V2V Routing in a VANET Based on the Autoregressive Integrated Moving Average Model

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Abstract — **With the development of vehicle networks, the information transmission between vehicles is becoming increasingly important. Many applications, particularly regarding security, are based on communication between vehicles. These applications have strict requirements for factors such as the quality of communication between vehicles and the time delay. Many theoretical communication protocols ignore the presence of buildings or other obstacles that are present during practical use, especially in urban areas. These obstacles can cause a signal to fade or even block direct communication. Many vehicles are often parked at the roadside. Because of their location, these parked vehicles can be used as relays to effectively reduce the shadowing effect caused by obstacles and even solve communication problems. In this paper, we study the problem of parked-vehicle-assistant relay routing communication in vehicle ad hoc networks. We propose an efficient Parked Vehicle Assistant Relay Routing (PVARR) algorithm that is composed of four parts: a periodic Hello packet exchange mechanism, candidate relay list update, communication link quality evaluation and candidate relay list selection. Simulation results reveal obvious advantages for indexes such as the quality of communication, success rate, and time delay.**

Index Terms — **VANET; Parked vehicle; V2V; Relay routing; Shadowing effect**

I. INTRODUCTION

WITH the widespread rise of the Internet of Things (IoT), vehicular ad hoc networks (VANET) have undergone rapid development, and they are beginning to improve the driving experience. The most obvious benefit is improved vehicle safety. In a VANET, a driver can obtain real-time information and anticipate traffic problems, which can greatly reduce the occurrence of traffic accidents. The VANET is created through information interactions between vehicles.

Using the IEEE 802.11p/dedicated short-range communication (DSRC) protocol, vehicles periodically broadcast information, including vehicle information such as speed, location, direction, and surrounding road information. Thus, surrounding vehicles can exchange information in a timely manner. However, this broadcasting is subject to problems. For example, in some densely populated areas, signals cannot pass through buildings to reach other vehicles due to the attenuation of wireless signals. Conversely, when a sufficient number of vehicles are present, the large number of relays can exchange information, but this may lead to excessive delays. A vehicle itself has fluidity, which imposes strict requirements on the delivery time of information; otherwise, when another car receives this information, the sending vehicle will already be in another state. In environments with few vehicles driving on the road at night, there may be no vehicle that can act as a relay node, which will prevent the broadcasting of information and pose a potential safety hazard.

In response to these problems, many scholars have proposed valuable ideas such as the utilization of vehicles parked on the roadside. To overcome the shadowing effect mentioned above, the use of roadside parked vehicles as relay nodes has been proposed [1], which both effectively solves the problem of communication caused by obstacles and improves the utilization of resources. However, the proposed relay method is too simple. To prevent a broadcast storm, the relay must be limited to two hops, which will cause problems such as information redundancy. Other scholars have proposed that the vehicle interaction problems in cities and suburbs are due to the large number of buildings, which seriously affect information transmission in a VANET. The use of vehicles parked next to buildings as relay nodes has been proposed to expand the scope of information transfer [2]. However, the proposed method uses the same relay limited to two hops.

The importance of relay nodes to whole-network propagation has been recognized. A relay node selection algorithm was previously proposed to select the node with the highest connectivity [3,4], but this algorithm is too complicated. A series of processing steps are required before forwarding, which greatly increases transmission delays. Some scholars have also proposed that the next node can be selected based on the link quality, which can improve the accuracy of information transmission, but the link quality assessment is based on statistics over a period of time, is insufficiently accurate, and lacks flexibility. Moreover, the above methods do not fully consider the problems that can arise in practical applications. For example, if only mobile vehicles can relay, communication will not be possible when there are few driving vehicles, and if the distance between two vehicles is greater than the distance required for signal transmission. In areas with obstacles, the shadowing effect will interrupt the signal, and communication cannot be achieved simply via mobile vehicles.

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In this paper, we aim to address the above problems. We propose that parked vehicles can be used as relay nodes in addition to mobile vehicles; this will allow selection of the appropriate nodes for relay communication. In an environment with obstacles, this strategy can effectively reduce problems such as shadow attenuation and greatly improve communication quality. We also design an appropriate relay node selection algorithm to avoid broadcast storms, reduce redundant information, and minimize transmission delays. Finally, this strategy takes full advantage of idle parked vehicles. The main contributions of this paper are as follows:

- We design an efficient resource utilization framework for vehicular ad hoc networks.
- We employ both moving and parked vehicles as relay nodes to improve the communication quality in vehicular ad hoc networks.
- We propose an efficient algorithm for relay node selection and model the link quality assessment by using an autoregressive integrated moving average (ARIMA) model.
- We conduct extensive simulations to evaluate the performance of our proposed approach.

This paper is organized as follows. Section II reviews the related work. Section III describes the problem to be solved in detail. Section IV presents the algorithm we designed to address the problem. Section V presents the simulation and an analysis of the results. Section VI concludes this paper.

II. RELATED WORK

In the city of Montreal, Canada, there are nearly 61000 cars parked in an area of 5500 square kilometers, of which 69.2% are parked on the roadside, 27.1% are parked in outdoor parking lots, and 3.7% are parked indoors [5]. Thus, the nearly 98% of parked vehicles are outdoors, and the average total parked time is approximately 6.64 hours [6]. In Ann Arbor, researchers conducted an investigation lasting six weeks. Although parking time was random and irregular, the utilization rate of parking lots was high and stable, reaching more than 90%. Even in low utilization periods, the utilization rate was maintained at approximately 80% [7]. Driving vehicles accounted for only 1/24 or 4.17% of the total number of vehicles [8], whereas more than 95% of vehicles were parked. Studies have shown that the average parked time of vehicles reaches 23 hours a day [9]. In summary, these studies show that the number of parked vehicles is much larger than the number of driving vehicles. In a traditional VANET, after a vehicle stops, the engine is shut down, and the equipment is automatically withdrawn from the VANET, which is a waste of resources. If we can make full use of the resources of parked vehicles and return them to the VANET, the performance of the VANET will be improved.

Researchers have attempted to use parked vehicles to solve a number of problems and developed various applications. Some applications use parked vehicles as roadside units (RSUs) that can share the work of fixed RSUs [10]; this strategy can relieve RSU resource pressure and reduce the high costs associated with RSUs. Some researchers have used parked vehicles to deliver Certificate Revocation Lists (CRLs) [11] to protect the privacy of vehicles. Vehicles parked on the roadside are usually passed by many driving vehicles. Some scholars have used this feature to allow parked vehicles to distribute messages to the vehicles driving past them to reduce the download latency [12].

Vehicles communicate via the IEEE 802.11p/DSRC protocol, a short-range to medium-range communication service for providing safe or unsafe information to vehicles and RSUs in vehicle-to-vehicle (V2V) and vehicle to roadside (V2R) communications [13,14]. Both the RSU and the vehicle are DSRC devices that can communicate according to this protocol [15]. Vehicle safety applications periodically send cooperative awareness messages (CAMs) through the protocol and even decentralized environmental notifications (DENs) [16,17]. These messages are important for vehicle safety, especially emergency messages, which can greatly reduce the occurrence of sudden safety accidents. If a message can be relayed in advance of an accident, there will be sufficient time to make judgments and choices that avoid a second accident caused by the rear vehicle. In practice, however, these messages can be obscured by obstacles such as buildings, and many emergency messages are not delivered quickly and accurately [16]. If emergency news is lost or the delay is too great, serious harm can occur [18].

