New Multi-Hop Clustering Algorithm for Vehicular Ad Hoc Networks

Degan Zhang, *Member, IEEE*, Hui Ge, *Member, IEEE*, Ting Zhang, *Member, IEEE*, Yu-Ya Cui, *Member, IEEE*, Xiaohuan Liu, *Member, IEEE*, and Guoqiang Mao, *Fellow, IEEE*

***Abstract*— As a hierarchical network architecture, the cluster architecture can improve the routing performance greatly for vehicular ad hoc networks (VANETs) by grouping the vehicle nodes. However, the existing clustering algorithms only consider the mobility of a vehicle when selecting the cluster head. The rapid mobility of vehicles makes the link between nodes less reliable in cluster. A slight change in the speed of cluster head nodes has a great influence on the cluster members and even causes the cluster head to switch frequently. These problems make the traditional clustering algorithms perform poorly in the stability and reliability of the VANET. A novel passive multi-hop clustering algorithm (PMC) is proposed to solve these problems in this paper. The PMC algorithm is based on the idea of a multi-hop clustering algorithm that ensures the coverage and stability of cluster. In the cluster head selection phase, a priority-based neighbor-following strategy is proposed to select the optimal neighbor nodes to join the same cluster. This strategy makes the inter-cluster nodes have high reliability and stability. By ensuring the stability of the cluster members and selecting the most stable node as the cluster head in the N-hop range, the stability of the clustering is greatly improved. In the cluster maintenance phase, by introducing the cluster merging mechanism, the reliability and robustness of the cluster are further improved. In order to validate the performance of the PMC algorithm, we do many detailed comparison experiments with the algorithms of N-HOP, VMaSC, and DMCNF in the NS2 environment.**

***Index Terms*— Vehicular ad hoc networks, reliability, routing, multi-hop cluster, neighbor following strategy.**

Manuscript received July 24, 2017; revised February 3, 2018, April 15, 2018, and June 3, 2018; accepted June 28, 2018. This work was supported in part by the National Natural Science Foundation of China under Grant 61571328, in part by the Tianjin Key Natural Science Foundation under Grant 13JCZDJC34600, in part by the CSC Foundation under Grant 201308120010, in part by the Major Projects of Science and Technology in Tianjin under Grant 15ZXDSGX 00050, in part by the Training Plan of Tianjin University Innovation Team under Grant TD12-5016 and Grant TD13-5025, in part by the Major Projects of Science and Technology for their services in Tianjin under Grant 16ZXFWGX00010 and Grant 17YFZC GX00360, in part by the Key Subject Foundation of Tianjin under Grant 15JCYB JC46500, and in part by the Training Plan of Tianjin 131 Innovation Talent Team under Grant TD2015-23. The Associate Editor for this paper was L. Yang. *(Corresponding author: Ting Zhang.)*

D. Zhang, H. Ge, T. Zhang, Y. Y. Cui, and X. Liu are with the Key Laboratory of Computer Vision and System, Tianjin Key Lab of Intelligent Computing and Novel software Technology, Ministry of Education, Tianjin University of Technology, Tianjin 300384, China (e-mail: gandegande@126.com; 1464736574@qq.com; zhangdegan@tsinghua.org.cn; 844511468@qq.com; 815215568@qq.com).

G. Mao is with the Center for Real-Time Information Networks, School of Computing and Communications, The University of Technology Sydney, Sydney, NSW 2007, Australia (e-mail: g.mao@ieee.org).

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Digital Object Identifier 10.1109/TITS.2018.2853165

I. Introduction

WITH the continuous development of wireless communication technology and embedded system, intelligent transportation system has become a hot research field in recent years. As a special MANET (Mobile Ad hoc Networks), the Vehicular Ad hoc Networks (VANET) is an important part for the ITS (Intelligent Transportation System). VANET architecture [1] is divided into two communication architectures, including vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). With the flexibility of self-organization of vehicles, V2V architecture can easily implement information sharing and data communication between vehicles; V2I architecture enables the vehicle to access the Internet, achieves long-distance communications and meets the needs of traffic and vehicular entertainment etc. As the main application field of VANET, ITS requires VANET to provide real-time and effective information to the driver[2], such as road condition information and traffic jam, to ensure efficient and safe travel.

Dedicated Short-Range Communication (DSRC) uses IEEE 802.11p protocol for communication, which has the advantages of smaller overhead and is the main way to achieve inter-vehicle communication. DSRC can meet the requirements for the rapid establishment of a network between vehicles. However, considering the characteristics of vehicle nodes moving fast, uneven distribution and continually changing network topology, it is unrealistic to only use V2V to realize the communication in ITS. Therefore, the V2I-based network architecture has been widely studied by scholars and research institutions. In the V2I network architecture, the third-generation cellular system UMTS (Universal Mobile Telecommunications System), which is a fixed infrastructure, has been used in the Project Cooperative Car (Cars) [3]. UMTS can provide long-distance effective data transmission, and transmission delay is less than 1s.

The fourth-generation cellular system LTE (Long Term Evolution) [4] adds capacity and speed on the basis of UMTS, which can provide that the maximum downlink speed is 300Mb/s, the uplink speed is 75Mb/s, transmission delay is far less than 5ms, and the transmission range reaches to 100km. Although LTE has a higher rate and longer transmission range, only communicating with each vehicle node through LTE will result in more handshaking packets between vehicles and base station, resulting in a great waste of network bandwidth. In particular, in the case of large vehicle densities, this overhead is extremely large. The self- organizing nature of the V2V architecture further reduces this overhead.

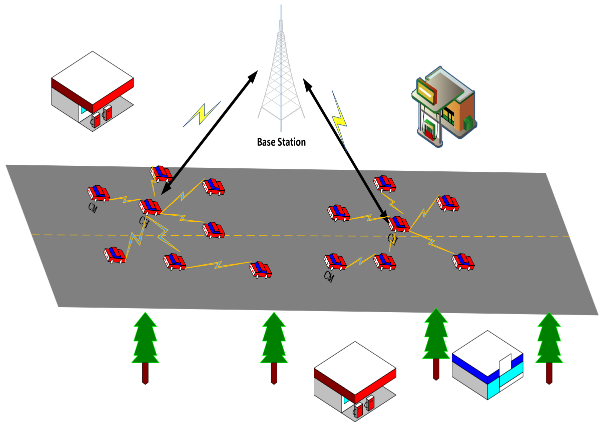

Fig. 1. Hybrid network architecture model.

In recent years, some hybrid network architectures have been proposed [5], [6]. The basic network model is shown as Figure 1. The hybrid network architecture fully combines the advantages of a lower network overhead and flexible deployment of V2V and the advantages of lower transmission latency and wide propagation range of LTE. In this hybrid architecture, inter-vehicle communication utilizes the IEEE 802.11p protocol. By clustering the vehicles and exchanging the packets with the base station only by the cluster head node, the number of handshakes between the vehicle node and the base station is greatly reduced and the overhead is effectively dropped. This hybrid architecture can improve the performance of the network, but its problems are also serious: first of all, it requires a high level of stability of the cluster, and as little cluster head node as possible to ensure maximum bandwidth utilization in the entire network; secondly, in order to ensure the reliability of communication, the cluster structure should have higher link reliability. However, affected by the nature characteristics of VANET, it is a challenge to solve these problems which are mentioned above. Designing efficient clustering algorithm becomes the main task of this paper.

The traditional single-hop clustering algorithm does not show good performance affected by the dynamic change of topology in VANET. In recent years, some clustering algorithms based on multi-hop have been proposed [7]–[9]. Multi-hop clustering algorithm allows the distance between cluster members and the cluster head to be N-hop, which can effectively expand the cluster coverage. The large cluster coverage can not only effectively reduce the number of cluster head, but also enhance the clustering stability to some certain extent. However, some problems remain to be resolved, for example:

1. In the process of forming a stable cluster (that is, the maintenance time of the cluster head and cluster members in a cluster is stable), the energy consumed by the frequent exchange of information will consume more energy than without cluster.
2. Traditional clustering algorithms do not apply to VANET. Due to the high speed of the vehicle nodes, the stability and reliability of the cluster are poor performance in VANET.
3. Because the vehicular nodes have large transmission range, inter-cluster interference may occur among neighboring nodes.

