GPSFR: GPS-FREE ROUTING PROTOCOL FOR VEHICULAR NETWORKS WITH DIRECTIONAL ANTENNAS

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ABSTRACT

Efficient and practical communications between large numbers of vehicles are critical in providing high level of safety and convenience to drivers. Crucial real-time information on road hazard, traffic conditions and driver services must be communicated to vehicles rapidly even in adverse environments, such as "urban canyons" and tunnels. We propose a novel routing protocol in vehicular networks that does not require position information (e.g. from GPS) but instead rely on relative position that can be determined dynamically. This GPS-Free Geographic Routing (GPSFR) protocol uses the estimated relative position of vehicles and greedily chooses the best next hop neighbor based on a Balance Advance (BADV) metric which balances between proximity and link stability in order to improve routing performance. In this paper, we focuses primarily on the complexity of routing in highways and solves routing problems that arise when vehicles are near interchanges, curves, and merge or exit lanes of highways. Our simulation results show that by taking relative velocity into account, GPSFR reduces link breakage to only 27% that of GPSR in the dense network. Consequently, GPSFR outperforms GPSR in terms of higher data delivery ratio, lower delay, less sensitivity of the network density and route paths' length.

KEYWORDS

Geographic Routing Protocols, GPS Free, Wireless Vehicular Ad Hoc Network, Relative Position Maintenance Algorithm, Directional Antennas

1. INTRODUCTION

In the future, large scale vehicular ad-hoc networks will be available to provide drivers with higher level of safety and convenience. For instance, multi-hop wireless communication between vehicles can enhance ACC (adaptive cruise control) systems by enabling rapid adaptation of longitudinal control in response to traffic accidents that just occur a short distance ahead of it (possibly a few wireless hops). It can also enable smart vehicles to react rapidly to sudden braking when a "hidden" vehicle that is ahead of it by several vehicles is braking. Such capabilities will be instrumental in improving highway traffic safety. As reported in [12] by the National Highway Traffic Safety Administration (NHTSA), in U.S. alone, vehicle crashes on the highway resulted in the loss of as many as 40,000 lives and an overall economic losses of more than $230 billion. The motivation to reduce accidents on highways has sparked increasing interest in research on improving vehicle safety through inter-vehicle communication in the vehicular ad-hoc networks [1, 2, 3, 4, 26, 27], including an effort by IEEE on a standard for inter-vehicle communication.

There are three possible network architectures of vehicular networks: infrastructure-based, ad-hoc networks and hybrid. In this paper, we focus on vehicular ad-hoc network (VANET) architectures because the cost of building such a network is very low and it can even operate in the events of disasters. Deployment of such networks is flexible and self-organizing. The other architectures require infrastructure support which has three drawbacks: high operating cost, limited bandwidth and symmetric channel allocation for uplink and downlink. There have been a number of research efforts on vehicular ad-hoc networks. For instance, the medium access control (MAC) problem was addressed in [5, 6]. To improve safety and commercial services, a multi-channel MAC protocol was proposed in [5]. Routing issues were addressed in [1, 2, 3, 7], including vehicle-assisted trajectory-based routing protocol [1], mobility-centric data dissemination [2] and position-base routing [7]. To further solve the network disconnection problem, [3] used the historical traffic data from digital maps to compute the probabilities of network connectivity of all road segments. Then, the path with the highest probability of network connectivity will be selected to forward packets.

However, all the above routing protocols rely on the positions of nodes and require vehicles to be equipped with GPS receivers. Though GPS will become standard equipment in vehicles in the future, it may still fail when the power source is depleted or the signals from satellites are blocked by tall buildings in "urban canyons", tunnels or bad weather. In this paper, we present a GPS-free geographic routing (GPSFR) protocol that uses only relative positions of vehicles which can be determined dynamically. Based on the relative distance and velocity, a new routing metric called balance advance (BADV) is designed to balance between proximity and link stability. Unlike other route optimization metrics [2, 7], BADV improves performance in routing without relying on nodes' locations. Our simulation results of vehicular networks in highway scenarios show that GPSFR outperforms GPSR [16], achieving fewer link breakage, higher data delivery ratio and low network delay.

The remainder of this paper is organized as following. In Section II, we summarize several related work. Then, we discuss our motivation and assumptions in Section III. The Relative Position Maintenance (RPM) and routing algorithms are described in Section IV. In Section V, we discuss our simulation environment and present the simulation results. Section VI presents the conclusion and future work.

