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Fast Data Transmission Method in Wireless Vehicle Ad-hoc Networks

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In vehicular ad-hoc networks, the current method does not consider the delay of data transmission, resulting in a slower vehicle data transmission speed. A vehicle data transmission method based on a backbone network is proposed in this paper. Firstly, the characteristics of the vehicle ad-hoc network are analyzed. Based on the statistics of the road, the vehicle cluster is composed of the vehicles parked on the roadside and non-roadside parking areas in both directions of the vehicle driving. The backbone network is constructed on the basis of the cluster of vehicles, and the data transmission between the vehicles is implemented by the data transmission method of an overlay network. This method can overcome the disadvantages of traditional data transmission methods, improve the efficiency of on-board data transmission, and complete the research on a fast data transmission method in wireless vehicle ad-hoc networks. The experimental results show that the proposed method can achieve higher data transmission success rates with lower data transmission overhead and smaller transmission delay.

Keywords: Wireless ad-hoc network, Vehicle data, Fast transmission, Backbone network

1. INTRODUCTION

Traffic accidents are still a bottleneck restricting the development of society (Tao et al., 2015). Taking intelligent transportation measures can reduce the incidence of traffic accidents, improve road utilization and vehicle travel efficiency, and effectively guarantee the safety of people's property and lives (Afanasiev et al., 2017). The rise of vehicle ad-hoc networks has provided a new direction for the development of intelligent transportation; this has attracted the attention of scholars from various countries (Bamiedakis et al., 2015). Vehicle ad-hoc networks are mainly constructed through the infrastructure between vehicles using roadside communication as the basis. They are used to provide the optimal decision route information to the driver, and to guide driving; meanwhile, the traffic information is given for road management, providing data support for the road supervision and management department (Chen et al., 2016; Zhang, Hao & Xu, 2016). However, vehicle ad-hoc networks have unique technical requirements and constraints, so the vehicle data transmission network is facing great challenges (Wang, Li, Wang, 2015).

In this regard, researchers have put forward some data transmission methods in vehicle ad-hoc networks. Gao et al (Gao, Che, Li, 2015) proposed a reliable transmission method of vehicle remote data. In the area covered by the network, the 3G technology was used to transmit the remote data of the vehicle. In the area where the network could not be covered, the communication of the Beidou navigation system was used to carry on the transmission of the vehicle data. The experimental results showed that the method had the reliability of data transmission, but the speed of data transmission was slow. Wang et al (Peng, Wang & Huang, 2016) proposed a transmission optimization strategy of vehicle data based on the stopping theory. The stopping problem of data transmission constraints and the effective range of the transmission data are constructed, and the transmission rate of the transmitting terminal of the vehicular radio in the periodic channel is obtained. Experimental results showed that this method had relatively small data transmission energy consumption, and the success rate of data transmission was relatively high, but there was still a slow speed of data transmission.

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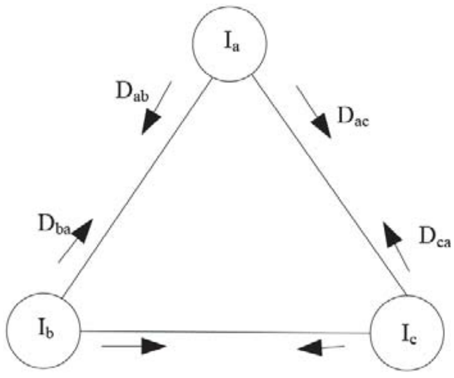

Figure 1 Network Diagram of Road.

2. FAST DATA TRANSMISSION METHOD OF A WIRELESS AD-HOC NETWORK VEHICLE

2.1 Vehicle routing decision

In order to transmit the data of the wireless vehicular ad-hoc network quickly, the decision is made on the route selection, and the transmission delay is evaluated at different time periods. d_{ij} is the link that the message passes through, and e_{ij} is the delay generated by data transmission. According to the length of the section e_{ij}, the density and the average speed of the vehicle, the calculation is carried out. It is assumed that the data is sent from the intersection I_i, and the data transmission delay passes through the section e_{ij} to the destination is $D_{ij} \cdot N(j)$ is the intersection set adjacent to the intersection I_i. Then,

