A novel k-means powered algorithm for an efficient clustering in vehicular ad-hoc networks

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ABSTRACT

Considerable attention has recently been given to the routing issue in vehicular ad-hoc networks (VANET). Indeed, the repetitive communication failures and high velocity of vehicles reduce the efficacy of routing protocols in VANET. The clustering technique is considered an important solution to overcome these difficulties. In this paper, an efficient clustering approach using an adapted k-means algorithm for VANET has been introduced to enhance network stability in a highway environment. Our approach relies on a clustering scheme that accounts for the network characteristics and the number of connected vehicles. The simulation indicates that the proposed approach is more efficient than similar schemes. The results obtained appear an overall increase in constancy, proven by an increase in cluster head lifetime by 66%, and an improvement in robustness clear in the overall reduction of the end-to-end delay by 46% as well as an increase in throughput by 74%.

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1. INTRODUCTION

Nowadays, vehicular ad hoc network (VANET) has attracted extensive research interest [1]–[3]. This type of network is considered a subclass of mobile ad-hoc networks (MANET) [4]–[6]. VANET aims to improve the intelligent transportation system (ITS) by reducing energy resources, reducing lost time, solving problems of supervision and management of transport abroad, and reducing car accidents [7]–[10]. The high speed of a vehicle, the continuous movements, and the instability of the network are unique features of VANET [11]–[13]. In this sense, offering an efficient and effective routing protocol is one of the main challenges of VANET applications for exchanging data [14], [15]. Therefore, clustering algorithms are considered one of the suitable methods, which aim to reduce the overhead of information exchanged between vehicles, facilitate network management, control bandwidth in each cluster, and reduce message transmission costs [16]. However, to guarantee the efficiency of these algorithms, it is mandatory to adapt them to the characteristics of VANET networks.

Several clustering approaches have been introduced in the literature to overcome disconnections in vehicular networks. Hajlaoui *et al.* [17] proposed a clustering algorithm based on K-medoids for VANET to enhance the lifetime of all established links and to enhance network stability. However, it fails to account for the buffer size that affects the ability to be a cluster head (CH) when selecting one. Abbas and Fan [18] have suggested a routing scheme based on clustering called (CRLLR) for VANET to ensure high reliability, reduce end-to-end latency, and provide high throughput including the usage of ant colony optimization (ACO) to select the optimal routes for communication in VANET. However, this method generates more overhead in the route discovery process. Liu *et al*. [19] proposed a new method based on clustering and probabilistic broadcasting (CPB) for data dissemination in VANET. In this work, cluster formation is based on driving directions and geographic locations of vehicles, where data can be exchanged in a clustered manner with a more sufficient connection duration. Unfortunately, it did not involve a maintenance step.

Sutagundar *et al*. [20] have proposed a stability-oriented cluster dynamism in VANET (SOCDV), to avoid clustering instability, and enhance the cluster lifetime. Hubballi *et al*. [21] suggested a clustering scheme for hybrid VANET to facilitate reliable communication. This scheme uses an RSU-based agent to form the clusters according to their transmission range, while the selection of CHs is based on the list of vehicle neighbors and the position of vehicles. As the usage of roadside units (RSU) is diminishing, approaches [20], [21] are falling out of favor. Khan and Fan [22] introduced a new triple cluster-based routing protocol for VANET. This scheme combines a modified k-means method and the Floyd-Warshall algorithm to form the clusters and select the CH. The high mobility of vehicles in VANET induces failures in the cluster formation, this work did not include any cluster maintenance logic to recover.

To summarize, the presented clustering algorithms are based on clustering, but they have at least one of the following drawbacks and limitations: i) CH selection and the cluster formation are based on road shapes and disposition instead of the mobility of vehicles; ii) The proposed clustering methods use the RSU to form clusters and to select CHs. The roadside units (RSU) may not be available in the future due to the cost of deployment; and iii) The maintenance phase is absent or, it is not well exploited. Thus, this paper suggests an efficient clustering approach using an enhanced k-means algorithm for VANET. It is a suitable clustering method that is based on appropriate parameters in order to provide a complete and efficient routing process.