2. RELATED WORK

There are a number of existing techniques for finding the location of nodes in wireless ad hoc network [19, 20, 21, 22, 23, 24, 25]. As stated in [18], these techniques require nodes to be able to measure the distances between itself and the neighbors using signal strength or time differences. Therefore, the effectiveness of this sort of approaches will rely heavily on the accuracy of distance or time estimation which may be adversely affected by large spurious variation in signal strength and time synchronization, the absence of line of sight, and specialized signal processing hardware or software.

A fully distributed, infrastructure-free positioning algorithm for mobile ad hoc network has been proposed in [8] that do not rely on anchor nodes. However, it is not suitable for vehicular networks for two reasons. First, after determining the relative positions of neighbors, each node must change its local coordinate system to the network coordinate system. Such update overhead increases as the network size increases. In fact, it is proven in [9] that the volume of message exchanges in [8] increases exponentially with the node density. Secondly, in highly mobile vehicular networks, the overhead of updating location reference group composed of nodes with lower moving speed is significant. Although cluster-based method in [9] can generate less communication overheads compared to [8], the number of message exchanges is still huge because it requires coordinate translation of master nodes throughout the network.

A scheme was proposed in [10] which can localize nodes through fewer message exchanges. However, the scheme in [10] is applicable to ad-hoc networks with less mobility, such as sensor networks, but unsuitable for vehicular networks. The high mobility in vehicular networks will result in large network overhead because of periodic bootstrapping beacons. The number of flooding nodes during the bootstrapping phase will increase as network size increases [10]. Relative position is also used to warn if a collision is happening by checking the relative distance between vehicles [11], but has not been used for solving the routing problem.

Unlike all the existing methods, the relative position information of nodes in GPSFR can be maintained through only localized broadcasting and hence significantly reduces position update overhead compared to those that require flooding the entire network. In addition, to the best of our knowledge, GPSFR is the first method to improve the performance of geographic routing in VANET without reliance on nodes' position.

3. ASSUMPTIONS

We focus primarily on vehicular networks in the rural highway scenario. A rural highway provides a link between urban areas. To determine and maintain neighbors' relative position, each node requires a compass and two directional antennas [13] pointing in opposite directions. One antenna is for sending/receiving data to neighbors in front of it, and the other for those behind it. Other advantages of directional antennas are longer radio ranges, absence of exposed stations problems and reduction of co-channel interference. We also assume that the coverage area of each antenna is a semi-circle, thus the area covered by the two antennas will form a circle.

4. ROUTING PROTOCOL

4.1. Relative Position Maintenance

While moving at the same direction on highways, vehicles will construct a linear network, as shown in Figure 1. Problems of vehicles at interchanges and ramps will be discussed later. For now, we will just focus on linear networks. In such networks, the delivery of packets can be categorized as forwarding or backwarding. In forwarding (backwarding), the routing algorithm needs only to choose the next hop from neighbors that are moving in the same (opposite) direction as packets being delivered. In order to achieve this, each node has to compute and maintain the relative positions of all its neighbors. As shown in Figure 1 (a), suppose all nodes from 1 to 6 are neighbors, then from node 3's perspective, node 5 is at a closer relative position than node 6. Also from node 3's perspective, the relative position of node 1 should be further than node 2's.

Suppose the forward and backward directional antennas are *f_antenna* and *b_antenna*, respectively. If the message arrived at one's *f_antenna*, then it must be sent by a node in front of the receiver; otherwise, it comes from a rear node. Therefore, each node can divide its neighbors into two groups (*fgroup* and *bgroup*) by checking from which antenna the messages are received. For example in Figure 1, the *fgroup* of node 3 should be {4, 5, 6} and the *bgroup* is {1, 2}. Even on a curve, as shown in Figure 1 (b), vehicles can also divide neighbors into two groups (assume the curve is not be very sharp which is reasonable on the highway). In addition, we can easily distinguish packets received from the vehicles moving in the opposite direction because if such message was sent from *f_antenna* (or *b_antenna*) of nodes moving at the opposite direction, then the receiver will obtain it also from the *f_antenna* (or *b_antenna*).

