A Distributed Multi-hop Clustering Algorithm for Infrastructure-Less Vehicular Ad-Hoc Networks

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Abstract. Vehicular Ad-hoc Networks (VANETs) aim to improve travailing safety, comfort and efficiency via enabling communication between vehicles and between vehicles and infrastructure. Clustering is proposed as a promising technique to efficiently manage and deal with highly dynamic and dense features of vehicular topology. However, clustering generates a high number of control messages to manage and maintain the clustering structure. In this paper, we present our work that aims to facilitate the management of the disconnected infrastructure-less VANET areas by organizing the network topology using a distributed multi-hop clustering algorithm. The proposed algorithm is an enhanced version of the distributed version of LTE for V2X communications (LTE4V2X-D) [7] framework for the infrastructure-less VANET zone. We are able to improve the performance of LTE4V2X-D to better support clustering stability while decreasing clustering overhead. This is made possible due to a judicious choice of metrics for the selection of cluster heads and maintenance of clusters. Our algorithm uses a combination of three metrics, vehicle direction, velocity and position, in order to select a cluster-head that will have the longest lifetime in the cluster. The simulation comparison results of the proposed algorithm with LTE4V2X-D demonstrate the effectiveness of the novel enhanced clustering algorithm through the considerable improvement in the cluster stability and overhead.

Keywords: Infrastructure-less VANET · Distributed multi-hop clustering
Cluster stability

1 Introduction

Vehicular Ad-Hoc Network (VANET) enables mobile vehicles to communicate with each other in infrastructure-less mode through vehicle to vehicle (V2V) communication and with the road side infrastructure in infrastructure-based mode through vehicle to

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infrastructure (V2I) communication. VANET is important to enhance traffic safety, comfort and efficiency. However, due to vehicles' high mobility and sparse topology, it is challenging to route the messages to their final destination in VANET and gain aforementioned benefits effectively and efficiently [1]. One of the most frequently used solutions to address this challenge is clustering. Clustering involves organizing a set of vehicles in smaller groups based on some predefined criteria like density, velocity, and geographical location. Clustering in VANET exhibits good scalability because it can provide a simple information management mechanism and improve communication efficiency [2]. In fact of this, various types of clustering algorithms have been proposed.

There are at least three phases in clustering algorithms. Neighborhood detection phase is the first phase in which vehicles in proximity are detected. This is possible because each vehicle broadcasts a periodic simple HELLO message containing its identifier, position and list of its neighbors. The next phase is cluster formation. In this phase, actual clusters are formed according to clustering algorithms and for each cluster, a cluster head (CH) is elected. The cluster head is a vehicle selected as a group leader or intra-cluster control server and has the responsibility of ensuring functionalities such as routing. The third phase, cluster maintenance phase, updates the cluster whenever there is any change in the structure of the cluster, due to the arrival of new vehicles, the exit of member vehicles or the transfer of the CH role to another vehicle in the cluster.

Clustering has got a lot of attentions in researches due to its many merits. Some of the literatures that deal with clustering are [1–5]. Clustering reduces network management, limits message broadcasting, allows hierarchical routing and network self-organization, reduces resource contention, facilitates scaling, etc. The difficulty of clusters management due to the high dynamic/dense topology and the overhead due to a large number of messages exchanged between vehicles for the maintenance of clusters represent the main challenges in clustering.

The reliability of any network depends largely on its ability to maintain a satisfactory level of stability. The adoption of clustering in the design of a vehicular network must take care of this problem given the highly dynamic nature of the topology of this type of network and the high mobility of the vehicles that characterizes it. Numerous researches have been carried out to meet this requirement and have proposed solutions that integrate the presence of base stations to ensure the maintenance of network stability through centralized management of clusters and CHs [4, 14]. As the focus of our study is the deployment of VANETs in areas with insufficient or no fixed infrastructure, centralization based on the use of roadside infrastructure is no longer considered. In our approach self-organization of the vehicles is possible by interconnecting vehicles using wireless technology especially IEEE 802.11p[1] that assists in forming a temporary and dynamic network without the help of pre-existing infrastructure, centralized administration or a fixed medium. That is in infrastructure-less VANET each vehicle in the VANET network is a vehicle that acts as the sender,

