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A Node Backup Strategy for Routing Protocol in Software-Defined Vehicular Networks

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***Abstract*—Vehicle Ad-hoc Networks have laid an essential technical foundation for realizing intelligent transportation. Unexpected mobility change of a specific node often causes a communication link failure. Thus, this work proposes a node backup strategy for routing protocol in software-defined vehicular networks. The core of the strategy is to promote communication link stability through backup nodes. A node backup routing algorithm is designed to search for alternative nodes for each node in a communication link. A node can flexibly select the next-hop node during packet transmission based on actual conditions. When an unexpected mobility change of a specific node causes a communication link failure, we can restore the link by enabling the alternative nodes. The influence of various factors on packet reception rate and communication delay is studied through simulation experiments. By comparing with two existing routing protocols, the effectiveness of the proposed approach is verified.**

Keywords*—Software-defined vehicular networks, inter-vehicle communication, communication link stability

I. Introduction

Vehicle Ad-hoc Networks (VANET) is an advancing technology that allows vehicle-to-vehicle communications to facilitate various applications in intelligent transportation [1]-[7]. The development history and the future direction of the VANET are in detail in [8]. Software-defined networking (SDN) centralizes management by abstracting the control plane from the data forwarding function in discrete networking devices. Software-Defined Vehicular Networks (SDVN) combine SDN and VANET [9].

Due to the vehicle's dynamic nature, how to ensure the stability of a communication link is one of the main problems faced by SDVN [7]. A great deal of work has been done on this topic. The preliminary studies of this problem can be divided into several aspects. Scholars have improved communication link stability by selecting more stable and better-quality links. For example, Dong *et al.* [10] take the ratio of the mean and standard deviation of vehicle speed on the road as the evaluation index of link stability. Lin *et al.* [11] use the packet error rate and link duration to evaluate the link stability. Ghafoor *et al.* [12] use the ratio of signal to interference and noise power to evaluate the link quality. Machine learning and data-driven approaches [13]-[14] have been significantly used in recent years. Some studies use artificial neural networks and microscopic traffic flow models to predict vehicles' mobility and the communication time among vehicles for selecting a better link [15], [16]. Zhang *et al.* [17] propose a long short-term memory-based (LSTM-based) framework that combines intention prediction and trajectory prediction to improve prediction accuracy. By studying an inter-vehicle communication channel, packet collision probability can be reduced, and a more stable link is selected. For example, Ghafoor and Koo [7] propose that two vehicles can communicate if they reach a consensus on a common idle channel. Sudheera *et al.* [18] study the coordinated scheduling of channels to deal with the problem that packets encounter conflicts during transmission. More stable links can be obtained by applying different transmission methods in different road conditions. For example, a cross-layer routing switching mechanism based on road connectivity probability is proposed in [19]. Besides, scholars improve link stability by improving the stability of the entire vehicle network. For example, load balancing is studied in [20] and [21], where tasks are distributed on different communication links to achieve the purpose of improving stability. A clustering algorithm is proposed in [22] to improve link stability by joining vehicles to different clusters. Alouache *et al.* [23] enhance robustness by adding vehicles to different clusters.

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The aforementioned studies analyze various influencing factors before transmission begins but pay less attention to the communication link failure after transmission starts. In [24], the controller first finds a sufficiently stable and short communication link and then continuously monitors the nodes on the communication link. It is proposed in [25] that if a vehicle cannot receive the confirmation message from the next-hop vehicle, it transmits a message to the controller and requests the controller to recalculate the communication link. However, in practical application, extensive information will be processed by the controller, and these methods undoubtedly impose an additional computational burden on the controller.

The contributions of this paper are briefly summarized as follows. Aiming at the stability of the routing protocol in SDVN, this paper proposes a lightweight, simple and easy-to-implement routing strategy named Node Backup Strategy (NBS). This strategy aims to improve link stability so that the link can continue to transmit packets at a link failure. First, the communication time among vehicles is used for choosing a link meeting the time requirements, and we minimize the link hops as much as possible while improving link stability. Then, a node backup routing algorithm is designed to find alternative nodes for each node in the communication link. Suppose the link is disconnected during the transmission process due to the mobility of a node in the communication link. In that case, it can continue to transmit packets by transmitting packets to alternative nodes. This way, we can reduce the possibility of link failure and improve links' fault tolerance.

