Relay-node Selection Method Based on Weighted Strategy for 3D Scenario in Internet of Vehicles

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Abstract

In recent years, Internet of Vehicles (IoV), as a supporting technology for Intelligent Transportation System (ITS), is flourishing with the emergence and development of new technologies such as edge computing, 5G communication, and Artificial Intelligence (AI). However, the more complexity of wireless channels and vehicle distribution in 3D scenario brings a great challenge for relay-node selection in ITS. In this paper, we focus on how to alleviate the problem that the decline of two-hop distance and two-hop connection probability caused by the relative fading of inter-layer communication radius in 3D scenario with Vehicle-to-Vehicle (V2V) communication. To face this challenge, we develop a Relay-node Selection method based on Weighted Strategy for Overpass scenario (RSWSO). The simulation results show that RSWSO achieves improvement in two-hop distance, and an increase of up to 11.2% in terms of two-hop connection probability.

Keywords: Relay-node selection, Internet of Vehicles, 3D scenario, Two-hop connection probability, Two-hop distance

1 Introduction

Internet of Vehicles [1-3] is a critical enabling technology with the intelligent connections among roadside infrastructures, vehicles, and pedestrians in Intelligent Transportation System (ITS) [4-5]. Through the acquisition and sharing of the rich sensed information, Internet of Vehicles (IoV) provides strong support for the practice of the safety-assisted driving and ultimately enables the vehicles to achieve autonomous driving. The relay-node selection plays an essential role in the Internet of Things (IoT) [6-10] and ITS. The main idea of relay-node selection is to select the optimal node as relay-node through a reasonable algorithm, which helps to achieve the minimum delay and maximum coverage of message transmission [11]. Thus, it can transmit messages faster, improve the efficiency of transportation and reduce traffic accidents.

To improve transportation efficiency while saving valuable land resources, more and more large and medium-sized cities are accelerating the construction of 3D roads such as overpasses, tunnels and urban expressways. These 3D roads have far more complex characteristics than 2D roads. For example, within the communication range of the sender on the overpasses, the road structure is multi-layer. Due to the obstacles between the sender and receiver, the wireless channel is worse in different layers than that in the same layer. Therefore, there are two types of communication between the sender and receiver in 3D scenario: intra-layer communication and inter-layer communication [12]. The radius of inter-layer communication R' will be smaller than that of intra-layer communication R due to the obstacles between layers [13-16]. This further brings the problems that two-hop distance decreases and two-hop connection probability reduces. To address these issues, this paper proposes a Relay-node Selection method based on Weighted Strategy for Overpass scenario (RSWSO). The significant contributions of this paper are threefold: (1) The problem of relay-node selection caused by the complexity of communication and vehicle distribution in 3D scenario represented by overpass scenario is analyzed. And the influencing factors and their optimal level are designed; (2) A Relay-node Selection method based on Weighted Strategy for Overpass scenario (RSWSO) is developed to alleviate the problem that the two-hop distance decreases and the two-hop connection probability reduces; (3) The results of simulations to assess the proposed RSWSO achieves performance improvements in terms of the two-hop distance and the two-hop connection probability.

The rest of this paper is structured as follows. Section 2 describes the related work briefly. Section 3 analyses the two problems that exist in 3D scenario. Section 4 proposes RSWSO for the relay-node selection in 3D scenario. We make simulations in Section 5. Section 6 concludes the paper.

2 Related Work

For the relay-node selection methods, the existing research mainly focuses on beacon or black-burst [17] methods. And Greedy Perimeter Stateless Routing (GPSR) [18] is the most representative method of the former. GPSR gains the location information of neighbors through beacon, and determines the node closest to Destination as relay-node.

Urban Multi-hop Broadcast protocol (UMB) [19] achieves low latency by using black-burst [20] to block the channel and determine the farthest node as the relay-node. The period of black-burst is proportional to the distance

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from the sender. Thus, the one-hop propagation distance reaches maximum value. Binary-Partition-Assisted Broadcast protocol (BPAB) [21] and Trinary Partitioned Black-Burst-based Broadcast protocol (3P3B) [22] applies iterative partitioning to determine the furthest nonempty segment via black-burst. BPAB and 3P3B select relay-node in the furthest nonempty segment by randomly backing off for a certain amount of time. These two methods achieve higher message delivery speed by smaller partition delay, but have higher contention delay at high vehicle density. Our team previously proposed a robust distance-based relay selection [23]. This method achieves a high message propagation speed in general scenarios and an admissible propagation delay in unfavourable situations. What's more, mobile relay communication system is researched for Unmanned Aerial Vehicle (UAV) [24] to maximize the number of completed tasks on both UAV and Access Point (AP).