[1] The IEEE 802.11p standard is an amendment to the IEEE802.11 standard that the IEEE Working Group (TGP: Task Group p) began developing in 2004 for wireless access in Intelligent Transport Systems. It defines the specifications of the MAC and PHY layers in the context of vehicular networks.

receiver, and router. In these conditions, the importance of maintaining the stability of the network becomes even more important.

Therefore, the solution we propose to address this challenge is to develop a distributed clustering protocol based on the choice of CHs that are as stable as possible. For this purpose, we have introduced election criteria for favoring the vehicle that will remain the longest time in its cluster. Our contribution relies on the distributed version of LTE for V2X communications [7] framework (we call it in this paper LTE4V2X-D protocol) for organizing the network. The new clustering protocol has five phases which can be mapped to the three general phases discussed above.

The rest of this paper is organized as follows. Section 2 describes background and motivation including a brief literature review. Section 3 presents the proposed clustering protocol. Simulation results are explained in Sect. 4. Finally, conclusion is drawn and future works are stated in Sect. 5.

2 Background and Motivation

2.1 Clustering in VANET

In clustering, the whole vehicular network is divided into groups (clusters) each one having a leader, known as CH. The cluster member vehicles transmit data to their respective CH and the CH performs aggregation/diffusion operations on this data. There are different ways of cluster formation and cluster head selection. Based on whether a central component is used or not, it can be centralized or distributed. In distributed approach cluster formation and CH selection is done by the vehicles themselves [7]. In centralized approach cluster formation and CH selection are performed at central component by roadside units [4]. Based on the number of hops separating a cluster head from its cluster member vehicles, clustering algorithms can be classified into two: 1-hop algorithm and k-hop algorithm. In a 1-hop algorithm, the distance between two member vehicles in a cluster does not exceed 2 hops so that the distance between the member vehicles and their associated CH is maintained at a single hop [8–10]. In k-hop algorithms, the CH can reach member vehicles of its most remote cluster by performing multiple jumps through intermediate member vehicles [11, 12]. Therefore, it is no longer required to maintain a direct connection with its associated vehicles. Various algorithms have been proposed for each clustering approach and each of them has its own advantages and disadvantages. There are many other ways to classify clustering mechanisms. For more details readers are advised to refer [1, 6].

2.2 LTE for V2X Communications -LTE4V2X

An innovative solution for a centralized organization of vehicular network using Fourth Generation Long Term Evolution (4G LTE) cellular network is proposed in [4]. In this paper, Rémy et al. come up with an idea of using LTE for centrally managing VANET clusters by observing widespread nature of the LTE network that has high potential to extend the coverage area of fixed infrastructure of a network through the use of eNodeB base stations to replace the Road Side Units (RSUs). LTE4V2X jointly uses both

802.11p and LTE technologies to provide an efficient means for periodically collecting data from vehicles and send them to a central server. The evaluation results of the proposed framework showed performance improvement over decentralized approach. As continuity of their work in [4], the authors have presented two extensions of the clustering protocol, LTE4V2X: a centralized version (we called it LTE4V2X-C) with one-hop for the areas covered by the fixed LTE-infrastructure, and a multi-hop distributed version (LTE4V2X-D) for areas not covered by the LTE- infrastructure [7]. Recently, in [5] Ucar et al. have proposed a hybrid architecture, called MaSC-LTE, combining IEEE 802.11p-based multi-hop clustering and 4G LTE, with the goal of achieving a high data packet delivery ratio and low delay while keeping the usage of the cellular architecture at a minimum level. In this method, CH selection is based on the relative mobility metric calculated as the average relative speed with respect to the neighboring vehicles and cluster connection with minimum overhead. This is achieved by introducing a direct connection to the neighbor that is already a head or a member of a cluster instead of connecting to the CH in multiple hops.

