Research on Relay Selection Technology Based on Regular Hexagon Region Segmentation in C-V2X

Zhigang Li [1], Xinan Yue [1], Xin Wang[1], Baozhu Li[2*] and Daoying Huang[1]
[1] The School of Computer and Communication Engineering, Zhengzhou University of Light Industry
Zhengzhou, 450002 P. R. China
[e-mail: Lizg. cn@hotmail. com, 1950572443@qq. com, xinwang_m@163. com, dyhuang@zzuli. edu. cn]
[2] Internet of Things & Smart City Innovation Platform, Zhuhai Fudan Innovation Institute
Zhuhai, 519000 P. R. China
[e-mail: tiger_1984@yeah. net]
[*]Corresponding author: Baozhu Li

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Abstract

Traffic safety and congestion are becoming more and more serious, especially the frequent occurrence of traffic accidents, which have caused great casualties and economic losses. Cellular Vehicle to Everything (C-V2X) can assist in safe driving and improve traffic efficiency through real-time information sharing and communication between vehicles. All vehicles communicate directly with Base Stations (BS), which will increase the base station load. And when the communicating vehicles are too far apart, too fast or there are obstacles in the communication path, the communication link can be unstable or even interrupted. Therefore, choosing an effective and reliable multi-hop relay-assisted Vehicle to Vehicle (V2V) communication can not only reduce the base station load and improve the system throughput but also expand the base station coverage and improve the communication quality of edge vehicles. Therefore, a communication area division scheme based on regular hexagon segmentation technology is proposed, a relay-assisted V2V communication mechanism is designed for the divided communication areas, and an efficient communication link is constructed by selecting the best relay node. Simulation results show that the scheme can improve the throughput of the system by nearly 55% and enhance the robustness of the V2V communication link.

Keywords: Communications link, C-V2X, regular hexagon segmentation technology, relay selection.

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1. Introduction

As the number of cars grows, traffic safety and urban congestion become more and more serious. The frequent occurrence of traffic accidents has caused great casualties and economic losses [1-2]. In order to improve driving safety and reduce the occurrence of traffic accidents. The combination of 5G technology and Internet of vehicles technology forms Cellular Vehicle to Everything (C-V2X) to realize real-time information sharing between vehicles, which can effectively alleviate traffic congestion and improve driving safety [3-5]. C-V2X introduces cellular communication technology, and all vehicles communicate directly through the base station, which will increase the load of the base station. Therefore, how to choose vehicle-to-vehicle (V2V) communication assisted by relay nodes can reduce the load of the base station, improve the system throughput, expand the communication coverage of the network, and enhance the communication quality of the network. When vehicles are used as communication nodes in V2V communication, network topology changes rapidly, and communication links between vehicles are unstable or even interrupted due to complex geographical environments and buildings. Due to the limited coverage of the network, vehicles at the edge of the network have a low chance to obtain information [6-8]. Therefore, the research on multi-hop V2V relay selection technology has become a hot spot for current researchers.

C-V2X communication utilizes physical proximity between vehicles and infrastructure to enable direct communication between adjacent vehicles in a cellular network and between vehicles and infrastructure while ensuring the availability of cellular communications. Overall spectrum utilization can be significantly improved by allowing V2X (Vehicle to Everything) communication to share the same spectrum resources as cellular communication [5, 9]. But between vehicles and between vehicles and infrastructure in the process of communicating with each other, because of distance, speed, or obstruction, et al, the sender's information vehicles (source vehicles) can’t directly and infrastructure or other mobile vehicles direct communication, so need to using cooperative relaying information, and then implement and infrastructure and other vehicles communicate with each other. By using relay vehicles to forward data packets, the load of base stations will be reduced, the system throughput will be improved, and the communication range will be expanded.

In this paper, idle vehicles are used as relay nodes to assist V2V communication. In C-V2X, auxiliary V2V communication through relay can reduce the load of the base station and improve the throughput of the system, so that the vehicles at the edge of the base station signal have more communication opportunities and expand the communication range. Due to the mobility of vehicles, the received signal strength of communication vehicle pairs may vary greatly. When the distance between the sender and receiver exceeds a certain distance, the communication link may be released and interrupted. This problem is even more challenging for multi-hop V2V communication because when any node on the communication path leaves, the entire path becomes unavailable. In order to solve the above problems, this paper proposes to simplify the routing problem in dynamic scenes by using regular hexagon segmentation technology. We first divide the communication range into several regular hexagons of equal size, then find the communication link with the highest communication weight from the source vehicle to the destination vehicle, and select relay vehicles from each regular hexagon on the communication link to construct the communication path. When the intermediate vehicles move out of their original regular hexagon area, we can choose another relay vehicle with high communication weight in the same area as the new relay, thus improving the stability of the communication link between the source and destination vehicles.

