CAMVC: Stable Clustering Algorithm for Efficient Multi-hop Vehicular Communication on Highways

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***Abstract*—Research and development on vehicular ad hoc networks (VANETs) have expanded rapidly in the last few years. VANETs have many challenges due to the high nodes mobility and dynamic topology, which lead to frequency network disconnections. Clustering algorithms are effective techniques to reduce network disconnections by organizing the work of the network nodes. This paper proposes a stable clustering algorithm for efficient multi-hop vehicular communication (CAMVC), which takes the cluster's speed, acceleration, closeness centrality, and position parameters into consideration. Our approach aims to increase the cluster lifetime by electing the best cluster heads and find the best gateways to connect the clusters with each other by improving the calculations of their link connectivity duration. We compared our proposed algorithm with other clustering and gateway selection algorithms in terms of stability to prove the effectiveness of CAMVC.**

***Keywords*—clustering; DBSCAN; gateway selection; VANETs; V2V communications**

I. Introduction

In recent years, Vehicular Ad Hoc Network (VANET) has drawn the attention of researchers from different fields, and intensive research and development efforts have been devoted to this regard. It surfaced to provide efficient communication between vehicles in an ad hoc manner [1][2]. As an essential element of Intelligent Transportation Systems (ITS), it aims to combine the intelligence aspects of safety and luxury applications with the transportation, e.g., control traffic flow, collision alarm, video streaming, mobile announcements, and so on [3]. VANET architecture consists of two communication entities, which are Road Side Unit (RSU) and On-Board Unit (OBU). OBU is a communication device installed in the vehicles, while RSU is a stationary unit located on the roadsides or close to traffic lights. In general, two modes of communication can be established by these communication units, Vehicle-to-Vehicle (V2V), which allows the vehicles to communicate directly and Vehicle-to-Infrastructure (V2I), in which vehicles be able to make contact with the infrastructure of RSUs [4]. The standard IEEE 802.11p is used to make reliable communication between neighboring vehicles over Dedicated Short-Range Communications (DSRC) wireless channels [5]. VANETs are a special kind of Mobile Ad Hoc Network (MANET), in which mobile nodes in these networks are vehicles supplied with wireless communication devices. However, variable network density, rapid changes in network topology are among challenging issues and which leads to frequency network disconnection between V2V and V2I communication. One of the possible solutions to handle this problem is clustering [6], [7]. In VANET, clustering intents to categorize vehicles into groups depends on some particular features. Each member of the cluster needs to broadcast its information within the cluster, and according to some rules set, the Cluster Head (CH) of that particular cluster is elected [8].

In this paper, a Stable Clustering Algorithm for Efficient Multi-hop Vehicular Communication (CAMVC) is proposed in which two major contributions are listed

- Extending the cluster lifetime by using Density-Based Spatial Clustering of Applications with Noise (DBSCAN) to configure the cluster and using the Fuzzy Logic Control (FLC) to select the best CH.
- Selecting the best gateway by improving the link connectivity duration calculation to elongate the life of the link communication between clusters as long as possible.

CAMVC algorithm was compared with other algorithms and showed better results in terms of cluster lifetime and gateway selection. This paper is organized as follows. Section 2 presents the background and related works. In Section 3, the proposed CAMVC approach is described, while The performance evaluation results are introduced in Section 4. Finally, Section 5 concludes the paper.

II. Related Work

In the literature, several clustering techniques and gateway selection methods have proposed to make vehicular communication more efficient and simplify some vital functions like media access management, quality of service achievement, and bandwidth allocation, etc.

An Intelligent Naïve Bayesian probabilistic estimation practice for Traffic flow has been developed to form a Stable Clustering in VANET, briefly named ANTSC [9]. The goal of the proposed algorithm is to enhance the stability of the cluster as well as the lifetime of the CH by utilizing the knowledge of the current traffic flow in addition to employing several factors, like direction, speed difference, connectivity level, and the distance between the node and its neighbors by using the naïve

Bayesian probabilistic estimation technique. The proposed technique was compared with other algorithms and showed improvements in cluster and CH lifetime. Regardless of the efficiency of the ANTSC algorithm in selecting the CH and increasing the cluster lifetime, it is applied for a particular scenario, so it was unclear whether it could be used in different scenarios. Moreover, as it is known, the naïve Bayesian network is a supervised learning technique, which means it needs real datasets for each zone, which makes it inapplicable in case lack of dataset.