In this paper, we are particularly interested in the distributed multi-hop version of LTE4V2X-D based on V2V communications and dedicated for non-covered areas by the fixed network infrastructures. Despite its proven effectiveness, LTE4V2X-D has certain limitations because the method used elects the closest vehicle to the end of cluster segment as CH. This damages stability of the clusters as the vehicles moving at a high speed have a short life as CH. It also causes high control overhead due to the frequent execution of the CH election process. Moreover, the immediate disconnection of CH as soon as it leaves its cluster lets the cluster without coordinator during the whole re-election phase of a new CH, which can destabilize the whole structure. The last limitation we have observed is when a vehicle leaves a cluster, it is immediately disconnected from its CH and will not be assigned to any other cluster until the next maintenance cycle.

Therefore, starting from the limitations observed in the LTE4V2X-D algorithm, we propose a novel enhanced protocol that is able to overcome these limits and ensures a higher stability of the structure while reducing control overhead. In our method based on a fixed geographical division of the road segment, cluster head election is decided by vehicle's closeness to the beginning of the segment. This resolves most of the aforementioned problems. For the last limitation, if a member vehicle leaves its cluster, it remains connected to its CH until it synchronizes and gets integrated with its new CH in the new cluster.

3 A Distributed Multi-hop Clustering Algorithm for Infrastructure-Less VANET

This section presents our new distributed multi-hop clustering algorithm for the organization and management of vehicular networks in non-covered areas (infrastructure-less VANET). Architectures based on a fixed infrastructure like RSUs for V2I communications have many limitations. Firstly, the RSUs coverage area is very short and connectivity between a vehicle and an RSU is often intermittent. Moreover, deployment of infrastructure is expensive and the number of RSUs is often insufficient.

Our contribution involves the introduction of a distributed multi-hop protocol that depends mainly on V2V communications, enabling it to be implemented in an environment with poorly fixed infrastructure or where the infrastructure is absent at all. This is possible since each vehicle is equipped with an integrated unit called On Board Unit (OBU) with IEEE 802.11p interface which allows direct communication from vehicle to vehicle.

3.1 Basic Idea

The basic idea of our algorithm is inspired by the work LTE4V2X in [7]. This architecture uses a centralized one hop version (*i.e.,* LTE4V2X-C) based on cellular infrastructure in cases where there is LTE coverage and a distributed multihop extension (*i.e.,* LTE4V2X-D) is used in the areas where there is no LTE coverage for example in tunnels. LTE4V2X-D is based on the decentralized self-organizing protocol, Clustering Gathering Protocol (CGP) in [14]. A fixed geographical clusters topology is used to organize the network. The road is segmented into equal length segments and each segment representing a cluster, see Fig. 1.

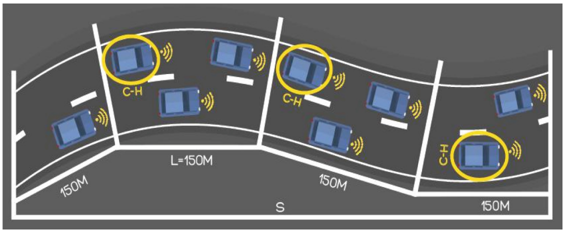

Fig. 1. The static equal road segments in our algorithm.

Even though the experimental coverage range of the IEEE 802.11p interface is about 300 m, we opted for segments of length 150 m to ensure the vehicle in the adjacent segments reach each other [7]. Note that CH is a vehicle closest to the beginning of each segment and with the slowest speed.

For correct functioning of our solution we assume that;

- In addition to OBU with IEE802.11p interface, each vehicle is equipped with Global Positioning System (GPS) which will indicate its position in real time,
- Traffic is constant on the road and a vehicle that breaks down is not taken into consideration, so the network remains reliable.

