Toward Strongley Connected Clustering Structure in Vehicular Ad hoc Networks

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***Abstract*— Clustering in Vehicular Ad-hoc Networks (VANET) is one of the control schemes used to organize media access and make VANET global topology less dynamic. Most VANET clustering algorithms are derived from Mobile Ad-hoc Networks (MANET). But, these algorithms model clustering schemes considering only position and direction of vehicles located in a geographic proximity regardless of the degree of the speed difference among them. Since the existence of VANET nodes in the same geographic location doesn't mean that they exhibit similar mobility pattern, we believe that VANET clustering models need to be redefined such that, their characterization is identified by considering the full status elements; speed, location, and direction instead of considering location and direction only. In this paper, we propose a new approach for grouping vehicles, showing similar mobility patterns, in a cluster and at the same time try to minimize the total number of created clusters. A new multi-metric Cluster Head (CH) election technique has also been developed. This technique can be used by vehicles to determine their suitability on the fly to lead the cluster. The simulation is conducted to evaluate the proposed technique and compare it with the most common methods. The simulation results show that our technique increases the cluster stability by about 50% compared to that of the most commonly used techniques.**

Keywords-component; Vehicular networks, vehicle to vehicle communication, clustering schemes in VANET, CH election.

I. INTRODUCTION

Driven by the increasing demand for enhancing drivers' and passengers' safety and comfort, future vehicles are expected to be equipped with efficient computer systems and wireless communication interfaces. Employing these systems equip vehicles with the means to readily communicate with one another and create the so called VANET. The Vehicle to Vehicle (V2V) is one type of VANET communications, which operates in the 75 MHz Dedicated Short Range Communications (DSRC) spectrum. The spectrum is divided into 7 channels, one of these channels is called control channel, and the remaining six are called service channels.

VANET nodes are characterized by their high mobility and abundance. Due to the high relative speed of nodes, VANET global topology keeps changing despite the constraint and predictable movements of vehicles [1]. A large number of vehicles on a highway pose serious media access problem. For this reason, several control functions have been proposed to organize media access [1-4]. One of the methods used to control VANET topology is partitioning the network into logical groups called clusters [1] [5-7]. Clustering can be used to organize media access, support Quality of Service, and simplify routing. Most of the existing VANET clustering algorithms are derived from MANET clustering schemes. However, these algorithms lack a technique to capture the mobility characteristics of nodes, and fall in a major drawback of modeling clustering considering only position and direction of vehicles located in geographic proximity regardless of their high relative speed [1] [5-7]. We believe that, the existence of group members in the same geographic area doesn't mean that they exhibit similar mobility characteristics [8]. Since the main goal of clustering is to make global topology less dynamic, we believe that, changes in the network topology on the global scale are directly related to the stability of local clustering structure. Therefore, in order to enhance their stability, clustering models need to be redefined so that they are characterized based on the full status elements; speed, location, and direction rather than considering only position and direction.

In this paper, we introduce a new approach that can be used as a base for developing new techniques for modeling clustering schemes in VANET. This approach takes the speed, in addition to the location and direction, into consideration to accurately identify nodes showing similar mobility pattern and group them in one cluster. The main contributions of the paper are: first, partitioning the network into minimum number of clusters, so that when the clusters are finally formed the distribution of vehicles among them based on their mobility pattern similarity is achieved with high probability; second, new multi-metric election technique that can be used by nodes to determine their suitability to become the Cluster Head (CH).

The rest of the paper is organized as follows: Section II presents cluster members identification. Section III introduces the clustering process and describes the CH election technique. Section IV shows the performance evaluation of the algorithm. Section V concludes the paper.

