An Optimized Timer-Based Passive Clustering Algorithm for Vehicular Ad Hoc Networks

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Abstract. In order to overcome the high mobility problem of nodes in vehicular ad hoc networks (VANETs), the clustering algorithm can effectively improve the overall communication performance. This paper proposes an optimized timer-based passive clustering algorithm (OTPCA) for VANETs. Vehicles can choose to actively leave the cluster or not join the cluster based on the communication environment and performance. The vehicle can choose to communicate directly with the road side unit (RSU) and force it to remain for a timer. After the timer expires, it is re-evaluated whether it is suitable to join a cluster, and then repeat the operation. This can effectively solve the problem of node state stuck and improve the average communication performance. Simulation results show that the proposed algorithm is better then the passive multi-hop clustering algorithm in terms of average communication delay and control information transmission ratio.

Keywords: VANETs · Clustering · Timer-based · Performance evaluation

1 Introduction

In typical highly dynamic networks such as vehicular ad-hoc networks (VANETs), the vehicles in the network generally have high mobility. Clustering can be considered as an effective approach to improve routing scalability and reliability. Based on the correlated spatial distribution and relative velocity, it groups vehicles to a cluster for distributing formation of hierarchical network structures.

Cluster-based routing technology is a method for solving routing problems in mobile ad hoc networks (MANETs) and VANETs. Clustering is to divide nodes into interconnected networks called clusters [1]. Each cluster has a cluster head (CH), which is as a coordinator in the interconnected network, and it can help the data transmission and communication between the vehicle and the cluster. The traditional passive cluster algorithm (PC) has many problems, such as the communication performance of the end nodes is poor and the control information packets occupy a large amount of channels during cluster maintenance [2–5].

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This paper proposes an optimized timer-based passive clustering algorithm (OTPCA) for vehicular ad hoc networks. It retains the characteristics of no contention and less control information overhead in passive clustering. At the same time, a vehicle can periodically evaluate its own communication role through a timer. Under the high-speed changing communication environment and topology, the vehicle can maintain an independent communication state based on the timer. Firstly, it reduces the cost of cluster maintenance. Secondly, it guarantees the communication performance of the node itself.

This paper is organized as follows. Section 2 briefly introduces passive clustering and its typical problems. Section 3 introduces the optimized timer-based passive clustering algorithm. Section 4 gives the comparison and analysis of the performance evaluation results. Section 5 proposes conclusion.

2 Typical Problems of Passive Clustering Algorithm

Passive clustering mainly solves the contradiction between cluster communication and routing communication that exists in active clustering. This contradiction will generate additional communication, thereby competing for bandwidth to increase the packet loss rate, and then cause normal communication. Passive clustering enables the two system to cooperate, reducing communication requirements and competition [6]. Some recent studies have optimized the transmission of shared data packets and control information sending and processing [7, 8]. And there is active and a hybrid (active–passive) clustering technique that try to solve this problem [9].

There are also some problems of the traditional PC algorithm.

Problem 1: Vehicles broadcast and share their own information by periodically broadcasting HELLO message packets, and choose to join the cluster through priority comparison. The worst node of communication performance is the cluster end node. When the network topology changes or clusters merge to increase the number of hops, the communication quality will become very bad, mainly reflecting the node communication delay is too large. Generally, after a node joins a cluster, it will maintain its cluster member identity until the cluster dies or out of cluster head communication range. This makes it difficult for vehicles to get out of this problem.

Problem 2: When cluster heads are choosed or replaced, most of them will set hysteresis threshold to ensure the stability of clusters [10, 11]. This will make small-scale car groups unable to form clusters. Multiple vehicles may not be cluster heads, but they frequently send out control information requests to join a cluster. At the same time, because there is no cluster head, the vehicles cannot get rid of the decision state. Not only will this cause excessive control information transmission and broadcast storms, but the vehicles will also fall into a state where they cannot communicate.

