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Research on the Prediction-Based Clustering Method in the Community of Medical Vehicles for Connected Health

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ABSTRACT Combined with the Internet of Vehicles, some intelligent systems for connected health can make medical vehicles transport medical supplies more safely and timely in response to catastrophic natural disasters or serious accidents. However, in an urban scenario, the crisscrossing of roads and the uneven distribution of vehicles exist, which lead to problems such as the high mobility of vehicles and the attachment of data. These have become important contributors to the low stability of the vehicle community and the high distortion of the data among medical vehicles. Focusing on the above problems, this paper proposes a prediction-based multirole classification community clustering method (PMRC) for the vehicular ad hoc network (VANET). The experimental results show that the method can effectively improve the stability of the community in VANET and reduce the probability of data distortion.

INDEX TERMS Community clustering, Internet of Vehicles, load balancing, medical supplies, connected health.

I. INTRODUCTION

Prompt medical supplies transportation takes an important role in some situations, such as emergency response, where multiple vehicles are utilized to transport plenty of medicines and armamentariums timely. However, as shown in Fig. 1, the traffic on urban roads is complex, and the moving directions of the ordinary vehicles are uncertain, which obstruct the transportation of medical supplies. Nowadays, with the advance in vehicle-mounted systems and the arrival of 5G network, increasingly more studies on VANET have been carried out [1], and VANET-based smart management systems have been developed for connected health. VANET is utilized to transmit information among nodes instantly in some emergency response management systems [2] and smart accident management systems [3], which provide effective strategies and decisions in route planning, intelligent scheduling, cotransport, etc.

The complicated urban roads cause the position of the medical vehicles to change frequently. Meanwhile, the vehicles on the roads are often unevenly distributed, thus their routing and forwarding capabilities change with their position. These problems above result in an unstable network connection of the Internet of Vehicles, which has a negative influence on the stability of these smart management systems. This paper focus on these problems in the network among medical vehicles to make these VANET-based systems work stably and efficiently.

Usually, the application based on the Internet of Vehicles requires the Internet of Vehicles wireless communication technology to interact with other vehicles or other vehicular networking entities (such as infrastructure, network access cloud service providers, etc.) under the guidance of the Internet of Vehicles routing protocol to achieve the corresponding functions. Therefore, establishing a stable and reliable

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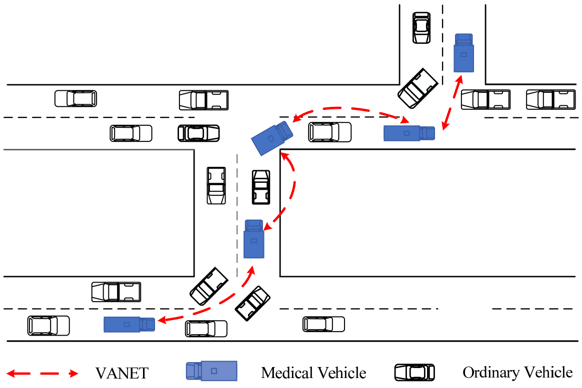

FIGURE 1. **Example of cotransport on urban roads.**

data transmission link through the vehicle network routing protocol is the basic guarantee for the VANET-based emergency response system. Traditional vehicular network routing protocols which are adapted from the greedy algorithm, usually choose some single node as the primary forwarding node and select the node closest to the destination node as the forwarding node, such as greedy perimeter coordinator routing (GPCR) [4] and greedy perimeter stateless routing (GPSR) [5]. These methods cannot discover the relationship between connected nodes and cannot fully adapt to highly dynamic topological network changes. To solve this problem, in recent years, some routing protocols based on the clustering of vehicular networking communities have emerged. These protocols first cluster vehicle nodes into several communities and then use the clustered communities and information between the communities as the basis to guide the routing to adapt to the rapidly changing network, thus establishing a relatively stable data transmission link [7]–[11].

Traditional vehicular networking clustered community usually selects some central nodes or nodes that are closely related to other communities in the community as key nodes for routing and forwarding [13]–[20]. The vehicle networking community routing usually emphasizes the role of a few key nodes in data forwarding. The limited forwarding capacity of the node is not considered, and some key nodes are frequently selected as data forwarding nodes, resulting in data aggregation on these key nodes. The load of each key node is too high, and data packets are easily lost, resulting in data distortion. This phenomenon is more obvious when the vehicle nodes are dense and the data transmission tasks are numerous. Therefore, the location variability of vehicle nodes and the integration of data in urban roads are important factors affecting the stability and the development of routing in the community of medical vehicles.

To reduce the influence of vehicle node location variability on the stability of the medical vehicular community, the existing studies mainly use the current position, speed and moving direction of the vehicle to predict the topology changes of the community in the future and take this as the basis for community clustering to improve the stability of the medical vehicular community.

In view of the above problems, this paper comprehensively considers the influence of a medical vehicle's attributes, the road information and the driving behavior of the driver to predict the position of the vehicle node. The predicted locations of the medical vehicle are used to guide the clustering of the community. At the same time, community members are divided into different roles, according to which alternative nodes for forwarding are selected to balance the load. Based on the above basis, this paper proposes a prediction-based multirole classification (PMRC) community clustering method in VANET to improve the stability of the medical vehicular networking community, balance the load of nodes, establish a reliable data transmission channel, and reduce the occurrence of data distortion. The contributions of this article are as follows.

1) To improve the stability of the community in VANET, factors such as the medical vehicle's attributes, the road information and the driving environment that affect driving the vehicle are all considered. Based on the vehicle location prediction model [6], we present a multirole classification community clustering strategy to improve the stability of the community in VANET.

2) To solve the problem of data distortion caused by the high load on key nodes, we propose a scheme for selecting candidate nodes for key nodes.

This article is organized as follows. Section II introduces the related work. Section III introduces the symbols and definitions used in this paper. Section IV presents the VANET multirole classification community clustering method. Section V discusses the results and analysis of the simulation experiments. Section VI summarizes this paper.

II. RELATED WORK

A. COMMUNITY STABILITY PROBLEM

Different from traditional community clustering, vehicle nodes move faster in the Internet of Vehicles, and the topological relationship between nodes changes rapidly. Using a traditional community clustering method in the IoV will result in a short community life cycle and low stability.

A community clustering methods designed for the Internet of Vehicles, AMACAD [7], proposed by Morales *et al.*, comprehensively considers the current position of the node in community clustering, the current speed and the end position of each node to estimate the topological changes of the vehicle nodes for a period of time in the future, which are used as the clustering basis to extend the survival time of the community.

