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A COMPREHENSIVE REVIEW OF CLUSTERING PROTOCOLS IN VEHICULAR ADHOC NETWORKS (VANETS)

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ABSTRACT:

Vehicular Adhoc Networks (VANETs) are essential for improving Intelligent Transportation Systems (ITSs), passenger convenience and road safety. The purpose of Dedicated Short-Range Communications (DSRC) innovation is to enable efficient communication between vehicles and infrastructure in VANET. Nevertheless, the Vehicle-To-Vehicle (V2V) network configuration of VANET might give rise to intricate challenges such as hidden terminal problems, scalability limitations and resource insufficiency. To overcome these difficulties and improve the efficiency of the network, clustering protocols have been implemented in VANET. This paper provides a thorough examination of the latest clustering protocols in VANET, arranging them in chronological order. Additionally, it evaluates the capabilities, limitations, and effectiveness of these methods, offering valuable perspectives on potential advancements in this field.

Keywords—VANET, DSRC technology, Clustering, ITS, V2V communication, Scalability

I. INTRODUCTION

Private automobiles significantly contribute to traffic accidents due to reckless driving, poor road conditions, and weather. VANETs, using DSRC technology, aim to address this issue by enabling wireless communication between vehicles, transmitting safety and non-safety data. Safety information helps cars make informed decisions, while non-safety information enhances passenger convenience [1]. VANET communication can be categorized into three forms: V2V, Vehicle-to-Infrastructure (V2I) and Infrastructure-to-Infrastructure (I2I), as shown in Figure 1. V2V facilitates wireless message transmission between cars, while V2I connects vehicles to infrastructure-based networks for data exchange. I2I enables bidirectional data transmission between infrastructure and surrounding automobiles. VANET design connects the Roadside Unit (RSU) and Onboard Unit (OBU), enhancing throughput and efficiency [2]. The OBU oversees information exchange between vehicles and RSUs, using a central processing unit, random access memory, network interface, and sensors. VANETs' suitability for monitoring and safety applications depends on factors like vehicle motion, power availability, network density, real-time communication requirements, data processing difficulties and topology [3].

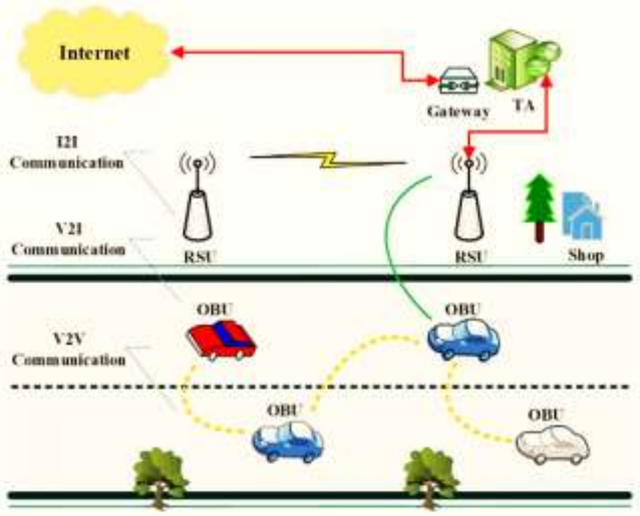

Figure 1. Architecture of VANET

VANETs provide various applications [4], including vehicle safety, traffic management, road condition monitoring, emergency assistance, infotainment, parking assistance, environmental monitoring, fleet management and cooperative driving. ITSs use vehicular communication protocols, presenting issues like bandwidth limitations, delay constraints, privacy concerns, cross-layering protocols, and security threats. To combat these issues, efficient clustering and communication protocols are essential [5]. Clustering is a technique used to group vehicles based on their geographical proximity, forming clusters consisting of Cluster Head (CH), Cluster Members (CM) and Cluster Gateways (CG). Figure 2 demonstrates an architecture of cluster-based VANET.