This paper contributes to the body of knowledge the following: i) an enhanced k-means algorithm to divide vehicles into clusters and ii) the initial number of clusters and the positions of CHs are selected using a mathematical model that considers the number of connected vehicles and the network characteristics. The remainder of this work is laid out: section 2 outlines the specifications of the proposed scheme. In order to evaluate our algorithm, we define in section 3 the simulation environment as well as a pinpointed analysis in terms of key performance indicators such as throughput, end-to-end delay, packet delivery ratio (PDR), CH lifetime, and cluster member (CM) lifetime in a highway scenario. Then, section 4 provides the conclusion of this work.

2. PROPOSED APPROACH

The use of the clustering method in the routing process in VANET has shown several advantages such as reduction of overall packet costs, efficiency in the face of changes caused by frequent connection and disconnection of nodes, high mobility, and high density [23], [24]. Therefore, an efficient approach based on an adapted k-means clustering algorithm has been proposed, with the aim of partitioning network vehicles into multiple clusters. The proposed clustering scheme is divided into three phases: initialization; building the clusters; maintenance phase. To start, the algorithm is initialized with the output of a mathematical formula that considers the topology and count of connected vehicles in the network. Then, the distribution of vehicles in the clusters is based on a similarity function that depends on the position, and velocity vectors of the vehicles. Finally, in the maintenance step, the expected transmission count (ETX) and the size of the free buffer are factored-in to select the CHs.

2.1. Initialization

2.1.1. Initial definition of cluster count

We start with calculating the needed number of clusters ahead of launching the k-means clustering algorithm, and this is based on the length of the road, the transmission range, and the number of connected vehicles, as stipulated in (1) [25],

$$K = max\left\{\frac{L}{K}, \frac{N}{N_{max}}\right\} \tag{1}$$

where R is the transmission signal coverage, L indicates the length of the road, N is the total vehicle count, and N_{max} is the maximum vehicle count in each cluster.

2.1.2. Initial positions of centroids

Our work is based on the use of a clustering algorithm in the routing process. An initialization phase is required to start this algorithm. In this work, we obtain the initial positions of the centroids as an output of the k-means algorithm, whereas these centroids are uniformly distributed at a distance of $\frac{L}{K}$ as shown in Figure 1, L is the length of the road and K is the initial number of clusters.

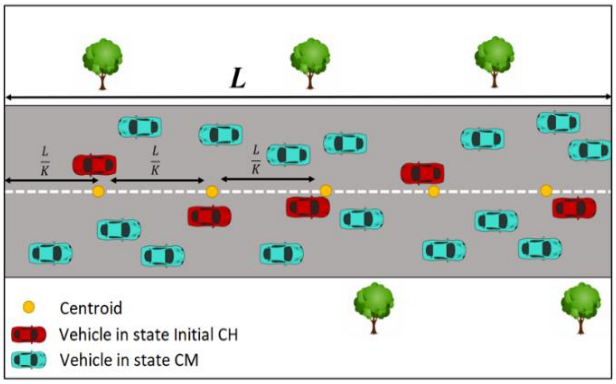

Figure 1. An illustration of a road section

2.2. Building the clusters

The classic k-means algorithm uses the Euclidean distance to assign a node to its respective cluster based on its position. However, excluding the speed and direction of the nodes reduces the effectiveness of the k-means algorithm. Consequently, a similarity function *(SF)* accounting for all the aforementioned parameters is conceived as part of this work, the outcome is a better cluster assignment due to the proper estimation of time that a vehicle can remain within signal coverage.