Based on the analysis and research of multi-hop clustering algorithm published in recent years, we propose a passive multi-hop clustering mechanism called PMC in this paper. In the clustering phase, this paper proposes a priority-based neighbor following strategy by improving the vehicle following strategy [10].

The main contributions of this paper are as follows:

1. In the network initialization phase, vehicles are organized by the priority neighborhood following mechanism. A vehicle node and its highest priority neighbor are divided into the same cluster. The most stable node in N hop becomes the cluster head node passively, which effectively improves the stability and reliability of clustering and reduces the cost of cluster.
2. In order to reduce the inter-cluster interference, in the cluster maintenance phase, the cluster merger mechanism further improves the stability and reliability of cluster.
3. The comparisons with other existing algorithms are presented to validate the proposed algorithm.

The rest of this paper is organized as follows: Section 2 reviews related works. In section 3, the system model and the priority neighbor following strategy are discussed in detail. In section 4, the mechanism of PMC algorithm is discussed in detail. Section 5 gives the experimental results. Section 6 summarizes the paper and gives the next research direction.

II. Related Works

As a method of establishing ad hoc network, clustering algorithm has been extensively studied in the traditional MANET. Among them, the most representative cluster head selection mechanism has the minimum ID algorithm [11], the highest node degree algorithm [12] and the weight-based WCA algorithm [13]. These algorithms fully consider the mobility and energy of node, and mainly focus on the utilization of energy resources. However, resource issues are not an important factor for vehicle nodes. The high mobility of vehicles is the main factor that causes cluster instability. So the clustering algorithm in MANET can't be directly applied in VANET and a large number of clustering algorithms have been proposed [14] in VANET.

Reactive clustering algorithm is a more efficient clustering algorithm and each vehicle node owns a state. When a vehicle node receives a beacon packet or when the cluster architecture changes, it will change its state to perform cluster maintenance process rather than re-clustering, which can reduce the clustering cost effectively. Wang and Lin [15] proposed a passive clustering routing algorithm called PassCAR. In the cluster formation phase, PassCAR uses node degree as the criteria to select the cluster head. However, because it uses a single-hop mechanism, the cluster coverage and stability are poor. Li *et al.* [16] proposed a clustering algorithm CCA (Criticality-based Clustering Algorithm) based on critical metrics. CCA utilizes both passive and critical measures to cluster, but it does not consider the coverage and scalability. And the link reliability is not guaranteed.

Some MAC-based clustering algorithms have been proposed in VANET. Su and Zhang [17] proposed a cluster- based multi-channel communication mechanism CM- MMAC. The proposed mechanism consists of three parts: cluster configuration protocol, inter-cluster communication protocol and inter-cluster coordination protocol. The cluster configuration protocol is used to divide the vehicles in the same direction into the same cluster. The inter-cluster communication protocol guarantees the real-time transmission of security and non-security data packets between two vehicle nodes. The inter-cluster coordination protocol uses the multi-channel MAC algorithm to cause the cluster head (CH) nodes to collect or send data packets to the cluster members (CM) nodes. Hafeez [18], Dror *et al.* [19], Liu and Zhang [20], Javaid *et al.* [21], and Zhang *et al.* [22] proposed a clustering algorithm based on fuzzy logic, he used fuzzy process to deal with link reliability problem to improve the cluster stability, since speed is the main reason for link instability. In the process of cluster head selection, when the optimal cluster head speed changes, the sub-optimal node is used as the temporary cluster head to improve the stability of the cluster. This algorithm is applied in high-speed scenes. Although sub-optimal cluster head nodes are introduced, frequent cluster-head switching leads to unstable clustering and high cost of cluster maintenance.

The above mentioned clustering algorithms based on single-hop may generate more cluster heads in the network, reducing the stability of the cluster in VANET. Therefore, in recent years, some multi-hop clustering algorithms have been widely studied [23]–[28]. In the multi-hop clustering algorithm, the size of the cluster is controlled by the number of hops. Each cluster only has one cluster head. The distance between the cluster members and the cluster head must be less than or equal to the predefined maximum hop count. Zhang *et al*. [7] proposed a multi-hop clustering algorithm based on mobility measurement. Each vehicle node is required to broadcast the beacon information to its one-hop neighbor node. The neighbor nodes receive two consecutive Hello beacon packets from a certain vehicle to calculate the relevant mobility. Based on the relevant mobility, each vehicle can calculate the Aggregate Mobility (AM) value and then the AM value is broadcast to the N-hop range. Zhang and Sayed [8] proposed a new K-HOP clustering scheme. In the cluster-head selection phase, the highest connectivity, vehicle mobility and minimum node ID are added to select the cluster head node. Dror *et al*. [19] proposed a distributed random 2-hop clustering algorithm HCA (hierarchical clustering in Vehicular Ad-Hoc Networks). HCA is a fast clustering algorithm without specific choice of cluster head or building a stable cluster architecture, while it clusters as quickly as possible and the cluster optimization is done in the cluster maintenance phase.

Chen *et al*. [10] and Cheng *et al*. [27], [28] proposed a distributed multi-hop clustering algorithm. It uses the vehicle following strategy to organize the vehicle and then selects the cluster head passively. The vehicle following strategy can reduce the cost of cluster formation greatly, and

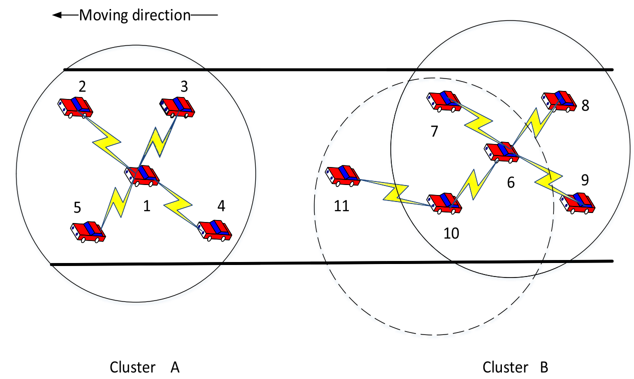

Fig. 2. Multi-hop clustering model.

the passive clustering method can improve the clustering stability effectively. However, when it chooses the following vehicle, it does not take into account the reliability of the inter-node link so that the cluster reliability is poor. Compared with the single-hop clustering algorithm proposed in this paper, the multi-hop clustering algorithm extends the coverage of clusters and reduces the number of cluster heads greatly in VANET, thus it can effectively improve the utilization of network bandwidth. In the multi-hop clustering algorithm, we use the following three indicators to evaluate the performance of clustering algorithm:

1) Cluster Head Duration: Cluster head maintenance time is the time interval from node selection to cluster head state to transition to non-cluster head.

2) Cluster Member Duration: The cluster member duration refers to the time interval from when the vehicle connecting to the cluster to leaving the it.

3) The Number Of Cluster Head Change: The number of cluster head changes is the number of vehicle changing from cluster head state to non-cluster head state.

Cluster head duration and the number of change of cluster heads can effectively evaluate the switching frequency of cluster heads. The cluster member duration reflects the stability of the cluster member in the cluster. These allow us to evaluate the stability of the cluster and the reliability of the inter-cluster links.

III. System Modeling

In this section, we first present a multi-hop cluster architecture model and related definitions based on priority neighbor following strategy; then we give the calculation method of priority neighbor following strategy.

A. Multi-Hop Cluster Architecture Model

The multi-hop cluster model based on the priority neighbor following strategy is shown in Fig.2, where cluster A is similar to traditional single-hop cluster structure because it has fewer neighbors. In the cluster B, a multi-hop cluster structure is formed in which the distance from the vehicle 11 to the cluster-head vehicle 6 is 2 hops. We assume that each vehicle is equipped with an on-board unit with a maximum communication radius R and communicates with other vehicles by the WAVE communication protocol [20]. In [20], the whole network, the vehicle nodes in the cluster member (CM) state can only communicate with the CM or cluster head (CH) nodes by the WAVE protocol and can't communicate directly with the roadside unit. The vehicle node in CH state can communicate with not only CM node by WAVE, but also can communicate with roadside unit by 4G network. This communication model allows the CM node to communicate with the roadside unit only through CH. An information table (INFO_TABLE) is stored in each vehicle, which contains motion-related information of vehicle nodes within a pre-defined maximum hop count (MAX_HOP). The multi-hop cluster structure formed by priority neighbor following strategy has the following properties:

Property 1: Multi-hop. Each cluster comprises a CH and CMs. Each CM connects to its CH directly or indirectly via multi-hop method.

