ISSN: 2454-4248
124 – 129

An Congestion Control Based Cluster Approach for Effective Communication in VANET

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Abstract: Clustering in VANET is major controlling method used to make VANET worldwide topology less dynamic. Many of the VANET clustering methods are derived from mobile ad hoc networks (MANET). In any case, VANET hubs are portrayed by their high versatility, and the presence of VANET hubs in the same geographic area does not imply that they show a similar portability designs. Along these lines, VANET grouping plans should contemplate over the level of the speed distinction among neighboring hubs to create moderately stable clustering structure. In this paper, we present another bunching system reasonable for the VANET condition on thruways with the point of upgrading the steadiness of the system topology. This method takes the speed distinction as a parameter to make moderately stable group structure. In this paper proposed to built up another multi-metric calculation for cluster head decisions. A reproduction was directed to assess our strategy and contrast it and the most usually utilized grouping strategies.

Keywords: *VANET, Routing, Security, Traffic, Cluster*

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I. INTRODUCTION

Vehicle-to-vehicle (V2V) communications are one of the most challenging. They are the only type of communication that will be available all the time, making it suitable for the most important services such as collision prevention and other safety features. On the other hand, data dissemination between vehicles can be a difficult task due to their high mobility and relatively low communication range on the 5.9-GHz band where DSRC is defined [1]. To lessen the effect of high mobility, vehicles with a similar movement pattern can be grouped together in clusters.

Clustering is a process of grouping elements with similar properties in clusters and can be used in many different fields. One of the uses is also in the wireless *ad hoc* communications where clustering is used to make the network appear more stable on the logical level, providing solid foundation for upper layer protocols. Wireless *ad hoc* networks are further divided into different categories, such as mobile, wireless sensor, and vehicular, each category with its own specifics. These specifics are the reason that algorithms designed for one category do not scale very well when used in another. For vehicular *ad hoc* networks (VANET), the specifics are the high speed of nodes that are obliged to move according to traffic regulations and the relatively unconstrained energy and computing resources[2].

Designing a good clustering algorithm for VANET is a challenging task due to the variety of situations where vehicles are present. Highways and city centers, congestions, and empty roads, etc. all influence the communication parameters, but clustering should provide decent performance for all of them. However, because clustering is one of the fundamental parts of V2V communications, dependence on other services such as positioning should be avoided to prevent compromising the communications in case of unavailability of the other services.

Many clustering algorithms for VANET have been proposed in the recent years [3], of which the majority are Global Positioning System (GPS) based, with the main goal of stabilizing the clusters and minimizing the number of cluster heads. We took a different approach and set the goal of increasing connectivity and lowering the number of disconnects, thus providing better usability of the V2V communications. We designed a new clustering metric based on beacon frames sent between vehicles that exposes the vehicles' similarity in movement from the communication point of view. This metric is used in the proposed clustering algorithm, which requires each node to be connected with two cluster heads to improve the connectivity. The working principle of this algorithm is also inverted, so unneeded cluster head elimination is used instead of cluster head election.

Figure 1 Vehicular Ad hoc Network.

This paper offers the following original contributions. Firstly, we propose an improved vehicle interconnection metric that exposes the similarity of vehicles' movement pattern in time without using positioning services. Secondly, we propose a tightly coupled variant of the clustering protocol based on the interconnection metric. Thirdly, we provide a mathematical analysis of the clustering protocol's overhead. Fourthly, we prove the overhead analysis with simulation results. Last but not the least, we compare the performance of our clustering solution to the MOBIC [4] clustering protocol.

In [5], the authors proposed the cluster-based location routing (CBLR). Nodes use HELLO messages to distribute their states. When a node enters the system, it enters the undecided state and then announces itself as a CH if it does not receive a HELLO message within a period of time from other nodes; otherwise it registers at a CH as a member node. To cope with the VANET topology changes, nodes maintain a table containing a list of the neighboring nodes with which they can exchange information. The protocol mainly focuses on improving routing efficiency in VANET. The nodes are supposed to know their position and the position of their destination and therefore, the packets are forwarded directly toward the destination.

