DCEV: A Distributed Cluster Formation for VANET Based on End-to-End Realtive Mobility

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***Abstract*— This paper presents a distributed clustering algorithm, called DCEV, which constructs multi-hop clusters. DCEV places vehicles into non-overlapping clusters which have adaptive size based on their relative mobility. The cluster formation is based on a D-hop clustering scheme where each node selects its cluster head in at most D-hop distance. To create clusters, DCEV uses a new metric to let vehicles choose the most stable route to their desired cluster head within their D-hop neighbourhood. For this purpose, each node calculates the mean relative mobility value of each discovered route (end-to-end relative mobility). DCEV considers the route which has the least end-to-end relative mobility as the most stable route. Extensive simulations were conducted for different scenarios to validate the performance of DCEV clustering algorithm. Results show that DCEV efficiently manages to build stable clusters.**

Keywords—clustering; vehicular ad-hoc networks; cluster stability; multi-hop; vehicular cloud; cloud formation

I. INTRODUCTION

In VANETs, vehicles communicate with each other in order to enable new services, such as traffic management, accident avoidance and resource sharing [1]. Dense and high dynamic network topologies are characteristics of VANETs which make it challenging to perform resource sharing, routing functions and bandwidth reservations.

Clustering of vehicles provides better scalability for resource sharing and routing functioning in VANETs by grouping nodes[1] in a geographic vicinity together. However, clustering can also improve communication efficiency by making network management easier [2]. Re-clustering causes problems, such as data loss and increasing clustering/routing overhead. Therefore, it is necessary to design clustering schemes which provide the lowest possible cluster changes. Stability of a cluster needs to be evaluated to have predictable network performance. Stability can be evaluated by measuring: (1) the time cluster heads (CHs) remain in their role of managing clusters; (2) the time cluster members (CMs) remain within their clusters; (3) the changes in CHs [3].

Different clustering methods have been proposed in VANETs [2]. However, most of these methods propose one-hop clustering schemes where CHs and CMs are within direct communication range of each other [2, 4]. The small coverage of one-hop clusters requires inter-cluster communication between CHs; this increases communication cost and decreases routing efficiency. A multi-hop cluster increases the cluster coverage area and decreases the number of clusters (CHs subsequently) [3]. In multi-hop clusters, CMs have the possibility to communicate with their CHs, through other neighbours which belong to the same cluster. This provides the possibility to CMs to remain in the same cluster even if their movement may change the cluster topology.

In this work, we propose DCEV, a clustering algorithm based on D-clustering [5, 6]. In general, in D-clustering algorithms, CHs construct dominating sets, where each node has a maximum D-hop distance to its CH. In the context of high mobility of vehicles, we propose using relative mobility between neighbouring nodes for constructing D-hop clusters. To determine relative mobility, each node calculates the difference between its speed and location, and those of its neighboring nodes. We assume that each vehicle uses WAVE standard [1] and therefore access to its one-hop neighbours' mobility information through broadcasted periodic beacons. In DCEV, each node discovers all its D-hop neighbours. This D-hop neighbours' discovery, allows to calculate routes to possible CHs that are at most D-hop far away. For a node to be considered in route calculation, relative mobility between each neighbouring nodes should be below a threshold. After all routes have been calculated by a node, the later chooses its CH to be a node which is at most D-hop away, in the most stable route. Stability of a route is considered by DCEV, to be the average relative mobility of all edges of the route.

The rest of paper is organized as follows. Section 2 presents related work. Section 3 describes DCEV in detail. Section 4 evaluates DCEV through extensive simulations. Section 5 concludes the paper.

[1] Hereafter, we use the terms node and vehicle interchangeably.

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II. RELATED WORK

The vast majority of existing clustering schemes have been designed for mobile ad-hoc networks. However, the high mobility and abundant energy resources of vehicles, give VANETs particular characteristics which make most of those schemes not suitable for their particular context. Some specific characteristics of vehicular networks, such as predictable movement pattern (i.e. road networks), can be used to develop more suitable clustering schemes. In general, proposed clustering schemes in VANETs use parameters, such as position, velocity, movement pattern, vehicles density, radio propagation strength and degree of connectivity [2] to construct clusters. However, most of these VANETs clustering schemes construct only one-hop clusters [4, 7, 8]. For example, Dynamic Clustering Algorithm (DCA) [7] uses a specific mobility metric, called spatial density (SD), to construct clusters. SBCA [4] is a clustering algorithm which uses relative mobility as a clustering metric. In SBCA, cluster stability is addressed by providing, for each primary CH, a secondary CH which is used when the primary CH is not available (e.g. left the cluster). Hang et al. [8] propose a clustering algorithm that uses the movement direction of vehicles as a clustering metric.