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II. IDENTIFYING CANDIDATE CLUSTER MEMBERS

The degree of the speed difference among neighboring vehicles is the key issue for constructing relatively stable clustering topology. The neighborhood relationship is built using the position information embedded in the periodic messages broadcasted by vehicles. Vehicles broadcast their current state to all other nodes within their transmission range *r*. Therefore, two vehicles are considered *r*-neighbors if the distance between them is less than *r*. Based on this definition, we derive another term called the *nodal degree*, which is defined as the total number of *r*-neighbors. Since clusters are formed by vehicles traveling in the same direction, all *r*-neighboring vehicles traveling in the opposite direction are not considered. Therefore, all *r*-neighboring nodes used in our analysis are limited to those vehicles traveling in the same direction. However, the variation of the speed levels among *r*-neighbors might be high; therefore, not all *r*-neighboring nodes are suitable Candidate Cluster Members (CCM). In our proposed technique, vehicles classify their *r*-neighbors into Stable Neighbors (SN) and Unstable Neighbors (UN). Two vehicles are considered stable neighbors if their relative speed is less than some threshold, $\pm\Delta v_{th}$. Hence, only stable neighbors participate in the cluster formation process. However, stable neighbors can also be members of nearby clusters. Therefore, they can't participate in the cluster formation process. In our work, all non-clustered (don't belong to any other cluster) stable neighbors are considered candidate cluster members.

In this work, we assume that the speed of the vehicles is a random variable following the normal distribution with mean, μ, and variance, σ^2, [9]. Thus, the probability density function (pdf) is:

$$f_V(v) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(v-\mu)^2}{2\sigma^2}} \tag{1}$$

Since the speed of the *r*-neighboring vehicles follow the normal distribution, the speed difference, Δv, between a vehicle and its *r*-neighbor also follows normal distribution with pdf expressed as follows:

$$f_{\Delta v}(\Delta v) = \frac{1}{\sigma_{\Delta v}\sqrt{2\pi}} e^{\frac{-(\Delta v-\mu_{\Delta v})^2}{2\sigma_{\Delta v}^2}} \tag{2}$$

Where $\Delta v = v1\text{-}v2$, $\mu_{\Delta v} = \mu 1\text{-}\mu 2$ and $\sigma_{\Delta v}^2 = \sigma_1^2 + \sigma_2^2$. The probability that, the speed difference between two *r*-neighbors falls within the threshold Δv_{th} can be obtained by:

$$f_{\Delta v}(-\Delta v_{th} < \Delta v < \Delta v_{th}) = \frac{1}{\sigma_{\Delta v}\sqrt{2\pi}} \int_{-\Delta v_{th}}^{\Delta v_{th}} e^{\frac{-(\Delta v-\mu_{\Delta v})^2}{2\sigma_{\Delta v}^2}} .d\Delta v \tag{3}$$

From (3), we note that, for a given Δv_{th}, the $f_{\Delta v}$ value decreases as $\sigma_{\Delta v}$ increases. Thus, the expected number of SN will vary. So, in order to avoid having high variation of this number, the threshold can be set as a function of the standard deviation, e,g,. $\Delta v_{th} = \beta\sigma$, where $\beta > 0$. Thus, the threshold is a dynamic parameter which depends on the speed characteristics of the vehicles within the vicinity.

III. CLUSTERING PROCESS AND PROTOCOL STRUCTURE

Vehicles are assumed to use control channel to exchange periodic messages and gather information about their neighborhood, and use one service channel to form the clusters and perform all intra-cluster communication tasks. Remember, the transmission range, *R*, of the control channel is always greater than the transmission range, *r*, of the service channel used for intra-cluster communications and management. In this paper, we assume that $R = 4r$. Thus, vehicles can build a complete picture about their neighbors which can even go beyond the cluster boundaries. Based on this, a vehicle can determine whether it has the slowest speed among all neighbors within *R* communication range. The idea is to have the slowest vehicle among non-clustered neighbors initiate the cluster formation process. Using this technique, we can avoid grouping vehicles whose relative velocity is greater than the threshold, Δv_{th}, in one cluster. Note that, not all nodes, as opposed to the classical clustering schemes, are suitable to initiate the cluster formation process.