Many obstacles exist in the real world, such as buildings, dense plants, traffic lights, billboards and even large cars [19] [20]. These obstacles can affect normal wireless communication, including V2V and vehicle-to-infrastructure (V2I) in a VANET [21,22]. Blockages between the sender and the receiver created by buildings or other obstructions causes slow fading of the signal, which is also known as the shadowing effect [19]. The shadowing effect can greatly increase communication delays between vehicles [23] and even interrupt communication between vehicles. Thus, ensuring efficient and accurate message transmission despite the shadowing effect is an important challenge [24]. Scholars have proposed many signal attenuation models to address this problem [25-27], such as the NAKAGAMI channel attenuation model [28], the RICE channel attenuation model [29], and the WEIBULL model [30]; these models can simulate the attenuation effect of obstacles. Ensuring efficient and accurate message transmission that can overcome the shadowing effect is an important challenge.

If information, whether CAMs or DENs, is directly broadcast, vehicles in the vicinity can receive it as long as they are sufficiently dense, thus effectively avoiding the shadowing effect. This strategy can solve the above problems to a certain extent. However, the strategy does not ensure that a vehicle arriving at an accident area will receive an emergency message in time because the message may have to pass through a large number of forwarding processes. Greater numbers of steps during message transmission increases the delay [31]. Emergency messages have strict delay requirements and cannot be broadcast blindly [32]. In addition, blindly broadcasting information is likely to cause a broadcast storm [33], which can result in significant resource scrambles and packet clashes [34] and can severely cripple the network, hampering services and preventing task implementation [35].

Because of the problems associated with broadcasting information blindly, some scholars have attempted to select suitable vehicles as relay nodes to transfer information. However, many routing protocols do not completely consider the impact of obstacles, and thus, information transmission is not sufficiently accurate [36]. Some papers that aimed to address the shadowing effect have noted that the transmission range of wireless communication is very limited in urban areas, and thus, it is important to choose a good relay node [3]. In [4], it was proposed that node selection should target those with the highest probability of connection in a multi-obstacle environment; however, the resulting algorithm is complex, resulting in large delays [37]. In [38], it was suggested that the statistical value of the packet rate be used to express the quality of the link; however, this method also has shortcomings. The statistical value will slow the packet rate from a stable value to 0 after interruption of the communication; thus, it will not accurately reflect the change in link quality and will cause a node selection error. [39] proposed that appropriate routing information should be selected based on the current location, but topology changes rapidly as a vehicle moves, which can also cause excessive delays. As a result, many relay protocols do not take into account actual conditions. We assume that the worst scenarios will occur in places where traffic is heavy and intense, such as crossroads [40]. Crossroads have a dense traffic flow, and vehicles have different communication needs; these needs depend on the rate of information exchange. In addition, at crossroads or in traffic jams, it is especially crucial to obtain real-time road information quickly, and thus, there are strict requirements regarding the speed of information exchange and the transmission delay [4]. An appropriate relay protocol is important. If only driving vehicles are considered, the network load will be too heavy due to the large number of vehicles and the large amount of network topology information [41]. Driving vehicles are not sufficient to achieve efficient and accurate information transmission. If all vehicles are considered, including parked vehicles near the roadside, this would relieve the load pressure of the VANET and disperse some of the tasks to unused parked vehicles. If the parked vehicles are selected as relay nodes, they will be able to bypass the buildings and send information to the vehicles that would otherwise be influenced by the shadowing effect.

III. PROBLEM STATEMENT AND MOTIVATION

For the problems of resource shortage and high network pressure in the VANET, we propose to reconstruct the vehicle network framework by allowing idle parked vehicles to rejoin the vehicle network, as shown in Figure 1.

Building on the above analysis, we suggest that parked vehicles can be used for relay as a way to resolve the shadowing effect. The problem to be solved in this paper is how to make the parked vehicles and driving vehicles work well together to perform the relay work without causing other negative effects, such as a broadcast storm and information redundancy.

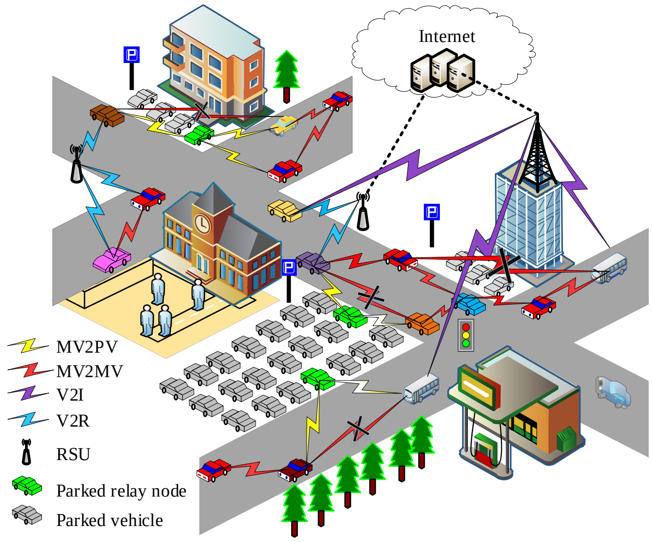


Fig. 1. An example for VANET architecture.

Based on the analysis of related work in the previous section, we know that using the Internet of vehicles for wireless communication requires taking into account the shadowing effect caused by obstacles such as buildings [20]. Although many scholars examined this problem, none of them has yet proposed a practical solution. Many buildings such as shopping malls are equipped with roadside parking lots, in which many parked vehicles are parked for a long time [3]. When these parked vehicles are re-added to the VANET to solve the above problems, they do not need to send broadcast information periodically; rather, they should act as simple repeaters. When two driving vehicles cannot exchange information because of interference from buildings, vehicles parked next to the buildings may instead be within the range of the two driving vehicles. When a parked vehicle receives broadcast information, it can directly relay and forward the information without any processing or waiting and broadcast the information to other vehicles to ensure that they receive the information in time. Additionally, more vehicles are parked at night, so there will be no shortage of relay vehicles for driving vehicles, as shown in Figure 2.

This represents a good solution to the problems caused by the shadowing effect but also greatly improves the utilization of resources and reduces the network burden. When parked vehicles join the VANET, appropriate relay nodes must be chosen from mobile and parked vehicles. A relay node selection algorithm must be designed so that parked vehicles and driving vehicles mutually complete information transmission. To accomplish this goal, several problems must be solved.

(1) It must be possible for vehicles to differentiate between parked vehicles and mobile vehicles. Because the driving environment of the vehicle is continuously changing, this information must be collected periodically. A traditional VANET includes only mobile vehicles, and thus, there is only one vehicle state. When parked vehicles also join the VANET, distinguishing between different vehicle states is the first problem to be solved.

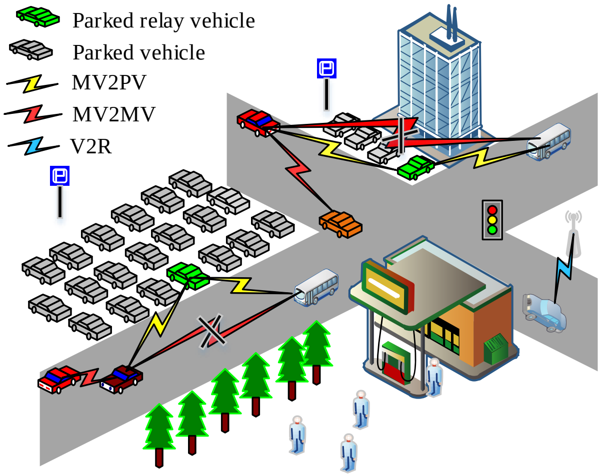


Fig. 2. Using parked vehicles to solve the shadowing effect.

