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Cache-based Routing for Vehicular Ad Hoc Networks in City Environments

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***Abstract*—*Most of routing protocols in* VANETs *are position-based due to their well scalability. The forwarding decisions of such protocols are simply based on the location information of forwarders' neighborhood and the destination node. Due to high mobility of vehicles, location-service protocols are required to provide the destination location. Location services protocols can be categorized as flooding-based and quorum-based. They are unrealistic for* VANETs*. In the former approaches, global network flooding require extreme high cost, while in the latter approaches, quorums' hand-off is impossible because of high volume of exchange data. In this paper, we present a routing by utilizing locality of vehicles' traces (i.e., left location information). Besides, by the aid of high mobility of vehicles and news exchange (new information about vehicles' location), vehicles' location information can be spread to improve the possibility of meeting a vehicle which has the location information of the destination. Our protocol is realistic and practical because neither global network flooding nor quorums are required. The simulation results show that our protocol works efficiently for VANETs in city environments and has higher successful query rate and lower cost.*

***Index Terms*—Location, location service, mobility, routing protocol, vehicular ad hoc networks (VANETs)**

I. Introduction

With the improvement of wireless communication technology and transportation, vehicular ad hoc networks (VANETs) become an interesting research topic in recent years. Due to high mobility of vehicles, one of the main concerns in VANETs is to design scalable and robust routing protocols. Several studies have shown that geographic routing is a well-suited solution in mobile environment [8, 11, 14, 16]. Position-based routing has good salability and low overhead since its forwarding decisions are simply based on the location information of forwarders' neighborhood and the destination node. However, providing location service so that a source node can obtain the location of the destination node is a hard challenge in VANETs.

Most of location-service protocols are proposed for MANETs, such as RLS [8], GLS [10], HLS [9], and GrLS [6]. Few are for VANETs, such as RLSMP [15], ILS [4, 5], and VLS [3]. These approaches can be categorized as flooding-based and quorum-based. The former approach requires periodically/on-demand global network flooding, which results in severe performance degradation and low salability [8], [13], [14]. In the latter approach, location servers (i.e., quorums) are chosen and responsible for maintaining node's location information and replying location query [3], [4], [5], [6], [9], [10], [12], [15]. Due to substantial number of nodes involved in VANET, location servers should maintain extremely lot of information. To make matters worse, high mobility of vehicles results in frequent hand-off, which further results in incomplete hand-off. Besides, location servers may need to maintain location information of far-away nodes, which is costly and impractical in low connected VANETs. Although some approaches allow location server maintains nodes in their vicinity, they have unacceptable query latency.

In this paper, we present a routing by utilizing locality of vehicles' traces or footprints. Obviously, two traces of a specific vehicle occurring in near time should occur at near location. Hence, once a trace of the target vehicle is found, all other traces can be found one by one, which implies that the target vehicle can be found. Besides, by the aid of high mobility of vehicles, vehicles' traces information can be efficiently spread to increases the probability of meeting trace holders (i.e., vehicles which have the trace information of the target vehicle). Simulation results show that the number of trace holders exponentially increases over time. Our protocol is low-cost and practical for VANET since no location servers and no global flooding are required. The rest of this paper is organized as follows. Section II and Section III describes motivation and detail of our protocol. Simulation results are presented in Section IV. Section V concludes this paper.

II. Motivation

To achieve high packet delivery ratio, flooding-based approaches require global network flooding in destination discovery. Clearly, global network flooding is unacceptable if there are a large number of queries. In order to reduce such high cost, the flooding is accomplished by the aid of hello beacons. However, hello beacons which are used to maintain neighbors' information are not frequent in VANETs because the neighborhood of a specific vehicle does not change frequently.

In fact, a vehicle's neighborhood changes if it crosses an intersection. Hence, beacon-based flooding has unacceptable packet delay time. Suppose there are 500 meters between two intersections and each vehicle has speed 40km/hr. If the distance between the source and the destination is 4 km, then at least 6 minutes needed to find the destination and the source has to spend 6*2=12 minutes to obtain destination location information, which is usually unacceptable.