3.2 Algorithm Description

In our proposed distributed algorithm, all vehicles participate in the CH election and maintenance. The CH acts as a control server for all member vehicles in its cluster and will also manage intra-cluster and inter-cluster communications using a multi-hop method to route packets between different clusters. The algorithm implements the distributed clustering protocol in five phases. The first phase of this protocol is the initialization phase that will trigger the clustering algorithm. It will be followed by four periodic phases, the aim of which will be the formation of clusters, the election of the CHs, the maintenance of the clusters and finally the collection and routing phase, as illustrated in Fig. 2.

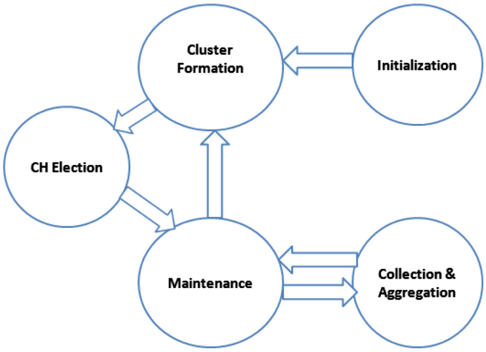

Fig. 2. Phases of the proposed algorithm.

During the initialization phase, each vehicle calculates its Floating Car Data (FCD), *i.e.*, its position, speed, and direction. This phase is carried out only once, when the protocol starts and allows the mobile vehicles to know their data information necessary for the proper operation of the following phases. The next phase, cluster formation phase, is executed in a distributed way and is ensured by all the vehicles. Each vehicle according to its position calculated from the GPS and the information provided by the road map can determine on which cluster it is located and therefore to which cluster it belongs. A cluster includes all vehicles that run in the same direction and are on the same segment.

After the cluster formation phase, each vehicle will run the CH election algorithm to determine a CH in each segment. A CH once elected will retain its status until it leaves its cluster. Distance, speed and direction are the metrics used for the choice of the best CH candidate. Based on these criteria, we determined a heuristic to calculate the weight of each vehicle to determine the best candidate to be CH. The travel time of a vehicle is represented by the ratio between the distance separating this vehicle from the end of its segment and its speed. The distance is determined by the position of the vehicle inside its cluster. The travel time for i^{th} vehicle ($T_{\text{Traveling}}$ (i)) is therefore calculated as follows:

$$T_{\text{Traveling}}(\mathrm{i}) = \frac{Distance(position(i), Segment\_End)}{Speed(i)} \quad (1)$$

At the beginning of CH election, each vehicle will potentially broadcast a CH_ANNOUNCE (CH status) message after observing a wait time. This timeout represents the back-off time plus the time required for sending a packet from one end of the cluster to the other, called sending time (T_S) [7]. As one tries to determine the vehicle that has the highest traveling time of its segment it is to say the vehicle having the smallest back-off time. Therefore, the back-off time of vehicle *i* ($T_{bac\text{-}koff}$ (i)) is equal to the inverse of the segment travel time and it is given by the following formula:

$$T_{back-off}(i) = \frac{\text{Speed (i)}}{\text{Distance (position (i), Segment\_End)}} \tag{2}$$

The application of this back-off time calculation formula will determine which vehicle is the most likely to be CH. The sending time of a message from one end to the other of the segment is obtained by the following formula:

$$T_s(\mathrm{i}) = \frac{\text{Length of Segment}}{\text{Packet\_Sending\_Speed(i)}} \tag{3}$$