A. *Cluster radius and DSRC channels' transmission range*

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 Fig.1 in which three vehicles *u, v* and *w* are located within geographical area. For node *u*, node *v* 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 *u* is greater than *r* which is the maximum range of the service channel. Node *w* is considered a neighbor from the perspective view of both service and control channels. As nodes exchange their status information via *control channel*, it would be easy for node *u* to identify that *v* is within 2*r* distance. Although neighborhood relationship is built using the *control channel*, it will be represented using *r-neighborhood terminology*. For example, node *w* is called a

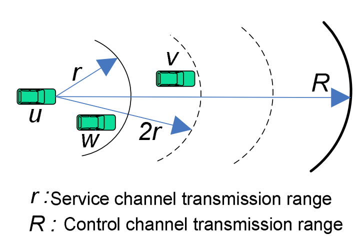

Fig. 1, Illustration of the relation between the transmission range of the control channel and service channel

2r-neighbor because it's within 2r distance.

B. The cluster formation algorithm.

In order to execute the algorithm properly, each vehicle is assumed to maintain and update a set, $\Gamma(t)$, which contains the IDs of all 2r-stable neighbors at time t. These IDs are classified into two subsets: The $\Gamma(t)\_G$ and the $\Gamma(t)\_L$ which contain the IDs of the 2r-stable neighbors whose velocity is greater than and less than the velocity of the current vehicle respectively. At any time, there should be a vehicle whose speed is the lowest among its 2r-stable neighbors, and as a result, the $\Gamma(t)\_L$ list maintained by this vehicle is empty. The pseudo code of the algorithm is shown in Fig. 2. The algorithm basically requires that the slowest vehicle or the vehicle whose $\Gamma(t)\_L$ members belong to other clusters originate the cluster formation process. This vehicle is called the Cluster Originating vehicle (COV). Line 3 of the algorithm shows that, COV sends its ID as a temporary cluster ID to all $\Gamma(t)\_G$. Then, all $\Gamma(t)\_G$ non-clustered members react upon receiving this request by setting their cluster ID temporarily to be the ID of COV as shown in line 7. Vehicles then start calculating their eligibility to become a CH. The vehicle announces its CH suitability *only* if its suitability is greater than previously received ones announced by other vehicles in the $\Gamma(t)\_G$. This is shown in lines 9 through 12. The suitability of a node, as it will be shown later, is calculated with respect to *only* its r- neighbors that $\in$ $\Gamma(t)\_G$ of the COV. The winner node declares itself as cluster head and announces its ID as shown in lines 13 to 15. Finally, all r-neighboring nodes of the winner, which $\in$ $\Gamma(t)\_G$ of the COV change their temporary cluster ID to the ID of the winner node and become cluster members of the corresponding cluster. Vehicles that $\in$ $\Gamma(t)\_G$ of the COV and couldn't associate with the formed cluster, set their temporary cluster ID to the default state (non-clustered), modify their $\Gamma(t)$, and start the cluster formation process again. Due to the space limitation, we can't show in detail the cluster updates like, joining, leaving and merging. In general a node joins the cluster if its relative speed to the CH is within the threshold. The member that leaves the range, r, of the cluster head losses its cluster membership. Two clusters perform cluster merging if the distance between the cluster heads of both clusters is less than r, and the difference of the average speed and the speed of both cluster heads is within some threshold. To avoid interference between clusters, we follow the method in [5].

Algorithm 1: Cluster formation algorithm

```
     For vehicle vi
01.  if (Γ(t)_L is Φ  || All Γ(t)_L members ∈ to other clusters) then
02.      CLS_ID_temp := vi _ID;
03.      Send (CLS_ID_temp) to all Γ(t)_G members

                /* All members of the Γ(t)_G */

04.  For every vj ∈ Γ(t)_G
05.      On Receiving msg(CLS_ID_temp)
06.          if (vj ∉ other clusters) then
07.              vj _CLS_ID := CLS_ID_temp
08.              vj calculates its suitability to become CH
09.              if vj_CH_Suitability > received CH_Suitability) then
10.                  Send (vj_CH_Suitability)
11.              else
12.                  Suspend sending

        /* Announcing the CH winner and set the cluster ID */

13.  CH := Winner vehicle
14.  CLS_ID of the CH := CH_ID
15.  Send (CH_ID)

                /* All members of the Γ(t)_G */

16.  For every vj ∈  Γ(t)_G
17.      On Receiving msg (CH_ID)
18.          if(vj ∈  Γ(t)_G && Veh_j_Position < 1-hop from CH) then
19.              vj _CLS_ID := CH_ID
20.          else
21.              vj _CLS_ID := default
22.              Re-construct Γ(t)_G
```