(2) The mobile vehicles and the parked vehicles must work together. In some scenarios, both mobile and parked vehicles can relay information. Thus, the work of vehicles in two different states must be simultaneously coordinated. Inherent in solving this problem is the question of whether different priorities should be set or different choices made.

(3) A vehicle should be able to transmit information. In some areas, there is a very large number of both parked and mobile vehicles. If all vehicles work together to pass the same information, information redundancy will occur, and network overhead will increase. However, if only some of the vehicles are selected to transfer information, appropriate selection criteria must be determined.

(4) The working methods for the selected vehicles need to be determined. When parked vehicles are considered for relaying messages, there may be many parked vehicles nearby. Ensuring that information is delivered to the desired vehicle without creating a broadcast storm in the parked area is also essential.

IV. ALGORITHM DESIGN

As mentioned in last section, there are several issues that need to be solved while using parked vehicles as relay nodes in VANET communications. To guarantee the vehicle-to-vehicle communication in VANET, we propose an efficient Parked Vehicle Assisted Relay Routing (PVARR) algorithm to select the appropriate relay nodes (i.e., vehicles) for the purpose of information forwarding. Our proposed PVARR algorithm is composed of three main parts: Hello packet interaction, link quality evaluation, and relay node selection.

***Algorithm* 1: PVARR Algorithm**

```
while TRUE do [PERIOD = $T_{update}$]
    Call ALV Update Algorithm;
    Call Link Quality Evaluation Algorithm;
    Call Relay Node Selection Algorithm;
end while
```

A. *Hello Packet Interactions*

Before starting to broadcast information, a vehicle needs to send Hello packets to detect the surrounding environment; that is, the vehicle needs information about one-hop neighbor nodes for subsequent relay node selection. The structure of a Hello packet is as follows: broadcast ID, location coordinates, and an adjacency list of vehicles (ALV), where adjacency refers to single hop connections. The broadcast ID is expressed by the MAC address, and the location coordinates are obtained by GPS or GNSS and the cluster ID. The basic Hello packet structure is shown in Figure 3.

ID	Location Coordinates	Adjacency List of Vehicles	Cluster ID

Fig. 3. Basic Hello packet structure.

The MAC address of a single hop node adjacent to a given node is stored in the ALV. For example, for two nodes *A* and *B*, when node *A* receives a Hello packet from node *B*, it updates its own ALV and adds node *B* into the ALV. Because the vehicle is in motion, each node sends Hello packets periodically to update its single hop neighbor node information. Due to the mobility of the vehicles involved and the rapid changes in the surrounding environment, after a certain time T_u, the ALV will be emptied so that it can be updated in time, which can effectively avoid selecting nodes that do not belong to the vehicle's transmission range during follow-up operation.

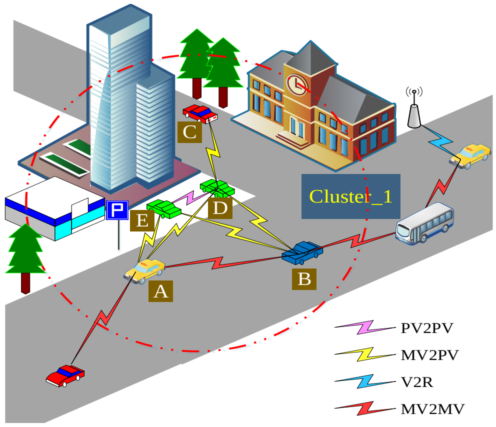
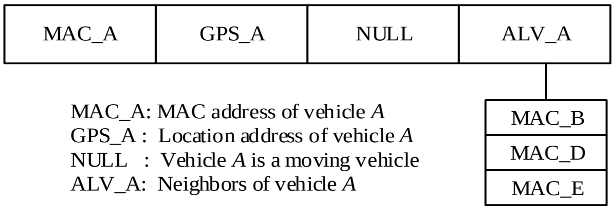


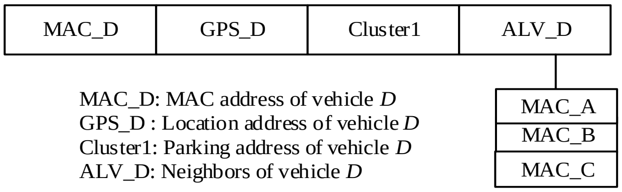
Fig. 4. Hello packet example.

If a structure includes only these three components, problems will occur when a parked vehicle is selected as a relay node. There are a large number of parked vehicles around a mobile vehicle, all of which are in a quiescent state, and the quality of their links is better. Thus, it would be easy to select all those vehicles parked in the area as relay nodes, causing a broadcast storm. To solve this problem, we add the *Cluster_ID* into the Hello data package structure. Thus, all vehicles parked in a certain area have the same ID, and the *Cluster_ID* of driving vehicle is null. When a parked vehicle updates the ALV, it will not add to its own ALV if the received Hello packet was sent from the same area. When choosing a relay node, this strategy avoids selecting parked vehicles in the same area and creating a broadcast storm.

In the example shown in Figure 4, vehicles *A*, *B*, and *C* are driving on the road, and *E* and *D* are vehicles parked in front of a shopping mall. Vehicle *A* can communicate with mobile vehicle *B* as well as with parked vehicles *E* and *D*, but due to interference from the surrounding buildings, vehicles *A* and *C* cannot communicate directly. Similarly, parked vehicle *D* can communicate normally with mobile vehicles *A*, *B*, and *C*; however, it can also communicate with parked vehicle *E*. To avoid a broadcast storm, parked vehicles *D* and *E* are placed in the same cluster, and thus parked vehicle *E* will not be added to the ALV of vehicle *D*. The Hello packets of vehicles *A* and *D* are then as shown in Figure 5.



(a) Hello packets of vehicle *A*.



(b) Hello packets of vehicle *D*.

Fig. 5. Examples of Hello packet structure.

The proposed update algorithm for ALV is as follows.

***Algorithm* 2: ALV Update Algorithm**

```
If ($T_{current}$ -$T_{initial}$ < $T_u$) then
    If (Receive Hello packet) then
        Extract ID and Cluster_ID from the packet;
        If (Cluster_ID != null && Cluster_ID = own Cluster_ID)
            Return
        else
            Update own ALV and add packet's ID;
        end if
    end if
end if
If (arrive $T_u$) then
    Clear ALV;
end if
```

B. Link Quality Evaluation Algorithm

Researchers have adopted several evaluation methods that use the number of Hello packets that can be received in a period of time as a standard for evaluating link quality [42]. In this paper, vehicles send Hello packets when updating their adjacency node information; thus, we use a similar approach to evaluate link quality. When evaluating the link quality between nodes *A* and *B*, traditional methods will count only the number of Hello packets that can be received by node *B* within a certain period of time. To assess link quality, this number is then divided by the number of packets that *A* sent. However, these assessment methods are problematic because vehicles are highly mobile. If we simply use the statistical data in a cycle to represent the quality of a link, accuracy will be a problem. For example, let the number of packets received at a node be (100, 100, 100, 0, 0). Because of interference from buildings, communication is interrupted when using the traditional assessment method. Let the statistical data link quality be 60 and the number of packets for the other node be (0, 0, 80, 100, 100). In this case, the quality of the statistical data link will be 56, far less than the link quality of the first node. Even though in reality the first node will have moved beyond the reach of its communications, the traditional assessment will still consider the first node better than the second. Thus, statistics are not sensitive to changes in link quality. A slow response will inevitably affect subsequent node selection.