The waiting time required for a vehicle *i* to transmit its message CH_ANNOUNCE is obtained by adding the back-off time and the time of routing a message from one end of the segment to the other:

$$T_{waiting}(i) = T_{back-off}(i) + T_s^{-1}(i) \tag{4}$$

Each vehicle will calculate its back-off time using formula (2), and then wait for a certain calculated time in formula (4) before sending a CH_ANNOUNCE message. If a vehicle receives a message CH_ANNOUNCE then it will have to cancel the sending of its own message and considers that the source vehicle of the message is a better candidate than him to be CH. Thus, the vehicle that receives no message will be elected CH because it was the first to send its message CH_ANNOUNCE because having the smallest back-off time is due to the fact that it has the smallest weight. Finally, the newly elected CH broadcasts to all the vehicles of the segment to inform them that it is the new CH. The algorithm for the election of CH is summarized below:

```
Initially all vehiclesare considered cluster members.
For Each vehicle i do
    Calculate the back-off time
    Wait for the expiration of a certain delay (T_waiting)
    If a message CH_ANNOUNCE_j is received then
          Cancel sending CH_ANNOUNCE_i (do nothing)
          Otherwise, Log in as CH and Distribute a message CH_ANNOUNCE in
       the cluster
    End if
 End For
```

The maintenance of clusters is a crucial phase in order to guarantee the stability of the clustering structure, which is very important due to the highly dynamic nature of the VANETs. The objective of this phase is to maintain connectivity between the clusters in spite of the changes that may occur, because of the arrival or departure of a vehicle, through periodic checks. A new vehicle arrives and indicates its presence in the new cluster by broadcasting a HELLO_MEMBER message (the message contains its ID, its IP, as well as its POSITION). This message will enable the vehicle to ask the CH to integrate it into its cluster. Receiving a CH_ANNOUNCE message will indicate that the message is part of the cluster. The newly arrived vehicle will then update its cluster ID. The CH will also update the data concerning its member clusters. Finally, an updating of the topology packet is carried out by the CH and diffused accordingly during the periodic operations. If the new vehicle does not receive a message CH_ANNOUNCE for the duration of one cycle, the vehicle that has just arrived automatically becomes the cluster-head. This CH status of the newly arrived vehicle is justified by the fact that it is at the beginning of the segment thus meeting the criterion of the election of the CH which stipulates that it is the vehicle furthest from the end of the segment that constitutes the best candidacy to play the role of CH. Algorithm for integration of a new vehicle is summarized next:

```
    As long as the number of new unassigned vehicles remaining > 0 do
          Broadcast of a HELLO_MEMBER message by the newly arrived vehicle
          Wait for a CH_ANNOUNCE message to be received.
          If the new vehicle has received a message CH_ANNOUNCE then
           The vehicle sends its coordinates to the CH.
           The CH integrates the new vehicle into its list.
           The new vehicle updates the information in its new cluster
          End if
          If the new vehicle does not receive any message then
            The new vehicle is elected as the CH of the new cluster
         End if
End As long as
```

The departure of a vehicle can seriously disrupt the stability of a cluster especially if the vehicle is a CH. If a vehicle crosses the boundary of its segment, its CH will be able to detect its departure by comparing its new position with the boundaries of the segment. However, the vehicle always remains connected to the CH of its old cluster until it is integrated into a new cluster. This choice has been made so that even if the vehicle has left the segment it always remains in the coverage area of the CH of its former segment. This approach has double advantage of overcoming the problem of changing the topology inherent in the VANETs and of avoiding an early loss of information which will affect the reliability of the network. This mechanism is largely inspired by the concept of seamless handover in cellular networks. Once the vehicle is connected to its new CH, it will be removed from the member list of its old CH during the periodic checks step in the next cycle. During the periodic operations step, the new CH will update the topology packet and distribute it accordingly. In the event that the vehicle that is about to leave the segment is CH, it must first start the phase of electing a new CH from its cluster vehicles to ensure polling before disconnecting. A lapse of time is observed to guarantee the continuity of the service during which the old CH transmits the data packets collected during its mandate to the new CH. High level algorithm for the departure of a vehicle is described below:

```
As long as the vehicle is no longer part of the segment
         If the outgoing vehicle is CH then
           Start CH election phase
           Perform data transfer
         Disconnect from the old cluster.
         Else
          Disconnect from the old cluster.
          Delete the vehicle from the CH list of the old cluster
         End if
 End As long as
```

After the initialization phase, periodic checks are carried out at all times in order to maintain a stable structure and ensure the longest possible lifetime at the CH. The objective of this phase is to initiate different operations and functions of the algorithm with each change in the topology of the network.

