Mesopotamian journal of Computer Science
Vol. (2023), 2023, pp. 115-123
DOI: https://doi.org/10.58496/MJCSC/2023/014 ; ISSN: 2958-6631
https://mesopotamian.press/journals/index.php/cs

Research Article

Clustering Algorithms and Comparisons in Vehicular Ad Hoc Networks

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ARTICLE INFO

Article History

Received 05 Mar 2023
Accepted 15 May 2023
Published 04 Jul 2023

Keywords

VANET

Clustering algorithms

Performance parameters

ABSTRACT

Vehicular Ad hoc Network (VANET) is a new era in the transmission of dynamic information across communities. Intelligent Transportation Systems is only one of the many applications for VANET (ITS). The topology of VANET is extremely dynamic, and connections are irregular. These features cause information transmission in the VANET to be unreliable. Vehicle clustering is a successful strategy to increase the network's scalability and connection dependability. Characteristics of the VANET have an impact on clustering performance as well. An extensive explanation of VANET clustering algorithms is given in this article. A complete evaluation of clustering in VANETs is provided based on the clustering procedure. Most methods examine the clustering process in terms of Cluster Head selection metrics, formation, and its maintenance. The clustering methods are contrasted based on factors such as stability, convergence, overhead, and latency. There is also discussion of some of the most typical issues and the solutions used. Also, a summary of the performance metrics used to assess clustering algorithms is provided.

1 INTRODUCTION

Future generations of transportation technology will largely consist of the Intelligent Transportation System (ITS), that combines all types of vehicle communications. Services from ITS include traffic management, safety software, emergency alerts, and driving assistance [1]. A self-organizing network built from moving vehicles is known as a VANET. Mobile ad hoc network (MANET) is a subset of VANET. MANET is a self-configuring network of nodes that move without a fixed infrastructure. When automobiles are used in place of mobile nodes in MANETs, the network then adopts fixed pathways, such as roadways. In a VANET, nodes move and accelerate on average relatively quickly, which causes the network's topology to change quite quickly [2].

The On-Board Units (OBUs) and Roadside Units (RSUs) of VANET are its components. A RSU, that is set up alongside the road, record all vehicle data, which is then sent to other OBUs. RSUs have no control over any operations requiring the transmission of information in OBUs or vehicles. OBUs are additional components that are built into dynamic vehicles to help with information sharing between RSUs and vehicle components.

The two main VANET communication types are vehicle to vehicle (V2V) with vehicle to infrastructures (V2I) communication. OBU-equipped vehicles are able to interact with each other within their radio ranges while V2I communication, along in addition to the placing of infrastructure along roadside the medians as well as the use of different applications which can improve the excellence of service offered by infrastructure to vehicles, aren't practical. Communications between a vehicle to an object (V2X) can include V2V and V2I.

The name of the communications system designed exclusively for use in cars (DSRC) is Dedicated Short-Range Communication. It has a transition range of 100 to 1000 meters and is designed for information transfer and vehicle-to-vehicle communication [3]. Like Wi-Fi, the DSRC technology operates in a similar manner. The United States' Federal Communication Commission (FCC) has designated a higher spectrum band with a 75 MHz bandwidth [4-6]. DSRC supports both V2V and V2I communications.

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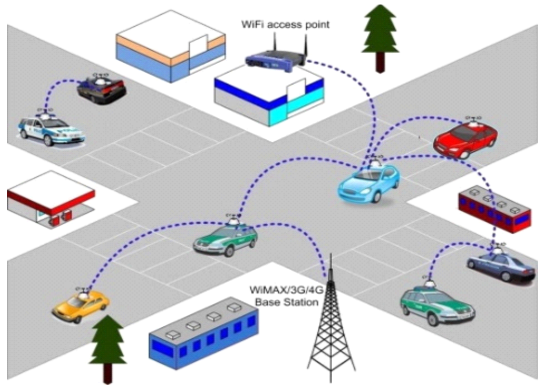

Fig. 1. Vehicular communication types [6]

