A Geographical Routing Protocol Based on Link Connectivity Analysis for Urban VANETs

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Abstract

Vehicular Ad hoc Networks (VANETs) are important parts of Intelligent Transport System (ITS). As a special kind of mobile ad hoc networks (MANETs), VANETs support dynamic inter-vehicle communications. However, the high mobility of vehicular nodes results in a highly dynamic network topology and the network fragmentations, which brings a great challenge to routing in VANETs. In this paper, we propose a new routing scheme called LCGL for urban VANETs, which is formed by Link Connectivity analysis based on Geographical Location, to overcome the common failures of VANETs routing in urban areas. Combined with a digital city map, LCGL manages the geographic location information of nodes and the connectivity of links. LCGL selects the shortest connected path to forward the packets by calculating the path length and the connectivity of links. Simulation results have shown that LCGL offers stable end-to-end communications, and outperforms existing typical VANETs routing protocols in urban environment, especially in terms of packet delivery rate and average hops. In addition, LCGL achieves a lower delay and jitter, as well as a higher throughput.

Keywords: VANETs, Routing protocols, LCGL

1 Introduction

Various types of vehicles are becoming indispensable in our daily life. With the increasing number of vehicles, new problems have emerged: road congestion, traffic accidents, road resource utilization, etc. In this situation, Vehicular Ad Hoc Networks (VANETs) are proposed to build a safer transport system [1]. VANETs use Dedicated Short Range Communication Technology (DSRC) exclusively to realize reliable vehicle to vehicle (V2V) and vehicle to roadside infrastructure (V2I) communications [2-3]. In VANETs, vehicles can transmit numerous safety and non-safety related communication applications to each other [4].

In VANETs, communications depend on distributed nodes by forming a multi-hop network [5]. VANETs' special characteristics, such as high node mobility, network fragmentation, and diverse quality of service requirements of potential applications [6], bring significant challenges in the design of efficient routing protocol. Consequently, finding and maintaining routes become much more complex and challenging tasks especially in urban environments. It is of great significance to select a stable link of high connectivity in V2V as well as V2I communications [7]. By analyzing the characteristics of VANETs, we propose a new routing algorithm based on Link Connectivity analysis on Geographic Location (LCGL) for urban VANETs. LCGL takes the path 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, LCGL uses an improved greedy forwarding strategy to pass the packets between adjacent intersections.

This protocol is applied to V2V scenarios or Vehicle to Infrastructure to Vehicle (V2I2V) scenarios. There are not any Road Side Units (RSUs) in V2V scenarios, while a V2I2V scenario is progressed with the assistance of RSUs. Compared with some existing routing algorithms, the protocol we proposed has higher expansibility and flexibility, and outperforms other routing protocols in terms of routing success ratio, average number of hops and transmission delay. The remainder of this paper is organized as follows: In section 2, we illustrate an overview of the related work. In sections 3, we discuss the system model. The design process and the new routing algorithm are detailed in section 4. In section 5, we evaluate the simulations and performance of our proposed protocol. Finally, section 6 concludes the paper.

2 Related Work

Because of the high mobility of nodes in the networks, routing protocols for Mobile Ad Hoc Networks (MANETs) display poor performances in

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VANETs [8]. New routing protocols were investigated and proposed in the last decade considering the characteristics of VANETs. Nowadays, position-based routing protocols attract much more attentions and become increasingly popular in VANETs. Some typical position-based routing protocols are presented as follows.

Greedy Perimeter Stateless Routing (GPSR) [9] is one of the best known position-based routing protocols. In GPSR, each node maintains a neighboring table to execute greedy forwarding. When greedy forwarding strategy fails, GPSR uses the right-hand rule to find a perimeter. However, the right-hand rule solves the local optimum at the expense of routing path length. Moreover, GPSR is often restricted at the intersections in a city scenario because direct communications between nodes may be blocked by obstacles.

Greedy Perimeter Coordinator Routing (GPCR) [10] specifies that packets should always be forwarded on a junction, and uses a repair strategy to get out of the local optimum, so that GPCR solved the communication problem caused by obstacles. As a result, GPCR can be used in a city environment. But this scheme sacrifices a degree of average number of hops and latency.