As shown in Fig.2, two clusters are formed in VANET, which are cluster A and cluster B respectively. Where cluster A is a single-hop cluster and cluster B is a multi-hop cluster. In the cluster B, the vehicle node 6 is the cluster head, 7 to 11 are the cluster member nodes, and the distance from the CM node 11 to CH node 6 is two hops.

Property 2: Distributed management. In this cluster architecture, CH node does not directly manage each CM node, but CM nodes are managed in a distributed manner. The nodes directly connected to the cluster members are managed by the cluster members.

As shown in Fig. 2, in the cluster A, since the vehicle nodes 2∼5 are directly connected to the cluster head node vehicle 1, the cluster head manages those nodes directly. In cluster B, however, vehicle 11 can not communicate directly with cluster-head node 6, which joins to the cluster by following the neighbor vehicle 10. The vehicle 10 has information about the vehicle 11 and is responsible for managing the vehicle node 11. The maximum number of members that a vehicle node can connect and manage is MAX_CM.

Property 3: Shared cluster head. In this cluster model, each node considers only the most stable neighbor node in its one hop range as its parent to follow, and shares the same cluster head node with the parent node.

As shown in Fig. 2, in the cluster A, the vehicle node 1 has the highest priority according to the priority neighbor following strategy, so that the vehicles 2, 3, 4, 5 select the vehicle 1 as its parent and share the cluster heads with the vehicle 1. Similarly, in cluster B, vehicle node 6 acts as a cluster-head node. The vehicle nodes 7, 8, 9, 10 share the cluster head node 6. According to the priority neighbor following strategy, the vehicle 10 has the higher priority for 11, so the vehicle 11 takes 10 as its parent and shares cluster head node 6 with it.

B. Priority Neighbor Following Strategy

In the traditional multi-hop clustering algorithm [7], vehicle nodes and cluster head nodes with less relative mobility are added to the cluster as cluster members to form a stable cluster structure. However, in the multi-hop cluster architecture, it is difficult for a vehicle node to get precise motion information from its multi-hop nodes. Therefore, when there are multiple cluster head nodes in the multi-hop range, it is difficult for a vehicle to decide which node is its cluster head node. And a large number of broadcast packets will cause great network overhead. In contrast, a vehicle can easily determine which vehicle is the most stable node within its one-hop range. If the two nodes are divided into the same cluster, the clustering cost can be reduced and the clustering stability can be greatly improved. In this section, a priority neighbor following mechanism is proposed. In the cluster formation phase, a vehicle is not required to proactively detect the cluster head nodes within multi-hop distances. However, it is necessary to select the most stable node within its one hop range by the priority neighbor following strategy and share the same cluster head. They are merged into the same cluster. Next, we introduce the priority neighbor following strategy in detail and give the calculation method.

In VANET, the rapid changes in vehicle speed can seriously affect the reliability of inter-vehicle connections and the stability of the cluster. In order to find the most reliable neighbor vehicle to follow, the following three aspects are evaluated: node following degree, expected transmission number and link life time in the priority neighbor following strategy.

Definition 1: The Following Degree N_{follow}.

In MANET, node degree is used as an evaluation factor for clustering which plays a crucial role in clustering algorithms [23], [24]. In this paper, we expand it and define it as the following degree. The following degree consists of the number of directly and indirectly following vehicles. To a certain extent, the following degree can reflect the node stability, its formula is as follows:

$$N_{follow} = D_{Neig} + f_c \tag{1}$$

Where D_{Neig} denotes the number of neighbor nodes on the same lane, and f_c denotes the number of the connected nodes. Because each vehicle node periodically broadcasts Hello packets to its neighbor nodes, it is easy to get the value of D_{Neig}.

Lemma 1: The more the number of neighbor nodes on the same lane is, the more stable the node is.

Proof: Suppose that the communication radius of the vehicle is R, the length of a single vehicle is L, and the road is a single-lane road. All vehicles are on the same road and appear as a straight line. Assuming that the average inter-vehicle distance is $\overline{d}$, we can get:

$$\overline{d} = \frac{2R}{D_{Neig}} \tag{2}$$

We assume that a driver's response time is t_δ as a constant, and then the vehicle's speed is:

$$v = \frac{\overline{d} - L}{t_\delta} \tag{3}$$

As the D_{Neig} increases, the $\overline{d}$ decreases, so the relative movement of the vehicle node decreases. This proves that the greater the D_{Neig} on the same lane is, the more stable the node is.

The number of vehicle following f_c refers to the number of vehicles that are followed directly or indirectly. As shown in Fig.2, the vehicle 10 follows directly the vehicle 6, and the vehicle 11 indirectly follows the vehicle node 6 through the vehicle 10 in the cluster B. We assume that the one-hop neighbor node of the vehicle node 6 directly follows the vehicle 6, then $f_{c_6} = 5$ and $f_{c_{10}} = 1$. Now suppose that vehicle x follows vehicle y directly, and let f_{c_y} denote the following number of vehicle y, then the direct following function f can be defined as:

$$f : x \to y \wedge y \in NBHD(x) \tag{4}$$

In indirect following, if a vehicle node y does not belong to *NBHD* (x), but a follower chain exists from $x \mapsto y$, such as $x \to \ldots i \to \ldots y$, then it follows the following relation, indicated with the symbol $x \mapsto y$. Therefore, f_{c_y} can be calculated by the following formula:

$$f_{c_y} = \{x | x \to y \vee x \mapsto y\} \tag{5}$$

Lemma 2: The greater the following number f_c is, the more stable the node is.

Proof: In the formula (5), the value of f_c has been given by the sum of direct and indirect following vehicles. According to the priority neighbor following strategy proposed in this paper, a vehicle chooses the most stable node in its one hop neighbor to follow. In cluster B of Fig.2, vehicle node 6 has the largest value of f_c. If it is not the most stable node, the node 6 will follow other vehicles, resulting in a neighbor node in node 6 having a larger f_c, which is obviously contradictory. So this proves that the larger the value of f_c is, the more stable the node is.

Theorem 1: The larger the value of N_{follow} is, the better the stability is.

Proof: According to Lemma 1 and Lemma 2, it is easy to judge the correctness of Theorem 1. If the maximum hop is N, the node with the largest N_{follow} will be the most stable node in the N hop range.

Definition 2: The Expected Transmission Count.

The expected transmission count (ETX) [21] is used to represent the quality of bidirectional links between nodes. A stable link not only determines the reliability of communication between vehicle nodes, but also can ensure the stability of clustering. In order to evaluate the link reliability between nodes, we assume that the ETX between vehicle node i and vehicle node j is ETX_{ij}. According to the literature [21], the ETX_{ij} is calculated:

$$ETX_{ij} = \frac{1}{d_f \times d_r} \tag{6}$$

Where d_f and d_r denote respectively the transmission rate and the reception rate. Since each vehicle sends Hello packets to its one hop neighbor vehicle, it is easy to calculate the values of d_f and d_r. So the ETX_{ij} can be calculated easily. From the formula (6), we can see that the smaller *ETX* is, the better the link quality is.

Definition 3: Link Life Time.

In a highly mobile network such as VANET, it is easy to break the link between nodes, and the link life time is an important evaluation index. If the node with the higher link maintenance time is selected as the follower target, which can improve the reliability of the cluster effectively. Therefore,we need to take link life time into account when calculating priority. Here, we use LLT(Link Life Time) to express the link duration time of two vehicles, the greater the *LLT* is, the longer the link will be.