The primary purposes of VANET are to ensure vehicle safety, manage traffic, and communicate precise vehicle information as shown in figure 1. To get the most data for communication in VANET, the latest clustering techniques are provided. The primary contributions of this paper are as follows: First, we provide a summary of the observed and researched evolution of clustering methods in VANETs from 2010 to 2022. Moreover, the majority of these techniques were not listed in past studies. Second, we compile a list of the current clustering tactics and group them into three categories: Cluster Head selection, cluster formation, and cluster maintenance. Then, we evaluate these algorithms against a variety of criteria. Thirdly, various problems are presented together with the methods employed to solve them. After that, a thorough examination of the most popular metrics for assessing the effectiveness of clustering methods is presented. Network performance metrics and cluster efficiency parameters make up the performance metrics. The simulation tools for each clustering approach are also presented.

2 CLUSTERING IN VANET

Clustering is a well-liked VANET technology that offers a practical approach to improving network services and management. It performs significantly better in a range of applications than the conventional flat structure. Network nodes can be organized into distinct groups known as clusters [7-9]. A group of neighbouring automobiles often forms as a result of numerous significant details and measures. The names of the node in this group include

1. Cluster Head (CH) – This node performs the role of coordinator or cluster leader.The major responsibility of the CH is to enable communication and information sharing among cluster members and other CHs. Several factors are taken into consideration before choosing the CH.
2. Cluster Member (CM) – The nodes in the cluster are the CMs.By sending broadcast messages to one another, these nodes communicate with one another.
3. Gateway Node (GW) – It is not necessary for this node to provide RSU to every cluster in order to aid communication with it.

The cluster-based communication structure used by the VANET is shown in Figure 2. The CH is solely responsible for internal cluster communication. Inter-cluster and intra-cluster communication are the two distinct channels that separate a cluster's internal communication. Predicting node-to-node failure links during cluster maintenance improves the cluster's stability [6].

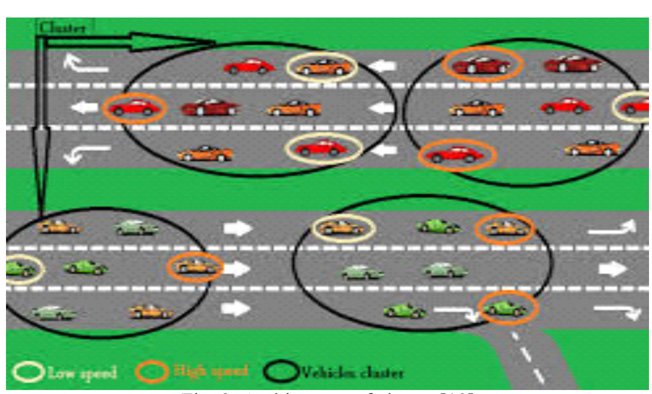

Fig. 2. Architecture of cluster [10]

2.1 VANET clustering algorithms

Due to mobility of VANETs, clustering algorithms that were previously employed in MANETs cannot be employed. Due to the length of time required to complete the clustering phases, additional control overheads can be necessary. In order to maintain the cluster structure dynamically while without dramatically raising network costs, an effective clustering technique should only create a small number of clusters. Three MANETs clustering algorithms—Mobility Based Clustering (MOBIC), Weighted Clustering Algorithm (WCA), and Distributed and Mobility Adaptive Clustering (DMAC)—were created to satisfy the particular needs of vehicular communications. Moreover, the VANET's clustering strategies were mostly borrowed from older MANETs. Since 2010, when the VANET began to expand and develop, several clustering techniques for VANETs have been developed. Table 1 lists numerous VANET clustering techniques that were presented between 2010 and 2022 [11-13].