Lochert et al. [11] also proposed Geographic Source Routing (GSR) to deal with the problems of GPSR. GSR determines routes with the aid of a static street map [12]. Before starting the communication, GSR computes the shortest physical path using the Dijkstra shortest path algorithm [13]. GSR marks the sequence of intersections as Anchor Points (AP), which compose the routing path. GSR employs greedy forwarding strategy to forward packets between adjacent Anchor Points. However, the physical path is too stuffless to represent the influence of urban environments on routing. Besides path length, a great deal of factors (traffic density, etc.) also affect routing performance. Therefore, on the basis of GSR, Jerbi et al. [14] put forward Greedy Traffic Aware Routing (GyTAR) that quantifies both the length and traffic density of path. With the help of the real time road traffic variation, GyTAR has lower end-to-end delay and packet loss than GSR. But GyTAR assumes that the effect of routing is linear with traffic density and distance, which lacks sufficient theoretical evidence.

In 2014, Oubbati et al. [15] presented a new routing protocol called Intelligent Routing protocol which utilized real time Traffic Information in urban Vehicular environment (IRTIV). IRTIV aims to find the most connected and the shortest path using its proposed calculation formula of connectivity and the Dijkstra Algorithm. In contrast to GyTAR, IRTIV gives better performance in terms of packet delivery ratio and delay. But the assumption of IRTIV that road weight is inversely proportional to the shortest path from the current intersection to the destination node and directly proportional to the traffic density, also lacks adequate theoretical basis.

3 System Model

In this section, we elaborate the system model of our proposed routing protocol for urban environments. Based on these prerequisites, we plan to design a reasonable and efficient routing scheme based on link connectivity management. Hypothesis: for the network, we make some assumptions as follows.

- Every node is equipped with a GPS device.
- Vehicle sensors provide measurements of vehicle velocity and direction.
- An open geographic information system, e.g. Google Map [16] is applied to locate junctions and obtains geographic location information (coordinate, road length, density, etc.).
- Relative to the maximum radio range of vehicles, ignoring the size of the vehicle.

One-dimensional road model: according to [17], the frame-success-ratio is greater than 0.9 when the maximum radio range of a vehicle node is 400m. Commonly, the width of a lane is 3.5m. Road width is much smaller than the maximum radio range. So the road width has little influence on wireless transmission and routing strategy. Therefore, we regard the road as one-dimensional model [18]. In this paper, we set the radio range of a vehicle node as 250m.

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 located on any position of the road is the same, i.e. the position of vehicle nodes on the road segment follows uniform 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 $X_i = (i = 1, 2, ..., n)$ respectively, the above assumptions can be expressed as: $X_1, X_2, ..., X_n \sim U(0,1)$.

4 LCGL

4.1 Cost Function Based on Link Connectivity

Our proposed routing protocol takes into account of the link connectivity with overall consideration of factors (path length, traffic density, etc.) which may have influences on routing. The link connectivity means the path weight for route planning. A higher connectivity leads 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

$X_i = (i = 1,2,...,n)$ of urban road model in order, and mark the ordered variables as $X_{(i)} = (i = 1,2,...,n)$ satisfying $X_{(1)} \le X_{(2)} \le ... X_{(n)}$. Defining random variables $Y_j\,(j = 1,2,...,n)$, which $Y_1 = X_1, Y_2 = X_2 - X_1, ..., Y_n = X_n - X_{n-1}, Y_{n+1} = 1 - X_n$. $Y_j\,(j = 1,2,..., n+1)$ indicates the distance of two neighboring nodes in Figure 1. Notice that $Y_j \ge 0$, $\sum_{j=1}^{n+1} Y_j = 1$, according to the conclusion of [19], the joint probability density of Y_j obeys the Dirichlet distribution with parameters $v_1 = ... = v_{n+1} = 1$.

