CARSO: Clustering Algorithm for Road Surveillance and Overtaking

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Abstract – Research and development on video streaming over vehicular ad hoc networks (VANETs) have expanded rapidly in the last few years. High-quality video streaming in the vehicular environment is very challenging due to the high nodes mobility, frequently changed network topology as well as video streaming is a high-bandwidth-demanded service and causes network congestion when different vehicles are streaming it in the vehicular network at the same time. Clustering algorithms are effective techniques to reduce network congestion by organizing the work of the network nodes. This paper proposes a clustering algorithm for road surveillance and overtaking (CARSO) which takes in the consideration the vision area, direction, and distance parameters to increase the scalability and provide the video streaming service to the highest number of vehicles. We compared our proposed algorithm with another clustering algorithm in the term of scalability and stability to prove the effectiveness of CARSO.

Index Terms—vehicular ad hoc Network (VANET), clustering, video streaming, Road Surveillance

I. INTRODUCTION

Nowadays, the Vehicular Ad Hoc Network (VANET) is one of the most important topics which is acquiring significant research attention. It is a special kind of Mobile Ad Hoc Network (MANET) which aims to provide efficient communication between the vehicles by enhancing live video delivery, road safety, traffic control, and emergency states. Different wireless technologies in VANET are using vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), and infrastructure-to-vehicle (I2V) communications to enable the vehicles to participate their state information with each other [1]. One of the most important challenges are being worked on recently by VANETs research community is video streaming. Video streaming in VANET enrich drivers and passengers with substantial information comparing to a textual message [2][3]. Clustering is one of the transmission strategies that was applied in VANETs and MANET to improve routing scalability and reliability by grouping them into groups according to their position, speed, direction, and etc. Even though VANET is derived from MANET, the traditional clustering algorithms designed for MANET cannot be applied to VANET directly because VANET has its own characteristics when compared with MANET. Firstly, the nodes in VANET have higher mobility and thus resulting in a highly dynamic topology. Secondly, the node suffers from frequent disconnections. Even in VANET itself, there are many clustering approaches which depend on the purpose of these clusters. Unlike most ad-hoc networks that usually assume a restricted network size, VANETs can be expanded on the whole topology, which involves potentially a great number of vehicular nodes [4]. clustering algorithms provide a good system performance, a good management and stability of the network. Due to the significance of the vehicle clustering, a wide range of algorithms have been proposed for VANET. Most of these algorithms are generic clustering schemes that concentrate on achieving a stable network topology. In general, VANETs clustering algorithms divide associating mobile nodes into virtual groups called clusters. According to some rules set, each cluster selects a cluster head (CH) and the other nodes as cluster members (CM), in which the CH is responsible for cluster maintenance and coordinating the transmission among CMs in the same way as a wireless access point [5][6].

In this paper, an enhanced video streaming clustering algorithm is proposed, in which the CH that has a sufficient vision area is selected to provide video surveillance depending on onboard camera which is substantiated inside the vehicle which gives the conditions of the road to all CMs in the same cluster. This algorithm was compared with another algorithm and showed an effective result in reducing the number of vehicles that are in need of a video streaming service.

This paper is organized as follows. Section II presents the background and related works. In Section III the proposed clustering approach is described, while Section IV shows the simulation environment and the methodology. The performance evaluation results are introduced in Section V. Finally, Section VI concludes the paper.

II. RELATED WORK

Clustering strategy is a mechanism which applied to manage the media access, achieve the quality of service, etc. In the clustering mechanism, there are three states of nodes: cluster head (CH), normal state (NS), and cluster member (CM). in some papers, these names may be different but still the same concept. The CH is the coordinator of the cluster, and the NS is a state when a vehicle does not belong to any cluster. When it joins to a cluster it becomes a CM or it can declare itself as a CH when elected by nearby nodes. Fig. 1. presents an example of vehicular networks with three clusters, where each cluster contains a single CH. The figure also illustrates how the different nodes states are located and grouped.