In regard to gateway selection, most of the proposed gateway selection algorithm in VANET domain is either on cluster or non-cluster formation basis, depending on how the vehicular nodes are arranged before the gateway is selected. In [10], two levels (L1, L2) clustering technique have been proposed to transmit data in 5G V2X communications efficiently. In the proposed scheme, L-1 cluster heads are elected by a fuzzy logic algorithm using three factors, which are relative velocity factor, k-connectivity factor and link reliability factor, while the L-2 cluster heads are selected by an improved Q-learning to decrease iterations number in the gateway election to LTE base station. The proposed protocol achieved good results when evaluating it under different network conditions, but excessive iterations in gateway discovery will be generated in case of high dense topology. The authors in [11] proposed the Fuzzy QoS-balancing Gateway Selection (FQGwS) algorithm that selects a gateway to connect the source vehicle to the LTE advanced infrastructure that forms part of (V2I) communications. The FLC is used to select the best gateway based on QoS traffic class constraints, as well as the criteria. The main parameters used in the algorithm are the received signal strength (RSS), load, V2V and V2I link connectivity duration, which are related to the CH and gateway candidates. Simulation results showed that the algorithm performs better results in terms of delay and packet loss. The calculations of link duration do not give accurate results and may cause wrong gateway selections. It happens because the speed of vehicles, which has been adopted in the calculation, does not represent their actual average speed.

Most of the proposed methods either address the issues of forming stable clusters or deal with the gateway selection under the scope of V2I communication. This motivates us to design an algorithm that has the ability to form stable clusters by selecting the best CH for each cluster and find the best gateway between clusters to enable a multi-hop data dissemination under the scope of V2V communication without resort to the infrastructure.

III. Proposed Scheme

The aim of the CAMVC scheme is to create stable clusters and find the best gateways to connect them with each other. The purpose of this is to provide reliable multi-hop data dissemination.

In this paper, we assume each vehicle is equipped with an OBU to be able to deal with the IEEE802.11p as a DSRC system. The vehicles can share their information periodically by broadcasting cooperative awareness message (CAM), which is a single hope broadcast communication. This CAM message is sent periodically at concrete heartbeat rate messages. Based on these messages, each vehicle will know its immediate neighbors.

A. Cluster Formation

The cluster configuration begins when the density of vehicles increases on the highway so that any vehicle on the street does not have enough vision area and needs to know the road conditions can trigger the DBSCAN algorithm based on the dataset collected from neighbors. DBSCAN evaluates the number of vehicles to determine whether there are enough nearby vehicles close to each other to form a cluster with respect to ε and *MinPts*. Where ε represents the maximum distance between two points, which means that if the distance between two points is lower or equal ε, these points are considered neighbors, while *MinPts* represents the minimum number of points counted neighbors for that point. With respect to DBSCAN complexity, the average execution time for a single region query is O(log n) [12].

B. Cluster Head Selection (CHS)

CHS plays an essential role in cluster stability, which in turn represents one of the performance criteria in VANETs. Fewer CH changes mean more stable clusters. The CHS process starts after cluster creation in which one of the vehicles in the cluster will be elected as a CH. The FLC is the technique used to find the most suitable CH in the cluster. Three parameters are considered in the CHS phase: Cluster Speed (*CS*), Vehicle Acceleration (*VAcc*), and Closeness Centrality (*CC*). *CS* is determined by calculating the average speed of the vehicles in the clusters. *CC* represents the degree of closeness to the cluster center. Thus, the more central a vehicle is, the closer it is to all other vehicles in the cluster. The *CC* metric is calculated for each vehicle in the cluster by

$$CC(x) = \frac{N-1}{\sum_{x \neq y} d(x,y)}. \tag{1}$$

Where N is the number of vehicles in the cluster, $d(x,y)$ the distance between the vehicle (x) and other vehicles in the cluster, these three metrics are fuzzified using the fuzzy logic system. Fig.1 shows our CHS System. After determining the CHS value to all vehicles in the cluster, the vehicle with maximum CHS value will declare itself as a CH.