All the above relay-node selection methods are suitable for 2D scenario. However, in 3D scenario, there may be a multi-layer structure, which makes the distribution of nodes and the conditions of wireless channel more complicated. Therefore, the performance of relay-node selection method in 2D scenario is deficient when directly applied to 3D scenario, so it is necessary to investigate relay-node selection method in 3D scenario. The paper [10] proposed a Greedy Opportunity Forwarding (GOF) algorithm to alleviate the problems of increased hops and decreased delivery rate that exist in two-layer straight road scenario. However, GOF does not consider its applicability in complex 3D scenario such as overpass scenario. This paper proposes a Relay-node Selection method based on Weighted Strategy for Overpass scenario (RSWSO), which alleviates the decline of the two-hop distance and the two-hop connection probability due to the smaller inter-layer communication radius than the intra-layer communication radius. The method is applicable to relay-node selection in overpass scenario. Compared with GPSR, the method improves the two-hop distance and the two-hop connection probability, thus enhancing the real-time and effectiveness of message transmission.

3 Problems Description and Analysis

In this section, we describe and analyse the two-hop distance decreases and the two-hop connection probability reduction that exist in 3D scenario.

Problem 1: As shown in Figure 1, Lane1 and Lane2 are the upper road and the lower road along the direction of message propagation, respectively. Direction of message propagation is from north to east. The sender S transmits the packet to Destination D along the path of S-B1-B2 marked by the orange arrow obeying GPSR. However, it is found that there exists a longer two-hop of S1-A1-A2 marked by the red arrow.

Problem 2: As is shown in Figure 2, according to the GPSR, the sender S will select the farthest neighbor B1 as the next hop. But there are no nodes within the transmission range of B1, which will lead to the interruption of message transmission. However, along the path of S-A1-A2 the message can be delivered successfully.

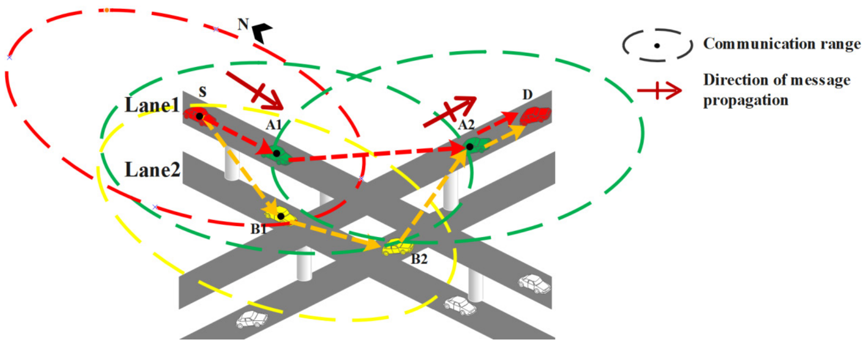

Figure 1. The two-hop distance decreases in 3D scenario

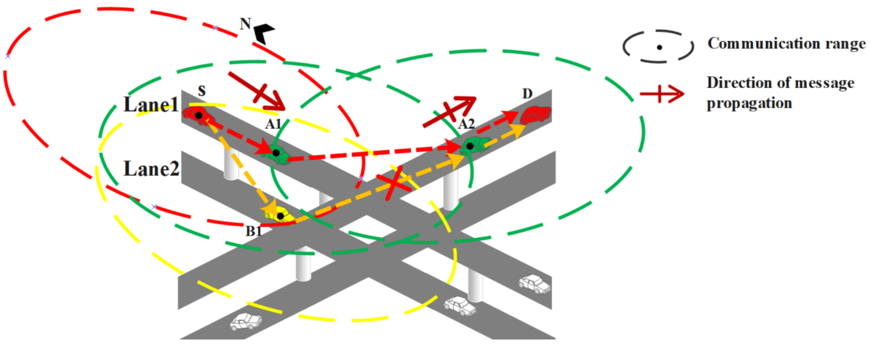

Figure 2. The two-hop connection probability reduction in 3D scenario

Through the above analysis, the differences in communication range between the inter-layer and the intra-layer may cause the problems that both the two-hop distance and two-hop connection probability decrease with the rule of GPSR in 3D scenario. Therefore, in the next section, we investigate a new proposal to address these problems.