ASPIRE [8] was proposed by Koulakezian and aims to establish a large-scale community. When the head nodes of two communities enter the mutual area, the head node of each community maintains a relatively stable connectivity state and then merges the community to reduce the separation and merger of the two communities. Daeinabi et al. added the direction of vehicle movement, the number of neighbor nodes and some uncertain factors to the basis for clustering in VWCA [9]. MC-DRIVE [10] was proposed as a direction-based clustering algorithm for the intersection area, which attains a good stability and accurate density estimation within the clusters. VANET QoS-OLSR [11] is a new QoS-based clustering algorithm that considers a tradeoff between QoS requirements and high speed mobility constraints, which aims to form stable clusters and maintain the stability during communications and link failures while satisfying the quality of service requirements. The methods discussed above simply select the most obvious factors that influence vehicle location and discard a large number of road conditions that may affect future vehicle locations. As a result, when the community is clustered by using these influencing factors, the stability of the community is not improved. The community after clustering still shows the characteristics of a short life cycle and a fast change in node attribution. Reference [12] proposed a model to accurately evaluate the network connectivity of a highly dynamic IoV, which can be adapted to a clustering basis to make the community stable.

B. LOAD-BALANCING PROBLEM

The community clustering method for the Internet of Vehicles usually assigns roles to the vehicle nodes as the basis for the selection of the forwarding node. Zegorz proposed the MDMAC [13] community clustering model, which divided the vehicle nodes into a cluster head node (CH) and multiple cluster member nodes (CM). In [14], Poongodi and Tamilselvi assigned different roles to nodes in the community, including a cluster head node, several gateway nodes (GW) and multiple cluster members.

In [15], Dror *et al.* also proposed to divide the vehicle nodes in the community into a cluster head node, cluster relay nodes (CR) and common nodes (slave). MOBIC [16] uses aggregate mobility to select the CH node. Every node calculates relative mobilities between all of its neighbors and itself based on the received signal strength (RSS). The node with the lowest aggregate mobility is chosen as the CH. New-ALM [17] also chooses a node with less variance relative to its surroundings as a CH. New-ALM calculates the relative distance between two nodes, rather than using the RSS parameter. To choose a better forwarding node, Reference [18] proposed a k-hop clustering approach. K-hop uses the ratio of the packet delivery delay of two consecutive packets to calculate the relative mobility. FQGwS [19] is a QoS-balancing gateway selection algorithm, where the decision over the gateway depends on the class of traffic to be transmitted to the infrastructure. The load-balancing algorithm proposed in [20] considers the equalization load on the gateway nodes. However, these methods do not provide a load-balancing strategy for the head nodes with higher load.

C. SUMMARY

At present, increasingly more studies focus on the clustering of the Internet of Vehicles community. They use the motion state of the vehicle, the steering of the vehicle intersection, the direction of vehicle movement and the speed of the vehicle as the basis for clustering, while the impact of vehicle positions at future times is ignored. Thus, the effect of improving the stability of the community is not particularly obvious. Some algorithms select gateway nodes to balance the load of the head node, but they lack reasonable allocation strategies, resulting in massive data on the forwarding node.

Aiming at solving the problem of low stability and data distortion of the VANET community caused by node location variability and data attachment, this paper studies the scheme of community clustering and role allocation based on the vehicle location prediction model. At the same time, considering the load balancing of key nodes in the community, we provide the multirole classification community clustering method in the VANET scenario to make the emergency response management system work stably and efficiently.

III. FORMAL SPECIFICATION

A. FORMAL SPECIFICATION OF MEDICAL VEHICULAR COMMUNITY PROPERTIES

In this section, we transform the medical VANET into a weighted undirected graph, denoted by G. The medical vehicle nodes in VANET are transformed into nodes in the graph, the set of which is denoted by $V_g = \{ve_1, ve_2, \ldots\}$. The connections between vehicle nodes in VANET are transformed into the edges in the graph, the set of which is denoted by $E_g = \{e_1, e_2, \ldots\}$. The community in VANET can be translated into a subgraph of G, denoted by

$$COM_k = \{V_k, E_k | V_k \subseteq V_G, E_k \subseteq E_g\} \tag{1}$$

If two vehicles are in the communication range of each other, an edge exists between the nodes representing the two vehicles. The weight of the edge denoted by w_e is measured by transmission factor (see Definition 1). The weight of the node denoted by w_{ve} is measured by expected neighbor connection centrality (see Definition 4).

Definition 1: The transmission factor (TRF) represents the reliability of the connection between two vehicle nodes, which satisfies (2)

$$TRF(ve_i, ve_j) = \begin{cases} 0, & dist_t(ve_i, ve_j) < TR \\ \dfrac{TR^2 - (dist_t(ve_i, ve_j))^2}{TR^2}, & 0 < dist_t(ve_i, ve_j) \leq TR \end{cases} \tag{2}$$

where the following apply:

1) Transmission range (TR) is the maximum transmission range for vehicle communications.

2) $dist_t(ve_i, ve_j)$ is the distance between ve_i and ve_j at time t.

When the distance between vehicles is within the maximum transmission range, TRF is negatively correlated with the distance between vehicles. The closer the distance is, the more reliable the connection is between the two vehicle nodes.

Definition 2: The neighbor nodes of ve_i are the nodes that satisfy $TRF(ve_i, ve_j) > 0$.

Definition 3: Neighbor connection centrality (NCC) is the sum of TRFs between ve_i and its neighbor nodes at time t, denoted by

$$C_{i,t} = \sum_{ve_i \in NS_i} TRF(ve_i, ve_j) \tag{3}$$

where NS_i is the neighbor set of ve_i.

Definition 4: Expected neighbor connection centrality (ENCC) represents the weighted average of the NCC values of the node over a period of time, starting from the current moment. The ENCC value of ve_i at time t is denoted by

$$C_{i,\bar{t}} = \sum_{w_k \in WS, dt_k \in DTS} w_k C_{i,t+dt_k} \tag{4}$$

where DTS is the set of time intervals, denoted by $DTS = \{dt|dt = 0, \Delta t, 2\Delta t, 3\Delta t, \ldots\}$, WS is the set of weights, denoted by $WS = \{w|w = w_1, w_2, w_3, \ldots\}$, and w_i is the weight of the NCC value at time $t + (i-1)\Delta t$.

Definition 5: Community neighborhood connection centrality (CNCC) represents the sum of TRFs between ve_i and the nodes within the community COM_k at time t, denoted by

$$C_{i,t}^{COM_k} = \sum_{ve_j \in NS_i^{COM_k}} TRF(ve_i, ve_j) \tag{5}$$

where $NS_i^{COM_k}$ is the set of neighbor nodes of ve_i in COM_k.