In [6], the authors adopted the same algorithm used in the CBLR for the cluster formation. Nodes can be members in more than one cluster. In this case they are called Gateways and used to route packets to their destination. Nodes track changes in the topology and adapt their states to the situation using two tables; one for the neighboring nodes and the other one for the adjacent clusters. When two cluster heads come into a direct communication range, one should give up its cluster-head role and merge with the other. The decision about which one keeps its state and which one loses its CH role is based on a weighted factor W_v, which takes into consideration the mobility, the connectivity, and the distance to the neighbors. These parameters are multiplied by their given weights and then summed to produce the total weight W_v. The smaller the W_v, the more qualified the node is to become a cluster head. The work also focuses on the media access control in the cluster-based VANET environment to improve the QoS support. The time division multiple access (TDMA) technique is used to divide the medium into time slots, which are then grouped into frames. The time slots are assigned to cluster members according to their needs.

Another clustering algorithm was proposed in [7]. The proposed algorithm is basically the lowest ID used in MANET with a new modification. The authors included the leadership duration as well as the direction in the lowest ID algorithm to determine the node to be a cluster head. The leadership duration (LD) is defined as the period the node has been a leader since the last role change. The higher the leadership duration, the more qualified the node is to be a cluster head. Therefore, the cluster-head rule is: choose the node with the longest leadership duration and then choose the one with the lowest ID. The formation of clusters is based on beacon signals broadcasted by the VANET nodes. Each node announces itself as a cluster head and broadcasts this to all neighbors. If it receives a reply from a neighboring node with a lower ID and a higher leadership duration, then the node changes its state to a cluster member. When a node leaves its cluster, it looks for another cluster in the neighborhood to join. If none of the neighboring nodes or the neighboring cluster head satisfy the cluster head election rules, then the node claims itself as a cluster head.

The work in [8] was modified and presented in [9]. In addition to the LD and the moving direction (MD), the authors introduced the projected distance (PD) variation, which means distance variation of all neighbors over a period of time. Each node is associated with a utility weight (uW) of three parameters (LD, PD, and ID), where the ID is the identifier of the node. The LD parameter is given the highest weight. To define the total utility weight, a lexicographical ordering of the three parameters (LD, PD, and ID) is used. For example, the utility weight (LD1, PD1, ID1) is greater than (LD2, PD2, and ID2) if either LD1 > LD2 or (LD1 = LD2 and PD1 < PD2) or (LD1 = LD2 and PD1 = PD2 and ID1 < ID2). Based on this, the LD value has maximum importance and its value is the primary factor to determine the total uW. However, in both works [10, 11], the node that has higher connectivity degree might not be elected to lead the cluster if there is another node that has longer leadership duration. This will produce less stable cluster structure, because having longer leadership duration does not mean that the node has high connectivity degree that gives it the ability to lead the cluster.

In [12], the authors proposed a distributed cluster-based multi-channel communications scheme for QoS provisioning over V2V-based VANET. The goal is supporting the QoS for timely delivery of the real-time data (e.g., safety messages, road condition, etc.) and increasing the throughput for the non-real-time traffic over the V2V networks. The formation of the clusters is implemented using the traditional algorithms mentioned earlier, e.g., when a vehicle enters the road, it checks for nearby clusters to join. If there are no clusters, then the vehicle announces itself as a cluster head and forms a new cluster. The cluster merging can happen only when two cluster heads come within the transmission range of each other. The cluster with less members is dismissed and its cluster head joins the neighboring cluster, while the other members start cluster formation process if they cannot join any nearby clusters. The proposed scheme assumes that each vehicle is equipped with two sets of transceivers, which can operate simultaneously on different channels. The cluster members use one transceiver to exchange safety messages and stay connected with the cluster head over the service channel; and use the other one to communicate with other members to exchange non-safety data. The cluster head communicates with its members via the service channel using one transceiver; and uses the other one to communicate with the neighboring clusters via the control channel.

