Clustering Review in Vehicular Ad hoc Networks: Algorithms, Comparisons, Challenges and Solutions

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Abstract—The Vehicular Ad-hoc Network (VANET) represents a new future for dynamic information dissemination between societies. VANET has a wide range of applications in a variety of aspects, including Intelligent Transportation Systems (ITS). VANET has some characteristics, like highly dynamic topology and intermittent connections. These characteristics lead to untrustworthy information transmission in VANET. Vehicle clustering is an efficient approach to improve the scalability of the network and connection reliability. The performance of the clustering is also affected by VANET characteristics. This article provides a comprehensive description of VANET clustering algorithms. The most notable clustering algorithms introduced between 2010 and 2021 are reviewed. A complete survey on clustering in VANETs is provided based upon the clustering process. The clustering process in most algorithms is explored in the aspects of CH selection metrics, cluster formation, and cluster maintenance. The clustering techniques based on some parameters like stability, convergence, overhead, and latency are compared. Some of the most common problems, as well as the approaches employed to solve them, are also discussed. Also, the performance parameters which evaluate the clustering approaches are summarized.

Keywords—VANET, clustering algorithms, performance parameters

1 Introduction

An important next-generation transportation technology is the Intelligent Transportation System (ITS), which includes all types of vehicle communications. ITS provides a variety of services to passengers including driving assistance, safety applications, emergency warnings, congestion control, and so on [1]. A VANET is a self-organizing network made up of moving vehicles. Because of the expanding number of applications aimed at passenger safety, VANET is garnering a lot of interest from wireless network manufacturers and academics. VANET is a subset of Mobile Ad Hoc Network

(MANET). MANET is a network of mobile nodes connected via wireless communication that does not have a fixed infrastructure and is self-configuring. The network becomes a VANET when the mobile nodes in MANETs are exchanged by cars and then begin to follow fixed routes, like roads. The major advantage of VANET is to provide congestion control and road safety to the vehicles by making communication among them to share the information. The average speed and mobility of nodes in VANET are quite high, resulting in a rapid change in the network structure; these are its distinguishing features [2]. In the early 1990s, people began to pay greater attention to VANET technologies, and it has grown in importance in subsequent years.

VANET's components are; Road side units (RSUs) and On-Board Units (OBUs). The RSUs are put alongside the road, and saved all information of the vehicle then forwarded to other OBUs. RSUs have complete control over the transmission of information jobs in OBUs or vehicles. Moreover, OBUs are devices that are installed in dynamic vehicles to facilitate information sharing between the cars and RSUs.

Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communication are the two types of VANET communications. In V2V communications, Vehicles equipped with OBUs can communicate directly with each other inside their radio ranges, whereas V2I communication, as well as the deployment of infrastructure along roadsides and the various applications that can increase the quality of service provided by infrastructures to vehicles. V2V and V2I can be included as Vehicle to X (V2X) communications. It is the communications between vehicles and communications between vehicles and other terminals, such as RSUs [3], [4].

A Dedicated Short-Range Communication (DSRC) is a communications system designed specifically for use in automobiles. It is proposed for transmission information and communication among vehicles with a transition range of 100 to 1000m [3]. The DSRC system works in a similar way to how Wi-Fi works. The Federal Communication Commission (FCC) of the United States has assigned a higher spectrum band with a range of 75 MHz [5], [6]. Both V2V and V2I communications are supported by DSRC.

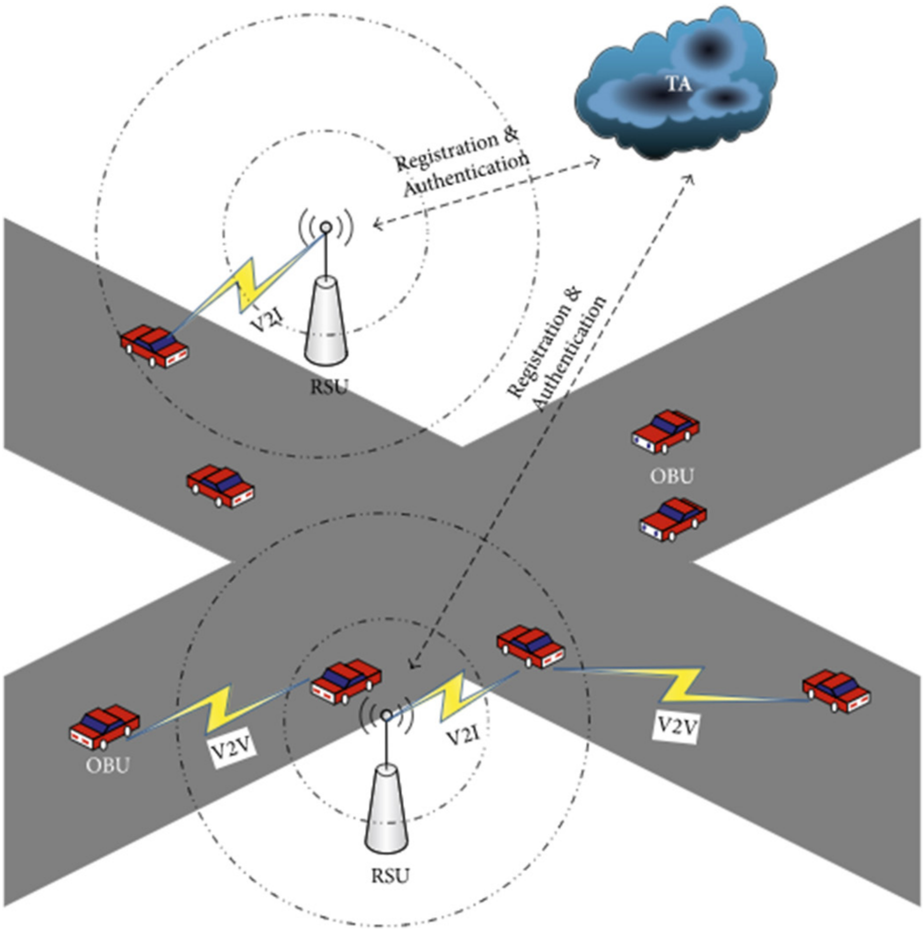

Fig. 1. Vehicular communications types [6]