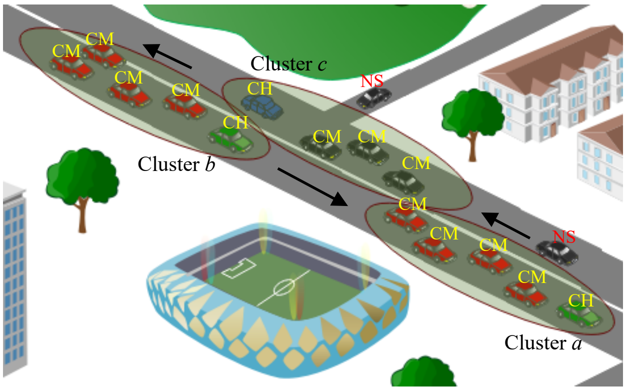

Figure 1. An example of a cluster network topology.

Some researches dealing with clustering mechanism are introduced in this section. In the work of [7], a beacon-based clustering algorithm has been used to prolong the cluster lifetime in VANETs. The proposed clustering technique uses Aggregate Local Mobility. It incorporates a contention method to avoid triggering frequent re-organizations when two cluster heads encounter each other for a short period of time. This approach also prevents over-eager re-clustering upon an accidental contact. A direction-based clustering algorithm (DCA) is presented in [8] by Tal et al. In DCA, the neighbors of one vehicle are classified based on neighbor distance. The algorithm relies on the direction and distance metrics, while the cluster head is chosen as the vehicle with the highest number of close neighbors. This algorithm has been used to increase scalability and stability with considerably reduced overhead and high performance. In. [9] the proposed clustering algorithm computes Aggregate Local Connectivity for each node by aggregating the total number of beacon messages received within a time slot. The leadership nodes then participate in cluster-head election and efficient cluster reorganization. The simulation results show that the proposed approach reduces the overhead of CH nomination and re-nominations. The proposed scheme also leads to fewer status changes by a node within the cluster and has trivial improvement in low vehicle density scenario. The basic idea of a Cluster-Based Overlay algorithm presented in [10] is that any vehicle can be a cluster head if it requires a video and hears no status message about the video. A cluster is created for vehicles that cannot access the RSU (Road-Side Unit) due to the limited number of RSUs that are located on one side of the road in the highway scenario. Most of the papers mentioned above depend on parameters which are not suitable to be considered in the video surveillance and overtaking algorithm. With regard to video streaming and live road surveillance, Effective-Vision-Area-Based Clustering Algorithm with the Adaptive Video-Streaming Technique (EVAC-AV) [11] was proposed as a solution for this kind of clustering. The cluster is originated when a vehicle sends a request to join a cluster for having a live road surveillance service. This operation triggers the vehicles, which are ahead of it to calculate their own vision area. They are considered as candidate CHs if their own vision area is larger than a predefined vision area threshold. The vehicle with the largest vision area will declare itself as a CH and all the vehicles behind it join the cluster including candidate CHs. It also proposes a distance threshold to limit the size of each cluster to prevent the vehicles that are too far from joining to the cluster. This can cause a problem in this algorithm which is that many vehicles that do not have vision area and need to identify their road conditions cannot find a suitable CH. The reason for this problem is that some candidate CHs join clusters as CMs despite of their ideal position to be CHs for these vehicles which are incapable of joining any cluster as well as the limited cluster size. This gave rise to the idea of proposing a new clustering algorithm is capable to construct additional clusters if needed taking into account the stability of them. These additional clusters overcome this problem by absorbing the vehicles which need video services.

III. Proposed Algorithm

Many proposed clustering algorithms used different techniques in selecting the most appropriate cluster head and considered multiple clustering metrics like mobility, proximity, relative speed, etc. We assume each vehicle is equipped with an onboard unit (OBU) to be able to deal with the IEEE802.11p as a Dedicated Short Range Communications (DSRC) system. The vehicles share their information periodically by broadcasting *Hello* messages. Based on these messages, each vehicle will know its immediate neighbors. This will enable it to participate in cluster head selection. In our proposed algorithm for road surveillance and overtaking, we defined requirements that must be taken into consideration when selecting the CH: (i.) the CH vehicle must be in front of the group, (ii.) The vehicle must have enough vision range in order to provide efficient video streams to cluster members. The main steps of our proposed algorithms are discussed in details in the following subsections.

A. *Creating Neighbor Table*

Each participating vehicle shares its information with other neighbor vehicles within a communication range that is used to create and maintain a neighbor table. Table I shows the information of *Neighbor Table*.