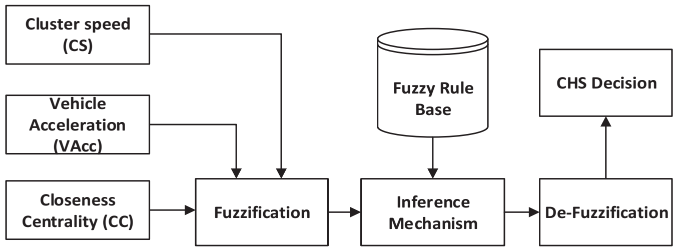

Fig. 1. Cluster head selection system

C. Gateway selection

Gateway selection enables the clusters to communicate with each other and transmit the data from source to destination efficiently by allowing multi-hop communication. Our proposed algorithm considers each vehicle in the cluster has a direct connection to a CH in the adjacent cluster is a Candidate GateWay (CGW). The CGW, with the highest stable connection, is elected as a gateway. The connection stability is calculated by Link Connectivity Duration (LCD), which represents the time duration between two vehicles remaining in a connection. LCD is computed using this formula, inspired by [11]:

$$LCD_{ij} = \frac{\sqrt{\left(\alpha^2+\gamma^2\right)R^2-\left(\alpha\delta-\beta\gamma\right)^2}-\left(\alpha\delta+\beta\gamma\right)}{\alpha^2+\gamma^2} \quad (2)$$

Where

- $\alpha = v_i \cos\theta_i - v_j \cos\theta_j$
- $\beta = x_i - x_j$
- $\gamma = v_i \sin\theta_i - v_j \sin\theta_j$
- $\delta = y_i - y_j$
- (x_i,y_i) and (x_j,y_j) are the Cartesian coordinates of locations of two vehicles *i* and *j*, respectively.
- v_i and v_j are the velocities of vehicles *i* and *j*.
- θ_i and θ_j are the direction angles of vehicles *i* and *j*.

Each CGW has two LCDs, one with its CH (LCD_{CH2W}) and the other with the CH of the adjacent cluster (LCD_{GW2CH}), so The LCD of CGW is equal min {LCD_{CH2GW}, LCD_{GW2CH}}. The CGW with the highest LCD is elected as the best gateway. The calculation of LCD is optimized by using the average speed rather than the current speed. This done by using the percentage change of speed, for example, the average speed of vehicles for the last 10 time-steps speed readings is defined by

$$v_t^* = 0.9 \cdot v_{t-1} + 0.1 \cdot v_t \quad (3)$$

Where $v_{(t)}$ represents the current speed, and $v_{(t-1)}$ represents the speed of the last time-step. This procedure is used to reduce the impact of sudden changes in speed that occur momentarily, causing wrong LCD calculations.

IV. PERFORMANCE EVALUATION

This section presents the performance evaluation of the proposed CAMVC scheme, including the clustering algorithm and gateway selection mechanism. The efficiency and the performance of our proposed scheme are evaluated by exploiting MATLAB R2017b, while the mobility of vehicles has been simulated with Simulation of Urban Mobility (SUMO) to confirm its validity [13].

SUMO and MATLAB blocks have been joined together by Traffic Control Interface (TraCI). TraCI creates a TCP connection to allow communication between the two software. SUMO acts as a server (TraCI-Server) and MATLAB as a client (TraCI Client) [14]. Simulation parameters are listed in Table I.

TABLE I: SIMULATION PARAMETERS

Parameters	Values
Highway Distance	20 Km
Simulation Time	400 sec
Number of vehicles	120
Vehicles speed	90-120 Km/h
Coverage area	300 m

Regarding of clustering technique, we compared our simulation outcome with the LID technique proposed in [15] and the MOBIC technique proposed in [16].

Fig. 2 illustrates the average cluster lifetime of three CHS algorithms in three different traffic densities. As shown in this figure, the obtained results show that the proposed CAMVC algorithm increases cluster lifetime by 13% and 38% on average compared to MOBIC and LID, respectively. It also shows better results in decreasing the number of clusters per vehicle, as illustrated in Fig 3.

