

Research Article

Hybrid Position-Based and DTN Forwarding for Vehicular Sensor Networks

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Received 30 January 2012; Accepted 24 March 2012

Academic Editor: Mo Li

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Efficient data delivery in vehicular sensor networks is still a challenging research issue. Position-based routing protocols have been proven to be more suitable for dynamic vehicular networks or large-scale mobile sensor networks than traditional ad hoc routing protocols. However, position-based routing assumes that intermediate nodes can always be found to set up an end-to-end connection between the source and the destination; otherwise, it suffers from network partitions which are very common in vehicular networks and leads to poor performances. This paper addresses data delivery challenge in the possible intermittently connected vehicular sensor networks by combining position-based forwarding strategy with store-carry-forward routing scheme from delay tolerant networks. The proposed routing method makes use of vehicle driving direction to determine whether holding or forwarding the packet. Experimental results show that the proposed mechanism outperforms existing position-based solutions in terms of packet delivery ratio.

1. Introduction

Vehicular sensor network (VSN) [1–3] is emerging as a new sensor network application for monitoring the physical world of urban environments, which is also a type of vehicular ad hoc network (VANET) [4]. VSN is a high-speed mobile wireless sensor network containing set of smart vehicles which are equipped with different types of on-board sensors and can communicate with each other or predeployed road side units via wireless medium. VSNs aim to provide ubiquitous, efficient sensing and networking capabilities for mobile users on the road and also support a variety of urban monitoring and safety applications such as cooperative traffic monitoring, control of traffic flows, blind crossing, prevention of collisions, detection of toxic chemicals, and road surface monitoring. To realize this objective, the Federal Communications Commission (FCC) has allocated 75 MHz of spectrum for short-range vehicle-to-vehicle (V2V) or vehicle-to-roadside communications. IEEE also formed the new IEEE 802.11p task group which adds wireless access in vehicular environments (WAVE) [5]. Because of the increasing popularity of mobile wireless

devices and smart vehicles, in the near future, VSNs will become one of the important components of the next generation of Internet and Internet of Things.

Different from traditional wireless sensor networks, VSN has its unique characteristics which pose new challenges in the design of networking protocols, especially for routing protocols. For example, as vehicles move at relevant high speeds, the topology of network is highly dynamic and the network topology may be even frequently disconnected. Vehicles rely on wireless links to relay data, and communication bandwidth is consequently limited and unstable [6, 7]. Last but not least, vehicles are typically not affected by strict energy constraints and can have powerful processing units and storages. Even though some of the existing ad hoc and sensor network routing protocols can still be applied to vehicular networks (both VSNs and VANETs), simulation results [8–11] have showed that they suffer from poor performances because of the fast movements of vehicles and limited chances for information exchanges. Therefore, finding and maintaining stable route is a very challenging task in vehicular networks.

Considering the highly dynamic nature of node mobility in vehicular networks, many different routing protocols (traditional topology-based ad hoc routing, cluster-based routing, or position-based routing) have been proposed for VANETs or VSNs in recent years [12]. However, most of them assume that intermediate nodes can always be found to set up an end-to-end connection between the source and the destination, which is not the case in many VSN environments. On the other hand, the system can tolerate up to seconds or minutes of delay in some VSN applications, for example, those to collect information of the available parking lots or the road surface conditions. Such applications can be supported by network protocols designed for delay-tolerant networks (DTNs) and enable the new research direction in the routing design for VSNs.

In this paper, by leveraging the DTN technology, we study hybrid forwarding schemes for efficient data delivery in VSNs. Specifically, when a vehicle reports a delay-tolerant data to a fixed sink in the network, we propose hybrid forwarding techniques to efficiently route the packet by combining position-based forwarding (such as GFG [13] and GPSR [14]) and the idea of store-carry-forward from DTNs [15–17] where the data can be incrementally moved and stored throughout the network. In our proposed method, when the packet enters perimeter mode, according to the driving direction of the vehicle and the delivery direction of the packet, the vehicle will determine to either hold or deliver this packet. Our simulation results show that this proposed method outperforms existing position-based solutions in VSNs.

The rest of this paper is organized as follows. Section 2 briefly reviews related work on VANET/VSN routing. Section 3 describes the principle idea of our proposed method, and Section 4 presents simulation results on comparison of proposed scheme with GPSR. Finally, Section 5 concludes the paper by discussing some possible future work.

2. Related Works

Because of high-speed vehicular mobility and unreliable channel conditions, data delivery and ensuring delivery is one of the key research issues to both vehicular ad hoc networks and vehicular sensor networks. Routing in vehicular networks has been studied recently, and many different VANET/VSN routing protocols have been proposed.

