A Link State Aware Hierarchical Road Routing Protocol for 3D Scenario in VANETs

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Abstract. In urban VANETs, nodes on the road appear three-dimensional (3D) distribution. However, the existing protocols only consider the case of planar distribution. It may cause problems in 3D scenarios, like hop count increase and packet delivery ratio decrease. Moreover, most of plane-based protocols determine the road connectivity by collecting the node density information, but it does not accurately reflect the road connectivity. Hence, we propose a novel protocol named Link State aware Hierarchical Road routing (LSHR). LSHR selects the next intersection based on the distance and the road connectivity. Meanwhile, LSHR represents the road connectivity more accurately. In addition, considering the problems of hop count increase and packet delivery ratio decrease, LSHR prior selects the neighbor has the largest transmission range of two hops as the forwarder. Comparing with classic protocols, LSHR is shown to increase the packet delivery ratio and decrease the end-to-end delay and hop count in simulation.

Keywords: VANETs, 3D, link state, hierarchical road.

1 Introduction

Routing protocol is important to determine the performance of Vehicular Ad hoc NETworks (VANETs) [1]. Quite a lot of routing protocols have been proposed, which can be classified into two types [2]: topology-based and geographic routing. Topology-based routing [3-5] always suffers from routing breaks and does not suitable for VANETs. In geographic routing [6-15], routing decision is made hop by hop and nodes unnecessary to maintain topology map or exchange link state information. Therefore, this type of routing can better adapt to VANETs.

All of these routing protocols in VANETs are designed and applicable to the ideal plane scenarios. Nowadays, a large number of overpasses and viaducts are build up on roads and highways in order to make full use of urban space. These overpasses and viaducts make the urban network from planar to three-dimensional (3D), and the 3D of urban network leading to the vehicle distribution appears layered phenomenon. Fig. 1 is an example of 3D realistic scenario. Hence, applying existing plane-based routing protocols in 3D scenarios is inappropriate. Although there have been some works for 3D scenarios in MANETs [16-18], it can't be directly applied in VANETs,

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Fig. 1. An example of realistic three-dimensional scenario

because VANETs have some own features that are different from MANETs. To address this issue, we present a new geographic routing named Link State aware Hierarchical Road routing (LSHR). LSHR aims to reduce routing hop count and the transmission delay, while increasing packet delivery ratio and enhancing the overall performance of the routing. It contains intersection judgment strategy and data transmission strategy on 3D sections. LSHR selects the next intersection based on the distance factor and the road connectivity. Meanwhile, LSHR represents the road connectivity more accurately. In addition, considering the problems of hop count increase and packet delivery ratio decrease, LSHR prior selects the neighbor that has the largest transmission range of two hops as the forwarding node.

The rest of the paper is organized as follows: In Section 2, we will analyze issues of the existing plane-based routing protocols. Section 3 will present the details in the proposed LSHR scheme. The performance evaluations of the proposed scheme are presented in Section 4. The last section is the conclusion.

2 Issues and Analysis

In this section, we will analyze the issues of the existing protocols.

2.1 Analysis about the Determination of Road Connectivity

There is a kind of geographic routing protocol which based on road topology [19, 20] for the urban scenario. In Geographic Source Routing (GSR) [19], the source node first selected the shortest path to the destination. However, GSR does not consider whether there are sufficient forwarding nodes on the selected streets, and the packet transmission disruptions may occur. Greedy Traffic Aware Routing protocol (GyTAR) [20] is a classic intersection based geographic routing. Different from GSR, GyTAR dynamically determine its intermediate intersection. The process is determined according to the real-time node density information. The node density refers to the average number of vehicles on the candidate road, not the actual distribution of vehicles. GyTAR thinks the greater the density, the better the quality of links, which

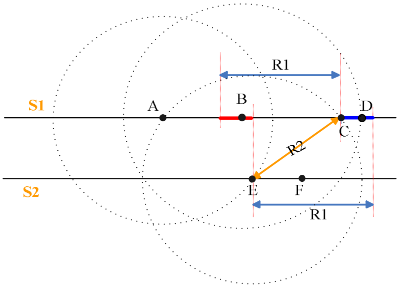

Fig. 2. An auxiliary abstract scenario graph

in fact is unreasonable. There are many routing protocols that use the density information for routing judgment and have the same problem with GyTAR, i.e. the collected density information can't accurately reflect the actual road connectivity.