Where the *VehID* is a unique number assigned to each vehicle for identification, *Position* represents the standard GPS coordinates of the vehicle, *Distance* determines the distance between the neighbor vehicle and the vehicle itself, *Direction* acts the direction of the vehicles expressed as angular value, *VehVision* represents a logical value, which is set to 1 if the vehicle has a sufficient vision area and set to 0 if it does not have. *The state* describes the current state of the neighbor vehicles (CH, NS or CM) and finally, *SSID* represents the cluster identification which is taken from the vehicle name that plays the role of the CH in the cluster.

TABLE I: NEIGHBOR TABLE INFORMATION

VehID	Position	Distance	Direction	VehVision	State	SSID
'70'	[1222,2375]	158.1624	323	0	'CM'	'45'
'B2'	[1208,2394]	134.3985	324	0	'CM'	'45'
'B7'	[1280,2304]	250	320	0	'CM'	'45'

B. *Vehicle Vision Area*

Vision area plays a crucial role in constructing the cluster and specifying the CH, therefore no vehicle can be nominated to be a CH if it does not have sufficient vision area. We suppose all vehicles have a camera installed to capture live road condition. The vision area is determined by specifying the *Distance Threshold (Dth)*. We can say any vehicle has enough vision area if the distance between it and the front neighboring vehicles is greater than the distance threshold and vice versa.

C. *Cluster formation*

At the beginning of clustering, each vehicle is an NS node that means it is not a member of any cluster yet. The vehicles start sensing their neighbors by exchanging status information with their neighbors. Every vehicle collects this information and constructs *Neighbor Table*, which is updated periodically via a specific time called T_{update}. Every vehicle compares its direction θveh with the direction of the vehicles θnei in the neighbor table and maintains only vehicles that have the same direction or have limited direction deviation so that the difference is $|\theta veh- \theta nei| \leq \theta th$. where θth represents the direction deviation threshold. This step is done to prevent the vehicles in the reverse side or in a different street from momentarily participating in the cluster which would have an extremely negative impact on cluster stability. With regard to the angle of deviation, it has been used because the real roads may contain some deviations and the difference in the direction angle of traveling vehicles does not necessarily mean that the vehicles will take different roads. The front and rear vehicles are determined by the location and direction of adjacent vehicles relative to the location and direction of the concerned vehicle. Each vehicle checks its vision area and if it is enough, it will enter Cluster Heading Procedure (CHP) otherwise it will enter Cluster Membership Procedure (CMP) as shown in Fig. 2.

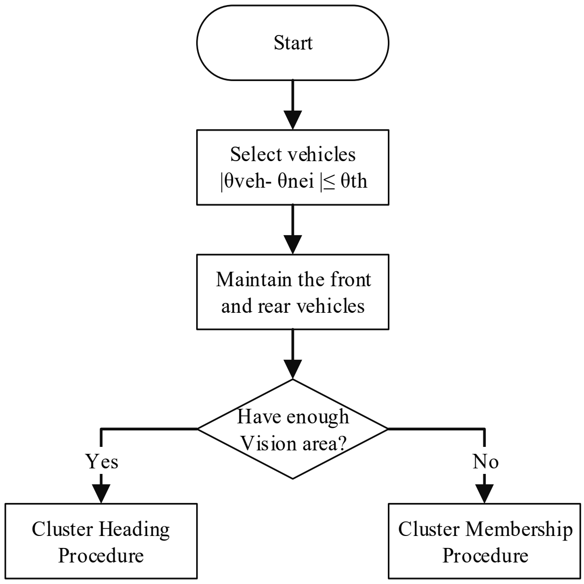

Figure 2. Cluster formation.

In CHP phase, the vehicle will monitor the rear vehicles and it will become a CH if it receives any request from them. Fig. 3 depicts the flowchart of the Cluster Heading Procedure. In CMP phase, the vehicle examines the neighbor table to find a suitable CH (the closest one). If it is found, the vehicle will join the cluster otherwise it will search for any NS vehicle that has a sufficient vision area. If there is more than one vehicle that has road surveillance service, it will select the vehicle which has the lowest distance and sends a request to it. It will join the cluster as CM after the front vehicle becomes a CH. These steps of cluster membership procedure are introduced in Fig. 4.