Multi-hop clusters can provide better cluster stability; indeed, a cluster's wide coverage area makes it possible for CMs to stay within the same cluster even if the topology changes. Routing efficiency, smaller overhead, and smaller maintenance cost are other improvements which can be achieved by using multi-hop clusters rather than one-hop clusters.

HCA [9] is a fast randomized 2-hop clustering algorithm where clustering optimization is postponed to the maintenance phase. The algorithm does not consider mobility of vehicles for clustering. Modified DMAC [10] is a multi-hop clustering algorithm which considers direction of vehicles as a clustering parameter. However, clusters constructed by DMAC are not very stable because the algorithm overlooks mobility information. Zhang et al. [3] propose a multi-hop clustering algorithm which uses relative mobility as a metric. For this purpose, each vehicle aggregates and broadcasts the calculated beacon delays from N-hop neighbors. The node with the least aggregated delay selects itself as CH. VMaSC [11] is similar to the clustering scheme proposed Zhang et al. [3] with some differences. For example, in VMaSC, a vehicle selects itself as CH if it has the least mobility (aggregated speed differences) with neighboring vehicles within D hop. VMaSC achieves better performance compared to the scheme proposed by Zhang et al. [3]. Another D-hop clustering scheme that has been proposed is DHCV [12], which allows each node to choose CH based on relative mobility calculation within D-hop neighbors. In DHCV, each node starts clustering by choosing a one-hop neighboring node with the least relative mobility. Then, it chooses the 2nd hop node which has the least relative mobility with the first one-hop neighbor. This procedure continues for D hop. Simulations show that DHCV achieves better stability and much less overhead compared to VMaSC. In this paper, we compare DCEV to DHCV in terms of clusters' stability.

III. PROPOSED SCHEME

In this section, we present DCEV, a D-hop distributed cluster algorithm for VANETs based on end-to-end relative mobility.

A. *Cluster formation:*

We assume all vehicles send beacon messages with their neighboring vehicles, based on WAVE standard. In DCEV [12], each vehicle looks for a CH which is at most D-hops away. DCEV will construct variable size clusters depending on relative mobility conditions between neighboring vehicles. For clustering purposes, each node first calculates relative mobility with one-hop neighboring vehicles. To calculate relative mobility, we use the same metrics defined in DHCV, and as shown in Eq. 1 to Eq. 7 bellow. A vehicle calculates relative mobility with its neighbors based on their speed and location differences as in Eq. 7. Information about neighbors' speed and location is obtained from received beacon messages. After calculating relative mobility, each vehicle discovers routes comprising up to D-hops. Then, the vehicle computes end-to-end relative mobility for each route. Here, end-to-end relative mobility stands for the mean value of relative motilities on each route. The vehicle compares end-to-end relative mobility of routes and selects the route with the least value. The selected route is considered the most stable route for DCEV. Once the vehicle has made the route selection, it proceeds to select a CH in that route. For this purpose, the node selects a node (including itself), from the selected route, which has the highest degree of connectivity. If there are two or more nodes with the highest degree, the node selects the one which has the minimum deviation from the average speed of vehicles on the route. Since, in DCEV, each vehicle needs information about speed of vehicles in the selected route, and also relative mobility calculated by each vehicle in the route, in order to select CH, this information is piggybacked in beacons exchanged among vehicles.

The process described above, is the general process for route and CH selection. However, Similar to DHCV [12], some exceptions apply as follows:

<u>Exception 1</u>: If a vehicle selects a route, which a) comprises a node which has already been chosen as a CH (called CH_j) by another vehicle, and b) CH_j is closer (in hops) than the CH calculated by the general process for CH selection, then CH_j is chosen as the CH for the current vehicle.

<u>Exception 2:</u> If a vehicle selects a CH (called CH_i) , and CH_i has already chosen another CH for itself (called CH_j), then CH_j will be chosen as CH for the current vehicle, provided that CH_j is at-most D-Hops away. Else, the vehicle choses CH_i as its CH, as determined by the general process for CH selection. Furthermore, CH_i selects itself as its own CH (reverting its previous choice of CH_j as its CH).