In previous quorum-based approaches, each vehicle updates its location information to location servers periodically/on demand. Suppose that there are 5 vehicles in every 500 meter road segment. Suppose that there is one north-south (west-east) avenue every 500 meters along west-east (north-south) direction. Every avenue has at least four lanes for each driving direction. For a location server which is responsible for a 6*6 km^2, it should stores the location information of vehicles on 6000/500*2=24 distinct avenues, i.e., at least (24)*4*2*(6000/500)*5=11520 vehicles' location information are maintained by the location server, which results in quorums' hand-off impossible (since payload length of an IEEE 802.11b packet is at most 2312 bytes, the quorum hand-off require more than a dozen packets). On the other hand, updating location information of these vehicles also leads to high cost because of their high volume and each update averagely requires a 1.5 km-transmission, which results in high collision rate and high communication cost. To make matter worse, easily broken communication paths between vehicles leads to higher communication cost and unreliable updates.

In order to prevent quorum's hand-off problem and unreliable update, our protocol aims to reduce both quorums' burden and the distance between vehicles and their corresponding quorums. In our protocol, vehicles' location information is stored distributedly in their own neighboring vehicles' caches. No hand-off is required. Notice that the location information of

When a vehicle (i.e., querying) wants to get a route to another vehicle (i.e., queried vehicle), the querying vehicle initiates a local flooding for searching a vehicle v who has the location information of the queried vehicle no matter how old the location information is. When such a v receives the query packet, it sends the query packet to the location which is recorded in its cache that queried vehicle had ever located in. If another vehicle which receives/relays the query packet has newer location information of the queried vehicle, it redirects the query packet to the newer location. By this way, the query packet can be send to a vehicle which has the newest location information of the queried vehicle. Then a limited flooding is used to find the query vehicle.

III. The Proposed Scheme

To overcome the drawbacks of previous position-based approaches, we propose a cache-based routing protocol for VANETs in city environments. There are two schemes in our location-service protocol: (1) update scheme and (2) query scheme. In the update scheme, each vehicle send update packets for disseminating location information in the network. When a vehicle needs to query the location of a specific queried vehicle, it will use the query scheme to retrieve location information.

In our location-service protocol, we assume each vehicle is movable and can get its own location in a network through Global Positioning System (GPS). The querying vehicle and queried vehicle both change their positions over time. Each vehicle has digital maps, i.e., each vehicle has information about road segments and intersections. The vehicles in network can obtain the locations of intersections through digital map. Thus, each vehicle can be aware well that it is on a road or crossing intersection. In the following sections, the schemes of our location-service protocol will be presented thoroughly.

1. Update scheme

Recall that the quorum hand-off is impossible and long distance between vehicles and corresponding quorums results in unacceptable high communication cost. In order to solve the quorum hand-off problem and reduce the communication cost of update, in our protocol, vehicles' location information is cached locally in their nearby vehicles. Vehicles exchange their location information at intersections by the aid of hello beacons and cache the information they received from other vehicles' hello beacons. The hello beacon includes sender's name, sender's location, sender's driving direction, and news (i.e., other vehicles' new location). That is every vehicle has its corresponding virtual location server within one hop. So, the update cost can be much reduced. Besides, no hand-off problem exists because virtual location servers do not exchange the whole knowledge they have but exchange their newest news (e.g., newest n pieces of location information).

The detail of update scheme described below. Each vehicle sends update packets per crossing I intersections, i.e., I is an *update threshold*. The update packet consists of not only the location information of the sender but also newest n pieces of location information in sender's cache. It needs one-hop broadcasting for each update. We define the vehicles which have location information of queried vehicle to be *guideposts*. Through news exchange and the movement of guideposts, the number of guideposts increases over time. The region which may have guideposts of queried vehicle is called *guidepost region*.