4 Our Proposed RSWSO

Considering the complex road scenario such as overpass, the propagation distance is defined as the distance covering the road along the direction of message propagation. Due to larger communication range of intra-layer than that of inter-layer, nodes distributed in the same layer with the sender should be given higher priority. Therefore, this paper combines the propagation distance and the elevation difference to set the priority for each node. A common analysis method is the Analytic Hierarchy Process (AHP) proposed by Saaty [25]. AHP is designed to obtains the weight for propagation distance and the elevation difference as follows:

(1) Establish the hierarchical model of relay-node selection based on AHP

Relay-node selection model includes three layers: target layer, index layer and scheme layer. The scheme layer contains all the neighbouring nodes of the sender. The index layer considers two factors that affect the performance of relay-node selection, which are propagation distance and elevation difference. Relay-node selection is placed in the target layer. We can build a hierarchical model as shown in Figure 3.

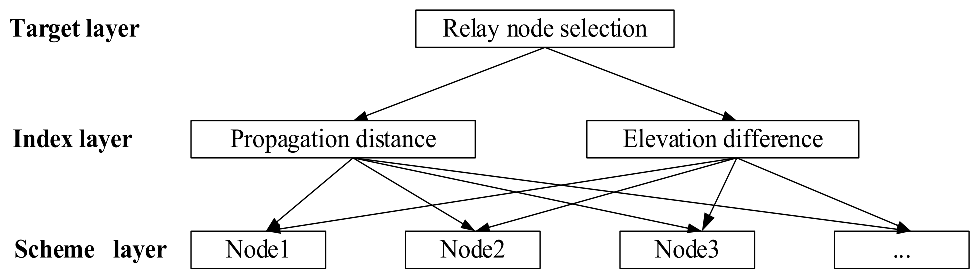

Figure 3. The hierarchical model of relay-node selection

(2) Constructing judgment matrix

After establishing the hierarchical model, it is necessary to quantify relative importance of the propagation distance and the elevation difference. We mark all the factors of index layer as U_1, U_2, ..., U_n. We can use 1-9 and its reciprocal as a scale by AHP in Table 1, then form a judgment matrix $\mathbf{A} = (a_{ij})_{n\times n}$.

Table 1. The definition of scale 1-9

a_{ij}	Implication
1	U_i is equally important than U_j
3	U_i is slightly important than U_j
5	U_i is significantly important than U_j
7	U_i is strongly important than U_j
9	U_i is extremely important than U_j
2,4,6,8	The median value of the above two adjacent judgments
Reciprocal	Results of comparing U_j with U_i

The value of a_{ij} show the importance of U_i relative to U_j. The larger the value of a_{ij} is, the more important U_i is relative to U_j. We set propagation distance and elevation difference as U_1 and U_2 respectively. Therefore, a_{12} represent the importance of the propagation distance relative to the elevation difference. The propagation distance is significantly important than the elevation difference in our paper, so the value of a_{12} is 5 in Table 1. Similarly, a_{11}, a_{21} and a_{22} can be obtained from Table 1. Then **A** is given by

$$\mathbf{A} = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} = \begin{pmatrix} 1 & 5 \\ 1/5 & 1 \end{pmatrix}. \quad (1)$$

(3) Consistency test

In order to obtain the weight that satisfies the consistency test, we need calculate characteristic vector, maximum characteristic root, and consistency ratio *CR*. In this paper, the characteristic vector is represented by **w** and the maximum characteristic root is represented by $\lambda_{\max}$. The calculation process is as follows:

Normalize the column vectors of matrix **A** to obtain matrix $\mathbf{B} = (b_{ij})_{n\times n}$, with

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, \quad (2)$$

where n is the order of the judgment matrix **A**.

Compute the characteristic vector $\mathbf{w} = (\omega_1, \omega_2)$ of **B**, with

$$\omega_i = \frac{\sum_{j=1}^{n} b_{ij}}{\sum_{i=1, j=1}^{n,n} b_{ij}}. \quad (3)$$

Calculate the maximum characteristic root $\lambda_{\max}$, with

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(\mathbf{Aw})_i}{\omega_i}. \tag{4}$$

The consistency problem can be solved by introducing average random consistency index *RI*, *CR*, and consistency index *CI*. It is stipulated that *CR* can be considered as consistent when it meets certain values. If $CR < 0.1$, *CR* can be considered as consistent, then ω_1 and ω_2 can be used as weight of the propagation distance and the elevation difference, respectively. Certain values are the numbers less than 0.1. *CI* is given by

$$CI = \frac{\lambda_{\max} - n}{n-1}. \tag{5}$$

RI are shown in Table 2.