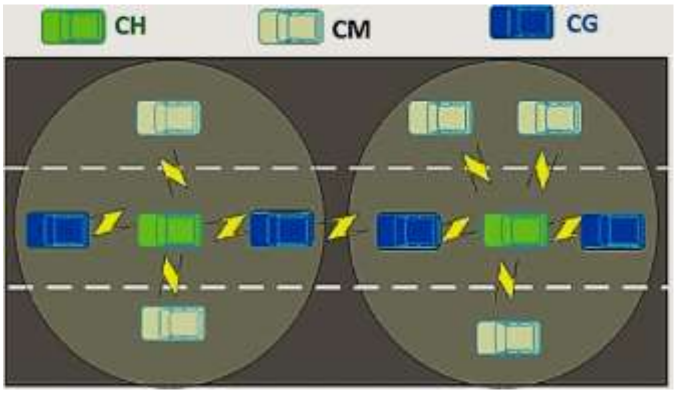

Figure 2. Architecture of Cluster-based VANET

Cluster topologies can be one-hop or multi-hop, with one-hop neighbors joining to form a cluster. Multi-hop clusters provide more stable clusters but are more complicated to implement and maintain. Within multi-hop clusters, CHs can communicate indirectly with CMs, and CMs can communicate with their CHs via other CMs [6]. In a dynamic VANET, CH is chosen for each cluster to manage traffic and ensure balanced message transmission. Vehicles use HELLO messages to gather neighbor information, compute metrics and select CHs. Nearby vehicles become CMs and some CGs, and their status is monitored and taken action. Table 1 provides a brief description of important performance metrics for clustering protocols, along with the desired limits for each metric to achieve an effective clustering algorithm.

Table 1. Standard Measures Utilized for Assessing Clustering Protocols in VANETs

Performance measures	Description	Required limit
Cluster lifetime	The duration of a cluster	High
CM lifetime	The entire amount of time a CM remains linked to a single cluster.	High
CH lifetime	The time between a vehicle being designated by the state as a CH and when it isn't.	High
Cluster efficiency	Proportion of participating vehicles in the clustering process to all vehicles in the network at the time of the simulation.	High
Connectivity level estimation	Amount of links that are currently operational with the CH.	High
CM disconnection frequency	A sum of all CM disconnections from their CH in a certain duration.	Low
Cluster convergence	It describes the amount of time needed for every node to join a cluster when a clustering strategy first starts.	Low
Clustering overhead	The average communication needed by the clustering protocol to create and maintain clusters in terms of bytes or packets.	Low
Number of clusters	The total number of clusters in a particular network that formed in a certain amount of time.	Low

Stable clustering is crucial for facilitating effective communication amongst vehicles. VANETs use various clustering protocols to create and manage traffic networks [7]. Figure 3 provides a detailed taxonomy of various clustering protocols addressing these issues.

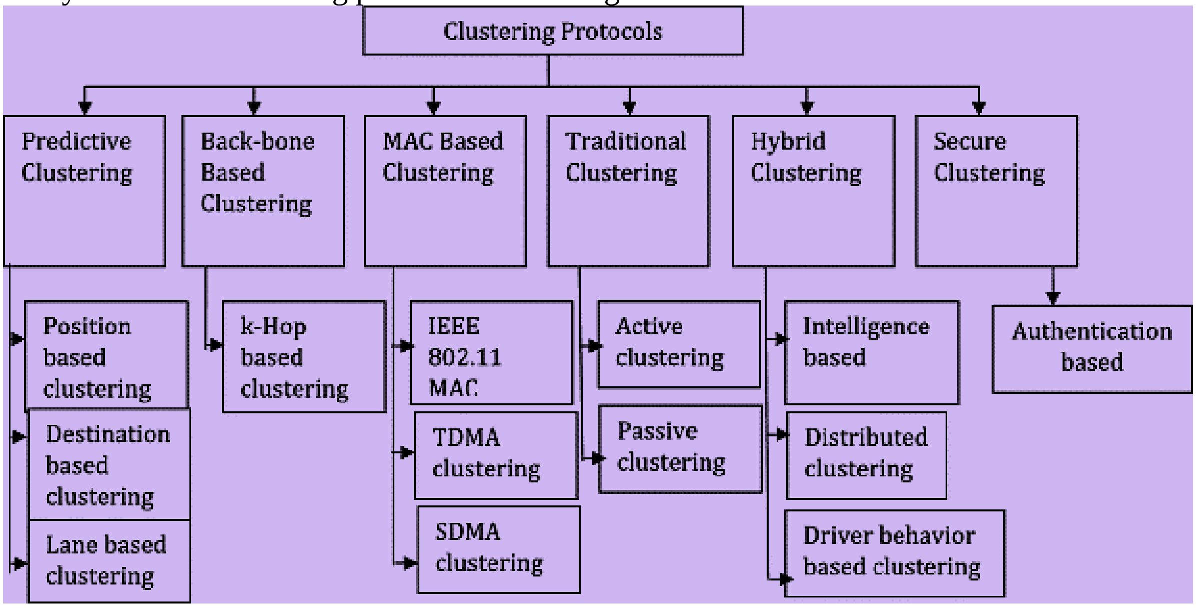

Figure 3. Classification of VANET Clustering Protocols

Predictive clustering uses geographical location and future vehicle actions to establish cluster structures and prioritize relationships. Backbone clustering establishes communication among clusters, while k-hop-based clustering uses hop distance to determine cluster structure. MAC-based clustering uses IEEE 802.11 MAC protocol, Time Division Multiple Access (TDMA) and Space-Division Multiple Access (SDMA) protocols. Traditional clustering is active or passive, with passive methods reducing overhead. Hybrid clustering integrates AI and fuzzy logic for better stability. Secure clustering is crucial for VANETs, but challenges like efficient message authentication and secure clustering need to be addressed. Public Key Infrastructure (PKI)-based algorithms are proposed for communication security in VANETs.