In this paper, after multiple statistical cycles, we can obtain a time-axis sequence regarding the success rate of data transmission. With this sequence, we can predict the link quality for the next statistical period. However, for nonstationary sequences, digital features such as the variance and mean will change over time. That is, the random behavior of the nonstationary sequence will differ through time; it is difficult to predict the randomness of the sequence based on known information. To address such problems, Box-Jenkins proposed the ARIMA method of time series analysis based on random theory in 1970 [43]. Its basic principle is to regard a time series as a random process and to describe or simulate it with a mathematical model. This allows the prediction of future values based on past values and current observations.

The VANET is a dynamically changing network. The links between vehicles change all the time. Because of the changes in topology and interference from the surrounding environment, the link quality also changes [44]. Thus, the ALV update cycle T_u must be carefully chosen. If T_u is too long, it will not adapt to the dynamic characteristics of vehicles and may fail to update links in time, probably resulting in errors. For example, if the states are not updated rapidly, vehicles that have left the current communication range will still be regarded as candidate nodes, which may cause information interruptions. If T_u is too short, the evaluation of the current link will not be sufficiently accurate. If the node is still receiving the packet, but the cycle has ended, the link quality will be much lower than the actual value.

Based on a previous study [38], we set T_u equal to 5 seconds, which will not only update the link rapidly but also ensure that the time is sufficiently long to evaluate the link.

To determine whether two nodes are connected, we propose the following method. Take the example of two adjacent nodes, *A* and *B*. Node *A* broadcasts a Hello packet, which is received by *B*. Node *B* then adds node *A* into its ALV and broadcasts its own Hello packet, which *A* receives. Node *A* analyzes the ALV of node *B* and finds itself present, which means that *B* can accurately receive the information sent by *A* and that *A* can communicate with *B*.

When a Hello packet is not sent correctly for some reason, as shown in Figure 6, it is assumed that the Hello packet sent to node *C* by *A* has an error and that the remainder of the Hello packets were correctly transmitted. Thus, when *A* receives the packet sent by *B* and finds itself in the ALV of *B*, normal communication is possible between *A* and *B*. However, if only node *B* is present in the ALV sent to *A* by *C* (i.e., *A* is not present), this means that *C* has not received the packet from *A* and that normal communication between the two nodes is not possible.

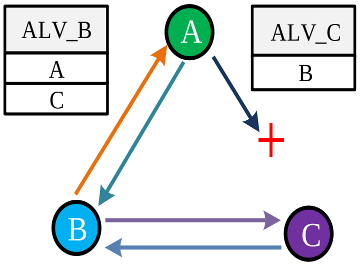


Fig. 6. ALV update case.

The link quality evaluation formula is as follows. T_u is the time required to update the ALV and T_s is the period of continuous transmission of Hello packets. Next, we need to evaluate the quality of the link based on the number of packets accurately received by the candidate nodes during the T_s. P_M represents the predicted number of normally communicated Hello packets between two nodes when the candidate node is a mobile vehicle. P_P is the predicted number of normally communicated Hello packets between two nodes when the candidate node is a parked vehicle. The next section discusses the modeling prediction. The denominator is the same and indicates the number of messages that can be transmitted normally under ideal conditions. The weights of the mobile and parked vehicles are represented by *a* and *b*, respectively, where *a* + *b* = 1.

$$LQM = \frac{P_M}{T_s/T_u} * a \tag{1}$$

$$LQP = \frac{P_p}{T_s/T_u} * b \tag{2}$$

***Algorithm* 3: Link Quality Evaluation Algorithm**

```
Set $IM = 0$, $IP = 0$;
new array move_array[ ], parked_array[ ],
while ($T_{current} - T_{initial} < T_u$) then
    $T_{initial\_2} = T_{initial}$;
    while ($T_{current} - T_{initial\_2} < T_s$)
        If (receive a Hello Packet) then
            extract ALV and Cluster_Id;
            If (ALV contains itself) then
                If (Cluster_Id == Null) then
                    $IM$ ++;
                else
                    $IP$ ++;
            end if
        end if
    end while
    $T_{initial\_2} = T_{current}$;
    Update $T_{current}$;
    Put $IM$ into the move_array[ ];
    Put $IP$ into the parked_array[ ];
    Reset: $IM = 0$; $IP = 0$;
end while
If (arrive $T_u$) then
    Input move_array[ ] and parked_array[ ] to the ARIMA model
    Predict $LQ$;
    Compute $LQM$, $LQP$;
    Set $T_{initial} = T_{current}$;
    Update $T_{current}$;
    Reset move_array[ ] and parked_array[ ];
end if
```

C. ARIMA Modeling

The ARIMA model examines the dynamics and continuity of the time series and evaluates the relationships between past and present and between future and present [43]. The sequence $\{X\}$ with d time difference can become stationary, and the ARIMA model is set up as follows:

$$\Phi(B)\nabla^d x_t = \Theta(B)\varepsilon_t \tag{3}$$

$$E(\varepsilon_t) = 0, Var(\varepsilon_t) = \delta^2, E(\varepsilon_t \varepsilon_s) = 0, s \neq t \tag{4}$$

$$E(x_t \varepsilon_s) = 0, \forall s < t \tag{5}$$

In addition,

$$\nabla^d = (1 - B)^d \tag{6}$$

$$\Phi(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p \tag{7}$$

The autoregressive coefficient polynomial of the stationary ARIMA (*p*, *q*) model is as follows:

$$\Theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q \tag{8}$$

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The smoothing coefficient polynomial of the smoothing reversible ARIMA (*p*, *q*) model, which can be written as follows:

$$\nabla^d x_t = \frac{\Theta(B)}{\Phi(B)} \varepsilon_t \tag{9}$$

As shown in the above equation, the ARIMA model combines the difference operation and an ARIMA model. Any nonstationary sequence can be fit using the ARIMA model after the difference of the proper order is calculated, as follows:

$$\nabla^d x_t = \sum_{i-1}^{d} (-1)^d C_d^i x_{t-1} \tag{10}$$

$$C_d^i = \frac{d!}{i!(d-i)!} \tag{11}$$

That is, the post-difference sequence is equal to the weighted sum of several sequence values of the meta-sequence.

1) Determination of *d*

A nonstationary random sequence must be smoothed using a differential treatment; *d* is the order of the differential operation. The first-order difference is calculated as follows:

$$\nabla x_t = x_t - x_{t-1} \tag{12}$$

The first-order difference operation of the sequence after the first-order difference is called the second order difference, which is expressed as follows:

$$\nabla^2 x_t = \nabla x_t - \nabla x_{t-1} \tag{13}$$

The d-order difference is then as follows:

$$\nabla^d x_t = \nabla^{d-1} x_t - \nabla^{d-2} x_{t-1} \tag{14}$$

For some periodic sequences, the step difference can be used, and the *K* step difference is the only difference between two sequences of *K*, as follows:

$$\nabla_k x_t = x_t - x_{t-k} \tag{15}$$

Notably, higher orders of the differential operation are not better because the differential operation is a process of extracting and processing information. Each differential operation will include a loss of information, and thus, these operations must be appropriately used in practical applications, avoiding an over-differential. The augmented Dickey-Fuller (ADF) [45] method can be used to evaluate differential sequences until the results are stable. Given the loss of information every time a differential operation is performed, the number of differential operations should be limited. The difference sequence is tested using ADF methods until the result is stable.