In [13], the authors proposed a heuristic clustering approach for cluster-head elections that is equivalent to the computation of the minimum dominating sets (MDS) used in graph theory. This approach is called position-based prioritized clustering (PPC) and uses geographic position of nodes and the priorities associated with the vehicles traffic information to build the cluster structure. For clustering purposes, each node is assumed to broadcast a small amount of information of itself and its neighbors, which is referred by five tuples (node ID, cluster-head ID, node location, ID of the next node along the path to the cluster-head, and node priority). A node becomes a cluster-head if it has the highest priority in its one-hop neighborhood and has the highest priority in the one-hop neighborhood of one of its one-hop neighbors. The priority of the node is calculated based on the node ID, current time and the eligibility function. A Node having longer travel time has higher eligibility value, and this value decreases when the velocity of the node deviates largely from the average speed.

II. CLUSTERING PROCESS AND PROTOCOL STRUCTURE

The inter-vehicle communication (IVC) operates in the 5.9 GHz band to support safety and non-safety applications. The dedicated short range communications (DSRC) uses 75 MHz bandwidth (5.850-5.925 GHz) which is divided into seven channels. One of the channels is called the control channel, and the remaining six are called service channels. Vehicles are assumed to utilize the control channel to exchange periodic messages and gather information about their neighborhood, and use one service channel to define the cluster radius and perform all intra-cluster communication tasks. According to the DSRC specifications, the data link layer can provide a transmission range of up to 1,000 m for a channel. VANET applications can use a longer range, R, for the control channel so that a cluster-head can communicate with neighboring cluster-heads for safety message disseminations, and a shorter range, r, for a service channel that is used for intra-cluster managements. Using the control channel, vehicles can gather status information of other neighboring vehicles and then can build a complete picture about their neighbors which can even go beyond the cluster boundaries.

Since in our technique, slower vehicles will be in one cluster and faster vehicles will be in a different cluster, we can start the cluster formation process either from the slowest or fastest vehicle. For example, if we start with the slowest vehicle, then all the neighboring vehicles of this slowest vehicle that satisfy the speed threshold will be in the first cluster. The remaining vehicles will then go through the same cluster formation process to create other clusters. By extracting the velocity data embedded in the periodic messages, any vehicle can determine whether it has the *slowest velocity* among all its neighbors within R communication range. The *slowest vehicle*, in our method, is supposed to initiate the cluster formation process by sending a cluster formation request and *only* its stable neighbors participate in this process. The neighboring vehicles whose relative velocity, with respect to the slowest vehicle, is greater than the threshold, Δv_{th}, will not be grouped in the same cluster.

III. NEIGHBORHOOD RELATIONSHIP

The neighborhood term is directly associated with the transmission zone of the node. But, the DSRC is a multi-channel interface with different transmission ranges. Therefore, the neighborhood term needs to be re-defined according to the channel being used for the communications. To illustrate this, consider Figure 1 in which three vehicles l, m and n are located within geographical area. For node l, node n is considered a neighbor from the perspective view of the control channel, but not a neighbor from the perspective view of the service channel because the distance to l is greater than r which is the maximum range of the service channel. Node m is considered a neighbor from the perspective view of both service and control channels.

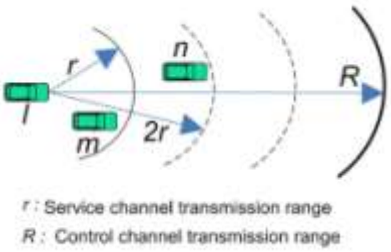

Figure 2 Illustration of the neighborhood relationship of a given node.

