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# Stable Clustering Algorithms for VANETs: A Survey

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*Abstract*— **Stability is a critical factor in Vehicular Ad-hoc Networks (VANETs) because it directly affects the performance and reliability of the network. VANET has a dynamic, high-traffic topology, where vehicles can join and leave the network frequently. This dynamic nature of VANET poses several challenges to network stability, such as frequent disconnections, link failures, and topology changes. A set of algorithms that contribute to maintaining the stability of the VANETs network were studied during this work. This survey introduces the recent state of clustering algorithms in VANETs, discusses various algorithms, and presents a comparison among them considering advantages, disadvantages, and stability.**

***Keywords*— *VANET, Stability, Clustering, SCalE, CBSC.***

## I. INTRODUCTION

The development in the world of technology and the acceleration of technologies requires us to stand on our duties in the constant search for the best solutions to the problems that we face in our daily lives.

Due to the growing population and subsequent rise in the number of vehicles and transportation options, there is an urgent need to discover contemporary methods and technologies for organizing the transport and vehicle sector. Ensuring the safety of individuals and safeguarding their lives has become paramount. Therefore, prioritizing street safety is crucial for enhancing street efficiency, protecting people, and preserving their lives [4]. The field of Intelligent Transportation System (ITS) technology has made significant strides in recent years, showcasing remarkable advancements. Various models have been proposed and implemented to support this technology [2]. That is why we can take advantage of the development in information technology by establishing a reliable connection between vehicles through an installed unit known as On Board Unit (OBU) [4].

This module allows vehicles to communicate with each other through Vehicle to vehicle technology (V2V), as well as Vehicle – to – infrastructure (V2I) technology, or communication between the vehicle and the roadside communication unit. The Vehicular ad hoc network (VANET), an integral component of Intelligent Transportation Systems (ITS), plays a crucial role in addressing numerous challenges. Among the primary issues it tackles are traffic congestion problems and establishing secure emergency paths. This is achieved by establishing a dependable connection between vehicles through Vehicle-to-Vehicle (V2V) technology using On-Board Units (OBU). Communications within VANETs can be categorized into two main groups based on the radio interfaces employed. One class utilizes Dedicated Short-Range Communication (DSRC) as its foundation, while the other type leverages existing cellular technologies [1].

Additionally, with the aid of long-term evolution (LTE) and handover technology, it was crucial to create mature VANET models to address a variety of network performance concerns, such as those related to throughput, stability, scalability, security, and robustness [1]. An important model for improving the performance of the network as a whole is VANET clustering. Clustering is used in vehicular ad hoc networks (VANETs) to control data distribution among vehicles. However, because of their high dynamic mobility, vehicles have a tendency to re-cluster frequently, which can reduce cluster stability.

The types and classifications of clustering in VANET are diverse. Topology, mobility, and contextual information are all types of information that can be used to cluster VANETs. V2V and V2I can both be used to collect this information either locally or globally. Researchers have recently been encouraged to investigate the potential of leveraging V2I to create an effective, stable, and high-performing VANETs clustering by the rapid development and expansion of the road infrastructure. Clustering technology has been used to improve connectivity by grouping nodes in a geographical area together. Frequency reuse allows the ability to reduce congestion and increase QoS.

In VANET, stability refers to the ability of a network to maintain its connectivity and performance in the presence of node mobility, network congestion, and other factors that can affect the network’s operation. Clustering in VANET is crucial for enhancing the stability of the collaborative environment. It helps reduce communication overhead and improve the network’s scalability and reliability. Clustering algorithms can be used to group vehicles based on their location, speed, and other parameters. This can help to reduce the number of messages transmitted and improve the network’s performance [6]. In General cluster stability is often affected by cluster fragmentation and cluster size [3].

Given the importance of network stability and its immediate responsiveness to traffic, it becomes a top priority and a key metric for evaluating cluster performance. To achieve optimal performance, a cluster should exhibit the following characteristics: stability, minimal overhead, extended Cluster Head (CH) lifespan, and extended Cluster Members' (CM) lifespan. These factors contribute to a more efficient and effective system [4].