Definition 6: Expected community neighborhood connection centrality (ECNCC) represents the weighted average of the CNCC values of the node over a period of time, starting from the current moment. The ENCC value of ve_i at time t is denoted by

$$C_{i,\bar{t}}^{COM_k} = \sum_{w_k \in WS, dt_k \in DTS} w_k C_{i,t+dt_k}^{COM_k} \tag{6}$$

where WS and DTS are defined in *Definition 4*.

Definition 7: The residual load capacity (RLC) of the node represents the buffer space remaining for the node to forward data at the current time. The RLC value of ve_i at time t is denoted by $RLC_{i,t}$. Sending packets larger than $RLC_{i,t}$ to ve_i at time t will cause the packet to be lost.

B. FORMAL SPECIFICATION OF MEDICAL VEHICULAR COMMUNITY ROLES

To distinguish the position of different nodes and to characterize the status of them in the community and their contributions to the routing of the vehicular network, different roles are defined for the nodes in the medical vehicular network community. Typically, there is at least one cluster head and several members in a community. The head node manages the information of the community, such as the set of CM nodes, the location of each node and routing tables. In the process of community evolution, due to the high direct connectivity and the important information of the community, the head node is often regarded as an important forwarding node, which can usually determine whether a new node can join the community.

In addition to the CH node and CM nodes, to study the association between the current community and other communities, some clustering methods put forward the concept of a gateway node, which belongs to a community and is directly connected to nodes of other communities. Usually, the number of GW nodes and the quality of connections to the other community can indicate how closely the community is connected to the other one. In the routing protocol based on community clustering, the GW nodes are often used as the relay nodes of intercommunity communication, which are responsible for forwarding packets to other communities.

In a routing protocol based on community clustering, the special position of the head node and the gateway nodes leads to a high load of data forwarding on these nodes. To balance the load of the head node and gateway nodes, this section newly defines collaboration nodes of the head node and the gateway nodes and thus divides the nodes in a community into the head node, gateway nodes, collaboration nodes of the head node, collaboration nodes of the gateway nodes and the ordinary member node. Nodes that are not subsumed into the community are defined as single nodes.

Definition 8: The cluster head (CH) is the node with the highest ECNCC value in the community. ve_i is thought to have the best connection quality in the community at time t, if it satisfies

$$C_{i,t}^{COM_k} \geq C_{j,t}^{COM_k}, \quad \forall ve_j \in V_{COM_k} \tag{7}$$

If there is more than one node with the highest ECNCC value, select the node with the lowest number as the CH node.

Definition 9: The CH collaboration node (CHC) is a node in the community with a relatively high ECNCC value. In COM_k, whose CH node is ve_h, a CHC node must satisfy

$$C_{i,t}^{COM_k} \geq \delta C_{h,\bar{t}}^{COM_k}, \quad 0.5 \leq \delta < 1 \tag{8}$$

where δ is a factor that controls the number of CHC nodes. At the beginning of the community formation, the CH node and the CHC nodes have a lower load of data transfer. δ can be set to a larger value to reduce the number of CHC nodes. This enables the connection quality and forwarding features of the selected CHC nodes to be closer to the CH node. With more packet forwarding tasks, the CH node and the selected CHC nodes have reached a high data load, and δ can be reduced appropriately to select more CHC nodes that can assist in data forwarding.

Definition 10: The set of gateway nodes between COM_k and COM_l is denoted by $GWS_{k,l}$, which satisfies

$$GWS_{k,l} = \{ve_i | ve_i \in V_{COM_k} \wedge \exists (ve_j \in NS_i \wedge ve_j \in V_{COM_l})\} \tag{9}$$

as shown in Fig. 2.

Definition 11: The gateway node between COM_k and COM_l, denoted by $GW_{k,l}$, is the one in $GWS_{k,l}$ with the largest ECNCC value on COM_k. If $ve_i \in GWS_{k,l}$ satisfies $C_{ve_i}^{COM_l} \geq C_{ve_j}^{COM_l}, \forall ve_j \in GWS_{k,l}$, it is chosen to be $GW_{k,l}$.

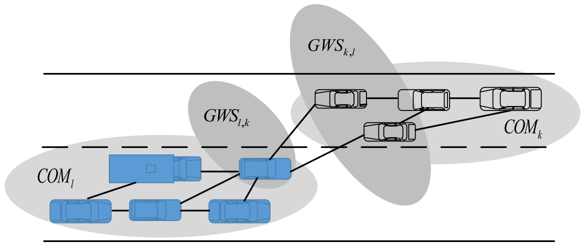

FIGURE 2. Example of VANET Community Gateway Node Set, where COM_l is the medical community and COM_k is ordinary community.

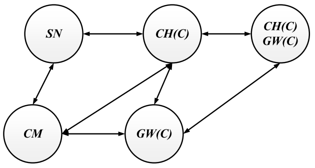

FIGURE 3. Community node role conversion.

TABLE 1. Information table of neighbor nodes.

Field Name	Type	Meaning
LUT	Time	Indicates the time when this entry was last updated
NID	long	ID of the neighbor node
CID	long	ID of the neighbor node's current community
NR	enum	The role of the neighbor node in the community, including CH, CHC, GW, GWC, CM and SN
ENCC	float	ENCC value of the neighbor node
ECNCC	float	ECNCC value of the neighboring node for its community
Positions	array	The location of neighbor nodes at different times
CV	vector	The current speed of the neighbor node, including the direction
ECT	long	The estimated length of time that the neighbor node is connected to the current node. The unit is BEAT_ LENGTH
RLC	float	Residual load capacity of neighbor nodes

If there is more than one node with the highest ECNCC value, select the node with the lowest number as $GW_{k,l}$.

Definition 12: The collaboration nodes of the gateway node between COM_k and COM_l, denoted by $GWC_{k,l}$, are nodes in $GWS_{k,l}$ except $GW_{k,l}$. The set of $GWC_{k,l}$ is denoted by $GWCS_{k,l}$, which satisfies

$$GWCS_{k,l} = \{ve_i | ve_i \neq GW_{k,l}, ve_i \in GWS_{k,l}\} \quad (10)$$

CM nodes refer to all community nodes in the community other than the CH node, the CHC nodes, the GW node and the GWC nodes, which satisfy the following:

1) The CM node is a single-hop neighbor node of the CH node. There must exist an edge between the CM node and the CH node.

2) If ve_i is a CM node in COM_k, it satisfies $\forall(ve_j \in NS_i) \Rightarrow (ve_j \in V_{COM_k})$.