2.2 Analysis about Plane-based Routing Protocols Applied in 3D Scenarios

In this section, we use GPSR [6] as the research object. We consider a simple 3D scenario which composed of two or more than two parallel but with different height roads. Fig. 2 shows an auxiliary abstract scenario. S1 and S2 are two parallel road segments which have different layers. R1 and R2 represent the transmission ranges of the same layer and the inter-layer. The inter-layer transmission occurs between nodes A and E. Packets can be transmitted to the farthest position of the location of node C. But if there are some nodes in the red region, through the layer transmission, packets can be transmitted to the blue region. It indicates that when the source and destination on the road settled, the number of hop count between inter-layer transmissions is bigger than that of layer transmission. When node E reaches a local maximum, GPSR uses the perimeter mode. However, if the node E forwards packets to node B instead of switching into the perimeter mode, packets can avoid entering the local maximum area. It could reduce the risk of packet delivery ratio dropping.

Similar with GPSR, the existing protocols that use greedy forwarding can't show the best performance because of the inevitable inter-layer transmissions. So, it is need to propose a routing protocol for 3D scenarios.

3 Link State aware Hierarchical Routing Protocol

Based on the above analysis, we put forward a geographic routing protocol called Link State aware Hierarchical Road routing (LSHR), which aims to address the increase of routing hop count and transmission delay. LSHR contains intersection judgment strategy and data transmission strategy on 3D sections. Firstly, when LSHR selects the next temporary objective intersection, besides considering a general distance factor, it focus on the effect of road connectivity which expressed by the unit of communication delay. Therefore, the selected path not only has shortest possible transmission distance, but also has stable network connectivity to ensure rapidly and effectively packet transmission. Secondly, during the transmission of a packet, the agreement combines the 3D characteristics of the actual scenarios and the 3D distribution of nodes, and prior selects the neighbor who has the largest transmission range of two hops as the forwarding node.

Table 1. The format of Hello packet

Node ID	Node position	Road segment ID	Intersection ID	d_f	d_b

In VANETs, each node periodically broadcasts a Hello packet for its neighbors and creates or updates its neighbor list information based on received Hello packets. The format of Hello packet in LSHR is shown in Table 1. The node position is the 3D coordinates which provided by GPS. If the node is located at an intersection, the road segment ID is marked as null. If the node is not located at an intersection, the intersection ID is marked as null. The d_f refers to the distance between the current node and the node that is nearest to the front port of the road segment (i.e. front intersection). The d_b represents the distance between the current node and the node that is nearest to the back port of the road segment (i.e. back intersection).

3.1 Intersection Judgment Strategy

Assume that road topology is known. In LSHR, the current node determines the destination intersection according to its location. There are two destination intersection determination mode, i.e. road mode and intersection mode.

If the current node is located on the road segments, then it chooses the road mode, i.e. selects the port that nearest to the destination as the destination intersection from two ports of the road segment which the node is located on. Record the ID of the port in the dynamic address field of the packet. Here, we use (x_F, y_F, z_F), (x_B, y_B, z_B) and (x_D, y_D, z_D) express the locations of the road segment's front port, back port and the destination respectively. The distance between the destination and the front port is

$$d_F = \sqrt{(x_F - x_D)^2 + (y_F - y_D)^2 + (z_F - z_D)^2}, \tag{1}$$

and the distance between the destination node and the back port is calculated by

$$d_B = \sqrt{(x_B - x_D)^2 + (y_B - y_D)^2 + (z_B - z_D)^2}. \tag{2}$$

Compare d_F and d_B, and the smaller one is the temporary destination intersection.

Table 2. The format of a data collect packet

I_i	t_1	t_2

If the current node is located at an intersection, then it chooses the intersection mode. This node checks its cache to see whether there is a sort table which reflects the connectivity of the adjacent road connections. If not exists, the node establishes this sort table. It needs to collect the real-time traffic information and the process is as follows: The node *Ns* who needs to establish a sort table sends a collect packet (CPi) to each candidate adjacent intersection *Ii*, and records the time when the CPi is sent in the CPi. The node *Nr* which is located within the one hop transmission range of the intersection at where the node *Ns* is located receives the CPi, and records the time when the CPi is received in the CPi. Table 2 is the format of CPi in LSHR. The node who received the CPi calculates the unit of communication delay τ_{ji}, and records the τ_{ji} and the corresponding intersection's ID in a reference packet. Then broadcasts the reference packet to all neighboring nodes, and the τ_{ji} is calculated as:

$$\tau_{ji} = (t_2 - t_1) / l_{ji} \, . \tag{3}$$

t_1 and t_2 represent the timestamps when the CP corresponding to the candidate intersection j is sent and received, respectively. l_{ji} is the length of road segment between the candidate intersection whose ID is j and the current intersection i. Then, the node who receives the reference packet extract the intersection's ID and the unit of communication delay in reference packet, and sorts both of them by ascending values of the unit of communication delays. The node stored the sort table in its cache, and then broadcasts the sort table to all neighboring nodes. Finally, calculates a weight value for all candidate adjacent intersections according to the contents of the sort table and the positions of the intersections:

$$W_j = \alpha \cdot \tau_{ji} + \beta \cdot D_j \, . \tag{4}$$

W_j in the formula represents the weight value of the candidate adjacent intersection whose ID is j. D_j refers to the distance from the candidate adjacent intersection j to the destination. α and β are constants for two different values, and both of them are greater than 0 and the sum of them is equal to 1. The selecting temporary destination is the intersection that has the minimum weight value, and fills in the packet's dynamic address field with the ID of the corresponding intersection.