This study aims to investigate the crucial methods and techniques implemented to enhance the stability and usability of the VANET network, even under challenging circumstances. Additionally, it seeks to explore the individual roles of different network components and assess their impact on overall network stability and performance. Through this analysis, a comprehensive understanding of the network's behavior and the factors influencing its stability and performance can be obtained.

This paper focuses on analyzing several algorithms to identify key areas for improvement to enhance and enhance stability within the VANET network. Furthermore, it examines how the implementation of clustering methods can contribute to increasing stability, control, and effectiveness in information exchange. By investigating these aspects, the study aims to provide insights into potential strategies for optimizing the VANET network's stability and overall performance.

## II. BACKGROUND

The VANET clustering process involves organizing nodes within the network based on their behavior, resulting in the formation of different groups known as clusters. Within a cluster, there are two types of nodes: Cluster Heads (CH) and Cluster Members (CM). The selection of a CH is based on its ability to establish reliable communication with other nodes in the cluster. The primary responsibility of a CH is to facilitate communication among CMs and other cluster heads [2].

Cluster algorithms in VANET can be categorized into two main types: cluster establishment with CH selection and cluster formation, and cluster maintenance. The first type focuses on the initial creation of clusters and the selection of suitable CHs. The second type, cluster maintenance, involves ensuring the ongoing stability and efficiency of the clusters once they are formed [2].

By employing these clustering algorithms, the VANET network can enhance communication, improve coordination, and optimize information exchange among nodes within clusters, leading to improved overall network performance and stability. The stability of the cluster is improved in cluster maintenance by predicting the link failure among the nodes. Figure 1 shows the arrangement of cluster-based communication in the VANET.

A CH is selected by determining the parameters of the network, and other nodes are considered the cluster members. The CH takes all the responsibility for internal cluster communication. The internal communication of a cluster uses two specific routings known as intra-cluster communication and internal-cluster communication. The cluster formation also reduces the high execution of load on the nodes in the VANET. The cluster plays a vital role in radio transmission by accessing the channels that make less collision and interference in communication information [1].

The stability of the network is one of the most important factors that are considered when proposing new technologies, and to be able to measure the stability of the network, several metrics are relied upon, the most important of which are:

The performance metric for stability in VANET: Cluster Head lifetime, Cluster member lifetime, average cluster head change, packet loss, and cluster formation time are important performance metrics in VANET that affect the stability and efficiency of communication.

- *Cluster Head lifetime*: This metric represents the duration for which a node remains a cluster head. The longer the cluster head lifetime, the more stable the network. This is because frequent changes in cluster heads can cause disruptions in communication and increase overhead.
- *Cluster member lifetime*: This metric represents the duration for which a node remains a member of a cluster. The longer the cluster member's lifetime, the more stable the network. This is because frequent changes in cluster members can also cause disruptions in communication and increase overhead.
- *Average cluster head change*: This metric represents the number of times a node changes its role from a cluster head to a cluster member or vice versa. A high average cluster head change indicates instability in the network, as frequent changes in cluster heads can cause disruptions in communication and increase overhead.
- *Packet loss*: This metric represents the percentage of packets that are lost during transmission. A high packet loss rate indicates instability in the network, as lost packets can result in delays, retransmissions, and increased overhead.
- *Cluster formation time*: This metric measure the duration required for a cluster to establish itself. A longer cluster formation time may suggest network instability, as it can lead to communication delays and higher overhead.

These performance metrics are important for evaluating the effectiveness of clustering algorithms and protocols in VANET. By optimizing these metrics, it is possible to improve the stability and efficiency of communication in VANET and ensure reliable and timely delivery of messages [1][3][4].

## III. STABLE CLUSTERING ALGORITHMS

In this section, a concise overview of the studied algorithms and their operational mechanisms will be provided.

Communication in VANETs can be broadly categorized into two groups based on the radio interfaces utilized. One class of approaches relies on Dedicated Short Range Communication (DSRC) as the foundation. The other class involves utilizing existing cellular technologies that are already in use. With the rapid progress of mobile cellular networks, some researchers propose leveraging the existing infrastructure and technologies for VANET communications. Various techniques have been suggested to effectively manage VANETs and utilize the established mobile cellular networks for data transmission. Consequently, there has been a search for a reliable clustering approach in VANETs to prevent frequent cluster reformation. [1].