Nodes that do not belong to any community are defined as single nodes (SN). The role transformation of the nodes is shown in Fig. 3. The arrow direction in the figure indicates role conversion. CH(C) represents a CH or CHC node. GW(C) refers to a GW or GWC node. In a community, the CH(C) node can also be a GW(C) node.

IV. CLUSTERING METHODS OF MEDICAL VEHICULAR COMMUNITY

Community clustering is the process of dividing nodes in the Internet of Vehicles into different communities. This section divides the process of clustering into two stages: community formation and community maintenance. The definition given in Section III is used as the standard for dividing nodes into communities.

A. COMMUNITY FORMATION

In the initial stage of VANET, each medical vehicle node is initialized as an SN node. Then, whether in the community formation phase or in the community maintenance phase, the node will periodically broadcast heartbeat (HB) packets to the neighbor node. The HB packet carries information of the node, including current position of the node, predicted position of the node, id of the current community, ENCC of the node, ECNCC of the node and RLC of the node. The neighbors' information table (NIT) is maintained for all nodes to calculate and compare neighbor node's ENCC, ECNCC and other indicator data. The items of the table are shown in Table 1. BEAT_ LENGTH in the table represents a time interval between two adjacent HB packets.

The node updates the NIT based on the received HB packets and calculates its ENCC value according to (4). Suppose that the current node is ve_i and the current time is t; the table of neighbor vehicular information stored by node i is used to obtain the position of neighbor nodes at time t, $t+1$, $t+2$, and $t+3$. In combination with the predicted position of ve_i at the corresponding time, the distances between the ve_i node and its neighbor nodes are calculated to obtain the ENCC of ve_i. Since the data of the NIT are updated when receiving the periodically broadcasted HB packets, there may be a situation that the update is not timely, and there is no position information at $t, t+1, t+2$, and $t+3$. In this situation, the node is no longer a neighbor of ve_i. At this time, the TRF value at the corresponding time is assigned to 0, thus reducing the contribution to the ve_i node ENCC value. If the HB packet is missing for a long time, it is considered that the neighbor node is disconnected from ve_i, and its information is removed from the neighbors' information table.

Community formation begins with the election of the CH node. When a node updates its ENCC value, it compares its ENCC value with that of its neighbor nodes to find the node with the largest ENCC value, which will be selected as the CH node. When there are multiple nodes with the largest ENCC value, the node with the smallest ID is selected as the CH node. After the CH node is selected, the new community ID is marked as the ID of the CH node, and the neighbor nodes are informed of the establishment of a new community through the HB packet broadcast by the CH node. If the neighbor node is an SN, it joins the community directly and notifies the

CH node by sending a joining community (JC) request. If the neighbor node belongs to other nodes, it needs to be judged whether it is suitable to join the new community. The judgment basis will be detailed in the community maintenance (Section IV-B) stage. The CH node updates the community membership table based on received JC packets. If the JC packet requests to join this community, the node is added to the table. If the JC packet requests to join another community, the node is removed from the table. After several iterations, the community gradually tends to a relatively stable state. This completes the process of community formation.

B. COMMUNITY MAINTENANCE

In the phase of community maintenance, it is necessary to address the situation of nodes joining or leaving the community dynamically and the situation of communities merging, splitting and dying. At the same time, the role assignment of CHC, GW and GWC nodes is also carried out in this phase.

1) PROPERTIES OF NODES AND COMMUNITIES

At this stage, the ownership of nodes needs to be disposed. When a node receives the HB packet broadcast by its neighbor node, it estimates the duration of the connection between the node and its neighbor node based on the speed and the current and the predicted position and then updates the information table of neighbor nodes. The implementation is as shown in Algorithm 1, where *calculateFreshness* is proposed in [13].

After updating the NIT, if a new CH node is found in the table, it can be judged whether the new one is more suitable to be a CH node than the old one. We improve the *testClusterHeadChange* algorithm in the MDMAC method. Suppose that ve_i receives the HB packet sent by ve_h, where ve_h is the new CH node in the neighbor nodes' information table, and ve_h is considered superior to ve_i if it meets the following criteria:

1) ve_h is the CH node in its community.

2) $C_{i,\bar{t}} < C_{h,\bar{t}}$.

3) The expected connection time of ve_h and ve_i as estimated by Algorithm 2 is long enough to be greater than the threshold value α.

4) The angle between ve_h and ve_i is less than the threshold β.

5) $C_{i,\bar{t}}^{COM_m} < C_{h,\bar{t}}^{COM_n}$.

If ve_h is more suitable as a CH node, then ve_i chooses to join ve_h's community. Based on its role, ve_i performs the following operations:

1) If ve_i is not a CH node, it broadcasts JC packets to request to join ve_h's community. The original community of ve_i was informed that ve_i left this community.

2) If ve_i is a CH node, it broadcasts JC packets to request to join ve_h's community and notify other nodes in the original community that the community died. Other nodes in the community become SN nodes. The SN node selects to join a new community according to the HB packets of other CH nodes or becomes a CH node of a new community and attracts surrounding nodes to join.

Algorithm 1 Calculation of the Expected Remaining Connection Time

```
Input: current position of the node $\vec{pos}$, current speed $\vec{v}$, positions of neighbor node $npos$, speed of neighbor node $\vec{nv}$, current time $t$, predicted positions of the node after 1 s, 2 s, and 3 s $posSet$, predicted positions of neighbor node after 1 s, 2 s, and 3 s $nPosSet$, BEAT_ LENGTH, Maximum transmission range of the vehicle $TR$
$freshness \leftarrow calculateFreshness(\vec{pos}, \vec{npos}, \vec{v}, \vec{nv})$
$freshtime \leftarrow freshness \cdot BEAT\_LENGTH$
$coff \leftarrow 0$
for all $i \in \{1s, 2s, 3s\}$ do
    if If the position of neighbor node at $t + i \in nPosSet \wedge dist(nPosSet[t + i], posSet[t + i]) < TR$ then
        $coff \leftarrow i$
    end if
end for
if $freshtime < coff$ then
    $remainTime \leftarrow coff$
else if $coff = 3s$ then
    $remainTime \leftarrow \lfloor freshtime/BEAT\_LENGTH \rfloor$
else
    $remainTime \leftarrow \lfloor coff/BEAT\_LENGTH \rfloor$
end if
return $remainTime$
Output: Remaining connection time with neighbor nodes $remainTime$
```

According to the above rules, nodes can complete the dynamic change of community ownership, and communities can die out, split and merge.