The structure of this paper is as follows, and related work is discussed in section 2. The third section analyzes the communication scene of the Internet of vehicles based on regular hexagon segmentation technology, and we design the corresponding communication mechanism for the communication scene. The fourth section analyzes the construction of communication links based on regular hexagon segmentation technology and the influence of vehicle mobility on the communication link and discusses the experimental results. Finally, the fifth part summarizes the thesis.

2. Related Works

V2V communication in C-V2X plays a key role in IoT (Internet of Things) security applications. Vehicles can communicate with each other about the current traffic situation on the road. If there is a traffic accident on the road ahead, the information can be transmitted through communication between vehicles to give an early warning to the rear vehicles and make the rear vehicles deal with it in time. Many scholars have done relevant research on how vehicles transmit road safety information to rear vehicles through multi-hop V2V [10, 11]. How to efficiently select the next hop relay node has become a hot research issue in the Internet of vehicles.

Due to the complex geographical environment, the communication signals between vehicles may be blocked by obstacles, and this problem can be improved by selecting appropriate relay vehicles to forward messages. A low-complexity relay selection algorithm is designed by Q-learning to enhance the communication and network performance of Telematics using UAV (Unmanned Aerial Vehicle) assistance, and the relay selection problem is considered as a multi-objective optimization problem [6]. Consider the influence of the building shadow effect on relay selection at intersections. In literature [7], a map-based relay selection algorithm is proposed to dynamically determine whether to transmit data through the gray area of the intersection according to the position of the vehicle and the road information in the digital map. The relay nodes are then selected considering the relative positions of vehicles and intersections to avoid direct data transmission through gray areas. Considering the moving speed and direction, Rahimi S et al. [12] proposed a routing protocol that combines fuzzy logic with geographic routing when forwarding packets. Based on fuzzy logic, the optimal relay nodes around the vehicle are selected according to the vehicle’s speed and direction. An improved AODV routing method was proposed based on fuzzy logic [13], which took the difference between the speed, direction of the vehicle, and the direction of message occurrence as well as the relative difference between the distance of the vehicle and the destination as the input of the modular logic system, and the result generated by the system was considered to be the optimal path. In reference [14], a relay node transmitting power adaptive selection (TDARS) algorithm based on traffic density was proposed to deal with different traffic densities in urban scenes.

In order to solve the broadcast storm problem, Jafer M et al [15]proposed an optimized relay selection scheme based on a multi-objective genetic algorithm. Literature [16] proposed a message broadcast technology to select the next hop of broadcast messages according to the distance to the previous sender and the expected propagation range, so as to reduce redundant transmission and broadcast storms. Li G S et al. [17] proposed a sender- and receiver-oriented broadcast protocol to improve the speed of message transmission by assigning dynamic wait times to sender-oriented relays. An expected transmission speed metric was proposed to evaluate the performance of broadcast transmission speed and to assess the impact of the selected relays on the expected transmission speed. Rehman O M H et al. [18] proposed a bidirectional stable communication (BDSC) relay node selection scheme. Select the appropriate node by considering the link quality with the relay node. The BDSC scheme aims to improve packet transmissibility and reduce end-to-end communication delays in dense networks. Literature [19] proposes a hybrid relay node selection scheme, which takes into account the spatial distribution of the next-hop relay node relative to the current transmitting node while retaining the best features of the existing message transmission protocol. This scheme can improve the performance of vehicle navigation terminals under different node densities, traffic load, and moving speed scenarios.

Considering the selfish behavior of relay users, Xiao Hailin et al [20]. proposed an optimal relay selection algorithm based on the trust evaluation of credit card social network users, which evaluated the trust of users and offer incentives and compensation to users with good trust, and finally selected users with high trust as relay users. Literature [21] proposed an incentive allocation mechanism that rewards honest nodes and punishes malicious nodes and proved its effectiveness against node collusion by using game theory. Many scholars also studied the effect of the selfish behavior of relay nodes on the performance of D2D users in cellular networks. Use an incentive mechanism to encourage relay to actively participate in forwarding information. Literature [22] proposed a signaling-based incentive mechanism for content sharing to encourage relay users to participate in content sharing and select the best relay through optimal strategy to ensure the maximum benefit for relay users. Literature [23] proposed a low-complexity greedy relay selection algorithm combined with an incentive mechanism, which allocated the base station to the channel resources of the information sender to increase the capacity of relay users. Relay users can use these resources to transfer more of their own data. This incentive mechanism can ensure that all users who participate in the relay can benefit from it, and the greedy algorithm can improve the performance of the network.

