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MC^{2}R : Multi criteria based cluster routing for software defined VANET

Manish Kumar †
Department of Computer Science and Engineering
University School of Information, Communication and Technology
Guru Gobind Singh Indraprastha University
Dwarka 110078
Delhi
India

Ram Shringar Raw *
Department of Computer Science and Engineering
Netaji Subhas University of Technology
Geeta Colony 110031
Delhi
India

Abstract

VANET (Vehicular Ad-hoc Network) facilitates real-time and efficient communication among vehicles via vehicle-to-vehicle and vehicle-to-infrastructure interactions. The continuously evolving topology of VANET raises significant concerns about scalability and dependability. Many manufacturers produce vehicles, making it crucial to consider the heterogeneity in VANET routing. Using Software Defined Networking (SDN) and Vehicular Ad Hoc Networks (SD-VANET) together makes it easier to handle heterogeneity and scalability. However, the Roadside Unit's (RSU) workload is still a big issue. This study proposes a cluster-based routing method for SD-VANET, termed MC^{2}R (Multi Criteria based Cluster Routing for Software Defined VANET). The Multiple Criteria Decision Making (MCDM) method has been used to identify the cluster head that minimizes the expenses associated with cluster head selection. The Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) are used for decision-making purposes. The efficacy of the suggested work has been assessed in comparison to leading routing algorithms. The suggested routing protocols demonstrated

† *E-mail:* **manishk19071984@gmail.com**
* *E-mail:* **ramshringar.raw@nsut.ac.in (Corresponding Author)**

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commendable performance in throughput, end-to-end latency, and cluster head longevity. The finding indicates a significant reduction in the burden of RSU.

Subject Classification: *68M12, 68M10.*

Keywords: *Vehicular ad hoc networks, Software-defined networking, MCDM based routing, AHP, TOPSIS, SD-VANET routing.*

I. Introduction

The continuous technological advancements in automobiles communication technologies have led to the development of a special vehicle network, known as vehicular ad hoc networks (VANETs) [1],[2],[3],[4],[5]. VANETs with SDN [6] i.e. Software Defined-VANETs (SD-VANETs) [7], [8] represent a significant evolutionary advancement in VANET implementation [9]. This amalgamation of SDN and VANET provides the better network management and flexibility which further improves the traffic management and road safety applications [10],[11]. The RSU Plays a crucial role in SD-VANET routing. The route is decided on the RSUs in SD-VANET. Therefore, the load on RSUs increases significantly. The highly mobile nature and frequently changing network topologies of vehicle networks provide considerable complications, particularly in routing [12].

Cluster heads are responsible for distributing the control packet load in the cluster-based routing strategy. The cluster-based routing approach is thus a possible solution for the challenges that are associated with SD-VANET routing, particularly with regard to reducing the load on RSU. It is important to note that the performance of the cluster-based routing is strongly dependent on the selection of cluster heads.

The cluster head selection relies on different parameters like speed of the vehicle, transmission range etc., so that the cluster heads are more stable. The stability of cluster heads leads the stability of VANET. This paper introduces a novel approach to cluster head selection in SD-VANETs by utilizing the AHP and TOPSIS [13], [14], [15]. The AHP has been used to find the weightage of criteria used to select cluster head. By applying TOPSIS, the ranking of the candidates of the cluster head is done. The vehicle having highest rank is selected as a cluster head and further routing is performed.

This method incorporation into SD-VANETs is the major step toward achieving the full potential of intelligent transportation systems. This not only enables diversified network communication in a more ascertainable and effective manner, but it is also essential for the security and sustainability of vehicular networks. This study, thus, provides an in-depth analysis of the proposed protocol as well as its service implementations and the range of advantages which it introduces to vehicular communications. By analyzing and simulating the performance of the proposed cluster-based routing protocol, we demonstrate the protocol's capability in enhancing network stability and scalability but also establishes a new standard for routing protocols in the rapid changing environment of SD-VANETs.

The organization of this paper is as follows: In Section 1, the introduction of the study is given. Section 2 highlights the literature review. In Section 3, we analyse and discuss our proposed architecture. Motivation and contribution have been discussed in section 4. In Section 5 the proposed cluster-based routing has been discussed in detail. Results of the simulation are analysed in detail in section 6. Finally, in section 7, we provide the conclusion.

II. Literature Review

The development of Software-Defined Vehicular Ad-hoc Networks (SD-VANETs) has become a focal point in recent research, owing to their pivotal role in the advancement of intelligent transportation systems. This literature review explores the existing body of knowledge surrounding SD-VANETs, with a particular emphasis on the methodologies and challenges associated with SD-VANET routing. A range of routing protocols have been proposed for SD-VANETs, each with its own unique approach and benefits.

