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Improvement of GPSR Protocol in Vehicular Ad Hoc Network

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ABSTRACT In a vehicular ad hoc network (VANET), vehicles always move in high-speed which may cause the network topology changes frequently. This is challenging for routing protocols of VANET. Greedy Perimeter Stateless Routing (GPSR) is a representative routing protocol of VANET. However, when constructs routing path, GPSR selects the next hop node which is very easily out of the communication range in greedy forwarding, and builds the path with redundancy in perimeter forwarding. To solve the above-mentioned problems, we proposed Maxduration-Minangle GPSR (MM-GPSR) routing protocol in this paper. In greedy forwarding of MM-GPSR, by defining cumulative communication duration to represent the stability of neighbor nodes, the neighbor node with the maximum cumulative communication duration will be selected as the next hop node. In perimeter forwarding of MM-GPSR when greedy forwarding fails, the concept of minimum angle is introduced as the criterion of the optimal next hop node. By taking the position of neighbor nodes into account and calculating angles formed between neighbors and the destination node, the neighbor node with minimum angle will be selected as the next hop node. By using NS-2 and VanetMobiSim, simulations demonstrate that compared with GPSR, MM-GPSR has obvious improvements in reducing the packet loss rate, decreasing the end-to-end delay and increasing the throughput, and is more suitable for VANET.

INDEX TERMS Vehicular ad hoc network, routing protocols, GPSR, greedy forwarding, perimeter forwarding, NS-2.

I. INTRODUCTION

Vehicular Ad hoc Network (VANET) is an application of mobile ad hoc network in traffic. Compared with other mobile ad hoc network, just as cellular networks that needs to focus on reducing the consumption of both energy and resource of mobile devices [1], VANET has the advantages, such as sufficient node energy, strong computing and storage capability, equipped with navigation system and movement predictability, hence VANET is becoming more and more popular in the intelligent transportation system [2]. The vehicle nodes in the network move rapidly, with the network topology changing frequently. When a node forwards packets, it often happens that the routing path is broken or reconstructed, which seriously affects the overall communication performance of VANET. Thus, the research on VANET is crucial [3]. There have already been some achievements made in vehicular networks. Some solutions and systems were proposed and designed to resolve the defects of VANET [4], [5]. A CQS system in SIoVs was designed by focusing on a reliability assurance and service quality promotion [6]. A SAGA framework was proposed to provide high link connectivity and capacity [7].

Routing protocol is important for mobile networks. There have already been many studies on routing protocol. Some protocols were designed to provide higher QoS and save more energy [8]–[11]. The representative routing protocol is Ad hoc On-demand Distance Vector (AODV) protocol which includes route discovery and route maintenance. The source node broadcasts a routing request packet to the destination node in the network. After receiving the routing request packet, the intermediate node will forward the packet until the destination node receives the routing request, while the repeated request packets will be discarded. At the same time, AODV routing protocol also adds sequence numbers to request packet in order to prevent routing loops. However in the process of routing discovery, AODV broadcasts the routing request packet by means of flooding, and a lot of sending packets were eventually abandoned, the excessive management load leads to a large amount of energy being wasted. The network overload will be augmented with the scale of the magnified network. So AODV protocol is not suitable for large-scale vehicle networks [12], [13].

DSDV (Destination-Sequenced Distance-Vector Routing) is an active routing protocol [14]. For DSDV, each node saves routing information to all other nodes and updates information periodically. The mobile node monitors the movement of other nodes in the network. When the network topology changes, the nodes will periodically broadcast routing packets and send routing information to all other nodes in the network, whether the communication is need or not. In this way, each node can get the latest topology information. Since all nodes need to maintain routing paths to the other nodes, of which some are unnecessary, this protocol will consume a great amount of resources and energy to maintain the normal function. DSDV has some advantages, for example, each node finds the built path directly in its own routing table during packets transmission, so that network delay becomes small.

ZRP (Zone Routing Protocol) is a hybrid routing protocol [15]. This routing protocol contains two situations: within one zone and across multiple zones. Within one zone, it uses proactive routing mechanism to find a path and the protocol is called intra-zone protocol. Across multiple zones, the reactive routing mechanism, called inter-zone protocol, is used to find a path. ZRP has a disadvantage: ZRP requires excessive routing overhead in a large-scale vehicular Ad hoc network.

DREAM (Distance Routing Effect Algorithm of Mobility) is a flooding protocol [16]. Before forwarding data packets, the source node obtains the position information of the destination node firstly; and then determines the forwarding direction and forwarding zone of packets based on the positions of the source node and the destination node; finally, the source node sends packets to the forwarding zone. Each intermediate node repeats the same procedure until the destination node receives packets successfully. DREAM can ensure packets forwarding in the direction of the destination node, which reduces the number of unnecessary forwarding and improves the network performance. DREAM needs timely and accurate position information of nodes. When the speed of nodes is low and the nodes are close to each other, resulting in low the update frequency of the routing table and few requests of position information, so the network load is low. The routing protocol performs well under this circumstance. However, in vehicular Ad hoc network with large number of high speed nodes, the update frequencies of both node positions and routing tables are fast, which forms large number of position information requests, and further leads to network failures [17].

Routing protocols for VANET are new extensions of the protocols for mobile networks. GPSR is a representative geographic routing protocol of wireless networks. For GPSR, nodes obtain the position information through the positioning system and store the neighbor information in neighbor lists. The forwarding methods of the GPSR protocol include greedy forwarding and perimeter forwarding. The node broadcasts its own position information to its neighbor nodes periodically by GPSR. After receiving the information of the new neighbor, the node will update its neighbor list. In the process of transmitting packets, the node gets the position of the destination node through position service, and then builds a path by greedy forwarding and perimeter forwarding. GPSR does not need to maintain the routing table when transmitting packets, it has a good performance even if topology changes frequently, hence GPSR is more suitable for VANET [18], [19]. However, in a network which topology changes frequently due of nodes with high speed, for GPSR, the communication with neighbor nodes becomes extremely unstable, the next hop node selected by greedy forwarding may have moved out of the communication range before it receives the packets. Perimeter forwarding will be used to forward packets after greedy forwarding fails, quite possibly with redundancy in building routing paths [20], [21].