In this paper, considering the mobility of vehicles in C-V2X, we use regular hexagon Mosaic technology to simplify the routing problem in dynamic scenarios: we first find the shortest regular hexagon path from source to destination, and select relay users from each regular hexagon path to construct the communication path; Then, when the user moves out of their original square, we can simply select another user in the same square as the new relay user. Considering the selfish behavior of users, we choose an incentive mechanism to encourage users to participate in forwarding messages.

3. Communication Scenarios and Analysis

We study multi-hop V2V communication in C-V2X, where V2V vehicles are independently distributed in each regular hexagonal area. A pair of V2Vs can communicate directly with each other or with one or more mobile vehicles acting as relay agents. We define mutually communicating source and destination vehicles as vehicle communication pairs, the source vehicle forwards the information to the destination vehicle via the relay vehicle. All vehicle information is stored in the base station and the source vehicle can obtain information about the vehicle from the base station. All vehicles within the same hexagon can communicate directly and when the destination vehicle has received the message it can send it to the other UEs in the area. the V2V vehicles (source, relay, or destination) communicate with each other directly or form a communication link via one or more relay vehicles. The communication link from the source vehicle to the destination vehicle of the communication pair is called the communication path. Considering the mobility of the vehicle, the communication link between the two may be interrupted, in order to improve the quality of dynamic scenarios user communication, maximize the system throughput, and expand the scope of communication, we will be the whole communication area divided into many small hexagons, a hexagon in each area, and select the idle vehicles as relay users to deal with the problem.

Regular hexagon segmentation technology is to divide the target region into regular hexagons, which is also suitable for regular polygon segmentation. With this technique, we can divide the C-V2X communication range into multiple regular hexagons, and effectively find the best communication link when all communication paths are given, as shown in **Fig. 1**. In this paper, we consider that vehicles in the same regular hexagon area or adjacent regular hexagon area can communicate directly.

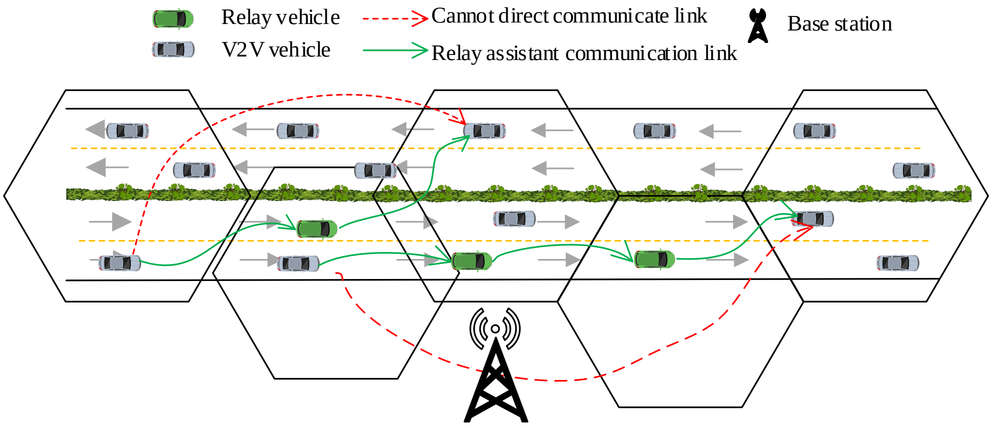

Fig. 1. Communication Scenarios

In the Internet of vehicles, due to the high-speed movement of vehicles and the complex road environment, the communication link between the two parties who want to communicate is unstable or even interrupted. Therefore, this paper proposes a relay selection method to select the optimal relay to assist communication between vehicles. The C-V2X communication area is divided into m regular hexagons of equal size by regular hexagon segmentation technology, and each regular hexagon contains N vehicles. Vehicles within each regular hexagon and vehicles between adjacent regular hexagons can communicate directly.

In this paper, we assume the side length of the regular hexagon and obtain the position of the six vertices of the regular hexagon through GPS technology. The position of the six vertices calculates whether the vehicle is in the regular hexagon region. As shown in **Fig. 2**.