Problem 3: Because of the characteristics of VANETs high-speed changes, it will cause instability of the communication link between vehicles. This feature will cause the situation where the vehicle on the edge of the cluster communication repeatedly join and exit the same cluster frequently. The result is that the edge vehicle itself cannot stabilize the communication, and it also causes a lot of control information to contend for the channel.

3 Optimized Timer-Based Passive Clustering Algorithm

3.1 System Model

Multi-hop: The algorithm take the multi-hop cluster model. When the node chooses the best node to follow, it will evaluate the hop count of the node [12]. And the node will consider the node whose hop count after connection does not exceed the limit hops. Cluster member could connect to cluster head in 1-hop or multi-hop.

Priority neighbor following strategy: Through priority comparison, the nodes will follow the strategy of the node with the most stable link in the communication range to form an affiliation. This simple following strategy makes the model algorithm easy to implement. Usually traffic density and communication quality can effectively evaluate and predict the communication performance of nodes [13, 14]. We use *PRI* to represent the priority [5], the formula is as follows. The smaller the PRI_{ij} value is, the higher the node priority is.

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

where PRI_{ij} represents the priority of node j for node i, N_{follow} represents the following degree which depends on the number of followers and neighbors, *ETXij* represents the the expected transmission count, and LLT_{ij} represents the expected link life time.

Communication routing: In this algorithm, in the entire network, the vehicles in the cluster member state cannot directly communicate with the RSU, and must communicate with the RSU through parent node and the cluster head which they belong to. The cluster head can communicate directly with the RSU or directly communicate with the members of the same cluster in the communication range. This will help to improve the integration of the cluster.

Passive: The algorithm uses passive communication technology. The vehicles do not need to through actively polling actively detect the nodes in the communication range. The node receives the information of the surrounding nodes by accepting the HELLO message packet and writes it into the information table. The node information written to the information table has an expiration date timer [15]. If the expiration date is exceeded, this information will be deleted.In this way, when the two nodes are out of the communication range and disconnected, the two nodes cannot immediately realize and react. After the information in the information table expires and is deleted, the node will not realize it. Although the node response will be delayed due to the validity period. However, the amount of control information sent by the nodes in the road network is reduced.

3.2 Cluster Head Selection

The cluster head selection is to solve how vehicles become cluster heads. Vehicles periodically send HELLO message packets to sense the communication environment and neighbors information [16]. Thus, through the priority neighbor following strategy in the system model, a general multi-hop network topology is constructed. Then, the vehicle with the best performance in the topology serves as the cluster head. The vehicle will not choose itself as a follower. So the vehicle with the best performance will also follow other vehicle first. Therefore, a recognized standard is needed to determine the cluster head. This algorithm uses the following degree [5] and the average mobility [17] to determine the cluster head. The larger the following degree and the smaller the average mobility, the more stable the vehicles and the more likely it is to become a cluster head.

$$CONDITION_{Be\ CH}(x) = \begin{cases} true \quad (N_{f\_x} > N_{f\_neighbors}) \wedge (AvgMobility_x < AvgMobility_{neighbors}) \\ false \quad Else \end{cases} \tag{2}$$

where N_f represent the following degree, and *AvgMobility* represent the average mobility.

3.3 Cluster Formation and Maintenance

The algorithm defines five communication states of vehicles in the road network [5]. Vehicles implement state switching through algorithms to match their own communication roles and complete their own communication tasks. The five communication states is defined as follow.The optimized timer-based passive clustering algorithm vehicle node state transition diagram is shown in Fig. 1, and OTPCA algorithm flow char is shown Fig. 2.