### *A. CBSC algorithm*

In cluster-based VANETs, a clustering algorithm is employed to form clusters from a set of unlabeled nodes. In this context, all vehicles within the clusters transmit their data to a base station known as an evolved Node B (eNodeB), which is part of the cellular network infrastructure. The clusters, in turn, are managed by the eNodeB. To facilitate communication between the eNodeB and Cluster Members (CMs), a Cluster Head (CH) acts as an intermediary. Within a cluster, a vehicle assumes the role of a CH and collects data from all CMs using the 802.11p communication standard. The CH then communicates with the eNodeB using a technology such as TLE [1].

In the referenced study [1], the authors made certain assumptions regarding clusters, which are outlined and discussed.

- 802.11p and LTE interfaces are present in every vehicle.
- Global Positioning System (GPS) devices are installed in every vehicle. As a result, they have accurate geolocation.
- Every vehicle is aware of its destination, maximum speed, and acceleration.

### a) *Cluster head selection*

A relative mobility metric M is developed for CH election to choose an optimal CH that can lengthen the cluster lifetime and lower the frequency of CH reselection. The relative mobility metric measures the differences in maximal acceleration, maximum speed, and relative location between one vehicle and every other vehicle in the same cluster. A lower relative mobility than other vehicles in this cluster is indicated by a smaller M, speed, and acceleration, which are added to the CH selection metric to make the cluster stabler and decrease the CH reselection frequency [1].

The process of selecting an appropriate Cluster Head (CH) involved following the steps outlined below:

Step 1: For a vehicle k, between it and all other N vehicles in the same cluster Ci is:

$$Dk = \sum_{n=1}^{N} \sqrt{(Xk - Xn)^2 + (Yk - Yn)^2}$$

Step 2: The speed difference between K and all other N vehicles in the same cluster is:

$$Vk = \sum_{n=1}^{N} |vk - vn|$$

Step 3: maximal acceleration difference between k and all other N vehicles in the same cluster is:

$$Ak = \sum_{n=1}^{N} |ak - an|$$

The relative mobility metric M is:

$$Mk = \propto \frac{Dk}{Max\{An|\forall n \in Ci\}} + \beta \frac{Vk}{Max\{An|\forall n \in Ci\}} + \gamma \frac{Ak}{Max\{An|\forall n \in Ci\}}$$

Where:

α: Vehicles are driving at a similar speed, the distance between vehicles has a greater effect.

β: Vehicles are driving at high speed.

γ: Vehicles enter an area in which the speed limit changes continually.

### b) *Cluster Maintenance and Reforming*

The cluster lifetime is merely brief due to the unpredictable and mobile nature of traffic. Reforming clusters regularly or in real-time is not practical. The authors suggest a cluster maintenance algorithm to reduce cluster reforming in frequency and cost. The cluster maintenance process is divided into four steps:

- No connections between CH and CM.
- No connections between eNodeB and CH.
- A vehicle joins the network.
- Two clusters are too close.

## B. *CEC-GP algorithm*

A Center-based Stable Evolving Clustering Algorithm with Grid Partitioning (CEC-GP) [2] placed more emphasis on VANET clustering. Some methods for clustering VANETs make use of statistical clustering techniques like K-means or other models that incorporate density measurements.

The study has focused on research that has used base stations on the road, which are becoming more prevalent in today's infrastructure, to carry out clustering in VANETs. To take advantage of the expanding range of V2I communication for LTE and to give a global view-based clustering, which makes the decision more stable and predictive; this paper has explored the clustering of the VANETs in the highway environment using a center-based approach.

The grid-partitioning step of data summary, which effectively divides the environment into grids, is the foundation of the approach, which is based on adding vehicle motion information. Each grid provides a high-level entity to aid in the decision to create outliers or clusters when grouping information. The approach is described as a broad framework for clustering VANETs that included assigning, choosing a cluster head, merging, and removing clusters.

## C. *CATRB algorithm*

Clustering algorithm using the traffic regularity of buses (CATRB) that takes into account the mobility characteristics of vehicles to address this issue (velocity, position, and direction) [3].