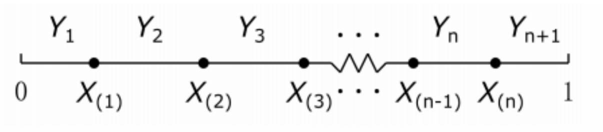


Figure 1. The relationship between random variables X_i and Y_i

The probability density function of Dirichlet distribution is

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

where

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

$$S_x = \{(x_1,...,x_n) : \sum_{i=1}^{n} x_i = 1, x_i \ge 0, i = 1,...,n\}. \quad (3)$$

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

$$f_{Y_1,...,Y_{n+1}}(y_1,..., y_{n+1}) = \begin{Bmatrix} n! & y_1,..., y_{n+1} \in S_y \\ 0 & else \end{Bmatrix}, \quad (4)$$

where

$$S_y = \{(y_1,..., y_{n+1}) : \sum_{i=1}^{n+1} y_i = 1, y_i \ge 0, i = 1,..., n+1\}. \quad (5)$$

Marking the ordered $Y_j\,(j = 1,..., n+1)$ as $Y_{(j)}\,(j = 1,..., n+1)$ meeting $Y_{(1)} \le Y_{(2)} \le ... \le Y_{(n)}$. The link is connected if the distance of two neighboring nodes is less than r, then

$$P_e(n,r) = P\{Y_{n+1} \le r\}, \quad (6)$$

where P_c denotes the connected probability. According to the conclusion of [20], the cumulative distribution function of Y_{n+1} satisfies

$$F_{Y_{n+1}}(x) = \sum_{j=0}^{n+1} (-1)^j \binom{n+1}{j} (1 - jx)_+^n\, n, \quad (7)$$

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

$$P_c(n,r) = P_{Y_{n+1}} \le r = F_{Y_{n+1}}(r) \quad (8)$$

$$= \sum_{j=0}^{n+1} (-1)^j \binom{n+1}{j} (1 - jr)_+^n \quad (9)$$

$$= \sum_{j=0}^{\min(n+1, \left[\frac{1}{r}\right])} (-1)^j \binom{n+1}{j} (1 - jr)^n. \quad (10)$$

(8) is the P_c after normalizing the road length. Put $r = \frac{R}{L}$ into (10):

$$P_c(n, L, R) = \sum_{j=0}^{\min(n+1, \left[\frac{L}{R}\right])} (-1)^j \binom{n+1}{j} \left(1 - j\frac{R}{L}\right)^n. \quad (11)$$

In addition, Google Map provides the road congestion information to estimate the traffic density. The method of estimating traffic density by monitoring radio beacon is introduced in literature [21], through which we can obtain the real time traffic density. Then the number of vehicle nodes n, is calculated by formula: n = λL. And we have:

$$P_c(n, L, R) = \sum_{j=0}^{\min(\lambda L+1, \left[\frac{L}{R}\right])} (-1)^j \binom{\lambda L + 1}{j} \left(1 - j\frac{R}{L}\right)^{\lambda L}. \quad (12)$$

Figure 2 depicts the relationship between link connectivity Pc and traffic density λ based on (12). It can be seen that when the link connectivity is greater than 90%, the increase of vehicular numbers and traffic density have less impact on it. And the link connectivities under different radio range R become the same if the traffic density reaches saturation state. To solve these problems, we propose a cost function based on road length and link connectivity:

$$Weight = \frac{L}{10000 P_c}. \quad (13)$$

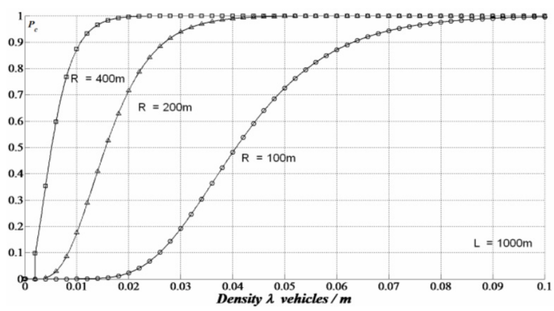


Figure 2. Link connectivity P_c versus traffic density λ (road length L=1000m, the maximum radio range R are equal to 100m, 200m and 400m, respectively)

Figure 3 shows the relationship between the road weight and the traffic density λ. It can be intuitively known from it that the road weight has the tendency to infinity when the traffic density tends to 0, while the link connectivity is equal to 0 represented in Figure 2.