The rest of the paper is organized as follows. Relevant basic knowledge is given in Section II. The description of the NBS is given in Section III, where detailed algorithms are designed. Experiments are conducted in Section IV, and the results are analyzed to show the effectiveness of the proposed approach. Section V concludes this paper and discusses future work.

II. PRELIMINARY

A. Problem Description

In SDVN, we consider a possible link failure before the transmission starts and formulate an efficient strategy to ensure link stability. Suppose that vehicle A transmits packets to vehicle B by relaying vehicle C. The links in vehicular networks are highly unstable due to the high mobility of vehicles [26]. We assume that C's position changes during packet transmission and is likely to cause link failure. In addition, as the link hops increase, the possibility of link failure due to the relay vehicle's mobility is also increasing.

B. Assumptions

In this work, we make the following assumptions.

- Each road has a road side unit (RSU) that keeps the information of vehicles on the road.
- Each vehicle can only communicate with those vehicles within its communication range, and only multi-hop transmission can realize communication with vehicles that are not within their communication range.
- Each vehicle keeps the real-time information of vehicles within its communication range, such as position, speed, and direction.

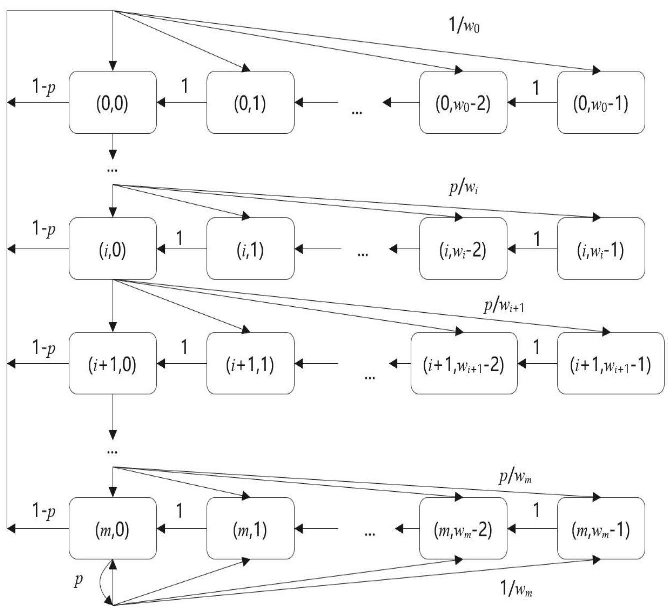


Fig. 1. Flowchart of the exponential backoff scheme.

C. Exponential Backoff Scheme

We adopt the basic idea of the exponential backoff scheme as shown in Fig. 1 [27]. When station A wants to transmit packets to station B, A firstly monitors whether the channel between them is idle. If it is idle, A transmits packets to B. Otherwise, A waits for r slot times ($r \in [0, w\text{-}1]$) before having the next try. p is the probability of a collision when a packet is transmitted on the channel, w is a contention window, and m is the maximum backoff stage.

The minimum value of w is w_0, where

$$w_i = 2^i w_0,\ 0 \le i \le m. \tag{1}$$

D. Factors Affecting Packet Reception Rate

a) Communication Time Among Vehicles

The calculation of communication time among vehicles is shown as follows. Let v_i denote vehicle i, (x_i, y_i) be the position of v_i, s_i be the speed of v_i, $t_{i,j}$ be the communication time that can be maintained between v_i and v_j, and R be the communication range of vehicles. Let v_i and v_j have the same driving direction. If the speed of the following vehicle is greater than that of the preceding vehicle:

$$t_{i,j} = \frac{R+\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}}{|s_i-s_j|} \tag{2}$$

Otherwise,

$$t_{i,j} = \frac{R-\sqrt{(x_i-x_j)^2+(y_i-y_j)^2}}{|s_i-s_j|} \tag{3}$$

b) Collision Probability

Let p_i be the probability that a packet has a collision when a vehicle transmits a packet to v_i, τ_i be the probability that a vehicle within the communication range of v_i transmits a packet to v_i, and N_i be the number of vehicles within the communication range of v_i. We have the following equations according to the exponential backoff scheme in Fig. 1 [27].

$$p_i = 1-(1-\tau_i)^{(N_i-1)} \tag{4}$$

$$\tau_i = \frac{2(1-2p_i)}{(1-2p_i)(w+1)+p_i w(1-(2p_i)^m)} \tag{5}$$

III. NODE BACKUP STRATEGY

This section proposes a node backup strategy that includes two parts: 1) an algorithm to find a link and alternative nodes for each node in the link; and 2) a method for nodes to deal with a link failure.

