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A Vehicular Ad Hoc Networks Clustering Algorithm based on Position-Competition

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The vehicular ad hoc networks(VANETs) presents uneven node density, fast moving speed and dynamic topology change etc. In order to improve the reliability of VANETs in information broadcasting and reduce the redundancy of multi-hop broadcast, a protocol based on the clustering position-competition of vehicular ad hoc networks is hereby proposed. Furthermore, the concept of connectivity-stability is introduced. In the paper, the road is divided into the segment model and the intersection model. The cluster head and the optimal nodes in the cluster are chosen as a radio relay node, which may reduce the broadcast redundancy and improve the broadcast efficiency. At the same time, for the isolated nodes in the network, the carry-forwarding method is taken, which may improve the broadcast reliability in sparse areas and in "hole" areas. Finally, we use the NS2 simulation tool for analysis. The simulation results show that the proposed routing protocol features better comprehensive performance on successful delivery rate, average broadcast time delay and broadcast overhead.

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1.Introduction

Vehicular ad hoc networks (VANETs), as a special kind of mobile ad-hoc network, will have a promising prospect in the future intelligent transportation system (ITS); however, the high nodes mobility, the frequently changed network topology and the unstable communication link in VANETs motivate the design of stable clustering algorithms. Much has been done on this topic and many methods have been explored. VANETs are subject to link dis-connectivity due to high mobility of vehicles and low density in rural areas[1].

At present, many clustering algorithms in VANETs stem from the MANETs. The typical one is the lowest-ID algorithm, in which every node has a unique ID and the node with lowest ID will be selected as the cluster head. According to the way how the nodes are grouped into clusters and how the cluster head is selected, the clustering algorithms can be classified into five varieties: the weight-based clustering[2], the mobility-aware clustering[3], the utility function based clustering[4], the traffic flow-based clustering [5] and the combine-metrics-based clustering [6].

2. Algorithm Design

A. Assumptions

The classic protocols are mainly based on the physical distance between nodes and hardly consider the connectivity of the roads. However, because of the characteristics of vehicular ad hoc network, it is not enough only to consider the connectivity. In this paper, we make two assumptions as follows:

1): All roads have the only identification and location range in network. Road model are divided into segment model and intersection model. The road marks of nodes are obtained through calculating the current location.

2): All nodes finish clustering by the way proposed by Fan P[7].

B. The Connectivity Analysis

The network connectivity [8] is the key factor which affects the performance of VANET and has been studied by many researches in recent years. As the vehicles' moving in the network, the vehicles' location, velocity and directions directly affects the stability of vehicles' distance and link. According to the characteristics of urban road environment, the roads are divided to the section model (the Segment Model) and the intersection model (the Intersection Model) and compute the connectivity time of nodes' link for nodes' connectivity prediction in VANET.

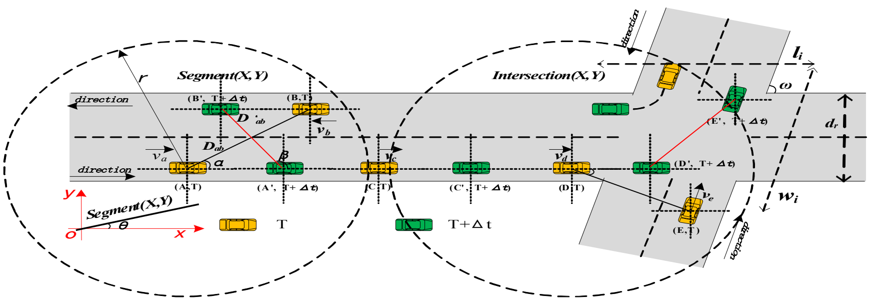

Figure 1: The Connectivity Time Prediction

1): The connectivity time prediction of the segment model

In the segment model, the location relation between the vehicles is just like a line and the vehicles' movement is divided into the same direction and the opposite direction. When the node i and j are connected at time t, the connectivity time Tij (t) satisfies Formula (2.1). Dth is the distance threshold and satisfies Dth≤r.