<u>Exception 3:</u> If a vehicle ends up selecting itself as its own CH, based on the general process for CH selection, and no other vehicle selects it as CH, then the vehicle choses as CH, the CH (called CH_j) of the neighbor with the least relative mobility, provided that CH_j is at most D-hops away. Else, the vehicle selects itself as its own CH, as previously determined by the general process for CH selection.

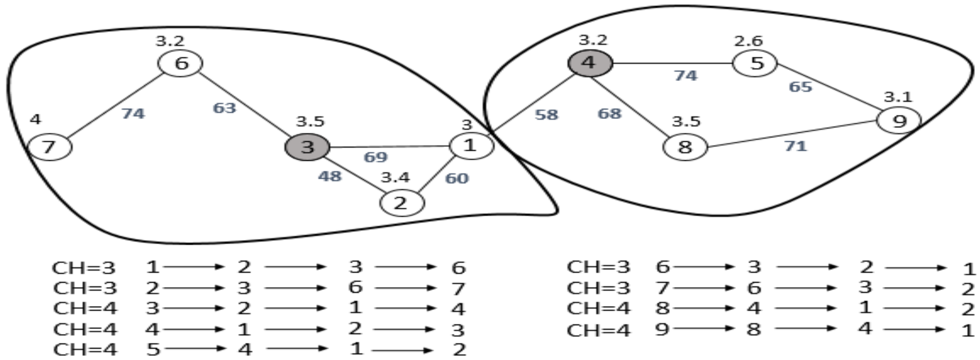

Figure 1 Cluster formation using DCEV (D=3).

Fig. 1 shows a clustered network using DCEV. In Fig. 1, nodes represent vehicles, and DCEV constructs D-clusters, with D being 3. The number on the top of each node represents the normalized speed. The normalized relative mobility is shown under each link (i.e. edge) between two nodes. After the DCEV execution, two clusters are constructed, where nodes 4 and 3 were selected as CHs. The route selected by each node is shown on the Fig. The CH selected by each node (from 1 to 9) is also shown beside that node. For example, let us consider node 3. Node 3 discovers all 3-hop routes originating from itself based on relative mobility and speed information received from nodes which are at most 3-hops away. Node 3 first calculates end-to-end relative mobility of each route and selects the route with the least value. Here that route is "3→ 2 → 1 → 4". After route selection, node 3 looks for the nodes with the highest degree, among all nodes in the route, to select its CH. Two nodes have the highest degree: node 3 and node 4. Node 3 chooses node 4 as its own CH, because node 4 has the least deviation from the average speed of vehicles on the route. However, after node 7 proceeds to route and CH selection, it selects node 3 as CH. Since node 3 has already selected another CH for itself (node 4), node 7 considers choosing node 4 as its CH. Node 4 is more than 3 hops away from node 7. Therefore, node 7 keeps node 3 as CH. Additionally, node 3 selects itself as its own CH, thereby reverting its previous CH choice (node 4) (Exception 2).

B. *Cluster maintenance:*

Each vehicle executes DCEV at the beginning of each Renewal Interval (RI) [12]. RI is a value that is predefined for each vehicle. Maintenance is performed at the beginning of each Examine Interval (EI) [12]. For maintenance purposes in DCEV, each node examines whether the route to its selected CH is still viable (the node can still reach the CH). During EI, RI and EI values can be determined empirically.

C. *Mobility metrics:*

We use the same metrics that were defined in [12] to calculate relative mobility. Each vehicle calculates the speed and location differences with its one-hop neighbor vehicles and adds these differences together (Equation 7). Relative mobility can be represented as a weight (of link) between two nodes. Whenever the weight is smaller, the link is considered stronger and more stable by DCEV. Vehicles broadcast the calculated relative mobility to their D-hop neighbor vehicles.

To calculate location differences, each vehicle *X*, follows the Equation (1).

$$D_{XY_t} = \left|G_{X_t} - G_{Y_t}\right|, \text{ where } Y \in N(X) \quad (1)$$

$$D_{XYN_t} = \frac{D_{XY_t}}{CD} \quad (2)$$

Where *Y* represents one of the neighboring vehicles of *X*. G_{X_t} G_{Y_t} are the locations of node *X* and *Y* at time *t*, respectively. D_{XYN_t} is the normalized location differences. Here, we define *CD* as the communication range.