During the last phase, data collection and aggregation phase, each CH receives information about its cluster vehicles and their data. Once collected, they are aggregated, compressed and possibly routed to the next CH in the case of a collection application.

```
For every second
   For each segment_i Make
          Initiate cluster maintenance
   End For
End For
```

Since the proposed protocol is based on distributed approach, routing and dissemination of data in the network will be done without the intervention of any fixed infrastructure component in a self-organized manner and under the supervision of CHs. Thus, the routing and dissemination of the data in our protocol are done in two ways, intra-cluster routing orchestrated by the CH and an inter-cluster routing from CH to CH. In intra-cluster routing, communication is made through the CH that provides coordination between its member vehicles. In inter-cluster routing, communication between clusters for the dissemination of information across the network is made between CHs. Each CH after having collected the information from its member clusters, aggregates them and transmits to the CH of the neighboring cluster, and so on.

3.3 Description of Some Packets Used by Our Algorithm

Different packets are used by our protocol during the different phases of its execution. *Vehicle Identification packet* contains the vehicle identifier, IPV4 address, direction, position, speed and collected data. The vehicle transmits this packet periodically to its CH to allow maintenance operations to keep the network structure up-to-date. *Cluster ID packet* identifies each cluster by cluster identifier, the CH, the number of vehicles in the cluster at particular time, the dimensions of the cluster (width and height), list of vehicles and their data. These data are compressed using an algorithm to decrease its volumes. *Notification packet*, on the other hand, is used to report accident alerts, blocked roads or incidents that require notification of the situation. In this case, the notification message is broadcasted to all vehicles or to only those which will be concerned with respect to the position, the zone and the time of the event. *Network topology packet* contains all the cluster information, the cluster member vehicles as well as the data scattered in the network that each CH needs to know to fulfill its mission. An example of network topology packets is shown in Fig. 3.

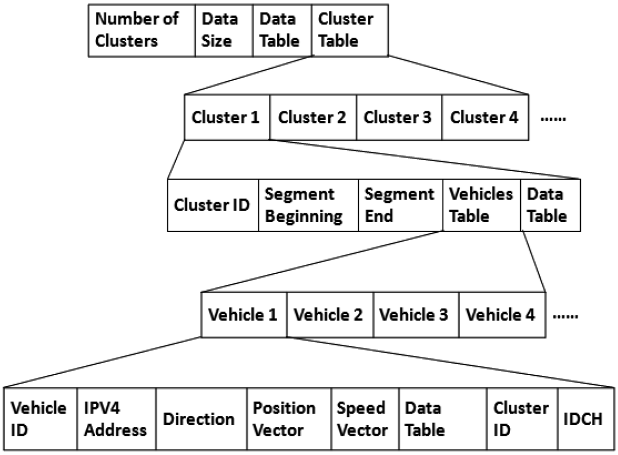

Fig. 3. Example of network topology packet.

4 Simulations Results

In order to evaluate the proposed clustering protocol, we have used discrete event network simulator ns-3 [15] for network simulation and the traffic simulator SUMO [16] to generate traffic mobility traces. The main propose of the simulation is to evaluate the stability and efficiency of our clustering algorithm/protocol in term of control overhead, cluster-head lifetime and re-election while comparing the performance with that of LTE4V2X-D.

For the simulation model, we use Open Street Map [17] to simulate an infrastructure-less road segment from Constantine city, Algeria deployed on 1200 × 1200 m area, as illustrated in Fig. 4. The road is divided into equal segments of 150 m each. The vehicle density is 20 vehicles and they communicate only using V2V multi-hop communication through IEEE 802.11p based interface. The transmission range of the IEEE 802.11p based interface is up to 300 m. The vehicle velocity is between 10 and 30 m\s. The simulation time is 180 s and the packet generation rate is 6 packets per second. The duration of the initiation phase is 2 s and the duration of each cycle is 3 s.