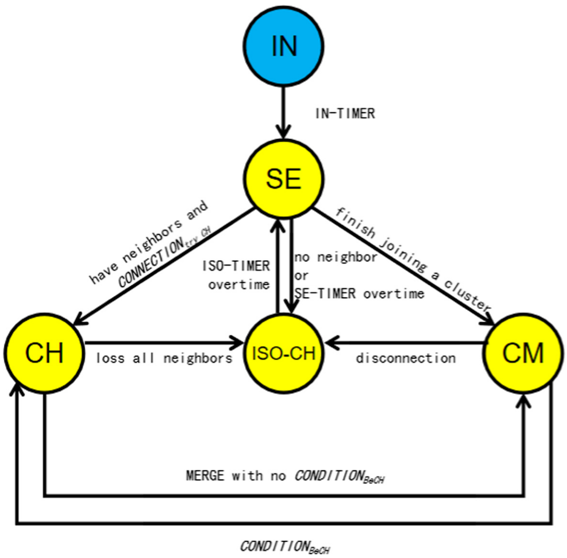

Fig. 1. OTPCA vehicle node state transition diagram

INITIAL (IN). IN is the initial state of the vehicle joining the road network, and receiving the HELLO packet of other vehicles to prepare for the SE.

STATE_ELECTION (SE). SE state will determine which state the vehicle enters.

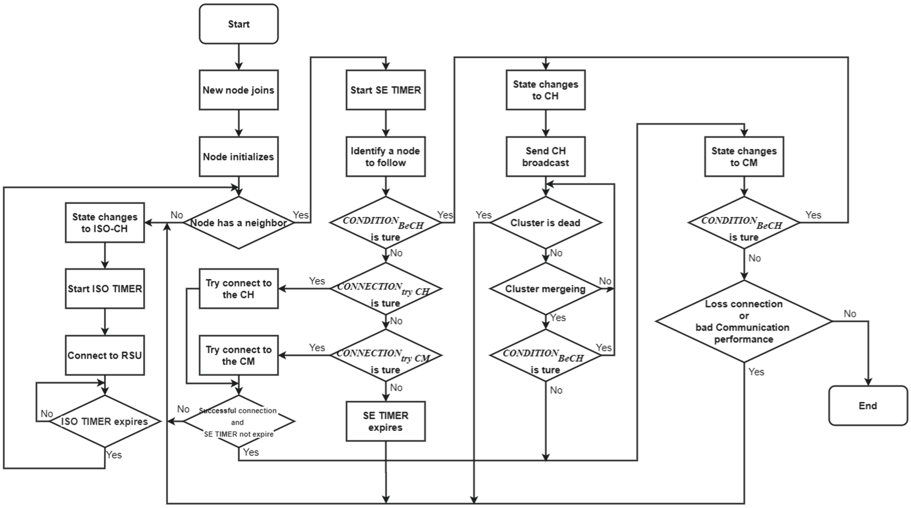

Fig. 2. OTPCA algorithm flow chart

CLUSTER_HEAD (CH). Cluster head state is similar to the role of traditional cluster head. It will manage communication between the cluster members and road side unit (RSU).

CLUSTER_MEMBER (CM). Cluster member is connected with CH in 1-hop or multi-hop.

ISOLATED_CLUSTER_HEAD (ISO-CH). The ISO-CH state is an independent node state. The node directly establishes a connection with the RSU to complete the communication task without going through the cluster.

The cluster formation depends on the change of vehicles node state. The algorithm realizes the orderly communication and state change of nodes by defining states and timers.

The vehicle first enters the IN state and starts a timer of IN. Before the timer expires, the vehicle will continue to maintain IN and continue to send and receive HELLO message packets. After the timer expires, the vehicle enters the SE state.

The vehicle entering the SE state will judge itself to enter the next state. And it will start a timer of SE. If the vehicle now has neighbors and $CONDITION_{BeCH}$ is ture, the vehicle directly enters the CH state and immediately broadcasts advertisement to announce that it becomes a cluster. If the vehicle has neighbors but does not satisfy $CONNECTION_{try\ CH}$, the vehicle will evaluate whether it is suitable for CM. At this time, if there is a cluster head in the vehicle's neighbors and meets $CONNECTION_{try\ CH}$, the vehicle will try to establish a connection with the cluster head directly. If there is no cluster head in the neighbors of the vehicle, but a vehicle in the neighbor that wants to follow meets $CONNECTION_{try\ CM}$, the vehicle establishes a multi-hop connection with the cluster head through the cluster member.