The location and shape of the guidepost region depend on vehicles' mobility pattern. Assume that each vehicle has near the same moving speed and the same probability of changing direction in each intersection. Fig. 3.1 shows the guidepost region of the queried vehicle if update threshold is one. Suppose that the queried vehicle's ith news exchange occurs at time t_i. Initially, the queried vehicle is at the center of network at time t_0 as shown in Fig. 3.1 (a). Then, the queried vehicle sends update packets in the intersection and moves to the next intersection. When the queried vehicle move to the first intersection at time t_1, the queried vehicle sends update packets similarly. At the same time, the *guideposts at t_0* (i.e., vehicles which having the information of queried vehicle's location at time t_0) move to their new location as shown in Fig. 3.1 (b). Similarly, at time t_2, the queried vehicle and guideposts for t_0 and t_1 move to their new location. The locations of queried vehicle and guideposts at time t_3 to t_5 are shown in Fig. 3.1 (d) to Fig. 3.1 (f), respectively.

There is no need to exchange all knowledge of vehicles. In fact, it is sufficient that vehicles exchange newest *n* pieces of location information in their caches. Although the guidepost region for smaller *n* (see Fig. 3.2) is smaller than that of Fig. 3.1, success rate is not significantly reduced as the time of vehicles stay in the network is long enough (See Section IV).

Suppose that the area of network is N^2, the length of update path of previous quorum-based approaches is $O(N)$ hops. The update cost of previous quorum-based approaches is $U_h \cdot O(N)$ where U_h is the cost of sending an update packet per hop. Comparatively, since the length of update path in our update scheme is one, our update cost is $O(U) \cdot 1$ where U is the cost of sending a hello beacon to exchange news in one intersection. Since vehicles exchange newest *n* location information in their caches every time, U is limited.

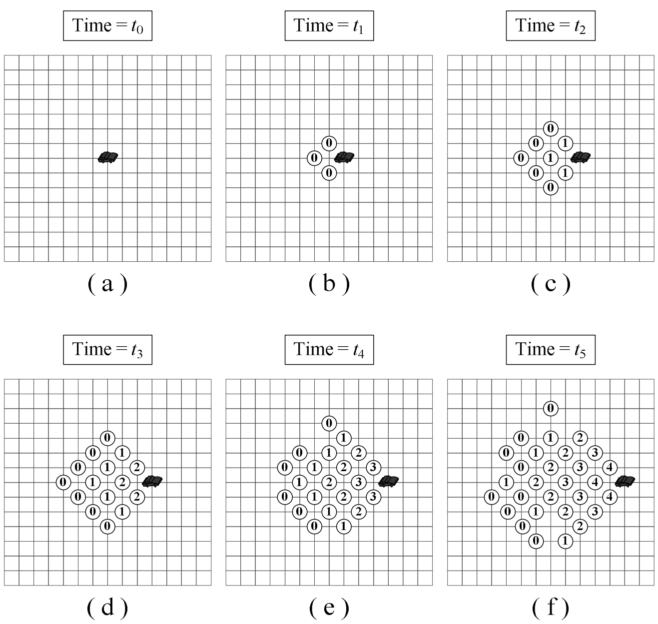

Figure 3.2 The guidepost region of one vehicle which updates per crossing one intersection and exchanges newest location information obtained from previous two intersections.

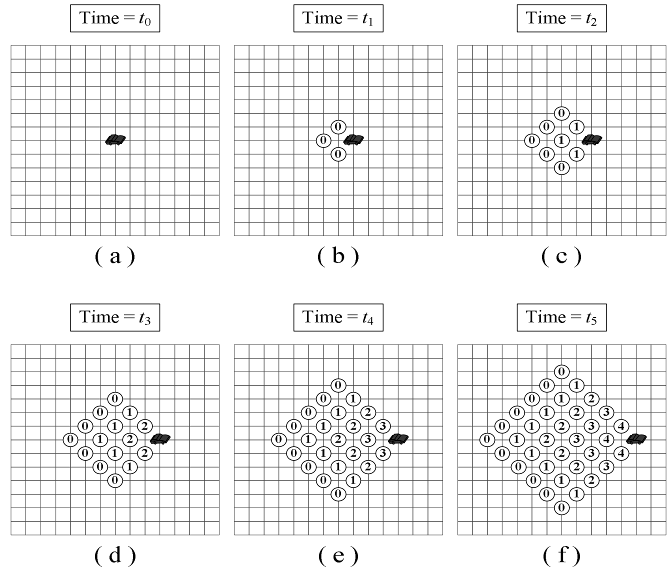

Figure 3.1 The guidepost region of one vehicle updates per crossing one intersection