Vehicle *X* calculates the speed differences with vehicle *Y* (one of neighboring vehicles) as formulated in Equation (5).

$$\overline{V}_{X_t} = V_{X_t} COS\theta \quad (3)$$

$$\overline{V}_{Y_t} = V_{Y_t} COS\theta \quad (4)$$

$$\overline{V}_{XY_t} = \left|\overline{V}_{X_t} - \overline{V}_{Y_t}\right|, where\ Y \in N(X) \quad (5)$$

$$\overline{V}_{XYN_t} = \frac{\overline{V}_{XY_t}}{LSR} \quad (6)$$

Where $\overline{V}_{X_t}$ and $\overline{V}_{Y_t}$ are speed vectors of node *X* and *Y* at time *t*. θ is the speed vector angle between *X* and *Y*. $\boldsymbol{\overline{V}_{XYN_t}}$ is the normalized speed difference. *LSR* is the permitted speed differences on the road (between highest and lowest).

A vehicle is able to calculate relative mobility after having the speed and location differences. The relative mobility between vehicle X and Y can be calculated as:

$$RM_{XY_t} = \alpha D_{XYN_t} + \beta \overline{V}_{XYN_t}, where\ Y \in N \quad (7)$$
$$\alpha + \beta = 1$$

Where α and β are weights to give equal importance to the location and speed differences.

IV. NUMERICAL RESULTS

The performance evaluation of DCEV is performed via simulations using SUMO [13]. The simulation scenario consists of four highway lanes. Simulation parameters are listed in Table 1. We consider a vehicular network of 30 vehicles where the maximum speed of vehicles varies from 10 to 40 m/s. The maximum allowed number of hops (D) is varied from 2 to 4 hop.

In the simulation, vehicles take into account safety distance for their maneuvers, and can take overtaking decisions based on the several parameters such as acceleration, deceleration and density of vehicles.

In the simulations, we compare DCEV to DHCV [12]. DHCV is a distributed clustering scheme defined for VANETs. In DHCV, each vehicle selects its CH by choosing relay nodes based on relative mobility calculations within its D-hop neighbors. DHCV demonstrated better cluster stability, and less overhead than other multi-hop distributed clustering algorithms for VANETs [12].

We used three metrics to measure the stability of the constructed clusters: (1) Average CM duration, which is the average time duration that CMs stay connected to their corresponding CHs; (2) Average CH duration which is the average time, from when a vehicle becomes CH, to when it leaves the role; (3) CH changes, which is number of changes from CH to CM roles during the simulation time.

Table 1 Simulation parameters.

Parameters	Value
Simulation Time	300 s
Number of vehicle	30
Mac and Physical	802.11P
Maximum speed	10- 40 m/s
EI	20 s
RI	150 s
Transmission Range	300 m

A. Cluster head duration

CH duration is one of the metrics which can be used to measure cluster stability. The average CH duration of DCEV for different values of D and speeds of vehicles is shown in Fig. 2. We observe that the average CH duration decreases as the speed increases. This can be explained by the fact that as vehicles move faster, the topology changes increase which makes it difficult for CHs to keep their roles. We also observe that CH duration increases by increasing D value from 2 hop to 4 hop. As D value increases, the clusters get larger, thereby comprising more CMs. Therefore, during cluster maintenance, CMs, have a higher probability to reach the CH through other CMs. Therefore, CHs can maintain their role for longer periods. CH duration results of DCEV outperform those of DHCV. In DHCV, each node selects the route to its CH by choosing a node in the first hop which has the least relative mobility. Conversely, DCEV checks all of the originating routes and calculates the end-to-end relative mobility to select the most stable route.

Not only the average duration of CH role in DCEV is better than that of DHCV, but also when DHCV changes CHs, it might uses secondary CHs whenever primary CHs are no longer reachable (to avoid extra overhead). Secondary CHs might not be the best choice in terms of cluster stability. Therefore, the duration of their role might be shorter.