TABLE I
RELATED DEFINITIONS

Notation	***Description***
IN	Initial State
SE	State Election
CH	Cluster Head
ISO-CH	Isolated Cluster Head
IN_TIMER	Initial State Timer
MERGE_TIMER	Merge Timer
MAX_MEMBER	Max Member Node can serve
MAX_HOP	Max Hop Node can serve
CH_ADV	CH's Advertisement Packet
V_{state}	Vehicle's Current State
AvgRelM	Average Related Speed
TO_CH_HOP	The number of hops to CH
MERGE_REQ	CH's Merge Request
MERGE_RESP	CH's Merge Response
Hello	Beacon Packet
JOIN_REQ	Join Request Packet
JOIN_RESP	Join Response Packet
NBHD	The neighbor of the node
Try_Connection	A flag attempt to communication
BeCH	Cluster head flag

Assuming that the speed of a vehicle h_m at time t is $v_m(t)$ and its position is $p_m(t)$. The Hello beacon packet is broadcast to its one-hop neighbor node at intervals δ_m seconds. The Hello packet contains the motion information of vehicle, including position, speed and direction. When a neighbor node h_n of vehicle h_m receives this Hello packet, it calculates the link maintenance time with h_m. Assuming that the speed of h_n at time t is $v_n(t)$, the position is $p_n(t)$, and we assume that in the ideal case, vehicles h_m and h_n have the same broadcast distance d. Then, at time t, the relative distance of the vehicle is calculated as

$$|p_m(t) - p_n(t)| < d \tag{7}$$

At the time $t + \sigma$, the positions between the two vehicles are:

$$p_m(t + \sigma) = p_m(t) + \sigma v_m(t) \tag{8}$$

$$p_n(t + \sigma) = p_n(t) + \sigma v_n(t) \tag{9}$$

When σ is equal to δ_m, we assume that the speed of the vehicles h_m and h_n is constant during the time interval δ_m. When the distance between the two vehicles reaches the maximum broadcasting range d, the link will be broken. So the link sustaining time satisfies

$$\begin{aligned} &|p_m(t + LLT_{m,n}(t)) - p_n(t + LLT_{m,n}(t))| \\ &\quad = |p_m(t) - p_n(t) + LLT_{m,n}(t)[v_m(t) - v_n(t)]| = d \end{aligned} \tag{10}$$

Here $LLT_{m,n}(t)$ represents the link life time. In order to effectively calculate the link life time, the position and the velocity vector are represented by two-dimensional coordinates. Assume that the coordinates of vehicles h_m and h_n are

$$\begin{cases} p_m(t) \equiv (p_{mx}(t), p_{my}(t)) \\ p_n(t) \equiv (p_{nx}(t), p_{ny}(t)) \end{cases} \tag{11}$$

Similarly, the speed vector of the vehicle is

$$\begin{cases} \upsilon_m(t) \equiv (\upsilon_{mx}(t), \upsilon_{my}(t)) \\ \upsilon_n(t) \equiv (\upsilon_{nx}(t), \upsilon_{ny}(t)) \end{cases} \tag{12}$$

Taking formula (11) and (12) into formula (10), then the link maintenance time will be calculated as formula (13), which is proved in the appendix.

$$LLT_{m,n}(t) = \frac{\sqrt{d^2(\Delta_{\upsilon x}^2(t)+\Delta_{\upsilon y}^2(t))-(\Delta_{px}(t)\Delta_{\upsilon y}(t)-\Delta_{py}(t)\Delta_{\upsilon x}(t))^2}}{\Delta_{\upsilon x}^2(t)+\Delta_{\upsilon y}^2(t)} - \frac{\Delta_{px}(t)\Delta_{\upsilon x}(t)-\Delta_{py}(t)\Delta_{\upsilon y}(t)}{\Delta_{\upsilon x}^2(t)+\Delta_{\upsilon y}^2(t)} \tag{13}$$

Where,

$$\begin{cases} \Delta_{px}(t) = p_{mx}(t) - p_{nx}(t) \\ \Delta_{py}(t) = p_{my}(t) - p_{ny}(t) \\ \Delta_{\upsilon x}(t) = \upsilon_{mx}(t) - \upsilon_{nx}(t) \\ \Delta_{\upsilon y}(t) = \upsilon_{my}(t) - \upsilon_{ny}(t) \end{cases} \tag{14}$$

In the neighbor following strategy, a vehicle node wants to follow its neighbor vehicle which has the highest priority and shares a cluster head node with it. Priority as a critical parameter, it takes into account the following degree, the expected transmission counts and link life time three factors. We use PRI to represent the priority, the formula is as follows:

$$PRI_{ij} = \alpha \cdot \frac{1}{N_{follow}(j)} + \beta \cdot ETX_{ij} + \gamma \cdot \frac{1}{LLT_{ij}} \tag{15}$$

Where α, β, γ represent the weights and $\alpha + \beta + \gamma = 1$. According to Lemma 1, the smaller $1/N_{follow}(j)$ is, the better the stability is. According to formula (6), the smaller ETX is, the better the link quality is. According to definition 3, the smaller $1/LLT_{ij}$ is, the longer the link is. We can see from the formula (15), the smaller PRI is, the higher the priority is. The vehicle node i will select the vehicle node j which has the highest priority as the target vehicle to follow. Considering that all the three factors have relatively high specific gravity, we take them as average value.

IV. PMC Algorithm

Figure 3 is the PMC algorithm flow chart. In this section, the PMC algorithm is introduced. First, the state definition of vehicle in the network is given, then the concrete process is introduced in detail.

A. State Definition

Each vehicle has a state in the cluster architecture. The vehicle changes its own role in the cluster by modifying its state. We define all the states of the vehicle as follows:

1) INITIAL(IN). The initial state when a vehicle is to be connected to the network.

2) STATE_ELECTION(SE). The first state after the vehicle is connected to the network.

3) CLUSTER_HEAD(CH). Cluster head state, which is similar to the role of cluster head in traditional cluster structures.

4) CLUSTER_MEMBER(CM). Cluster member state, the distance from the cluster head to cluster_member is one-hop or multi-hop.

5) ISOLATED_CLUSTER_HEAD(ISO-CH). Indicating that a vehicle in the network becomes an isolated node that can not join any cluster and does not have any neighbor vehicle.

B. Info-Table Generation and Update

In VANET, a neighbor table called INFO_TABLE is maintained in each vehicle, which contains its own vehicle information and the information of neighbor nodes within MAX_HOP range. The INFO-TABLE mainly includes the vehicle's unique ID, vehicle states and location-related information. The routing entries are shown in Table II. In table II, the location-related information contains the vehicle's traveling direction, speed, location and other information. The number of follower is the total number of direct followers and indirect follower. Parent_ID is the target vehicle ID. TO_CH_HOP represents the number of hops from the vehicle node to the cluster head node, which can be calculated by adding 1 to the value retrieved in the parent vehicle. The number of one-hop neighbor node is the number of direct followers, its maximum value is MAX_MEMBER. The CH_ID is the cluster head ID shared with its parent vehicle. The time-stamp is the effective time of the route entry. When the vehicle state is changed or receives HELLO packet from neighbor node, the INFO_TABLE table is modified. The HELLO packet is broadcast to its neighbor node. Its main information includes node ID, speed, direction, CH_ID and hop count to CH node. If a node does not receive a HELLO packet from a neighbor node during a specified time interval, the route entry is deleted when the time-stamp expires.

C. Cluster State Transitions

A state transition diagram of a vehicle node is shown in Fig.4. Each vehicle in the network starts in the IN state and remains this state until the IN_TIMER timer expires. During the IN_TIMER interval, each vehicle node periodically sends and receives HELLO beacon packets from neighbor nodes to update its own INFO_TABLE. When the timer expires, it changes the state to the SE state. In the SE state, the node changes its state according to algorithm 1. When a vehicle receives a JOIN_RESP packet from a CH or CM, it changes the state from SE to state CM, indicating that it joins a cluster.