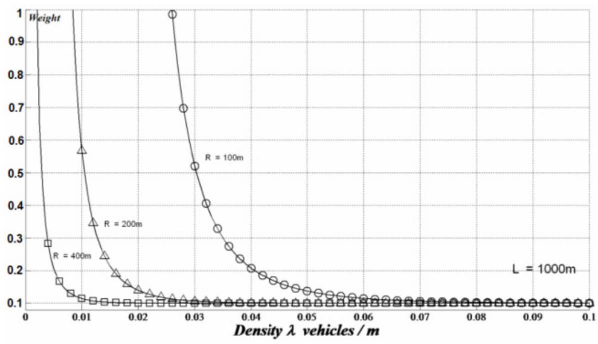
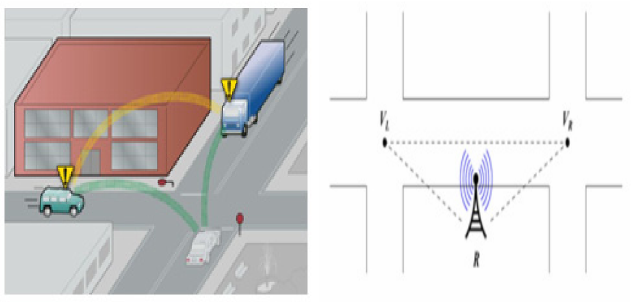


Figure 3. Road weight versus traffic density λ (road length L=1000m, the maximum radio range R are equal to 100m, 200m and 400m, respectively)

4.2 LCGL in Different Scenarios

Based on the above analysis and conclusions, we propose a routing protocol based on Geographic Link Connectivity management (LCGL). The implementation details of our protocol are different in different scenarios, so the LCGL in a V2V scenario and in a V2I2V scenario are introduced respectively, as shown Figure 4.



(a) V2V scenario (b) V2I2V scenario

Figure 4. Vehicle networking real scenarios

4.2.1 LCGL in a V2V Scenario

Maintenance of vehicle node information. Each vehicle node in LCGL broadcasts *"HELLO"* massage to its one hop neighbor to maintain necessary location information like GPSR. Differently, LCGL relies on a map to build routes. In order to predict the position of neighboring nodes, it needs to acquire the coordinate, the road segment identifier and the movement speed of neighbors. The specific fields of *"HELLO"* message in LCGL are shown in Table 1.

Table 1. The specific fields of *"HELLO"* message

Field	**Description**
ID	Identity of the node
Position coordinates	The position coordinates of the current node
Road segment identifier	The road segment identifier of the node at the current position
Movement speed	The velocity and direction of the node

The node will record the information in the neighboring information table after receiving the *"HELLO"* message from a neighboring node. The table entry includes fields like ID, position coordinates, road segment identifier and updating time. If a node does not receive a *"HELLO"* message from the same neighbor over a certain period of time, 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.

Acquisition of the target node position. LCGL 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 coordinate and velocity of the target node for the purpose of predicting the movement of the target node. GPSR protocol in [22] adopts flooding query to acquire the target node. Literature [23] utilizes Distributed Hash Table (DHT) [24] to maintain the corresponding relationship between the node ID and the latest geographic location. The analysis shows that using the DHT to maintain the location and velocity of global nodes in VANETs can achieve a better balance between overhead and delay.

Routing and forwarding algorithm. When the node in LCGL initiates communication with another node, it adds a header in each packet. The header contains the IDs, the positions, the velocity information of source node S and destination node D. Firstly, the weight of each road segment in the map has been already calculated according to (12) and (13). Node S uses Dijkstra algorithm to compute a sequence of vertices with the minimum weight from itself to node D. The position coordinates the passing k vertices marked as: $v_1, v_2, ..., v_k$. Node S adds this sequence information into the header of LCGL packet, and broadcasts the packet to its neighbors.