Fig. 2, The cluster formation algorithm

C. Cluster-head selection

Vehicles use the suitability function to determine their eligibility to become CH. The criteria of computing node's suitability are defined to increase the stability of the cluster structure and maximize its lifetime. Hence, the elected cluster head is expected to stay connected with its members for the longest period of time. Therefore, nodes having higher connectivity degree, maintaining closer distances to their neighbors, and having closer speed to the average speed of their neighbors are more qualified for winning the CH role. The connectivity degree, d, is computed by having the node consider **only** r-neighbors belonging to the CCM of the COV node. So, if the CCM of the COV node is $\Gamma(t)\_G=\{n_1,n_2,\ldots,n_k\}$, then the connectivity degree of vehicle $n_i \in \Gamma(t)\_G$ is:

$$d_i = \bigcup_{j=1, j\neq i}^{k} \{dis(n_i^{pos}, n_j^{pos}) < r\}$$

where n_i^{pos} and n_j^{pos} are the current positions of nodes n_i and n_j respectively, $dis(n_i^{pos}, n_j^{pos})$ is the distance between n_i and n_j, and r is the cluster radius.

Since the mean distance of n_i to its d_i neighbors can have large values, it's necessary to use the standardization technique to avoid having this parameter dominate the results of the calculation. This technique can be used by having each node calculate the mean position, μ_p, and the standard deviation, σ_p, of its d_i neighbors. Thus, the normalized mean distance, p_{norm}, of node n_i to its d_i neighbors is:

$$p_{norm} = \frac{n_i^{pos} - \mu_p}{\sigma_p} \quad (6)$$

The smaller the value of p_{norm}, the closer the position of the node to the center of its neighbors. The normalized mean speed, v_{norm}, can be calculated in the same way. The smaller the value of v_{norm}, the closer the speed of the node to the average speed of its neighbors. Finally, the suitability, s, of the node to become a cluster head is:

$$s = d * e^{-\alpha w} \quad (7)$$

where $w = |p_{norm}| + |v_{norm}|$ and $0 < \alpha \leq 1$ used to simplify the calculation. The higher the s the more qualified the node is to become a cluster head. The function also fairly prioritizes nodes that have high degree of similarity. Fig.3 shows that, the suitability of the node to win the cluster head role decreases as the distance and speed to the d_i neighbors deviates very large from the mean.

IV. SIMULATION AND PERFORMANCE EVALUATION

An extensive simulation study was conducted to evaluate the performance of our protocol. The C++ with graphical interface was used to develop the simulation. Vehicles are generated according to Poisson process. They enter the multi-lane highway and move for 10km. Vehicles keep time headway of 1.8 s. They can change lanes if there is room in the next lane, otherwise, they slowdown to match the speed of the vehicle in the front. The cluster radius is 200m and the control channel transmission range is 800m. We simulated two types of speeds taken from statistical measurements [9]. Each simulation run was done for 600 seconds of real time. Table I shows different speeds with different thresholds.