TABLE I. CLUSTERING ALGORITHMS

Reference	Year	Algorithm	Abbreviations
[3]	2010	Cluster-Based Directional Routing Protocol	CBDRP
[4]	2011	Vehicular clustering based on the Weighted Clustering	VWCA
[5]	2012	Fuzzy LogicBased clustering Algorithm	FLBA
[6]	2012	Stability-Based Clustering Algorithm	SBCA
[7]	2015	Distributed Multi-hop Clustering based on Neighborhood	DMCNF
[8]	2015	Direction based clustering and multi- channel medium	DA-CMAC
[10]	2016	Neighbor stability-based VANETclustering algorithm	NSVC
[11]	2016	MObility-aware and Single-hop Clustering scheme	MOSIC
[12]	2016	Clustering-Based VANET Routing algorithm Protocol	CBVRP
[13]	2018	Deep Reinforcement Learning	DRL
[14]	2018	Unified Framework of Clustering approach	UFC
[15]	2019	Enhanced Weight-basedClustering Algorithm	EWCA
[16]	2019	Hybrid ClusteringAlgorithm based on Roadside	HCAR
[17]	2019	Double-Head Clustering	DHC
[18]	2019	Mobility BasedClustering Algorithm	MBCA

2.2 Clustering in VANETs

To finish this process, there are two stages:

a. First phase- (Cluster Formation): During the cluster formation and CH selection phases, nodes send messages to choose the principal CH and CM; thereafter, regular data packets are sent between them. In order to create a stable cluster, numerous techniques may be used between the transmission of the marketing message and the CH selection.

b. Second phase- (Cluster Maintenance): In this stage, stable cluster merging, secondary CH selection, re-clustering, and cluster splitting take place.

These phases have each been explored separately by several researchers in literature. This section describes the steps and standards used in each clustering process, such as CH selection, cluster building based on hop count, and cluster administration.

c. Cluster generation phase. In order to complete the clusters that have been constructed, this step passes through two processes: cluster creation process and CH selection process. Few clustering algorithms start by choosing the CHs before starting to build clusters. Other clustering algorithms do the opposite.

d. Cluster head selection. The resilience and scalability of the network are significantly impacted by CH stability. Communication within and between clusters is assured by the stable CH. To boost VANET security, a reliable vehicle can only be a CH. Table 2 is a list of some of these techniques and the parameters employed for CH selection.

TABLE II. CH SELECTION METRICS

Reference	Algorithm	CH Selection Metric
[3]	CBDRP	Moving direction
[4]	VWCA	Distrust Level, Degree, Velocity, Direction
[5]	FLBA	Relative velocity
[6]	SBCA	Relative Speed, RSS
[7]	DMCNF	The propagation delay ratio, Number of the following car
[9]	VMaSC-LTE	Lowest average speed
[10]	NSVC	Rate of change of the number of neighbors
[11]	MOSIC	Relative speed, Relative distance, and Relative mobility
[13]	DRL	Q-learning based routing
[14]	UFC	UFC relative position, relative velocity, and link lifetime
[15]	EWCA	Speed, Position
[16]	HCAR	Lowest ID
[17]	DHC	Signal Strength, Relative Speed, Link Lifetime

e. Cluster formation. With the VANET, clusters can be created in a variety of ways, including centrally located and dispersed, single-hop and multi-hop, location service and user information based, etc. The development of clusters based on topology is covered in this section. A cluster architecture in VANETs can be modelled utilising the distance that existing between the CH with its other members, the communication range, or its cluster radius. As a result, only the single-hop and multi-hop categories of algorithms are distinct. (see Figure 3).

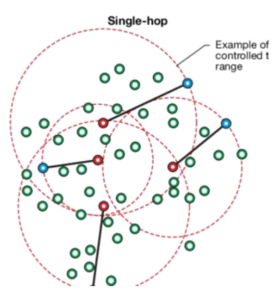

Fig. 3. Single hop model

Single-hop Clustering Algorithm

This is the technique that builds clusters in which every node and its CH are only one hop apart. This implies that each node has a direct connection to the CH. Several clustering techniques directly produce single-hop clusters based on the CH's transmission range or the limited cluster radius.

The performance of single-hop clustering technique is enhanced in terms of security, connection, and stability. Single-hop clustering methods offer CHs very efficient coordination and more dependable intra-cluster communication. Due to the small coverage area of this type of cluster, there are a lot of clusters and a high maintenance cost. Collisions can happen when the number of cars is highly dense, which results in a low PDR. Because the cluster performance will suffer, these two scenarios should be avoided. In summary, low latency and strong cluster stability are provided by single-hop techniques, although clustering coverage still has to be improved. The highest and lowest number of vehicles in a cluster may also be restricted in order to address the problem of both high and low density [14-16].