We make use of fountain codes in [25] to achieve more efficient and reliable data transmission. The advantage of fountain codes is that the receiver can decode the data as long as it receives sufficient coded messages. Different from Automatic Repeat-reQuest (ARQ) protocol, it cares less about packets loss when using fountain codes. The receiver only needs to send an ACK to the sender when all data are decoded successfully.

Pseudo code of LCGL algorithm is illustrated in Algorithm 1.

Algorithm 1. LCGL forwarding algorithm

Notation:
C : the current vehicle node
D : the destination node
N : the set of one hop neighbors of C
$V_i : V_i \in \{V_1, V_2, ..., V_k, 1 \le i \le k\}$
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**
else
if $Position(C) \in V_i$, areas $i \le k$ **then**
Delete V_i
$\{V_{i+1}, ..., V_k\} \leftarrow Dijkstra(weight)$
$Targetnode = V_{i+1}$
else if $Position(C) \in V_k$, areas **then** Delete V_k
else
  if $\exists \in N_{out}$ that $\|C - V\| - \|N - V\| > 0$
then $N_{next} = N_{argmax}\left(\|C - V\| - \|N - V\|\right)$
  else if $\exists N \in N_{in}$ that $\|C - V\| - \|N - V\| > 0$
then
$N_{next} = N_{argmax}\left(\|C - V\| - \|N - V\|\right)$
else
C drops the packet
  end if
  end if
 end if
end if

4.2.2 LCGL in a V2I2V Scenario

Representation of RSUs. communication between a RSU and another RSU goes through the wired network, which has higher reliability, wider bandwidth and less delay. The location of RSUs are fixed, they can be added to the undirected graph G of the city map. Because RSUs use the wired network or other network access methods to communicate, the weight calculation in (12) and (13) based on the link connectivity do not suit for RSUs. And the quality of the connection in RSUs is significantly better than the inter-vehicle network, so we give high priority to RSUs when establishing a route. Considering all these factors, LCGL sets the weight between adjacent RSUs to 0 to increase the probability of using RSUs when building a route.

Extension of the routing algorithm. the routing algorithm should be extended if it wants to make full use of RSUs to optimize the quality of connection in a V2I2V scenario.

5 Simulation Result and Evaluation

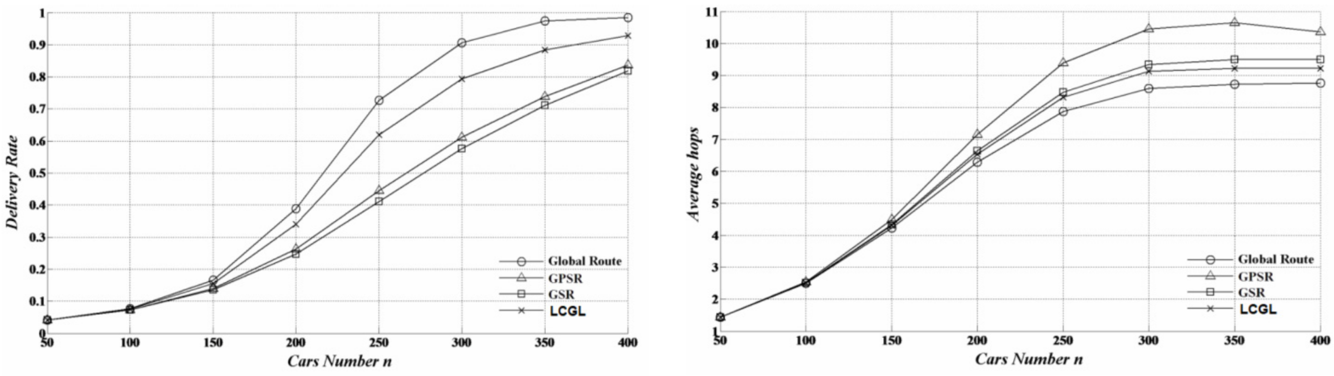
5.1.1 Simulation Scenarios

To estimate the performance of LCGL routing algorithm in static scenario, we apply the NetworkX graph theory calculation module on Python platform to simulate communications in VANETs under the urban environment. The NetworkX is a graph theory and complex network modeling tool developed by python language [26]. It is convenient to simplify the modeling of VANETs static communication scenario with the assistance of the NetworkX.