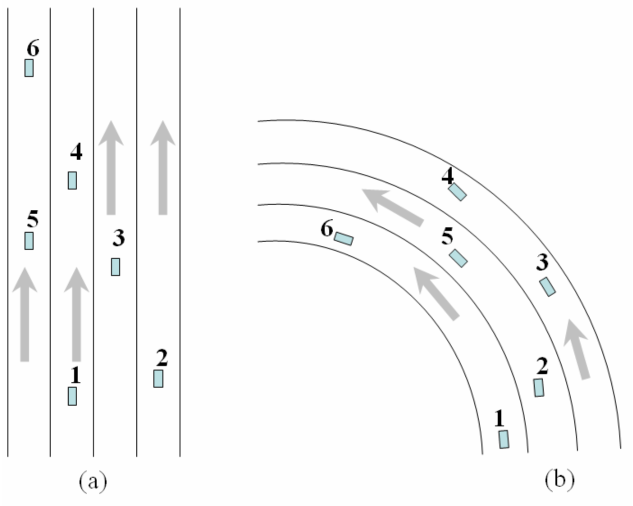

Figure 1. Illustration of nodes' relative positions on straight and curve road

After dividing neighbors into proper groups, each node will send such group information periodically. The format of this beacon message (called *group_update*) is: <*bgroup*, *id*, *velocity*, *direction*, *fgroup*>. If no *group_update* was received after a certain time-out period *T*, the neighbor will be considered out-of-range and deleted from the neighbor list. Actually, we could make GPSFR's beacon mechanism fully reactive, in which nodes will solicit beacons only when they have data to transmit. However, we felt this is unnecessary since the one-hop beacon overhead does not cause too much congestion.

Although computing the relative positions of nodes are straightforward, there is still a *hidden neighbor* problem. Suppose vehicle A has two apparent neighbors B and C in front (or behind), but B and C are not neighbors; then we can say B and C are the *hidden neighbors* of A. For example, as shown in Figure 2, node 2 and 4 are the *hidden neighbors* of node 1.

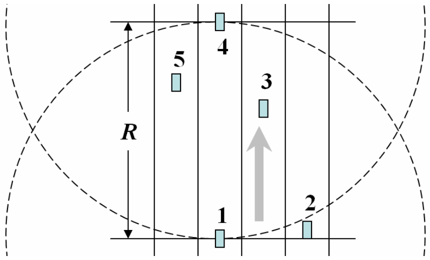

Figure 2. Node 2 and 4 are *hidden neighbors* of node 1

Since the *hidden neighbors* are actually not neighbors, then it is not always possible to obtain their relative positions through directional antennas. As shown in Figure 3, let the communication range of nodes be *R* and the width of each lane be *d*. On each lane, there is only a small area where *hidden neighbors* may exist. We denote the length of such area as l_i, which can be calculated as follows:

$$l_i = R/2 - \sqrt{(R/2)^2 - i^2 \times d^2} \tag{1}$$

where m is the number of lanes which is usually from 2 to 6, R is 250 meters and d is 3.6 meters, which is the typical width of lanes in highways [14]. Then the length of each piece will be very short, so the *hidden neighbor* problem is an unlikely event in vehicular networks. Note that the *hidden neighbor* problem also arises when vehicles are side by side, close to an interchange or try to leave the highway. In our protocol, the *hidden neighbors* are not included in the neighbor list, since they are only hidden for a short time.

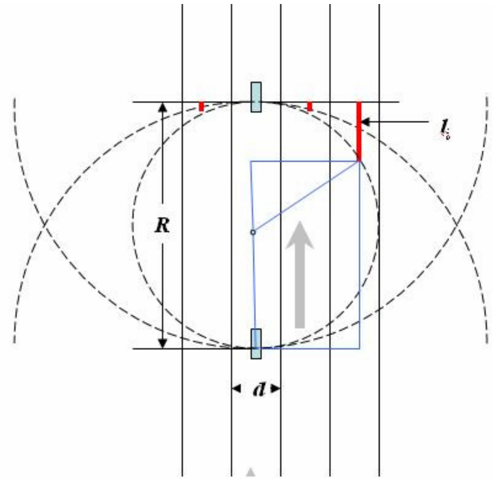

Figure 3. There are only small pieces where *hidden neighbors* may exist

4.1.1. Relative Position Maintenance (RPM) Algorithm

Within a certain neighborhood, except for those *hidden neighbors*, each node can determine whether or not a neighbor is in front or not through the directional antennas. The Relative Position Maintenance (RPM) algorithm uses *group_update* message exchanges to compute and maintain nodes' relative positions. As shown in the Table 1, each node n_i will maintain two linked lists F_i and B_i. F_i is used to record the front neighbors and B_i is for rear neighbors. Elements of each linked list are ordered by the nodes' relative positions.