To estimate the space and time distribution of other vehicles, their model also consults fixed bus routes. To select the best CH in the VANET, CATRB uses the incenter, circumcenter, and centroid of an equilateral triangle. Due to its central location inside the cluster, the resulting CH manages the entire system more effectively. Additionally, the CH conveniently and successfully transfers data to other CMs due to the proximity between the CH and CMs. The authors employ real traffic data from Taipei in their simulations, and the findings demonstrate that the proposed strategy considerably increases cluster stabilities by lowering the likelihood of the CH changing [3].

In CATRB, a three-stage method, to address the different VANET issues. In the first stage, they record the TCHT of each BN as well as the CHT and CMT of the vehicle node. They suggest a CH election procedure in the second stage to lessen cluster fragmentation. To increase cluster stability, BNs determine the ideal CH. In the final stage, a secondary

CH election process is suggested to lessen cluster instability brought on by a cluster with too many nodes [3].

### *D. SC-GDRV algorithm*

A Stable Clustering Approach based on Gaussian Distribution and Relative Velocity in VANETs" (SC-GDRV) [4], a novel approach was proposed to analyze clusters in VANETs. This approach utilized the average speed of vehicles and the standard deviation to classify clusters into two distinct levels of stability.

The first level consisted of the most stable clusters, which encompassed approximately 68% of the vehicles. The second level included the less stable clusters, encompassing about 95% of the vehicles. Within these clusters, any vehicle with a velocity equal to or close to the average value could be chosen as the Cluster Head (CH) [4].

By employing this approach, SC-GDRV aimed to establish stable clusters based on a statistical analysis of vehicle velocities. The selection of CHs based on relative velocities and adherence to the average value contributed to enhancing the stability and effectiveness of communication within the VANET network [4].

This work aims to increase the network stability and reduce the topology dynamically. The Gaussian normal distribution principle is used to accept and reject compounds during the cluster formation process, in addition to the method of velocities and standard deviation. The Clustering is used to reduce Routing Overhead and enhance message delivery. The role of the algorithms is divided into two parts, and each section has its functions [4]:

•*Cluster formation*: Create clusters, CH selection, Set CM, Getaway, and Assist Connection.

•*Cluster maintenance*: Improve the links, describe leaving, joining vehicles, and merging clusters.

A normal distribution (Gaussian distribution) was relied upon for its ability to model random phenomena (Model random phenomena). There is a strong correlation between sample size and the possibility of Gaussian distribution of samples. The cluster stability will be increased with the decrease in the suggested velocity limit.

The proposed solution is based on creating two types of clusters [4]:

- *Type 1*: The number of vehicles in a specific part of the street is calculated, and Velocity means and standard deviation are calculated. The largest part of the curve represents 68% of the vehicles and they are the most stable, and about 32% of the vehicles that affect the stability of the network are excluded, and the selected vehicles are close in speed.
- *Type 2*: This type includes 95% of the vehicles according to the curve, and can be used to form a fixed cluster and exclude 5%. The relative speed between the vehicles here is greater than the first type.

### *E. MABSC-CD algorithm*

Multi-Agent-Based Stable Clustering and Collision Detection (MABSC-CD) present a new technology called (Dynamic Clustering Technique) which was devised to overcome the problem that the network faces when a vehicle leaves the Cluster. In addition to solving the problem of traffic congestion, where this problem is addressed, places of congestion are detected and reported, and an algorithm that takes into account mobility has been devised in BS to overcome the problem of the Routing Protocol. When a congestion or collision is detected, an alternative route is searched directly, and attention is paid to the Mobility of the BS node, and Sensor Node when making routing decisions [5].

This work presented the possibility of dealing with cases of traffic congestion and collisions in the VANET network, where a technology was devised to detect cases of traffic collisions, and the weight factor was relied upon to choose CH, and the new approach proved its ability to reduce data loss and increase its transfer rate.

### *F. SCalE algorithm*

Stable Clustering algorithm for vehicular ad hoc networks (SCalE), presenting a stable cluster head selection scheme that is achieved using the knowledge of the vehicle’s behaviors [7].