Table 2. Average random consistency index

n	*RI*
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45

CR is given by

$$CR = \frac{CI}{RI}. \tag{6}$$

We set $a_{12} = 5$, get $\mathbf{w} = (\omega_1, \omega_2) = (5/6, 1/6)$ by calculation, finally get $CR < 0.1$. So ω_1 and ω_2 can be used as the weight of the propagation distance and the elevation difference, respectively.

RSWSO is designed with the combined the propagation distance and the elevation difference mapping priority parameters C_p. C_p is used to determine the priority of the nodes within the sender's communication range. Finally node with the largest C_p is selected as relay-node.

Since there may be multiple nodes in the communication range of the sender, RSWSO needs to set the serial number *i* of each node in the communication range. The number of these nodes is N_{node}. $node_i$ is used to represent the *i*th node in the communication range, and the priority parameter corresponding to $node_i$ is C_{p_i}. C_{p_i} is given as

$$C_{p_i} = \omega_1 \cdot \frac{d_{node_i}}{\max\left\{d_{node_1}, d_{node_2}, \cdots, d_{node_i}\right\}} + \omega_2 \cdot \left(1 - \frac{h_{node_i}}{\max\left\{h_{node_1}, h_{node_2}, \cdots, h_{node_i}\right\}}\right), \tag{7}$$

where ω_1 and ω_2 is the weight of the propagation distance and the elevation difference, respectively. d_{node_i} is the propagation distance of $node_i$ from the sender, h_{node_i} is the elevation difference between $node_i$ and the sender.

To alleviate the two-hop distance decreases and the two-hop connection probability reduction that exist in 3D scenario, we propose the algorithm of RSWSO, shown in Algorithm 1.

Algorithm 1. The algorithm of RSWSO

1. Input: the location information of the sender and neighbors
2. Output: relay-node
3. Mark all the factors of index layer as U_1, U_2
4. Set the propagation distance and the elevation difference as U_1 and U_2, respectively
5. Set the value of a_{ij} by Table 1
6. Construct the judgment matrix $\mathbf{A} = (a_{ij})_{n\times n}$
7. Normalize the column vectors of matrix **A** to obtain matrix **B** by Equation **(2)**
8. Compute the characteristic vector $\mathbf{w} = (\omega_1, \omega_2)$ of **B** by Equation **(3)**
9. Set ω_1 and ω_2 as the weight of the propagation distance and the elevation difference, respectively
10. For $i = 1$: N_{node}
11. Calculate the priority parameter C_{p_i} of $node_i$ by Equation **(7)**
12. End
13. The neighbor with the largest priority parameter is selected as relay-node.

5 Simulation Results and Analysis

The purpose of relay-node selection for IoV is to improve the real-time and effectiveness of message transmission. Two metrics are adopted to assess the two performance as follows.

(1) Two-hop distance *d*: The two-hop distance is the propagation distance that covering the road along the direction of message propagation with two hop.

(2) Two-hop connection probability p: The two-hop connection probability is the probability of successful forwarding in the second hop under the condition of successful first forwarding of messages.

To verify the effectiveness of the introduced algorithm, we construct a 3D overpass scenario as shown in Figure 1. The Lane1 is a higher level and Lane2 is a lower level. Assuming that the vehicle space obeys the exponential distribution, and the vehicle distribution parameter of Lane1 and Lane2 are λ_1 and λ_2. Moreover, we consider the radius of intra-layer communication as *R* and the radius of inter-layer communication as R'. δ is the transmission loss of communication radius, which is given by

$$\delta = \frac{R'}{R}. \tag{8}$$

In 3D overpass scenario, the direction of message propagation is from north to east. We mark the vehicle on Lane1 closest to north as the sender, and set the node density unit as vehicle/meter. In the simulation, GPSR as a benchmark method is selected for comparison.