A. Node Backup Routing Algorithm

Let B be the number of alternative nodes for each node, $l_{i,j}$ be the distance between v_i and v_j, and T be the time needed to transmit a packet from v_i to v_j, which is set as 0.65s [28], $G = (V, E)$ be the network graph, where V and E refer to the nodes representing vehicles and edges connecting the nodes, respectively. It is assumed that v_s wants to transmit a packet to v_d that is out of the communication range of v_s and $B = 1$. We give a node backup routing algorithm as shown in Algorithm 1, which includes three steps. Algorithm 2 is used to obtain the next-hop nodes. $t_{i,j}$ is calculated by (2) and (3), and p_i is obtained through (1), (4), and (5).

1) We select v_1 as the 1-st hop node and v_{a1} as an alternative node for v_1 satisfying the following conditions ($v_{a1} \ne v_1$)

$$\begin{cases} t_{1,s} \geq T \\ t_{a1,s} \geq T \end{cases} \tag{6}$$

$$l_{a1,d} \leq l_{1,d} \leq l_{s,d} \tag{7}$$

and for any $v_k \in \{v_i | t_{i,s} \geq T,\ v_i \neq v_1,\ v_i \neq v_{a1}\}$)

$$\begin{cases} l_{1,d} < l_{k,d} \\ \text{or} \\ l_{1,d} = l_{k,d}\ , p_1 \leq p_k \end{cases},\ \begin{cases} l_{a1,d} < l_{k,d} \\ \text{or} \\ l_{a1,d} = l_{k,d}\ , p_{a1} \leq p_k \end{cases} \tag{8}$$

2) We select a middle hop node. Suppose that the node in the previous hop is v_n and v_{an} is the alternative node of v_n ($n \geq 1$). We select $v_{(n+1)}$ as the (n+1)-th hop node and $v_{a(n+1)}$ as an alternative node for $v_{(n+1)}$. $v_{(n+1)}$ and $v_{a(n+1)}$ satisfy the following conditions

$$\begin{cases} t_{n,(n+1)} \geq (n+1)T \\ t_{an,(n+1)} \geq (n+1)T \end{cases} \tag{9}$$

$$\begin{cases} t_{n,a(n+1)} \geq (n+1)T \\ t_{an,a(n+1)} \geq (n+1)T \end{cases} \tag{10}$$

$$l_{a(n+1),d} \leq l_{(n+1),d} \leq l_{an,d} \leq l_{n,d} \tag{11}$$

and for any $v_k \in \{v_i | t_{i,n} \geq (n+1)T,\ t_{i,an} \geq (n+1)T,\ v_i \neq v_{(n+1)},\ v_i \neq v_{a(n+1)}\}$

$$\begin{cases} l_{(n+1),d} < l_{k,d} \\ \text{or} \\ l_{n+1,d} = l_{k,d}\ , p_{n+1} \leq p_k \end{cases},\ \begin{cases} l_{a(n+1),d} < l_{k,d} \\ \text{or} \\ l_{a(n+1),d} = l_{k,d}\ , p_{a(n+1)} \leq p_k \end{cases} \tag{12}$$

3) We determine whether the algorithm is terminated. Suppose that the node in the previous hop is v_n and v_{an} is the alternative node of v_n ($n \geq 1$). The algorithm stops if v_n and v_{an} satisfy the following conditions

$$\begin{cases} v_{an} \text{ is } v_d \\ \text{or} \\ v_n \text{ is } v_d \\ \text{or} \\ \begin{cases} t_{n,d} \geq (n+1)T \\ t_{an,d} \geq (n+1)T \end{cases} \end{cases} \tag{13}$$