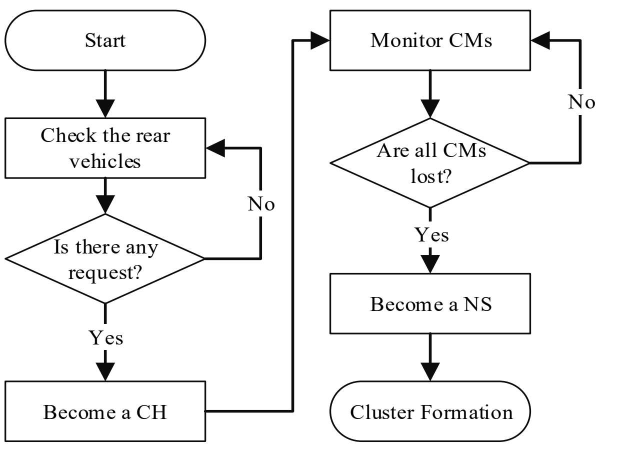

Figure 3. Flowchart of CHP.

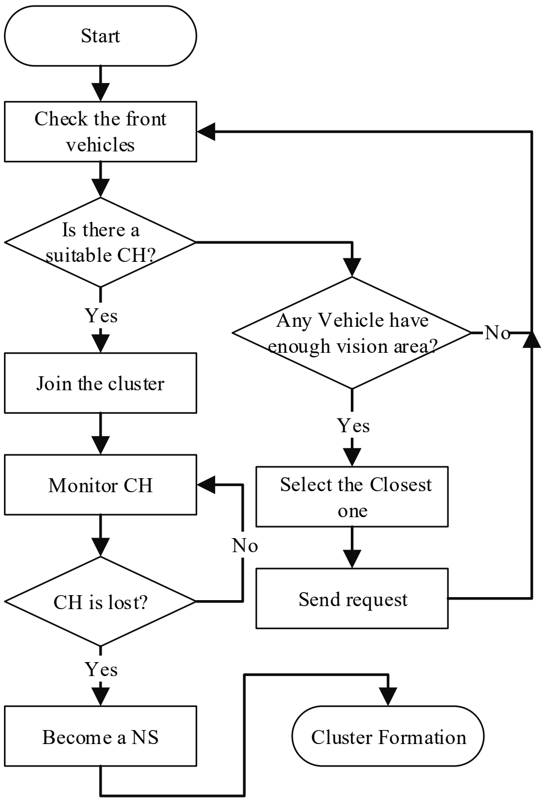

Figure 4. Flowchart of CMP.

D. *Clustering Maintenance*

The clusters after their formation successfully need frequent and continuous maintenance because of the high speed of the vehicles which cause a highly dynamic topology and disconnect frequent network. Clustering maintenance is done in two cases:

Case 1: When the vehicle is a cluster member (CM), it checks two things:

- it checks whether the vision area is sufficient and it does not need road surveillance from the cluster
- it always monitors the CH and in case it has lost the vehicle, the vehicle will leave the cluster and return to the NS and search for another suitable cluster.

Case 2: When the vehicle is a Cluster Head it checks two things:

- if the vision area is not sufficient then the cluster will be disbanded and the CH will return to NS
- the cluster will be disbanded when the CH discovers that all CMs have left.

IV. TOOL & METHODOLOGY

Our proposed clustering algorithm has been evaluated using MATLAB R2017b, while the mobility of vehicles has been simulated with SUMO. The vehicular simulator and MATLAB blocks have been joined together by TraCI (Traffic Control Interface). TraCI creates a TCP connection to make a communication between SUMO and MATLAB. SUMO acts as a server (TraCI-Server) and MATLAB as a client (TraCI-Client) [12].

In our experiments, we have chosen OpenStreetMap (OSM) data because we can get free maps from all around the world. OpenStreetMap is a collaborative project whose aim is to provide a free map of the whole world [13]. The network used in simulation consists of vehicles moving in the urban scenario of Budapest city as shown in Fig. 5.

Figure 5. Map of Budapest city used in the simulation

SUMO includes another tool called *RandomTrips* which generates a file with multiple random trips and generates the flow of vehicles on the map [14]. The values of the main parameters used in the simulation are summarized in Table II.