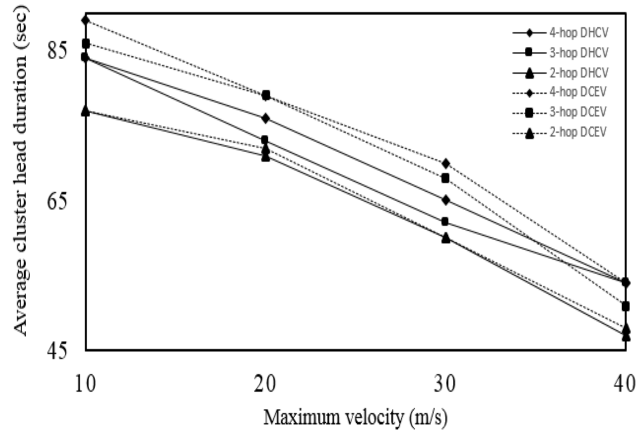

Figure 2 Average cluster head duration.

B. Cluster member duartion

Fig. 3 shows the average CM duration for different values of D. CM duration is also a metric to evaluate the stability of constructed clusters. As shown in the Fig., CM duration increases as D value increases (larger clusters). Larger clusters make it possible for CMs to reach their CHs through other neighbour members. Fig.3 also shows that CH duration decreases as the speed of vehicles increases. Compared to DHCV, DCEV algorithm shows longer CM durations. This can be explained by the fact that end-to-end relative mobility can better determine the most stable routes. In DHCV, it is possible to choose a route because it has the most stable connection at the first hop (to CH), but the overall route might not have stable edges after the first hop, making it less stable.

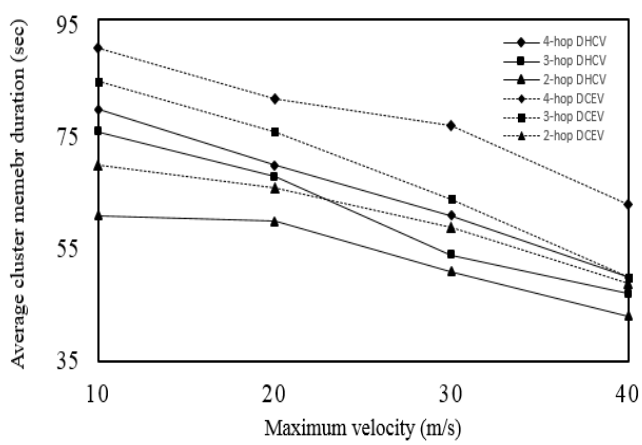

Figure 3 Average cluster member duration.

C. Cluster head change number

CH change number is also a metric which is indicative of cluster stability. The lower the number of CH changes, the better the stability. Fig. 4 shows CH change number for different values of D and velocity. As shown in Fig. 4 the CH change number increases when vehicles move faster and topology becomes more dynamic. Also, the constructed clusters using bigger D values have less CH change numbers. The reason is similar to the one described before; larger clusters provide better moving flexibility for CMs while still belonging to the same cluster. In DHCV, CH change number is higher than DCEV.

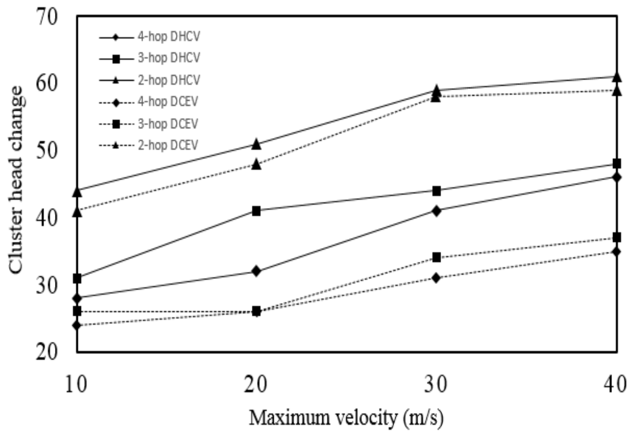

Figure 4 Cluster head change number.

DCEV shows better stability than DHCV in terms of cluster head changes, cluster head duration, and cluster member duration. This enhancement in cluster stability, comes, however, at the expense of more overhead. Indeed, DHCV uses only one-hop information to construct clusters, while DCEV uses D-hop information.

V. CONCLUTION

In this paper, a distributed D-hop clustering algorithm is proposed (DCEV). DCEV constructs stable clusters (compared to DHCV), by using end-to-end relative mobility as a metric for cluster construction. The end-to-end relative mobility stands for the average of relative motilities on each edge of a selected route, intended for cluster head selection. Simulation results show better clustering stability, as measured by cluster head duration, cluster member duration, and cluster head changes, compared to DHCV. As future work, we have plan to analyze the messaging overhead of DCEV.

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