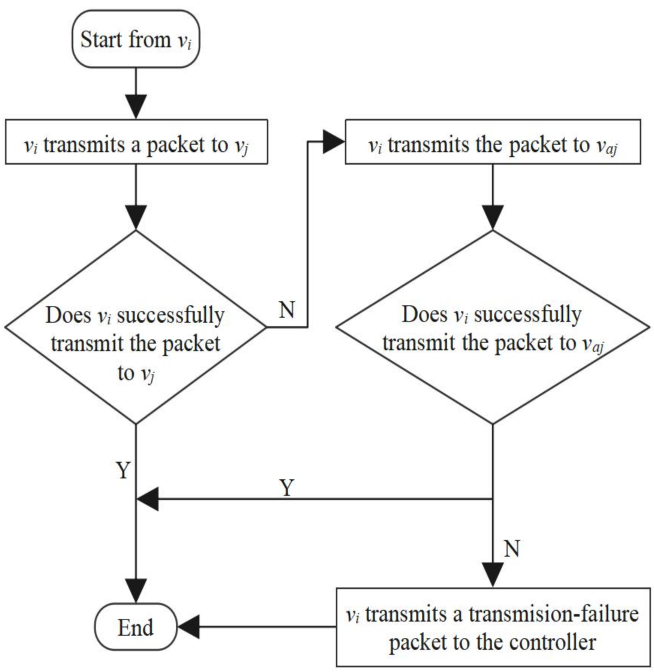


Fig. 2. Flowchart of transmitting a packet.

Algorithm 1. The Node Backup Routing Algorithm

Input: (G, v_s, v_d, T, B).
Output: L.
$L[0] \leftarrow v_s$
while (13) is not met **do**
  L(length(L))←getNextHopNodes(L(length(L)-1), G, v_d, B)
end while
return L

Algorithm 2. getNextHopNodes

Input: (L(length(L)-1), G, v_d, B).
Output: L'.
$L' \leftarrow$ []
while length(L') < B **do**
  $L' \leftarrow$ Get a point from G that satisfy conditions (6)-(8) or (9)-(12)
end while
return L'

B. *Dealing with Link Failure*

When v_s needs to transmit a packet to v_d, v_s transmits the route-request-packet to the controller through RSU. After receiving the packet, the controller uses the Algorithm 1 to search for a communication link according to the global topological map and traffic information. As shown in Fig. 2, suppose that a node on the link is v_n, and its next-hop node is v_{n+1}. v_n tries to transmit a packet to v_{n+1}. If the packet transmission fails, then v_n transmits the packet to $v_{a(n+1)}$. If it fails, v_n transmits a transmision-failure packet to the controller.

We assume that L = <v_s, …, v_n, v_{an}, v_{n+1}, $v_{a(n+1)}$, v_d>. Especially, v_d has no alternative node. In order to improve the packet reception rate of v_d, we make some changes to the last-hop transmission process: v_n or v_{an} transmits a packet to v_{n+1} and $v_{a(n+1)}$, and v_{n+1} and $v_{a(n+1)}$ transmits the packet to v_d.

IV. Experimental Evaluations

A. *Experimental Design*

In this experiment, MATLAB is used for simulation, and a traffic simulation platform Simulation of Urban Mobility (SUMO) is used to generate road and vehicle tracking data. Let s_{max} denote the vehicle's maximum speed, and σ be the slot time size. The values of parameters are shown in Tables I and II. The simulated road situation in this experiment is shown in Fig. 3. To simulate different road conditions, we randomly generate start location and destination of each vehicle. The length of each road is 1km. The source vehicle is v_s and the destination vehicles are v_d and v_d', respectively.

B. *Analysis of Experimental Results*

We choose the classical mobile ad hoc network protocol AODV [29] and SVAO [10] as comparisons. SVAO uses a two-level design. The Global Level is distributed and responsible for calculating which Local Controller (LC) the communication link should go through. The Local Level is centralized, using the Bellman-Ford algorithm to find the communication link between two adjacent LC. We test the packet reception rate and time delay of the three methods.

