GLCV: A Routing Scheme Based on Geographic Link Connectivity Management for Urban Vehicular Environments

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Abstract. Vehicular Ad Hoc Networks (VANETs) is an important part of Intelligent Transport System (ITS). As a special kind of mobile ad hoc networks (MANETs), VANETs supports dynamic inter-vehicle communications. However, the high mobility of vehicular nodes results in a highly dynamic network topology and the network fragmentations. All these bring a great challenge to routing in VANETs. In this paper, we propose a new VANETs routing scheme called GLCV (Geographic-based Link Connectivity for Vehicular Networks), based on Geographic Link Connectivity management, to overcome the frequent failures of links. Combined with a digital city map, GLCV manages the geographic location information of nodes and the connectivity of links. GLCV selects the shortest connected path to forward the packet by calculating the length and the connectivity of links. Simulation results have shown that GLCV offers stable end-to-end communications, and outperforms existing typical VANETs routing scheme in urban environment, especially in terms of packet delivery rate and average hops. Thus GLCV achieves a lower delay and jitter and a higher throughput.

Keywords: VANETs · Routing scheme · GLCV

1 Introduction

With the development of Intelligent Transportation System, Vehicular Ad Hoc Networks (VANETs) is proposed to build a safer transport system [1]. Obviously, VANETs will play a vital role in the future transportation network. Given the current limited spectrum resources, various governments have invested a lot

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of resources and technologies in car networking. In America, the U.S. Federal Communications Commission has allocated the specific spectrum for Dedicated Short Range Communication(DSRC) exclusively to realize reliable vehicle to vehicle (V2V) and vehicle to roadside infrastructure (V2I) communications [2,3]. Similarly, the European Conference of Postal and Telecommunications Administrations (CEPT) has allocated a 50 MHz bandwidth dedicated to VANETs communications.

VANETs special characteristics, such as high node mobility, network fragmentation, and diverse quality of service requirement of potential applications, result in significant challenges in the design of an efficient routing protocol. In urban environments, finding and maintaining routes is a much more challenging task. Its significant to select a stable link of high connectivity in V2V and V2I communications [6]. The Greedy Perimeter Stateless Routing (GPSR) [11] is one of the best known position-based routing protocols. In this protocol, each node in the network maintains a neighboring table to execute greedy forwarding. When greedy forwarding strategy fails, GPSR uses the right-hand rule to find a perimeter. Moreover, because direct communications between nodes may be blocked by obstacles, GPSR is often restricted at the intersections in a city scenario. The work [4] proposed a Software-Defined-Networking-based geographic routing protocol for VANETs. In this protocol, the controllers gathered basic information of vehicles and provided a global view to compute the optimal routing paths. While Jin *et al.* [5] have proposed a geographic routing protocol for cognitive radio mobile ad hoc networks, which provides three routing modes for this protocol. Oubbati [8] presented a new routing protocol, called Intelligent Routing protocol using real time Traffic Information in urban Vehicular environment (IRTIV). IRTIV aims to find the most connected and the shortest path by using its proposed calculation formula of connectivity and the Dijkstra Algorithm.

By analyzing the characteristics of VANETs, we propose a new routing algorithm, Geographic-based Link Connectivity for Vehicular Networks(GLCV). GLCV takes the length and the connectivity of links into account when determining a routing path. With the help of a digital map, vehicle nodes simplify the dynamic network topology as an undirected graph. Nodes dynamically maintain connected links and the connectivity of links in this graph. After path planning, GLCV uses an improved greedy forwarding strategy to pass the packet between adjacent intersections. The proposed scheme is applied to V2V scenarios or Vehicle to Infrastructure to Vehicle (V2I2V) scenarios. In terms of key indicators, such as routing success ratio, average number of hops, and transmission delay, GLCV has better performance than some other routing schemes. The rest of this paper is organized as follows: In Sect. 2, we discuss the system model, and we will detail the design process and the new routing algorithm in Sect. 3. In Sect. 4, we evaluate the simulations and performance of our proposed protocol. In Sect. 5, we present concluding remarks.

2 System Model

In this section, we present the system model of our proposed routing scheme for urban environments. Based on these prerequisites, we managed to propose a reasonable and efficient routing scheme based on link connectivity management. We defined the connectivity as the maximum interval between adjacent nodes is no more than r(radio range). In the proposed scheme, we assume that every node is equipped with a GPS device, and vehicle sensors can provide measurements of vehicle velocity and direction. Moreover, an open geographic information system is required, e.g. Google Map, which is used to locate junctions and obtain geographic location information (coordinate, road length, density, etc.).