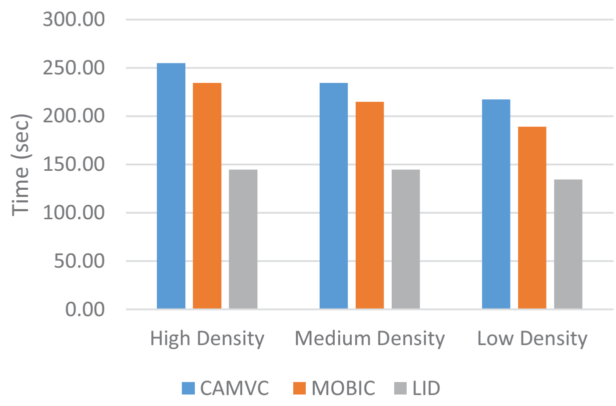

Fig. 2. Average cluster lifetime

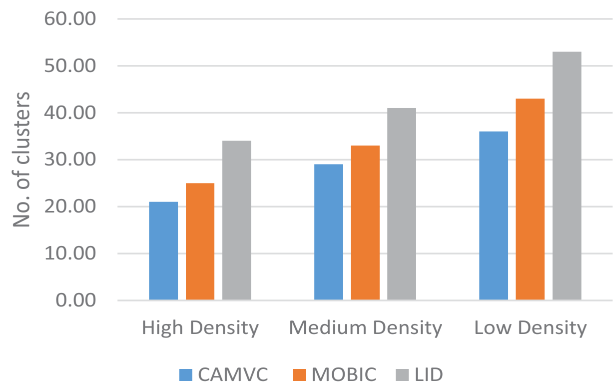

Fig. 3. Number of Clusters

As for gateway selection, the comparison was limited to CAMVC and FQGwS algorithms only because LID and

MOBIC propose that any node which can hear two or more cluster heads is a gateway. Therefore, there no mechanism for selecting the best gateway to make a comparison with it. Different numbers of speed readings for average speed have been adopted to test the effect of the sudden changes on LCD, which is the average speed of 20,10, and 5 last readings. These LCD calculations are compared to FQGwS, which adopted the current speed in its calculation.

As shown in Fig. 4, LCD calculations with the average speed of 20 last readings give results close to real link connectivity duration, which means the more last speed readings in average calculation, the less affected by sudden speed change in LCD calculation. Consequently, CAMVC showed better results in selecting appropriate gateways that have higher LCDs than FQGwS, by increasing the ratio of LCD to the optimal calculation to 87% in average while FQGwS achieves 61% as depicted in Fig. 5.

It should be noted that the optimal calculation represents the LCD of the best gateways obtained by observing the CGWs throughout the simulation time.

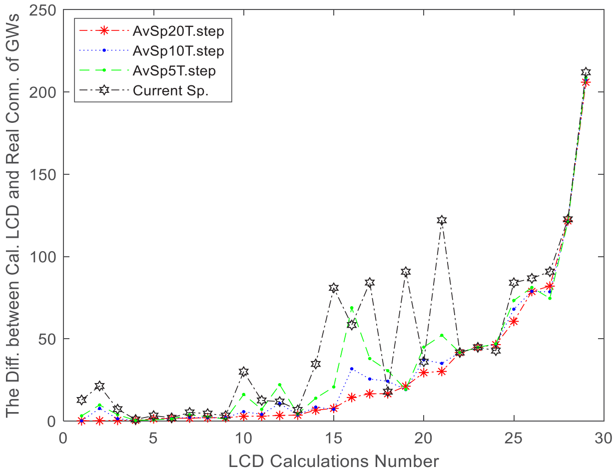

Fig. 4. LCD Calculation with different speeds relative to real LCD

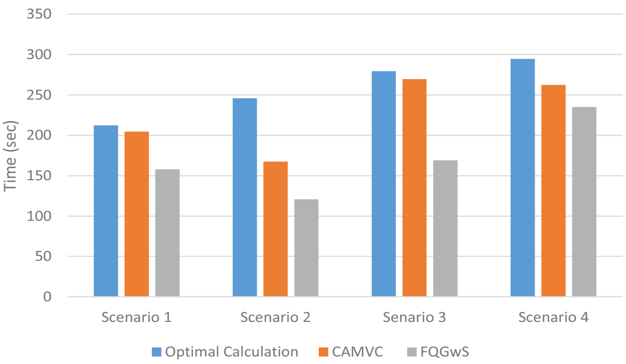

Fig. 5. Average LCD of gateways relative

V. Conclusion

In this paper, we presented a clustering algorithm based on DBSCAN, FLC, and LCD, with the aim of creating stable clusters for efficient multi-hop data dissemination over V2V communication. DBSCAN algorithm is responsible for forming the clusters, while FLC is used to select the CH based on the metrics, which are cluster speed, acceleration, and closeness centrality. Regarding gateway selection, LCD has been improved to select the best gateway. Simulation results show that our proposed scheme performs better results in terms of cluster stability and gateway selection.

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