If a message is received from n_j, then node n_i will first check whether or not this message is in its cache. If this message matches an entry, then there will be no change on n_j in the list. It just updates the lifetime of node n_j in the list. If it is a new message, n_i will first add/update the message in its cache and then arrange n_j's new relative position in the list. Line 2-9 is used to deal with the scenario of new vehicles merging into the networks, which will be examined later. Line 14-28 arrange node n_j in the corresponding list. We note when node n_j overtook n_i during the last beacon period, the distance between n_j and n_i should be approximately equal to 0. From n_i's perspective, n_j will be an anchor node since its exact relative distance is known now. In the later beacon periods, we can estimate n_j's new relative distance from the length of beacon period and the relative velocity between n_j and n_i. Clearly, the relative distances of anchor nodes are more accurate.

So far, we have established the relative positions of all neighbors, but we do not know the relative distance between them. As described above, some neighbors may become anchor nodes that have more accurate position. Thus, we can use those anchor nodes' relative distance to estimate other distances. If there is no anchor node in the list, then nodes' distances will be estimated to be evenly distributed between each neighbor.

Table 1. Relative position maintenance algorithm.

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Algorithm: Relative Position Maintenance (RPM)
Input: Message $m_j$ <$GF_j$, $ID_j$, $V_j$, $D_j$, $GB_j$> received from $n_j$
Output: Ordered link list $F_i$ and $B_i$ for current node $n_i$
$C$: Cache for all recently received messages
$F_i$: Ordered link list of neighbors located in front of $n_i$
$B_i$: Ordered link list of neighbors located behind $n_i$
$e$: Temp variable holding the element of the ordered link list
$GF_i$: Neighbors located in front of $n_i$
$GB_i$: Neighbors located behind $n_i$
f-antenna: whether message received from f antenna
Interval: Period of beacon message
if($m_j$ is not in $C$) then
    if(size of $m_j$ == 2&&$D_i$==$D_j$)
        if(f-antenna) then
            add $ID_j$ into $GF_i$;
        else
            add $ID_j$ into $BF_i$;
        endif
        exit
    endif
    if (size of $m_j$ >=3 && $D_j$ is on clock-wise direction of $D_i$) then
        drop this msg.
    endif
    add/update the entry of<$GF_j$, $ID_j$, $V_j$, $D_j$, $GB_j$> in $C$
    if($ID_j$ is in $B_i$ && f-antenna) then        /* $n_j$ overtake $n_i$ */
        $e$←remove element corresponding to $ID_j$ from $B_i$
        set $e$ as an anchor and reset $e$'s life time
        e.position←0;
    endif
    if($ID_j$ is in $F_i$ && !f-antenna) then       /* $n_j$ move backwards of $n_i$ */
        $e$←remove element corresponding to $ID_j$ from $F_i$
        set $e$ as an anchor and reset $e$'s life time
        e.position←0;
    endif
    if(f-antenna) then                    /* add $n_j$ into the corresponding list */
        Insert($F_i$, $GF_j$, $GB_j$, $ID_j$, $V_j$)
    else
        Insert($B_i$, $GF_j$, $GB_j$, $ID_j$, $V_j$)
    endif
    update $GF_i$ and $GB_i$ by new $F_i$ and $B_i$
    if(one Interval passed) then
        RPU($V_i$, $F_i$, true) and RPU($V_i$, $B_i$, false)
    endif
else
    reset the life time of element related to $ID_j$ in $F_i$ or $B_i$
endif
```

4.1.4. Vehicles Leaving Highways