If a vehicle meets the CH_CONDITION condition, then the vehicle changes from SE to CH. The CH_CONDITION

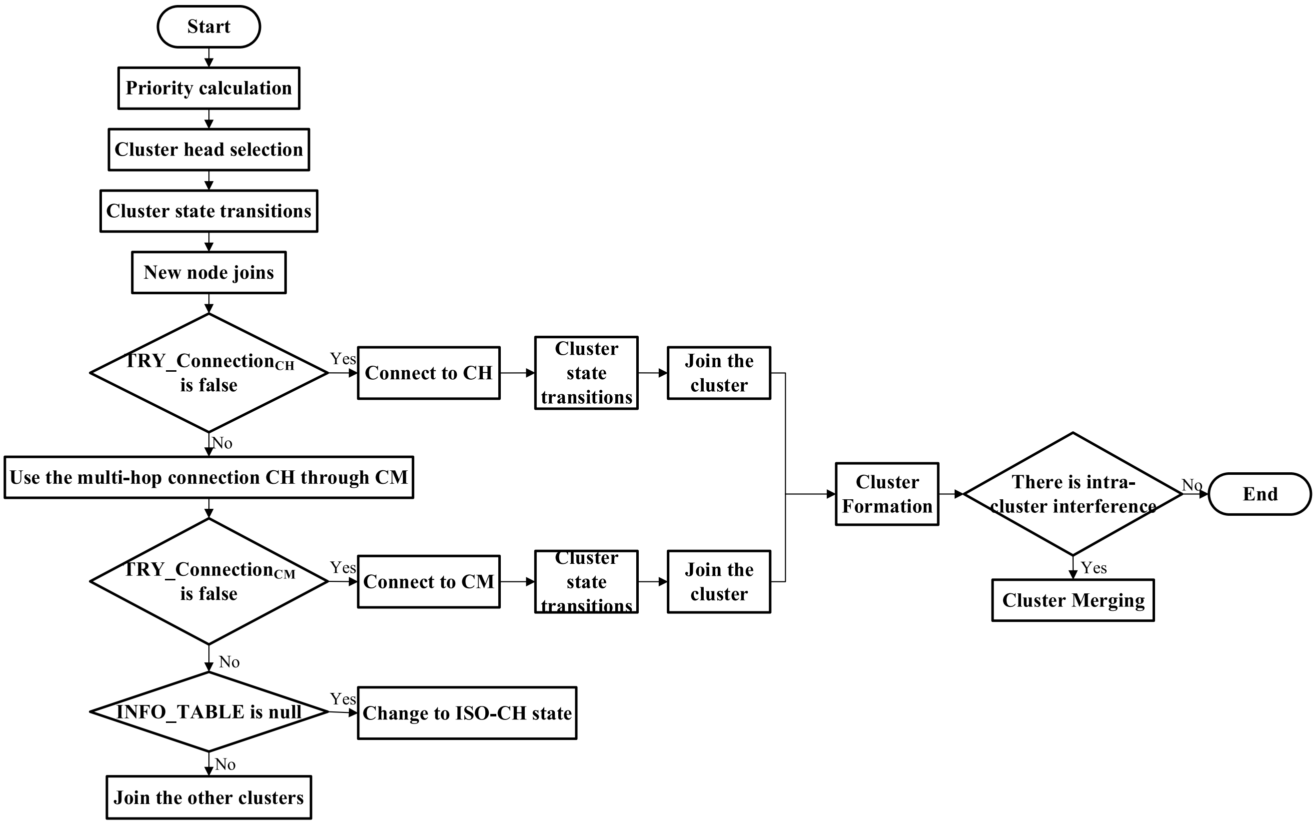

Fig. 3. PMC algorithm flow chart.

TABLE II
INFO_TABLE TABLE ENTRIES

Vehicle_Id	Vehicle_State	Location-Related information	Number of followers	Parent_Id	TO_CH_HOP	NBHD	CH_Id	Time Stamp

is the cluster head selection condition, which is described in the cluster head selection in detail. If the MAX_MEMBER of CH is 0, then the CH node will switch its state to ISO-CH, indicating that it has become an isolated node. When a vehicle is in ISO-CH state, its neighbor node is not 0, and it satisfies the condition of CH_CONDITION, then it switches its state to CH. Otherwise, if it does not satisfy CH_CONDITION, it switches to CM. A node in the CM state, if it loses the connection to the Parent_ID and has no followers, it changes to the ISO_CH state. A vehicle in the CH state, when it receives a MERGE_RESP from other CH nodes, it will switch to state CM, indicating that the cluster merges successfully. If a cluster member CM satisfies the condition of being a cluster head, and is more stable than the current cluster head, it changes state to CH.

In order to better understand the cluster state transition, we use an example to illustrate. As shown in Fig.2, we assume that the state of the vehicle 11 is SE. Then vehicle 11 receives JOIN_RESP packet from vehicle 10. If vehicle 11 meets the CH_CONDITION condition, it changes its state to CH, otherwise it changes its state to CM. Obviously, in this case, the vehicle 11 does not satisfy the CH_CONDITION condition, so it changes its state to CM. If vehicle 11 loses the connection to vehicle 10 and has no follower, vehicle changes its state to ISO_CH. When vehicle 11 reconnects with Parent_ID or satisfies CH_CONDITION, the vehicle 11 re-enters the above transition. If the vehicle 6 receives the MERGE_RESP packet from the vehicle 1, then vehicle 6 changes its state to CM, which also indicates that cluster A and cluster B merge successfully.

D. Cluster Head Selection

In the network initialization phase, each vehicle sends HELLO beacon packets to its one-hop neighbor node. The neighbor node updates its own INFO_TABLE by parsing the received HELLO packet. According to the priority neighbor following strategy, each vehicle calculates the priority value through its neighbor node to determine the target vehicle to follow. The vehicle node sends JOIN_REQ to request to follow the target vehicle. The target vehicle sends JOIN_RESP to allow it to follow, and at the same time, it modifies the item

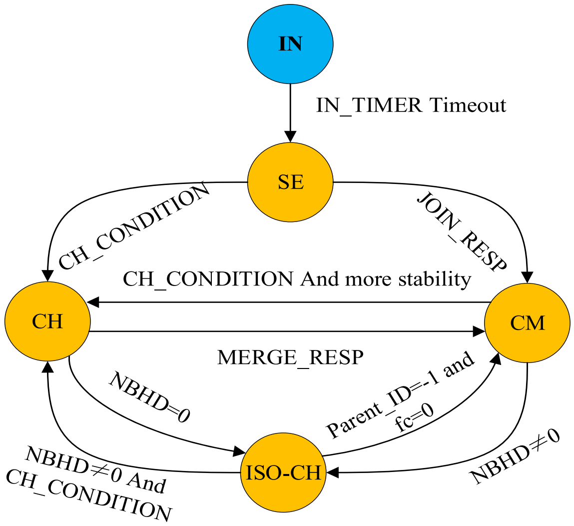

Fig. 4. Vehicle node state transition diagram.

number of followers in the routing table plus 1. The vehicle changes the Parent_ID to the target vehicle ID. Initially, there is no cluster head node in the network, we set the item of CH_ID to −1. In VANET, it is important to select a stable cluster head because its topology changes rapidly, which can improve not only the stability of clustering, but also the lifetime of clusters. Therefore, when we choose the cluster head, the number of follower is not only considered, but the vehicle relative mobility is also an important indicator. The more followers are, and the smaller the average relative mobility is, the easier the vehicle is to be selected as the cluster head. The cluster head selection formula is as follows:

$$BeCH(x) = \begin{cases} true\ (N_{follow}(x) > N_{follow}(y)) \\ \qquad \wedge (AvgRelM_x < AvgRelM_y) \\ false\ Else \end{cases} \tag{16}$$

Where N_{follow} (x) is the degree of followers of vehicle x and N_{follow} (y) is the degree of followers of vehicle y and they can be found in the routing table. According to Theorem 1, the bigger the value is, the more stable the node is. $AvgRelM_x$ represents the average relative mobility of the vehicle, and its value is calculated as follows:

$$AvgRelM_x = \frac{\sum_{y \in NBHD(x)} RelM_{x,y}}{|NBHD(x)|} \tag{17}$$

Where $NBHD(x)$ denotes the number of neighbor nodes of the vehicle x.