2) ROLE ALLOCATION OF CHC, GW AND GWC NODES

At this stage, the role allocation of CHC, GW and GWC nodes also needs to be addressed. The CH and CHC nodes maintain the same list of community members. The CH node and CHC nodes maintain a gateway information table, respectively, according to the updated information of GW and GWC nodes in their neighbor nodes. The CH node maintains a list of community members to know the status of each node in the community. The common node does not have a list of community members, so it is impossible to know the status of each node in the community. The CH node can select nodes whose community statuses are similar to the CH node as CHC nodes. Since other nodes in the community can get to know their adjacent communities and calculate the ECNCC value of the adjacent communities, GW and GWC nodes can be selected by common nodes in community, and the CH node and adjacent CHC node are notified of the results.

CHC nodes are selected according to the ECNCC value. The closer they are to the ECNCC value of the CH node, the more suitable they are to be CHC nodes. Assuming that maxCHCN nodes will be selected, the specific selection steps are as follows: finding all the node IDs whose ENCC value is greater than $\delta C^{COM_k}_{h,\bar{t}}$ in the NIT, taking maxCHCN nodes with the smallest IDs into newCHCSet and broadcasting the newCHCSet to all nodes in the community.

The selection of GW and GWC nodes is based on the ECNCC value of the adjacent community. The selection process is shown in Algorithm 2, where the adjacency community information table records the ID values of all adjacent communities of the node and the ECNCC values of the node for these communities.

Algorithm 2 Selection of GW and GWC Nodes

```
Input: $NIT$, current node $n$, CH node $h$
$neighborClusters \leftarrow$ find all neighboring communities of $n$ in NIT
$newNClusterSet \leftarrow \emptyset$
for all $cluster \in neighborClusters$ do
    cc $\leftarrow$ Calculate ECNCC of $n$ for the $cluster$ according to Definition 6
    $newNClusterSet \leftarrow newNClusterSet \cup \{(cluster, cc)\}$
end for
if $newNClusterSet \neq \emptyset$ then
    for all $CHC \in CHCSet$ do
        Broadcast $newNClusterSet$ to all $CHC$ nodes to notify that $n$ becomes a $GW$ node
    end for
    if $h.id \neq n.id$ then
        Send $newNClusterSet$ to $CH$ node to notify that $n$ becomes a $GW$ node
    end if
end if
$isGW \leftarrow newNClusterSet \neq \emptyset$
return $isGW$, $newNClusterSet$
Output: Whether the node is a GW/GWC node $isGW$, Adjacent community information $tablenewNClusterSet$
```

The CH node and CHC nodes need to maintain their own lists of community members, including CH node lists (only one CH node in the table), CHC lists, GW/GWC lists, and CM lists. The list of the CH node, CHC and GW/GWC are collectively called the key node member list. In the process of CHC and GW/GWC election, CH nodes and the corresponding CHC nodes update the list of key node members according to the election results. As new nodes join the community, CH nodes and their corresponding CHC nodes update their CM lists. When a CM node leaves the community, the CH node and the CHC node remove the corresponding member and make a new role selection according to the role of the removed member. There are two situations in which a member node leaves the community:

1) The member node joins other communities and proactively notifies the CH node and corresponding CHC nodes. In this case, the CH node and CHC nodes remove the member node from the corresponding lists.

2) The member node is disconnected from the CH node. In this case, if there are not enough CHC nodes, reselect new nodes to fill the gap. If these new CHC nodes are GW nodes as well, remove them from GWSet.

Finally, in addition to updating the table entries maintained by the node itself when receiving the HB or other notification packets of the neighbor node, each node in the community will periodically update its node state to determine the situation of the neighbor node losing the connection. At the same time, the CH node needs to select or update the lists of CHC and GW/GWC. The node ve_i in COM_k, at time t, is updated as follows:

1) Update $C^{COM_k}_{i,\bar{t}}$.

2) Subtract 1 from the expected remaining connection time of the neighbor node. If the value is reduced to 0, the neighbor node is considered to be disconnected with ve_i, and reselect new CHC nodes if necessary.

3) If ve_i is the CH node, the CHC nodes need to be selected or updated, and all nodes in the community are notified of the result of the selection or update.

4) Update the ECNCC values between the node and other communities. If this value changes, the CH node and CHC nodes are notified to update the community GW nodes' information table.

3) MULTIROLE MEDICAL VEHICULAR COMMUNITY LOAD-BALANCING ALGORITHM

In routing protocols based on community clustering, the CH node and GW nodes often play important roles in packet forwarding and are frequently selected as packet forwarding nodes. For example, the algorithm in [21] adapts the AODV routing algorithm of the traditional vehicle network and stores the routing table between communities in the head node. When a node in the community sends a packet to a non-neighbor node, the packet is first sent to the head node, which determines whether the destination node is in the community. If the destination node is in this community, the packet is forwarded directly; otherwise, according to the maintained information in the routing table, the packet is forwarded to the corresponding gateway node. Therefore, the header node and gateway node become the key nodes in the packet sending path, and the load is heavy. According to the community node role definition in Section III-B, this section presents an algorithm to balance the load of the CH node and the GW node to avoid an excessive load of the CH node and the GW node.

When the CH node needs to be selected for data forwarding, CHC nodes are used as the alternative nodes for the head node for load balancing. The set of CH nodes and all the CHC nodes in the community are considered as a CH node pool (CHP) of the community. The node with relatively high ECNCC and RLC from the pool is selected to forward data. At time t, the evaluation factor of ve_i is defined as

$$\tau_{i,t} = C^{COM}_{i,\bar{t}} \cdot l(RLC_{i,t}) \tag{11}$$

Algorithm 3 Selection of the Forwarding Node From the CHP

```
Input: CH node $h$, set of CHC nodes $CHCSet$, $NIT$
$neighborNodeSet \leftarrow$ find all neighboring nodes of $h$ in NIT
$nCHCSet \leftarrow neighborNodeSet \cap CHCSet$
if $nCHCSet \neq \emptyset$ then
    $fhid \leftarrow n.id$
else
    $\tau_{h.id} \leftarrow NeighborTable[h.id][ENCC] \cdot l(NeighborTable[hid][RLC])$
    $\tau_{max} \leftarrow 0$
    for all $CHC \in CHCSET$ do
        $C_{ENCC} \leftarrow NeighborTable[CHC][ENCC]$
        $C_{RLC} \leftarrow NeighborTable[CHC][RLC]$
        $\tau \leftarrow C_{ENCC} \cdot l(C_{RLC})$
        if $\tau > \tau_{max}$ then
            $(\tau_{max}, \tau_{max}CHC) \leftarrow (\tau, CHC)$
        end if
    end for
end if
if $\tau_{max} > \tau_{h.id}$ then
    $fhid \leftarrow \tau_{max}CHC$
end if
return $fhid$
Output: ID of the selected forwarding head node $fhid$
```