2）ADF application

ADF detection is used to determine the stability of the sequence. The regression equation and the nihilism hypothesis of the ADF verification are expressed as follows:

$$\nabla x_t = \rho x_{t-1} + \beta_1 \nabla x_{t-1} + \cdots + \beta_p \nabla x_{t-p} + \varepsilon_t \tag{16}$$

$$\rho = \phi_1 + \phi_2 + \cdots + \phi_p - 1 \tag{17}$$

$$\beta_1 = -\phi_{j+1} - \phi_{j+2} - \cdots - \phi_p,\ j-1,2,\cdots,p-1 \tag{18}$$

If the sequence is stable, it must satisfy the following expression:

$$\phi_1 + \phi_2 + \cdots + \phi_p < 1 \tag{19}$$

which means $\rho < 0$. If the sequence is nonstationary, there must be at least one unit root; that is, $\rho = 0$. The ADF verifies that if all roots are in the unit circle, the sequence is a stationary time series.

3) Calculation of the ACF and PACF

Based on the related characteristics of the autocorrelation function (ACF) and the partial autocorrelation function (PACF), we must find the value of the correlation coefficient $\hat{\rho}$ and the partial correlation coefficient $\hat{\phi}_{kk}$ in order to select an appropriate model. These values are determined as follows:

$$\hat{\rho} = \frac{\sum_{t=1}^{n-k} (x_t - \bar{x})(x_{t+k} - \bar{x})}{\sum_{t=1}^{n} (x_t - \bar{x})^2}, \forall 0 < k < n \tag{20}$$

$$\hat{\phi}_{kk} = \frac{\hat{D}_k}{\hat{D}}, \forall 0 < k < n \tag{21}$$

These expressions can be written as follows:

$$\hat{D} = \begin{vmatrix} 1 & \hat{\rho}_1 & \cdots & \hat{\rho}_{k-1} \\ \hat{\rho}_1 & 1 & \cdots & \hat{\rho}_{k-2} \\ \vdots & \vdots & \vdots & \vdots \\ \hat{\rho}_{k-1} & \hat{\rho}_{k-2} & \cdots & 1 \end{vmatrix} \tag{22}$$

$$\hat{D}_k = \begin{vmatrix} 1 & \hat{\rho}_1 & \cdots & \hat{\rho}_1 \\ \hat{\rho}_1 & 1 & \cdots & \hat{\rho}_2 \\ \vdots & \vdots & \vdots & \vdots \\ \hat{\rho}_{k-1} & \hat{\rho}_{k-2} & \cdots & \hat{\rho}_k \end{vmatrix} \tag{23}$$

TABLE I
PATTERN RECOGNITION PRINCIPLE

$\hat{\rho}$	$\hat{\phi}_{kk}$	**Model**
Tailing	*p* order truncation	AR (*p*)
q order truncation	Tailing	MA (*q*)
Tailing	Tailing	ARIMA(*p*, *q*)

4) Model recognition

After the autocorrelation coefficient and the partial autocorrelation coefficient are obtained, a suitable model is fit based on their properties. The principles of the selected model are shown in Table I.

5) Determination of *p* and *q*

Commonly used methods for determining the *p* and *q* parameters are the final prediction error, the Akaike information criterion (AIC), the Bayesian Information Criterion (BIC) and the singular value decomposition method [43]. The principle of AIC is to minimize the following formula:

$$AIC(p,q) = \ln \delta_d^2 + 2(p+q)/N \tag{24}$$

where δ_d^2 is the variance of the sequence residual, and *N* is the sequence length. The BIC requirements are more stringent, as follows:

$$BIC(p,q) = \ln \delta_d^2 + (p+q)\frac{\ln N}{N} \tag{25}$$

Of course, the order can also be limited using an empirical method. For example, when N ranges from 20 to 50, the maximum order is *N*/2; when N ranges from 50 to 100, the maximum order is between *N*/3~*N*/2; and when N ranges from 100 to 200, the maximum order is 2*N*/ln (2*N*). Precise estimation of parameters can be achieved using moments estimation, maximum likelihood estimation, least squares estimation and other algorithms.

6) Testing

After the fitting model has been determined, it is necessary to perform tests and select the model with the smallest error.

D. Link Selection Algorithm

Link selection takes into account link quality but also uses the distance between nodes as a reference factor. That is, it takes into account the link quality $LQ \times d$, where *LQ* includes *LQM* and *LQP*; and *d* is the distance between two communication nodes. For candidate node selection, the current node is one hop node, and the node must also satisfy a condition regarding the distance *d*, as follows: $d \le \bar{d}$, $\bar{d} = (d_1 + d_2 + ... + d_n)/n$, which is the average distance. That is, the candidate nodes must be within the average distance of all nodes, and the selection of nodes that are too far away should be avoided. Thus, the stability of the signal transmission can be ensured.

Assuming that there are *j* candidate nodes, each link quality is calculated as $LQ_j \times d$, where $j = 1, 2, \ldots, n$. According to the link quality, each node is arranged in descending order and then stored in the array. To avoid selecting too many nodes to transmit messages, which will cause information redundancy and increase the network burden, we select only the first 5 nodes. Their index ranges from 0 to 4 because it is in descending order; the lower the subscript, the better the link quality.

To prevent all nodes from forwarding data at the same time, which will result in redundant information and increased network pressure, different relay times are set for each selected relay node. Obviously, the nodes in the front of the array are of higher quality, and subsequent nodes are also prioritized to ensure shorter waiting times. Therefore, we set up the relay waiting time $t_i = i \times \sigma$, where *i* is the corresponding index of the above array nodes. For the selection of σ, we refer to the results of [45] and set σ = 10 ms. When the candidate nodes include both parked and driving vehicles, the parked vehicle itself has no tasks other than functioning as a relay node. It can make its relay wait time shorter, and thus, the parked vehicle is given a value at random in the theoretical time t_i to avoid conflict.

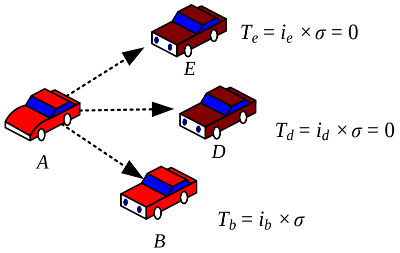


Fig. 7. An example for communications.

As shown in Figure 7, we abstract the communication about node *A* in the example shown in Figure 4. Based on the above, vehicle *A* can communicate with vehicles *B*, *D* and *E*, where the vehicle *E* and *D* are parked vehicles. Their respective relay times are shown on the right side of Figure 7, and the contents stored in the array are shown in Table II.

TABLE II
VEHICLE A RELATED DATA

Array subscript	***Node_id***	***LQ***	***d***	***LQ × d***
0	D	0.7	100	70
1	E	0.8	80	64
2	B	0.5	120	60

When node *A* selects the next relay node, its single hop direct connection has three EDB nodes, and each of their $LQ \times d$ values are calculated. The results are listed in descending order as above. Since node *D* is ranked first, it forwards directly without waiting. The waiting time of node *E* is a random number between 0 and $1 \times \sigma$, while node *B* must wait $2 \times \sigma$ before relaying.