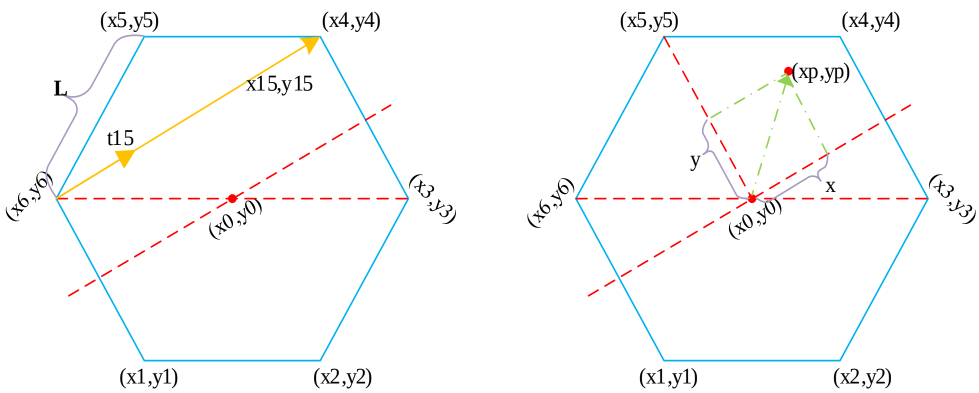

Fig. 2. Identify the regular hexagon area of the vehicle

The central coordinates of a regular hexagon are expressed in (1):

$$\boldsymbol{o}=(x_0, y_0)=\left(\frac{x_6+x_3}{2},\frac{y_6+y_3}{2}\right) \tag{1}$$

The unit vector with (x_4-x_6, y_4-y_6) as the positive direction can be expressed as:

$$\boldsymbol{T}=\left(\frac{x_4-x_6}{\sqrt{3}L},\frac{y_4-y_6}{\sqrt{3}L}\right) \tag{2}$$

The vector $\boldsymbol{top}$ established by the center point o and point p can be expressed as:

$$\boldsymbol{top}=\left(x_p-x_o, y_p-y_o\right) \tag{3}$$

then $x=\boldsymbol{top}\cdot\boldsymbol{T}$, $y=\sqrt{\|\boldsymbol{top}\|^2-x^2}$, if $y>L$ or $x>\sqrt{3}/2L$ then the vehicle is not in the regular hexagon area. If $L<x/\sqrt{3}+y$, the vehicle is also not in the regular hexagon area, otherwise the vehicle is in the regular hexagon.

Many scholars have done relevant research on how vehicles transmit road safety information. Next, we will detail the multi-hop V2V communication mechanism and solve the following problems:1) how to build communication paths and 2) how to handle user mobility. Our relay-assisted V2V communication mechanism works as follows.

Build communication links: In this process, the base station identifies the regular hexagon regions in which communication begins in the time slot and constructs communication paths for them. We represent the set of regular hexagon area pairs that communicate with each other in the current time slot as communication pairs, and the set of vehicles, other than the source and destination units on the link, that is not involved in the communication during the communication time slot and are willing to pick up for others are indicated as idle users, the length of time to maintain vehicle communication is expressed as communication time, and by calculating the communication time between vehicles, the communication time is used as the communication link weight, and the best relay vehicle is selected according to the maximum communication link weight. We consider the actual road distribution, as shown in **Fig. 3** in the street scene in Cologne. The specific steps are as follows.

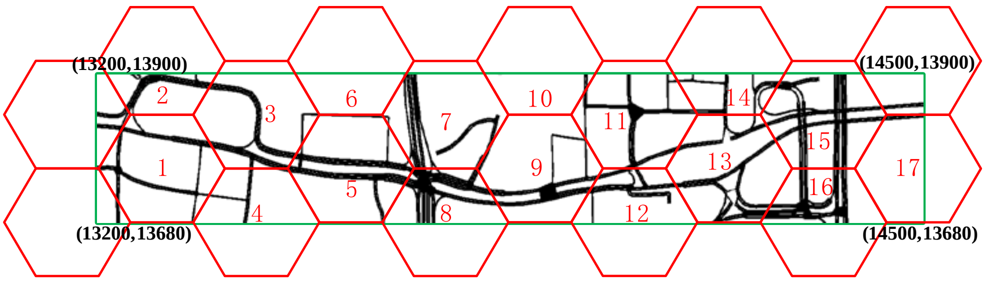

Fig. 3. Exploring the communication link

(1) Determine the regular hexagon area of communication through the base station, and we take the regular hexagon area pairs that communicate with each other as communication pairs. The idle vehicles in the remaining regular hexagon area on the communication pair area path are regarded as relay vehicles and represented as idle users. We take the communication

duration that can be maintained between communication vehicles in the adjacent regular hexagon area within the time slot as the weight of the communication link, and construct the communication path for the communication pair.

(2) For the ith communication pair, we first construct a regular hexagon path. The idle vehicles in the adjacent regular hexagon area are used as the relay, and the communication time is calculated as the weight of the communication link to construct the communication path. Then we use the maximum weight $Q_{\max}$ to find the best communication path between the source block and the target block.

$$Q_{\max} = \sum_{i=1}^{n} l_i \tag{4}$$

where l_i and $i = (1,...,n)$ indicate the weight of a one-hop link.