Multi-hop Clustering Algorithm

Every node in a cluster is a multi-hop distance from their CH when it is built using the multi-hop distance method. The number of clusters can be decreased, the cluster coverage area can be increased, and cluster stability can be improved with multi-hop clustering techniques. The multi-hop approaches provide exceptional cluster stability and coverage, especially in terms of the amount of CM re-affiliation, CH modifications, and cluster endurance. Although the formation of multi-hop clusters is more challenging, it will take a long time for the cluster to form, which can cause a delay in the data transmission. Also, there is room for improvement in the cluster overhead. Also, certain simulation results show that when there are more than three hops, the cluster performance suffers. In other words, cluster performance will suffer as the hop count rises. Table 3 compares the clustering techniques in terms of transmission distance, vehicle density, vehicle speed, hop count, and traffic scenario [17-19].

TABLE III. COMPARISON OF VARIOUS CLUSTERING ALGORITHMS

Algorithm	Transmission	Vehicle	Vehicle Velocity	Hop Count	Traffic
EWCA	300m	50–150	30m/s	Single	Highway
VWCA	Dynamic	10–350	19–33.3m/s	Single	Highway
UFC	300m	200	10–35m/s	Single	Highway
FLBA	200m	0.05–0.4/m	22–33.3m/s	Single	Highway
AMACAD	100–200m	50	11–31 m/s	Single	Urban
HCAR	100m–300m	100	10–40m/s	Single	Highway
MOSIC	200m	100	10–35m/s	Single	Highway
LRCA	200, 500m	1500	10–30m/s	Single	Urban
DHC	300m	50–200	13.830m/s	Single	Highway, urban
NCABAT	150m	60	–	Single	Random
JCV	200m	100	10–35m/s	Single	Highway
DMAC	–	30–200	2, 5, 10m/s	Multi	Random
ALM	–	50–1000	10–30m/s	Multi	Highway
DMCNF	100–300m	100	10–35m/s	Multi	Highway
DMMAC	200m	100–800	22–33.3m/s	Multi	Highway
VMaSC-LTE	200m	100	10–35m/s	Multi	Highway
Sp-Cl	80m, 125m	20–150	22–44m/s	Multi	Highway
TB	150–300m,	400	19, 25, 30m/s	Multi	Highway
AWCP	1000m	25–200	33.3–41.6m/s	Multi	Highway
PMC	100–300m	100	10–35m/s	Multi	Random
RCMS	250m	1200	10–30m/s	Multi	Urban

f. Cluster maintenance: There is high packet loss due to VANET's dynamic topology and frequent vehicle reconnections and disconnection. The cluster management process maintains strong connectivity and also provides a consistent link lifetime through CH by reducing often occurring vehicle re-clustering. The technique involves cluster merging, vehicle acceptance, vehicle leaving, and additional cluster maintenance processes.

When a new vehicle transmits a signal to the CH, then a new vehicle is assigned to cluster then takes over as the CM of that particular cluster. Then CH sends signals often as vehicles join and leave. A local database change will then be made by the CH. The data for a member car is erased from the CH's local database when it can no longer communicate with it. Cluster merging, which can lower the number of clusters and improve clustering efficacy, happens when two or more clusters can be represented by a single merged cluster. The cluster merging requirements varies for each strategy.

2.3 Clustering algorithms comparison

Several distinct parameters are frequently considered when comparing clustering methods. Any clustering algorithm can be built and specified using these parameters. Some crucial factors include cluster security, latency, convergence, and overhead. Table 4 contrasts the benchmark techniques based on these settings. High stability, little overhead, latency, and convergence are features of a successful clustering technique.