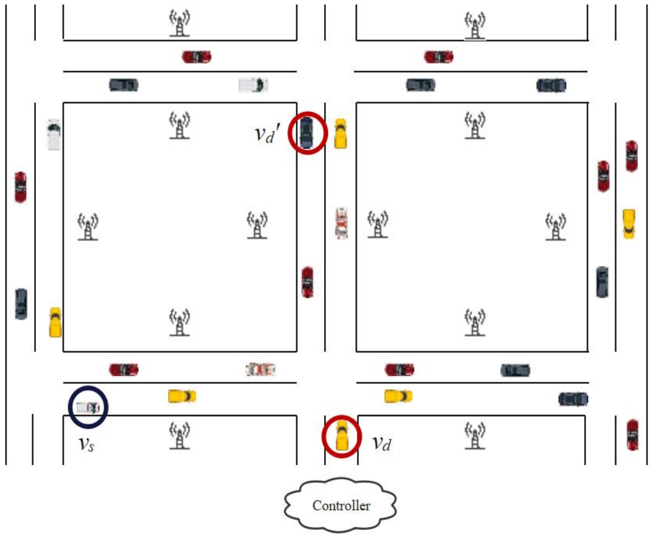
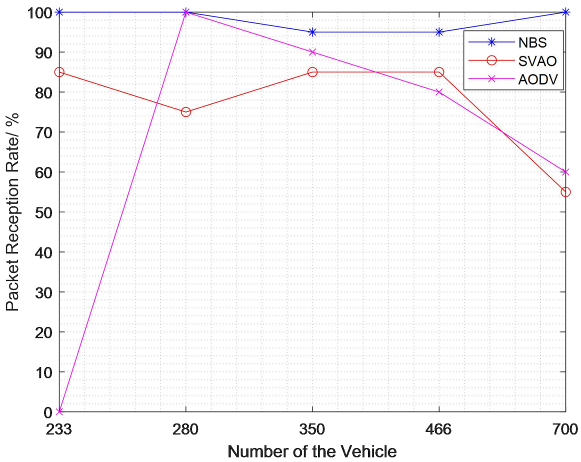
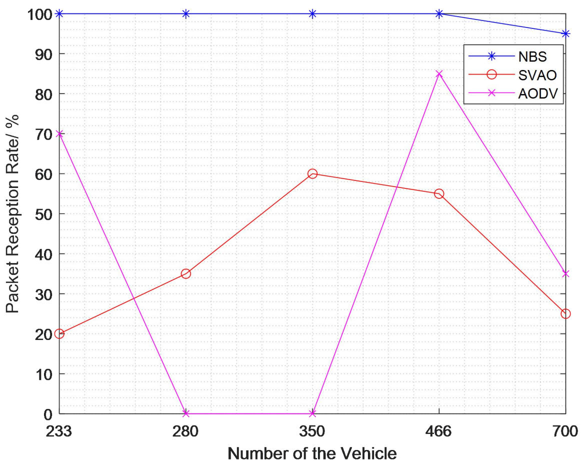


Fig. 3. A road structure.



(a) Packet reception rates of v_e.



(b) Packet reception rates of v_e'.

Fig. 4. Packet reception rates of different destinations.

Let B = 1, smax = 25m/s, R = 300m, and m = 2. It can be seen from Fig. 4 (a) that when the destination vehicle is vd, the packet reception rates of the three methods are high. However, the packet reception rates of SVAO and AODV decrease with the increase of the number of vehicles. It can be seen from Fig. 4 (b) that when the destination vehicle is v_d', the results obtained by NBS are better than that of the other two methods. The results of AODV fluctuate a lot and it may not find a communication link. Table III shows the average packet reception rate of the three methods with respect to the increase of the number of vehicles when m = 1 or 2.

TABLE I. CONFIGURATIONS OF VEHICLES

Vehicle Configuration	***Value***
number of vehicle types	6
max speed of vehicle	15m/s, 20m/s, 25m/s, 30m/s
vehicle-following model	IDM
vehicle length	5m
lane change model of vehicle	SL2015
vehicle acceleration	1m/s^2
vehicle deceleration	2m/s^2