(3) Next, we from in addition to the source and destination of hexagonal region, belong to the ith a communication of the hexagonal region of communication path to relay users, we according to the communication from each intermediate hexagonal slot relay on the vehicle and a jump in the communication between the time to choose a belong to free the user collection vehicles as a relay, And remove the occupied relay vehicles from the idle user set; Otherwise, the communication between the source and destination is considered unavailable in the current time slot, and we remove the ith communication pair from the communication pair set and add it to the idle user set.

(4) The base station builds a communication path for the communication pair by repeating steps (2) and (3). Each time after building the communication path, we need to remove the selected relay vehicles from the idle users.

However, due to the mobility of vehicles, ongoing V2V communication links may be interrupted. This can be reduced by properly screening candidate relay vehicles in the first step of exploring communication links. More specifically, the base station can remove vehicles with high moving speeds from idle vehicles in the current timeslot to avoid using such vehicles as relay vehicles. Then the communication link will not be interrupted by the mobility of the relay user within each timeslot.

Update the link: When a vehicle moves in a communication area, the relay, source, and destination may leave their original regular hexagon area, and some communication links will become unavailable. Therefore, the base station needs to perform an update operation: replan the communication path. There are two types of vehicle mobility, relay vehicle mobility and V2V source and destination vehicle mobility. Here, we assume that the position of the vehicle is known. In each timeslot, the update operation is as follows.

(1) Update the location of each vehicle.

(2) Check whether the source or destination vehicle of the communication pair is far away from its original regular hexagon area. If so, repeat steps (1)-(2).

(3) Check whether one or more relay vehicles on the communication link have moved away from their original regular hexagon area and if so, check whether there are other idle relay users in the regular hexagon area where the relay vehicles are located. If so, the vehicles that are willing to be relayed and have a high weight of communication links are selected from these regular hexagonal areas as relay vehicles to replace the previous relay nodes and repeat step (2) only.

(4) If not, this means that the original communication path is disconnected. Repeat steps (1)-(2). If no relay vehicles, source, or destination vehicles leave their original regular hexagon area, then simply repeat step (2).

4. Analysis of Experimental Results

The vehicle mobility data set used in this article is based primarily on data provided by the TAPASCologne Project. The street layout of cologne city was obtained from the OpenStreetMap (OSM) database, and the micro-mobility of vehicles was simulated using the Simulation of Urban Mobility (SUMO) software. The data set collected mobility data of over 700, 000 vehicles for 24 hours, covering an area of 400 square kilometers [24, 25]. We analyzed the proposed relay selection scheme in the network of vehicles by selecting vehicle mobility data of 286000 square meters covering an area for four hours in a row from the dataset. We construct an efficient communication link by selecting the best relay node, and calculate the weight of the communication link as the communication time that can be maintained by the vehicles communicating with each other in the adjacent regular hexagon region. The scheme in this paper can effectively improve the stability of communication links in the Internet of vehicles and reduce the interruption of communication links caused by vehicle mobility.

We selected the road scene of 286000 square meters in Cologne as shown in **Fig. 3**, and selected the vehicle data of 4 hours. For the convenience of analysis, we initialized the corresponding vehicle numbers in the data. We divide the road scene into 16 regular hexagons through the regular hexagon segmentation scheme, and each regular hexagon has a side length of 100m. We assume that the maximum communication distance of each vehicle is (200m - 300m). Specific data are shown in **Table 1**.

Table 1. Simulation parameters

Parameter	Parameter value
Simulation area	286000m^2
Number of vehicles	871
Maximum radius of vehicle transmission	200m ~ 300m

As shown in **Fig. 4**, we randomly select a vehicle with ID=389 from the no. 1 regular hexagon area in **Fig. 3** as the source vehicle to communicate with the target vehicle in the no. 5 regular hexagon area. The vehicle ids that communicate in the no. 1 and no. 5 regular hexagon area are 378, 377, 379, 401 respectively in the communication time slot, where the numbers on the connecting lines indicate the link weights between the communicating vehicles. Link weights are calculated as shown in **Fig. 4**. According to our proposed relay selection method, the base station determines the pairs of positive hexagonal communication areas in the communication time slot, and in **Fig. 4**. determines the communication in areas 1 and 5, and selects the relay vehicle in area 3. The link weight between the selected relay vehicle and the source vehicle in area 3 within the communication time slot is 3. Therefore, both vehicles with ID = 393 and ID = 397 can be used as relay vehicles for the source vehicle with ID = 389. According to the proposed maximum link weight as the best relay vehicle mechanism, the maximum link weight for a relay vehicle to communicate with area 5 during the communication time slot is 14, i. e. the link weight for a relay vehicle with ID = 397 to communicate with area 5 with ID = 378. Therefore the best relay vehicle is ID = 397 and the best communication link that can be constructed between 1 and 5 is 389 -397 -378.