Node movements in vehicular networks are usually restricted in just bidirectional movements constrained along roads and streets. Thus it is reasonable to use geographical location information obtained from GPS devices on-board the vehicles to make routing decisions. This fact receives support from a number of studies that compare the performance of topology-based routing (such as AODV and DSR) against position-based routing strategies in urban as well as highway traffic scenarios [10, 18]. Therefore, position-based routing (geographic routing) has been identified as a more promising routing paradigm for vehicles. In position-based routing, forwarding decisions are made based on location information. For example, *greedy routing* always forwards the packet to the node that is geographically closest to

the destination. *Greedy-face-greedy* (GFG) [13] and *greedy perimeter stateless routing* (GPSR) [14] both combine the greedy forwarding with face routing by using face routing to get out of the local minimum where greedy forwarding fails. It works best in a free open-space scenario with evenly distributed nodes but suffers from various obstacles in city conditions. To fix such problems, several position-based routing protocols [19, 20] specifically designed for VANETs in city environments were proposed. For example, *greedy perimeter coordinator routing* (GPCR) [20] utilizes the fact that the nodes at a junction in the street follow a natural planar graph. Thus a restricted greedy algorithm can be followed as long as the nodes are in a street. Junctions are the only places where actual routing decisions are taken. Therefore, packets should always be forwarded to a node on a junction rather than being forwarded across the junction.

Most existing position-based or topology-based VANET/VSN routing protocols [10, 14, 18–22] assume that intermediate nodes can be found to set up an end-to-end connection; otherwise, the data packet will be dropped by the protocols. However, finding end-to-end connections sometimes is extremely difficult for a sparse vehicular network. On the other hand, the high mobility of vehicular networks introduces opportunities for mobile vehicles to connect with each other intermittently. There are ample opportunities for vehicles to set up a short path with few hops in a highway model, as shown in [9]. In addition, a moving vehicle can store and carry the packet when routes do not exist and forward the packet to the new receiver that moves into its vicinity. This *store-carry-forward* fashion enables a new type of routing protocols: *delay-tolerant network* (DTN) routing [23], which can deliver packets to the destination without an end-to-end connection for delay-tolerant applications. Recently, there are also new trends to enhance the traditional store-carry-forward DTN routing for VANET/VSN applications by considering the vehicular mobility or geographic characteristics of vehicular networks. LeBrun et al. [24] described several opportunistic forwarding schemes for VANETs where location or relative velocity of vehicles is used for relay selection. Zhao and Cao [25] also proposed a vehicle-assisted data delivery (VADD) protocol, which calculates the predictable vehicle mobility and takes it into consideration to choose the relay with the lowest data delivery delay. Lee et al. [2] proposed a proactive urban monitoring system which adopts an opportunistic diffusion scheme by exploiting vehicle mobility. Lee et al. [2] also proposed a DTN-based routing protocol for VSNs where each node delivers its packets to a neighboring node which is estimated as the best carrier based on a utility function of distances to the destinations and sizes of its packets. Leontiadis and Mascolo [26] proposed a DTN routing algorithm that exploits the availability of suggested route information from the navigation system in order to opportunistically route a packet to certain geographical location. Cheng et al. [27] also proposed a hybrid geographic and DTN routing, GeoDTN+Nav, which has three forwarding modes: greedy mode, perimeter mode, and DTN mode. The first two modes are the same with those in GPSR and can be switched to each other. In the perimeter mode, if the network is disconnected,

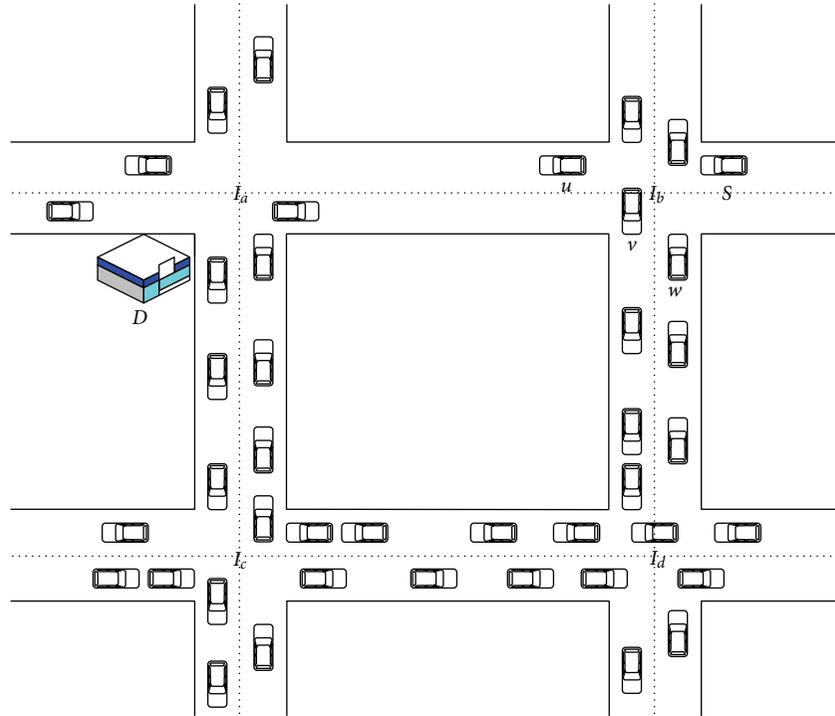


FIGURE 1: An example of routing problem in VSNs: vehicle S wants to send a packet to a fixed sink D at the parking deck.