The work [7] has proved that, the frame-success-ratio is greater than 0.9 when the maximum radio range of a vehicle node is 400 m on the One-dimensional road scenario. Commonly, the width of a lane is about 3.5 m, which is much far smaller than the maximum radio range. In this case, the road width has almost no influence on wireless transmission and routing strategy. Therefore, we regard the road as one-dimensional model. As we known, the Manhattan Grid Model, an urban road scenario, is a widely used urban road model in VANETs. We adopt this model to describe the urban road scene in our proposed routing scheme. Every road segment is a line segment according to the above one-dimensional model. We use an undirected graph $G < V, E >$ to depict the Manhattan Grid Model, where vertices V are intersections of the grid and edges E represent road segments.

Now we discuss one of road segments in the city map. Based on the assumption of ignoring the size of the vehicle, the probability of a node locating on any position of the road is the same, i.e. the position of vehicle nodes on the road segment follows even distribution. Assuming the road segment length is L, and the maximum radio range of each node is R. We normalize the road length as 1, radio range $r = \frac{R}{L}$. N nodes are distributed in the interval (0, 1) of uniform distribution, and each node is independently in position. Supposing that the position of N nodes are $X_i(i = 1, 2, \cdots, n)$ respectively, the above assumptions can be expressed as: $X_1, X_2, \ldots, X_n \sim U(0, 1)$.

3 Routing Scheme

3.1 Cost Function Based on Link Connectivity

Our proposed routing scheme takes the link connectivity into account with overall consideration of factors (path length, traffic density, etc.) affecting routing. The link connectivity affecting the path weight for route planning, and a higher connectivity will lead to a lower path weight. In this section, we managed to derive a more reasonable cost function of the path weight in accordance with the link connectivity. We sort the N random variables $X_i(i = 1, 2, \ldots, n)$ of urban road model in order, and mark the ordered variables as $X_{(i)}(i = 1, 2, \ldots, n)$ satisfying $X_{(1)} \leq X_{(2)\leq\cdots\leq X_{(n)}}$. Defining random variables $Y_j(j = 1, 2, \ldots, n+1)$, which $Y_1 = X_{(1)}, Y_2 = X_{(2)} - X_{(3)}, \cdots, Y_n = X_{(n)} - X_{(n-1)}, Y_{n+1} = 1 - X_{(n)}$.

Y_j presents the distance of two neighboring nodes (Fig. 1). Notice that $Y_i \geq 0$, $\sum_{i=1}^{n+1} Y_j = 1$, according to the conclusion of [12], the joint probability density of Y_j obeys the *Dirichlet* distribution with parameters $v_1 = \cdots = v_{n+1} = 1$. The probability density function of *Dirichlet* distribution is:

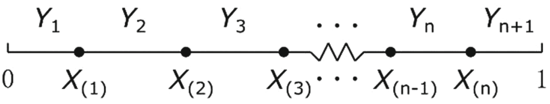

Fig. 1. The relationship between random variables X_i and Y_j

$$f(x_1, \cdots, x_k) = \begin{cases} C(v_1, \cdots, v_k) \prod_{i=1}^{k} x_i^{v_i - 1}, x_1, \cdots, x_k \in S_x \\ 0, else. \end{cases} \tag{1}$$

where

$$C(v_1, \cdots, v_k) = \Gamma(v_1 + \cdots + v_k) \prod_{i=1}^{k} \frac{1}{\Gamma(v_i)} \tag{2}$$

$$S_x = (x_1, \cdots, x_n) : \sum_{i=1}^{n} x_i = 1, x_i \geq 0, i = 0, \ldots, n \tag{3}$$

$\Gamma()$ is Gamma function. Put $v_1 = \cdots = v_{n+1}$ into Eqs.(1) and (2), we have

$$f_{Y_1, \cdots, Y_{n+1}}(y_1, \cdots, y_{n+1}) = \begin{cases} n!, y_1, \cdots, y_{n+1} \in S_x \\ 0, else. \end{cases} \tag{4}$$

The link is connected if the distance of two neighboring nodes is less than r,then

$$P_c(n, r) = P\{Y_{n+1} \leq r\} \tag{5}$$

where P_c denotes the connected probability. According to the conclusion of [12], the cumulative distribution function of $Y_{(n+1)}$ satisfies

$$F_{Y_{n+1}}(x) = \sum_{j=0}^{n+1} (-1)^j \binom{n+1}{j} (1 - jx)_+^n \tag{6}$$

where $(x)_+ = \begin{cases} x, & x > 0 \\ 0, & else \end{cases}$. Thus

$$P_c(n, r) = P_{Y_{n+1} \leq r} = F_{Y_{n+1}}(r) = \sum_{j=0}^{min(n+1, \frac{1}{r})} (-1)^j \binom{n+1}{j} (1 - jr)^n \tag{7}$$