TABLE IV. CLUSTERING ALGORITHMS COMPARISON

Algorithm	Cluster Stability	Latency	Overhead	Convergence
EWCA	High Stability	Low Latency	High overhead	Medium
VWCA	High Stability	–	–	Low
DRL	–	Low Latency	Low overhead	–
AWCP	Low Stability	Medium Latency	Low overhead	Medium
DMMAC	High Stability	Low Latency	–	High
VMaSC-LTE	High Stability	Low latency	High overhead	Low
ALM	Low stability	Low latency	Low overhead	Low
UFC	High stability	–	Low overhead	–
ALCA	Improves stability	High latency	High overhead	–
AMACAD	Medium Stability	High latency	–	Low
DMCNF	Improves Stability	–	Low overhead	Low
SBCA	Improves stability	–	Low overhead	Low
CBSC	High Stability	–	–	–
PMC	High stability	Low Latency	Low overhead	Low
CBDRP	High stability	Low Latency	Low overhead	High
HCAR	Improves stability	High latency	Low overhead	Medium
MOSIC	Improves stability		Low overhead	High
LRCA	Improves Stability	Low Latency	Low overhead	–
DHC	High stability	–	Low overhead	Low
NCABAT	Low Stability	Low Delay in High Density	–	–
JCV	High stability	Low latency	Low overhead	–
RCMS	High stability	Low latency	–	High

2.4 Challenges and techniques used for solution

There are numerous studies using various clustering methods available to improve the performance of the network. As stated in Table 5, we examine some of these issues in this section along with the methods used to overcome them. To find solutions, the researchers have looked at a range of problems and applied a range of clustering algorithms.

TABLE V. CHALLENGES AND SOLUTION TECHNIQUE

Reference	Problem	Techniques Used	Performance
[3]	Rapid data transmission, link stability and	CBDRP	Reduces latency and increases the packet delivery ratio and link stability
[6]	Vehiclesfrequently joint and leave the clusters.	SBCA	Improves the stability of the network by reducing the overhead and the cluster lifetime
[7]	Weakness in the network because of high	Multi-hop clustering algorithm (DMCNF)	Improves the stability
[8]	Shortcommunication period	DA-CMAC	Reduces collision and increases reliability of packets
[10]	Problem of delivering data in urban vehicular	NSVC	Guarantees the reliability of delivering emergency messages, increases clustering stability.
[12]	Route selection, stable clustering suitable for	CBVRP	Increases communication efficiency, deliversinformation with ensures reliability, and decreases the routing cost.
[15]	CH Stability.	EWCA	A better clusterstability and overhead delay reduction performance
[16]	High mobility, big data clustering	RSU based Multi-Hop Clustering	Improves cluster stability, and proves the efficiency of the algorithm in theoretical way.
[18]	Stability of Link	MBCA	Multimedia broadcasting has been improved.

3 PERFORMANCE EVALUATION METRICS

Cluster efficiency and network efficiency are both metrics that are most usually used to assess how effectively clustering techniques function. Any clustering technique's effectiveness can be tested and evaluated using a range of parameters.

3.1 Cluster performance parameters

Cluster performance indicators demonstrate the effectiveness of clustering solutions and represent the reliability of the network's core nodes. These variables are used to evaluate the cluster's overall performance and stability. Several metrics for cluster performance include:

- **a. Cluster/CH Stability:** It shows how frequently a particular vehicle has been chosen as a CH overall.
- **b. Cluster number:** It refers of the quantity of clusters that develop throughout network operation. With fewer clusters, the clustering process becomes more successful [6].
- **c. Cluster/CH lifetime:** The vehicle has led the cluster for the longest time ever.
- **d. CM lifetime:** That is how long a node may remain CM. We split the total amount of instances the CM has switched states by the CM's lifetime to obtain its average.
- **e. CH change rate:** It shows the typical progression of the CH number over the course of time.
- **f. Cluster change rate:** Over the duration of a single time unit, each vehicle's average cluster number changes.
- **g. Cluster size:** The total number of vehicles.

High cluster shapes and sizes, lengthy CH and CM a lifetime, limited cluster numbers, and moderate cluster and CH shift rates are characteristics of a good and trustworthy clustering technique. However, these traits fall short in their ability to describe the precise nature of communication links between networked cars.