$$D_{ij}(t+T_{ij}(t)) \leqslant D_{th} \tag{2.1}$$

Set pi(x, y) as the location coordinates of the node i at the time t. xi(t) and yi(t) are respectively the horizontal and vertical coordinate. vi(t) is the the velocity vector of the node i at the time t and r is the node communication radius. The distance between the node i and j at the time t+Δt is expressed by Dij(t+Δt) as follows:

$$D_{ij}(t+\Delta t)=\sqrt{\left(\sqrt{(x_i(t)-x_j(t))^2+(y_i(t)-y_j(t))^2}\cdot\cos(\alpha)-\overrightarrow{\Delta v_{ij}}\cdot\Delta t\right)^2+d^2} \tag{2.2}$$

When $D_{ij}(t+T_{ij}(t)) \leqslant D_{th}$, the link connectivity time Tij (t) which the node i and j can maintain at t can be calculated by the formula as follows:

$$T_{ij}(t)=\frac{-\sqrt{D_{th}^2-d^2}\cdot\cos(\theta)+|x_i(t)-x_j(t)|+d\cdot\sin(\theta)}{\overrightarrow{\Delta v_{ij}}\cdot\cos(\theta)} \tag{2.3}$$

Just as shown in Fig. 1, Vehicle A and C's movement is at the same direction and in the same lane at Time t. Vehicle A and B's movement is the opposite direction and the adjacent lane. In spite of the vehicle's mobility prediction, Vehicle A can calculate the location of Vehicle B and C at the time t+Δt and the connectivity time Tab(t) and Tac(t) at Time t.

2): The connectivity time prediction of the intersection model

At the intersection model, the relative moving direction at the same road direction or the intersection direction. The connectivity prediction of the intersection model is more complicated.

Just as showed in the Fig. 1, Dij (t) is the distance of the node i and j of the intersection at Time t. And the link connectivity time Tij (t) which the node i and j can keep can also satisfy Formula 1. The connectivity time prediction between vehicles from different road directions is the key analysis. Upon analysis of the vehicles' movement, the definition is shown as follows:

a): When Vehicle i and j are both at the intersection intersection(x, y) and the vehicle leaves the road to enter different sections, if the distance Dij(t) of i and j satisfy Formula (4), Tij(t)=0.

$$D_{ij}(t)>\sqrt{l_i^2+w_i^2-2\cdot l_i\cdot w_i\cdot\cos(\omega)}/2 \tag{2.4}$$

b): If the movement direction of Vehicle i and j is not at the same section and does not satisfy the above condition, the connectivity time prediction is shown as follows:

$$D_{ij}(t+\Delta t)=\sqrt{[x_i(t+\Delta t)-x_j(t+\Delta t)]^2+[y_i(t+\Delta t)-y_j(t+\Delta t)]^2} \tag{2.5}$$

When the distance of is less than or equal to D^{th}, the link connectivity time Tij(t) is calculated as follows:

$$T_{ij}(t)=\frac{-(\Delta v_x\cdot\Delta x+\Delta v_y\cdot\Delta y)+\sqrt{[(\Delta v_x)^2+(\Delta v_y)^2]D_{th}^2-(\Delta v_x\cdot\Delta y-\Delta v_y\cdot\Delta x)^2}}{(\Delta v_x)^2+(\Delta v_y)^2} \tag{2.6}$$

As shown in Fig. 1, Vehicle D and E are at different sections. When D and E enter the intersection area, the connectivity time Tde (t) at Time t can be calculated by obtaining the current location information with each other.

C. Information maintenance

1): Node degree: the node degree $Degi(t)$ is the sum of nodes that can be directly connected with i at t.

2): Node average connection time: the average connection time $\overline{T_i(t)}$ represents that at time t the average length of time of node i can directly connected with neighbor j. The value is used to measure the connectivity quality of nodes.