A. Evaluation crireria .

The multi-metric Weight-Based (WB) method and our Threshold-Based (TB) technique with different Δv_{th} were evaluated using the same environment variables. Due to the space limitation, we present only some topology-related metrics used for the evaluation. The first metric is the cluster lifetime C_i^{life} which is directly related to the lifetime of its cluster head. The cluster head lifetime is defined as the period of time from its winning the cluster head state until losing it due to merging or mobility. The cluster lifetime can be directly measured in the simulation. The mean cluster lifetime, denoted by $C_{i,mean}^{life}$, can be calculated using: $C_{i,mean}^{life} = \frac{1}{L}\sum_{i=1}^{L} C_i^{life}$, where L is the total number of

TABLE I. NORMAL-SPEED AND THRESHOLD

μ(Km/h)	σ (Km/h)	Δv_{th}
90	27	σ, 1.5σ, 2σ
110	33	σ, 1.5σ, 2σ

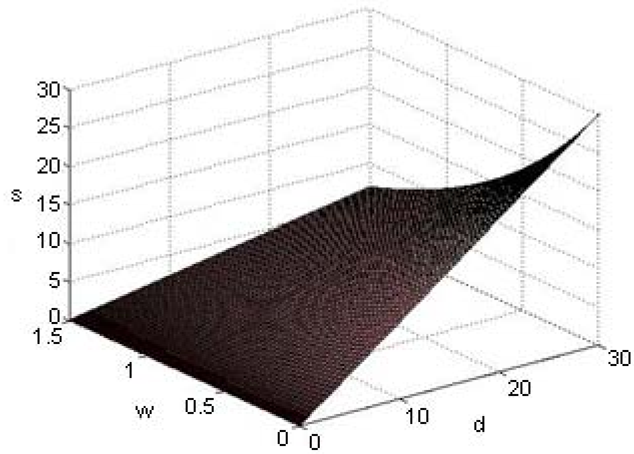

Fig. 3, Suitability of a node to become a cluster head

clusters created during the simulation time. The second metric is the cluster stability which, depends on the change rate of the cluster. Let $C_{nodes}(t)$ be the total number of nodes participating in the cluster formation at time t, and $E1$ and $E2$ be the events that nodes join or leave the cluster during its lifetime, respectively. The rate of change of $C_{nods}(t)$ with time can then be expressed as $\lambda_c = \frac{E1+E2}{C_i^{life}}$ .Thus, the mean change rate for clusters is given by $\lambda_{c,mean} = \frac{1}{L}\sum_{i=1}^{L}\frac{E1+E2}{C_i^{life}}$ where L is the total number of clusters in the network over the simulation time. Fig. 4 and 6, depict the average lifetime of the clusters for the TB technique with different Δv_{th} and the WB method. Both figures show that for the TB method (Δv_{th} = σ), the average cluster lifetime is about 50% higher. The figures also show that, even for Δv_{th} = 2σ, the average cluster lifetime of the TB method is always greater than that of the WB method. This is due to the high variation of the speed difference among cluster members of the WB method. This deviation leads to the following: first, in the WB method, the probability that two cluster heads come into direct communication range becomes high which results in cluster merging. But, in the TB method, the cluster merging can't be performed unless the difference between the average speed of the neighboring clusters and the speed difference of the cluster heads of both clusters are within some threshold; second, the probability that the cluster members and the cluster head get separated soon due to mobility is high, especially when the cluster is composed of few nodes. The figures show that, for the TB method, the average lifetime of the cluster is decreased when Δv_{th} is increased. This is true because the deviation of the speed difference becomes high. Fig. 5 and 7 depicts the average change rate per cluster. The figures show that the change rate of the TB is about 45% lower than that of the WB. Our TB method outperforms the WB method even when Δv_{th} = 2σ. This is due to the high variation of the speed difference number of cluster members that lose their connectivity with the cluster head due to high

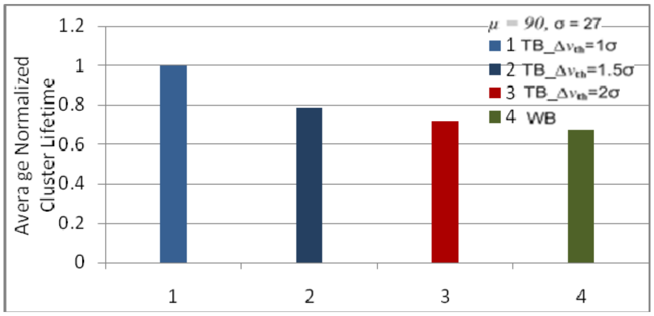

Fig. 4, Average normalized lifetime of the cluster (μ=*90* Km/h)