Equation (7) is the P_c after normalizing the road length. We put $r = \frac{R}{L}$ into Eq. (7). In addition, Google Map provides the road congestion information to estimate the traffic density. And a method of estimating traffic density by listening to radio beacon is introduced in literature [9]. We can obtain the real-time traffic density through these ways. After that, the number of vehicle nodes N, is calculated by formula: $n = \lambda L$. And we have:

$$P_c(\lambda, L, R) = \sum_{j=0}^{min(\lambda L+1, \frac{L}{R})} (-1)^j \binom{\lambda L+1}{j} (1 - j\frac{R}{L})^{\lambda L} \tag{8}$$

Figure 2 tells that when the link connectivity Pc versus traffic density λ is greater than 90%, the contribution of increasing in cars number and traffic density becomes smaller and smaller to the link connectivity, until it reaches a saturation state. To solve these problems, we propose a cost function based on road length and link connectivity:

$$Weight = \frac{L}{P_c} \tag{9}$$

The main reasons why we use Eq. (9) as our cost function are described as follows: Firstly, the shorter distance usually means the fewer hops. However, if the density of the chosen path is too low, route is more likely to fail. In Eq. (9), the link connectivity probability is pulled-in as a compensation. In addition, Fig. 3 shows that the relations between the density of vehicles and Weight. Using Eq. (9) as the cost function, not only the influence of road length and traffic density on hops is considered, but also ensures the successful ratio of routing and avoids too frequently message forwarding.

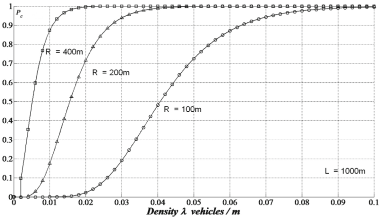

Fig. 2. Link connectivity

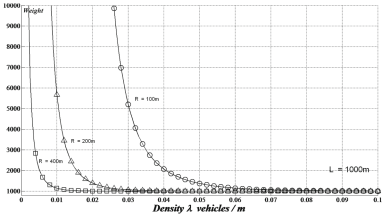

Fig. 3. Road Weight

3.2 GLCV in Different Scenarios

Based on the above analysis and conclusion, we propose a routing scheme named Geographic-based Link Connectivity for Vehicular Networks (GLCV). The implementation details of our scheme are different in the different scenarios, so the GLCV in a V2V scenario and in a V2I2V scenario are introduced respectively.

A. GLCV in a V2V Scenario

We assume that communication only occurs between vehicles in this scenario. The undirected graph we mentioned in Sect. 2, $G < V, E >$, the vertices set V represents a set of road intersection points, the edge set E represents a set of roads. We use Google Map to locate junctions and obtain road length.