Qi et al. [16] devised a routing system for SD-VANET that facilitates the assessment of a hybrid vehicular network integrating Dedicated Short-Range Communications (DSRC) and Cellular-Vehicle-to-Everything (C-V2X) technologies. Utilizing cellular connections for data transfer may result in significant cellular bandwidth costs. This research introduces a Traffic Differentiated Clustering Routing (TDCR) method in a Software Defined Network (SDN)-facilitated hybrid vehicular network. The proposed methodology includes a centralized one-hop clustering system and an optimization tool for data transmission. The optimization seeks to equilibrate the expenses of cellular bandwidth and end-to-end latency for Cluster Heads (CHs) relaying their aggregated data through either multi-hop Vehicle-to-Vehicle (V2V) communications or cellular networks. In [17], an ant colony algorithm-based routing protocol (ACA-RP-SDVN) for software-defined vehicular networks is proposed. It is designed to tackle the challenges of low transmission success rates and suboptimal routing performance. The protocol delineates a software-defined vehicular network architecture, utilizes forward and backward ants to investigate and refresh ideal pathways, and implements a greedy method for data packet transmission. Experimental findings indicate that the proposed protocol surpasses the existing AODV and GPSR protocols regarding network routing longevity, routing alteration frequency, and communication efficacy. Chahal et.al. [18] introduces a SVDN communication utilizing heterogeneous wireless interfaces. Network selection is conducted through the use of utility functions and a game theory method inside the framework of Software-Defined Networking (SDN). The suggested technique incorporates a data distribution strategy inside the selected network, utilizing the principles of controller layering and link duration. In [19], a centralized SDN-based routing algorithm named Multi-Flow Congestion-Aware Routing (MFCAR) is suggested. The proposed scheme tackles the routing difficulties in 5G-enabled vehicle networks. MFCAR utilizes the coordination capabilities of SDN to identify appropriate V2V multi-hop pathways and transfer traffic from V2I to V2V communications, employing both cellular and Wi-Fi technologies. Realistic simulations demonstrate that MFCAR surpasses conventional centralized routing algorithms, such as Dijkstra's, in packet delivery ratio, goodput, and average packet delay, achieving performance improvements of up to five times. In order to enhance the performance of cluster-based routing protocols in VANETs, Abuashour et.al. [20] have introduced three algorithms namely, CBLTR, IDVR, and CORA. They are expected to enhance the performance in implementation of VANETs. The proposed routing protocols for cluster based routing enhance the stability and throughput of routes, control overhead messages, and end-to-end delay. The IDVR protocol determines the most efficient path by considering its present position, target destination, and a maximum of the minimum average throughput. The suggested processes were validated through simulation tools, and the outcomes proved that these were even better than a vast number of the alternative protocols encompassed within the research literature. In [21], the author introduces a novel Congestion-Aware GPCR Routing Protocol (CA-GPCR) to mitigate network congestion in vehicle ad-hoc networks (VANETs), especially in metropolitan environments. The protocol takes into account both the available buffer capacity and the distance to the destination while determining the next hop, unlike the original GPCR protocol, which relies only on distance.

Simulation findings indicate that the CA-GPCR protocol surpasses conventional VANET routing methods regarding packet delivery ratio and latency.

III. Proposed Architecture

In this section, the proposed architecture for Cluster based Software Defined VANET has been discussed. The proposed architecture has been divided into four planes. The first plane is acts as a data plane of the SDN. The data plane is responsible for the data forwarding. We have divided the control plane into two parts. The Cluster Head (CH) works as a control plane -I. Whenever the route is required, the CH node provides the route to the cluster member. The node belongs to the control plane-I will deal with the control packets. The RSUs have been used to work as control plane also. If the route is not available at the control plane I, the nodes at control plane-I communicates with the control plane-II to get route. The Control plane-II has the topological view of its own region. If the route is not available at control plane-II, the control plane-II contacts to the cloud storage. The cloud storage has global view of the topology. The cloud storage work as a control plane and application plane both. The high storage and computing power enable the cloud to work as a both. The Figure 1 illustrates the proposed architecture.

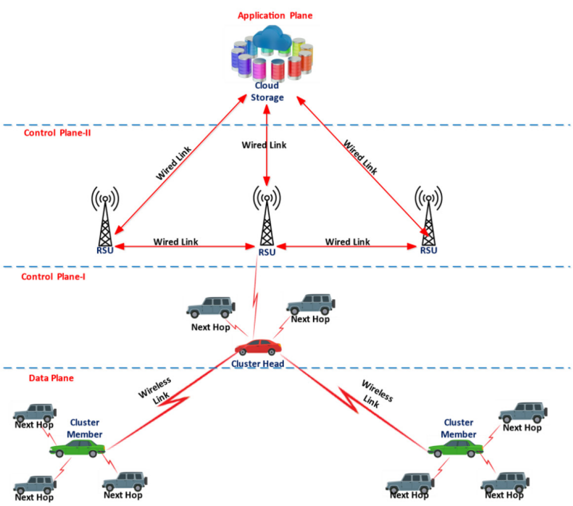

Figure 1

Proposed Architecture

IV. Motivation and Contribution

Software Defined Networking become popular in networking research community. The integration of SDN and VANET, collectively known as SD-VANET, have drawn the attention of researchers. Much research has been contributed on routing issues in SD-VANET. The SD-VANET uses the centralised system to decide the rules for routing. This puts on the load on the cartelised system, in our case RSUs. This is the major problem which must be dealt with while proposing a routing protocol for SD-VANET. This work aims to reduce the control plane load from the RSUs in SD-VANET routing. Followings are major contribution of this work.