$$D_{ij} = d_{ij} + \sum_{k \in N(j)} P_{jk} D_{jk} \tag{1}$$

In formula (1), P_{jk} is the probability that data is transmitted from intersection I_i to intersection e_{ij}. Due to the discontinuous connection of a wireless ad-hoc network, when the data carrier passes through the intersection I_i, it may encounter an unsuitable vehicle, resulting in the data being unable to be transmitted in the expected direction, so that the actual data transmission direction has probability (Hanawal, Abdelrahman & Krunz, 2016). As a result, $\sum_{k \in N(j)} P_{jk} D_{jk}$ indicates the delay required so that the data will be transmitted from the intersection I_i to the destination. Using the Formula (1), the D_{mm} equation corresponding to the road segment e_{mm} in the wireless ad-hoc network is listed. Figure 1 shows the network diagram of the road. If the destination of the data transmission is the intersection I_e, the corresponding equation is expressed by Formula (2):

$$\begin{cases} D_{ab} = d_{ab} + P_{ba} D_{ba} + P_{bc} D_{bc} \\ D_{ac} = d_{ac} \\ D_{ba} = d_{ba} + P_{ab} D_{ab} + P_{ac} D_{ac} \\ D_{bc} = d_{bc} \\ D_{ca} = 0 \\ D_{cb} = 0 \end{cases} \tag{2}$$

The solution of the equation can be resolved, and the corresponding D_{mm} in the outlet section e_{mm} can be obtained. D_{mm} is used to make decisions on road selection.

The data cannot be accurately transmitted to the vehicle in the current direction, and the transmission speed is slow, which makes the vehicle worse so under the condition of the data carrier segment e_{jkc}, the probability of data transmission along different roads is:

$$P_{jkn/jkc} = \begin{cases} P'_{jkm}\cdot & \forall m \prec c \\ 1 - \sum_{s=1}^{c-1} P'_{jks}, & m = c \\ 0, & \forall m \prec c \end{cases} \tag{3}$$

By the Formula (3), complete the statistics of vehicle data transmission at intersections. The probability in the direction e_{jkc} is Q_{jkc}, and P_{jkn} can be obtained as follows:

$$P_{jkn} = \sum_{c=1}^{n} Q_{jkc} P_{jkn/jkc} \tag{4}$$

2.2 Design of the backbone network of vehicles

Usually, there are non-roadside parking lots on both sides of the road in the city, and the roadside has a large number of parking spaces. The parking vehicles on roadside and non-roadside on the same road are formed into a cluster of vehicles. As the average occupancy rate of a parking lot is relatively high, the probability that the vehicle parking on the roadside can find nearby parked vehicles in the range of its communication is greater. Therefore, the parked vehicles on the roadside can be connected with the rest of the parked vehicles in the cluster (Nemov et al., 2016).

Figure 2 represents the vehicle's parking cluster. Among them, $H1$ and $H2$ are the two cluster heads in the cluster, and $M1$ and $M10$ are the nodes of the members. The process of building a vehicle cluster is that the roadside node at the end of the road is a cluster head, and when the vehicle enters or leaves, it will meet one of the cluster heads. The cluster head mainly manages the network to deal with the joining and leaving of the vehicle nodes. As noted as $QH1$ and $QH2$ in Figure 2, the standby cluster head is a vehicle that is parked close to the cluster head. The standby cluster head has a robust effect on the vehicle cluster (Sun et al., 2016).

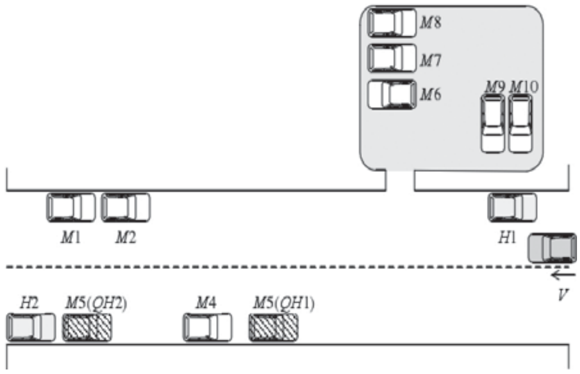

Figure 2 Vehicle Cluster.