This algorithm uses a clustering technique, neighboring vehicles grouped into one cluster, with a particular vehicle elected as a Cluster Head (CH) in each cluster. Each vehicle (Cluster Member CM) in this cluster communicates with Unmanned Aerial Vehicles (UAVs) or base stations through the CH of the associated cluster. Two features are incorporated into the algorithm: Knowledge of the vehicle's behavior for efficient selection of CHs, and employment of a backup CH to maintain the stability of cluster structures.

- Step 1: Vehicle Behavior (Bk) the value is set to 1 if the vehicle intends to leave the system and to 0 otherwise, it is used to filter out unstable vehicles as cluster heads.
- Step 2: Relative Mean Speed (Sk) The stability of the clusters can degrade rapidly in a highly mobile environment. it represents a measure of the stability of a vehicle in a VANET. It calculates by taking the difference in velocities (v) between the vehicle (k) and all Neighboring (N) vehicles within its range, the value is between 0 and 1.
- Step 3: Mean relative distance (Dk) indicates that the neighboring vehicles are closer to the potential CH. By GPS coordinates of two vehicles k and n, can calculate the distance between the two at an arbitrary time.
- Step 4: The value of Index ξk serves as an indicator that is computed through the exchange of messages between the network and each K vehicle. These messages, referred to as Cooperative Awareness Messages (CAMs), contain safety-related information such as vehicle speed and position. The vehicle with the lowest index ξk is selected as the Cluster Head (CH), while the remaining vehicles within the same cluster become Cluster Members (CMs). The index ξk is determined by adding Sk and Dk. During the periodic exchange of CAMs between vehicles, each vehicle records the values of Sk and Dk and shares them with others. Subsequently, the vehicle with the lowest index is designated as the CH.

## IV. SUMMARY AND DISCUSSION

In this section, we make a comparison in Table 1 of the advantages and disadvantages of each of the algorithms studied. In Table 2, the algorithms that were studied and compared were dealt with in terms of the 3 most important factors affecting stability in VANETs networks, and these factors are, CH duration, CM duration, and Number of clusters in every network.

TABLE I. SUMMARY OF PREVIOUS STUDIES (ADVANTAGES & DISADVANTAGES)

| **Algorithm** | **Advantages and disadvantages** | | |
|---|---|---|---|
| | ***Advantages*** | ***Disadvantages*** | ***Paper reference*** |
| CBSC | • Improve the reliability and efficiency of communications.<br>• Provides a cluster maintenance algorithm to reduce cluster reforming's frequency and cost, which can improve the stability of the system.<br>• Able to outperform SCalE average CH lifetime, packet loss rate, and average CM lifetime. | • Require significant infrastructure investment to install GPS devices and 802.11p and LTE interfaces in every vehicle, which can be costly and time-consuming.<br>• It fails to outperform ScalE in the average CH lifetime. | [1] |
| CATRB | • Improves cluster stability by decreasing the number of cluster head changes.<br>• Takes into account the mobility characteristics of vehicles, such as velocity, position, and direction, to increase cluster stability. | • The algorithm requires each vehicle to calculate the route with the minimum cost for every destination in the network. This calculation can be time-consuming and may cause a delay in the transmission of data. | [3] |
| CEC-GP | • Allows for multi-level data aggregation, leading to better clustering decisions based on data reduction and summary phases.<br>• The incorporation of base stations on the road can lead to effective, stable, and high-performing VANET clustering.<br>• The proposed clustering model utilizes higher moments of the mobility variables, such as acceleration in addition to velocity and position, which offers a novel evolving aware VANETs clustering. | • The study does not take into account the cost of implementing the proposed clustering model, which may be significant and limit its practical application.<br>• The proposed clustering model may be complex and difficult to implement, requiring a high level of technical expertise. | [2] |
| SC-GDRV | • Reducing congestion and enhancing message delivery.<br>• Increase the network stability and reduce the topology dynamic by integrating the Normal probability distribution function, which considers the relative velocity and standard deviation of the vehicles to design new reliable and stable clusters. The smaller the relative speed between CM and CH, the more stable it is. | • The proposed scheme was evaluated using a vehicle system consisting of only 21 vehicles, which may limit the generalizability of the results. | [4] |
| MABSC-CD | • Improved head life of the cluster<br>• Increased stability, especially in difficult cases such as congestion and traffic accidents.<br>• Addresses the problem of traffic congestion and detects and reports congested areas.<br>• Faster cluster head election time, especially in emergency cases. | • Power consumption is high in the proposed method | [5] |
| SCalE | • Enhance the cluster stability in average CH lifetime and reduce the data loss rate. | • It needs a complex infrastructure to be able to get all the requirements of this algorithm.<br>• Compared to CBSC the average Life Time of CM was lower. | [7] |