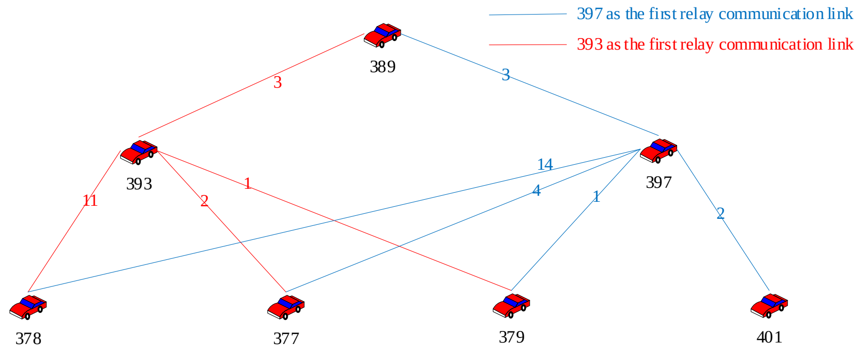

Fig. 4. Relay selection without link interruption caused by vehicle movement

Considering the mobility of the vehicle, when the vehicle walks randomly in the regular hexagon area, the relay vehicle, the source vehicle and the destination vehicle may all move away from their original unit, so the communication link will become unavailable. In this case we need to reexplore the communication link. As shown in **Fig. 5**, we analyze the situation of re-selection of relay vehicles when they move in the communication link constituted by regular hexagon area 1, 3 and 5 in **Fig. 3**. Where the numbers on the connecting lines indicate the link weights between the communicating vehicles. Through the proposed method, the communication time between all vehicles that can communicate in the communication time slot is calculated, and the weight of the communication link is taken as the time to maintain the communication. Select the idle vehicle that can maintain the longest communication time as the best relay vehicle.

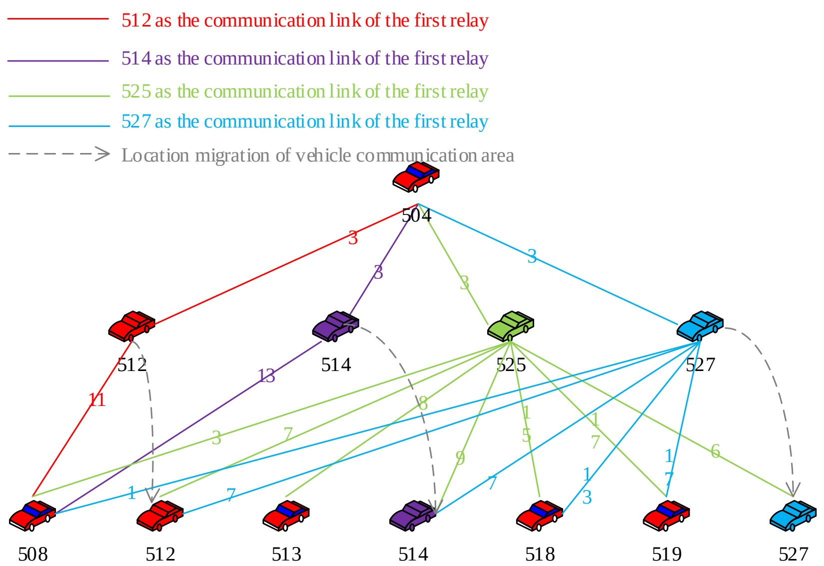

Fig. 5. Relay selection of link interruption caused by vehicle movement.

As shown in **Fig. 5**, source vehicle ID=504 in regular hexagon area no. 1 can communicate with vehicle ID=512, vehicle ID=514, vehicle ID=525 and vehicle ID=527 in regular hexagon area no. 3 in communication time slot, and the communication weight is 3. Vehicle 504 can randomly select a vehicle as a relay vehicle. However, when the information is transmitted to the regular hexagon area no. 5, it can be seen from **Fig. 5** that the communication pair that can maintain the longest communication duration is ID=525 in area no. 3 to ID=519 in area no. 5 and ID=527 to ID=519 in area no. 3. Considering the mobility of the vehicle, the vehicle with ID=527 in the communication time slot moved from regular hexagon area 3 to regular hexagon area 5, causing the interruption of link 504 - 527 - 519. Therefore, the best communication link is 504 - 525 - 519.