Vehicle safety, traffic management, and accurate vehicle information communication are the main functions of VANET. The topology of VANET is dynamic and can be anticipated using GPS because of the high speed of vehicles. In order to supply ad hoc connectivity in VANET, a wireless communication facility equips in the vehicles. Scalability issues are caused by the dynamic nature of the VANET. In VANET architecture, data distribution requires an effective and efficient routing strategy. The VANET environment is evolving to provide vehicle safety and security [7], [8]. Cluster stability is important for the VANET's reliability and scalability, as it guarantees minimal intra- and inter-cluster communication, lowering the overhead associated with these issues [6]. To achieve the best information of communication in VANET, the most recent clustering algorithms are described. We also concentrate on VANET's intelligent clustering algorithms. This leads us to explore different clustering strategies. This study is an extended survey for the previous study which has introduced in [6]. The main contributions of this work; firstly, we provide an overview of the development of clustering algorithms in VANETs from 2010 to 2022, which have been observed and studied. Also, most of these algorithms have never been summarized in previous research. Secondly, the existing clustering techniques are summarized and classified in terms of clustering procedure: CH selection, cluster formation, and cluster maintenance, and then we compare these algorithms using different key parameters. Thirdly, different challenges are introduced and the techniques used to solve them. Finally, a comprehensive analysis of the most common parameters used for evaluating the performance of clustering algorithms is introduced. The performance parameters are cluster performance parameters and network performance parameters. Also, simulation tools of each clustering algorithm are presented. The following is our study's structure: Section 2 focuses on VANET clustering, including its algorithms, history, and process, followed by a comparison of clustering algorithms based on some key parameters. Section 3 discusses various problems and the clustering approaches utilized to resolve them, as well as each cluster technique performance. In Section 4, we describe the performance evaluation parameters for some clustering techniques. The survey's conclusion and our future work are reported in Section 5.

2 Clustering in VANET

Clustering is a common VANET technology that offers an appealing approach for simplifying and optimizing network functions and services. When compared to the traditional flat structure, it has dramatically improved performance in a variety of applications. Clustering is a technique for organizing network nodes into small groupings called clusters. Typically, vehicles in close proximity are grouped together in a cluster based on various key parameters and metrics. The vehicles present in the cluster are known as [9]:

1. Cluster Head (CH) – This is the node that is the coordinator or head of the cluster. The CH is selected according to different criteria and its main task is allowing cluster members to communicate and share information with other members and CHs.
2. Cluster Member (CM) – The remaining nodes in the cluster are the CMs. These nodes exchange information by broadcasting messages to each other.
3. Gateway Node (GW) – This node helps to communicate with RSU, it does not need to present it to every cluster.

Figure 2 illustrates the VANET's cluster-based communication structure. Internal cluster communication is handled entirely by the CH. There are two specific routings that divide a cluster internal communication; intra-cluster communication and inter-cluster communication. The cluster's stability is increased during cluster maintenance by forecasting node-to-node failure links [6].

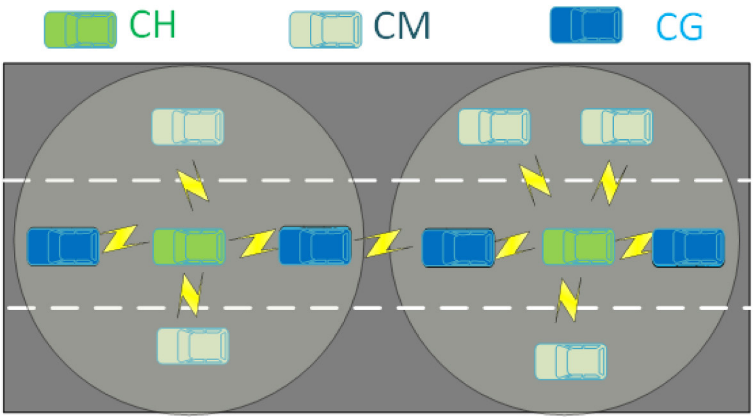

Fig. 2. The cluster architecture [10]

2.1 VANETs clustering algorithms history

In the early 1990s, the clustering techniques for VANETs began to be developed and have expanded in recent years.

Researchers discovered that prior clustering algorithms in MANETs were no longer appropriate for VANETs due to their predictable mobility and specified route topology. Additional control overheads may be imposed due to the time it takes to complete the clustering phases. As a result, a good clustering method should construct a small number of clusters and dynamically maintain the cluster structure without creating significant network overhead. Furthermore, to avoid wasteful cluster re-formations, an effective cluster maintenance plan is required. Some clustering algorithms of MANETs were introduced to fit the specific characteristics of vehicular communications such as Mobility Based Clustering (MOBIC) in [11], Weighted Clustering Algorithm (WCA) in [12], and Distributed and Mobility Adaptive Clustering (DMAC) in [13]. Also, most of the VANET clustering algorithms were derived from the previous MANETs. Several clustering techniques for VANETs have been proposed, particularly after 2010 as a result of the expansion and development of the VANET. In Table 1, several VANET clustering algorithms and the number of citations for each algorithm are highlighted, which have been presented from 2010 to 2022. We can note that the Passive Multi-hop Clustering (PMC) in [14] has the highest mean citations.