TABLE II. SUMMARY OF PREVIOUS STUDIES (METRICS PERFORMANCE)

| **Algorithm** | **Table Column Head** | | |
|---|---|---|---|
| | ***CH Duration*** | ***CM Duration*** | ***Number of Clusters*** |
| CBSC | Medium | High | Low |

| Algorithm | Table Column Head | | |
|---|---|---|---|
| | *CH Duration* | *CM Duration* | *Number of Clusters* |
| CEC-GP | Medium | High | Low |
| CATRB | Low | Medium | Medium |
| SC-GDRV | High | Low | Low |
| MABSC-CD | Low | Low | Low |
| ScaLE | High | Low | Medium |

Upon comparing CBSC with CEC-GP, it becomes evident that these two algorithms exhibit similar performance characteristics. However, thorough testing has revealed that the performance of CEC-GP declines as traffic density increases. In contrast, CBSC employs image processing techniques, rendering it more sensitive to dense clusters. Consequently, as traffic density escalates, the CH (Cluster Head) duration proves to be more advantageous in CBSC. Furthermore, according to the findings from experiments conducted by the research team at [1], CBSC demonstrated complete superiority over SCalE. However, it fell short of surpassing SCalE in terms of CH lifetime.

In the CATRB algorithm, a new algorithm was not invented to reduce the number of clusters, but a new algorithm was used to increase the speed of selecting a new CH each time, and thus the problem of CH duration was not solved.

As for the SC-GDRV algorithm, CH duration has been improved, as the method used in selecting CH is very efficient and depends on choosing the most stable compound to be CH. However, this method relies mainly on grouping vehicles with similar speeds together in a cluster, which can lead to a significant increase in the number of clusters or poor quality in the resulting cluster. In addition, this method depends on the speed of data processing, the greater the number of vehicles and their speed, the greater the amount of energy consumed in the formation of the cluster, which leads to instability.

The MABSC-CD algorithm was able to reduce the number of clusters by making a dynamic cluster capable of changing the radius and size depending on the speed and density of the vehicles, but it did not improve the CH lifetime and CM lifetime, as the author indicated that the CH duration decreases significantly as the speed increases.

As shown in Table 2, there is no perfect category that could be used for all networks' scenarios. For example, the CBSC algorithm can effectively improve the stability in VANETs networks, but it will face a problem in terms of infrastructure due to the need to always have advanced technology in each vehicle, as well as in terms of controlling the Cluster head time rate, which will negatively affect the stability of the network in some cases. Therefore, it is good to combine the advantages of more than one algorithm to make it hybrid and dynamic to be able to adapt to the general situation of the network.

## V. CONCLUSION AND FUTURE WORK

Network stability is a critical concern in the implementation of VANETs, particularly when designing clustering algorithms. This survey explores stable clustering algorithms to identify the best algorithm that maintains essential metrics for network stability. The algorithms are classified based on their ability to sustain Cluster Head (CH) lifetime and Cluster Member (CM) lifetime. Algorithms with higher capabilities in preserving these factors tend to have longer average cluster lifetimes. Additional metrics considered include data loss rate and average cluster formation time for each algorithm.

The survey examines the advantages and disadvantages of each algorithm in terms of requirements, performance, and methodology. Table 2 demonstrates that the CBSC and SCalE algorithms outperform other algorithms across most parameters. However, CBSC falls short of SCalE in terms of CH lifetime, resulting in a higher average CH change and reduced stability for CBSC.

Future work will involve identifying the factors contributing to CBSC's failure to outperform SCalE in terms of CH lifetime. The aim is to enhance the CBSC algorithm and develop a hybrid approach that combines both CBSC and SCalE algorithms. This hybrid approach can leverage the strengths of both algorithms to improve the average cluster head lifetime.

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