$$CONNECTION_{try\ \ CH}(x) = \begin{cases} true \quad N_{CH\ followers} < N_{\max\ \ members} \\ false \quad Else \end{cases} \tag{3}$$

$$CONNECTION_{try\ CM}(x) = \begin{cases} true & (N_{CM\ followers} < N_{\max\ members}) \wedge (Hop_{CM} + 1 \leq Hop_{\max}) \\ false & Else \end{cases} \quad (4)$$

where $N_{CH\,followers}$ represent the number of followers of the CH, $N_{CM\,followers}$ represent the number of followers of the CM, $N_{max\ members}$ represent the number of max members, HOP_{CM} represent the hop count between the CM and the CH, HOP_{CM} represent the allowed max hop count between the CM and the CH,

If the vehicle has no neighbors, it will enter the ISO-CH state. And if the vehicle does not leave the SE state after the timer SE expires, the node will also directly enter the ISO-CH state. This will solve the Problem 2. Multiple nodes that cannot be clustered due to $CONDITION_{BeCH}$ will enter ISO-CH state and normally communicate after the timer expires, without being stuck in SE.

Then nodes will switch between the three main communication states which are CM, CH and ISO-CH. Multiple nodes follow the following state transformation method to achieve cluster maintenance.

For the CH state, cluster merging may cause the node state to change from CH to CM. When two cluster heads enter communication range of each other, in order to avoid cluster group interference, the cluster groups will be merged. The node with poor performance will give up the CH state and become a follower of the other cluster head. At this time, the two clusters are merged, and the state of this vehicle will also change from CH to CM. In addition, when the CH loses all its followers, the cluster will die and the vehicle will enter the ISO-CH state.

For the CM state, when the vehicle meets CONDEION_CH compared to the following parent vehicle node, the vehicle will enter the CH state. When the vehicle is disconnected from the parent node, or when its communication performance is poor, the node will give up the CM state and enter the ISO-CH state. And this will solve Problem 1.

For the ISO-CH state, in the traditional algorithm, this state is triggered by parameter changes. It is redefined that this state is no longer triggered by whether or not vehicle nodes own a neighbor. Instead, there is an timer of ISO-CH, and the node state must maintains ISO-CH state during this timer. After the timer overtime, the state directly changes to the SE state to determine its next state. When the node is in the ISO-CH state, it still receives and sends HELLO messages packet. But the state change mechanism is no longer triggered. And nodes no longer sent join request packet to join a cluster. Nodes will communicate directly through RSU. This can effectively avoid the Problem 3. Besides, because when the SE state is changed to the ISO-CH state without neighbors, there only the decision is passed, no control information is sent, and the delay is very small. Therefore, a node that has been in an independent state for a long time under real road conditions can also maintain ISO-CH state for a long time. When there are no neighbors around the node, there is less chance of joining the cluster in a short time, and the timer can be set longer. On the contrary, there are some nodes around the node, but they cannot join clusters because of the algorithm limitation. This kind of node has chances to become a state that can join the cluster in a short time. And the timer can be set shorter.

4 Performance Evaluation

We used the SUMO version 0.30.0 traffic generator [12] and OMNeT++ 5.6 [13] in the simulation. We compared the communication performance between the OTPCA and the PMC algorithm.

The main VANETs simulation parameters setting is shown in Table 1. The vehicles speed is limited to 10 to 30 m/s, the transmission range of the vehicle is 200 m, and the IN TIMER of the vehicle is 10 s. The SE TIMER of the vehicle is set to 500 ms, which is to ensure that the node has a delay in the initial period of time in the cluster. The ISO TIMER of the vehicle is set to 20 s, which is to ensure the vehicle have good communication quality for a certain period of time, and also to allow the vehicle to enter a new communication environment after the timer expires to judge its next state again. This is to improve cluster stability, reduce cluster maintenance costs, and improve topology effectiveness. We compared PMC and OTPCA, and the three main performance indicators are: average transmission delay, Average CM duration and Cluster overhead. They can effectively evaluate communication performance of vehicles, cluster stability and channel occupancy.