3): Connectivity stability: the calculation formula of node i connectivity stability:

$$W_{stability}(i)=\omega_1\cdot\overline{\Delta t(i)}+\frac{\omega_2\cdot Deg_i}{Deg_{th}}+\omega_3\cdot\Delta v(i)+\frac{\omega_4\cdot N_c}{N} \tag{2.7}$$

Where $\overline{\Delta t(i)}=\frac{\bar{T}_i}{max\{\bar{T}_i,(\bar{T}_j(j=1,2,\cdots N))\}}$ is the average connection time normalized value that represents relative size of average connection time of the current node with neighbor nodes. Meeting $\overline{\Delta t(i)}\le 1$; $\frac{Deg_i}{Deg_{th}}$ characterizes the connectivity of the current node i. The higher the value is, the better the connectivity will be. Meeting the condition $\frac{Deg_i}{Deg_{th}}\leqslant 1$; $\Delta v(i)=\frac{1}{(1+\delta(i,t))}g\frac{\ln(v_{max})-\ln(v_i)}{\ln(v_{max})}$ characterizes the motion state of the vehicle. Meeting $\Delta v(i)\le 1$; $\frac{N_c}{N}$ characterizes the moving direction correlation of the current node i with the neighbor nodes and $\frac{N_c}{N}\leqslant 1$. N is the number of neighbor nodes; N_c is the number of neighbor nodes whose direction of motion is the same as node i; $v_{\max}$ is the maximum speed; $\delta(i,t)$ is the speed variance of node i from time $t-\Delta t$ to time t; $\omega 1$, $\omega 2$, $\omega 3$ and $\omega 4$ are the weight factors.

3. Routing Protocol Description

A. Send multi-hop broadcast packets

When the nodes in the network need to broadcast data to the whole network, it will firstly obtain the location information of all neighbors. Then the corresponding data will be filled in the broadcast packets and the survival time of broadcast packets will be set. If the neighboring list is empty, the node will wait for a period of time and then detect whether the neighboring list is still empty. If the neighboring list is not empty, the node will directly broadcast the pocket.

B. Select relay nodes

1): The relay node selection in segment model

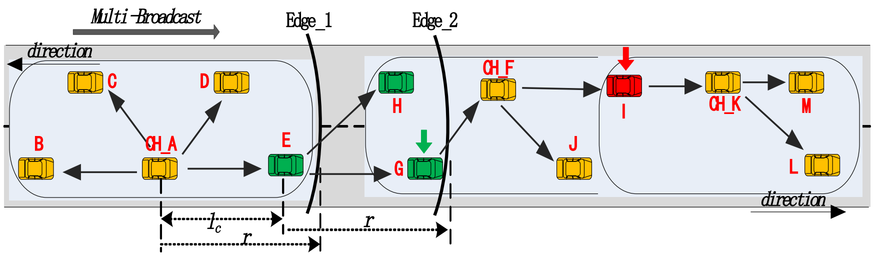

Figure 2: Schematic Diagram in Segment Model

In the segment model, the nodes are divided into following position states:

State_Intersect: the nodes are both in the communication radius of M(f) and M(k), such as Vehicle I;

State_Nearby: the nodes are only in the communication radius r of the cluster M(f), but at the same time the nodes are in the communication range L of neighbor clusters M(a) .The communication range of the cluster L is defined as $L = lc + r$, such as the vehicle G and H;

State_In: the nodes are only in the communication radius r of the cluster M(a), such as the vehicle B, vehicle C, vehicle D ;

The steps of the algorithm are described as follows:

Step 1: when a node receives a data packet, it firstly determines the value of the survival time <Life_Time>. If Life_Time is equal to 1, then read the broadcast packet data and end the judgment. If the Life_Time is more than 1, then takes the next step.

Step 2: when the node is a cluster head node CH, it analyses the source IP address and the broadcast sequence number Sn, judging whether it has received and forwarded the broadcast packets. If the node receives the pocket for the first time, go to Step 6.Or discards the broadcast packets and end the judgment.