To overcome the drawbacks of GPSR mentioned above, there have been a lot of related improvements. In [22], by taking account of the influence of the neighbor number, data deliver rate, driving direction and positions between two-hops, the authors proposed the OinO strategy to make sure the worst result acceptable. In [23], the improvement was made on GPSR by estimating the future position of the participating nodes and using the estimated information to select adequate next hop node. In [24], based on street connectivity, a street-centric protocol was proposed to improve the delivery ratio and reduce end-to-end delay for urban VANET. In [25], by analyzing the endside-to-endside routing performance, SRPMT protocol along the streets for VANET was proposed to achieve higher data delivery rate and shorter average end-to-end delay. In [26], based on predictions for inter-vehicle encounters, the message forwarding metric is designed, to characterize the capability of a vehicle to successfully geocast the message. In [27], based on the mobility dynamics of the nodes and the forwarding patterns, the Adaptive Position Update strategy was proposed to improve the routing performance.

Aiming to solve the problems of GPSR on the instability of communication due of the changeable positions of nodes in greedy forwarding and the redundancy when building paths in perimeter forwarding, MM-GPSR is proposed based on maximum cumulative communication duration and minimum angle in this paper.

The remainder of this paper is organized as follows. Section II describes the problem of GPSR protocol. Section III provides the improved methods of GPSR.

Section IV presents the simulation and the experimental results analysis. Finally, Section V draws the conclusion.

II. PROBLEM DESCRIPTION

The forwarding methods of the GPSR protocol include greedy forwarding and perimeter forwarding, and GPSR need not store or maintain the routing tables. Before transmitting data packets by GPSR, each node needs to obtain the position information of both the neighbor node and the destination node by beacon broadcasting in advance, and then relies on the received position information to transmit data packets. Greedy forwarding is the core of the GPSR routing protocol. After the greedy forwarding fails, GPSR will use perimeter forwarding to forward data packets. The detailed process of GPSR: the source node invokes the greedy forwarding to find the nearest node to the destination node in the neighbor list and selects the nearest node as the next hop node to forward packets, after receiving packets, the next hop node repeatedly invokes the greedy forwarding to forward the packet and go on; when routing holes appear in greedy forwarding, this mid node will forward packets by perimeter forwarding. Greedy forwarding or perimeter forwarding is invoked until the data packets are sent to the destination node.

A. THE PROBLEM OF GREEDY FORWARDING

In greedy forwarding, GPSR always selects the node nearest to the destination node in the neighbor list as the next hop. However, the selected next hop node is usually at the edge of the communication range. The position of neighbor node is very easy to change because nodes move quickly, which means that the next hop node is very likely to move out of communication range of the current node before the packet have been received by the next hop node. As shown in Fig. 1, the current node is S, the destination node is D, the node B is nearest node to D in the neighbor node of S. The corresponding neighbor nodes after nodes moves: the positions of S', A', B' are after the movement; the positions of S, A, B are before movement. In greedy forwarding, S will select B as the next hop to forwarding packets. However, B has moved to the position of B' which is out of the communication range of S, making node B fail to receive packets. In detail, after the neighbor list of S is updated, B is no longer the neighbor node of S, but S has selected B as the next hop to forward packets, which leads to greedy forwarding failure and communication link broken, and finally resulting in packet retransmission or loss, which degrades the overall performance of the network.

B. THE PROBLEM OF PERIMETER FORWARDING

GPSR will turn into perimeter forwarding after greedy forwarding fails. Perimeter forwarding uses the *right-hand rule* to forward data packets, but there is redundancy in building routing paths. As the solid lines shown in Fig. 2, in the communication range of S, there is no neighbor node that has shorter distance to D than S. So the routing path is built as S→A→B→C→E→K→G by

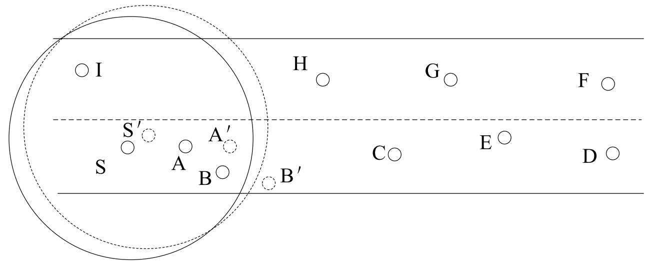


FIGURE 1. Unstable next hop node in greedy forwarding.

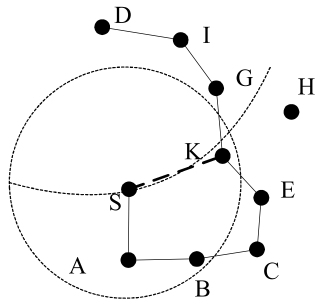


FIGURE 2. Redundant path and the best path in perimeter forwarding.

perimeter forwarding. G→I→D is built by greedy forwarding, because the distance from G to D is shorter than the distance from S to D. When the source node S selects the next hop node from the neighbor nodes, as indicated by the dashed lines in Fig. 2, it can be seen that K is preferable to be selected as the next hop, and the path will be S→K→G→I→D. By comparing the two links, it is found that the path redundancy exists in perimeter forwarding.

III. IMPROVED METHOD OF GPSR PROTOCOL

Aiming at solving the problems of neighbor relationship instability in greedy forwarding and path redundancy in perimeter forwarding in GPSR protocol, this paper proposes the following improvements.

