. GB Traffic Volumes (May 2005), `http://www.mapmechanics.com`
13. Highway capacity manual. Transportation Research Board, Special Report 20, National Research Council, Washington, DC (1985)

14. TIGER (Topologically Integrated Geographic Encoding and Referencing), `http://www.census.gov/geo/www/tiger`
15. Simulation of urban mobility (SUMO), `http://sumo.sourceforge.net`
16. NS-2 simulator, `http://www.isi.edu/nsnam/ns/`
17. Karnadi, F.K., Mo, Z.H., Lan, K.C.: Rapid Generation of Realistic Mobility Models for VANET. In: IEEE WCNCI (2007)
18. ITU-T G.1010, End-User Multimedia QoS Categories (2001)