After the construction of the undirected graph G for grid road and the undirected graph H for vehicles connection, in this section, we implement global routing [27], GPSR routing, GSR routing and LCGL routing algorithms employing Python language. The global routing uses the global topology information to determine a route, providing the maximum packet delivery rate and the minimum average hops. In practice, it is difficult for vehicles to know the global network topology information. Therefore, the global routing is not feasible, and we regard it as an ideal route for reference. The simulations evaluate the packet delivery rate and the average hops of these four routing algorithms.

5.1.2 Simulation Results and Analysis

Simulation results of V2V scenarios. Fiture 5(a) demonstrates that GSR protocol has the worst capability of the packet delivery rate. The reason is that GSR uses the path length to build a route in the simulation. Due to the randomness of distributed nodes, the number of nodes in each road segment is different, so is the connectivity of each road segment. And a link of high connectivity no doubt realize a higher delivery rate. That is why our protocol LCGL performs better in delivery rate. Path planning based on only path length prefers to forward the packets to a road segment with a low nodes density, which leads to routing failures. Premeditating link connectivity when building a route, our proposed LCGL has lower average forwarding hops than GSR and GPSR (seen from Fiture 5(b), and avoids the local optimum caused by the right-hand rule in GPSR.

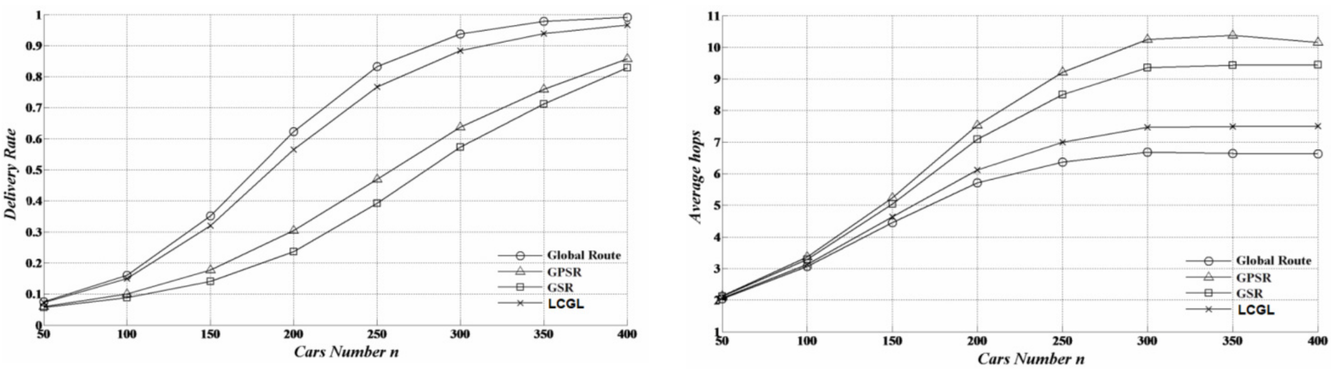


(a) The packet delivery rate versus cars number

(b) The average forwarding hops versus cars number

Figure 5. Static simulation results of V2V scenarios

Simulation results of V2I2V scenarios. As for GPSR and GSR, they don't use RSUs to serve the forwarding. That is why their performances are not obviously improved in V2I2V scenarios. As shown in Fiture 6(a) and Fiture 6(b), for global route, using RSUs significantly reduces the number of hops for the multi-hop forwarding, and improves the packet delivery rate when the traffic density is low. Our protocol LCGL turns to RSUs initiatively to support the multi-hop forwarding, so its performance has been definitely improved in V2I2V scenarios.