where

$$l(x) = \frac{1}{1 + e^{-\rho(x-\mu)}} \tag{12}$$

Select the node with the largest τ value as the head node of data forwarding. When the residual load capacity (RLC) of the node is relatively high, $l(RLC_{i,t})$ is close to 1, and $C_{i,\bar{t}}^{COM}$ will become the dominant factor of selection. When RLC falls below the threshold, $l(RLC_{i,t})$ rapidly approaches 0, and RLC becomes the dominant factor of selection. At this point, the load of the node is already relatively heavy, and the corresponding value of τ is relatively small. According to the selection rules of CHC nodes in Section IV-B, CHC nodes and CH nodes have similar ECNCC values. Therefore, nodes with higher RLC are more likely to be selected, and the nodes in CHP share the load with each other to balance the load. The curve of $\tau_{i,t}$ is shown in Fig. 4, where $\rho = 3$, $\mu = -1.67$, the x-axis represents $C_{i,\bar{t}}^{COM}$, the y-axis represents $RLC_{i,t}$ and the z-axis represents $\tau_{i,t}$.

The implementation of the selection of forwarding the header node is as shown in Algorithm 3.

When a CH node or a CHC node needs to select a GW node for data forwarding, the GWC nodes can be used to share the load of the GW node. When selecting a GW or GWC, the set of the GW node and GWC nodes are treated as a gateway node pool (GWP). An appropriate evaluation factor is used to find the nodes that are closely connected with the current community and the target community, and the nodes with higher residual load capacity are used as the gateway node for data forwarding. The specific selection steps are as shown in Algorithm 4, where the selected evaluation factor $h'_{i,t}$ satisfies

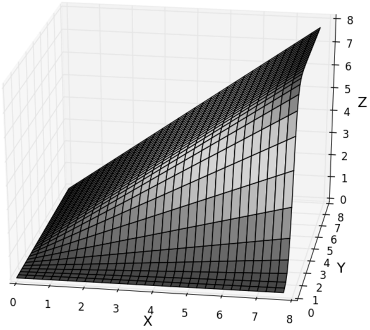

FIGURE 4. The curve of $\tau_{i,t}$.

Algorithm 4 Selection of the forwarding gateway node

```
Input: ID of the current community $cid$, ID of the destination neighbor community $ncid$, set of GW nodes between $COM_cid$ and $COM_ncid$ $GWSet$, ECNCC threshold of GW nodes for $COM_cid$ $\vartheta_{in}$, ECNCC threshold of GW nodes for $COM_ncid$ $\vartheta_{out}$, ECNCC weight of GW nodes for $COM_cid$ $w_{in}$, ECNCC weight of GW nodes for $COM_ncid$ $w_{out}$, $NIT$
$AvailGWSet \leftarrow \emptyset$
for all $GW \in GWSet$ do
    $gwid \leftarrow GW.id$
    $gwInnerC \leftarrow NIT[gwid][ECNCC]$
    $gwOuterC \leftarrow gw[ECNCC]$
    if $gwInnerC \geq \vartheta_{in} \wedge gwOuterC \geq \vartheta_{out}$ then
        $AvailGWSet \leftarrow AvailGWSet \cup \{(gwid, gwInnerC, gwOuterC)\}$
    end if
end for
for all $gwItem \in AvailGWSet$ do
    $(gwid, gwInnerC, gwOuterC) \leftarrow gwItem(gwid, gwInnerC, gwOuterC$
    $aw \leftarrow NIT[gwid][RLC]$
    $h' \leftarrow (w_{in} \cdot gwInnerC + w_{out} \cdot gwOuterC) \cdot l(aw)$
    if $h' > h'_{max}$ then
        $(h'_{max}, fgwid) \leftarrow (h', gwid)$
    end if
end for
return $fgwid$
Output: ID of the selected GW node $fgwid$
```

$$h'_{i,t} = (w_{in} \cdot C_{i,t}^{COM_m} + w_{out} \cdot C_{i,t}^{COM_n}) \cdot l(RLC_{i,t}) \tag{13}$$

and

$$w_{in} + w_{out} = 1. \tag{14}$$

w_{in} and w_{out} are set to 0.5 here. The node with the largest $h'_{i,t}$' is selected as the gateway node. Similar to Algorithm 3, when RLC is larger, $C_{i,t}^{COM_m}$ and $C_{i,t}^{COM_n}$ are dominant factors

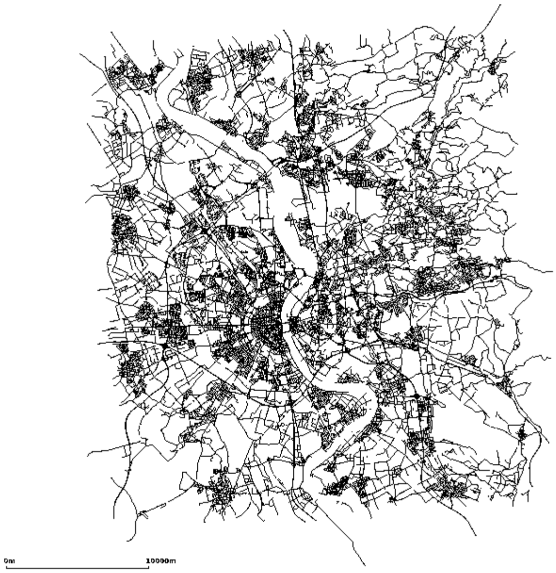

FIGURE 5. **Topology of TAPASCologne dataset road.**

for selection. When RLC is less than the threshold value, the influence of RLC gradually increases, and the nodes with larger RLC are more likely to be selected. Thus, the nodes in the GWP share the load with each other to balance the load. Factor h' takes into account the ECNCC values between the node and current community and the connected neighboring communities. During the forwarding process, the selected gateway node has a close relationship with the current community and the destination community; thus, the probability of packet loss during forwarding is reduced.

V. SIMULATION EXPERIMENTS AND RESULT ANALYSIS

A. THE DATA AND METHOD OF SIMULATION EXPERIMENTS

1) SIMULATION ENVIRONMENT AND DATASET

The simulation experiments in this section use the Veins [22] vehicular networking simulation framework. Veins is an open source framework for running vehicular network simulations, which is based on two well-established simulators: OMNeT++ [23], an event-based network simulator, and SUMO [24], a road traffic simulator. It extends these to offer a comprehensive suite of models for IVC simulation. And we use the TAPASCologne dataset [25], which is from the Institute of Transportation Systems at the German Aerospace Center (ITS-DLR), to create a simulation scenario that describes the traffic flow in an area of 400 square kilometers within the city of Cologne (Germany) for a whole day. The road topology of the dataset is shown in Fig. 5.