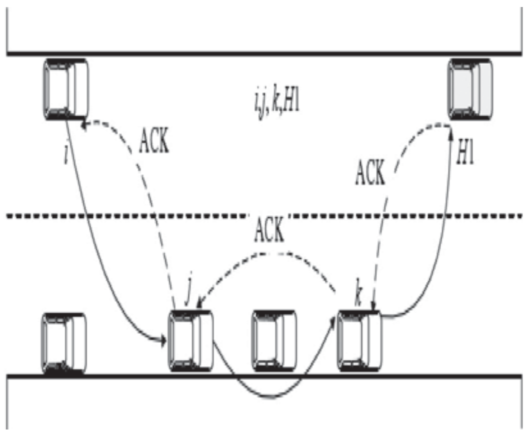

Figure 3 Transmission in Cluster.

Data transmission within the cluster occurs as follows: after the cluster head is determined, cluster members will transmit their data to cluster heads by broadcasting, and record the node ID. For nodes that cannot communicate with cluster heads, the cluster heads receive n data copies that first arrive when the data is received. According to the sequence of these duplicates reaching the cluster head, the data transmission path of the n data duplicates is marked as the optimal path. After receiving the copy of the n data, the cluster head replies with the path information along the optimal path. The above process is illustrated in Figure 3. The node i in the graph is the node of the vehicle cluster member. $H1$ represents the node of the cluster heads, and the vehicle path $(i, j, k, H1)$ is the best path from i to the cluster head.

In order to reduce the cost of vehicle data transmission, member nodes periodically report data to cluster heads. When cluster heads transmit data to nodes, the best path is selected first. If the optimal path does not exist, sub optimal can be selected.

In order to realize the fast transmission of the vehicle data in the wireless ad-hoc network, the virtual parking backbone is constructed on the basis of the vehicle cluster.

(1) Each vehicle cluster initiates the adjacent discovery process. For example, the cluster head nodes of the vehicle cluster J broadcast the data with the cluster head position and $NEi.REQ$ to the other vehicle clusters. After receiving the $NEi.REQ$ data, the vehicle cluster J is set as a neighbour cluster. If a vehicle cluster is surrounded by the main road, it is easy to cause the vehicle cluster to stay away from other vehicles, and thus the remaining nodes of the vehicle cluster cannot be found.

(2) In order to build all the vehicle clusters into a backbone network, the vehicle cluster and all the neighbouring vehicle clusters are connected into a virtual connection. Through this process, the network covered by vehicles can form a connected circle $G(V; E)$, where V is the node of vehicle cluster set, and E is the virtual path set of adjacent vehicles. The structure of the backbone network is shown in Figure 4.

(3) Assuming that members of a backbone network can understand the data and location of other nodes, the network can be implemented through a simple mechanism.

2.3 The selection of short-distance wireless transmission technology

In this paper, wireless bridge technology is adopted. A wireless bridge can connect two or more wired local area networks by wireless transmission. Wireless bridges have two transmission standards, 802.11b and 802.11a. Some specific parameters are shown in Table 1.

Wireless bridges are mainly composed of a small routing device with antennas. Most wireless bridges provide TCP/IP

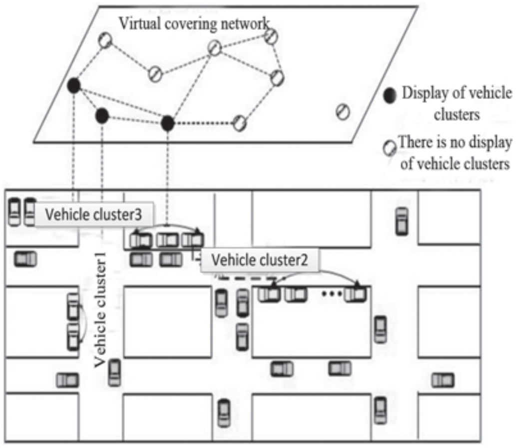

Figure 4 Virtual Overlay Network.

Table 1 Transmission Standards for Wireless Bridges.