If packets need to be forwarded to the front and the forwarder (vehicle) is trying to leave the highway, then this packet will go out of networks. To avoid this problem, a backup scheme is adopted to send the packet to another rear node. The following are the details of this scheme.

While vehicles make a right turn, two cases may occur: this vehicle is on a right-turn curve of the highway, or it is leaving the highway. In both cases, packets are both forwarded and sent to a rear neighbor. If the rear neighbor is also leaving the highway, this backup process continues for a certain number of times. Though this backup scheme can avoid routing packet out of the network, it still has some overhead while the vehicles are moving on a curve. Suppose the backup process is repeated *k* times, then the problem is how to choose a minimal *k*.

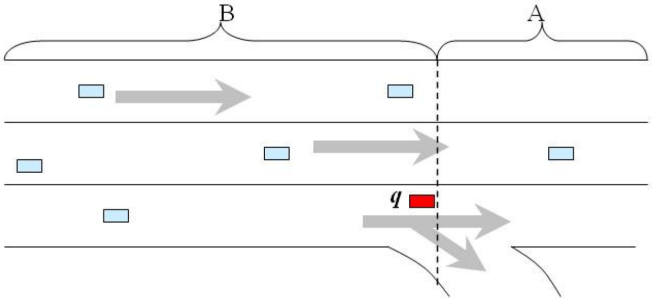

Figure 4. Vehicles moving nearby an exit of the highway

Suppose near the exit of a highway, as shown in Figure 4, there are *m* cars connected through wireless links and one of them (e.g. *q*) is located at the junction of the highway and exit. Then there will be $m + 1$ possible deployment of these nodes. For example, one is in the area *A* and $(m - 1)$ in the area *B*. If there are one or more nodes in the area *A*, then the packet will pass the exit successfully. The problem arises only if there is no vehicle in the area *A*, so the probability of this case will be $\frac{1}{(m+1)}$. Now suppose all *m* nodes are in area *B*, and then the probability of *k* continuous nodes leaving off the highway will be $\frac{1}{C_m^k}$. Therefore, we can obtain that after *k* times of backup, the probability of packet being routed out of the network is:

$$P_{out} = \frac{1}{m+1} \cdot \frac{1}{C_m^k} \cdot p^k \tag{2}$$

where *p* is the probability that the node leaves the highways and the largest value for it is 0.5. Now assume we are trying to forward a packet through a routing path with *n* exit junctions. Then the probability *p* of the last exit is 0.5, while the probability of the vehicle leaving at the first exit is $\frac{1}{(n+1)}$. Therefore, we can calculate the probability of the packet successfully reaching the destination as:

$$P_{suc} = \prod_{i=1}^{i=n} \left(1 - \frac{1}{m_i + 1} \cdot \frac{1}{C_{m_i}^k} \cdot \left(\frac{1}{i+1} \right)^k \right) \tag{3}$$

It should be noted that sometimes m_i might be smaller than k. In this case, the packet will be routed out of the networks. In fact, this failure is caused by a network partition, so it will not be considered in the performance of routing protocol. In most cases, m_i is larger than k, so the minimal value of P_{suc} can be obtained when m is equal to k. Now we have

$$P_{suc} > \prod_{i=1}^{i=n} \left(1 - \frac{1}{k+1} \cdot \left(\frac{1}{i+1} \right)^k \right) \tag{4}$$

Let k equals to 3, then the P_{suc} will be within [0.95, 0.96]. Although the value of P_{suc} increases as k increases, we believe the value of P_{suc} while k is 3 is already good enough for our network routing protocol. Therefore, we choose $k = 3$ in the implementation of our GPSFR protocol.

4.2. Routing Algorithm

4.2.1. Distance Advance

In GPSR [16], the current node n_i greedily selects one neighbor that is closet to the destination as the next hop. The implicit goal of such strategy is to maximize the distance advance and eventually minimize the total hop numbers. Let us denote such distance advance (ADV) of a neighbor n_j as