Algorithm 1 GLCV forwarding algorithm

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Require: $C$: the current vehicle node; $D$: the destination node
  $N$: the set of one hop neighbors of C; $V_i : V_i \in \{V_1, V_2, , V_k\}, 1 \leq i \leq k$
  $N_{next}$: the next hop; $N_{in}$: the set of internal road segment neighbors of C
  $N_{out}$: the set of external road segment neighbors of C
  if $C = D$ then
      return
  else
      if $D \in N$ then
          $N_{next} = D$
      else
          if $Positon(C) \in V_i$ areas$i < k$ then
              Delete $V_i$
              $\{V_{i+1}, \cdots, V_k\} \leftarrow Dijkstra(weight)$
              $Targetnode = V_{i+1}$
          else if $Positon(C) \in V_k$ areas then $DeleteV_k$
              $Targetnode = D$
          else
              if $\exists N \in N_{out}$ that $\| C - V \| - \| N - V \| > 0$ then
                  $N_{next} = \underset{argmax}{N} (\| C - V \| - \| N - V \|)$
              else if $\exists N \in N_{in}$ that $\| C - V \| - \| N - V \| > 0$ then
                  $N_{next} = \underset{argmax}{N} (\| C - V \| - \| N - V \|)$
              else
                  C drops the packet
              end if
          end if
      end if
  end if
```

Like GPSR, each vehicle node in GLCV broadcasts "HELLO" massage to its one hop neighbors to maintain necessary location information. Differently, GLCV relies on a map to build routes. In order to predict the position of neighboring nodes, it needs to acquire the information of coordinate, road segment identifier and the movement speed of neighbors. The node will record the information on a table after receiving the "HELLO" message from a neighboring node. The table entry includes fields like ID, position coordinates, road segment identifier and update time. If a node does not receive a "HELLO" message from the same neighbor over a certain period, the node deletes the corresponding table entry of this neighbor. The current node divides its neighbors by the road segment identifier into internal road segment neighbors (neighbors are in the same road segment with the current node) and external road segment neighbors (neighbors are in the different road segment with the current node). The below forwarding Algorithm 1 takes different processing to the two kinds of neighbors. Because a time δ exists between updating the neighboring information table and looking up the table, the position of the neighboring node being looked up has changed comparing with the original information in neighboring information table. To eliminate the inconsistency, the position of the neighboring node will be recalculated according to the movement speed field in the table when looking up. GLCV uses the position-based greedy algorithm to forward packets. Therefore, when a node wants to communicate with another node, it needs to acquire the position and velocity of the target node (for predicting the movement of the target node). Finally, we introduce the routing and forwarding algorithm. Firstly, the weight of each road segment in the map has been calculated according to Eqs. (8) and (9). Node S uses Dijkstra algorithm to compute a sequence of vertices with the minimum weight from itself to node D. The position coordinates of the passing k vertices are marked as: $V_1, V_2, \ldots, V_k$. Node S adds this sequence information into the header of GLCV packet, and broadcasts the packet to its neighbors. When a node C receives a packet from its neighbor, node C reads the header of the packet. If node C is not the destination node of the packet, C forwards the packet again. The process of forwarding obeys the following rules: Firstly, those passed vertices become invalid and will be deleted in the sequence. And secondly, middle nodes approximating to any one of vertices areas are responsible for updating the path. If the sequence of vertices has changed, the current node replaces the old vertices sequence with the new one. Thirdly, the other middle nodes regard the next vertex or the destination node as the target node to forward the packet by using an improved greedy forwarding strategy (they preferentially select their external road segment neighbors as the next hop). We use fountain code [10] to achieve more efficient and reliable data transmission. Different from Automatic Repeat-ReQuest (ARQ)protocol, packets loss is acceptable when using fountain code. Pseudo code of GLCV algorithm is illustrated in Algorithm 1.

B. GLCV in a V2I2V Scenario

In a V2I2V scenario, communication not only occurs between vehicles, but also occurs between vehicles and RSUs. With the help of RSUs, vehicles in the V2I2V scenario are typically able to achieve better performance than in the V2V scenario. In this paragraph, we will introduce the function of RSUs. RSUs communicate each other by the wired network, which has higher reliability, wider bandwidth and less delay. The location of RSUs are fixed and they use wired network to communicate. Therefore the quality of the connection in RSUs is significantly better than the inter-vehicle network, we give high priority to RSUs when establishing a route. GLCV sets the weight between adjacent RSUs to 0 to increase the probability of using RSUs when building a route.

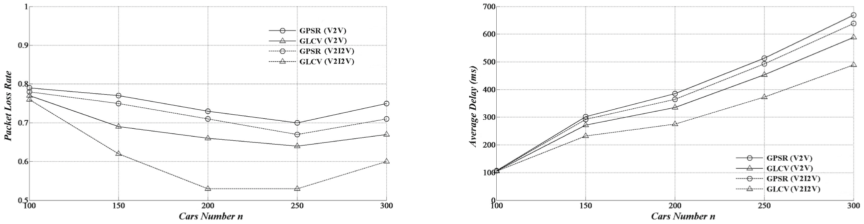