Standard	Data rate	Frequency band	Transmission distance
802.11b	11Mbps	2.4 GHz	Within 30 km
802.11a	54Mbps	5.8 GHz	Within 80 km

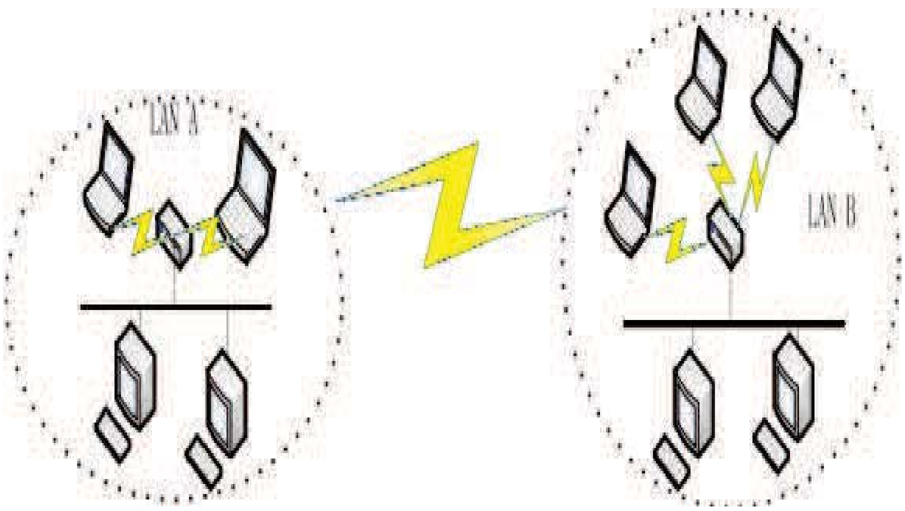

Figure 5 Point-to-Point Mode.

interfaces to facilitate Ethernet access. Wireless bridges have been widely used in the field of international and domestic communications, especially in remote monitoring where it is not convenient to lay communication cables. They can be used for medium and short-distance high-speed data transmission and long-distance low-rate data transmission. At present, data transmission based on wireless bridge technology has been applied to many fields, such as campus network coverage construction, industrial park security monitoring, anti-theft, fire and disaster prevention, highway pavement monitoring and so on.

As a widely used wireless network bearing technology, a wireless bridge has its unique advantages, which can be summarized as follows: high transmission rates, up to 54 Mbps; a strong anti-jamming capability; good concealment and confidentiality; strong multi-path interference capability; high security.

There are three networking modes for wireless bridges.

1. Point-to-point mode: this mode is usually used between two fixed networks. This type of network has long transmission distance, high transmission rate and little influence from the outside environment. This paper adopts the point-to-point mode, as shown in Figure 5.

2. Point-to-multipoint mode: this mode is applicable to a central station and multiple remote stations. The advantages of point-to-multipoint mode are as follows: low network cost, simple maintenance and easy debugging. However, this mode also has some shortcomings, which can be seen in the following aspects: multiple remote terminals share one central point device, therefore network delays increase, transmission rates decrease, and if the central device is damaged, the whole network will be paralyzed; the central device uses an omni-directional antennacausing the velocity of the wave to diffuse in all directions, this results in the transmission power

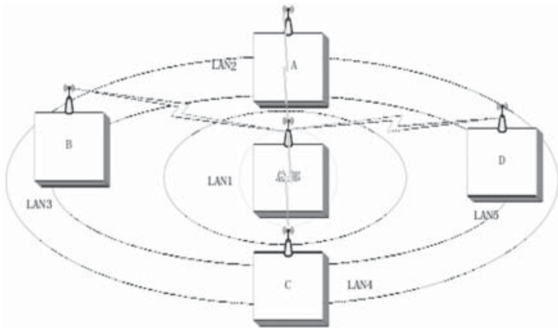

Figure 6 Point-to-Multipoint Mode.