TABLE II: SIMULATION PARAMETERS

Parameters	Values
Simulation Area	1000 m × 1000 m
Simulation Time	200 sec
Number of vehicles	100-300
Distance threshold	50m-150 m
Coverage area	300 m

V. RESULT

Evaluation the performance of the proposed clustering algorithm was done by comparing our results with EVAC-AV algorithm results only because EVAC-AV that was introduced in the related work section is the only clustering algorithm based on vision area estimations. Our aim is to improve the performance and the stability of EVAC-AV, therefore, it is adopted as a benchmark algorithm. The rest of the other algorithms have been excluded from the comparison because they differ in terms of purpose, parameters, and calibration. The following three performance metrics were used:

- the number of CHs, CMs, and NSs.
- percentage of remaining NS-No-Vision vehicles.
- vehicles status change.

The number of CHs, CMs, NSs is defined as the number of vehicles entering the clusters as CH, CM, and NS. It should be noted that we classified the NS Vehicles into two groups the first is NS-No-Vision Vehicles which represent the vehicles which do not have a sufficient vision area and the second is NS-Vision Vehicles which represent the vehicles that have enough vision area. We made this classification because we are interested in decreasing the number of NS-No-Vision Vehicles by providing a suitable CH for each one of them. However, it's not important at all to reduce NS-Vision Vehicles because they have already enough vision area. Fig. 6 and Fig. 7 show the distribution of Vehicles states of our proposed algorithm in comparison with EVAC-AV algorithm by using different *Dths.* The main goal of our algorithm is to increase the scalability of the network – while preserving its stability. Increasing the scalability can be achieved by reducing the NS-No-Vision Vehicles. Fig. 6 (c) and Fig. 7 (c) showed less number of NS-No-Vision vehicles in comparison with EVAC-AV algorithm.

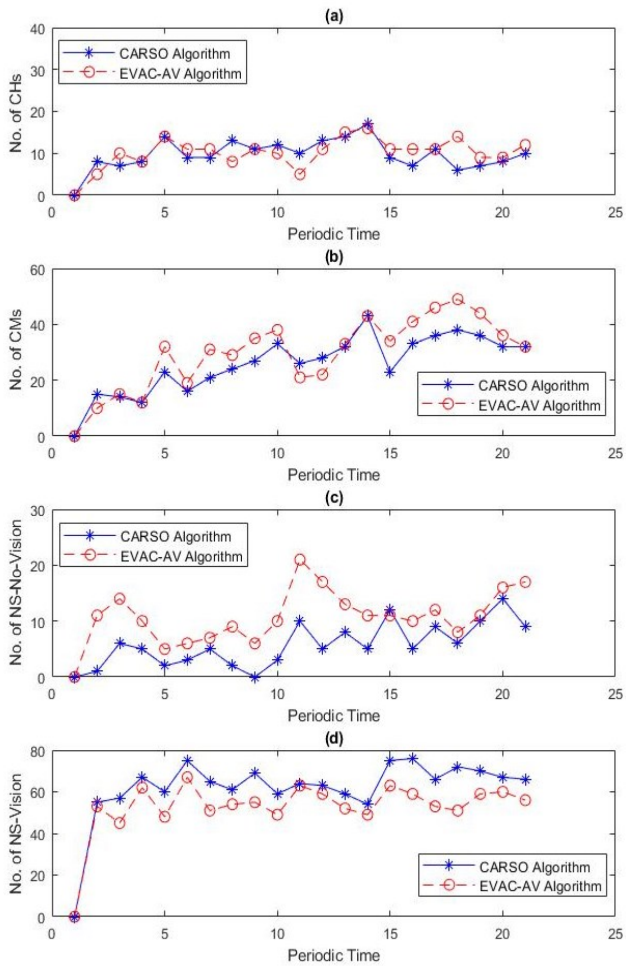

Figure 6. Number of vehicles with *Dth* = 50 m.

The percentage of remaining NS-No-Vision is defined as a ratio of the number of vehicles that do not have vision area and do not belong to any cluster to the total number of vehicles that do not have vision area (NS-No-Vision + CMs). The results have been showed the percentage of remaining NS-No-Vision Vehicles is 19% while EVAC-AV is 36% that means CARSO can provide a video streaming service to 81% of Vehicles that do not have vision area in comparison to 64% in EVAC-AV at Dth = 50 m. At Dth = 100 m, CARSO can provide a video streaming service to 77% of vehicles that do not have enough vision area versus 47% to EVAC-AV algorithm which means that our algorithm is more scalable than EVAC-AV algorithm under different Dths.