V2I2V communication process is similar to the V2V in our proposed scheme, so we extended the routing algorithm to fit V2I2V communications. The extended algorithm want to make full use of RSUs to optimize the quality of connection in a V2I2V scenario. Before communicating, source node S calculates the minimum weight path from itself to destination node D. If the path does not contain a RSU vertex or contain only one RSU vertex (indicates that the RSU is the destination node, i.e., V2I communication), then it turns as same as the GLCV in a V2V scenario. If the path contains two RSUs or more, then the sequence of vertices will obey the following form: $V_{i_1}, \cdots, V_{i_m}, R_{in}, \cdots, R_{out}, V_{i_{m+1}}, \cdots, V_{in}$. The above sequence of vertices are divided into two segments: before the entry of RSUs, $V_{i_1}, \cdots, V_{i_m}, R_{in}$, and after leaving RSUs, $R_{out}, V_{i_{m+1}, \cdots, V_{i_n}}$. The two segments can be regarded as two segments of V2V communications: in the first half, from the source node S to the vertex R_{in}; and in the second half, from the vertex R_{out} to the destination node D. So each intermediate node needs to determine whether it is in the first or the second segment. Then, the above routing algorithm is implemented with the target is a RSU vertex or the destination node D.

Table 1. NS3 simulation parameters

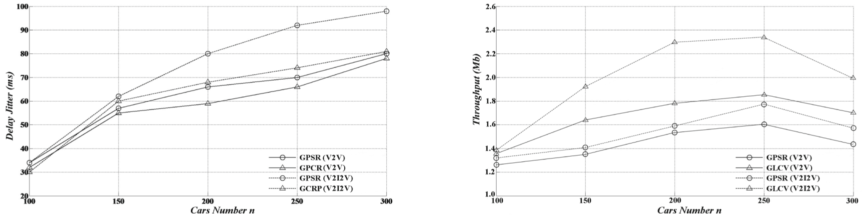
Parameter	Value
Number of grids	5 × 5
Map scale	2000 m × 2000 m
Road length	500 m
Number of OBU nodes	100, 150, 200, 250, 300
Number of RSU nodes	0, 4
Physical layer parameters	Bandwidth: 10 MHz, speed: 6 Mbps
Wireless channel model	Log distance propagation loss model
Radio transmit power	20 dBm
Network protocol stack	IPv4
Packet size	1024 bytes
Data flow type	Constant bit rate (CBR), speed: 100 Kbps

4 Simulation Result and Evaluation

The main characteristics of VANETs in the urban environment have a great impact on the performance of wireless communication. In this part, we present the simulation experiment based on the urban simulation platform SUMO, and the network simulation platform NS3. We analyze performance of GLCV in the urban environment and compare it with GPSR. In this section, we present the simulation of GLCV scheme and evaluate the performance of our algorithm in the simulations. The simulation experiment parameters are indicated according to Table 1. We simulated the GPSR and the GLCV in V2V scenarios and V2I2V scenarios. The simulation of each group is repeated 100 times to take the mean value(the selected communication node pairs are different at each time). The simulation results are shown in Fig. 4. Figure 4(a) shows the relationship between packet loss rate and cars number. With the cars number increasing from 100 to 250, intermediate nodes number for multi-hop forwarding and the successful rate of multi-hop forwarding have increased, which leading to a lower packet loss rate. However, when nodes number increases to 300, the probability of congestion becomes greater because of the increasing node density. Those plenty of safety and non-safety messages produced by nodes will compete to access the limited channel resources. GLCV has lower packet loss rate than GPSR. This is because GLCV considers the link connectivity in path planning. In V2I2V scenarios, since GLCV uses RSUs proactively to assist in routing forwarding, GLCV performs much better than that in V2V scenarios. Figure 4(b) shows the relationship between the average delay and the cars number. When the node density is low, the probability of multi-hop communication is low. In this situation, there is less competition of network resources and end-to-end communication delay is smaller. With the increment of nodes density, multi-hop communication is more likely to happen, and the number of forwarding packets from end to end has increased. We can see the performance of GLCV is better than GPSR in terms of delay. GPSR turns to perimeter mode when the greedy forwarding fails, resulting in unnecessary forwarding and an increment in average number of hops and average delay. GLCV labels non-connected paths to guide nodes to following the shortest path to forward packets, which decreases the delay. The result of Fig. 4(c) shows the relationship between the delay jitter and the cars



(a)The packet loss rate (b)The average delay



(c)The delay jitter (d)The throughput

Fig. 4. Simulation results of GLCV versus cars number n

number. The stability of multi-hop communication is worse than that of single-hop communication. So the increasing multi-hop communications bring a greater jitter. RSUs have a significant impact on the number of forwarding. Because of the changes of network topologies, the communication between nodes is switched on V2I2V and V2V, the delay jitter of GLCV and GPSR have increased when there are RSUs. GPSR uses RSUs to forwarding by random, so that the switch is more frequently, resulting in the increment of jitter delay.

The relationship between the throughput capacity and the cars number is shown in Fig. 4(d). With the cars number increasing from 100 to 250, the success rate and stability of multi-hop forwarding has increased, so the throughput has increased. But when the nodes number increases to 300, the competition in wireless resources is more fiercely, which result in the reducing of throughput. GLCV uses RSUs to assist in forwarding, so that the throughput is improved greatly in V2I2V scenarios.

5 Conclusion

Through our investigation and analysis of the existing VANETs routing scheme, this paper has presented a new VANETs routing scheme, based on geographical link connectivity management aimed at the shortages of those existing protocols in the urban environment. Simulation results have shown that our proposed scheme, namely GLCV, outperforms existing position-based routing protocols in terms of the packet delivery rate, the average hops, the packet loss rate, the average delay, the delay jitter and the throughput.

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