Let $V_{i,1\leq i\leq N}$ a vehicle, and $CH_{j,1\leq j\leq K}$ a CH, (x_i, y_i) and (x_j, y_j) are their respective position coordinates; v_i and v_j are their respective speeds, and d_{ij} is the angle of direction between V_i and CH_j. We have calculated the similarity function using (2),

$$SF_{ij} = w_1 \times d_{ij} + w_2 \times \Delta v + w_3 \times dist(i,j) \tag{2}$$

with

$$\Delta v = |v_i - v_j| \tag{3}$$

and $dist(i, j)$ is the Euclidean distance between V_i and CH_j. With

$$dist(i,j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{4}$$

w_1, w_2, and w_3 are the corresponding weight of each of d_{ij}, Δv and $dist(i, j)$.

2.3. Building the clusters

In VANETs, the continuous movement of vehicles with high-speed causes intermittent connections and additional overheads. Thus, a cluster maintenance phase is highly recommended to make a clustering algorithm more efficient in a vehicular environment. In this step, the CHs should be replaced periodically, and the process of partitioning the nodes into new clusters should be repeated. To ensure a long life for the CHs, we have introduced a cost function that involves the expected transmission count *(ETX)* and the size of the free buffer as parameters. *ETX* helps qualify the stability of inter-node communication [26].

CHs with large free buffer sizes and small ETX values are the ones selected based on the cost function with (5),

$$f_{cost} = \alpha \times \left(\frac{Bf}{Bf_{ini}}\right) + \beta \times \left(\frac{1}{ETX_{ij}}\right) \tag{5}$$

where $0\leq\alpha$, $\beta\leq 1$; Bf_{ini} and Bf are the initial and current free buffer size of node i respectively, ETX_{ij} is the expected transmission count between a vehicle member and its CH.

ETX is a value that indicates the quality of communication links in VANET. It is used in the maintenance step to reduce the retransmission of the packets and enhance the packet delivery ratio. It is obtained using two parameters: the probability of successful transmission of packets called *df*, and the probability of successful transmission of the acknowledgment packet (ACK) called d_r. To get these values, every two adjacent nodes periodically exchange fixed-size packets. We obtain *ETX* value applying (6).

$$ETX_{ij} = \frac{1}{d_f \times d_r} \tag{6}$$

The algorithm of the adapted k-means used in this approach is described in Algorithm 1. Then, the algorithm of the efficient clustering approach using an adapted k-means algorithm for VANET (ECKV) is described in Algorithm 2. The process of ECKV is described by the flowchart in Figure 2.

Algorithm 1. Pseudo code of the adapted K-Means

```
Input: Set of nodes V.
Output: Set of clusters with their CHs.
Begin
Get K the initial number of clusters using Eq.1.
Get C the set of initial centroids as shown in Figure 1.
Set the vehicle nearest to each centroid as CH: Let C_CH the set of initial CHs.
Repeat
For V_i in V do
Calculate the similarity function for each node with all accessible CHs.
Assign V_i to (CH_j in C_CH) with SF(V_i, CH_j)=min (SF(V_i,CH_x)/CH_x∈C_CH)
End for
For j=1 to K do
Let CH_j current CH for cluster j.
Set new CH_j'=(V_i/max(f_cost(CH_j, V_i)), V_i∈ nodes of cluster j).
End for
Until All nodes belong to a cluster or the maximum number of iterations is reached.
End
```