E. Cluster Formation

In cluster formation algorithm (shown in Table III), when INFO_TABLE is not empty, a vehicle is in the SE state, which first attempts to connect to an existing cluster to minimize the number of cluster heads. When a vehicle can connect to a CH or CM node at the same time, considering the delay time of packet transmission, if the maximum connection degree of CH does not reach the maximum, the vehicle will consider connecting to CH node, otherwise connecting to CM node. If the TRY_ConnectionCH flag is false when the vehicle connects to the CH node, it sends a JOIN_REQ packet to the CH node. If the vehicle receives JOIN_RESP packet within a given time interval called JOIN_TIMER, it indicates that the vehicle is allowed to join the cluster and change its state to CM. Otherwise, the vehicle sets TRY_ConnectionCH to TRUE, indicating that it is not allowed to connect to the CH node (see A1 L1-12, namely from Line 1 to Line 12 of algorithm 1). If a node can not directly connect to any CH node, then it attempts to connect to the CH through the CM

TABLE III

CLUSTER FORMATION ALGORITHM

	Algorithm 1 Cluster Formation Algorithm
1.	**For all** INFO_TABLE !=NULL **do**
2.	**if** TRY_Connection$_{CH}$==false **then**
3.	**if** NBHD$_{CH}$+1≤MAX_MEMBER **then**
4.	Send JOIN_REQ
5.	**if** JOIN_RESP received **then**
6.	V$_{state}$=CM
7.	**else**
8.	TRY_Connection$_{CH}$=true
9.	**end if**
10.	**end if**
11.	**end if**
12.	**End for**
13.	
14.	**For all** INFO_TABLE !=NULL && CH in Parent **do**
15.	**if** TRY_Connection$_{CM}$==false **then**
16.	**if** NBHD$_{curr}$+1≤MAX_MEMBER **then if**
17.	TO_CH_HOP<MAX_HOP **then**
18.	Send JOIN_REQ
19.	**if** JOIN_RESP received **then**
20.	V$_{state}$=CM
21.	**end if**
22.	**end if**
23.	**end if**
24.	**end if**
25.	**End for**
26.	
27.	**if** INFO_TABLE==NULL **then**
28.	V$_{state}$=ISO-CH
29.	**else if** BeCH(curr)==true **then**
30.	V$_{state}$=CH
31.	Broadcast CH_ADV
32.	end if

by multiple hops. According to the priority neighbor following strategy, the optimal neighbor is selected and shared with the same cluster head node. Similar to connecting to CH process, if the TRY_ConnectionCM flag is FALSE, the number of nodes connected to the target vehicle is less than the predefined maximum connection degree MAX_MEMBER and the hop count to CH is less than the predefined maximum hop count MAX_HOP, then the vehicle is allowed to join the cluster (see A1 L16-17). In the connecting process, a node sends JOIN_REQ packet to its neighbor target vehicle. If the node receives the JOIN_RESP from the target vehicle, it indicates that it is allowed to be followed. The node then switches the state to CM and its routing entry Parent_ID and CH_ID are also set accordingly. If the vehicle receives multiple JOIN_RESPs at the same time, it will preferentially select the CH node (see A1 L18-20). If the vehicle can not follow any target vehicle and also no any neighbor vehicle follows it, that is, there is no neighbor information in its INFO_TABLE, then it changes status to ISO-CH. If the vehicle's INFO_TABLE is not empty and the CH flag is −1, then according to the cluster head selection mechanism, the vehicle node satisfying the BeCH condition is selected as the cluster head. The vehicle changes state to CH and broadcasts the CH_ADV packet to the following vehicle (see A1 L 27-32).

F. Cluster Merging

In the process of cluster formation, the most stable target node is selected by the priority neighbor following strategy, which makes the clusters have higher stability. However, in the process of vehicle motion, when the cluster head nodes in two clusters become neighbor nodes due to the change of vehicle speed, the clusters will overlap, causing inter-cluster interference. At this time, the cluster merging mechanism is started for cluster maintenance. In the cluster maintenance algorithm (shown in Table IV), if the current node is a cluster-head node and there are other cluster-head nodes in its neighbor node. Then, when the timer MERGE_TIMER times out, it sends an MERGE_REQ packet to its neighbor node to request cluster merging (see A2 L1-5). During the merging process, the two cluster heads (CHs) keep adjacent and share the mobility information within the MERGE_TIMER. During the merging process, the cluster head periodically detects whether the two neighbor clusters can be merged. If one of the neighbor cluster heads has relatively high moving speed and smaller following vehicle, the cluster merging process is performed. If the more stable cluster head node receives MERGE_REQ, it will judge both variables MAX_MEMBER and MAX_HOP. If the condition is met, it sends the MERGE_RESP packet to the neighbor cluster head to indicate that the cluster is allowed to merge (see A2 L7-10). If the cluster merges successfully, the less stable cluster head node gives up the CH role and changes its state to CM (see A2 L11-13). Otherwise, it continues to serve as cluster head. In the process of cluster merging, it is required that the merged clusters must have the same moving direction. The number of neighbors must be smaller than MAX_MEMBER, and the number of hops must be less than the maximum hop count MAX_HOP. If the vehicle receives multiple MERGE_RESPs, it will select the CH node with the minimum relative speed of motion for merging.

TABLE IV

CLUSTER MERGING ALGORITHM

Algorithm 2 Cluster Merge Algorithm

```
1.  if INFOR_TABLE !=NULL && V_state(curr)==CH then
2.     if Other_CH∈INFO_TABLE then
3.        if MERGE_TIMER ≤ 0 then
4.           Send MERGE_REQ
5.        end if
6.     else
7.        if MERGE_REQ received then
8.           if TO_CH_HOP ≤ MAX_HOP && CH_MEMBER ≤
    MAX_MEMBER then
9.              Send MERGE_RESP
10.          end if
11.          if MERGE_RESP received then
12.             V_state=CM
13.          end if
14.       end if
15.    end if
16. end if
```

TABLE V

SIMULATION PARAMETERS

Parameters	***values***
Simulation time (sec)	300
Size of topology (m)	1000 x1000
Max speed(m/s)	10~35
Number of vehicles	100
Transmission range (m)	100-300
Propagation model	Two-way ground model
MAC Channel	MAC/802.11
The send interval of Beacon packet (ms)	300
Beacon packet size(byte)	64
Number of trials	50

V. PERFORMANCE EVALUATION

In this section, we verify the performance of the PMC algorithm by comparing it with the related multi-hop clustering algorithms. We use NS2 (release 2.35) network simulator to evaluate the PMC algorithm, and use VanetMobiSim to generate the vehicle running trace file. The detailed simulation parameters are shown in Table V. In the simulation experimental environment, the total simulation time is 300s, the vehicle

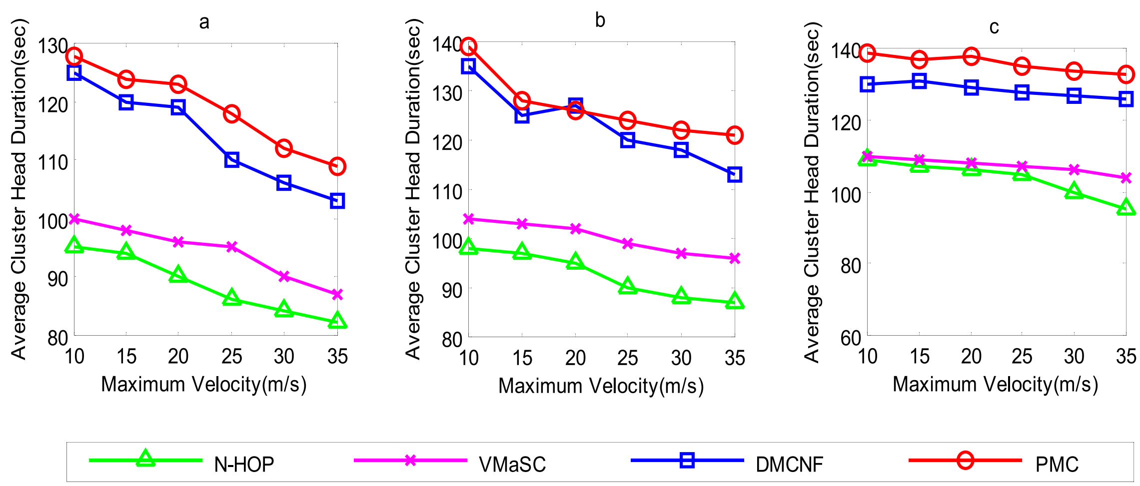

Fig. 5. Average cluster head duration time.

speed is limited to 10 to 35 m/s, and the vehicle's transmission range changes from 100 meters to 300 meters. The PMC algorithm proposed in this paper is compared with N-HOP [7], DMCNF [10] and VMaSC [9] algorithms respectively. As a typical multi-hop clustering algorithm, N-HOP is the earliest clustering algorithm using multi-hop clustering. It mainly uses the mobile metrics to evaluate the relative mobility between the vehicle nodes, and then according to the relevant mobility to determine whether a vehicle can be selected as a cluster head. DMCNF is a multi-hop clustering algorithm proposed in recent years, which improves the N-HOP algorithm and proposes the idea of distributed clustering for the first time. VMaSC is also a typical multi-hop clustering algorithm proposed in recent years.