(a) The packet delivery rate versus cars number

(b) The average forwarding hops versus cars number

Figure 6. Static simulation results of V2I2V scenarios

5.2 Dynamic Simulation of LCGL

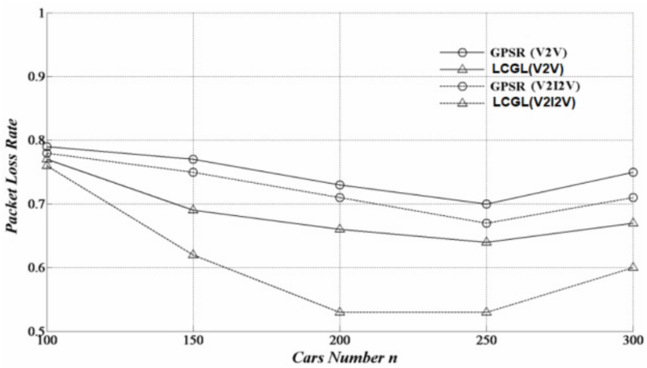
The main characteristics of VANETs in the urban environment have a great impact on the performance of wireless communication. Static simulation is unable to show the influence of these factors on performance of routing protocol. So in this part, we present the simulation experiment based on the urban simulation platform SUMO [28], and the network simulation platform NS3 [29]. We analyze the result of LCGL in the urban environment and compare it with GPSR.

Fiture 7(a) shows the relationship between packet loss rate and cars number. The packet loss rate, i.e. the proportion of lost packets during the 60 seconds simulation time, reflects the reliability of communications. With the number of vehicles ascends from 100 to 250, intermediate nodes number for multi-hop forwarding and the successful rate of multi-hop forwarding increase as well, which contributing to a lower packet loss rate. However, when nodes number rises to 300, the probability of congestion becomes greater owing to the increasing node density. Those plenty of safety and non-safety messages produced by nodes will compete to access the limited channel resources. Consequently, LCGL has lower packet loss rate than GPSR. This is because LCGL considers the link connectivity in path planning. In the other hand, the routing of LCGL is more stable than GPSR. Since LCGL uses RSUs proactively to assist in routing forwarding. In V2I2V scenarios, LCGL outperforms than that in V2V scenarios. Because GPSR uses RSUs to aid in routing forwarding randomly, the packet loss rate of GPSR has hardly been improved in V2I2V scenarios.

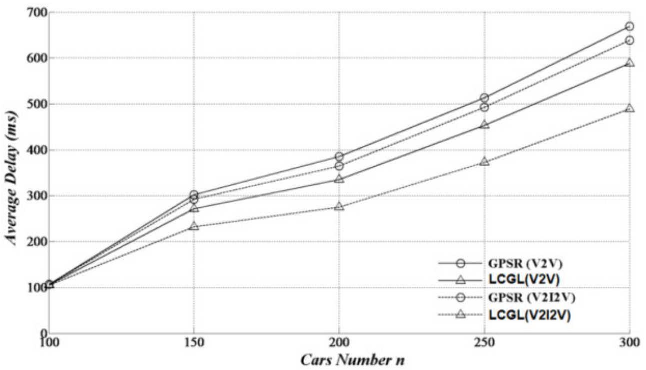
Fiture 7(b) shows that when the node density is low, the probability of multi-hop communication is low. In this situation, there is less competition of network resources, and end-to-end communication delay is smaller. With the increment of nodes density, multi-hop communication is more likely to take place, and the number of forwarding packets from end to end has grew. Moreover, the increment of node density results in a fiercer competition of network resources and a higher delay.

Fiture 7(c) describes the relationship between the delay jitter and the vehicle 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. When RSUs exist, the delay jitter is increased. Because of the changes of network topologies, the communication between nodes is switched on V2I2V and V2V, the delay jitter of LCGL and GPSR have increased when there are RSUs working. GPSR applies RSUs to forwarding by random, so that such switch happens more frequently, which resulting in the increment of jitter delay.