GeoDTN+Nav switches to DTN mode where the packet is stored and carried. To determine when to switch to DTN mode, the protocol calculates a “switch score” (based on the hop count a packet has traveled, estimated delivery quality, and direction of neighbors) and compares with a predefined threshold. When current vehicle finds a vehicle closer to the destination, the packet switches from DTN mode to greedy mode.

Notice that our proposed hybrid protocol also exploits the combination of position-based routing and DTN routing as in [2, 24, 26, 27]. However, we take different approaches to consider the traffic, geographical location, and driving direction information.

3. Hybrid Position-Based and DTN Forwarding

In this section, we will present the details of our proposed hybrid position-based and DTN forwarding strategy which is combining GPSR protocol [14] with DTN routing.

3.1. Assumptions. Position-based routing protocol (such as GPSR) is usually used in well-connected networks, where the destination node is set in advance and it broadcasts its position information periodically to the whole network so that every node gets the position information of the destination. However, vehicular sensor networks sometimes are sparse and disconnected networks. In this paper, we assume that vehicles are equipped with an onboard navigation system loaded with digital maps and a GPS receiver, which provides the location service for the whole region.

Mobile vehicle can obtain its location, velocity, and direction through the GPS and the unique location information of any fixed site via the navigation system as well. In addition, vehicles can communicate with nearby vehicles through short-range wireless channel (100 m–250 m) and learn their location information through periodic beacon messages. We assume that the packets of sensing data are generated at mobile vehicles and the destinations are fixed sinks.

3.2. Motivation. Let us first consider an example shown in Figure 1, in which a vehicle S sends a packet of its sensing data to the fixed sink D at the corner of intersection I_a . According to the GPSR protocol, vehicle u will receive the packet (because u is S 's closest neighbor to D), but u cannot find a closer neighbor to D ; thus the packet enters *perimeter mode* at u . Based on the right-hand rule, u will deliver the packet to v and the packet will be relayed through a path $I_b \rightarrow I_d \rightarrow I_c \rightarrow I_a$ to the destination. In this situation, there are enough vehicles along these three segments so that packet can be delivered to the destination. However, when the segment between intersections I_c and I_d is blocked by either traffic lights or a sudden accident, the route may become disconnected and the packets need to be detoured to a longer route or even be dropped. On the other hand, vehicle u is driving towards the destination, even it currently does not have a nice relay node but it can carry the packet and may deliver it to destination by itself within much shorter time than the route of $I_b \rightarrow I_d \rightarrow I_c \rightarrow I_a$. Therefore, it will be nice to exploit such enhancement to GPSR by considering possible store-carry-forward options.

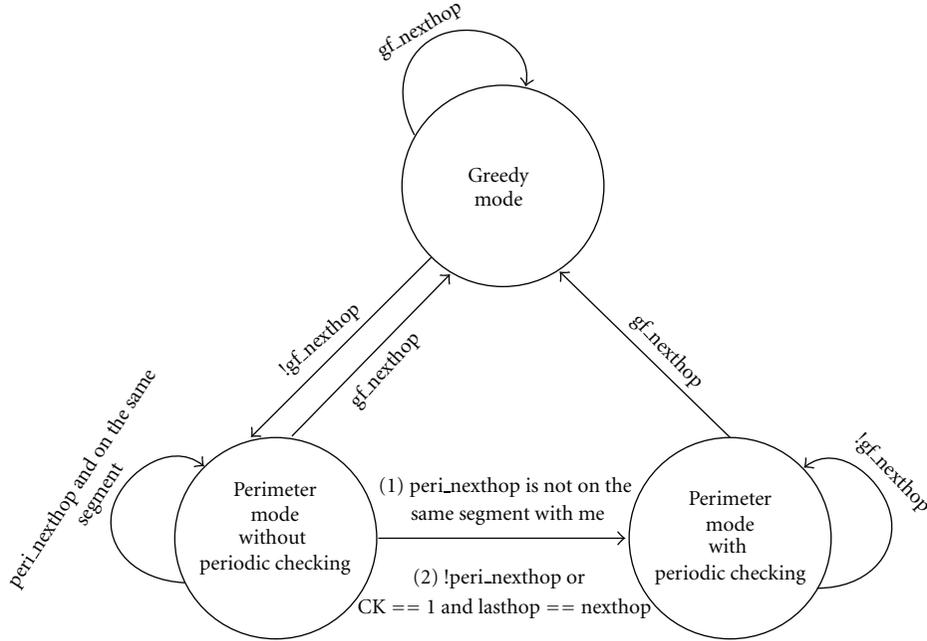


FIGURE 2: Transitions among the three possible statuses.