In the simulation experiments, we set the maximum hop count MAX_HOP of the N-HOP to 3, and set the parameter HI = 180 of the DMCNF algorithm, so that it can get the best result. VMaSC also takes its hop count of 3. The average cluster head duration time, average cluster member duration time and the number of cluster head changes can effectively evaluate the stability of the cluster and the reliability of link. By comparing the three indicators, we get the following experimental results.

A. Average Cluster Head Duration Time

The cluster head duration time means that a vehicle in the CH state is changed to non-CH state. For example, in the proposed PMC algorithm, a vehicle in CH state is changed to CM or ISO-CH state. The average cluster head duration time is the ratio of the total cluster head duration time to the number of cluster heads. The calculation formula is as follows:

$$AvgStime_{CH} = \frac{\sum_{i=1}^{n} Stime_{CH}(i)}{n} \tag{18}$$

Where $AvgStime_{CH}$ is the average cluster head duration time and $Stime_{CH}$ is the cluster head duration time. Through simulation, the experimental results are shown in the Figure 5.

The Figure 5 shows the relationship between average cluster head duration time and vehicle speed, where a, b and c represent the results that the communication radius of vehicle is 100 m, 200 m and 300 m, respectively. In Figure 5, we can see that with the increase of vehicle speed, the average cluster head duration time shows a downward trend. Due to the increase of speed, the topology of the network changes drastically, resulting in frequent cluster merger or loss of connection. It can be seen clearly from the above three graphs (a, b, c) in Figure 5 that the PMC algorithm proposed in this paper and the DMCNF algorithm have higher cluster head duration time, although the whole result shows a decreasing trend. Because the two algorithms adopt the following strategy, we can see that the neighbor following strategy can effectively improve the stability of the cluster. The cluster head duration time of VMaSC algorithm and N-HOP algorithm is relatively lower, although both of them regard the relevant mobility metric as cluster head selection factor. In VANETs, due to the rapid movement of vehicle nodes, the duration time of each CH is very short. From Figure 5, we can see that the PMC algorithm proposed in this paper can keep longer time than that of DMCNF, especially in the case that the vehicle speed is fast. This is because the PMC uses the priority neighbor following strategy to select the most stable target vehicle instead of just following the vehicle with the minimum relative speed. Compared with a, b, c in Figure 5, the CH duration time increases with the increase of transmission range. This is because the link between the vehicles becomes more stable with the increase of transmission range.

B. Average Cluster Member Duration Time

The cluster member duration time is the time interval from a vehicle joining a cluster to leaving this cluster. It is worth noting that when the cluster head changes, or when CM becomes CH, we will regard it as cluster changing. In determining which cluster that the vehicle will join, it is mainly to determine the CH shared with the target vehicle. Here, we still calculate the average cluster member duration time. The calculation method is similar to the calculation

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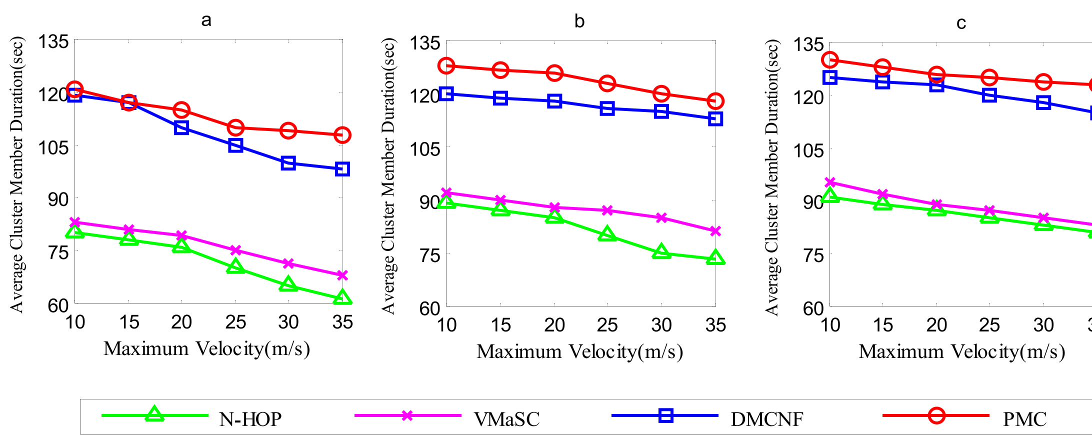

Fig. 6. Average cluster members duration time.

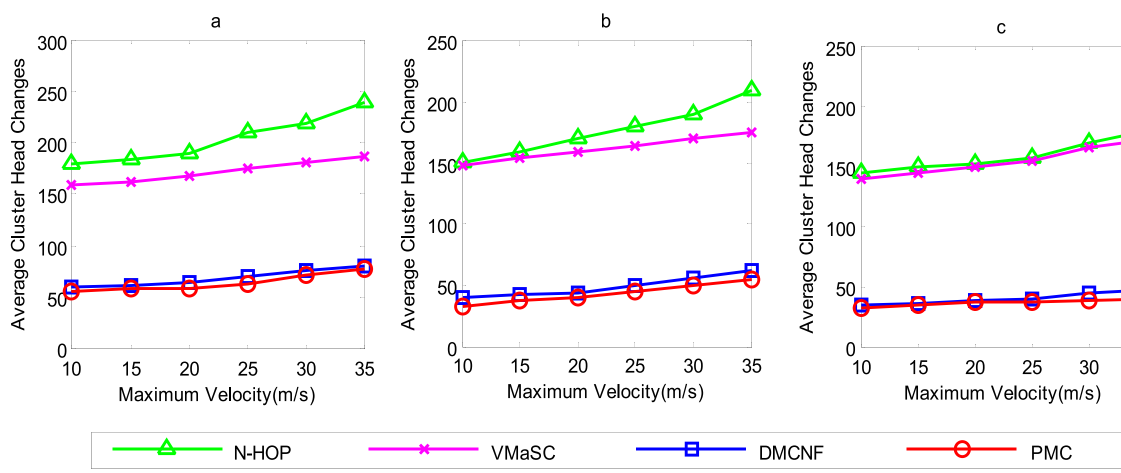

Fig. 7. Average cluster head changes.

of cluster head duration time. The experimental results are shown in Figure 6. As can be seen from Figure 6, the average cluster member duration time is affected by the speed. On the whole, the duration time of cluster member decreases with the increasing speed. However, as can be seen from a, b, and c in figure 6, the average cluster member duration time becomes higher gradually and tends to be stable with the increase of broadcasting radius. It can be seen from Figure 6 that the PMC algorithm proposed in this paper has higher cluster member duration time than the other three algorithms. Compared with the DMCNF algorithm, although the two algorithms both take the neighbor following strategy, the PMC selects following vehicle with the highest priority. When the speed of vehicle is high, it still has a good effect. In Figure 6, with the increase of communication radius, the two algorithms are relatively close. However, it is clear from Figure 6c that PMC is still higher than that of DMCNF. Compared with the N-HOP and VMaSC algorithms, the PMC uses the vehicle following strategy. When a vehicle changes the following target, it may still follow a new target in the same cluster, thus improving the cluster member's maintenance time. However, the other two algorithms are concerned about the average moving speed of the cluster head, so it is easy to join other clusters when the speed of the cluster becomes faster, thus shortening the cluster membership duration time.