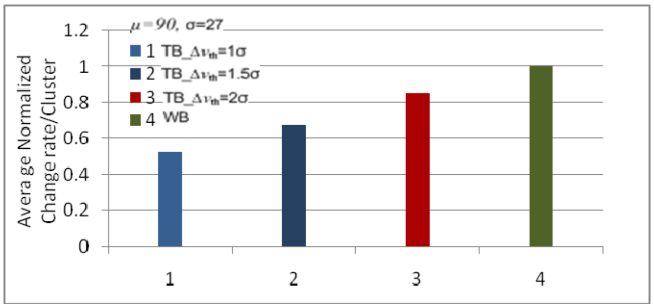

Fig. 5, Average normalized change rate/ cluster (μ=*90* Km/h)

or low speed are high. In addition to that, the high rate of cluster merging also contributes to change rate increase. Fig. 8 shows the total number of clusters created during the entire simulation run for different cases. Since the TB method takes vehicle dynamics into consideration for creating clusters, at any given time there could be more clusters (existing clusters) on the road due to TB method than WB method. However, the total number of clusters created during the entire simulation time is slightly higher for TB method than for WB method. Since the TB method significantly outperforms the WB method in terms of cluster lifetime and change rate/cluster, we believe that cluster formation using TB method will provide better global topology stability than the WB method.

V. CONCLUSION

The unique characteristics of VANET require a new approach to form clusters. This approach should take the vehicle dynamics, such as speed, into consideration. In this paper, we proposed a new VANET cluster formation

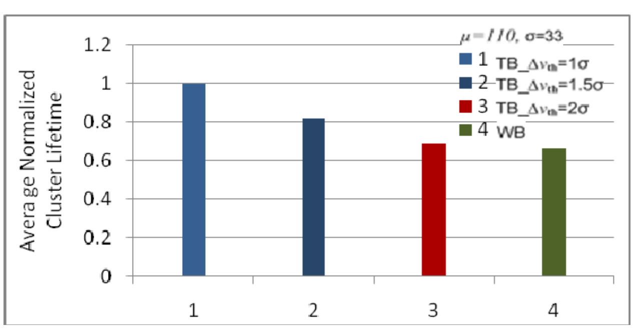

Fig. 6, Average normalized lifetime of the cluster (μ=*110* Km/h)

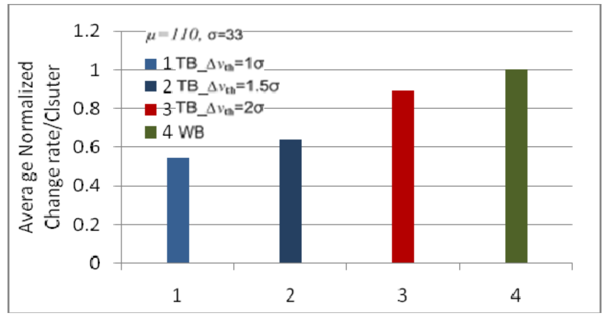

Fig. 7, Average normalized change rate/ cluster (μ=*110* Km/h)

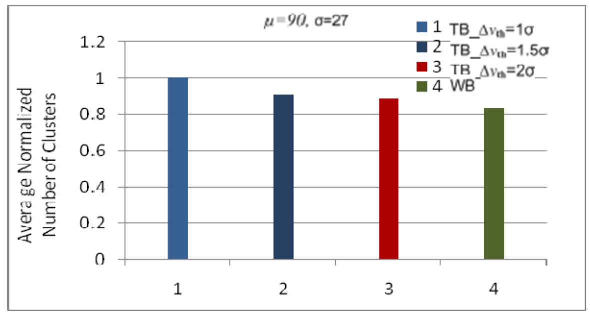

Fig. 8, Average normalized number of clusters

algorithm that tends to group vehicles showing similar dynamic characteristics. Our proposed algorithm significantly outperforms the existing algorithms in term of cluster stability.

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