2. *Query scheme*

Our query scheme exploits guideposts. It is obvious that high mobility of vehicles helps spreading location information: the number of guideposts increases over time. Besides there is locality between guideposts, guideposts at t_i are close to guidepost at t_{i+1}. Refer to Fig. 3.3, the square labeled as *i* is the location of the queried vehicle at time t_i (i.e., L_i). It is obvious that on every shortest path from a guidepost at t_0 to L_0, there are guideposts at t_1 and guideposts at t_2. Hence, the main idea of our query scheme is that when a query packet is received/relayed by a guidepost, say a guidepost at t_i, the guidepost sends the query packet to L_i. When a query packet which is originally send to L_i is received by a newer guidepost, say guidepost at t_j with $j>i$, the guidepost at t_j sends the packet to newer location of the queried vehicle, i.e., L_j. Even if no newer guidepost receives the query packet, by the aid of driving direction information in the queried vehicle's hello beacon received by the guidepost for t_i, we can go to (or get close to) the location of the queried vehicle at t_{i+1}. Repeat the process, we can find a newest guidepost, which is the closest to the queried vehicle.

Our query scheme contains four parts for retrieving the location of queried vehicle: (1) searching guideposts, (2) tracking queried vehicle with guideposts assisted (described in previous paragraph), (3) last-mile searching, and (4) replying to querying vehicle. The detail of parts (1), (3), and (4) are described below.

2.1. Searching guideposts

In order to find a guidepost, the querying vehicle uses a limited-scope flooding to send query packets as shown in Fig. 3.3. If the receiver (i.e., the vehicle that received the query packet) is exactly the queried vehicle, it simply replies its current location information to the querying vehicle. Otherwise, if the receiver is a guidepost, it invokes geographic greedy forwarding for tracking queried vehicle with guideposts assisted. If querying vehicle cannot find a guidepost through a local flooding (i.e., *h*-intersection flooding), it can try again (this is because the number of guidepost increases over time and applications in VANETs are usually not emergent due to unreliable nature of VANETs) or abort querying if a number of retries three times.

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Clearly, the success rate of searching guideposts increases as the value of h increases. However, higher value of h results in higher cost. The value of h depends on the importance of the queried vehicle.

2.2. Last-mile searching

Since each vehicle send hello beacon per crossing I intersection, the queried vehicle should be within I hops of the newest guidepost. Thus, we just need an I-intersection flooding to search the queried vehicle. As we observe in Fig. 3.1, we only need a flooding within I intersections while each vehicle sends update packets per crossing I intersections as shown in Fig. 3.4.

2.3. Replying to querying vehicle

Finally, when a query packet had been received by the queried vehicle, the queried vehicle will reply its current detail location (e.g. vehicle *ID*, X-Y coordinates, and timestamp) to querying vehicle. The reply packet is first sent to the querying vehicle's location recorded in the query packet. Then by the aid of the querying vehicle's guideposts, the reply packet can be sent to the querying vehicle.

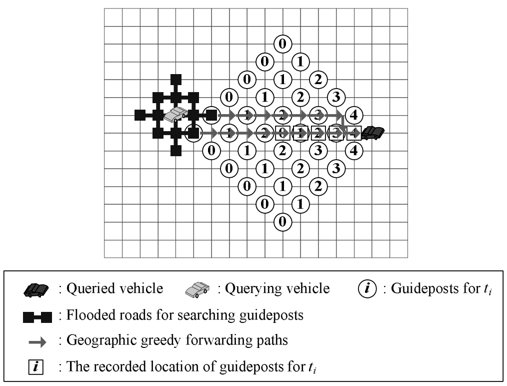

Figure 3.4 Our query scheme.