Step 3: when the node is a cluster member CN, it firstly determines whether the CN has repeatedly received the broadcast packets. And if so, it discards the broadcast packet. If the node receives the packet for the first time, go to next step.

Step 4: the cluster member node CN reads the position of the last forwarding node <Position_State>. If the state is State_Intersect, CN will not forward the broadcast packets and end the judgment; otherwise the node goes to Step 5.

Step 5: CN has a traversal for the cluster head list and the neighbor list, determines the forwarding priority of the position of current nodes, which from high to low is State_Intersect, State_Nearby, State_In. Forwarding-waiting time is $\tau(i)$. The value is set according to the state of the node's location. During the waiting period, if the node receives the same packet from other member nodes, the node will give up and end judgment. Or the node goes to step 6.

Step 6: the node will reduce the value of Life_Time by 1. Modify the field <Last hop> of broadcast packet header and the field about node position<Position_State>; and then broadcast.

2): The relay node selection in intersection model

In the intersection model, the implementation steps are almost the same as the method in the segment model. For the only difference, if the node is CN, and receives the broadcast packet for the first time, it will traverse the neighbor list <Neighbor_List>. If the position state of the last relay node is in segment, the current CN transmits the data. If the position state of the last relay node is in Intersection, judge the position of the current node by a waiting time before forwarding packet.

C. Processing for network isolated node

In the vehicle network, especially in case of sparse or uneven distribution of network nodes, the characteristics of the road can easily lead to the generation of isolated nodes in the network and the emergence of the "emptiness" of the network, and thus reduce the broadcast success rate. In this regard, PCMB uses the information of the carry-forward strategy under special situation. Vehicle is set to carry time t_r after receiving the broadcast package. At t_r time, when the vehicle detects that the neighbor list is not empty, the node forwards the broadcast packet; the carry time t_r is over, then directly drop the broadcast packet and end the judgment.

After the vehicle node has received the broadcast packet, if the vehicle is in the status of the following position, the vehicle enters the carry-forward process:

1): the vehicle node detects the current cluster member list or the neighbor list is empty, that is, the node is not in the communication radius of any vehicle and it is an isolated cluster head node.

2): In the Segment Model, the vehicle is in the $State\_In$ state, the moving direction of the node is in agreement with the broadcast direction. And node is located at the front position of the boundary of the cluster.

3): In Intersection Model, vehicle is in the moving state from intersection to segment. The moving direction of the nodes is consistent with the broadcast direction. And the node is located at the top of the moving direction.

4. Analysis of Simulation Results

In this paper, we use the NS2 simulation tool to compare with the flooding broadcast and P-probability-based broadcast strategy. The packet's successful reception rate, average delay and average cost are used to evaluate the performance of network. The simulation scenarios are set as follow.

Parameter type	Parameter values
Propagation model	Two-Ray Ground
Channel	Wireless Channel
Omnidirectional antenna	OmniAntenna
Channel bandwidth	2Mbps
MAC protocol	IEEE 802.11
Communication range	150m
Node number	[50,100,150,200,250,300]
Vehicle speed	[0-25]m/s
Packet length	512 Byte
Interval time of broadcast	15s
Simulation time	600s
The number of simulation	20

Table 1: Simulation Parameter List

A. Packet reception successful rate

As it can be seen, all the three broadcast success rates are showing the trend which firstly increases and decreases then with the increasing of number of nodes. At meanwhile, the success rate of the PCMB is the highest with the average acceptance rate of 85%.

When the increased movement speed the vehicle, PCMB consider relative connectivity between vehicle nodes in network clustering algorithm and selection policy of relaying node, improving the success rate of a broadcast, therefore have a high network speed adaptability than flooding and P probability.