Table 1. Simulation parameters

Parameter	Value
Simulation area size (m)	1000 × 1000
Simulation time (sec)	200
Number of vehicles	20–140
Transmission range (m)	200
MAC protocol	802.11p
Vehicles velocity (m/s)	10–30
Max hop	3
Max member	10
Number of lanes	Multi-lane
IN TIMER (sec)	10
SE TIMER (ms)	500
ISO TIMER (sec)	20
α, β, γ	0.3, 0.2, 0.5

Figure 3 shows the average transmission delay versus the number of vehicles. Usually the number of node hops has the greatest impact on communication delay. The OTPCA allows nodes give up the CM identity to become ISO-CH and communicating directly with RSU. Therefore, the transmission delay of such nodes is relatively low, thereby reducing the average transmission delay. It can be seen from the figure that the average transmission delay increases with the increase of the number of vehicles. In addition, it can be seen that the OTPCA algorithm is superior to the original PMC algorithm in average transmission delay. And the increase is more obvious in the case of medium traffic load. Because in the case of medium traffic load, the vehicles will encounter more problems. In the case of low traffic load, the increase is relatively small. Most nodes are always in the IN state or low-hop CM state. And most nodes have good communication performance, and most nodes will not actively leave the cluster. So the delay is low, and the difference is not obvious.

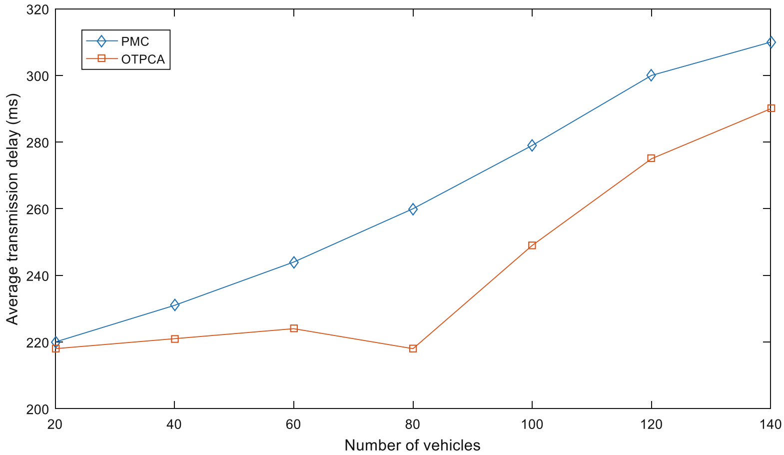

Fig. 3. Average transmission delay versus number of vehicles

Figure 4 shows the average CM duration and the number of vehicles. It can be seen from the figure that the OTPCA is smaller than the original PMC in the case of all the number of nodes situation. This is because the main idea of improving thinking is to maintain independent communication from the cluster. In some cases, the end node of clusters will voluntarily withdraw from the cluster, giving up the CM identity. Therefore, the average time for nodes to maintain CM will decrease. Similarly, in the case of medium traffic load, the CM duration is less. And the node has more opportunities to start the escape mechanism. This makes the average CM time of OPTCA lower. Compared with the PMC, the difference can be roughly estimated the extent to which the node actively exits the cluster. So the OTPCA also reduces the stability of the cluster. It is also more in the medium traffic load, and less in the low and high traffic load.