This study reviews clustering protocols in VANETs, comparing their benefits, drawbacks, and performance metrics. It identifies research gaps and suggests solutions for further expansions. The following is the outline for the remainder of the article: Section II reviews clustering protocols in VANETs and compares their performance. Section III concludes the review and suggests potential future directions in this field.

II. SURVEY ON CLUSTER-BASED PROTOCOL IN VANET

One innovative VANET routing system that was created by Divya et al. [8] is the Clustered Vehicle Location system using Hybrid Krill Herd and Bat Optimization (CVL-HKH-BO) to reduce energy usage and packet delay. Folsom et al. [9] proposed a Novel Routing and Hybrid-Based Clustering System (NRHCS) for VANETs. It involves re-clustering, electing CHs, adding or deleting clusters, and building new clusters based on vehicle connectivity and comparative displacement. Elira et al. [10] developed a clustering approach for VANET using Destination-Aware Context-based Routing Scheme (DACRS), reducing network burden, improving Packet Delivery Ratio (PDR), and reducing inter-cluster communication delays.

Ardakani et al. [11] developed VANET routing protocol called CNN, utilizing a compact, decentralized clustering mechanism for efficient network resource utilization and high PDR. Pandey et al. [12] developed the Overlapped Cluster-based Scalable Routing (OCSR) protocol using K-means clustering scheme for VANETs. Habelalmateen et al. [13] developed Traffic-Aware Clustering Routing Protocol (TACRP) for VANETs to enhance traffic management and reduce energy use by grouping cars in the same direction. Shah et al. [14] developed AMONET, a vehicular clustering scheme for VANETs, using the moth-flame optimizer to optimize cluster construction based on transmission range, vehicle direction, speed, network node count, and grid size. Sharma et al. [15] presented a weight-based clustering protocol using parameters like vehicle speed and degree to choose

CHs in VANETs.

An Enhanced Cluster-Based Lifetime Protocol (ECBLTR) [16] was developed for VANETs, which uses a fuzzy inference to select the optimal CH based on various parameters. It also determines the best route considering CH neighbors and destination positions. A Robust and Reliable Secure Clustering and Data Transmission (R^2SCDT) [17] was created for VANETs, which uses weight and trust values to identify malicious nodes for secure data transmission. Xie et al. [18] introduced a cluster-based routing protocol to decrease latency in VANETs. They categorized vehicles as aligned or non-aligned, identified movement patterns, and formed clusters based on current location for efficient message transfer. A cluster-based protocol with authentication [19] was used to enhance communication and resource sharing among vehicles. A Cluster-Based Protocol for Prioritized Message Communication (CBP-PMC) [20] was developed for VANETs that prioritizes emergency message transmission using vehicle speed and location. It includes features like temporary message storage, stable-node sampling and distributed backoff timer-based CH selection for secure emergency message dissemination.

Table 2 compares clustering protocols in VANETs, showing their impact on PDR, delay, throughput, and other factors.

Table 2. Comparative Study of Clustering Protocols in VANETs

Ref. No.	Protocols	Advantages	Limitations	Network Performance
[8]	CVL-HKH-BO	It achieved a high data transfer rate and low delay.	Scalability issues when number of vehicles increase substantially.	Data transfer ratio = 98%; Delay = 0.18sec
[9]	NRHCS	It achieved low latency and handled disconnection problems in sparse networks.	Periodically broadcasting messages between vehicles added extra overhead for forming and maintaining clusters.	PDR = 80%; Delay = 0.45sec
[10]	DACRS	It improved cluster stability.	Network performance was not effective.	PDR = 55%; Delay = 6.5sec
[11]	CNN	Delay and network congestion were low.	The network used single-hop clustering based on Hamming distance, resulting in more CMs and CHs. This led to higher routing costs for inter-cluster transmission.	Mean End-to-End (E2E) delay = 3.2sec; PDR = 90%
[12]	OCSR	It achieved better PDR and lower delay, allowing for handling of large networks.	It achieved low throughput.	PDR = 90%; Delay = 8sec
[13]	TACRP	It increased the cluster reliability, throughput, and PDR.	Packet loss and network overhead were high.	PDR = 98.37%; E2E delay = 152.71ms
[14]	AMONET	It can increase the cluster lifetime and reduce packet delays.	The cluster reformation was necessary because the network topology changed frequently.	Mean amount of CHs = 13; No. of clusters formed = 23
[15]	Weight-based clustering	It provided low network overhead and high PDR.	Increasing the number of vehicles impacted network scalability.	PDR = 90%