Algorithm 2. Pseudo code of ECKV

```
Begin
If the event has happened then
Clustering using algorithm 1.
Send data from source to destination.
Else
Do nothing.
End if
End
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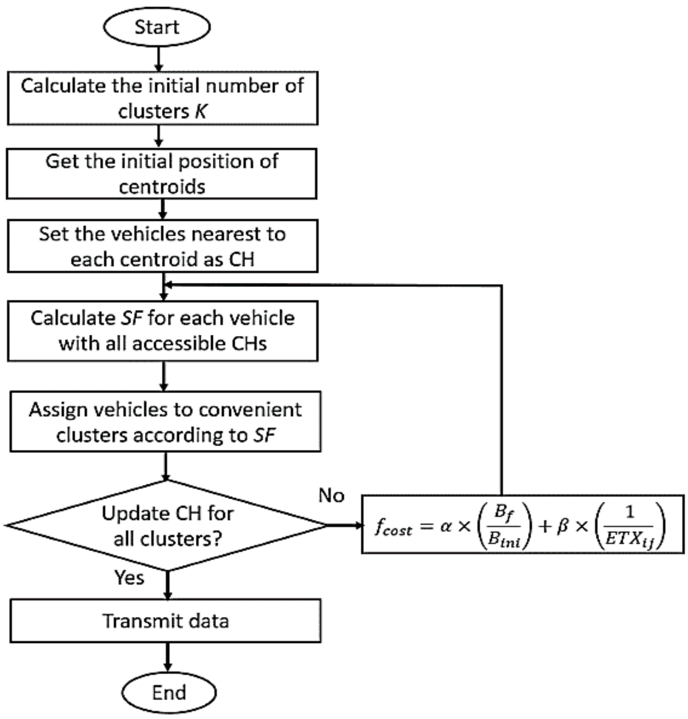

Figure 2. ECKV flow chart

3. SIMULATION AND ANALYSIS

3.1. Simulation setup

We present in this section the simulation scenario, the experiment parameters, and a report about the simulation results. The performances of the proposed scheme (ECKV) have been compared to an adjusted K-medoids clustering algorithm (AKCA) [17] and SOCDV [20] routing protocols conceived for the same objective. To validate the performance of our contribution, we used the NS2 simulator. Vehicle mobility has been managed by the revival mobility model (RMM) [27] in Figure 3, vehicles move in two lanes, in both directions, and at different speeds. We ran the simulation on a highway scenario in which we randomly distributed the vehicles and considered 40 to 240 vehicles. The transmission range of the vehicles used for the simulations has been set at 250 m. The weight values used in the selection of the new CH are: $\alpha=0.6$ and $\beta=0.4$, and the values of the clustering process are set to $w_1=0.2$; $w_2=0.5$; $w_3=0.3$. These values were calculated after several series of experiments in different scenarios. For more precise evaluation, the results are the average of 10 simulation runs per parameter set. The total simulation time is 1500 s. The robustness of the proposed scheme has been evaluated in terms of PDR, throughput, end-to-end delay, CH lifetime, and CM lifetime in low and high densities. Table 1 summarizes the different simulation parameters.

Table 1. Simulation parameters

Parameters	Values
Simulator	NS2
Nb of lanes	Two lanes
Topology	Highway
Number of simulations	10
Simulation time	1,500 s
Transmission range	250 m
Number of vehicles	40-240
Max speed of vehicles	120 km/h
Data traffic type	CBR
Packet rate	4
Mac protocol	IEEE 802.11
Queue length	50 packets
Compared protocols	ECKV, AKCA, SOCDV
w_1, w_2, w_3	0.2, 0.5, 0.3
α, β	0.4, 0.6
N_{max}	20

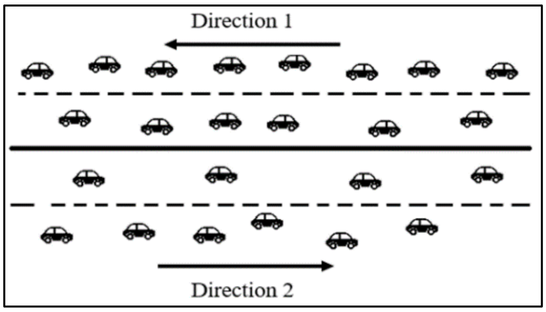

Figure 3. Revival mobility model

3.2. Simulation results

3.2.1. Packet delivery ratio