***Algorithm* 4: Relay Node Selection Algorithm**

```
If (the relay candidate is a parked vehicle) then
    Compute LQ according to Equation (2);
else if (the relay candidate is a moving vehicle) then
    Compute LQ according to Equation (1);
end if
Sort all nodes LQ in descending order;
Put the first five relay nodes' node_ID into the array;
if (the relay candidate is a moving vehicle)
    The relay waiting time $w = i \times \sigma$ ;
end if
if (the relay candidate is a parked vehicle)
    The relay waiting time $w = rand(0, i) \times \sigma$;
end if
Broadcast information after the w arrives;
```

V. SIMULATION RESULTS AND ANALYSIS

A. *Simulation Environment*

We use JAVA to build the simulation environment and simulate the data transmission algorithm based on the parked vehicle relay. We simulate the map of traffic flow based on an actual urban environment and then compare the operation results of the BDSC algorithm [43], GRPL algorithm [51] and PGRP algorithm [52] with our proposed PVARR algorithm. Because the choice of map environment strongly affects the performance evaluation, we chose the street area inside the First Ring Road of Chengdu in China as the actual testing environment, as shown in Figure 8.

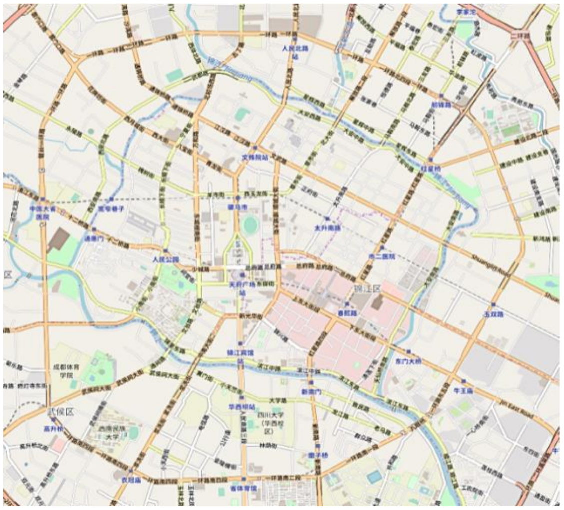


Fig. 8. Actual testing environment.

We measured the basic parameters of the actual area and modeled one of the blocks, as shown in Figure 9.

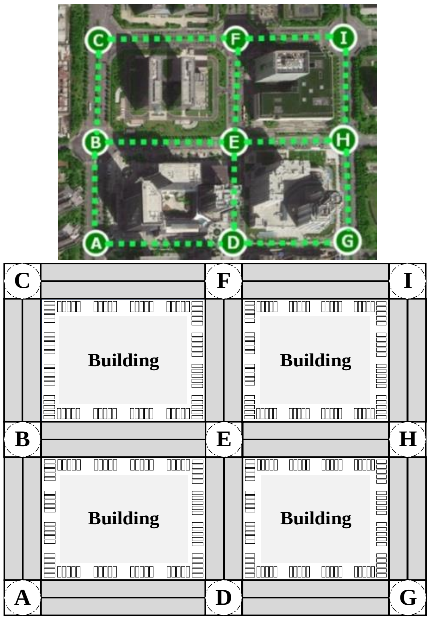


Fig. 9. Model of one block.

The model in Figure 9 consists of 9 crossroads, 12 two-way roads and 4 buildings or building groups. Each crossroad is identified separately by the letters A-I. In addition, there are a certain number of parking spaces that are equally spaced on either side of the road and can provide temporary parking for vehicles. For the entire testing environment, the basic parameters of each block are set as shown in Table III.

TABLE III
SIMULATION ENVIRONMENT PARAMETERS OF ONE BLOCK

Parameters	Identifications	Values
Building One	[ABED]	<1160 m, 860 m>
Building Two	[BCFE]	<1160 m, 960 m>
Building Three	[DEHG]	<960 m, 860 m>
Building Four	[EFIH]	<960 m, 960 m>
Road One	AB, DE, HG	<900 m, 10 m>
Road Two	BC, EF, HI	<1000 m, 10 m>
Road Three	AD, BE, CF	<1200 m, 10 m>
Road Four	DG, EH, FI	<1000 m, 10 m>

In addition, in our simulation experiments, the vehicles are divided into mobile vehicles and parked vehicles. Based on the different simulation scales, we set up different vehicle densities, as shown in the table.

For simulations with different vehicle densities, we set up various quantities of moving vehicles and parked vehicles on different roads based on the vehicle density to achieve a uniform distribution of vehicles in the area. The parameters of vehicle density are shown in Table IV.

TABLE IV
SIMULATION OF VEHICLE DENSITY PARAMETERS

Density (veh/km)	Min value	Max value	Step value
Moving vehicle density	20	240	20
Parked vehicle density	80	400	40

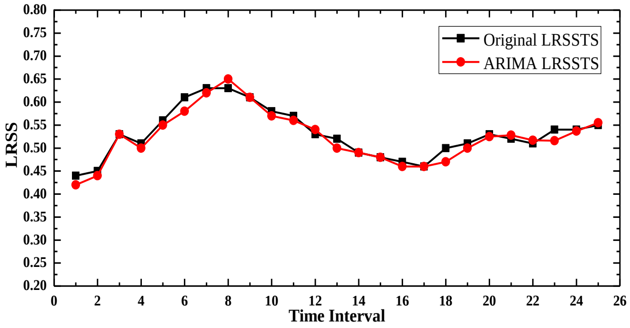
For the vehicle simulation, we assume that each vehicle is equipped with a wireless transceiver that conforms to the IEEE 802.11p standard, a GPS positioning device and a data processing unit. We set the driving speed between 10 and 90 km/h, and the basic vehicle parameters are in accordance with the specification parameters of a medium-sized SUV. In addition, we set the maximum communication distance between vehicles as 250 m, as described in [48]. The specific parameters of the simulation are shown in Table V.

TABLE V
SIMULATION PARAMETERS

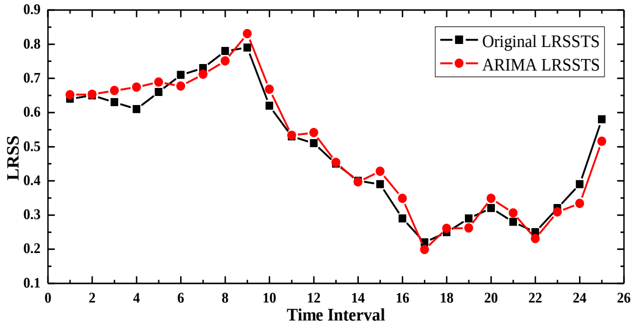
Parameters	Value
Vehicle speed	3.0 m/s – 20.0 m/s
Vehicle length	4.9 m
Vehicle width	2.1 m
Maximum communication distance	250 m
Hello packet generation interval	500 ms

B. *Analysis of Simulation Results*

We first conduct simulation testing on the ARIMA fitting process in our proposed Link Quality Evaluation Algorithm. To verify that the ARIMA model can efficiently fit the link relative signal strength time series (LRSSTS), we conduct simulations under two different scenarios, i.e., stationary communication process and nonstationary communication process. Figure 10 illustrates that the ARIMA model can be used to predict and evaluate the link quality under both scenarios.



(a) Stationary communication process



(b) Nonstationary communication process

Fig. 10. Comparisons of original LRSSTS and ARIMA LRSSTS.

After simulating vehicle communication in a variety of vehicle density cases, we calculated information statistics on the results of the BDSC [43], GRPL [51], PGRP [52] and PVARR algorithms. The metrics used to evaluate the performance of the compared algorithms are shown in Table VI.