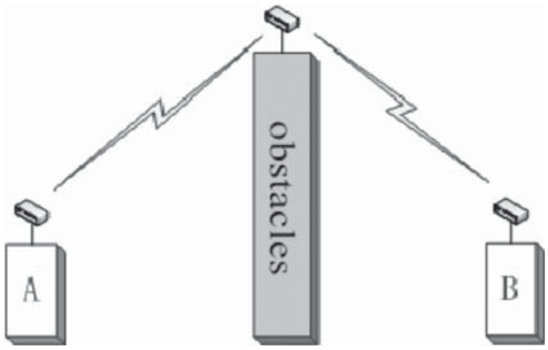

Figure 7 Continuation Mode.

being greatly attenuated, reducing the transmission rate of the network, and reducing the effective range of the wireless network; all bridge routers are set to use the same operating frequency, and if a remote station is disturbed, it will be replaced by another remote station. However, if the interference is serious and multiple remote stations are disturbed, the replacement frequency of remote stations will increase and many additional problems will be caused, as shown in Figure 6.

3. Relay station mode: this mode is used when there are obstacles between two local area networks that need to be connected. As there are no big obstacles between the two locations where the connection is established in this paper, this mode is not used.

According to the above analysis, this paper adopts the point-to-point bridge scheme using the 802.11b standard.

2.4 Characteristics of vehicle recording data

The data recorded by the vehicle SIBAS 32 system in a wireless adhoc network include the main transformer, converter, main circuit breaker, pantograph, battery, brake control unit, speed sensor, temperature sensor, contactor, relay, cab switch, air conditioner, etc.

The data can be downloaded from the U disk, the main file can be opened to see that the data is stored in a folder containing multiple ZIP files. The content of the file is packaged and named by the main CCU (central control unit), the slave CCU, the main TCU and the slave TCU. The main CCU is responsible for the vehicle control of the traction unit. It reads instructions and information from the peripheral and wire train bus (WTB), and sends control signals and feedback information to the peripheral WTB. In addition, the main CCU has the following functions: controlling the main circuit breaker and pantograph; setting the traction point of the traction control unit (TCU); protecting the transformer; controlling the vehicle power supply; controlling the front-end connection and front-end movable valve.

Control instructions are set for various control devices, such as the doors, air conditioning, lighting, etc.; the diagnosis of safety circuits, fire alarm systems and bogies is monitored; digital and analog inputs and outputs are controlled through decentralized input and output stations; the brake control is parked; central control unit diagnosis and WTB and MVB communication diagnosis; the configuration of the EMU and the long train set is determined and detected by connecting the gateway to the train bus (WTB).

The slave CCU is running the same program as the main CCU, however it cannot control the process actively. The slave CCU can monitor the working state of the main CCU and take over the work of the main CCU whenever the main CCU fails. However, both the main and the slave CCU have active protection functions for high-voltage hardware devices.

2.5 Adaptive transmission mechanism of vehicle-borne data based on transmission power control

Another important factor that affects the data transmission performance of vehicles is the transmission power of vehicle-borne data. In wireless ad-hoc networks, it is generally believed that the transmission power and distance of vehicle-borne data are one-to-one correspondence. The use of a higher transmission power means that it has a larger transmission distance, and the vehicle-borne data transmission is more robust. This also means it has a larger interference range to the vehicle-borne signal of the surrounding vehicles, and the higher the interference intensity of the vehicle-borne signal. On the contrary, lower transmission power means smaller transmission distance, the vehicle-borne data transmission is less robust, has a smaller interference range and lower signal interference intensity to surrounding vehicles. If all vehicles use the same data transmission power, the transmission range is the same. However, this obviously does not apply to the rapidly changing wireless ad-hoc network topology. Traditional power control schemes need to consider energy consumption. In wireless ad-hoc networks, for some roadside facility nodes that use renewable energy to supply power, the energy consumption problem needs to be considered, and there is no need to consider the vehicle nodes and the roadside facility nodes with power supply. For vehicle-borne data transmission, it is necessary to consider the appropriate coverage of vehicle-borne signals for different applications, as well as the large transmission range and channel load caused by large transmission power. Therefore, it is necessary to control the transmission power of vehicle-borne data adaptively so as to control the interference intensity of vehicle-borne signal and prevent the occurrence of channel congestion, under the condition that the channel can be used reasonably to meet the application requirements. Several adaptive transmission mechanisms of vehicle-borne data based on transmission power control have been proposed by researchers. These include:

Power control of vehicle-borne data transmission based on traffic density: the transmission power is adjusted to cover a certain number of vehicles by traffic density, and the traffic density is estimated by traffic flow theory. The corresponding relationship between vehicle speed and traffic density in free and congested traffic is analyzed in detail. Vehicles can estimate the current traffic flow state first, and then estimate the density based on the specific state, which improves the accuracy of the estimation. By using this method, the vehicle can adjust the transmission power without the need for extra information exchange, and the real-time performance is high. However, the dynamic change of topology in vehicular ad-hoc networks is not taken into account, and the fast switching of different traffic states is not taken into account in the algorithm design, which will affect the reliability of the algorithm.