ECKV outperforms both AKCA [17] and SOCDV [20] in terms of PDR as shown in Figure 4. The PDR of our proposed approach keeps a value greater than 90% on the different numbers of vehicles, while the PDR of AKCA and SOCDV is inversely proportional to the number of vehicles. In a high-density context, ECKV offers a great capacity to select the number and the size of the clusters according to the road and the topology of the network, while the CH ignores many packets in AKCA and SOCDV, due to packet flooding broadcasts during the route discovery phase.

3.2.2. Average end-to-end delay

ECKV provides better latency regardless of traffic density as shown in Figure 5. The delay of ECKV does not exceed 48 ms, while the delay of SOCDV and AKCA reaches 80 and 50 ms respectively.

The vehicle density greatly influences the route discovery process causing higher bandwidth usage and in turn an increase in packet transmission delay proportionally to the number of vehicles. However, ECKV factors velocity, direction, and a calculated number of clusters during the formation of the latter, subsequently delivering a higher end-to-end delivery performance.

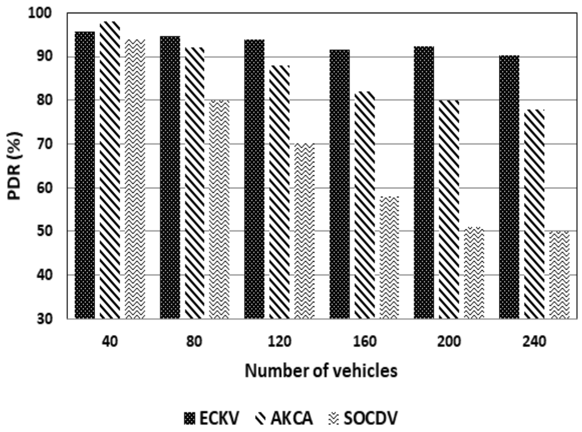

Figure 4. PDR versus number of vehicles

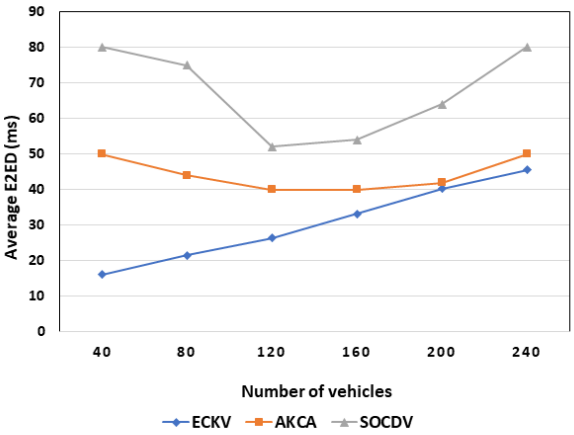

Figure 5. Average E2ED versus number of vehicles

3.2.3. Throughput

When varying the number of vehicles from 40 to 240, ECKV offers higher throughput than AKCA and SOCDV as shown in Figure 6. As the number of vehicles augments, the throughput of AKCA and SOCDV decreases, due to high overhead. On the other hand, ECKV selects the appropriate CHs using ETX and the free buffer size which makes ECKV significantly better in terms of throughput. Each CH relays data packets from one cluster to the other, leveraging the already established communication channel.

3.2.4. CH lifetime

ECKV offers a higher CH lifetime than AKCA, and SOCDV in terms of vehicle speed as shown in Figure 7. This demonstrates the ability to maintain the stability of clusters in very dynamic network topology, by selecting the appropriate CHs using metrics like ETX and free buffer size, therefore the selected CHs remain connected to a large number of neighbors with less disconnections. The choice of metrics such as ETX and free buffer size in our approach has shown its effectiveness over the lifetime of the CHs.