In this section, the vehicle trajectory data from 6:00 to 8:00 (am) is used to provide the vehicle node motion basis for vehicle network simulation. During this time period, more than 8,000 vehicles are driving on the road at the same time, which can simulate real road conditions and test the stability of the VANET-based smart management systems.

2) METHODS

The MDMAC method, the Nhop [26] method and the PMRC method given in Section IV are used to cluster the vehicles in the TAPASCologne dataset. The survival time of the VANET community formed under the three methods and the number of node community changes in the community were counted. The results were recorded, and the stability of the community formed by the PMRC, Nhop and MDMAC methods was compared. After the community is formed, the source node and the destination node sent by the data packet are selected randomly in the same manner, and the data packet is periodically transmitted. The number of data packets forwarded by each node in the community, the delivery rate of the data packet and the average end-to-end delay are recorded. The results were used to compare the performance of the VANET community formed by the two methods in the route of the car network community. The packet delivery rate indicates the ratio of the number of packets successfully arriving at the destination node to the total number of transmitted packets. The average end-to-end delay represents the average time it takes for a packet to be sent by the source node to the destination node.

According to the protocol [27], the selection rules for the data forwarding node are as follows:

1) If the destination node is a direct neighbor node of the current data packet holding node, the data packet is directly forwarded to the destination node.

2) If the current data packet holding node is a CM node, the node is selected from the head node pool according to Algorithm 3 as the next hop of the packet forwarding.

3) If the current data packet holding node is a CH node or a CHC node, it is first determined whether the destination node is a community node. If so, send the packet directly to the destination node. Otherwise, select the appropriate community to forward the packet in the neighbor community as described in protocol [27]. At this point, according to Algorithm 4, the node is selected from the pool of gateway nodes as the next hop to forward the packet.

4) If the current data packet holding node is a GW node or a GWC node, the next forwarding community node in the neighbor node table is selected as the next hop to forward the packet according to the information marked by the data packet.

5) If it is not one of the above four cases, the node continues to hold the data packet and waits for any of the above four cases to be satisfied.

In (12), ρ is taken as 1 and μ is taken as 20 KB. In (14), w_{in} and w_{out} are both 0.5. The rest of the experimental parameters are set as shown in Table 2.

B. RESULT ANALYSIS OF SIMULATION EXPERIMENT

1) COMMUNITY STABILITY ANALYSIS

Fig. 6 shows the average community survival time as a function of maximum vehicle speed. It can be seen from the figure that when the speed is small, the increase of the maximum

TABLE 2. Parameter setting.

Parameters	Values	Meaning
simTime	2 h	Simulation duration
MacProtocol	802.11 p	MAC layer protocol used in the experiment
TR	300 m	Vehicle communication radius
bitrate	18 Mbps	Bit rate.
pktSize	5 KB	Packet size
maxRLC	100 2048 KB	Vehicle node maximum buffer space
BEAT_ LENGTH	1 s	Interval at which the node updates neighbor node information.
WS	(1, 1, 0.75, 0.5)	Expected location weight set
δ	0.8	ENCC control factor of CHC node
maxCHCN	8	The maximum number of CHC nodes in the community

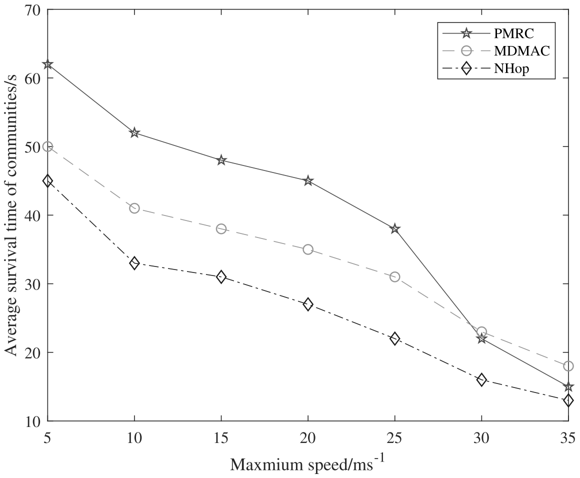

FIGURE 6. Comparison of average community survival time.

speed will lead to a rapid decline in the average survival time. When the speed is greater than 10 m/s and less than 25 m/s, with the vehicle speed increases, the average survival time of communities formed by the three methods slowly reduced. When the maximum speed is greater than 25 m/s, the average community survival time is short due to the low accuracy of the vehicle position prediction. After the speed reaches 35 m/s, the average survival time of communities is even slightly lower than that of MDMAC communities. Overall, the average survival time of communities formed by PMRC method presented in this paper is higher than that in MDMAC and NHop communities.

The community-changing number of the node refers to the number of times the node joined a new community. Fig. 7 shows the distribution of the number of nodes with the community-changing number of nodes. It can be seen from the figure that as the community-changing number of nodes increases, the number of nodes obtained by MDMAC, NHop and PMRC methods all increase rapidly first and then gradually decrease. In MDMAC clustering communities, the mode of the community-changing number is 8, and the average is 9.04. In NHop clustering communities, the mode of the community-changing number is 10, and the average is 9.51. In the PMRC clustering community, the mode of the community-changing number is 6, and the average is 8.45. In summary, communities formed by the PMRC method have the best stability in vehicular networking communities formed by PMRC, MDMAC and NHop methods.

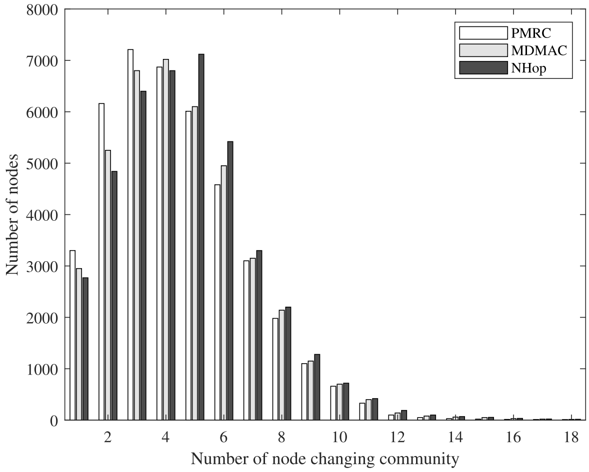

FIGURE 7. The number of nodes distributed with the number of node community changes.