3.3. Detailed Hybrid Forwarding Mechanism for VSNs. Our proposed mechanism is based on a position-based routing, GPSR, and the idea of store-carry-forward from DTN routing. In sparsely connected vehicular sensor networks, when a vehicle finds no better neighbors to be the next hop to relay during geographic forwarding, it can store and carry the packet. The key issues are when and how to store and carry the packet and which next hop node to choose for relaying the packet. The basic idea of our approach is smartly switching between position-based forwarding and store-carry forwarding based on the current traffic situation and locations of neighboring vehicles.

In our design, there are three possible statuses: *greedy mode*, *perimeter mode* without periodic checking, and *perimeter mode* with periodic checking, as shown in Figure 2. Initially, all packets are in *greedy mode* at the source node. When a vehicle receives a packet and the destination is one of current neighbors, it immediately forwards the packet to the destination. Otherwise, it checks the current status of the packet.

When a vehicle receives a packet in *greedy mode*, it tries to forward the packet based on greedy forwarding. If it can find a better next hop ($gf_nexthop$) based on location, it forwards to $gf_nexthop$. Otherwise, it enters *perimeter mode* and needs to further determine whether to store a copy and send the packet or just hold the current packet.

When a vehicle receives a packet in *perimeter mode*, if it has a closer next hop ($gf_nexthop$), the packet switches back to *greedy mode* and is forwarded to $gf_nexthop$ based on greedy forwarding. Otherwise, the vehicle carries a copy of the packet and sends the packet to the next hop ($peri_nexthop$) selected by right-hand rule, if it exists. However, not all of the packets in the *perimeter mode* must

be carried. For example, in Figure 1, vehicle v finds its $peri_nexthop$ (w) on the $I_b \rightarrow I_d$ segment. No matter what the direction of $peri_nexthop$ (w) is, v can just send the packet to w and do not need to carry the packet. Here, we use the segment of $peri_nexthop$ to determine whether to carry the packet or not. If both the current vehicle and its next hop are on the same segment, there is no need to carry the packet any more.

When the packet is carried by a vehicle (happening in *perimeter mode*), the vehicle needs to check its neighbor list periodically to see whether there is a possible next hop towards the destination. If there is a closer neighbor, it can switch back to greedy forwarding immediately. To save the store space, each packet is held for at most $MAXCTTL$ time units. When the timer $CTTL$ expires, the packet will be discarded.

The detailed forwarding algorithm and periodic checking mechanism are given as Algorithms 1 and 2, respectively. Figure 2 illustrates the possible transitions among three statuses. Here, CK is used to remember whether a packet has been switched from *perimeter mode* with periodic checking to *greedy mode*.

3.4. Examples for Close Look. Next, we use examples shown in Figure 3 (a close look at the intersection I_b from Figure 1) to explain how our algorithm works on a sparse segment when current vehicle v and the next hop vehicle u are on the same direction or on reverse directions.

Same Direction Case. Figure 3(a) illustrates the example when vehicles u and v are driving in the same direction towards the destination. When vehicle u receives a packet from v , the packet enters *perimeter mode* and u will send it back to v . When v receives the packet again (but in

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1: when generate a new packet  $p$  of sensing data:
2:  $mode = greedy\_mode$  and  $CK = 0$ 
3: continue to Line 5
4: when receive a data packet  $p$ :
5: if the destination of  $p$  is a current neighbor then
6:   forward the packet  $p$  to the destination
7: else
8:   if the packet  $p$  in  $greedy\_mode$  then
9:     if  $gf\_nexthop$  is found then
10:       $CK = 0$ 
11:       $lasthop = my\_id$ 
12:       $nexthop = gf\_nexthop$ 
13:      send the packet  $p$  to  $nexthop$ 
14:     else
15:       $nexthop = peri\_nexthop$ 
16:       $mode = perimeter\_mode$ 
17:      if  $CK == 1$  and  $lasthop == nexthop$  or
18:       $peri\_nexthop$  is not found then
19:        continue to hold the packet  $p$ 
20:        enter the Periodic Checking
21:      else
22:         $CK = 0$ 
23:         $lasthop = my\_id$ 
24:        if  $nexthop$  is not on the same segment with  $me$ 
25:        then
26:          store a copy of the packet  $p$ 
27:          enter the Periodic Checking
28:        end if
29:        send the packet  $p$  to  $nexthop$ 
30:      end if
31:    else if the packet  $p$  in  $perimeter\_mode$  then
32:      if  $gf\_nexthop$  is found then
33:         $lasthop = my\_id$ 
34:         $nexthop = gf\_nexthop$ 
35:         $mode = greedy\_mode$ 
36:        send the packet  $p$  to  $nexthop$ 
37:      else
38:         $nexthop = peri\_nexthop$ 
39:        if  $peri\_nexthop$  is not found then
40:          continue to hold the packet  $p$ 
41:          enter the Periodic Checking
42:        else
43:           $lasthop = my\_id$ 
44:          if  $nexthop$  is not on the same segment with  $me$ 
45:          then
46:            store a copy of the packet  $p$ 
47:            enter the Periodic Checking
48:          end if
49:          send the packet  $p$  to  $nexthop$ 
50:        end if
51:      end if

```

ALGORITHM 1: Hybrid forwarding scheme.