Figure 4 shows the two-hop distance varying with the node density, we set $R = 200$ m and $R' = 130$ m. The solid lines depict the results obtained by RSWSO and the dashed line for GPSR. When $\lambda_1 = 0.1 > \lambda_2$, RSWSO has the larger value of the two-hop distance than GPSR. The same phenomenon appears when $\lambda_1 = 0.05 > \lambda_2$. The reason is that λ_2 varying from 0.005 to 0.05 is smaller than that of Lane1. Then the message packets will be multi-hop transmitted along Lane1, thus increasing the two-hop distance. When $\lambda_1 = 0.005 < \lambda_2$, values of the two-hop distance for the two methods are the same. This is because λ_2 is always bigger than λ_1, then RSWSO selects the farthest neighbor on Lane2 as the relay-node with the identical way of GPSR. Furthermore, When λ_1 is relatively large, the two methods are stable in the two-hop distance as λ_2 increases. It is because λ_1 is always bigger than λ_2, and the packets will be transmitted multi-hop along lane1. When $\lambda_1 = 0.005 < \lambda_2$, values of the two-hop distance for the two methods increase as λ_2 increases. Since when λ_2 is always bigger than λ_1, the two methods select the farthest neighbor from Lane2 as relay-node. Then the value of the two-hop distance depends on λ_2.

Furthermore, When $\lambda_1 = 0.1 > \lambda_2$ or $\lambda_1 = 0.05 > \lambda_2$, values of the two-hop distance for the two methods aren't increase as λ_2 increases. The reason is that λ_1 is always bigger than λ_2, the message will be multi-hop delivered along Lane1 in RSWSO, which is the same as GPSR. When $\lambda_1 = 0.005 < \lambda_2$, values of the two-hop distance for the two methods increase as λ_2 increases. This is because λ_2 is always bigger than λ_1, the two methods select the farthest neighbor from Lane2 as relay-node. Then the value of the two-hop distance depends on λ_2.

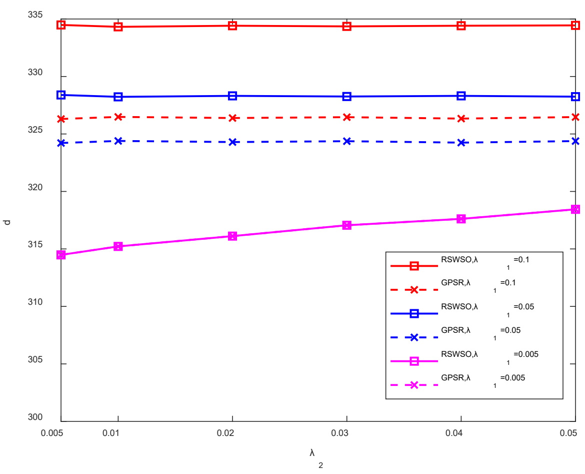

Figure 4. The two-hop distance versus node density

Let $\lambda_1 = 0.05 > \lambda_2$. Then, we give results for the two-hop distance varying with δ in Figure 5. In spite of the value of R, RSWSO provides a larger two-hop distance than that of GPSR. Moreover, all results of the two-hop distance for the two methods increase with δ. RSWSO gets the better performance in terms of two-hop distance when R increases with the same value of δ, and the same phenomenon also exist in GPSR. This is because as R increases, the sender is more likely to determine an usable neighbor as relay-node, and therefore the two-hop distance becomes larger.

From the result depicted in Figure 4 and Figure 5, RSWSO performs better than GPSR in varied vehicle density and transmission loss.