C. Number of Average Cluster Head Changes

The number of cluster head change refers to the number of nodes that are in the CH state changing to the other states. We take the average number of cluster head change by several experiments. The experimental results are shown in Figure 7. Figure 7 shows the relationship between the average number of cluster head changes and the speed of the vehicle. To illustrate the effect of different communication radius on the number of cluster head changes, we get the results of a, b, c respectively. It can be seen from Figure 7 that the number of cluster heads changes with the increase of vehicle speed. The communication radius of the vehicle has influence on the number of cluster head changes. The larger the communication range is, the smaller the number of the cluster head change is. It can be seen from Figure 7 that the number of cluster head change of N-HOP and VMaSC algorithm is larger with the increase of speed, which has a direct relation with only considering the related moving speed. The DMCNF and PMC algorithms select a cluster head based on

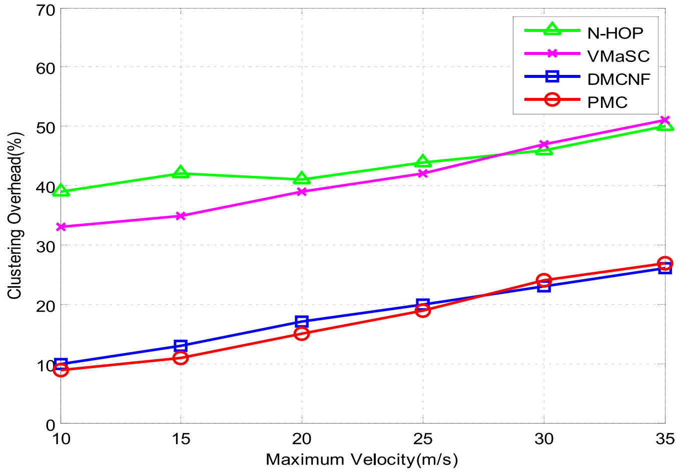

Fig. 8. Cluster overhead.

the vehicle following strategy, so the final selected cluster head node is the most stable node in MAX_HOP range. Therefore, these two algorithms have smaller number of cluster head change. In Figure 7c, VMaSC and N-HOP algorithms tend to approach because of the increased broadcasting radius. The PMC and DMCNF algorithms gradually become stable due to the higher reliability of the link when the broadcasting range is larger.

D. Clustering Overhead

We define the clustering overhead as the ratio that the number of control packets spent in the cluster formation phase and the cluster maintenance phase with the total number of packets. The formula is as follows:

$$overheadRatio = \frac{\sum_{i=1}^{n} Packet_{ctr}}{\sum_{i=1}^{n} Packet_{all}} \times 100\% \tag{19}$$

Where $overheadRatio$ denotes the clustering overhead. In the experiments, we set the vehicle node broadcasting radius to 300m. In the PMC algorithm, MAX_HOP takes 3 and MAX_MEMBER takes 10. The final experimental results are shown in Figure 8.

From Figure 8, it can be clearly seen that with the increase of speed, the overhead of cluster maintenance is increased. Compared with N-HOP and VMaSC algorithms, the PMC proposed in this paper is close to DMCNF, and the cost is relatively small. This is because it merely exchanges Hello packets with neighbor nodes to join a cluster. As can be seen from Figure 8, when the speed is slower, the PMC spends less than the DMCNF algorithm. When the vehicle speed reaches 30m/s, the overhead of PMC algorithm surpasses the DMCNF algorithm gradually, which is caused by the cluster maintenance mechanism in PMC algorithm. However, it can be seen that the cost is also small.

VI. Conclusions

We present a new multi-hop clustering algorithm PMC in this paper. First of all, the cluster model is presented based on the priority neighbor following strategy. We get the optimal neighbor by calculating N_{follow}, *ETX* and *LLT* of the neighbor node. Secondly, we adopt the cluster head selection mechanism to select the optimal cluster head. Then we adopt the priority neighbor following strategy to form a stable cluster. This strategy can improve the stability of clusters and reduce the cost of clustering effectively. Finally, the cluster merging mechanism not only improves the stability of the cluster, but also increases the coverage of the cluster. And the cluster merging mechanism effectively reduces the inter-cluster interference because of the occurrence of cluster overlap. Based on our experiments, we can see that our proposed algorithm can improve the stability and reliability of VANET. In the following research, the PMC-based routing algorithm should be studied in detail.

Appendix

This appendix is used to prove the formula 13.

Proof: The proof of formula 13 is given at the bottom of this page.

$$|p_m(t) - p_n(t) + LLT_{m,n}(t)[v_m(t) - v_n(t)]| = d$$

$$\begin{aligned}
LLT_{m,n}(t) &= \frac{d - (p_m(t) - p_n(t))}{v_m(t) - v_n(t)} = \frac{d - \sqrt{(p_{mx}(t) - p_{nx}(t))^2 + (p_{my}(t) - p_{ny}(t))^2}}{\sqrt{(v_{mx}(t) - v_{nx}(t))^2 + (v_{my}(t) - v_{ny}(t))^2}} = \frac{d - \sqrt{\Delta_{px}^2(t) + \Delta_{py}^2(t)}}{\sqrt{\Delta_{vx}^2(t) + \Delta_{vy}^2(t)}} \\
&= \frac{\sqrt{d^2(\Delta_{vx}^2(t) + \Delta_{vy}^2(t))} - \sqrt{\Delta_{px}^2(t)\Delta_{vx}^2(t) + \Delta_{px}^2(t)\Delta_{vy}^2(t) + \Delta_{py}^2(t)\Delta_{vx}^2(t) + \Delta_{py}^2(t)\Delta_{vy}^2(t)}}{\Delta_{vx}^2(t) + \Delta_{vy}^2(t)} \\
&= \frac{d\sqrt{\Delta_{vx}^2(t) + \Delta_{vy}^2(t)} - \sqrt{(\Delta_{px}^2(t) + \Delta_{py}^2(t)) * (\Delta_{vx}^2(t) + \Delta_{vy}^2(t))}}{\Delta_{vx}^2(t) + \Delta_{vy}^2(t)} \\
&= \frac{\sqrt{d^2(\Delta_{vx}^2(t) + \Delta_{vy}^2(t))} - \sqrt{(\Delta_{px}(t)\Delta_{vx}(t) - \Delta_{py}(t)\Delta_{vy}(t))^2 + (\Delta_{px}(t)\Delta_{vy}(t) + \Delta_{py}(t)\Delta_{vx}(t))^2}}{\Delta_{vx}^2(t) + \Delta_{vy}^2(t)} \qquad \square
\end{aligned}$$

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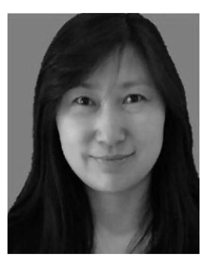
Degan Zhang (M'01) born in 1969. He received the Ph.D. degree from Northeastern University, China. He is currently a Professor with the Tianjin Key Lab of Intelligent Computing and Novel software Technology, Key Laboratory of Computer Vision and System, Ministry of Education, Tianjin University of Technology, Tianjin, China. His research interest includes ITS, WSN, and IOT.

Hui Ge (M'16) born in 1994. He is currently pursuing the Ph.D. degree. He is also a Researcher with Tianjin University of Technology, Tianjin, China. His research interest includes WSN and industrial application.



Ting Zhang (M'05) born in 1972. She is currently pursuing the Ph.D. degree. She is also a Researcher with the Tianjin Key Lab of Intelligent Computing and Novel software Technology, Key Laboratory of Computer Vision and System, Ministry of Education, Tianjin University of Technology, Tianjin, China. Her research interest includes ITS and WSN.

Yu-Ya Cui (M'17) born in 1992. He is currently pursuing the Ph.D. degree. He is also a Researcher with Tianjin University of Technology, Tianjin, China. His research interests include WSN and mobile computing.

Xiaohuan Liu (M'15) born in 1989. She is currently pursuing the Ph.D. degree. She is also a Researcher with Tianjin University of Technology, Tianjin, China. Her research interests include ITS and WSN.

Guoqiang Mao (M'02–F'18) was born in 1974. He joined the University of Technology Sydney in February 2014 as a Professor of wireless networking and the Director of the Center for Real-Time Information Networks. He has published about 200 papers in international conferences and journals, which have been cited more than 5000 times. His research interests include intelligent transport systems, Internet of Things, wireless sensor networks, and network performance analysis. He is Fellow of IET.