```

1: Initialization:
2:  $CTTL = MAXCTTL$ 
   Periodic Checking: for any packet  $p$  carried
3:  $CK = 1$ 
4: if  $CTTL > 0$  then
5:    $CTTL --$ 
6:   if  $gf\_nextHop$  is found then
7:      $nextHop = gf\_nextHop$ 
8:     if  $nextHop$ 's direction is different with  $mine$ 
       and  $nextHop == lastHop$  and  $my\_angle <$ 
        $nextHop\_angle$  then
9:       continue to hold the packet
10:    else
11:       $mode = greedy\_mode$ 
12:      send the packet to  $nextHop$ 
13:    end if
14:  else
15:    continue to hold the packet
16:  end if
17: else
18:   delete the packet form the buffer
19: end if
20: Repeat Periodic Checking at the next checking interval

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ALGORITHM 2: Periodic checking.

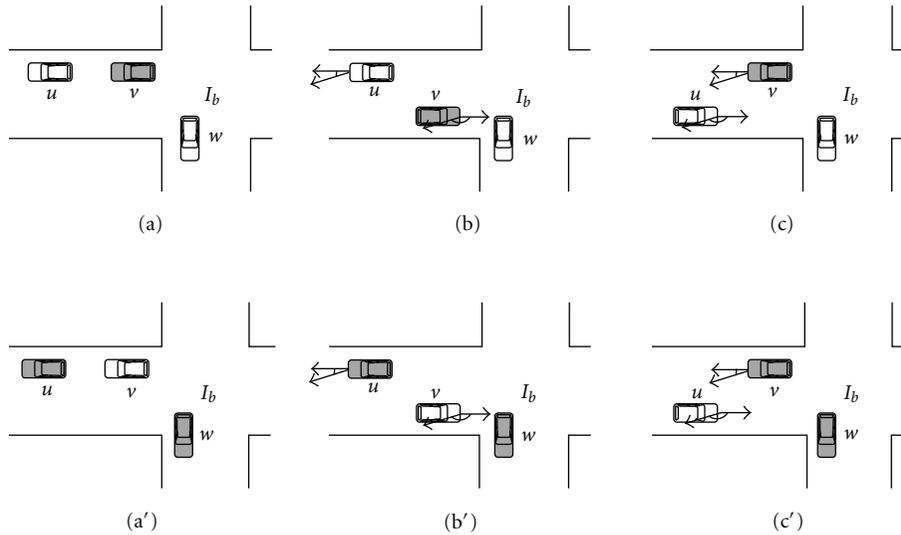


FIGURE 3: Examples of three different cases on the same segment: ((a) and (a')) u, v on the same direction; (b, b', c, and c') u, v on reverse directions. Here the shaded vehicles hold a copy of the packet.

perimeter mode), it finds vehicle w is the next hop and they are not on the same segment. According to Algorithm 1 (Line 43), v stores a copy of the packet and forwards the packet to w . Then the copy of the packet at v enters the periodic checking and marks the CK bit to 1. This means that the packet has experienced the periodic checking. v finds u is its best neighbor (Algorithm 2: Line 6) and they are driving in the same direction (Algorithm 2: Line 11), so v sends the copy to u again. When u receives the packet, it should hold this packet instead of sending it back (otherwise

causing a routing loop). Since the CK bit is 1 and $nextHop = lastHop$ (Algorithm 1: Line 17), u will only hold the packet. Therefore, there will be two copies of the original packet (w and u) as shown in Figure 3(a') which can explore both possible routes (DTN one and perimeter one).