3.2 Data Transmission Strategy on 3D Sections

When the current node receives a packet, it first determines the current temporary destination, after that, data transmission starts. From the above description, we can see the intersection that corresponding to the ID which is recorded in the packet's dynamic address field is the destination for packet transmission. The current node checks its neighbor list to see whether there exist some nodes that are closer to destination node than current node.

If there are some neighbors closer to the destination than current node, calculate a virtual distance for all these neighbor nodes. Here, the virtual distance refers to the node forwards the packet through one of its neighbors, the largest two-hop distance the packet can be transmitted to. It equals to the distance between the current node and the neighbor node plus the neighbor node's d_f or d_b. If the temporary destination intersection is the front port of the neighbor node, plus d_f ; otherwise, plus d_b. As shown in Equation (5):

$$d = \begin{cases} d_{nc} + d_f, \\ d_{nc} + d_b, \end{cases} . \tag{5}$$

Finally, choose the neighbor has the largest virtual distance as the next hop. The node received the packet checks the ID recorded in the packet's destination address field. If the ID coincides with the node's own ID, the received packets are submitted to the MAC layer and the routing process finish. Otherwise, check the ID recorded in the packet's dynamic address field, if the ID coincides with the intersection ID where the node is located at, the node selects the next temporary destination intersection.

If there are no neighbor nodes that are closer to the destination than current node, then current node will carry the packet for some distance until meeting with other nodes, that is, when a neighbor appears on the direction to approach the destination, forwards the packet to the neighbor node based on the above metric.

4 Performance Evaluation

We study the performance of LSHR via NS2 [21]. GPSR is the most fundamental geographic routing and first propose the most widely used strategy in VANETs, i.e. greedy forwarding. In addition, GPSR is the basis for most of the geographic routings and often used as the comparison protocol. Meanwhile, there is little agreement to consider a 3D scene and we use GPSR as the research object to analyze the issues in the Section 2. So, we evaluate the performance of LSHR with the 2D-GPSR and 3D-GPSR, respectively. The last comparison protocol is another classic routing AODV.

4.1 Simulation Settings

We set the simulation scenario as shown in Fig. 3, which presents a grid layout with 10 intersections, size 2500m*2500m. The intersection ID from the bottom to the top, from the left to the right is in the order of 1 to 10. The road between the intersection 7 and the intersection 8, i.e., on which the vehicle 19 and the vehicle 22 are located at

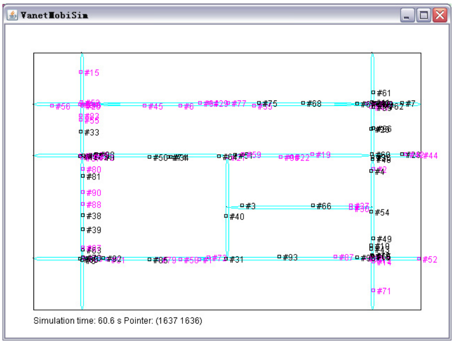

Fig. 3. Simulation scenario

this time, is the overpass. The height of the overpass is 10 meters. The transmission ranges of the same layer and the inter-layer are 250m and 200m, respectively. There are 60 vehicles randomly distributed on the roads and the vehicles velocity ranges from 10m/s to 20m/s. The simulation time is 150s and each simulation running contains 10 random source-destination pairs. A packet size is 512bytes. The values of α and β are both 0.5, it is because that we can get the best performance of the protocol LSHR when α and β are equal to 0.5. The map is generated by the VanetMobiSim. The mobility model in this scenario we used is Intelligent Driver Model (IDM). The mobile model makes the motion state of each vehicle in the scene such as velocity, acceleration by the surrounding vehicle restrictions to keep a safe distance. At the same time, this model also supports the simulation of lane change and overtaking behavior. We repeat the simulation process 20 times for a given scenario.