The cluster formation algorithm

Algorithm 1 Initiating clustering process

if ($\Lambda(t)$ is empty)‖($\Lambda(t)$ members ∈ other clusters) **then**
  $\mathrm{CID}_{tmp} \leftarrow v_i$.id
  send Initiate Cluster(CID_{tmp})
end if

Algorithm 2 CH competition and determination

if $v_j \in \Gamma(t)$ **then**
  On Receiving InitiateCluster(CID_{tmp})
  v_j.CID ← CID_{tmp}
  v_j.Suitability() //w.r.t its r-neighbors that ∈ $\Gamma(t)$
  $v_j.T_{wait} \leftarrow v_j$.DeferTime() //calculate the waiting time
  while $v_j.T_{wait} > 0$ **do**
    if FormCluster(CH_{id})isreceived **then**
      if received $\mathrm{CH}_{id} \in \Gamma(t)$ **then**

```
        QuitCompetition()           //give up CH competition
          Process FormCluster(CH_id)          //process received message
      end if
    else
      Decrement v_j.T_wait
    end if
end while
v_j.STATUS ← CH
CH_id ← v_j.id      //v_j declares itself as a CH
v_j.CID ← CH_id      //v_j sets its cluster id
Send FormCluster(CH_id)     //sends its cluster id to all vehicles
end if
```

IV. CONGESTION CONTROL APPROACHES WITHIN MANETS

Congestion control is a challenging subject in mobile ad hoc networks, mainly because of the shared nature of the wireless multihop channel and the frequent changes of the network topology. Indeed, routes changes due to dynamic and mobility of nodes result in unsteady packet delivery delays and packet losses, which should not be considered as congestion control faults. In addition, the use of a shared multihop channel allows only one data transmission at a time within the interference range of a node. Thus, congestion in ad hoc networks affects a whole area and not only overloaded nodes [4]. During the last years, several congestion control approaches have been presented, dedicated to operate within ad hoc networks. In this section, we cannot claim to present an exhaustive study of these approaches. However, we distinguish two congestion control techniques for wireless networks: end-to-end and hop-by-hop families. End-to-end protocols aim to ensure flows fluidity between senders and receivers, without worrying about the internal relay nodes, whereas hop-by-hop congestion control methods take into consideration the capacities of the internal links.

V. INTER CLUSTER COMMUNICATION

An essential part for multi-hop VANET communication is inter cluster communication, and many clustering algorithms fail to address this challenge while striving to minimize the number of cluster heads and maximize their lifetime. The majority of the proposed algorithms create non-overlapping clusters and as a consequence, cluster heads are unable to communicate directly one to another. This limitation is then handed over to the routing protocol or solved by defining cluster gateways. These gateways are nodes in the communication range of two or more cluster heads, but their behavior is commonly quite undefined and unpredictable which affects the link stability.

As shown in Figure 3, there might be more possible cluster gateways between two cluster heads, but usually there is no defined rule on what basis to choose the gateway in any specific moment or for a specific task. Every node, including the cluster heads themselves, requires connectivity with two other cluster heads, so no explicit gateways are needed. This implies a larger number of cluster heads compared to other algorithms, but on the other hand it simplifies network management and provides better scalability.

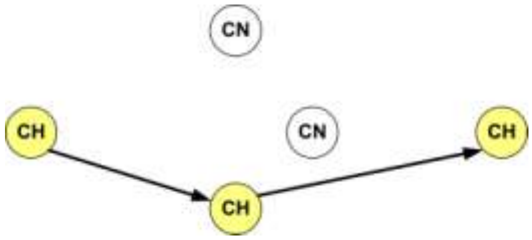

Figure 3 Data forwarding with direct cluster head to cluster head communication

The evaluation of both algorithms is done using the following metrics:

- The *average cluster head duration* shows how long a node stays in the cluster head state. The longer the time, the more stable the clusters. Because our algorithm strives to connect a node to two cluster heads instead of one, as in the case of MOBIC, the resulting values are divided by two to allow for a fair comparison.
- The *average number of full connectivity loss per node* shows how many times a node gets disconnected from the network. This happens when a node loses the connectivity to all of its cluster heads and needs to reconnect. A change of one cluster head in our algorithm is not interpreted as full connectivity loss, because the node stays connected to the other cluster head. Because the connectivity is one of the main goals of our algorithm, this metric plays an important role.
- The *average number of role switches per node* shows how many times a node switches its role from cluster head to cluster member and *vice versa*. This relates to cluster stability and the lower the number, the more stable the clusters. Because all the nodes in our algorithm begin as cluster heads, the numbers are not directly comparable to MOBIC, so the results are only compared between different runs of our algorithm.
- The *protocol overhead* was also measured for our algorithm to check the validity of the mathematical proof. This also exposes the influence of different vehicle densities on the protocol overhead.

VI. CLUSTER MAINTENANCE

Due to the high dynamic nature of the VANET, vehicles keep joining and leaving clusters frequently, thus, causing extra maintenance overhead. The events that trigger the maintenance procedure can be summarized as follows:

A. *Joining a cluster:* when a standalone (non-clustered) vehicle comes within *r* distance from a nearby cluster-head, the cluster-head and the vehicle check whether their relative speed is within the threshold $\pm \Delta v_{th}$. If the speed difference is within $\pm \Delta v_{th}$, then the cluster-head will accept the vehicle and will add it to the cluster members list. If there are more than one cluster-heads in the vicinity that can be joined, the vehicle calculates the time, RT, it will remain in the transmission range *r* of these cluster-heads. The vehicle joins the cluster-head where it will stay for the longest period of time. The RT could be computed from the information about the relative speed, current location, and the transmission range *r* as follows:

   a. If the standalone vehicle is following the cluster-head and its velocity at time *t* is less than that of the cluster-head, then

B. $RT(t)=r-dis(n,CH)\Delta v$

C. Where Δv is the speed difference, and dis(*n*,*CH*) is the distance between the standalone vehicle, *n*, and the cluster-head, CH. The above formula can also be used when the standalone vehicle is followed by the cluster-head but its velocity is greater.

   a. If the standalone vehicle is following the cluster-head and its velocity at time *t* is greater than that of the cluster-head, then

$RT(t)=r+dis(n,CH)\Delta v$

This formula can also be used when the standalone vehicle is followed by the cluster-head but its velocity is less.

- *Leaving a cluster:* when a cluster member moves out of the cluster radius, it looses the contact with the cluster-head over the service channel, *r*. As a result, this vehicle is removed from the cluster members list maintained by the cluster-head. The vehicle changes its state to a standalone if there is no nearby cluster to join or there is no other nearby standalone vehicle to form a new cluster according to our cluster formation algorithm.
- *Cluster merging:* when two cluster heads come within each others transmission ranges and their relative speed is within the predefined threshold Δv_{th}, the cluster merging process takes place. The cluster-head vehicle that has less number of members gives up its cluster-head role and becomes a cluster-member in the new cluster. The other cluster members join that neighboring cluster if they are within the cluster-head's transmission range and the speed is within the threshold. If there is any other nearby clusters, then vehicles calculate their RT and join the cluster where they can stay for the longest period of time. Finally, vehicles that cannot merge with the cluster nor can join a nearby cluster, start clustering process to form a new cluster according to our algorithm.

VII. CONCLUSION

VANETs are characterized by high node dynamics. Therefore, clustering methods should be designed to adapt to the VANET environment. These methods should take into account all vehicle dynamics. In this paper, we proposed a new VANET cluster formation algorithm that tends to group vehicles showing similar mobility patterns in one cluster. This algorithm takes into account the speed difference among vehicles as well as the position and the direction during the cluster formation process. After conducting a simulation experiment, we observe that our technique groups fast moving vehicles on the fast speed lanes in one cluster, while slow moving vehicles in another cluster. The simulation results show that our proposed algorithm increases the cluster lifetime and reduces vehicle transitions between clusters. The results show that our technique significantly increases the stability of the global network topology by reducing the rate at which clusters are created

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