IV. Simulation Results

We use ns-2 [3] with the IEEE 802.11 11 MBit/s MAC layer of version 2.33 and VanetMobiSim [13] to evaluate the performance of our protocol. In our simulations, we assume that each road segment has at least one vehicle that it moves over time for providing a basic connectivity. These vehicles are not involved in querying cases. We compare the performance of our protocol with flooding and the previous work GLS[10], HLS[9], and the part of location and path discovery in CAR[14]. All simulation results are obtained from the average of 10 runs and each run has 50 querying cases. We consider five measures in our simulations. The matrixes are: (1) success rate, (2) query cost, (3) maintain cost, and (4) total cost, and (5) query response time. The success rate is the ratio of the number of success queries to the number of cases in the simulation. The query cost is the number of packets for querying in the simulation, i.e., the packets from querying vehicle to queried vehicle and the packets that the queried vehicle replies its location information to querying vehicle. The maintain cost is the number of packets for saving location information in network in the time interval of the simulation (it is set to 45 seconds). In our protocol, the maintain cost is the cost of update scheme. In previous approaches, the maintain cost is the cost of updating and information handoff between location servers. The total cost is the summary of the query cost and the maintain cost. The query response time is the time interval from sending a query to receiving the location information in the simulation of successful querying cases.

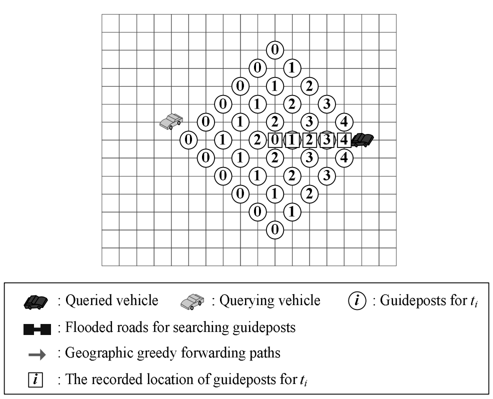

Figure 3.3. Guideposts and the location of the queried vehicles

The simulation programs of GLS and HLS that we used are obtained from the original author of HLS. We design a location-service protocol which uses flooding to be the best case of success rate of querying. In the flooding approach, vehicles who first receive a certain query packet should rebroadcast it no matter whether the packet has been rebroadcasted by other neighboring vehicles. In addition, we implement the part of location and path discovery in CAR according the paper [14] and the paper [13], i.e., the querying vehicle uses the adapted PGB to flood query to the queried vehicle and the queried vehicle uses AGF to forward the its location and route reply over the recorded anchored path.

In our location-service protocol, if the query time exceeds query threshold (It is set to 60 seconds in our simulations), we will abort this query and treat it as a query fail. The time interval between traffic light changes is set to 10 seconds because of the simulation time is not too long. Each vehicle will check that its current location is in an intersection or on a road. In our protocol, the threshold of the flooding for searching guideposts is one-hop. We define the *density* of vehicles as the number of vehicles in network per 100 m.

We use two maps for evaluating our location-service protocol. One of the maps is Manhattan type map, called map 1. Each road segment in map 1 is 300 m. Another map is the part of map in New York that we snapped from Google maps [1], called map 2.

1. Success rate

The simulation results of success rate of different maps are shown in Fig. 4.1. The success rate of our location-service protocol is close to the best case (i.e., flooding). Vehicles drop wrong packets easily in PGB which is used in CAR because of the limitations of roads, obstacles, and collisions in VANETs. Thus, the success rate of CAR (i.e., the part of location and path

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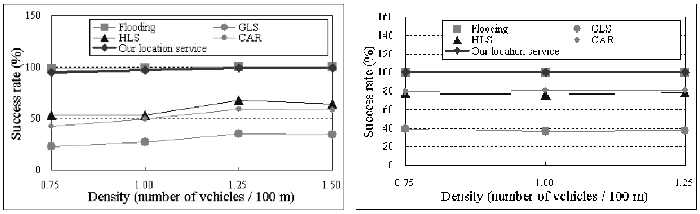
discovery) is lower than the flooding approach that each vehicle received a query will forward the query packet just once and does not drop packets even the vehicle hears that there are some vehicles rebroadcasted the packet. Our location-service protocol have better success rate than GLS and HLS, because the communication between location servers and querying vehicles is multi-hop in GLS and HLS. Multi-hop communications have high failure rate due to the high mobility, frequent topology changes, geographic constraint, and low connectivity in VANETs.