The method is extended to study the traffic flow models of three kinds of traffic time, including morning, morning peak and evening peak. A large volume of real data is used to study the accuracy of traffic density estimation, so as to better carry out adaptive control of vehicle data transmission power.

Power control of vehicle data transmission considering user fairness: in the above study, all vehicles in the default wireless ad-hoc network system follow the same adaptive transmission opportunity. This ensures fairness between nodes. The fairness of power control for vehicle data transmission is specially studied. The author believes that it is not enough for a single vehicle to know only the nodes within the communication range of one hop. Without knowing the environment of neighbor nodes, transmission power control cannot guarantee the fairness between users. The essence of the research is to propose a rigorous and fair power control scheme for vehicle data transmission. Therefore, a cooperative communication method between users is proposed to understand the status of nodes within multi-hop range. In this scheme, each vehicle node collects the transmission power information of the neighbor node at the current time and broadcasts the collected information. Through this cooperative mechanism, the nodes can expand the vehicle nodes' understanding of the transmission power of the nodes within and outside the communication range as much as possible. The author then proposes a transmission power control scheme. By calculating the maximum transmission power threshold under the global power situation, the transmission power of the vehicle itself is increased as much as possible to ensure the reliable acceptance of vehicle-borne data by the neighbour nodes. On the other hand, the maximum quotient of transmission power is constrained in the threshold to ensure that the channel load of the vehicle node itself and its surroundings will not be too large. The simulation results show that this method can guarantee the fairness between nodes skillfully and effectively, and all nodes can send vehicle data reliably. The disadvantage of this algorithm is that it relies too heavily on the cooperation between users. As data interaction also consumes channel resources, the effective utilization of the channel decreases.

Considering the fairness of users, a random transmission power selection strategy is proposed in the research process. After specifying an average transmission power and its variance, all vehicle nodes randomly adjust the on-board data transmission power based on the same average and variance. The method proves that a good average setting can guarantee the perception of the whole network. The simulation results show that this random selection method can effectively reduce the full-value collision of vehicle data and improve the global fairness.

2.6 Vehicle data transmission based on backbone network

Combined with the above, the backbone network is constructed into weighted connect graph $G(V;E)$, and the weight D_{ij} of E_{ij} represents the delay of data transmission between adjacent node i and j. Figure 8 shows the structure of the weighted connection graph.

The vehicle cluster itself is a road; therefore data transmission on the backbone network can be divided into two parts, these being the transmission of the cluster nodes and the path transmission. Supposing that the data transmission delay of each vehicle cluster node i is d_i. When the vehicle cluster node i sends data to the vehicle cluster, the data transmission delay from i node to k node is:

$$T_{ik} = \sum_{i=1}^{m} d_i + \sum_{(i,j)=1}^{n} D_{ij} \tag{5}$$

In Formula 5, m indicates the number of nodes that data needs to pass through, of which the node i passes through

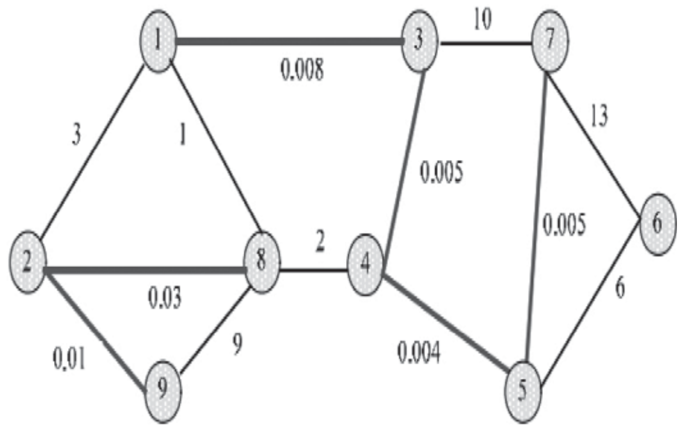

Figure 8 Weighted Connection Graph.