TABLE VI
SIMULATION INDEX DESCRIPTION

Metrics	Descriptions
Packet Delivery Ratio	For each message, the packet delivery rate is defined as the rate at which messages are successfully received by their subscribing users from the source node.
Packet Delivery Delay	For each message, the packet delivery delay is defined as the time it takes for the message to be sent from the source node to its subscribers' receipt of the message.
Packet Delivery Quality	For each message, the packet delivery quality is defined as the quality of the message received from the source node when it is received by the subscribing user.

For packet delivery quality, we selected the optimal product of the probability of a transmission link for each hop. This quantity can approximate the basic relationship between the number of hops and the quality of the selected link.

As shown in Figure 11, as the density of moving vehicles increases, the data delivery rate of communication messages also increases. For an area of a specific size, when the density of moving vehicles increases, the number of moving vehicles increases, and thus, more relay vehicles are available between vehicles. This increased availability can improve the delivery success rate of vehicle communication messages. In addition, when the PVARR algorithm is used to propagate packets, the overall packet delivery rate is higher than that of the existing algorithms. This improved performance is mainly because, in the PVARR approach, communication between mobile vehicles can be relayed by vehicles parked on the roadside, which greatly improves the delivery rate of data packets between moving vehicles.

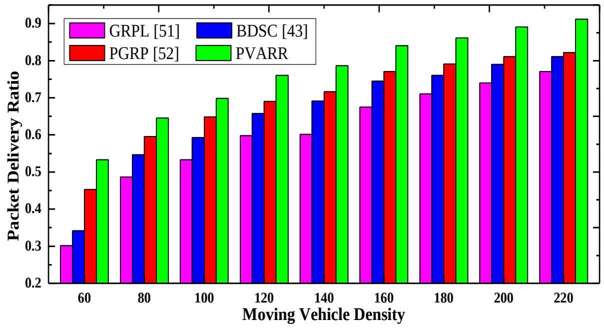


Fig. 11. Moving vehicle density *vs.* packet delivery ratio.

Figure 12 illustrates the relationship between the packet delivery rate and the roadside parked vehicle density. The packet delivery ratio of the PVARR algorithm is higher than that of the existing algorithms. For the BDSC algorithm, there is no significant correlation between the delivery rate of data packets and the density of vehicle parking on the roadside; the data show a steady trend. However, the packet delivery ratio is positively correlated with the increase in parked vehicles for the PVARR approach. This relationship is present because the increase in roadside parked vehicles increases the probability that a moving vehicle will relay to other moving vehicles through parked vehicles during message communication. However, when the density of parked vehicles increases past a certain value, the rate of increase of the packet delivery ratio slows, which occurs because when parked vehicles reach a certain density, the moving vehicles are fully capable of communication, and the effect of adding a parked vehicle is relatively small. Therefore, in the PVARR approach, increasing the number of parked vehicles can improve the packet delivery ratio to a certain extent.

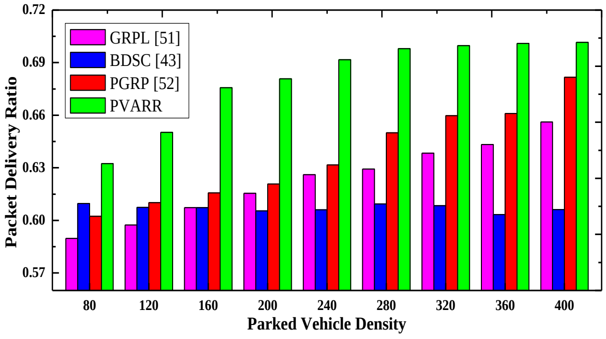


Fig. 12. Parked vehicle density *vs.* packet delivery ratio.

As shown in Figure 13, as the density of moving vehicles increases, the packet delivery delay for message dissemination among vehicles decreases. As the density of mobile vehicles increases, the number of relay hops propagating between vehicles decreases, and thus, the delivery delay of the entire data packet decreases. In addition, because the message waiting time for a parked vehicle is shorter than that for a moving vehicle, the packet delivery delay is shorter in the PVARR algorithm than in the existing algorithms.

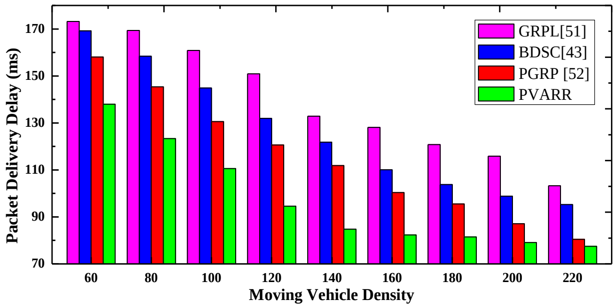


Fig. 13. Moving vehicle density *vs.* packet delivery delay.

As shown in Figure 14, when the simulation is in the BDSC approach, the delay in message transmission between vehicles shows a stable trend. This result is logical because the simulation mode does not depend on parked vehicles, and thus, a change in the density of parked vehicles will not affect the simulation results. In contrast, as the density of parked vehicles increases, the packet delivery delay between mobile vehicles decreases in our PVARR approach. The main reason for this negative correlation is that using parked vehicles as a relay greatly optimizes the transmission path of packets and the delivery delay of packets.

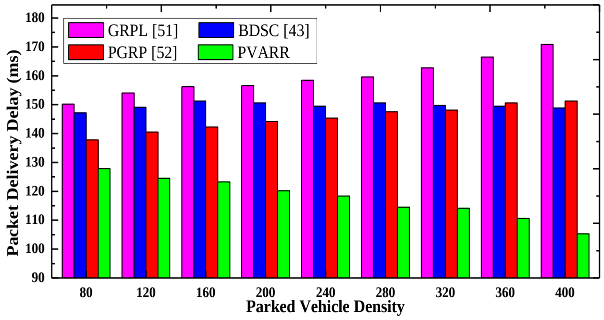


Fig. 14. Parked vehicle density *vs.* packet delivery delay.

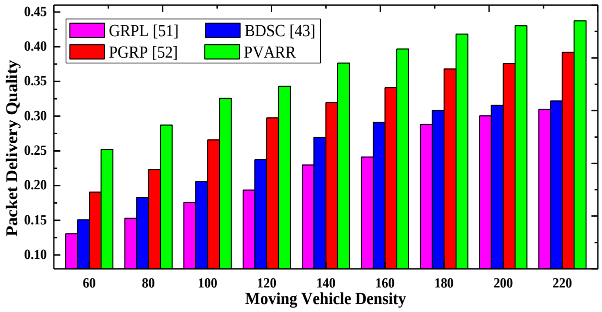


Fig. 15. Moving vehicle density *vs.* packet delivery quality.

As shown in Figure 15, as the density of moving vehicles increases, the packet delivery quality between moving vehicles increases. The main reason for this positive correlation is that as the number of moving vehicles increases, the number of available mobile relay vehicles increases. The message transmission path and thus the quality of the message can be optimized. In addition, the use of a parked vehicle as a relay can greatly improve the quality of the message compared to the use of only moving vehicles, which is the main reason the quality of packet delivery is better in the PVARR algorithm than in the existing algorithms.

Figure 16 shows that when the PVARR approach is used for message delivery, the delivery quality of the entire data packet is positively related to the density of the parked vehicles. The parked vehicles provide a stable, high-quality relay choice for data packet transmission. Therefore, the delivery quality of the data packets between the moving vehicles can be improved. We also find that the positive correlation with packet delivery quality diminishes when the density of parked vehicles reaches a certain threshold. In addition, we observe that in the BDSC approach, the delivery quality of the data packets is stable because the BDSC approach does not depend on parked vehicles for message relay; thus, this approach is not affected by the density of parked vehicles.