3.2 Network performance parameters

The performance of the entire network is determined by these variables, which include the following:

- **a. Throughput:** It is the quantity of bits sent over any network every second. The performance of the network is improved when throughput is increased.
- **b. Ratio of packet loss or collision:** The frequency of transmission-related packet losses.
- **c. Packet Delivery Ratio (PDR):** It is the proportion of packets received by the destination to all packets received.
- **d. Overhead:** The vehicle receives an average amount of control messages.
- **e. E2E Delay (End to End Delay) or Latency:** It measures how long a packet takes to travel from its source to its destination.

The dependent on context clustering algorithms for congestion prediction, routing, and data dissemination are estimated using all of these qualities. A reliable and effective clustering strategy results in high PDR, low packet loss rate, short E2E delay, high throughput, and minimal overhead. The factors that were investigated and the simulation tools used for each strategy are shown in Table 6.

TABLE VI. CLUSTERING ALGORITHMS EVALUATION PARAMETERS

Reference	Algorithm	Simulator	Evaluation Parameters
[16]	CBDRP	NS2	Latency, PDR, Average Routing Overhead
[18]	VWCA	MATLAB	CH and CM lifetime, PDR.
[20]	FLBA	NS2, MOVE,	Average CH time, AverageCM's dwell time, Average cluster size.
[26]	SBCA	NS2	Average cluster lifetime, overhead, and packet delivery.
[29]	DMCNF	NS2,	Average CH/CMdurations, Average number of clusters, Average CH change number, and average overhead.
[32]	DA-CMAC	NS3	PDR, CH Changes, Access collision.
[34]	NSVC	–	CH lifetime, CH change, throughput.
[36]	MOSIC	NS3	AverageCH/CM Duration, Average Number of clusters, Average Control Message Overhead, Average CH Changes Rate.
[37]	CBVRP	–	PDR, E2E delay, Number of cluster reconstruction, Routing cost.
[39]	DRL	QualNet7.1,	Average E2E delay, and average PDR.
[40]	UFC	SUMO	CH duration, CM duration, Clustering efficiency,
[44]	EWCA	NS2, SUMO	Cluster stability, number of clusters, and E2E.
[46]	HCAR	NS2, VANET	CH lifetime, average overhead, and number of cluster
[47]	DHC	SUMO	CH/CM lifetime, Number of changed states, packet overhead, Cluster formation rate, CH Alienation.
[52]	MBCA	OMNET++,	Average CH duration, average CM duration, PDR, network delay, and overhead.

4. CONCLUSION

VANETs have seen a number of applications in recent years. The primary purposes of VANET are to ensure vehicle safety, manage traffic, and communicate precise vehicle information. The VANET topology is dynamic because of the fast moving vehicles. Clustering represents one of the efficient solutions to the scalability problems caused by the constantly changing characteristics of the VANET. In order to address various VANETs challenges, this paper gave a thorough survey of the most clustering strategies. We discussed the clustering mechanism in VANETs. An overview of clustering methods over the course of 20 years, along with the quantity of citations they received, was first presented. The techniques and criteria for each clustering phase were then presented, together with the metrics for choosing the CH for each approach, cluster construction using hop distance, and cluster maintenance. We also compared these algorithms based on several important factors to determine how well they performed. Then, we discussed some of the difficulties faced by VANETs, along with the clustering strategies used to address them, and we evaluated the effectiveness of these strategies. We concluded by introducing some of the most used measures for assessing the effectiveness of clustering methods.
According to our survey, cluster stability is one of the main problems in VANETs and the majority of clustering techniques are made for roads. Future work will use hyper-graph theory to create a novel clustering method for VANET that is appropriate for urban settings with the goal of improving clustering stability.

Funding

No funding was received for this study. All expenses associated with this research were covered by the authors.

Conflicts of Interest

The authors declare no conflicts of interest in relation to this research. They have no financial or personal relationships with any individuals or organizations that could potentially influence the results or interpretation of this study.

Acknowledgment

The authors would like to acknowledge their respective institutions for their support and resources provided during this research.

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