A. THE IMPROVEMENT FOR THE INSTABILITY OF NEXT HOP IN GREEDY FORWARDING

The improved greedy forwarding deals with the instability of neighbor relationship by adding two parameters: the cumulative communication duration, named T, and the allowed communication area, named Q. As shown in Fig. 3, the small circle, such as S, A, B, K, C, represents the vehicle node. When S tries to send packets to D, S will find the nearest vehicle node to destination node from the neighbor vehicle nodes. The nearest node to the destination Fig. 3 is B. The maximum allowed hop distance is calculated based on the distance between B to D. By comparing the cumulative communication duration and evaluating the communication stability between all the neighbor vehicle nodes of S, the most stable next hop node is selected.

In Fig 3, S sends packets to D, the coordinates of S and D are set to (x_S, y_S) and (x_D, y_D) respectively. When transmitting packets in greedy forwarding, the source

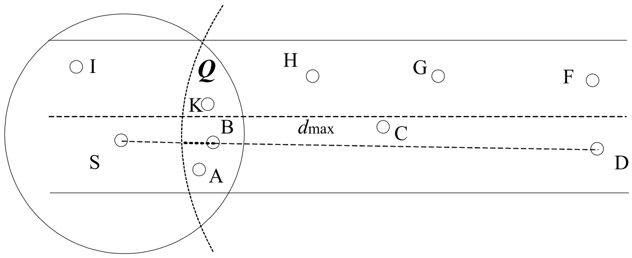


FIGURE 3. Improved greedy forwarding scene graph.

node S finds the nearest node to D in its own neighbor list, and the nearest node is B, with the coordinates of (x_B, y_B). The distance d_{BD} from B to D and d_{SB} from B to S are calculated respectively in (1), (2). The allowed communication distance $d_{\max}$ is calculated by (3). The overlapping area of two circles that one with D as center and $d_{\max}$ as radius, and the other with S as center and maximum communication distance as radius, is defined as the allowed communication area, and this allowed communication area is named as Q. Each node in Q is not only close to the destination node D but also within the communication range of node S, and is suitable to be selected as the next hop node of S.

$$d_{BD} = \sqrt{(x_D - x_B)^2 + (y_D - y_B)^2} \quad (1)$$

$$d_{SB} = \sqrt{(x_S - x_B)^2 + (y_S - y_B)^2} \quad (2)$$

$$d_{\max} = d_{BD} + \lambda \times d_{SB} \quad (3)$$

In (3), $\lambda \in [0, 1]$. Apparently, λ affects the size of Q. When λ is too large, Q will become larger, then the node near S is more easily selected as the next hop in Q, but the number of hops for this node to D may increase. When λ is too small, Q will become smaller, then the node near D is more easily selected as the next hop in Q, the distance from S to this node may go longer, and the link stability may become worse, causing the packet loss increase. By conducting several experiments, it has a decent performance in greedy forwarding when λ is set to 0.3.

In Fig. 3, Q contains A, B, K, and then the cumulative communication duration between three neighbor nodes and S, is calculated by (4).

$$T_i = T_{i-1} + t_i - t_{i-1} \quad (4)$$

In (4), T_i is current cumulative communication duration, T_{i-1} is last cumulative communication duration, t_i is the current time of receiving *hello*, t_{i-1} is the time of receiving the last *hello*. Here the initial conditions are set firstly, $T_1 = 0$ and t_1 is the moment of receiving the first *Hello* packet. By comparing T_i of A, B, K, the node with maximum T_i is steady to S and close to the destination, and will be selected as the next hop node of S. By following this method when forwarding packets, the probability of communication link broken is greatly reduced.

B. THE IMPROVEMENT FOR PATH REDUNDANCY IN PERIMETER FORWARDING

In order to resolve the path redundancy, the improved perimeter forwarding takes the positional relationship between the neighbor nodes and the destination node into account. As shown in Fig. 4, the neighbor nodes of S include A, B, and K. S will selects a next hop by using the *right hand rule* when greedy forwarding fails, which results in path redundancy. So our purpose is to find a next hop node which does not deviate from D. Draw a ray from S to D, and then draw rays from S to any neighbor node of S, each ray through neighbor node will form an angle with the ray through D, and this angle is named as θ. By analyzing and comparing the corresponding θ of all neighbor nodes of S, an optimal next hop of S will be selected.

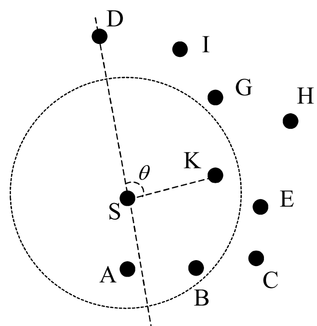


FIGURE 4. Improved perimeter forwarding scene graph.

In Fig. 4, the line that connects S and D divides the whole plane into two parts, the left half-plane and right half-plane. When forwarding packets in two part of the whole plane, the neighbor node with the smaller θ can build a shorter routing path with less redundancy. Neighbor nodes are randomly distributed on both the left half-plane and the right half-plane. The coordinate plane is introduced to analyze neighbor nodes. Based on the coordinates of each neighbor node, θ is calculated.

As shown in Fig. 5, when the neighbor node N is in the first quadrant, such as N1 with the coordinates of (x_{N1}, y_{N1}). Determined by SD and SN1 as the solid line indicating in Fig. 5, the θ_{right} is calculated by using (5), (6).

$$\cos\theta_{right} = \frac{y_{N1} - y_S}{\sqrt{(x_{N1} - x_S)^2 + (y_{N1} - y_S)^2}} \quad (5)$$

$$\theta_{right} = \arccos\left(\cos\theta_{right}\right) \quad (6)$$

When the neighbor node N is in the second quadrant, such as N2 with the coordinates of (x_{N2}, y_{N2}) shown in Fig. 5. Determined by SD and SN2 as the dashed line indicating in Fig. 5, the θ_{left} is calculated by using (7), (8).