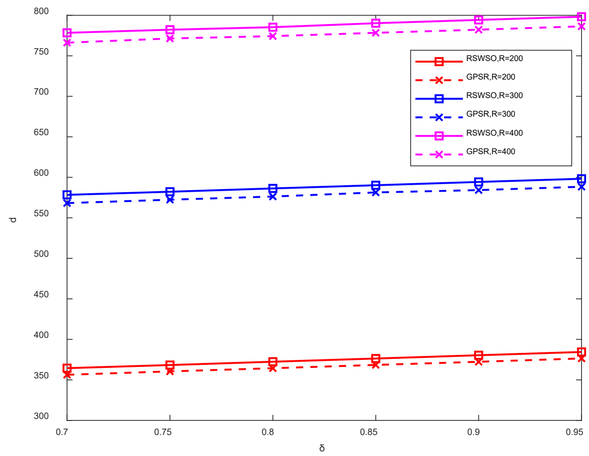

Figure 5. The two-hop distance versus δ

Figure 6 shows the two-hop connection probability versus node density. Let R = 200 m and R' = 130 m. When λ_1 = 0.005, RSWSO has better performance about the two-hop connection probability. The value of the two-hop connection probability for the two methods increases as λ_2 increases. The rationale behind this is that, as λ_1 is consistently smaller than λ_2, RSWSO and GPSR select the node on Lane2 that is furthest away as relay-node. Thus, the specific value of the two-hop distance is determined by the value of λ_2. However, the performance gain of RSWSO will be less obvious. This is because as λ_2 gradually increases, the influence of λ_1 on the two-hop connection probability will become smaller and smaller. When $\lambda_1 = \lambda_2 = 0.005$, The maximum performance gain of RSWSO is 11.2%. For λ_1 = 0.05, RSWSO has the same value of the two-hop connection probability with GPSR. Since λ_1 is always larger than λ_2 in the case. Then RSWSO uses the same approach as GPSR to select a relay-node by choosing the farthest neighbor on Lane1. Moreover, as λ_2 increases, the two methods exhibit stability in terms of the two-hop connectivity probability. The reason for this is that λ_1 is consistently bigger than λ_2, leading to the transmission of messages on Lane1 for multi-hop communication in RSWSO, which is the same as GPSR.

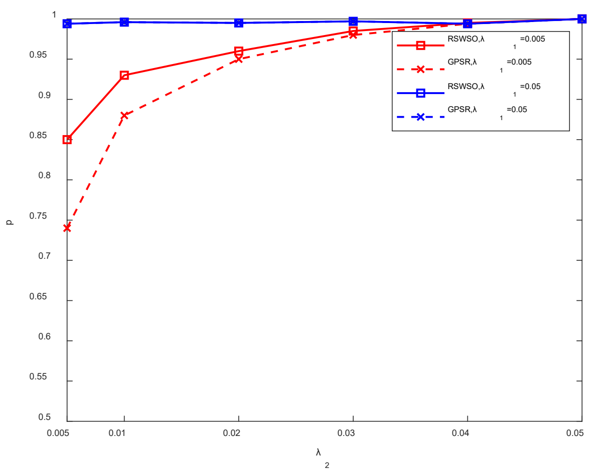

Figure 6. The two-hop connection probability versus node density

Let $\lambda_1 = 0.05 > \lambda_2$. Figure 7 shows the two-hop connection probability grows when δ increases continuously. This is because as δ increases, R' will be larger, and the node farther away from the sender on Lane2 is more likely to be selected as relay-node. With the same R, RSWSO shows a higher two-hop connection probability than GPSR. With the same δ, the smaller R is, the greater RSWSO gains in terms of two-hop connection probability. When $\delta = 0.7$ and $R =$ 200m, the maximum performance gain of RSWSO is 9.3%. The different color lines depict that the two-hop connection probability will increase when R increases under the same value of δ in RSWSO and GPSR. This is because as R increases, the sender is more likely to determine an usable neighbor as relay-node, and therefore the two-hop connection probability is higher.

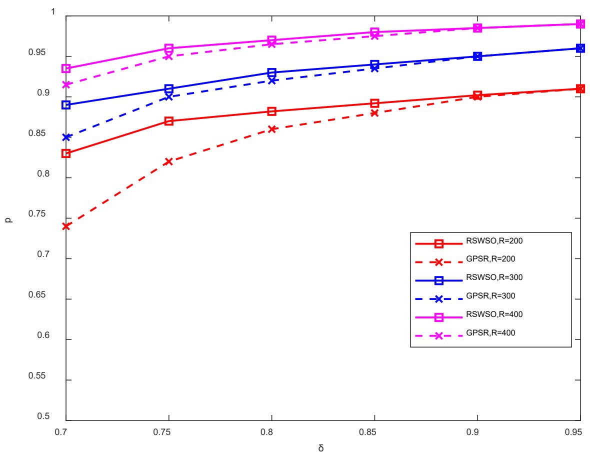

Figure 7. The two-hop connection probability versus δ

6 Conclusion

In this paper, the relay-node selection method for 3D scenario is investigated. We have proposed RSWSO and conducted simulations. The results have proved that RSWSO could alleviate two-hop distance decreases and two-hop connection probability reduction compared to GPSR. RSWSO can be well applied to relay-node selection in 3D scenario.

In the future, we will investigate relay-node selection method for more complex 3D scenarios [26-31] of IoV.

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