This paper evaluates the performance of the relay vehicle selection scheme through the probability of communication link interruption and the ratio of improving system throughput. Assume that all vehicles can conduct single-hop V2V communication or multi-hop V2V communication. Firstly, the selected communication area is divided into regular hexagon with the same size by the regular hexagon area segmentation technology. In the communication time slot, the communication area pair is determined by the base station, and the vehicles communicating with each other in the communication area pair serve as the V2V communication pair. Secondly, take maintaining the communication duration between vehicles as the link weight between each hop to select relay vehicles, and take the relay vehicle with the highest link weight as the best relay vehicle as the V2V communication pair to construct the best communication link. This chapter divides the selected communication area into 17 regular hexagon of equal size as shown in **Fig. 3**, and calculates the probability of communication link interruption with the increase of the number of relays within 4 hours. As shown in **Fig. 6**, the proposed scheme of selecting the best relay for the longest communication time is compared with the scheme of selecting relay through the shortest communication distance, and the problem of the probability of communication link interruption caused by the increase of the number of relay vehicles is analyzed. The result analysis shows that the more relay vehicles, the higher the probability of V2V communication link interruption. This is because the mobility of vehicles will lead to unstable communication links. Therefore, as the number of relay vehicles increases, the more unstable the communication link is, the higher the probability of interruption. We propose that the mechanism of dynamically updating communication links can better enhance the stability of V2V communication links.

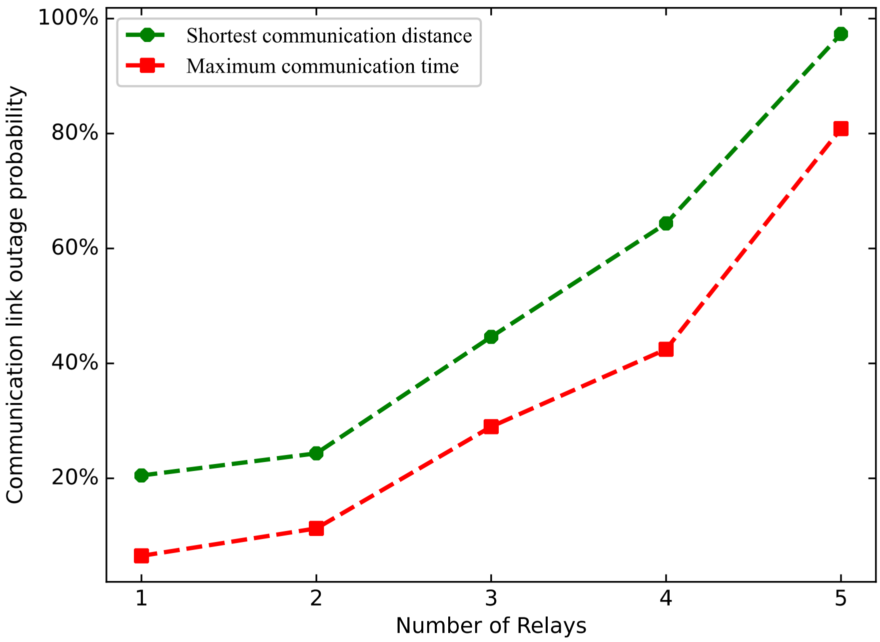

Fig. 6. Influence of different number of relays on the probability of communication link outage probability.

We use the same data to compare the impact of V2V communication with different hops on the throughput of the whole system. As shown in **Fig. 7**, the increase of system throughput when only one hop is considered is higher than that in scenarios where only two, three, four, and five hops are considered. This is because the higher the number of hops between V2V communication pairs, the higher the probability of communication link interruption. Therefore, as the number of hops of V2V communication pairs increases, the effect on improving system throughput becomes smaller. It can be seen from **Fig. 7** that the scheme of maintaining the communication duration as the communication link weight and selecting the relay vehicle through the maximum communication link weight is better than the scheme of selecting the relay vehicle through the shortest communication distance to improve the system throughput. Because the movement of vehicles will lead to instability or even interruption of V2V communication link, we propose to select relay vehicles by the maximum communication link weight, and dynamically select relay vehicles by judging the position of vehicles in the regular hexagonal area. When the relay vehicles in the communication link leave the area, relay vehicles with higher vehicle weight will be selected from the collection of idle vehicles to maintain communication, which can better enhance the stability of V2V communication link, this improves the system throughput.