the vehicle backbone and transfers the data to the node $k \cdot n$ indicates the number of paths that node i transfers the data needed to pass through the vehicle backbone network to node k. When the parking density is satisfied, the interior of the vehicle cluster i has connectivity. d_i is:

$$d_i = \sum_{f=1}^{t} \frac{P_{\text{size}}}{S} \tag{6}$$

In Formula (6), S represents the throughput of the wireless ad-hoc network, P_{size} represents the size of the data, and t represents the number of jumps that the data transmits within the vehicle cluster i. If the suspended vehicle density does not meet the data transmission, it is:

$$d_i = \sum_{i=1}^{t} \frac{P_{\text{size}}}{S} + \frac{l_i - t\int_0^R x\lambda e^{-\lambda x}}{v} \tag{7}$$

In the Formula (7), l_i represents the length of the vehicle cluster i, v represents the speed of the vehicle, and the R represents the range of the vehicle for communication. When the vehicle cluster i is connected, d_i will be very small. When the vehicle cluster does not generate connectivity, it needs to carry the data of vehicles, so d_i is relatively large.

$$D'_{ij} = \left\{ \begin{array}{ll} D_{ij}, & \mu \geq \frac{1n(1-\sqrt[m]{1/2})}{R} \\ D_{ij} + d_i, & \mu \prec \frac{1n(1-\sqrt[m]{1/2})}{R} \end{array} \right\} \tag{8}$$

In Formula (8), μ represents the vehicle density of a i parked in a cluster. After the changes produced by Formula (8), the delay of the data transmission generated by the node i to k of the vehicle cluster depends on the $\sum_{(i,j)=1}^{n} D'_{ij}$ and requires $\min\left\{\sum_{(i,j)=1}^{n} D'_{ij}\right\}$.

According to the statistical results, the parameter λ is mostly around 0.5. According to the traffic statistics of each vehicle on different roads and in different time periods, the value of d_{xy} is calculated according to Formula (8).

$$D_{ij} = \sum_{R_{xy}\in R_{ij}} \left[\frac{l_{xy}\left(1 - \lambda^2 \rho_{xy} l_{xy} \int_0^R e^{-\lambda x} dx \int_0^R x e^{-\lambda x} dx\right)}{v_{xy}} + \sum_{i=1}^{\rho_{xy} l_{xy} \int_0^R x e^{-\lambda x} dx} \frac{P_{size}}{S} \right] \tag{9}$$

After the value of D'_{ij} is calculated, the delay matrix of data transmission is constructed by the delay of data transmission between the clusters. According to the delay matrix of data transmission, the shortest path of data transmission delay can be obtained.

$$MSD = \min\left(\sum_{(i,j)\in E} D'_{ij}\right) \tag{10}$$

3. EXPERIMENTAL RESULTS AND ANALYSIS

In this paper, the simulation tool used is Network Simulator, and the parameters used in the simulation experiment are expressed in Table 2. In the experiment, the nodes are used to simulate the source nodes to transmit the data, the trajectory of the vehicle nodes is generated by Vanet MobiSim, and the simulation time is 500 s.

The ratio of the successful transmission of vehicle data at the intersection is tested. As shown in Figure 9, the average rate of source and target traffic are λ_1 and λ_2. The process of data arrival is Poisson process. The travelling vehicle will carry the corresponding data packet, transmit it in the intersection area, record the received data packets at the exit D of the road, and calculate the proportion of the transmission data to the original data as shown in Figure 9.

By changing the data of the carrying vehicle and the arrival rate of vehicles in different directions, we can get the relationship between data single hop transmission and data volume under different road conditions (Figure 10).

The single hop performance of the vehicle's data transmission method based on backbone network proposed in this paper is compared with that of the method based on a mobile gateway. The average arrival rates of vehicle are 0.1 and 0.5,

Table 2 List of Experiment Parameters.