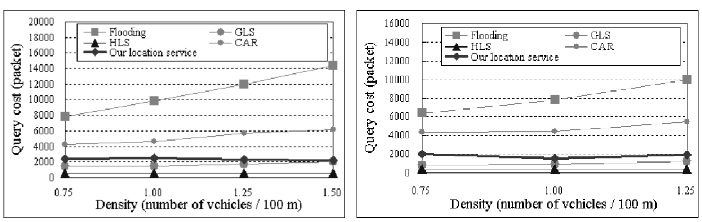


(a) (b)

Figure 4.1 The success rate (a) map 1, and (b) map 2.

2. Query cost

In Fig. 4.2, the query cost of flooding and CAR is higher than other three. Since the flooded region is limited in the part of location and path discovery in CAR, its query cost is lower than the query cost of flooding but still more than our location-service protocol. Our protocol's query cost is higher than GLS, and HLS, because we have multi-paths in tracking queried vehicle with guideposts assisted.



(a) (b)

Figure 4.2 The query cost (a) map 1 (b) map 2.

3. Maintain cost

The maintain cost for different maps are shown in Fig. 4.3. The results show that the cost of our update scheme is very low. Comparatively, previous work GLS and HLS need huge cost for updating and maintaining location information in location servers. The flooding and the part of location and path discovery in CAR do not have any maintain cost.

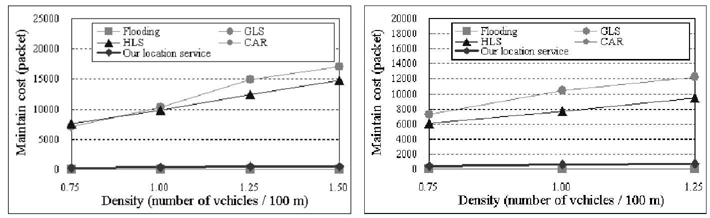
4. Total cost

Simulation results for the total costs are shown in Fig. 4.4. The total cost of our protocol is the lowest and nearly the same as the density of vehicles increases. Our protocol has query cost nearly the same to the cost of GLS and HLS and has maintain cost lower than that of GLS, HLS, and CAR. Besides, HLS have some additional cost for maintain location server or operation in cells.

5. Query response time

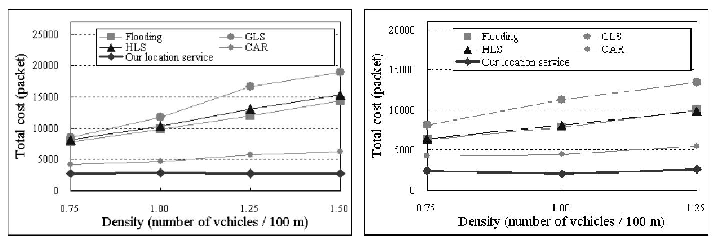
Fig. 4.5 shows the simulation results of query response time. GLS has the highest query response time because it needs to traverse a chain of vehicles and the chain is broken easily.

According to our simulation results, it shows our location-service protocol have lower cost than previous works. The success rate of our location-service protocol is near the success rate of flooding. The query response time can be tolerated and shorter in higher density. Thus, our location-service protocol works efficiently for VAENTs in city environments.



(a) (b)

Figure 4.3 The maintain cost. (a) map 1 (b) map 2.



(a) (b)

Figure 4.4 The total cost (a) map 1. (b) map 2.

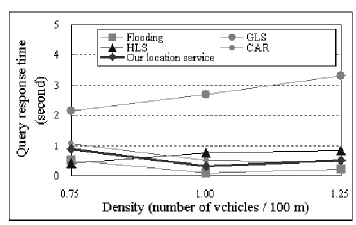


Figure 4.5 The query response time of map 2.

V. CONCLUSIONS

In this paper, we present a cache-based routing for VANETs in city environments. Our protocol consists of update scheme and query scheme. In update scheme, each vehicle sends update packets per crossing *I* intersections where *I* is an update threshold. Each vehicle which received update packets will cache and update the location information. In query scheme, we exploit the location information of queried vehicle in vehicles to query the current location information of queried vehicle. The simulation results show that our location-service protocol works efficiently for VANETs in city environments no matter in the Manhattan type map or the part of map in New York. The success rate of querying and the total cost are better than previous works. The query response time of our location-service protocol is tolerated.

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