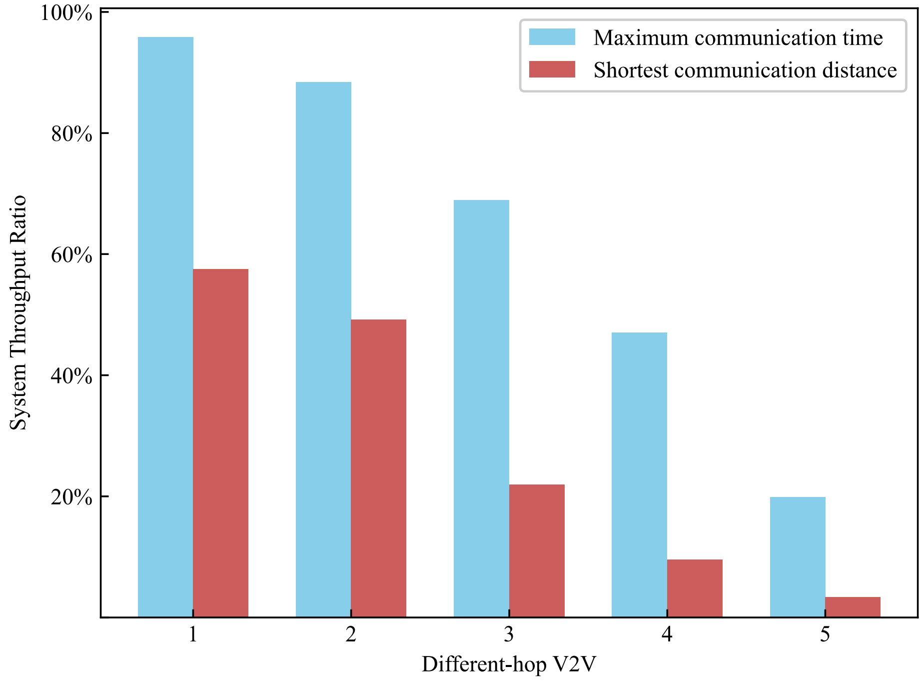

Fig. 7. Deferent-hop V2V improves the system throughput ratio.

5. Conclusion

In this study, an auxiliary V2V communication relay selection technology based on regular hexagon region segmentation in C-V2X is proposed. Idle vehicles in the region are used as relay vehicles to enhance the robustness of V2V communication links and improve the throughput of the system. We divide the communication area into several regular hexagon with equal size by regular hexagon segmentation method, determine the communication area pair in the communication time slot by base station, and select the vehicle that can maintain the longest communication link in the communication area as the relay vehicle of V2V communication. Considering the instability and even interruption of communication links caused by vehicle mobility, we propose a V2V communication mechanism of dynamic planning communication links, which can support multi-hop V2V communication in dynamic scenarios to ensure the stability of communication links. Through experimental analysis, the optimal relay selection scheme based on regular hexagon segmentation technology proposed by us can easily and quickly select the optimal relay, effectively improve the throughput of the system and enhance the robustness of V2V communication links. Because the simulated data cannot completely simulate the traffic scene in the real world, the design of the model is not comprehensive enough. In future work, relay vehicles will be selected through deep learning model training, so that the model can better adapt to the real environment.

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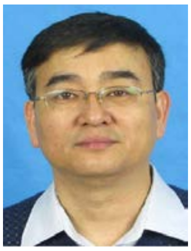
Zhigang Li received the Ph. D. degree from Beijing University of Posts and Telecommunications (BUPT) in 2016. He is currently a research staff of Zhengzhou University of Light Industry (ZZULI), Henan, China. His current research interests include mobile computing, cellular network and C-V2X.

Xinan Yue is currently working toward a master's degree with the School of Computer and Communication Engineering, Zhengzhou University of Light Industry (ZZULI), Henan, China. Her current research interests include VANETs and C-V2X.

Xin Wang is currently working toward a master's degree with the School of Computer and Communication Engineering, Zhengzhou University of Light Industry, China. His current research interests include VANETs and C-V2X.

Baozhu Li received the Ph. D degree in computer science and technology from Beijing University of Posts and Telecommunications, Beijing, China, in 2017. From 2013 to 2014, he was a Visiting Student with the Broadband Communications Research (BBCR) Lab, Electrical and Computer Engineering, University of Waterloo, Waterloo, ON, Canada. He is currently with the Internet of Things & Smart City Innovation Platform, Zhuhai Fudan Innovation Institute. His research interests include vehicular networks, mobile edge computing, machine learning and resource management.



Daoying Huang received the Ph. D. degree from PLA Information Engineering University in 2004. He is currently a professor of Zhengzhou University of Light Industry (ZZULI), China. His current research interests include mobile computing, computer network and artificial intelligence.