Table 1. Clustering algorithms citations

Reference	Year	Algorithm	Abbreviations	Citation	Mean
[15]	2010	Aggregate Local Mobility	ALM	127	10.6
[16]	2010	Cluster-Based Directional Routing Protocol	CBDRP	68	5.7
[17]	2010	Proposed in [17]	–	104	8.6
[18]	2011	Vehicular clustering based on the Weighted Clustering Algorithm	VWCA	141	12.8
[19]	2012	Distributed Medium Access Control	DMMAC	7	0.7
[20]	2012	Fuzzy Logic Based clustering Algorithm	FLBA	78	7.8
[21]	2012	Trust dependent Ant Colony Routing	TACR	49	4.9
[22]	2012	Threshold Based algorithm	TB	119	11.9
[23]	2012	Mobility-Aware Clustering Algorithm based on Destination positions	AMACAD	74	7.4
[24]	2012	Spring-Clustering	SP-Cl	53	5.3
[25]	2012	Stability-Based Clustering Algorithm	SBCA	57	5.7
[26]	2013	Agent Learning–based Algorithm	ALCA	77	8.6
[27]	2014	Adaptive K-Harmonic Means	AKHM	21	2.6
[28]	2015	Aggregate Relative Velocity	ARV	31	4.4
[29]	2015	Distributed Multi-hop Clustering based on Neighborhood Follow	DMCNF	94	13.4
[30]	2015	Adaptive Weighted Clustering Protocol	AWCP	54	7.7
[31]	2015	Neighbor Mobility-Based Clustering Scheme	NMCS	11	1.6
[32]	2015	Direction based clustering and multi-channel medium access control	DA-CMAC	11	1.6
[33]	2016	Vehicular Multi-hop algorithm for Stable Clustering-LTE	VMaSC-LTE	255	42.5
[34]	2016	Neighbor stability-based VANET clustering algorithm	NSVC	24	4
[35]	2016	MObility-aware and SIngle-hop Clustering scheme	MOSIC	10	1.7
[36]	2016	New Clustering Algorithm Based on Agent Technology	NCABAT	9	1.5
[37]	2016	Clustering-Based VANET Routing algorithm Protocol	CBVRP	28	4.7
[38]	2018	Proposed [38]	–	12	3
[39]	2018	Deep Reinforcement Learning	DRL	17	4.25
[40]	2018	Unified Framework of Clustering approach	UFC	62	15.5
[14]	2018	Passive Multi-hop Clustering	PMC	180	45
[41]	2018	Link Reliability-based Clustering Algorithm	LRCA	29	7.25
[42]	2018	Proposed in [42]	–	33	8.25
[43]	2018	Proposed in [43]	–	26	6.5

(Continued)

Table 1. Clustering algorithms citations *(Continued)*

Reference	Year	Algorithm	Abbreviations	Citation	Mean
[44]	2019	Enhanced Weight-based Clustering Algorithm	EWCA	16	5.3
[45]	2019	Center-Based Clustering algorithm	CBSC	35	11.6
[46]	2019	Hybrid Clustering Algorithm based on Roadside	HCAR	16	5.3
[47]	2019	Double-Head Clustering	DHC	36	12
[48]	2019	Proposed in [48]	–	1	0.33
[49]	2019	Enhanced Distributed Channel Access	EDCA	6	2
[50]	2019	Probabilistic-Direction-Aware Cooperative Collision Avoidance	P-DACCA	13	4.3
[51]	2019	Fuzzy-based Cluster Management Scheme	FCMS	23	7.7
[52]	2019	Mobility Based Clustering Algorithm	MBCA	2	0.7
[53]	2020	Naive Bayes Prediction Scheme	NBP	1	0.5
[54]	2021	Junction-based Clustering for VANET	JCV	0	0
[55]	2022	Proposed in [55]	–	3	3
[56]	2022	Region-based Collaborative Management Scheme	RCMS	0	0

2.2 Clustering process in VANETs

The cluster establishment in the VANET communication process is the most important part. There are two phases to complete this process:

- First phase- (Cluster Generation): cluster formation process and CH selection process; during this phase, nodes send advertisement messages to pick the primary CH and CM, and subsequently regular data packets are transmitted between them. In order to create a stable cluster, there may be a few techniques added between the advertisement message transmission and CH selection.
- Second phase- (Cluster Maintenance): Stable cluster merging, selection of secondary CH, re-clustering, and cluster splitting occur at this phase.

Some researchers in the literature had discussed these phases separately. This section provides an overview of the algorithms and criteria used in each clustering step, including CH selection, cluster formation according to the hop count, and cluster maintenance.

Cluster generation phase. This phase goes through two processes to complete the generated of clusters; the cluster formation process and the CH selection process. Some clustering algorithms elect the CHs first, on the basis of which the clusters are formed to complete the clustering process and others vice versa.

Cluster head selection. The network's robustness and scalability are strongly influenced by CH stability. The stable CH guarantees that intra- and inter-cluster communications are kept. To improve VANET stability, a reliable vehicle only can be a CH. The researchers considered various parameters for selecting the CH, such as received signal strength, relative speed, position, direction, and link lifetime. Many clustering approaches are relying on a combination of multiple metrics rather than a single metric for selecting the CH, like DHC in [47], CBSC in [45], TCAR in [21], AWCP in [30], and EWCA in [44]. Some of these algorithms and their metrics used for CH selection are tabulated in Table 2:

Table 2. CH selection metrics

Reference	Algorithm	CH Selection Metric
[15]	ALM	Priorities associated with each vehicle
[16]	CBDRP	Moving direction
[18]	VWCA	Distrust Level, Degree, Velocity, Direction
[19]	DMMAC	Speed and direction based
[20]	FLBA	Relative velocity
[21]	TACR	Relative velocity, packet forwarding reputation
[22]	TB	Distance, Relative velocity
[23]	AMACAD	Destination, Distance, Relative velocity
[24]	SP-Cl	Relative velocity, distance
[25]	SBCA	Relative Speed, RSS
[26]	ALCA	Velocity
[27]	AKHM	Transmission bandwidth
[28]	ARV	Relative velocity
[29]	DMCNF	The propagation delay ratio, Number of the following car
[30]	AWCP	Highway ID, direction, position, speed
[31]	NMCS	Change in degree
[33]	VMaSC-LTE	Lowest average speed
[34]	NSVC	Rate of change of the number of neighbors
[35]	MOSIC	Relative speed, Relative distance, and Relative mobility
[36]	NCABAT	Lowest ID
[38]	Proposed in [38]	Speed, Position
[39]	DRL	Q-learning based routing
[40]	UFC	UFC relative position, relative velocity, and link lifetime
[14]	PMC	Speed, Neighbors, Link lifetime, Position
[41]	LRCA	link reliability
[42]	Proposed in [42]	Mobility, direction, degree, and reputation
[44]	EWCA	Speed, Position
[45]	CBSC	Position, Relative Speed
[46]	HCAR	Lowest ID
[47]	DHC	Signal Strength, Relative Speed, Link Lifetime
[48]	Proposed in [48]	Trust, relative speed, and position
[54]	JCV	Relative position, movement at the junction, degree of a node, and time.
[55]	Proposed in [55]	Using PSO mechanism.
[56]	RCMS	Using SRP model and feature relevance between vehicles

Cluster formation. Cluster formation in VANET has various types and categories: center-based vs. distributed-based, single-hop vs. multi-hop, location service-based vs. user information-based, etc. This section discusses cluster formation on the basis of topology. This means a cluster structure in VANETs can be modeled according to a hop distance that separates the CH and its members, transmission range, and cluster radius. Accordingly, only two main categories of algorithms are distinguished: single-hop and multi-hop algorithms as in Figure 3.

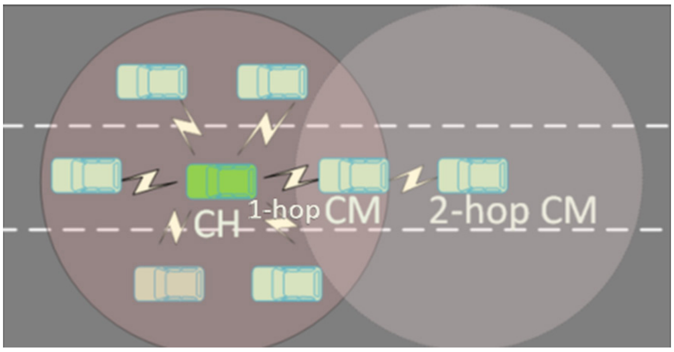

Fig. 3. Clustering model [10]

1. Single-hop Clustering Algorithm

It is the algorithm that creates clusters with a single-hop distance between each node and its CH. That means every node connects directly with the CH [55]. Many clustering algorithms form directly single-hop clusters based on the transmission range of the CH or the limited cluster radius. Some of the single-hop clustering algorithms are:

In [18], the VWCA was proposed. It is a single-hop clustering algorithm, and it improves the security, connectivity, and stability performance. The connectivity can be increased using the adaptive transmission range algorithm (AART) which is based on detected short-range communication standards. The AART helps to extend the transmission range dynamically from 100m to 1000m based on the vehicles' density.

Another single-hop clustering algorithm for VANETs was proposed in [23], it is called an AMACAD. Speed distance and position are the parameters used to elect the CH.

The stability of the CH in VANET was enhanced by designing a SBCA [25]. This algorithm is provided a more stable structure according to vehicle mobility and a number of neighbors. The cluster formation procedure does not take the vehicle's direction into account, which has an impact on the VANET system's performance.

In [31], the authors proposed a novel single-hop clustering algorithm for VANET named NMCS. The vehicle which has the lowest "neighbor vehicles mobility" value is selected as a CH. This algorithm provides reliable network topology.

MOSIC was proposed in [35]. Gauss Markov mobility (GMM) model is used by this proposed for mobility prediction that makes vehicle able to prognosticate its mobility relative to its neighbors.

NCABAT was introduced in [36]. The objective of this algorithm is to describe agent properties to vehicles with the purpose of improving traditional schemes in terms of performance.

Creating a stable cluster is the main goal of a distributed system-based passive data dissemination technique [38] that can overcome the VANET's communication delay. The message is efficiently transmitted using the passive cluster formation approach.

LRCA was proposed in [41] to grant reliable and efficient data transmission in urban VANET. LLT-based neighbor sampling scheme is used to select a group of vehicles with stable neighbor vehicles. In this proposed, the routing approach is prepared to support infotainment services in VANET which are not strict in delay constraints.

In [42], a new single-hop clustering scheme was presented that elects trustworthy CHs based on a hybrid approach combining trust factors and stability. Also, this research proposed a new adaptive trust function to assess the data trust between nodes according to the reported event's requirement in terms of trust severity, unlike other schemes which use a static trust function. The proposed scheme increases the reliability of sharing data compared with other recently proposed.

In [44], the authors proposed EWCA which is a single-hop clustering algorithm. In an emergency message transmission case, this technique reduces the formation of unstable clusters and enhances the clustering stability.

CBSC was proposed in [45] to help self-organized VANETs form stable clusters and decrease the status change frequency of vehicles on highways and two metrics. Also, a new CH selection algorithm was presented to minimize the impact of vehicle motion differences. In this proposed, two metrics are introduced to enhance VANETs security.

In [46], HCAR is a Hybrid Clustering Algorithm. It was designed on the basis of the RSUs for the Internet of Vehicles (IoV), and it is a single-hop clustering algorithm. The distributed RSUs are where the HCAR algorithm is centralized. After the RSUs have been controlled, a graph theory-based approach is used to form the clusters. The selection of secondary CH resolves the unavailability problem of CH. This proposed enhanced the stability of CH.