TABLE II. EXPERIMENTAL PARAMETERS

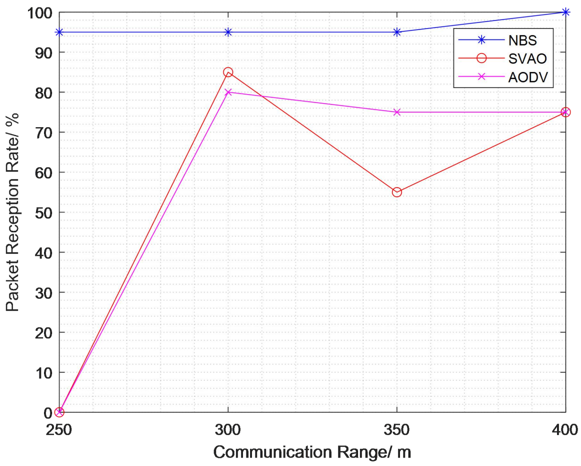
Parameter	***Value***
w_0	64
σ	8μs
number of vehicles	[233, 280, 350, 466, 700]
R	[250m, 300m, 350m, 400m]
m	[2,3]

TABLE III. AVERAGE PACKET RECEPTION RATES AT DIFFERENT MAXIMUM BACKOFF STAGES AND VEHICLE NUMBERS

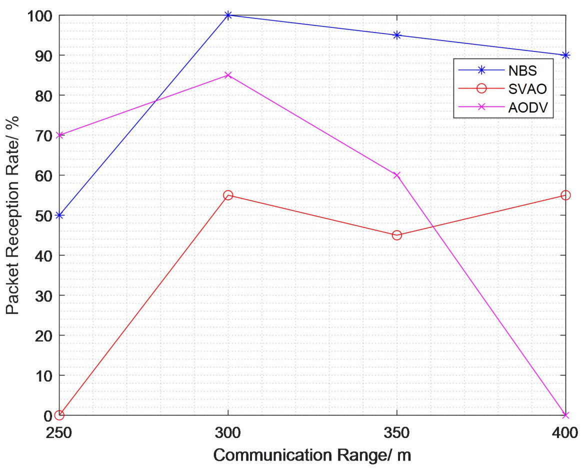
(*m*, number of the vehicle)	**Average packet reception rates**		
	NBS	***SAVO***	***AODV***
(2, 233)	100.00%	52.50%	35.00%
(2, 280)	100.00%	55.00%	50.00%
(2, 350)	97.50%	72.50%	45.00%
(2, 466)	97.50%	70.00%	82.50%
(2, 700)	97.50%	40.00%	47.50%
(3, 233)	100.00%	67.50%	50.00%
(3, 280)	95.00%	65.00%	50.00%
(3, 350)	95.00%	85.00%	40.00%
(3, 466)	100.00%	75.00%	95.00%
(3, 700)	100.00%	55.00%	85.00%

Let B = 1, s_{max} = 25m/s, m = 2, and the number of vehicles be 466, which represents a moderate density. It can be seen from Fig. 5 (a) that when the destination vehicle is v_d, the packet reception rate of NBS is 10% to 35% higher than that of the other two methods, and AODV performs better than SVAO. It can be seen from Fig. 5 (b) that when the destination vehicle is v_d', the performance of the SVAO is poor. When R > 300m, the packet reception rates of NBS and AODV decrease with the increase of the communication range. However, the decline in the AODV is more prominent. Overall, they all have situations where the communication link cannot be found. Table IV shows the average packet reception rate of the three methods with respect to the increase of the communication range when m = 1 or 2.

Let B = 1, R = 300m, m = 2, and the number of vehicles be 466, which represent a moderate density. It can be seen from Fig. 6 (a) that when the destination vehicle is v_d, the packet reception rate of NBS is 10% to 30% higher than that of the two other methods. The packet reception rates of the three methods decrease with the decrease of the vehicle's maximum speed. It can be seen from Fig. 6 (b) that



(a) Packet reception rates of v_e.

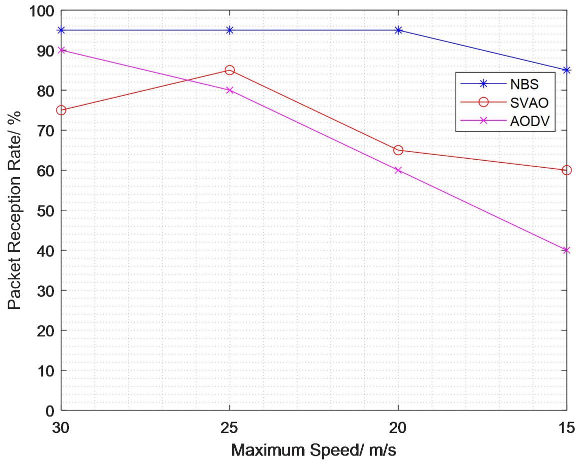


(b) Packet reception rates of v_e'.