$$\cos\theta_{left} = \frac{y_{N2} - y_S}{\sqrt{(x_S - x_{N2})^2 + (y_{N2} - y_S)^2}} \quad (7)$$

$$\theta_{left} = \arccos\left(\cos\theta_{left}\right) \quad (8)$$

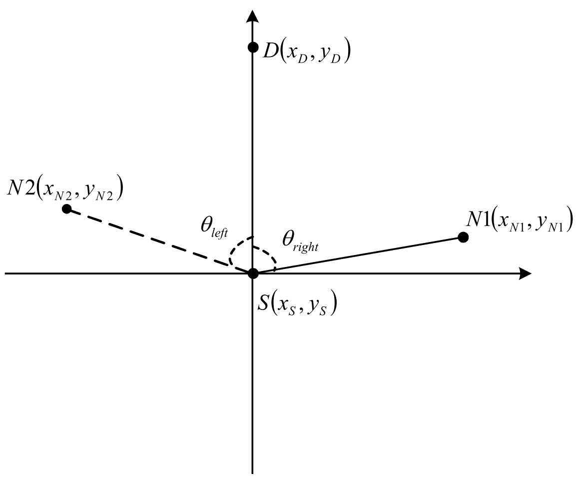


FIGURE 5. Neighbor node N is in the first or second quadrant.

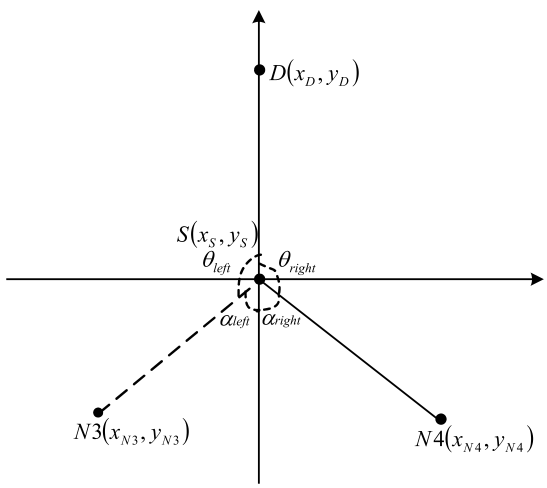


FIGURE 6. Neighbor node N is in the third or fourth quadrant.

As shown in Fig. 6, when the neighbor node N is in the third quadrant, such as N3 with the coordinates of (x_{N3}, y_{N3}). Determined by SD and SN3 as the dashed line indicating in Fig. 6, the θ_{left} is calculated by using (9), (10).

$$\cos\alpha_{left} = \frac{y_S - y_{N3}}{\sqrt{(x_S - x_{N3})^2 + (y_S - y_{N3})^2}} \tag{9}$$

$$\theta_{left} = \pi - \arccos\left(\cos\alpha_{left}\right) \tag{10}$$

When the neighbor node N is in the fourth quadrant, such as N4 with the coordinates of (x_{N4}, y_{N4}) shown in Fig. 6. Determined by SD and SN4 as the solid line indicating in Fig. 6, the θ_{right} is calculated by using (11), (12).

$$\cos\alpha_{right} = \frac{y_S - y_{N4}}{\sqrt{(x_{N4} - x_S)^2 + (y_S - y_{N4})^2}} \tag{11}$$

$$\theta_{right} = \pi - \arccos\left(\cos\alpha_{right}\right) \tag{12}$$

The minimum θ is determined by comparing all the neighbor nodes of S using (13).

$$\begin{cases} \theta = \theta_{left}, & when\ \theta_{left} \le \theta_{right}. \\ \theta = \theta_{right}, & when\ \theta_{left} > \theta_{right}. \end{cases} \tag{13}$$

In the improved perimeter forwarding, the neighbor node with minimum angle θ will be selected as the next hop node for S, which eliminates the path redundancy to a great extent.

C. THE IMPROVED MM-GPSR PROTOCOL

As described in sections III.A and III.B, by improving both greedy forwarding and perimeter forwarding of GPSR, this paper proposes Maxduration-Minangle GPSR (MM-GPSR) protocol. In greedy forwarding, the current node determines the allowed communication area firstly, and then calculates and compares the cumulative communication durations of neighbor nodes and finally selects the neighbor with maximum duration as the next hop. In perimeter forwarding when greedy forwarding fails, the current node calculates and compares the angles of corresponding neighbor nodes at first, and then selects the neighbor node with minimum angle as the next hop to forward packets. Algorithm 1 describes the procedure of MM-GPSR.

D. TIME COMPLEXITY ANALYSIS

As described in Algorithm 1, we assume that the number of nodes in set_C is n. When packet is forwarded using greedy forwarding at C, for GPSR, C needs to calculate and compare the distances of n nodes to find the neighbor node with the shortest distance as the next hop node. So for each node, the time complexity of greedy forwarding in GPSR is $O(n)$. For the whole network, the time complexity of greedy forwarding in GPSR is $O(n^2)$. For MM-GPSR in greedy forwarding, C needs to find the neighbor node with the shortest distance as GPSR in greedy forwarding, and then determines Q by calculating $d_{\max}$. We assume that the number of nodes in Q is m, obviously, $m \le n$. By calculating and comparing the current cumulative communication durations of m nodes in Q, C selects the neighbor node with the maximum cumulative communication duration as the next hop node to forward packet. So for each node, the time complexity of greedy forwarding in MM-GPSR is $O(n)$. For the whole network, the time complexity of greedy forwarding in MM-GPSR is $O(n^2)$ too.