[16]	ECBLTR	It can handle the uncertainty in choosing the best CHs.	The network's coverage was not effective.	Alive nodes = 6500
[17]	R^2SCDT	It reduced delay and control overhead.	The PDR value was low.	Delay = 0.3123sec; PDR = 79.43%
[18]	Clustering and frequent pattern discovery	Better PDR and data transmission delay.	Maintaining cluster and path stability in high-mobility networks was a challenge.	PDR = 88.56%; Delay = 24.566ms
[19]	Clustering and key distribution	Delay and overhead were low.	PDR was very low.	Authentication delay = 4ms; PDR = 28%
[20]	CBP-PMC	It achieved the highest PDR and lowest delay.	The cluster size was not optimized, which could affect network performance in different road conditions.	PDR = 99%; Delay = 5sec

The evaluation of protocols based on PDR and delay metrics showed that CBP-PMC [20] achieved the highest PDR for emergency messages, while TACRP [13] had the lowest delay, indicating minimal latency for data packets. However, a mechanism to dynamically optimize cluster size based on network conditions and application requirements is needed for improved network performance.

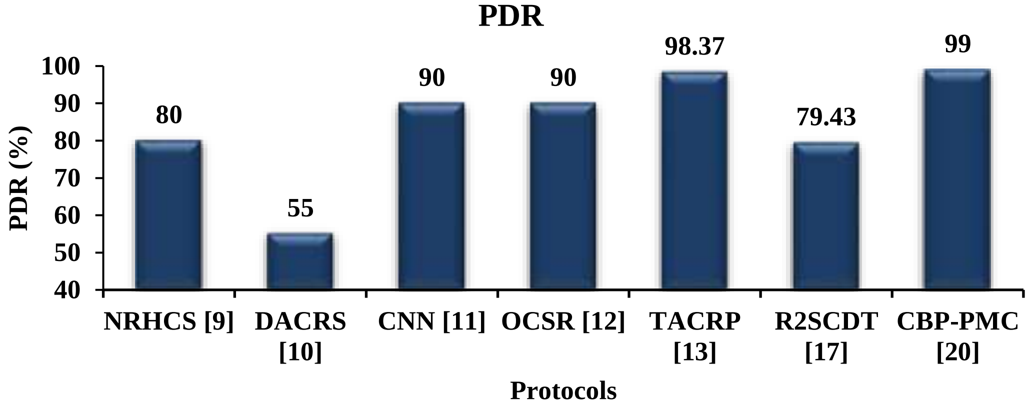

Figure 2(a). Comparison of PDR for Different Clustering Protocols in VANETs

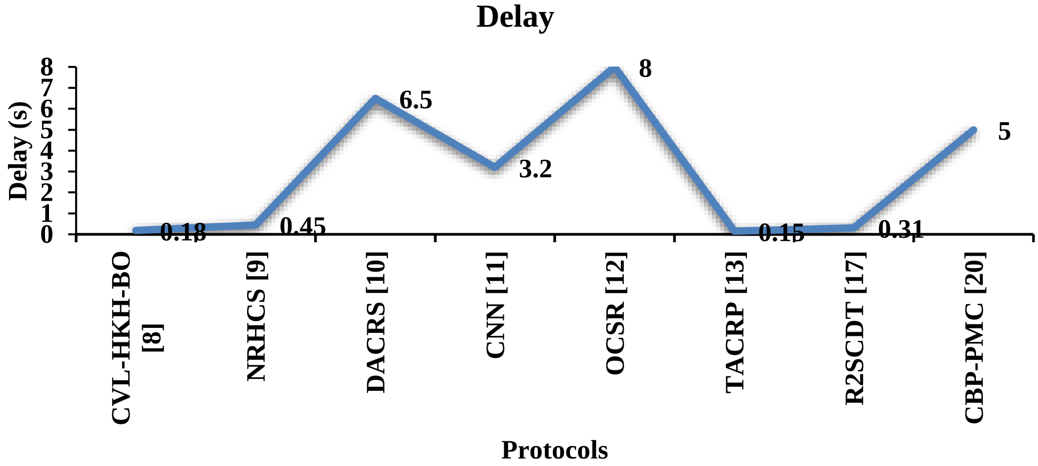

Figure 2(a). Comparison of Delay for Different Clustering Protocols in VANETs

III. CONCLUSION

This paper offers a comprehensive comparison of recent clustering protocols in VANETs, assessing their performance based on PDR and delay. The findings indicate that the CBP-PMC protocol excels in time-sensitive applications, enabling rapid communication of emergency messages. However, this protocol has limitations, such as the inability of CHs to manage the simultaneous distribution of multiple types of traffic, and the absence of an optimal cluster size determination. Future developments could focus on optimizing cluster size according to various road conditions and application requirements, as well as implementing data fusion and caching techniques for CHs to enhance network performance in VANETs.

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