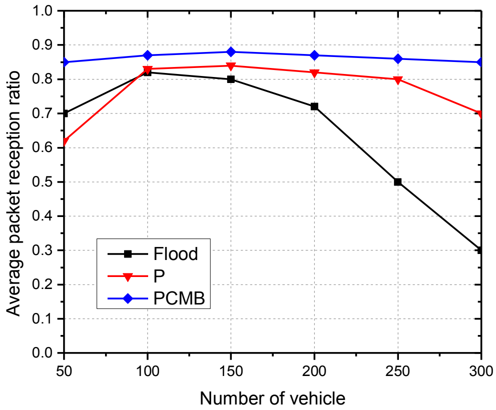

Figure 3: Different Number Nodes

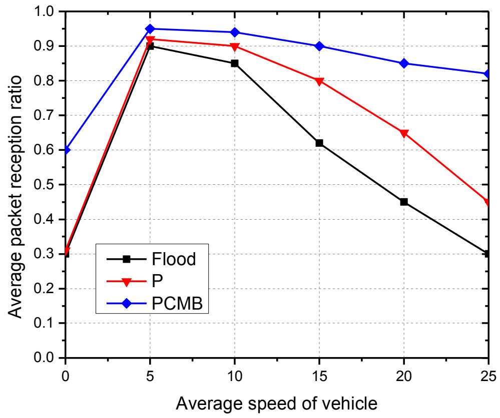

Figure 4: Different Average Speeds

B. Packet average broadcast delay

As seen from Fig. 5, when the number of network nodes is sparse, PCMB scheme has higher delay when compared to the flooding model because the scarce number of vehicles has led to the increased network segmentation and the network cavity, while PCMB is using the carry-forward strategy to improve the efficiency of the broadcast at the same time, to some extent at the expense of a broadcast delay.

C. Packet average broadcast overhead

The overhead of successfully sending a broadcast packet contains not only the overhead due to repeated broadcasts, but contains PCMB maintenance overhead for cluster during the broadcast. With the increase of number of network nodes, the cluster-based region is more stable, the cluster maintenance overhead did not increase with the number of vehicles increases, the cost of broadcasting is also maintained at a low level.

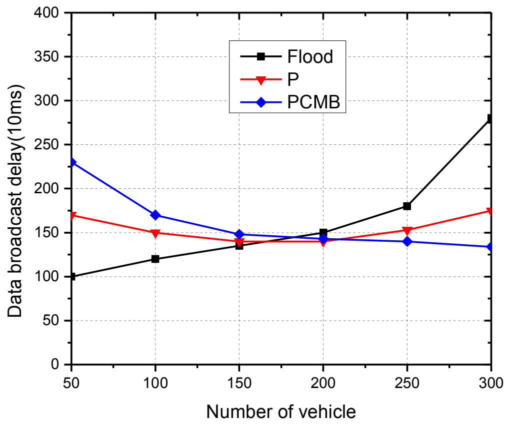

Figure 5: Packet Average Broadcast Delay

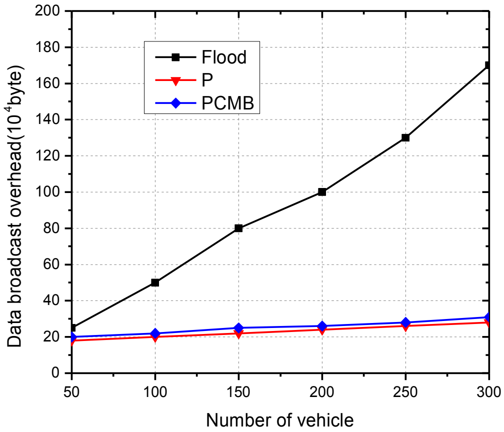

Figure 6: Packet Average Broadcast Overhead

5. Conclusion

This article has mainly surveyed partial promising clustering algorithms for VANETs. We studied every clustering algorithm including its objective, clustering metrics and performance. We also classified the algorithms according to certain criterion. The stability is highlighted in the design of the cluster algorithm. Besides, the drawbacks of the algorithms are also presented. In the future work, efforts will be concentrated on the more stable cluster-based MAC design and drivers' QoE requirement.

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