Packets will be forwarded using perimeter forwarding at C when greedy forwarding fails. In perimeter forwarding of GPSR, a no-crossing network based on the RNG or GG needs to be constructed firstly, with the time complexity $O(n^2)$ for each node [18], then C selects next hop node in the no-crossing network by using *right-hand rule*. We assume that the number of nodes in this no-crossing network is k, obviously, $k \le n$. So for each node, the time complexity of perimeter forwarding in GPSR is $O(n^2)$. For the whole network, the time complexity of perimeter forwarding in GPSR is $O(n^3)$. As the same as GPSR, a no-crossing network also needs to be constructed for MM-GPSR in perimeter

Algorithm 1: Procedure for MM-GPSR

```
Initialization:
    neighbor ← NULL
    d_min ← d_{C→D}
    neighbor_min ← NULL
    T_max ← 0
    d_max ← 0
    node_next ← NULL
    θ_left ← π
    θ_right ← π
    λ ← 0.3
Note:
    C : Current node.
    p : Data packet.
    D : Destination node.
    set_C : Set of neighbor nodes of C.
    d_{neighbor→D} : The distance from neighbor to D.
    T_neighbor : The cumulative communication duration of
        neighbor.
    θ_neighbor : The corresponding angle of neighbor.
    plane_{right−half} : The right-half plane by connecting
        C and D.
    Q : The allowed communication area.
while (C receive p) do
  if C == D then
    Finish transmitting p ;
  else
    if C meet the greedy forwarding method then
      for each neighbor ∈ set_C do
        Calculate d_{neighbor→D} by (1);
        if d_{neighbor→D} < d_min then
          d_min ← d_{neighbor→D};
          neighbor_min ← neighbor;
        end if
      end for
      Calculate d_{C→neighbor_min} by (2);
      d_max ← d_min + λ × d_{C→neighbor_min};
      Determine Q;
      for each neighbor in Q do
        Calculate T_neighbor by (4);
        if T_neighbor > T_max then
          T_max ← T_neighbor;
          node_next ← neighbor;
        end if
      end for
      Update p and then forward p to node_next;
    else
      for each neighbor ∈ set_C do
        if neighbor in plane_{right−half} then
          Calculate θ_neighbor by (6) or (12);
          if θ_neighbor < θ_right then
            θ_right ← θ_neighbor;
            node_right ← neighbor;
          end if
        else
          Calculate θ_neighbor by (8) or (10);
          if θ_neighbor < θ_left then
            θ_left ← θ_neighbor;
            node_left ← neighbor;
          end if
        end if
      end for
      if θ_left ≤ θ_right then
        node_next ← node_left ;
      else
        node_next ← node_right ;
      end
      Update p and then forward p to node_next;
    end if
  end if
end while
```

forwarding at first. Then C selects the neighbor node with the minimum corresponding angle as the next hop node in this no-crossing network. So for the whole network, the time complexity of perimeter forwarding in MM-GPSR is $O(n^3)$ too. The time complexity comparison of GPSR and MM-GPSR is shown in TABLE 1.

TABLE 1. Time complexity comparison of GPSR and MM-GPSR.

	GPSR	MM-GPSR
Greedy forwarding	$O(n^2)$	$O(n^2)$
Perimeter forwarding	$O(n^3)$	$O(n^3)$

IV. SIMULATION AND RESULTS ANALYSIS

The simulation experiments were conducted on NS-2.29. Without available GPSR routing protocol in NS-2.29, so GPSR routing protocol was transplanted to NS-2.29 at first, and then the improved MM-GPSR routing protocol was added in NS-2.29 [28], [29]. NS-2.29 only provides the network simulation platform, IDM_LC model of VanetMobiSim was used to generate the tracefile as the simulation mobile scenario [30]. The simulation of GPSR and MM-GPSR was conducted with different numbers of nodes and different maximum node speeds.

The performance metrics used in the simulation experiments are as follows:

1) Packet loss rate: Packet loss rate metric represents the ratio of the sum of the lost packets to the total number of packets sent at the source node.

2) End-to-end delay: This metric represents the average end-to-end delay measured by the ratio of the sum of the transmission packet delays to the number of successfully received packets.

3) Throughput: This metric represents the average amount of data that is successfully transmitted over a unit of time throughout the network.

We simulated 30, 50, 70, 90, 110 vehicle nodes with the maximum node speed of 15m/s, and 50 vehicle nodes with maximum node speeds of 5, 10, 15, 20, 25 m/s. All other simulation parameters were set to constants as shown in TABLE 2.

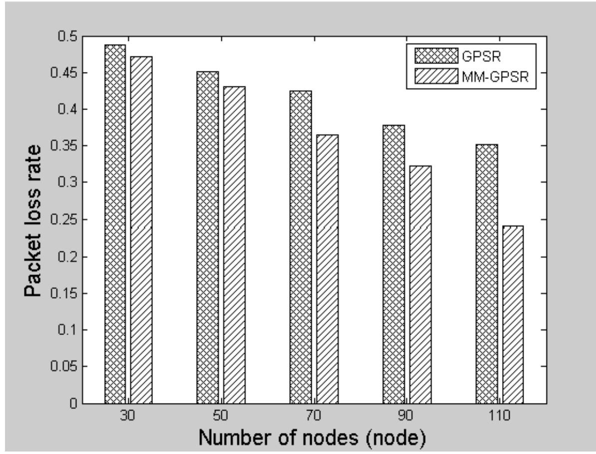
TABLE 2. Simulation parameters.

Description	Value	Unit
Simulation time	200	s
Network area size	1100×1100	m^2
Node transmission range	250	m
Data packet size	512	byte
Propagation model	Two-ray ground	-
MAC protocol	IEEE 802.11	-
Data packet type	CBR	-
Routing protocol	GPSR, MM-GPSR	-