DHC algorithm for VANET was proposed in [47] with a focus on rising clusters stability and reducing the number of clusters in the network under different conditions and scenarios. The proposed scheme performed better than other algorithms in terms of efficiency and cluster stability, under different channel models, vehicles density, and traffic scenarios, especially in dynamic mobility environments.

In [54], the authors suggested a robust and dynamic mobility-based clustering approach JCV. It takes into account the moving direction at the next junction in the cluster formation process. This technique provided high stability, preventing clusters from breaking at the junction frequently.

Single-hop clustering algorithms provide more reliable intra-cluster communication and highly effective coordination to CHs. The coverage area of this type of cluster is small, which leads to high maintenance overhead and a large number of clusters.

Also, in single-hop clustering algorithms, when the density of vehicles is very high, collisions can occur and can lead to a low packets delivery ratio. Also, when the density of vehicles is low, the vehicle may not find any member and stay single, so it cannot form a cluster. These two situations should be avoided because the cluster performance will be decreased. We can summarize that the single-hop algorithms provide good cluster stability and low latency, but clustering coverage requires further improvement. Also, to solve the problem of high and low density, the maximum and the minimum number of vehicles can be limited in a cluster.

2. Multi-hop Clustering Algorithm

Clusters are generated with multi-hop distance, where every node is at a distance of at most multi-hop from its CH. Some multi-hop clustering algorithms are presented in this section.

In [29], DMCNF was proposed; it allows vehicles to periodically select their targets from one-hop neighbors in a distributed manner. The CH selected depends on the relationship of neighborhood among vehicles. This algorithm improves the cluster's stability.

A hybrid backbone-based clustering algorithm was proposed in [15], also, it is a multi-hop clustering algorithm. The concept of a number of links and vehicular mobility are used for cluster formation and CH selection. During cluster formation, nodes with a relatively higher degree of connectivity initially form a backbone that is designated as leadership. The leadership then participates in CH election and efficient cluster re-organization using an aggregate relative velocity of vehicles in the leadership.

A multi-hop clustering approach was also presented in [22] called TB with the goal of maximizing the stability of the network topology and decreasing network dynamics. The speed difference among vehicles as well as the position and the direction were taken into account in this proposed during the cluster formation process. This algorithm increases CH lifetime and minimizes vehicle transition between clusters.

The multi-hop clustering algorithm was introduced in [33]. It is called VMaSC-LTE, and it is based on the amalgamation of a 4G cellular system with IEEE 802.11p to improve the VANET communication performance. The multi-hop technique ensures that CH selection and clustering are both stable. With the decrease in CH, the stability improves.

An AWCP was introduced by taking into account the speed information, direction, position, and highway ID to select the most stable vehicles among current vehicles to operate as CHs [30]. To maximize cluster structure stability, highway ID information is used. This technique improves cluster lifetime and minimizes communication overhead.

PMC algorithm in VANET was proposed in [14] to solve the lack in clustering algorithms performance in terms of stability and reliability. In this algorithm, the clustering is introduced depending on the priority neighbor following strategy, and the CH selecting technique is adopted to select the optimal CH.

In [48], the author introduced a heuristic algorithm for electing a vehicle as a CH in a cluster. In this method, weighted fitness values are used for electing a CH vehicle based on three parameters; trust value, absolute relative average speed, and position from the cluster boundary.

Multi-hop clustering algorithms can reduce the number of clusters; expand cluster coverage area, and enhance cluster stability. We can summarize that the multi-hop algorithms provide high clustering coverage, and good cluster stability, especially with regard to the number of CM re-affiliation, CH changes, and cluster lifetime. However, multi-hop cluster formation is more complex, which will take a long cluster formation time, and this may cause a delay in transmitting the information. Also, the cluster overhead requires more improvement.

Also, according to some simulation results, the cluster performance degrades when the number of hops is more than three. This means when the hop count increases the cluster performance will decrease.

A comparison between the clustering algorithms is shown in Table 3 in terms of transmission range, vehicle density, vehicle velocity, hop count, and traffic scenario.

Table 3. Clustering algorithms comparison

Algorithm	Transmission Range	Vehicle Density	Vehicle Velocity	Hop Count	Traffic Scenario
EWCA	300m	50–150	30m/s	Single	Highway
Proposed in [38]	300m	80–510	5.5–33.3m/s	Single	Highway
VWCA	Dynamic 100–1000m	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
NMCS	–	–	–	Single	–
AMACAD	100–200m	50	11–31 m/s	Single	Urban
SBCA	300m	50–150	25–35m/s	Single	Highway
CBSC	–	–	55.55m/s	Single	Highway
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
Proposed in [42]	–	10–60	10–120m/s	Single	Highway
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, 800, 1000m	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
CBDRP	–	60	25–35m/s	Multi	Highway
Proposed in [48]	600m	200	11m/s	Multi	Urban
Proposed in [55]	–	100	20–60m/s	Multi	Urban
RCMS	250m	1200	10–30m/s	Multi	Urban

Cluster maintenance. Because of VANETs dynamic topology, severe packet loss occurs due to frequent vehicle re-connection and disconnection. The cluster maintenance process ensures strong connectivity by reducing frequent vehicle re-clustering and also achieves a stable link lifetime through CH. Cluster maintenance involves vehicle joining, vehicle leaving, cluster merging, and other cluster maintenance methods. There are a lot of maintenance methods introduced in the literature; we discuss some of them in this section.

In vehicle joining and vehicle leaving process, the CH sends frequent signals and if it receives any signal from a vehicle, this new vehicle is assigned to that cluster and becomes CM of that particular cluster. Then the CH will update its local database. When the CH loses the connection with a member vehicle, the information for that member is deleted from the CH's local database. AWCP in [30], and DMCNF in [29] are an example of the algorithms which used this method.