Reverse Direction Case. In Figures 3(b) and 3(c), vehicles u and v are driving in opposite direction. Our proposed scheme will make use of the angle (i.e., my_angle), which is constituted by the vehicular driving direction and the destination's direction (as shown in Figures 3(b) and 3(c)), to

determine whether holding or forwarding the packet. Recall that in these examples the destination (i.e., the sink) is in the left-bottom corner of these figures. Like the previous example, when the packet reaches v again, v stores a copy and sends packet to w , then enters periodic checking. v will find u is its next hop which is closer to destination. As shown in Figure 3(b), the relationship between u and v ($my_angle > nexthop_angle$) does not satisfy Line 8 of Algorithm 2. Thus, v will send the packet to u again. The final result is same with the last example, as shown in Figure 3(b'). On the other hand, if u and v are driving as Figure 3(c) shows, since $nexthop = lasthop = u$ and $my_angle < nexthop_angle$, which satisfies Line 8 of Algorithm 2, v will continue holding the packet and driving towards the destination. Result is shown in Figure 3(c'). In both cases, the routing loop is prevented.

Notice that our proposed scheme can prevent certain types of routing loops. However, due to high mobility of nodes in vehicular sensor networks, it still possible that other types of loops occur during routing. It is very hard to ensure loop-free for vehicular routing.

4. Performance Evaluations

We evaluate the performance of our proposed protocol (GPSR-DTN) and compare it with GPSR and its variant via simulations conducted in NS-2 [28]. Since GPSR is not proposed for sparsely connected networks, to be fair, we extend GPSR by allowing that each node has buffers to hold packet. In this way, GPSR-B (GPSR with buffer) can be considered as combining a simple carry and forward protocol with GPSR but without any loop prevention. Notice that we do not compare our proposed protocol with any classical DTN routing in our simulations. However, [25] did provide some performance comparisons between GPSR-B and existing DTN routing solutions (such as epidemic routing [15]).

4.1. Simulation Environment. We implement the proposed routing scheme GPSR-DTN and GPSR-B in NS-2 [28] and use MOVE (mobility model generator for vehicular networks) [29] to generate realistic mobility model for VSNs. The street is designed in both directions, and traffic lights are deployed at each intersection. The distance between two adjacent traffic lights can have a significant effect on the network connectivity. Specifically, the network can be “fragmented” by the traffic lights when the radio transmission range is smaller than the distance between two adjacent clusters. In order to evaluate the proposed method, we test it in two types of network settings: *almost connected* and *intermittently connected*. In the intermittently one, the network is interrupted periodically because of the traffic lights. All networks are deployed in a 2052 m \times 2052 m square map. 100 vehicles are deployed to the street layout. Vehicles move between 0 and 20 m/s along the street. The communication range is set to 250 m, and the period of beacon message is 1 second. Ten vehicles are selected as data sources and keep sending sensing data with different intervals from 0.5 to 5 seconds. The destination of all data packets is

TABLE 1: Simulation setup.

Parameter	Value
Simulation area	2052 m \times 2052 m
Number of vehicles	100
Vehicle speed	0–20 m/s
communication range	250 m
Number of sources	10
MAC protocol	802.11
CBR rate	1 packet per 0.5–5 s
Vehicle beacon interval	1 s

a static sink at a predefined position. All experiment parameters are recorded in Table 1.

4.2. Simulation Metrics. In all experiments, we compare GPSR, GPSR-B (with buffer), and GPSR-DTN with the following routing metrics. If the destination receives multiple copies of the same packet, only the first arriving one counts towards statistics.

- (i) *Delivery ratio*: the average percentage of successfully delivered packets from the sources to the destination.
- (ii) *Average delay*: the average time duration of successfully delivered packets from the sources to the destination.
- (iii) *Average path length*: the average number of intermediate vehicles of successfully delivered packets passing through from the sources to the destination.
- (iv) *Number of packets*: the average number of copies of packets in the network at each second during the simulation.

4.3. Simulation Results. Figures 4 and 5 plot simulation results of our experiments for *almost connected* and *intermittently connected* scenarios, respectively.

As shown in Figures 4(a) and 5(a), GPSR has the lowest data delivery ratio; GPSR-DTN and GPSR-B have higher delivery ratio than GPSR does in both scenarios. This confirms that combining DTN routing strategies with position-based routing improves the chances of final delivery. Notice that GPSR-B may lead to more routing loops due to the lack of knowledge of moving directions; thus it has lower delivery ratio than GPSR-DTN. In GPSR-DTN, we carefully design the loop prevention mechanism based on the moving directions and whether two vehicles are on the same segment, so that the best vehicle is selected to hold or forward the packets. In addition, it is clear that all protocols have better performance under the almost connected scenario than under the intermittently connected scenario.