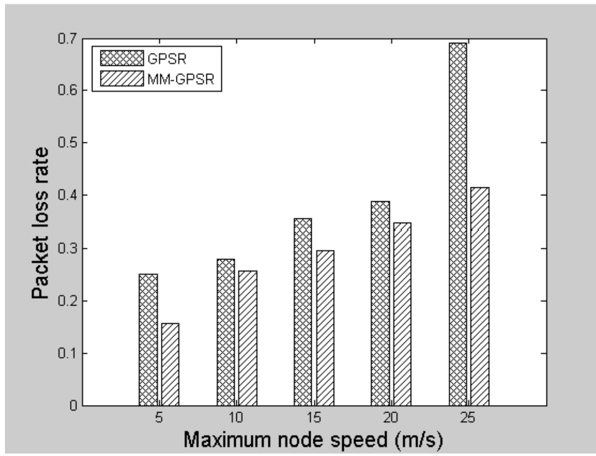
A. PACKET LOSS RATE

Fig. 7(a) shows the comparison of packet loss rate between GPSR and MM-GPSR with different number of nodes. It can be seen from Fig. 7(a) that the packet loss rate of both GPSR and MM-GPSR are decreasing with the increase of the number of nodes. When there are only a few nodes in mobile scenario, the distribution of nodes is relatively sparse, both GPSR and MM-GPSR are not easy to find the next hop forwarding node; when the number of nodes gradually increases, the distance between the nodes becomes short, resulting in significant decrease in packet loss rate. Compared with GPSR, MM-GPSR has the smaller packet loss rate in the whole process, and has better performance of avoiding communication interruption with more nodes. This is due to that MM-GPSR selects the neighbor node, which is more steady and not easy to move out of the communication range of the current node, as the next hop node when forwarding data packets, and the communication link is more reliable and robust; while GPSR selects the next hop node sometimes nearer to the communication range edge of current node, which makes the next hop node more likely to move out of the communication range, leading to the link failure and packet loss.

Fig. 7(b) shows the comparison of packet loss rate between GPSR and MM-GPSR with different maximum node speeds. As explained in Fig. 7(b), the packet loss rates of both GPSR and MM-GPSR are increasing as the node speed increases. The main reason is that the neighbor relationship is more unstable with the higher node speeds, and the link interruption is more likely to happen, thus the packet more tends to lose. Overall, MM-GPSR has lower packet loss rate than GPSR, because MM-GPSR takes the stability of neighbor relationship fully into account when transmitting packets, and the communication link is not easy to break, making the packet loss rate reduced. In particular, the packet loss rate of MM-GPSR is better than that of GPSR when the vehicle node speed is very high (25m/s).



(a)



(b)

FIGURE 7. Packet loss rate via (a) number of nodes, (b) maximum node speed.

B. END-TO-END DELAY

Fig. 8(a) shows the comparison of end-to-end delay between GPSR and MM-GPSR with different number of nodes. It can be found from Fig. 8(a) that when the number of nodes is small, the neighbor nodes of each node are less and the neighbor relationship is unstable and unreliable. When packets are transmitted, the perimeter forwarding needs to be started more frequently, generating more path redundancy and longer end-to-end delay; as the number of nodes increases, the stability of the neighbor relationship between the nodes increases, and the communication link is more steady and robust, so the end-to-end delay is reduced. On the whole, the end-to-end delay of MM-GPSR is shorter than that of GPSR, this is because MM-GPSR chooses the more stable neighbor node as the next hop node which reduces both the startup probability of the perimeter forwarding and the path redundancy effectively when forwarding packets.

Fig. 8(b) shows the end-to-end delay of GPSR and MM-GPSR for the different maximum speed of the vehicle nodes. Fig. 8(b) shows that when the speed of the vehicle nodes is slow, the end-to-end delays of GPSR and MM-GPSR are relatively small; as the node moves faster, the delays of both GPSR and MM-GPSR are increasing, this is because that the position information changes more frequently in condition of higher maximum node speed, making the end-to-end delay increase. Overall, the end-to-end delay of MM-GPSR is lower than that of GPSR, this is due to that MM-GPSR chooses the forwarding node with more stable neighbor relationship and builds a more robust path.

C. THROUGHPUT

Fig. 9(a) shows the throughput of GPSR and MM-GPSR under the different number of nodes. As shown in Fig. 9(a), the throughput of both GPSR and MM-GPSR increases with the increase of the number of nodes, this is due to that the communication load capacity of the network is gradually enhanced with more nodes participating in forwarding packets. In general, the throughput of MM-GPSR is larger than