The second method is the cluster merging process; it is more complex than the first one. Cluster merging takes place when two or more clusters can be represented by a single merged cluster, which can minimize the clusters' number and improve the clustering efficiency. The conditions of the cluster merging are different for each algorithm. For example, in the ALM algorithm [15], cluster merging occurs if two CHs are in each other's transmission range. The VMaSC-LTE in [33], the averaged relative speed of the two neighboring CHs, referred to as AVGREL-SPEED, is compared. The CH with the higher average relative speed relinquishes his CH job and becomes a CM for the CH with the lower average relative speed. Also, the PMC algorithm in [14] used the cluster merging method in the cluster maintenance phase, the CH node sends merge request packets to other neighboring CH to request cluster merging. If one of these two CHs has smaller following vehicles and high relative speed, the merging process is performed.

Other algorithms addressed the two processes (cluster merging and vehicle leaving or joining) in the cluster maintenance phase like TB [22], SP-CI in [24], DA-CMAC in [32], LRCA in [41], UFC in [40], and JCV in [54].

A selected of secondary CH is another approach used in the cluster maintenance phase. Some algorithms like EWCA proposed in [44], SBCA in [25], CBRDP in [16], and HCAR in [46] used this method. The secondary CH is selected by the CH according to different criteria. It resolves the unavailability of CH to increase the clustering stability.

Some algorithms used another cluster maintenance method; like Deep Reinforcement Learning (DRL) scheme in [39]. This scheme was designed for VANET and enhanced the safety and the QoS in the transmission of data. Q-learning tables determine the best route for data transfer. In the maintenance phase, the performance can be improved in terms of predicting connection failure and reducing overhead delays by updating Q-learning tables. While in [20], the maintenance phase in the FLBA algorithm is adjustable to drivers' behavior on the way and has a learning technique for predicting the future position and speed of all CMs using fuzzy logic inference system.

2.3 Clustering algorithms comparison

Various parameters are typically used to compare clustering techniques. These parameters are used to generate and characterize any clustering algorithm [6]. Cluster stability, latency, convergence, and overhead are some of these key parameters. The benchmark algorithms are compared in Table 4 based on these parameters. A good clustering algorithm achieves high stability and low latency, overhead, and convergence.

Table 4. 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	–
FLBA	High Stability	–	–	–
TACR	Improves stability	–	Low overhead	Low
TB	Improves stability	–	Low overhead	High
AMACAD	Medium Stability	High latency	–	Low
DMCNF	Improves Stability	–	Low overhead	Low
NMCS	Improves Stability	–	–	Low
Sp-Cl	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	–	–
Proposed in [42]	High Stability	–	Low overhead	Low
Proposed in [48]	Improves stability	Low latency	Low overhead	–
JCV	High stability	Low latency	Low overhead	–
RCMS	High stability	Low latency	–	High

3 Challenges and techniques used for solution

Many researches with several clustering algorithms are available in order to enhance the performance of the wireless network. The researchers have examined various issues and used various clustering algorithms to find solutions to them; in this section, we present some of these challenges as well as the approaches utilized to solve them as in Table 5.

For cluster formation in VANET, a DMCNF algorithm in [29] solved the network weaknesses that occur as a result of a dynamic topology. For highways, a CBDRP in [16] solved the problem of fast data transmission and link connectivity.

In order to increase the VANET's stability in an urban area, a lane-based clustering algorithm was introduced in [17]. Clustering reduces the overhead and provides a hierarchical network topology that is efficient. The CH improves the network's lifetime.

The hybrid backbone-based clustering algorithm in VANET uses the aggregate relative velocity to select the CH [28]. The nodes carry out an effective CH selection task with a minimum relative speed and high connection.

In [37], for desert and rugged situations, a VANET-based clustering routing protocol was introduced. The source and destination vehicles work to keep the stability of cluster architecture. The designed algorithm's tasks are CH selection, cluster structure formation, and routing protocols.

The overhead delay and cluster stability problems have been solved using the passive approach in [38], also, the message is transmitted efficiently using this approach.

In [32], For VANET, a DA-CMAC algorithm was implemented. The rearrangement cost for short-period connections is reduced using clustering. The CH manages the channel access and the time slots are assigned to the CM. Clustering the time slots into two groups depending on the direction of movement achieves the merging collision and channel access.

To improve the MAC routing protocol, an EDCA was introduced [49]. A fixed control channel interval (CCHI) and a variable CCHI are two problems of message transmission communication for safety. The EDCA scheme achieves optimal MAC routing parameters with priority given to the emergency message.

In [43], to address the problem of network connectivity failure, an intelligent forwarding-based stable and reliable data dissemination approach was proposed. Vehicles choose the next forwarding node based on the mathematical formula that represents link stability. The data transfer is handled by the greedy approach, and a separate algorithm is used to beat the network connection failure. To recover the information connection's break links, the edge weights are utilized.

The behavior of driver prediction has an impact on the cluster's stability in VANET. In [53], for efficient VANET clustering, machine learning based on a prediction of a driver behavior technique was proposed. The NBP algorithm estimates the behavior of the driver based on 2 factors: overtaking decisions and driving speed. The NBP classifiers divide a driver's habit into three categories: vehicle type, relative speed, and a number of traveled lanes. The VANET's optimum driving model is intended to obtain a stable clustering.

A major issue in VANET is Cooperative collision avoidance (CCA) which has an impact on cluster stability. In various two directions real traffic scenarios, a probabilistic direction aware (PDA) algorithm was proposed to dominance CCA [50]. Cluster formation is handled using a modified k-medoids method that integrates the Hamming distance metric for direct knowledge. The distance and speed of nodes are used to calculate a collision's probability between the vehicles. The benign factor is used to determine the vehicles' optimal safe speed, which is compared to the threshold range and delivers a collision warning. The communication overhead and collision latency are decreased.