$$ADV_j = \begin{cases} \dfrac{d_{ij}}{r_i} & (if \;\; d_{ij} \le r_i) \\ 0 & (if \;\; d_{ij} > r_i) \end{cases} \tag{5}$$

where d_{ij} is the relative distance between node n_i and n_j. Whether n_j is behind or in front of n_i, the value d_{ij} is always larger than or equal to zero. Clearly, the conventional geographic routing protocols try to maximize ADV of the next hop.

4.2.2. Balanced Advance (BADV)

Balanced Advance (BADV) aims to avoid choosing an unstable node as the next hop while gaining as much distance advance as possible. The goal of BADV is to balance between large distance advance and good link stability.

$$BADV_j = \alpha \cdot ADV_j + (1-\alpha) \cdot e^{-\frac{\Delta v_{ij}}{d}} \; (if \, \Delta v_{ij} < 0, e^{-\frac{\Delta v_{ij}}{d}} = 1) \tag{6}$$

where $\Delta v_{ij} = v_j - v_i$ is the velocity difference between n_j and n_i, and d is the distance from n_j's current position to the edge of n_i's communication range. Therefore, suppose t_j is the time used by n_j to move out of n_i's range; then a longer t_j implies a more stable link between n_i and n_j. If Δv_{ij} is less than zero, it means node n_j is moving closer towards n_i. In this case, we consider the link stability as one because such link will become stronger until n_j move into the different neighbor group of n_i. Since the beacon period is only a few seconds, Δv_{ij} will not change much within such a short time. Thus, we can trust this value for at least one beacon period.

Although the concept of BADV is simple, it has many benefits in wireless vehicular networks. First, the data delivery ratio will be increased because of reliable transmission links. While only the distance advance is used, as in GPSR, the link to the selected next hop may suffer from a poor quality due to larger distance. Second, the hit rate of finding next hop's MAC address from the cache table will be increased, so the times of ARP request and reply will be decreased. Consequently, network delay can be reduced because of fewer retransmissions due to stable links. Third, fewer changes in the next hop will reduce channel switching overhead. For example, if [15] was adopted as the MAC protocol, then there will be a huge time slot allocation overhead due to the frequent next hop change. However, if the data is an emergency message, GPSFR will then use the maximal ADV policy by setting α as 1, because there is more benefit to choose the shortest path than a stable one.

In summary, the GPSFR protocol will select a next hop with the maximal BADV to forward normal packets. Besides, it will utilize the original greedy forwarding policy to transmit emergency messages. When packets are routed around a exit ramp, the packets will be backup three time to make sure they are not delivering out of the highway networks.

5. SIMULATIONS AND RESULTS

We use ns2 (ns2.29) to simulate and measure the networking performance of GPSFR. To compare the performance of GPFSR with the prior work for vehicle ad hoc networks, we choose the well-known GPSR [16] protocol. Since modeling of complex vehicle movement is important for accurately evaluating protocols, we generated the movement of nodes using VanetMobiSim [17] whose mobility patterns have been validated against TSIS-CORSIM, a well known and validated traffic generator. In simulation, we focus on the two-lane two-direction highway scenario with different node densities and velocities. Details of the simulation's parameters are list in Table 2.

Table 2. Parameters of simulation setups.

Parameter	Value
Number of nodes	100