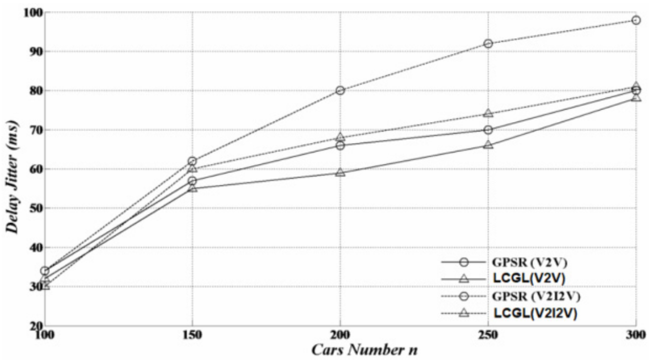
The nexus between the throughput capacity and the cars number is shown in Fiture 7(d). The throughput rate of nodes maintains at 100Kbps (the parameter setting in Table 2. With the cars number rise from 100 to 250, the success rate and stability of multi-hop forwarding have increased, so dose the throughput. But when the nodes number increases to 300, the competition in wireless resources is more fiercely, which causes the reducing of throughput. LCGL uses RSUs to assist in forwarding, so the throughput is improved greatly in V2I2V scenarios.



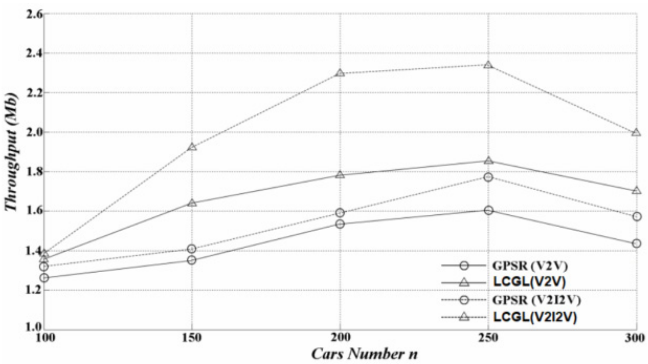
(a) The packet loss rate versus cars number n



(b) The average delay versus card number n



(c) The delay jitter versus the cars number n



(d) The throughput versus the cars number n

Figure 7. Dynamic simulation results of LCGL

6 Conclusions

Through our investigation and analysis of the existing VANETs routing protocols, especially those routing algorithms based on geographical location information, this paper has presented a new VANETs routing protocol LCGL, based on geographical link connectivity management aimed at surmounting the shortages of those existing protocols in the urban environment. Simulation results have shown that our proposed protocol 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. nevertheless, in the simulation on the NS3 platform, the channel simulation can not truly reflect the situation of building block, which brings about the difference between the simulation and the real environment. In the future work, we are interested in adding the obstacle channel model to obtain more realistic simulation results.

Table 2. NS3 simulation parameters

Parameter	Value
Number of grids	5*5
Map scale	2000m*2000m
Number of lanes	2
Road length	500m
Node type	OBU(mobile vehicle node), RSU(roadside unit node)
Number of OBU nodes	100, 150, 200, 250, 300
Number of RSU nodes	0,4
Mobility model	NS2/3 Mobility Model(for OBU), static location model(for RSU)
Network device type	802.11p(for OBU and RSU nodes), Ethernet(for RSU nodes)
Physical layer parameters	Bandwidth: 10MHz, speed: 6Mbps
Wireless channel model	Log Distance Propagation Loss Model
Radio transmit power	20dBm
Network protocol stack	IPv4
Routing protocols	GPSR, LCGL
Packet size	1024 bytes
Data flow type	Constant bit rate(CBR), Speed:100Kbps
Communication node pairs	5(random selection)
Simulation duration	60 seconds

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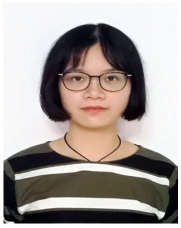

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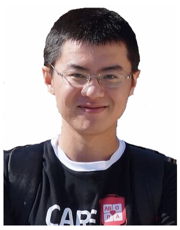

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