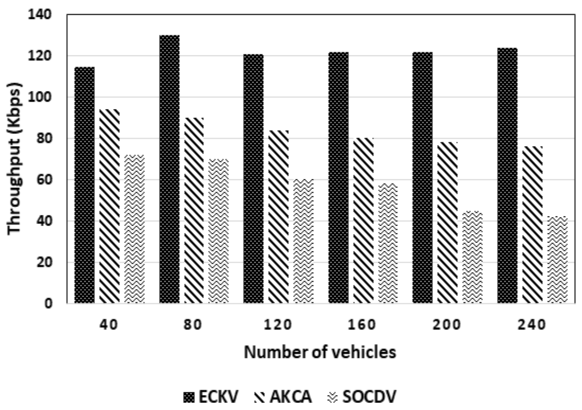

Figure 6. Throughput versus number of vehicles

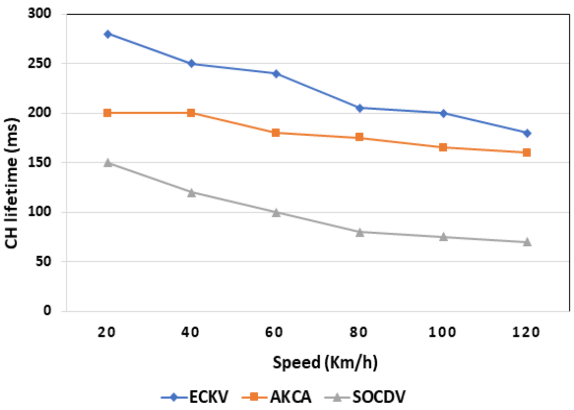

Figure 7. CH lifetime versus speed

3.2.5. CM lifetime

Figure 8 shows that ECKV outperforms AKCA and SOCDV in terms of CM lifetime for different vehicle speeds. In fact, when the speed of the vehicles is high, ECKV reaches a CM lifetime that exceeds 120 s, while the lifetime for other approaches does not exceed 100 s, whereas when the vehicle speed is low, ECKV and AKCA offer a higher CM lifetime than SOCDV, with a slight advantage of the proposed scheme. CM lifetime is affected by the frequent disconnections between CH and its neighbors. The dynamic nature of the topology requires frequent updates of the cluster structure triggering the cluster maintenance step multiple times. To deal with this challenge, ECKV uses ETX and free buffer size metrics to select vehicles as CHs, which ensures that these CHs keep their status for a long time. Also, the proposed scheme introduces mobility parameters such as distance, speed, and direction in the creation and formation of clusters. In this way, member vehicles remain attached to their clusters and are not affected by high mobility and a large change in topology.

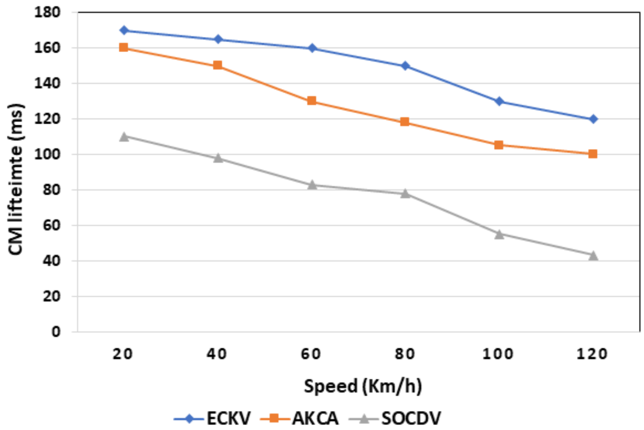

Figure 8. CM lifetime versus speed

4. CONCLUSION

ECKV is an efficient clustering scheme that builds on three key improvements. First, positioning the CHs using a mathematical model that considers network characteristics instead of random selection. Second, a similarity function helps construct clusters combining the speed, distance, and direction of vehicles in one metric. Third, reorganization of the network upon disruptive events is ensured by the use of a cost function factoring free buffer size and expected transmission count in each node. In this paper, we conclude that ECKV provides a significant performance improvement over other algorithm such as AKCA and SOCDV. We found that ECKV enhances the stability of the network by effectively increasing the throughput and PDR, while reducing end to end delay. For our future work, we intend to further improve our algorithm to accommodate an urban scenario.

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