Parameters	Value
Mobile generator	Vanet MobiSim
Experimental area/m^2	3000×150
Range of data transmission R/m	200–250
The rate of data transmission/($Mbit \cdot s^{-1}$)	6
Vehicle moving speed/($m \cdot s^{-1}$)	22.2–33.4
Number of vehicle nodes	30, 60, 120, 150
Experimental time/s	500
Beacon frequency/Hz	1

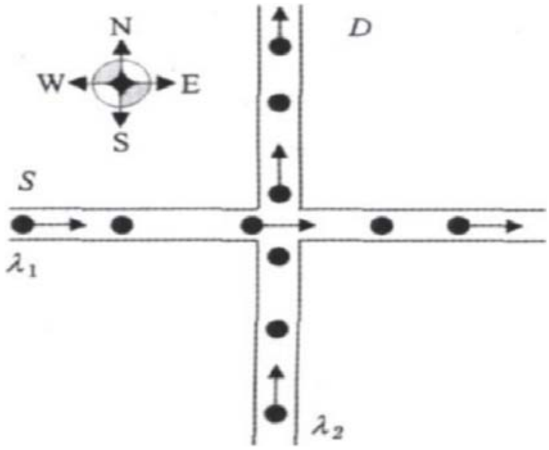

Figure 9 Model of Intersection.

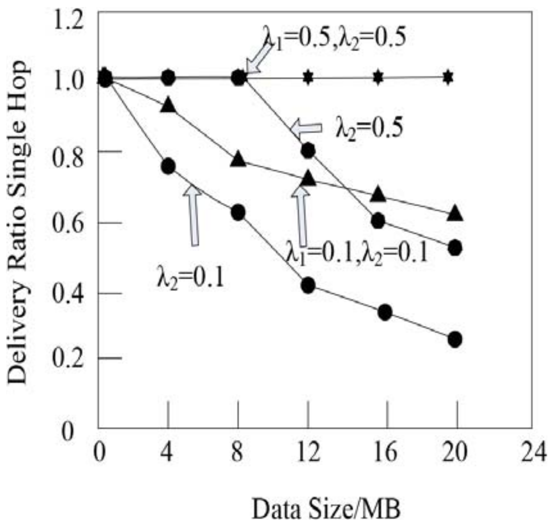

Figure 10 The Relationship Between the Rate of Transmission Success and the Amount of Data in a Single Hop.

and two cases of sparse and dense traffic flow are simulated. The effect of data transmission on a mobile gateway depends on the rate λ_2 of arrival of the recipient vehicle. As can be seen from Figure 10, in the case of dense traffic, the ratio of data transmission by the proposed method is kept at a higher level.

To verify the effect of data transmission delay on vehicle data transmission, the modes of data generation and transmission are reset. Figure 11 shows a delayed cumulative distribution map of vehicle data transmission. From Figure 11, it can be seen, compared with the data transmission based on mobile gateway, the vehicle data transmission based on backbone network has little transmission delay, about 90% of the data can be transferred within 120 s; therefore, using this method, the data of the wireless vehicle ad-hoc network can be transmitted quickly.

4. CONCLUSIONS

Data transmission is the basis of vehicular ad-hoc network application. Vehicular ad-hoc networks are data centric

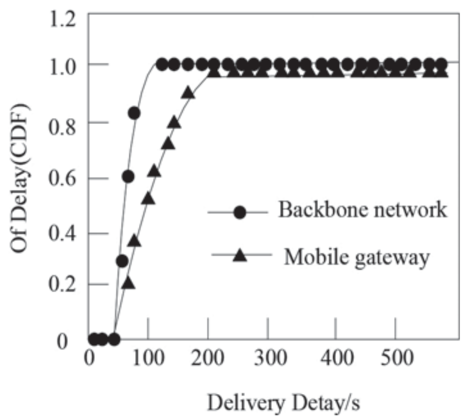

Figure 11 Accumulation Distribution of Data Transmission Delay Using Different Methods.

wireless networks. This paper proposes a fast transmission method for on-board data based on backbone network. Experiments show that this method can achieve higher data transmission rates with a smaller transmission cost and delay.

Future research:

(1) The distribution of parked vehicles needs to be improved by using actual survey data.

(2) The routing of data under unknown conditions needs to be implemented.

(3) The waste of resources and data redundancy caused by data transmission to parked vehicles needs to be reduced.

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