Communication range	250m
Velocity	65-80 miles per hour
Packet size	1024 Bytes
Data sending rate	1-8 packets per second
Beacon interval	5.0 seconds
Alpha	0.7

The simulation time is 2000 seconds and each scenario is repeated 20 times to achieve a high confidence level. At each run, arbitrary vehicle pairs were selected as the source and destination. To evaluate the performance on different data transmission density, we vary the data sending rate from 1 to 8 packets per second. The performances metrics are link stability, data delivery ratio and data delivery delay.

5.1. Link Stability

The link stability between two nodes is measured by the number of times wireless link breakage occurs. As shown in Figure 5, GPSFR always generate less link breakage than that of GPSR [16]. Network density is defined as the average number of neighbors at each node. In dense networks, the number of link breakages in GPSFR is only 27% of that in GPSR. This is because the next hop selected by maximizing BADV will be more stable, resulting in fewer changes in the next hop. However, in sparse networks, GPSFR outperforms GPSR to a lesser degree. This is because in spare networks, the number of candidate nodes that can be chosen as the next hop is limited. So GPSFR may have no choice but to choose the same nodes as GPSR. However, it still suffers from fewer link breakages. In Figure 5, the percentage value denotes the probability of velocity change at each vehicle, which is used to model how dynamic the network is. As we can see, the frequent velocity change of vehicles does not affect the link stability of GPSFR too much.

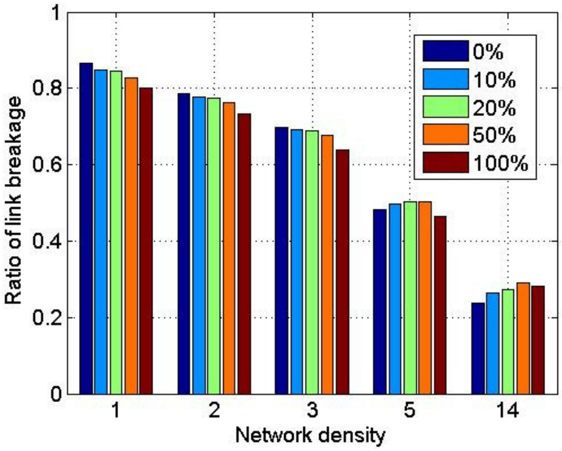

Figure 5. Percentage of next hop changes at various different network densities

5.2. Routing Path Length

Since BADV considers the trade-off between stability and distance advance, the length of routing path in GPSFR may be increased because of the slight reduction in distance advance at each hop. Figure 6 and 7 presents the histograms showing the extra routing hops of GPSFR compared to that of GPSR [16]. No matter how dense the network is, most of the routes in GPSFR have the same length as GPSR. In addition, the longer routes are mostly one or two hops more than that of GPSR. Therefore, to maximize BADV, we indeed increase the number of hops by just enough to ensure higher data delivery ratio and lower network delay. Figure 6 shows the scenario where all vehicles are in cruise control (no velocity change). In Figure 7, vehicles change their velocity all the time during the simulation. Note that no matter how dynamic the network, GPSFR always delivers large majority of packets along the path with the fewest number of hops.

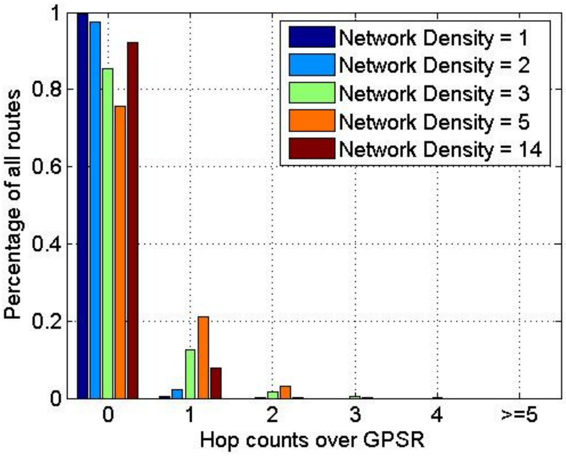

Figure 6. Path length beyond GPSR when there is no velocity change

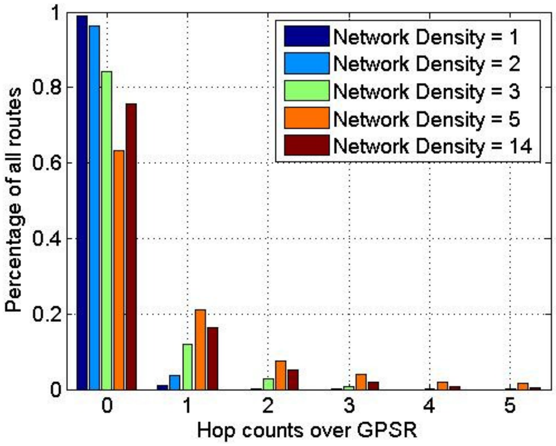

Figure 7. Path length beyond GPSR when velocity change probability is 100%

5.3. Data Delivery Ratio

Data delivery ratio is the number of packets received at the destination divided by the total number of packets sent into networks. GPSFR3 (GPSR3) denotes that the neighbor time-out period is 3 times the beacon period, while GPSFR (GPSR) means that the time-out period is equal to the beacon period. Geographic routing in VANET may suffer from the problem of out-of-date neighbors due to the high mobility of vehicles. One possible solution is to shorten the time-out period of neighbors. Since the neighbors' information is more accurate, higher delivery ratio can be achieved, as shown in Figure 8. At each hop, GPSR [16] always try to maximize the distance advance. However, the chosen one may be out of range after a short time, and this may cause packet loss. On the other hand, in GPSFR only those that still are in range after transmission will be considered as candidates. Therefore, the data delivery ratio of GPSFR is higher than that of GPSR.