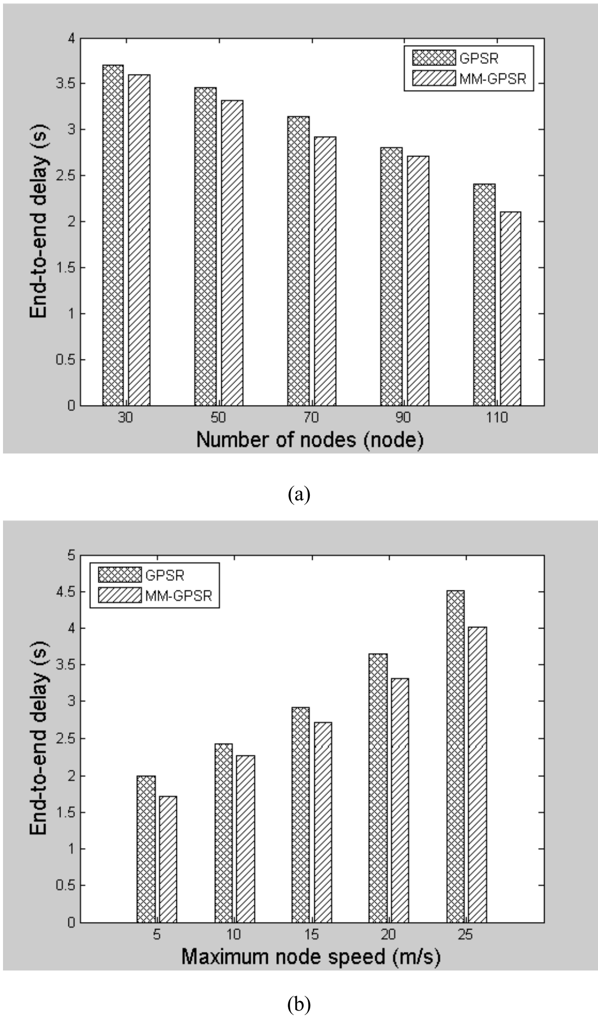


FIGURE 8. **End-to-end delay via (a) number of nodes, (b) maximum node speed.**

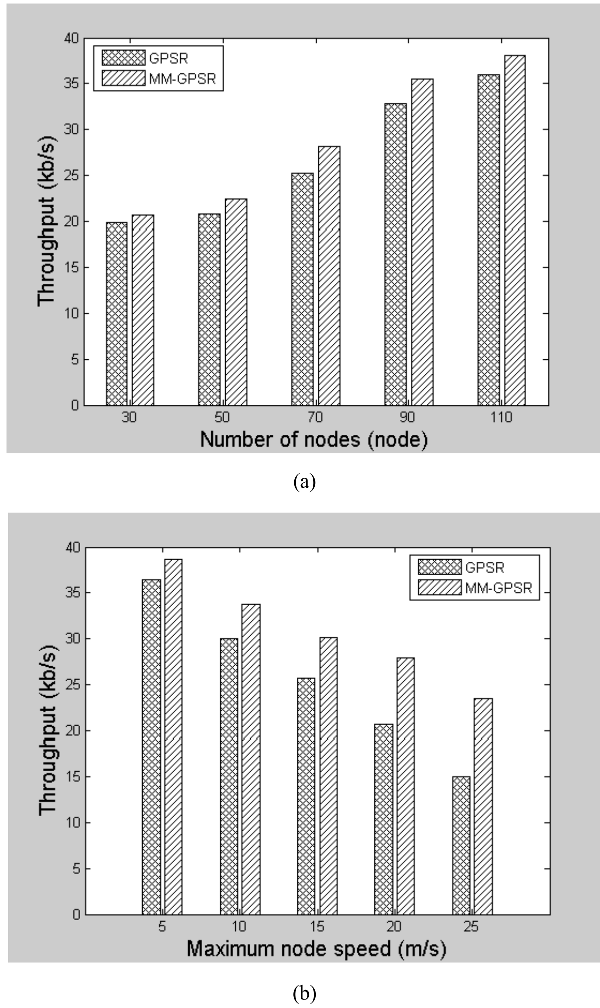


FIGURE 9. **Throughput via (a) number of nodes, (b) maximum node speed.**

that of GPSR, mainly because MM-GPSR builds more robust and reasonable link which improves the communication performance and makes the network throughput increase.

Fig. 9(b) shows the throughput of GPSR and MM-GPSR in cases of the different maximum node speeds. It can be found in Fig. 9(b) that the throughput of GPSR and MM-GPSR decrease with the increase of node speed. This is because that the communication links are easy to break and the load capacity of the network is weakened when the node speed is gradually getting higher. On the whole, the throughput of MM-GPSR is larger than that of GPSR, this is due to that MM-GPSR selects the next hop node with more stable neighbor relationship and can build the more robust path than GPSR.

From the simulation and result analysis of this section, it can be seen that MM-GPSR performs better than GPSR in the packet loss rate, end-to-end delay and the throughput under the different number of nodes and maximum node speed. Especially in larger number of nodes and higher node speed, MM-GPSR has notable performance improvement.

V. CONCLUSION

In VANET, nodes move quickly, and the topology changes frequently, so the design of routing is challenging. In this paper, we have made a deep study on GPSR which is more suitable in VANET compared with other protocols such as AODV. By discovering and considering the neighbor instability in greedy forwarding and the path redundancy in perimeter forwarding of GPSR, we have proposed MM-GPSR routing protocol based on GPSR. The main contributions of this paper can be summarized as follows:

1) In greedy forwarding, we introduce the allowed communication area and cumulative communication duration. By comparing the cumulative duration of neighbor nodes in allowed communication area, the neighbor nodes with maximum duration will be selected as the next hop. This novel method can build steady path and avoid the reconstruction of routing effectively.
2) In perimeter forwarding when greedy forwarding fails, we introduce the minimum angle. By comparing the angles of neighbor nodes, the neighbor node with

minimum angle will be selected as the next hop. This improved method can reduce the path redundancy and build shorter path so that can save the network resources and decrease the network delay.

3) According to the time complexity analysis, compared with GPSR, MM-GPSR does not add the time complexity.

Finally, experiments show that the proposed MM-GPSR has a better performance than GPSR, and verify the superiority of MM-GPSR.

REFERENCES

[1] J. Zhang *et al.*, "Energy-latency trade-off for energy-aware offloading in mobile edge computing networks," *IEEE Internet Things J.*, to be published, doi: 10.1109/JIOT.2017.2786343.

[2] S. Biswas, R. Tatchikou, and F. Dion, "Vehicle-to-vehicle wireless communication protocols for enhancing highway traffic safety," *IEEE Commun. Mag.*, vol. 44, no. 1, pp. 74–82, Jan. 2006.

[3] S. Yousefi, M. S. Mousavi, and M. Fathy, "Vehicular ad hoc networks (VANETs): Challenges and perspectives," in *Proc. 6th Int. Conf. ITS Telecommun.*, Chengdu, China, Jun. 2006, pp. 761–766.

[4] Z. Ning, F. Xia, N. Ullah, X. Kong, and X. Hu, "Vehicular social networks: Enabling smart mobility," *IEEE Commun. Mag.*, vol. 55, no. 5, pp. 49–55, May 2017.

[5] X. Hu, T. H. S. Chu, V. C. M. Leung, E. C.-H. Ngai, P. Kruchten, and H. C. B. Chan, "A survey on mobile social networks: Applications, platforms, system architectures, and future research directions," *IEEE Commun. Surveys Tuts.*, vol. 17, no. 3, pp. 1557–1581, 3rd Quart., 2015.

[6] Z. Ning *et al.*, "A cooperative quality-aware service access system for social Internet of vehicles," *IEEE Internet Things J.*, to be published, doi: 10.1109/JIOT.2017.2764259.

[7] Z. Ning, X. Wang, X. Kong, and W. Hou, "A social-aware group formation framework for information diffusion in narrowband Internet of Things," *IEEE Internet Things J.*, vol. 5, no. 3, pp. 1527–1538, Jun. 2018.

[8] K. Cengiz and T. Dag, "Energy aware multi-hop routing protocol for WSNs," *IEEE Access*, vol. 6, pp. 2622–2633, 2017.