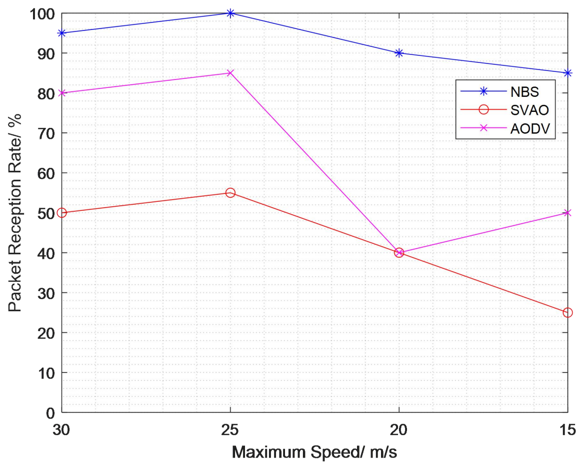
Fig. 5. Packet reception rates of different destinations.

TABLE IV. AVERAGE PACKET RECEPTION RATE AT DIFFERENT MAXIMUM BACKOFF STAGES AND COMMUNICATION RANGES

(*m*, *R*)	Average packet reception rates		
	NBS	***SAVO***	***AODV***
(2, 250)	72.50%	0.00%	35.00%
(2, 300)	97.50%	70.00%	82.50%
(2, 350)	95.00%	50.00%	67.50%
(2, 400)	95.00%	65.00%	37.50%
(3, 250)	75.00%	0.00%	40.00%
(3, 300)	100.00%	75.00%	95.00%
(3, 350)	100.00%	85.00%	90.00%
(3, 400)	97.50%	77.50%	47.50%



(a) Packet reception rates of v_e.



(b) Packet reception rates of v_e'.

Fig. 6. Packet reception rates of different destinations.

TABLE V. AVERAGE PACKET RECEPTION RATE AT DIFFERENT MAXIMUM BACKOFF STAGES AND MAXIMUM SPEEDS

(*m*, s_{max})	Average packet reception rates		
	NBS	***SAVO***	***AODV***
(2, 30)	95.00%	62.50%	85.00%
(2, 25)	97.50%	70.00%	82.50%
(2, 20)	92.50%	52.50%	50.00%
(2, 15)	85.00%	42.50%	45.00%
(3, 30)	100.00%	82.50%	100.00%
(3, 25)	100.00%	75.00%	95.00%
(3, 20)	90.00%	85.00%	70.00%
(3, 15)	100.00%	77.50%	70.00%

when the destination vehicle is v_d', the experimental results of SVAO are the worst. Table V shows the average packet reception rate of the three methods with respect to the decrease of the maximum speeds when m = 1 or 2.

Notice that the time delay of NBS is slightly higher than that of SAVO and AODV, but the additional delay is no more than 1.5s. However, a certain degree of time delay can be tolerated for transmissions that do not have strict time delay requirements. At the same time, with the application of

5G technology, the time delay will become smaller and smaller.

V. Conclusion

Due to the highly dynamic nature of vehicles, the vehicular network is characterized by frequent topology changes. Data transmission among vehicles is still a challenge with the existing technology. The emergence of SDVN provides a solution to this problem. By using global information, SDVN can make better routing decisions. This paper provides a node backup strategy for improving communication link stability. Firstly, the controller collects global information and estimates the communication time among vehicles. Then, we design the node backup routing algorithm to increase the packet reception rate by finding alternative nodes for each relay node on the link. At the same time, during the transmission process, the vehicle can flexibly select the next-hop vehicle according to the actual situation. Simulation experiments are conducted by MATLAB, and the results show that the strategy designed in this paper has good performance. We will further consider other factors that affect communication link stability and reduce time delay by refining the transmission process in future work. Intelligent optimization models and algorithms [30]-[36] will be used to solve the problem.

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