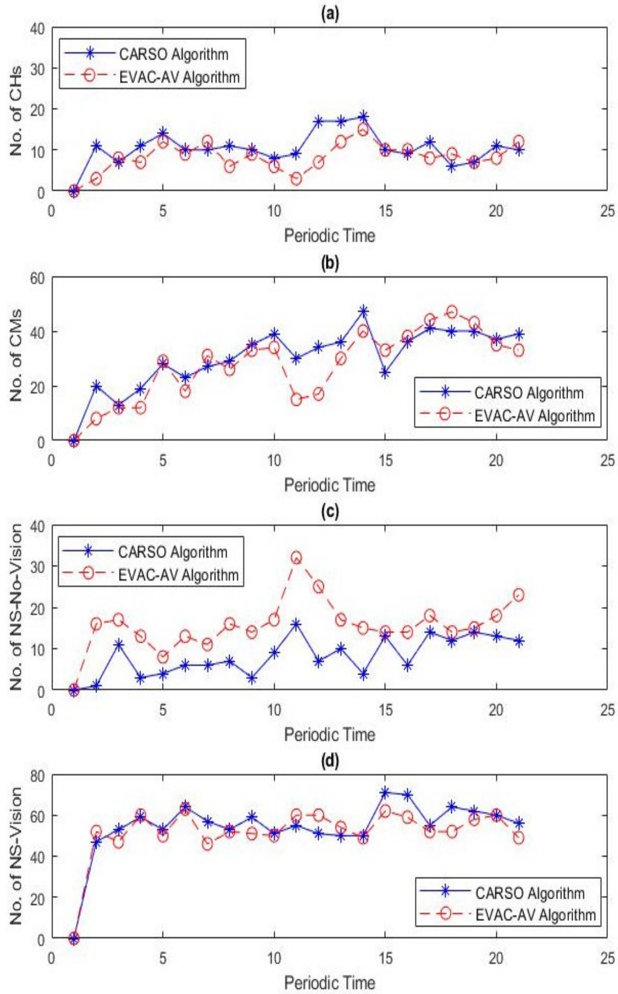

Figure 7. Number of Vehicles with *Dth* = 100 m.

Vehicle status change is defined as the number of status changes per vehicle during its lifetime. A higher value of this measure indicates less stable cluster. This was done by calculating the rate of total changes of status of the vehicles and applying this step by using a different *Dths* and comparing it with the EVAC-AV algorithm under the same conditions. As presented in Fig. 8, the simulation graph shows comparable results in some situations and some differences in others.

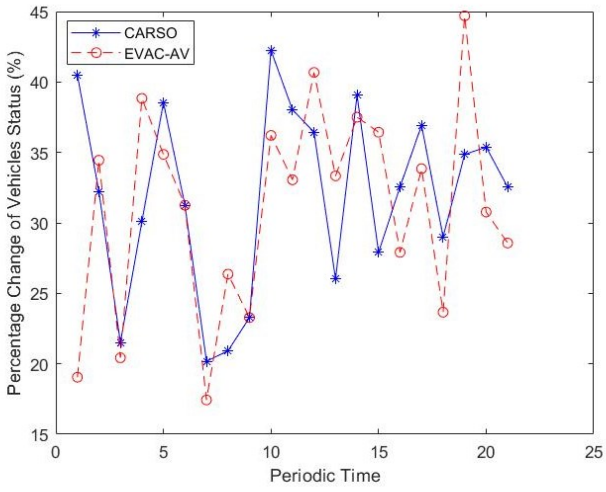

Figure 8. Vehicles status change over time.

VI. CONCLUSION

Video streaming enriches the drivers with substantial information for safety, emergency, and entertainments. Clustering algorithms can be used as effective methods to improve and organize the work of the network. In this paper, a Clustering Algorithm for Road Surveillance and Overtaking (CARSO) is proposed. The proposed algorithm uses the vision area, direction, and distance to decide which vehicle should become the CH. Simulation results showed that our proposed algorithm provides a lower number of NS-No-Vision Vehicles and provides a video streaming service to a higher ratio of vehicles that do not have a sufficient vision area compared to EVAC-AV algorithm with keeping on a comparable clusters stability. The results showed that the proposed algorithm is more scalable compared to EVAC-AV algorithm under different conditions.

In a future study, more metrics like relative speed can be considered in order to obtain more stable clusters and enhance the overall stability of the network.

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