One of the major issues in the VANET is security because of its impact on the performance of the network. It is done in [26] and [51]. The authors in [51] implemented a FCMS for detecting a reliable vehicle. For clustering in VANET, FCMS1 and FCMS2 models are compared. Three input factors are for FCMS1. Vehicle trustworthiness (VT) is the fourth input factors to the FCMS2 model. The FCMS2 model improves cluster stability over the FCMS1 model.

In [52], the MBCA was used to solve the problem of multimedia broadcasting content in a hybrid VANET topology. Cluster formation and CH selection are based on mobility measurements, which are utilized to determine the vehicles' relative speed. The cluster's stability is improved using the handshake process.

Table 5. Problem and solution technique

Reference	Problem	Techniques Used	Performance
[14]	Lack in reliability and stability of clustering algorithms	PMC approach	Improve the performance in terms of in reliability and stability.
[16]	Rapid data transmission, link stability and realizing reliable	CBDRP	Reduces latency and increases the packet delivery ratio and link stability
[17]	Cluster stability	A lane-based clustering algorithm	Improves the stability by increasing the CH Lifetime
[25]	Vehicles frequently joint and leave the clusters.	SBCA	Improves the stability of the network by reducing the overhead and the cluster lifetime
[29]	Weakness in the network because of high dynamic	Multi-hop clustering algorithm (DMCNF)	Improves the stability
[33]	Delay and delivering of the safety messages problems.	Hybrid architecture called VMaSC-LTE companies LTE and IEEE802.11P	Achieves low delay and high packet delivery ratio
[26]	Security	ALCA	Performing fast clustering, increases efficiency.
[28]	Frequent CH changing	Hybrid backbone based clustering algorithm	Improves cluster stability by forming the cluster leadership
[32]	Short communication period	DA-CMAC	Reduces collision and increases reliability of packets

(Continued)

Table 5. Problem and solution technique *(Continued)*

Reference	Problem	Techniques Used	Performance
[34]	Problem of delivering data in urban vehicular environments	NSVC	Guarantees the reliability of delivering emergency messages, increases clustering stability.
[37]	Route selection, stable clustering suitable for desert	CBVRP	Increases communication efficiency, delivers information with ensures reliability, and decreases the routing cost.
[38]	Cluster stability and Overhead delay.	Passive data dissemination approach	Improves cluster stability, reduces the communication overhead, and increases the efficiency of transmission messages.
[41]	Cluster stability	Reliability-based clustering algorithm (LRCA)	Provides efficient and reliable data transmission in VANETs
[43]	Failure in data delivery and communication Link	Algorithm based on intelligent forwarding	Minimizes delay, Improves cluster stability and communication Safety
[44]	CH Stability.	EWCA	A better cluster stability and overhead delay reduction performance
[46]	High mobility, big data clustering	RSU based Multi-Hop Clustering	Improves cluster stability, and proves the efficiency of the algorithm in theoretical way.
[49]	Transmission message delay	EDCA for transmitting emergency message	Reduces average delay and increases the probability of successful delivery
[50]	Clustering and cooperative collision avoidance	P-DACCA with K-medoids and Bengn factors	Reduces overhead delay, and collision Efficient stability
[51]	Security and trustworthiness detection	FCMS1 and FCMS2	Efficient vehicles' management in the cluster
[53]	Cluster stability, and behavior prediction of driver	NBP clustering	Increases cluster stability in real environments
[52]	Stability of Link	MBCA	Multimedia broadcasting has been improved.

4 Performance evaluation metrics

Any clustering algorithm's performance can be assessed and evaluated using a variety of parameters; Cluster performance and network performance are the most common metrics used for evaluating the performance of clustering algorithms:

4.1 Cluster performance parameters

Cluster performance parameters represent how well clustering techniques perform and mirror how stable the network's backbone nodes are. The overall cluster performance and stability are described using these parameters. Some of Cluster performance parameters are:

- Cluster/CH Stability: It is the number of times the same vehicle is elected as a CH out of all times.
- Cluster number: It refers to the number of clusters that form during network operation. The clustering algorithm is more efficient when there are few cluster numbers [6].
- Cluster/CH lifetime: It is the maximum time for a vehicle that has played the head's task in a cluster. It is computed by dividing the overall lifetime by the time spent in the head's role [57].
- CM lifetime: It is the maximum amount of time a node can be CM for. To get its average, we divide the total lifetime of the CM by the total number of state changes from CM to another state [57].
- CH change rate: It is the average CH's number change per time [57].
- Cluster change rate: Average cluster's number changes for each vehicle in a unit of time.
- Cluster size: Vehicles' number in one cluster.

A good and stable clustering algorithm should have a large cluster size, high CH and CM lifetime, few cluster numbers, and low cluster and CH change rate. However, these parameters only can't describe communication links' details between vehicles in the network.

4.2 Network performance parameters

The overall network performance is described by these parameters, which include:

- Throughput: It is the number of bits transmitted per second in any network. The higher value of throughput provides better performance of the network designed [6].
- Packet loss ratio or collision ratio: The rate of packets' loss during the transmission process.
- Packet Delivery Ratio (PDR): It is the ratio of the number of packets received by the destination to the total number of packets [57].
- Overhead: The average number of control messages is received by the vehicle.
- End to End Delay (E2E Delay) or Latency: It is the time taken for transmitting a packet from a source to a destination.

All these parameters are utilized to estimate the context-based clustering approaches, like traffic prediction, routing, and information dissemination. A good and efficient clustering algorithm leads to large throughput, short E2E delay, low packet loss rate, high PDR, and small overhead. Table 6 presents the evaluated parameters and the simulator tools used for each algorithm [58], [59], [60].