Figures 4(b) and 5(b) show the average delay of different protocols. It is obvious that all of three protocols have lower average delay for the almost connected scenario than for the intermittently connected scenario. Better connectivity provides better relay selection and thus leads to quicker transmissions. Both GPSR-DTN and GPSR-B usually have longer

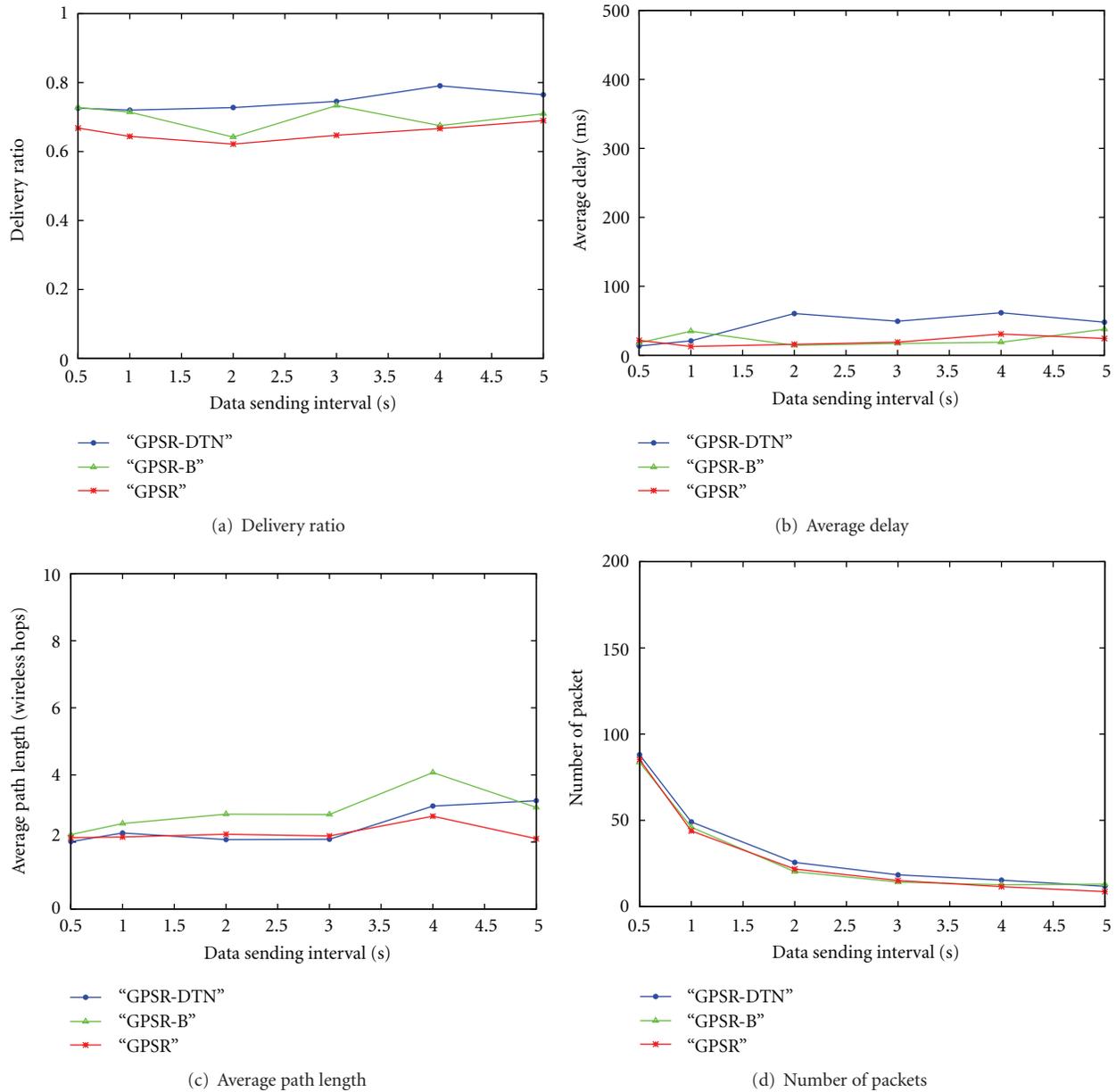


FIGURE 4: Simulation results for almost connected scenario.

delay than GPSR has, since they both apply store-carry-forward strategy which causes longer delay. For the same reason, the average path lengths of GPSR-DTN and GPSR-B are usually longer than those of GPSR, as shown in Figures 4(c) and 5(c). Note that GPSR-B has longer average path length than GPSR-DTN due to possible routing loops. Even though with longer delay and path length, GPSR-DTN/GPSR-B indeed improve the delivery ratio.

Finally, GPSR-DTN and GPSR-B will cause more packets in the network since both will create and hold new copies of the original packet. This can be verified by Figures 4(d) and 5(d). However, such increases are limited and acceptable as the cost of improvement of delivery ratios.

In summary, even though with longer delay and path length, the proposed GPSR-DTN indeed improves the delivery ratio, especially in intermittently connected networks.