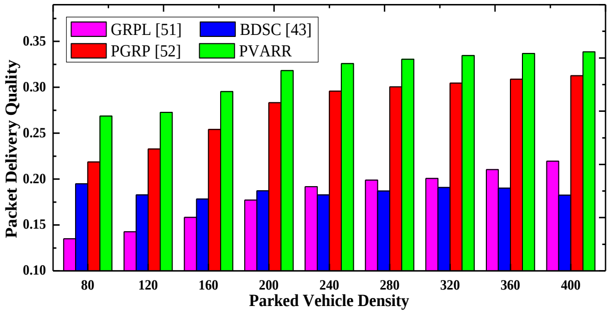


Fig. 16. Parked vehicle density *vs.* packet delivery quality.

Next, we compare the simulation results in the distance dimension to the simulations in the compared algorithms. When simulating the distance dimension, we set up a number of simulation vehicles with different relative coordinate schemes. The communication distance remained unchanged.

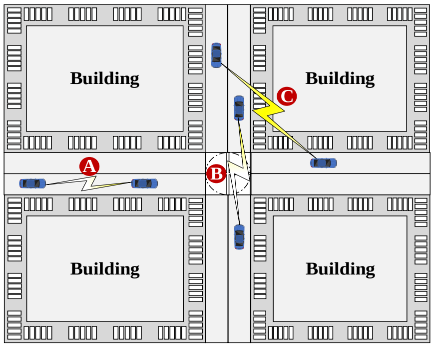


Fig. 17. Simulation distance environment of one block.

As shown in Figure 17, there are three types of relative coordinate scenarios for moving vehicles: straight line communication on the same road, straight line communication across crossroads, and corner communication across

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intersections. These three coordinate scenes cover basically all vehicle communication scenarios. Therefore, when simulating a specific distance, we used these three relative coordinate scenarios.

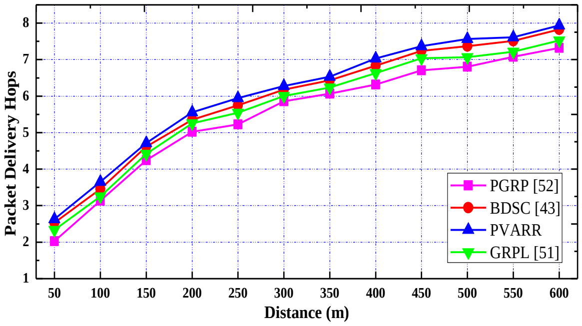

Fig. 18. Packet delivery hops *vs.* distance.

As shown in Figure 18, as the communication distance between moving vehicles increases, the number of hops involved in packet delivery gradually increases. Additionally, because the parked vehicles are involved in relaying messages, communication can be realized by using the parked vehicle relay under the special map scene, especially at crossroads. However, this leads to an increase in the number of packets transmitted per hop. Therefore, overall, the number of packet delivery hops is slightly greater in the PVARR algorithm than in the existing algorithms.

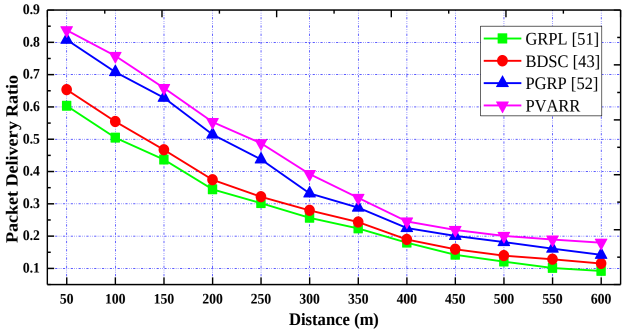

Fig. 19. Packet delivery ratio *vs.* distance.

As shown in Figure 19, as the communication distance between moving vehicles increases, the packet delivery ratio decreases. This negative correlation occurs because when the communication distance increases, due to shadowing effect and path attenuation, the message signal strength decreases, and the number of message propagation hops increases. As a result, the delivery ratio of the entire packet is inversely proportional to the distance. In addition, due to the relay function of the parked vehicles, the packet delivery ratio is higher in the PVARR algorithm than in the existing algorithms.

Figure 20 shows the packet delivery delay for different distances and different relay modes. As the communication distance increases, the relay hops and processing latency increase, and thus, packet delivery latency increases. In the previous section, we mentioned that the waiting and handling delays for a message relayed via a parked vehicle are much smaller than the delays for a message relayed by a moving vehicle. Therefore, although the average hop count in the PVARR algorithm is greater than the average hop count in the existing algorithms, the overall packet delivery delay is better in the PVARR algorithm than in the existing algorithms.

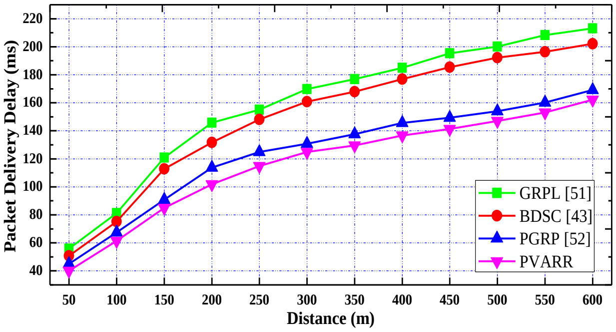

Fig. 20. Packet delivery delay *vs.* distance.

As shown in Figure 21, the packet delivery quality decreases as the communication distance between moving vehicles increases. As the communication distance increases, both relay hops and path attenuation increase. As a result, packet delivery quality decreases as distance increases. Between the two modes of delivery, using parked vehicles provides a better quality of relay links and thus improves the overall delivery quality of data packets.

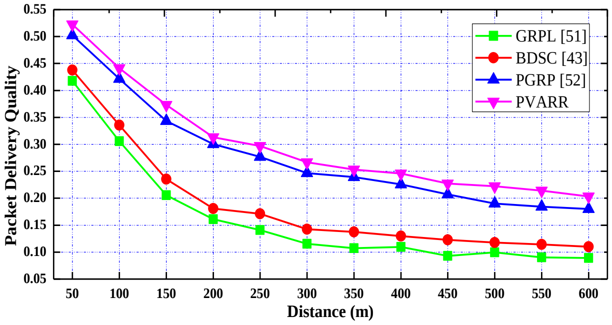

Fig. 21. Packet delivery quality *vs.* distance.

VI. CONCLUSION AND FUTURE WORK

There are many buildings and other obstructions in cities or suburban areas. These features cause poor or even interrupted communication in VANETs. In this article, we propose using vehicles parked on the roadside or near buildings as relays and design related broadcasting algorithms. The algorithm has three components: a packet updating algorithm, a link quality evaluation algorithm and a relay node selection algorithm. The above algorithms consider the advantages of unused parked vehicles and link quality. Based on this algorithm, moving vehicles and parked vehicles can work together to effectively avoid a broadcast storm, increase the utilization rate of resources, and effectively relieve pressure on the network. The simulation results show that the parked vehicle algorithm has obvious advantages in terms of time delay, link quality, information achievable ratio and the number of hops.

Several papers (e.g., [54-58]) have studied related security and wireless issues. Actually, there are some security issues need to be addressed in V2V communications. For example, a malicious user/ hacker may intrude or control a relay node (i.e., a parked car) and then intercept/wiretap important or private information of other users. In our future work, we are going to study the security problem in V2V communications.

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