The Cluster overhead as the ratio define comes from [5]. The Cluster overhead as the radio is used to represent 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:

$$P_{overhead} = \frac{N_{contral\ packet}}{N_{all\ packet}} \times 100\% \tag{5}$$

Figure 5 shows the cluster overhead versus the number of vehicles. It can be seen from the figure that the cluster overhead increases with the increase of the number

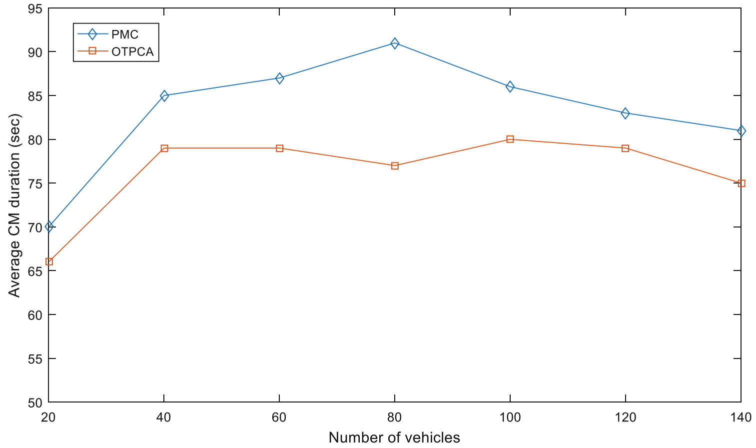

Fig. 4. Average CM duration versus number of vehicles

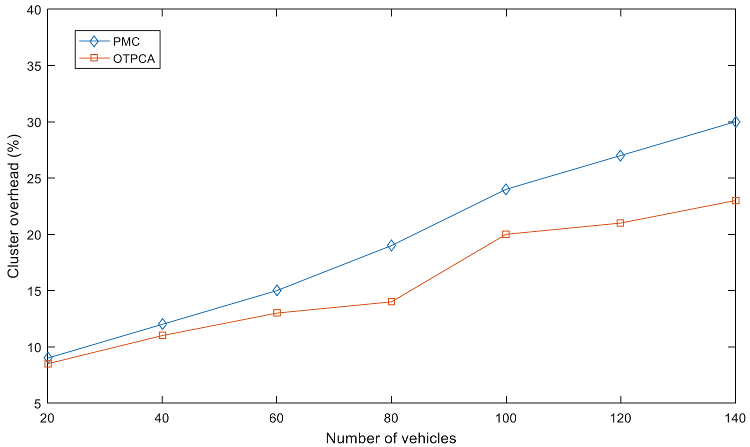

Fig. 5. Cluster overhead versus number of vehicles

of vehicles. This is because when the node density increases, the number of clusters and cluster heads increases, and there is interference between clusters. There are more cases of cluster maintenance and cluster merging, and more control information packets are sent.In addition, when the number of vehicles of the OTPCA increases, the cluster overhead gap gradually increases compared to PMC. In the case of the PMC algorithm, nodes preferentially maintain connections, so the overhead is large, especially in the case of large clusters caused by merging. However, usually the end node has a large proportion of control information packets due to the multi-hop situation. The OTPCA solves the end nodes, from CM to ISO, leaves the cluster, establishes and maintains the communication with RSU by themself. At the same time, due to the ISO TIMER, the node will not frequently change its own state, so as to avoid sending too many control information packets. Although the probability of collision is potentially increased, the overall control information transmission situation is better than the PMC for the channel.

5 Conclusion

The traditional PC algorithm lacks management of multi-hop nodes, and the communication performance of end nodes is poor. To solove these problems, an optimized timer-based passive clustering algorithm is proposed. Vehicles weighing their own communication performance can maintain direct communication mode with RSU or actively exit the cluster. The problems of PC is solved by timers based on passive technology. OTPCA evaluates and estimates the future communication performance of the node from various aspects to determine whether the node should continue to maintain the CM state or disconnect the link. When vehicles cannot join the cluster, OTPCA will make it preferentially maintain an independent state and maintain basic communication through the RSU. And evaluate the surrounding environment, set a timer to decide when to try to join the cluster. Finally, simulation results show that the OTPCA is better than the PMC in average communication delay and cluster overhead. This advantage works best at medium traffic load. At the same time, because of the mechanism, the average CM duration of the OTPCA is shorter than that of the PMC algorithm.

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