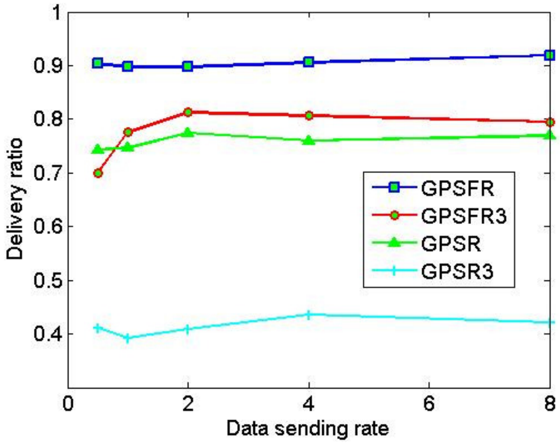

Figure 8. Data delivery ratio at various different data sending rate

5.4. End-to-End Delay

The end-to-end delay is defined as the average time taken for a packet to be transmitted from the source to the destination. Figure 9 shows that the delay of GPSFR is much lower than that of

GPSR [16]. This is because links selected by GPSR are not as stable as those in GPSFR. Thus link breakage happens more often in GPSR, requiring data retransmissions that increase delay. Another reason is that there is a smaller ARP delay in GPSFR. For example, if the chosen next hop is not a new one then the ARP request/reply process will not be required because the MAC information of receiver can be retrieved from the cache table. GPSFR prefers to use stable links, which means fewer changes in next hops. This reduces both the ARP delay and data transmission delay. We also note that shortening the time-out period does not help to reduce the delay because only successfully delivered packets are used for determining delay. Though shorter time-out period can increase the number of successfully delivered packets, it does not reduce the queuing, ARP and transmission delay.

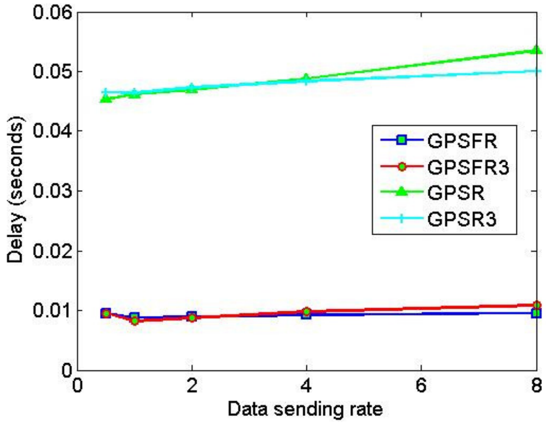

Figure 9. Network delays at various different data sending rate

5.5. Impact of Routing Distance

The data delivery ratio of GPSFR and GPSR [16] will decrease as route length increases, as shown in Figure 10. However, the delivery ratio of GPSFR is always higher than that of GPSR. For high and low density networks, the performance of both protocols is measured as the distance between the source and destination increases. For high and low density networks, the average distance between vehicles are 50m and 75m, respectively. In all cases, GPSFR has higher delivery ratio than GPSR. Note that GPSFR is also not as sensitive as GPSR to variation in network density.

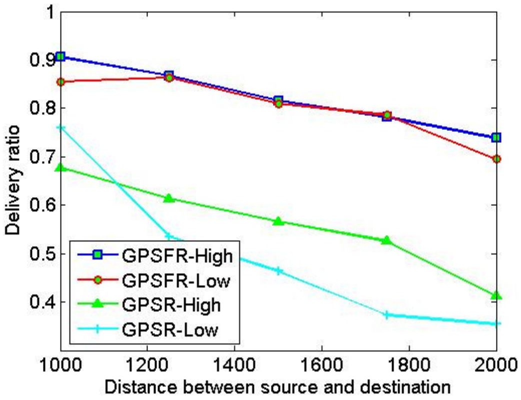

Figure 10. Data delivery ratio at various different routing path length

6. CONCLUSIONS

The GPS-Free Geographic Routing (GPSFR) algorithm uses relative positions and velocity to achieve higher packet delivery ratio, lower delay and smaller per-node routing state than GPSR [16], on densely and highly dynamic vehicular networks. Furthermore, it does not require nodes' positions. The BADV metric in this geographic routing ensures that only stable links are selected, resulting in a higher data delivery ratio and lower delay. Actually, the performance of GPSFR can be further improved if some nodes with GPS locations were added into the network.

Our future work is to design an enhanced protocol based on GPSFR to meet the communication requirement of vehicles in urban areas. While we have shown herein the benefits of GPSFR as a routing protocol for VANET, combining the GPSFR algorithm with a location database system will further reduce the overhead in using external geographic information for routing. An efficient distributed location service would enable the network to be more useful and powerful.

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