5. Conclusion

Traffic lights, accidents, or low density may lead to intermittent connectivity very common in vehicular networks. While traditional position-based VANET/VSN routing protocols are not suitable for sparsely connected vehicular sensor networks, in this paper, we propose a new hybrid forwarding protocol which combines position-based forwarding with the idea of store-carry-forward from DTNs. In the proposed

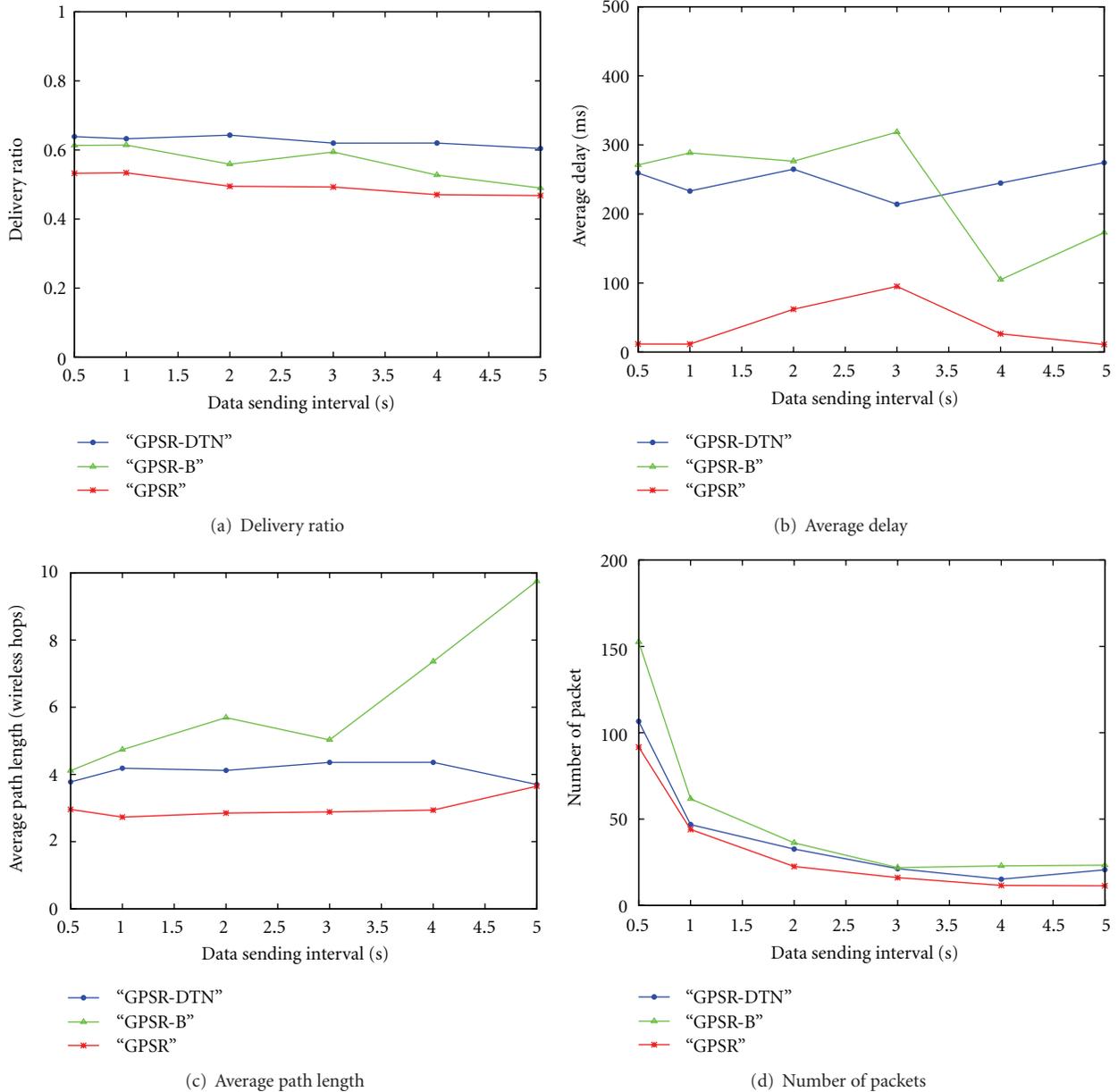


FIGURE 5: Simulation results for intermittently connected scenario.

method, driving directions of vehicles are used to make forwarding or carrying decisions, and a carefully designed loop prevention mechanism is also introduced. Experimental results show that the proposed hybrid method outperforms existing position-based solutions. In the future, we plan to test the proposed algorithm in more realistic scenarios (such as including transmission failures or unexpected vehicle mobility) and extend the proposed method to consider mobile destinations.

Acknowledgment

The work of F. Li is partially supported by the National Natural Science Foundation of China (NSFC) under Grant

60903151, the Beijing Natural Science Foundation under Grant 4122070 and SRF for ROCS, SEM. The work of X. Fan is supported in part by Projects of Major International (Regional) Joint Research Program from the NSFC under Grant 61120106010. The work of Y. Wang is supported in part by the US National Science Foundation under Grants CNS-0915331 and CNS-1050398.

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