[9] T. Abdelkader, K. Naik, A. Nayak, N. Goel, and V. Srivastava, "A performance comparison of delay-tolerant network routing protocols," *IEEE Netw.*, vol. 30, no. 2, pp. 46–53, Mar./Apr. 2016.

[10] A. Al-Saadi, R. Setchi, Y. Hicks, and S. M. Allen, "Routing protocol for heterogeneous wireless mesh networks," *IEEE Trans. Veh. Technol.*, vol. 65, no. 12, pp. 9773–9786, Dec. 2016.

[11] H. Zhang, X. Wang, P. Memarmoshrefi, and D. Hogrefe, "A survey of ant colony optimization based routing protocols for mobile ad hoc networks," *IEEE Access*, vol. 5, pp. 24139–24161, 2017.

[12] C. E. Perkins and E. M. Royer, "Ad-hoc on-demand distance vector routing," in *Proc. 2nd IEEE Workshop Mobile Comput. Syst. Appl. (WMCSA)*, New Orleans, LA, USA, Feb. 1999, pp. 94–95.

[13] R. Bala and C. R. Krishna, "Scenario based performance analysis of AODV and GPSR routing protocols in a VANET," in *Proc. IEEE Int. Conf. Comput. Intell. Commun. Technol. (CICT)*, Ghaziabad, India, Feb. 2015, pp. 432–437.

[14] C. F. Xing, L. Yang, and Q. L. Han, "Development of a new routing protocol based on GPSR for wireless sensor networks," *Appl. Mech. Mater.*, vol. 644, pp. 2973–2977, Sep. 2014.

[15] N. Ramakrishnaiah, P. C. Reddy, and K. Sahadevaiah, "Performance analysis of dynamic addressing scheme with DSR, DSDV and ZRP routing protocols in wireless ad hoc networks," in *Proc. 1st Int. Conf. Inf. Commun. Technol. Intell. Syst.*, vol. 1, Jul. 2016, pp. 41–50.

[16] S. Basagni, I. Chlamtac, V. R. Syrotiuk, and B. A. Woodward, "A distance routing effect algorithm for mobility (DREAM)," in *Proc. 4th Annu. ACM/IEEE Int. Conf. Mobile Comput. Netw.*, Dallas, TX, USA, Oct. 1998, pp. 76–84.

[17] G. Gokilavani, K. Sathyapriya, S. S. Suganya, and K. Hemalatha, "Designing mobility using distance routing effect algorithm," *Int. J. Eng. Sci. Res. Technol.*, vol. 3, pp. 647–655, Feb. 2014.

[18] B. Karp and H. T. Kung, "GPSR: Greedy perimeter stateless routing for wireless networks," in *Proc. 6th Annu. Int. Conf. Mobile Comput. New.*, Boston, MA, USA, Aug. 2000, pp. 243–254.

[19] A. Setiabudi, A. A. Pratiwi, Ardiansyah, D. Perdana, and R. F. Sari, "Performance comparison of GPSR and ZRP routing protocols in VANET environment," in *Proc. IEEE Region 10 Symp. (TENSYMP)*, Bali, Indonesia, May 2016, pp. 42–47.

[20] Z. Cui, D. Li, G. Zhang, C. Guo, and Y. Sheng, "The next-hop node selection based GPSR in vehicular ad hoc networks," *J. Comput. Commun.*, vol. 4, pp. 44–56, Aug. 2016.

[21] R. Alsaqour *et al.*, "Dynamic packet beaconing for GPSR mobile ad hoc position-based routing protocol using fuzzy logic," *J. Netw. Comput. Appl.*, vol. 47, pp. 32–46, Jan. 2015.

[22] J. Li, P. Wang, and C. Wang, "Comprehensive GPSR routing in VANET communications with adaptive beacon interval," in *Proc. IEEE Int. Conf. Intenet Things (iThings) IEEE Green Comput. Commun. (GreenCom) IEEE Cyber, Phys. Social Comput. (CPSCom) IEEE Smart Data (SmartData)*, Chengdu, China, Dec. 2016, pp. 1–6.

[23] Z. S. Houssaini, I. Zaimi, M. Oumsis, and S. El Alaoui Ouatik, "Improvement of GPSR protocol by using future position estimation of participating nodes in vehicular ad-hoc Networks," in *Proc. Int. Conf. Wireless Netw. Mobile Commun. (WINCOM)*, Fez, Morocco, Oct. 2016, pp. 87–94.

[24] Q. Ding, B. Sun, and X. Zhang, "A traffic-light-aware routing protocol based on street connectivity for urban vehicular ad hoc networks," *IEEE Commun. Lett.*, vol. 20, no. 8, pp. 1635–1638, Aug. 2016.

[25] X. M. Zhang, K. H. Chen, X. L. Cao, and D. K. Sung, "A street-centric routing protocol based on microtopology in vehicular ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 65, no. 7, pp. 5680–5694, Jul. 2016.

[26] R. Jiang, Y. Zhu, T. He, Y. Liu, and L. M. Ni, "Exploiting trajectory-based coverage for geocast in vehicular networks," *IEEE Trans. Parallel Distrib. Syst.*, vol. 25, no. 12, pp. 3177–3189, Dec. 2014.

[27] Q. Chen, S. S. Kanhere, and M. Hassan, "Adaptive position update for geographic routing in mobile ad hoc networks," *IEEE Trans. Mobile Comput.*, vol. 12, no. 3, pp. 489–501, Mar. 2013.

[28] J. Chung and M. Claypool. (2002). *NS by Example*. [Online]. Available: http://nile.wpi.edu/NS

[29] K. Fall and K. Varadhan. (2007). *The Network simulator (NS-2)*. [Online]. Available: http://www.isi.edu/nsnam/ns

[30] J. Härri *et al.*, "Vehicular mobility simulation with VanetMobiSim," *Simulation*, vol. 87, pp. 275–300, Apr. 2011.

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