Table 6. Clustering algorithms evaluation parameters

Reference	Algorithm	Simulator Tool	Evaluation Parameters
[15]	ALM	SUMO, SIDE/ SMURPH	CH lifetime, Status changes per Node, CH density.
[16]	CBDRP	NS2	Latency, PDR, Average Routing Overhead
[18]	VWCA	MATLAB	CH and CM lifetime, PDR.
[19]	DMMAC	SUMO, MOVE, NS2	Average cluster size, probability of received CH SMS, Probability of successful transmission, average travel time for an emergency SMS
[20]	FLBA	NS2, MOVE, SUMO	Average CH time, Average CM's dwell time, Average cluster size.
[21]	TACR	–	Routing Overhead, CH Selection Time, Cluster Creation Time, and Probability of message Transmission.
[22]	TB	C++	Average cluster change, Average cluster lifetime
[23]	AMACAD	Java	CH lifetime, Membership lifetime, Re-affiliation rate
[24]	Sp-Cl	–	Average cluster change, Number of clusters, and average cluster lifetime.
[25]	SBCA	NS2	Average cluster lifetime, overhead, and packet delivery.
[26]	ALCA	VANET MobiSim	Node participation time, Throughput, Efficiency, CH duration, Connectivity ratio
[27]	AKHM	C/C++	Clustering performance for crossroad scenario, Clustering performance for rectangle road scenario.
[28]	ARV	SUMO	Average Cluster-Head lifetime, Percentage of CHs.
[29]	DMCNF	NS2, VanetMobiSim	Average CH/CM durations, Average number of clusters, Average CH change number, and average overhead.
[30]	AWCP	NS2, JOSM, SUMO, MOVE	Average Cluster Lifetime, PDR, overhead.
[32]	DA-CMAC	NS3	PDR, CH Changes, Access collision.
[33]	VMaSC-LTE	NS3 & (SUMO)	CH/CM Duration, CH Change Rate, Overhead, Number of Vehicles in SE state.
[34]	NSVC	–	CH lifetime, CH change, throughput.
[35]	MOSIC	NS3	Average CH/CM Duration, Average Number of clusters, Average Control Message Overhead, Average CH Changes Rate.
[36]	NCABAT	JADE	Throughput, E2E Delay, and PDR.
[37]	CBVRP	–	PDR, E2E delay, Number of cluster reconstruction, Routing cost.
[38]	Proposed in [38]	OMNET++, SUMO	Overhead.
[39]	DRL	QualNet7.1, VanetMobiSim	Average E2E delay, and average PDR.

(Continued)

Table 6. Clustering algorithms evaluation parameters *(Continued)*

Reference	Algorithm	Simulator Tool	Evaluation Parameters
[40]	UFC	SUMO	CH duration, CM duration, Clustering efficiency, Number of initial CHs, CM disconnection rate, CM re-clustering delay, and CM re-clustering success ratio.
[14]	PMC	NS2, VanetMobiSim	Average CH/CM Duration Time, Number of Average Cluster Head Changes, Clustering Overhead.
[41]	LRCA	NS2, SUMO	CH/CM duration, CH change rate, PDR,E2E delay, overhead
[42]	Proposed in [42]	OMNET++, SUMO	CH/CM duration, Overhead, CH selected time, PDR, Trust/Untrust packets delivery rate.
[43]	Proposed in [43]	NS2, SUMO	Latency, throughput, PDR.
[44]	EWCA	NS2, SUMO	Cluster stability, number of clusters, and E2E.
[45]	CBSC	OMNeT++, SUMO	Average CH/CM Lifetime, Average Number of Re-affiliation Times, Packet Loss Rate.
[46]	HCAR	NS2, VANET MobiSim	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.
[48]	Proposed in [48]	OMNET++, SUMO	Throughput, Delay, No. of packets generated, PDR, No. of clusters
[49]	EDCA	MATLAB	Control channel interval, service channel interval.
[50]	P-DACCA	NS2	Cluster stability, overhead, and collision probability.
[51]	FCMS1, FCMS2	–	Vehicle speed, vehicle cluster, degree of centrality, and trustworthiness.
[52]	MBCA	OMNET++, SUMO, and VIENS	Average CH duration, average CM duration, PDR, network delay, and overhead.
[53]	NBP	SUMO	CH election, CM election, and lifetime of CH.
[54]	JCV	SUMO, CVANETSIM, JAVA	CH duration, CM duration, CH change rate, number of cluster, cluster participation, number of CM. number of EN, ratio of CM, EN duration, overhead, delay
[55]	Proposed in [55]	NS2	PDR, Throughput.
[56]	RMCS	OMNET++, SUMO	Cluster lifetime, PDR, delay, overlap rate, reconstruction time

5 Conclusion and future work

In recent years, VANETs have been used in a variety of applications. Vehicle safety, traffic management, and accurate vehicle information communication are the main functions of VANET. Due to the high speed of vehicles, the VANET topology is dynamic. Scalability issues are caused by the dynamic nature of the VANET and the clustering represents one of the reliable solutions. This work presented an intensive survey for the most clustering techniques to solve different VANETs issues. We provided an overview of the clustering technique in VANETs. At first, a history of 51 clustering algorithms for two decades with the number of their citations was highlighted. Then, we have introduced the algorithms and the criteria of each of the clustering steps, including the metrics used for selecting the CH for each algorithm, cluster formation according to the hop distance, and cluster maintenance. Also, to see the performance of these algorithms, we have made comparisons between them based on some key parameters. Then, we presented some of VANET's challenges as well as the clustering approaches utilized to solve them and see the performance of these approaches. Finally, we introduced some of the most common metrics used for evaluating the performance of clustering algorithms.

From our survey, we can see most clustering algorithms are designed for highways, and cluster stability is one of the major issues in VANET. In future work, we will design a new clustering algorithm for VANET suitable for urban environments using hypergraph theory, and our approach will aim to increase the clustering stability.

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