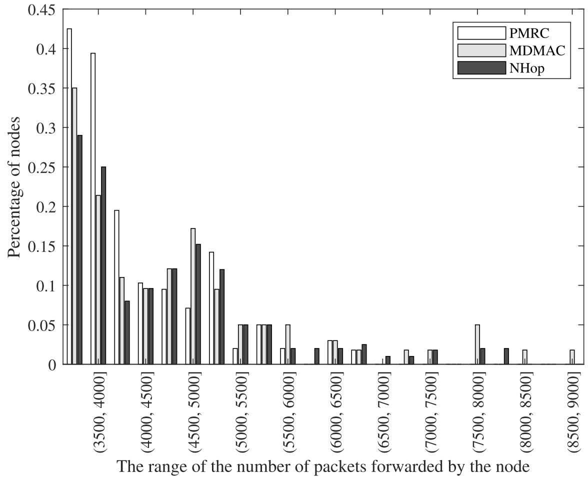

FIGURE 8. High load node packet forwarding amount distribution.

2) COMMUNITY ROUTING PERFORMANCE ANALYSIS

Fig. 8 shows the distribution of the proportion of high-load nodes among all nodes with the number of packets forwarded by nodes. It can be seen from the figure that in communities formed by MDMAC and NHop methods, there are no load-balancing nodes, and there are cases where a few nodes forward too many data packets. However, the PMRC method considers load balancing. When the node load is too high, the residual load capacity is used as the main factor for selecting the forwarding node. Therefore, the PMRC method prevents excessive load nodes from appearing in the community.

Fig. 9 shows the comparison of packet delivery rates in communities formed by the MDMAC, NHop and PMRC methods. As seen from the figure, when the packet

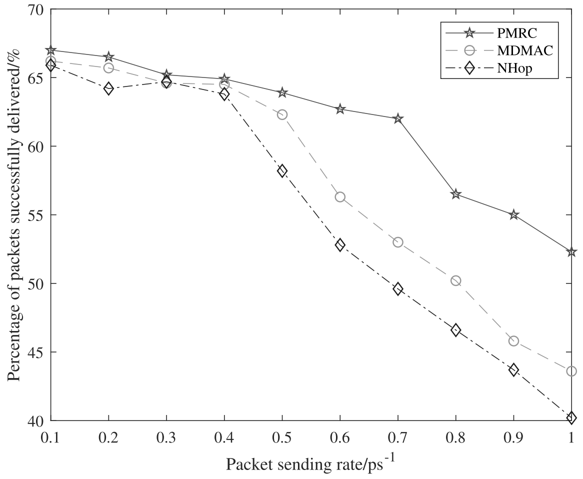

FIGURE 9. **Comparison of packet delivery ratio.**

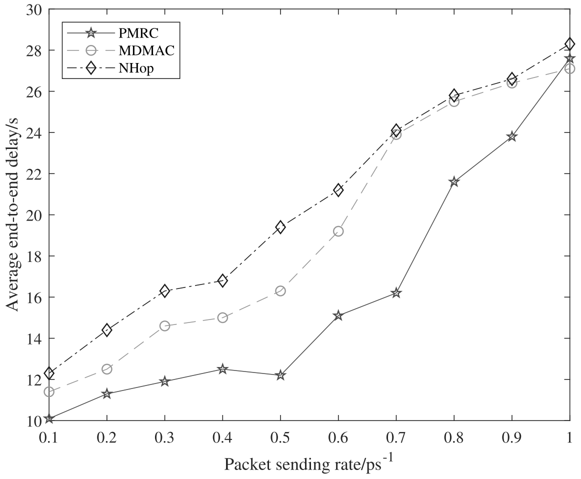

FIGURE 10. **Comparison of average end-to-end delay.**

transmission rate is low, communities obtained by the three methods have similar packet delivery rates in the route of the car network community. As the packet transmission rate increases, the forwarding node load increases, and the packet delivery rate of all three methods decreases gradually. Since the MDMAC method and the NHop method do not select alternate forwarding nodes for the head node in the community, the data transmission rate is excessively dependent on the head node after the data packet transmission rate is greater than 0.4 p/s, and the data packet delivery rate decreases rapidly. Communities obtained by the PMRC method select the candidate nodes, namely, the CHC node and the GWC node, for the head node and the gateway node. When the data transmission rate increases and the head node and the gateway node are heavily loaded, the appropriate data forwarding node is selected from the CHP and the GWP, thereby avoiding data concentration. Therefore, after the data transmission frequency is greater than 0.4 p/s, the packet delivery rate drops slowly. When the packet transmission rate is greater than 0.7 p/s, the load of the CHC node and the GWC node begin to approach saturation and the packet delivery rate also has a rapid decline. At this time, increasing the number of CHC nodes and GWC nodes in the community can improve the load capacity. Overall, compared to the MDMAC and NHop communities, communities formed by the PMRC method have the highest packet delivery rate in the route of the car network community, and the probability of data loss is the smallest.

Fig. 10 shows the average end-to-end delay as a function of the packet transmission rate. As seen from the figure, as the packet transmission rate increases, the average end-to-end delay in the MDMAC method, NHop method and PMRC method increases. At low packet transmission rates (sending rate ≤ 0.4 p/s), the node load is low, and the average end-to-end delay is similar. As the packet transmission rate increases, the load of key nodes in communities formed by the MDMAC method and the NHop method gradually increases and becomes saturated, resulting in a decrease in forwarding performance, and the average end-to-end delay grows faster than that in PMRC. When the packet transmission rate is greater than 0.7 p/s, the candidate nodes in the PMRC community also tend to load saturation, resulting in a rapid increase in the average end-to-end delay. At this point, increasing the number of candidate nodes can be considered.

In summary, communities formed by the PMRC method presented in this paper have the highest community stability compared with communities formed by the MDMAC method and the NHop method, which can effectively balance the node load, improve the packet delivery rate, reduce data loss, reduce end-to-end delay and improve routing and forwarding performance.

VI. CONCLUSION

Based on the vehicle position prediction model given in [6], this paper presents a multirole classification community clustering method PMRC for the VANET scenario. The method considers the location of the medical vehicle in the future as a guiding factor of community clustering to improve the stability of the medical vehicular community. Furthermore, the method selects the candidate nodes for balancing the load for the head node and the gateway node in the community to reduce the probability of an excessive node load and improve the packet delivery rate, thereby reducing the occurrence of data distortion. The rationality and effectiveness of the PMRC method are verified by simulation experiments. This proposed method provides a reliable network for the smart management systems for connected heath, thus medical vehicles can transport medical supplies more efficiently and safely.

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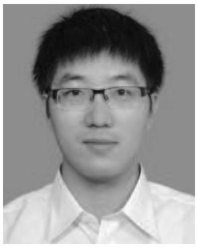

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