The performance metrics we used are:

- *Cluster-head lifetime*: is the elapsed time between the election of a cluster-head and the time when it leaves the cluster. It represents the cluster stability.

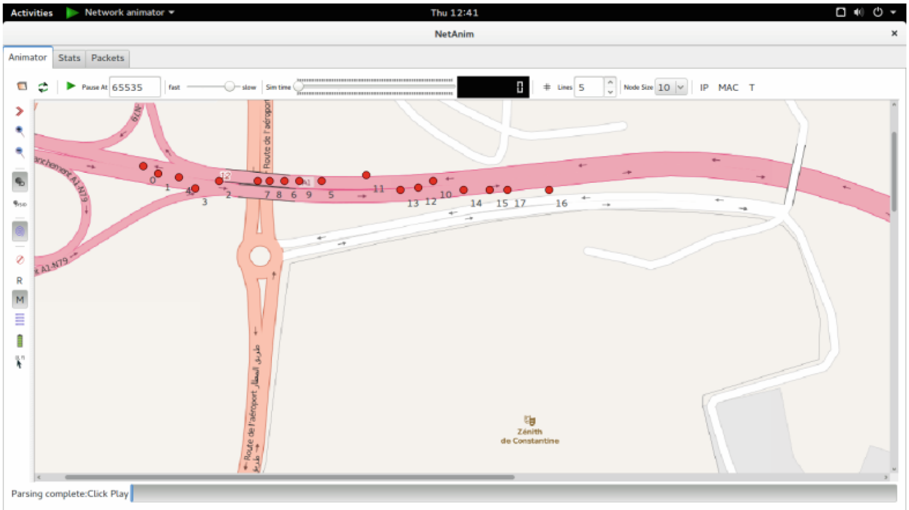

Fig. 4. The simulated scenario.

- *Control overhead message*: it represents the number of control messages used for the clustering procedure.
- *Number of cluster-head re-election*: it represents the number of CH election during a period of time.

In the evaluation results illustrated in Fig. 5, the average CH lifetime in our clustering algorithm for a different number of vehicles is depicted and compared with that of LTE4V2X-D.

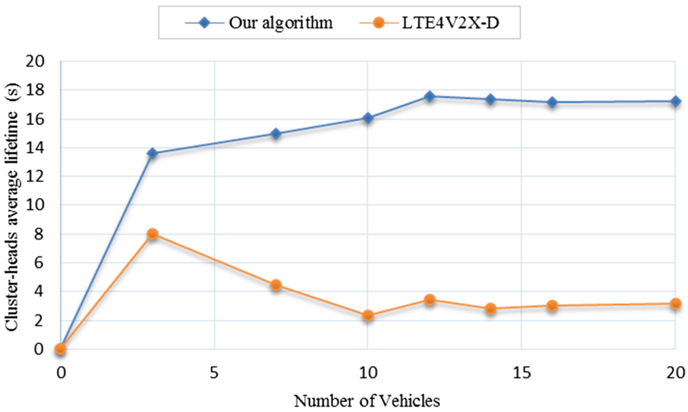

Fig. 5. Impact of vehicles number on the cluster-head lifetime.

It can be seen from Fig. 5 that the CH average lifetime of our clustering algorithm increases regularly with the increase of vehicles number before stabilizing. Contrarily, in LTE4V2X-D the cluster head average lifetime decreases with the increase of the number of vehicles. Moreover, our enhanced algorithm largely overcome LTE4V2X-D in term of the cluster-head average lifetime and can ensure a better stability for the clustering structure and thus for the whole network. This can be justified by the use of good CH election metrics that involves selection of the vehicle nearest to the beginning of the road segment and that has a slow speed. Exactly, the inverse of LTE4V2X-D that elects a vehicle which is nearest to the end of road segment (cluster) and that has the fastest speed use as cluster-head. Our algorithm CH election metrics can ensure good cluster stability via enhancing the cluster-head traverse time (lifetime).