4.2 Simulation Results

As shown in Fig. 4, we compare the packet delivery ratio of four protocols. The average packet delivery ratio of LSHR is about 81.4%, while that of 2D-GPSR and 3D-GPSR are about 70.4% and 63.5%. Since LSHR can obtain the road connectivity

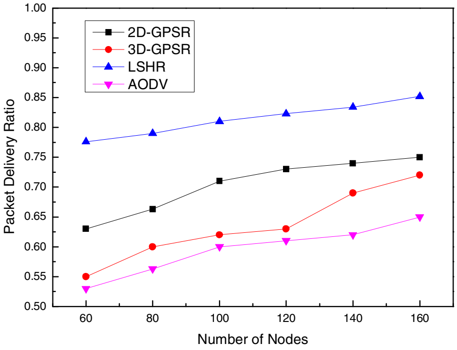

Fig. 4. Packet Delivery Ratio vs. Number of Nodes

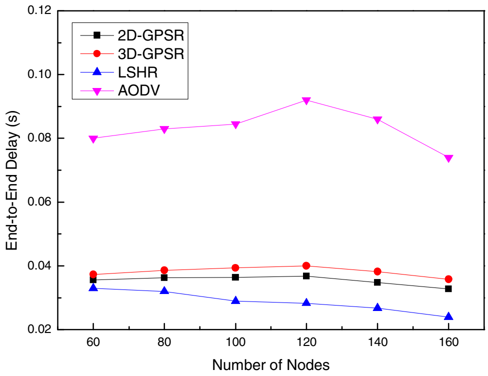

Fig. 5. End-to-End Delay vs. Number of Nodes

more accurately, it selects the sections that in good conditions to transmit packets, increasing the packet delivery ratio. However, GPSR uses perimeter mode when the greedy forwarding fails that will increase the probability of packet dropping. So, the packet delivery ratio of LSHR is higher than that of GPSR. Meanwhile, the packet delivery ratios of geographic routings are higher than that of AODV, it is because AODV uses the information about links to perform packet forwarding. Due to the highly dynamic topology changes, AODV suffers from routing breaks.

Fig. 5 illustrates the variation of end-to-end delay with the number of nodes. The end-to-end delay of 2D-GPSR ranges from 0.033s to 0.036s, while that of 3D-GPSR increases from 0.036s to 0.037s. However, we find that the end-to-end delay of LSHR is always lower than that of both 2D-GPSR and 3D-GPSR. For one reason, during the transmission of a packet, LSHR prior selects the neighbor who has the largest transmission range of two hops as the forwarding node. For the other reason, LSHR selects the sections that in good conditions to transmit packets, and the selected path not only has shortest possible transmission distance, but also has stable network connectivity. It increases the probability of successful transmission of a packet, and reduces retransmission. So, the end-to-end delay of LSHR is reduced. Moreover, the end-to-end delay of AODV is much higher than that of other three protocols. It is because AODV is not suitable for highly dynamic networks, and suffers from frequently routing breaks. It needs to often re-establish the route, and it will take a long time.

Fig. 6 shows the performance of the hop count. The hop count of LSHR is nearly 5.6. For 2D-GPSR, the hop count ranges from 6.6 to 7.4, while that of 3D-GPSR ranges from 6.8 to 7.9. The hop count of LSHR achieves 1.2 and 1.6 average gain compared with 2D-GPSR and 3D-GPSR, respectively. It is because LSHR selects the node that has the largest value of virtual distance as the next hop. When packets were transmitted to the same distance, LSHR needs fewer hop count than GPSR. Since AODV selects route hop by hop, while GPSR based protocols take greedy forwarding which always chooses the farthest neighbor in the current node's communication range. The hop count of AODV is higher than that of GPSR based scheme.

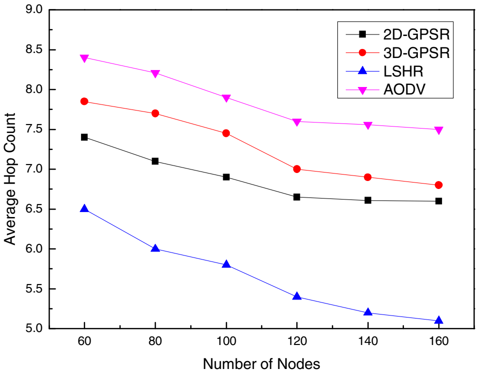

Fig. 6. Average Hop Count vs. Number of Nodes

5 Conclusion

In this paper, we propose a Link State aware Hierarchical Road routing (LSHR) which contains intersection judgment strategy and data transmission strategy on the 3D sections. Moreover, LSHR can represent the roads connectivity more accurately. To verify the performance of the protocol, we compare it with 2D-GPSR, 3D-GPSR, and AODV in a simple 3D scenario. The simulation results show that when the number of nodes changes, LSHR's packet delivery ratio is increased, and the end-to-end delay and the hop count is reduced. It indicates that in such a hierarchical 3D scenario, LSHR could reduce routing hop count and the end-to-end delay, while increasing packet delivery ratio and enhancing the overall performance of the routing.

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