The evaluation figure in Fig. 6 compares the clustering overhead of our clustering algorithm with that of LTE4V2X-D for a different number of vehicles.

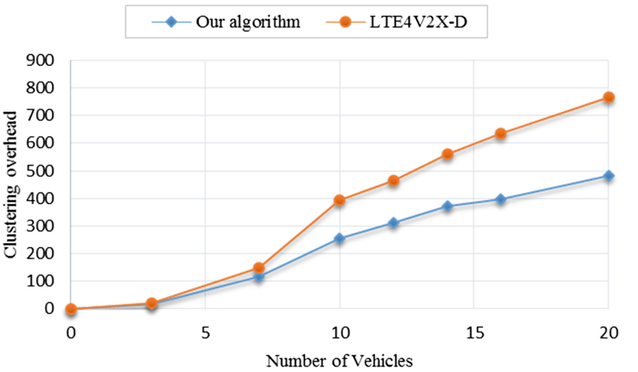

Fig. 6. Clustering overhead versus vehicle number.

The comparison results in Fig. 6, show that the number of messages exchanged in our protocol is clearly lower than LTE4V2X-D and this demonstrates the efficiency of our algorithm in reducing the clustering overhead. This is due to the stability of the clustering structure and the longer CH lifetime as the election is triggered only when it is needed. Therefore, our algorithm decreases the number of CHs re-elections and thus the clustering messages exchanged.

Figure 7 illustrates the comparison of the performance of our enhanced clustering algorithm with LTE4V2X-D in term of cluster-head re-election number for a different number of vehicles.

As we can clearly see from the comparison result above, the performance of our enhanced algorithm is largely better than LTE4V2X-D and can reduce three times the cluster-head re-election number. This can be justified again by the long lifetime of the CH in our algorithm compared to that in LTE4V2X-D.

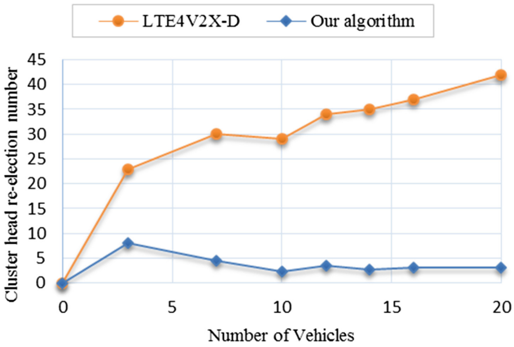

Fig. 7. Cluster head re-election number versus vehicle number.

5 Conclusion

In this paper, we have presented an enhancement of the multi-hop distributed clustering algorithm (LTE4V2X-D) in [7] to better support clustering stability and reduce overhead messages. The analysis carried out on the LTE4V2X-D protocol showed its limitations in terms of maintaining the stability of vehicular network and reducing the overhead, which are two decisive criteria for evaluating the effectiveness of a clustering protocol. On the basis of these limitations, we formulated proposals that were the basis of our solution. We have defined and introduced new metrics for the election of the cluster-head so that the choice is made for the one with the longest service lifetime, thus ensuring more stability for the network. The other outcome of our algorithm is a reduction of the overhead by reducing the number of cluster-head re-election. The protocol, which has taken advantage of the concept of seamless handover, also reduces the rate of packet loss and reduce the risk of a change in topology by providing a connectivity delay for an unexpected cluster-head change. The simulation comparing results of our algorithm with that of LTE4V2X-D, demonstrates the effectiveness of our enhanced clustering algorithm in term of two of the most important clustering metrics: cluster stability and overhead.

As future work, we plan to extend our algorithm for dealing with network partitioning problem and exploit its logic for a dissemination and collection application in infrastructure-less Vehicular Delay Tolerant Network (VDTN).

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