1. This work proposes the cluster-based architecture for SD-VANET to distribute the load of control plane.
2. A novel routing protocol using multi-criteria decision making has been proposed
3. The proposed architecture reduces the control plane load on RSU without adding new infrastructure.

V. MC^{2}R: Multi Criteria based Cluster Routing for Software Defined VANET

In this section the proposed routing protocol has been discussed in detail. First, the utilisation of AHP and TOPSIS for decision making of clustering is discussed then MCDM based clustering algorithm for SD-VANETs has been discussed in subsequent subsection.

A. *AHP and TOPSIS for choosing Cluster Head*

The cluster head selection depends upon the different criteria. In our previous work [22], the criteria have been chosen for routing in SD-VANET. The AHP [23] has been used for the weightage calculation of the chosen criteria. The criteria are decided based on the test simulation results [24]. After finalising the criteria, the pairwise matrix is created. The MC^{2}R calculates the pairwise matrix dynamically. Hence, the criteria weight differs time to time. A sample criteria weight is given in table 1.

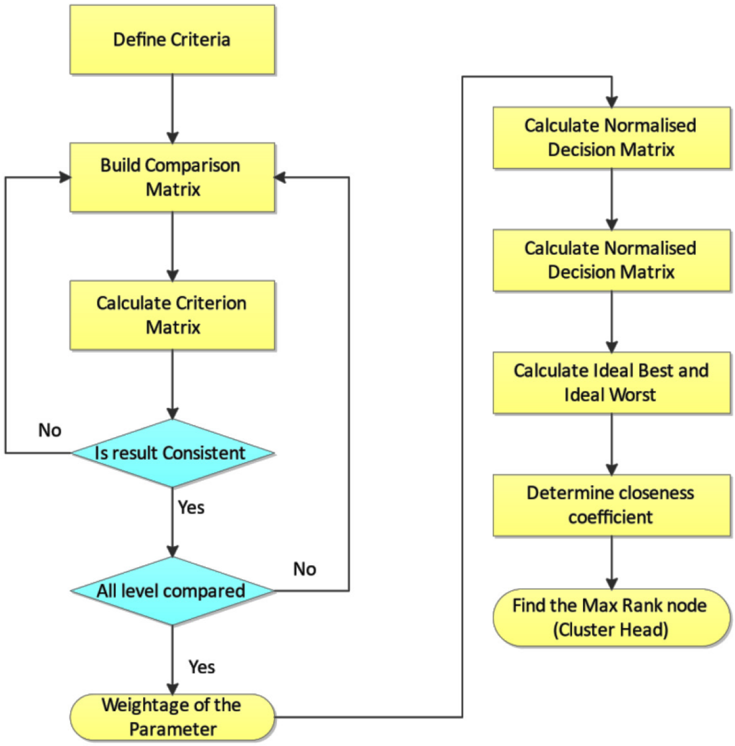

Figure 2

The AHP and TOPSIS process flow for cluster head selection in MC²R

Table I

AHP Calculated Criteria Weight

Criteria	Criteria Weight
Distance	0.224665336
Location	0.057752022
Stability	0.344927798
Data Transmission Rate	0.149863454
Speed	0.093227439
Signal Strength	0.129563951

The TOPSIS allows for a quantitative comparison of multiple contender nodes based on several criteria which leads to the efficient selection process. It can handle any number of vehicles and criteria that allows it to be applicable for dynamic VANET. Since VANETs are highly dynamic, TOPSIS can facilitate quick decision-making by using real-time data to evaluate and ranking of contender vehicles. The proposed work selects the cluster head based on the stability, signal strength, speed, location, data transfer rate and distance [22]. To choose the best cluster head node, it is essential to find the weightage of each criterion. The figure 2 illustrates the steps of AHP and TOPSIS for cluster head selection.

B. *MCDM based clustering algorithm for SD-VANETs*

Each vehicle in the network initializes by broadcasting its initial status including position, speed, direction, and a unique identifier. RSU evaluate their suitability as a cluster head based on predefined criteria. RSU calculates a score based on the predefined criteria using algorithm 1. The vehicle with the highest score within a neighbouring range becomes the provisional cluster head. The cluster heads broadcast their status to their neighbouring nodes. Non-cluster-head vehicles receive multiple potential cluster head announcements. Each vehicle decides which cluster to join based on signal strength, relative speed, and direction alignment with the cluster head. Vehicles send a join request to the chosen cluster head. After receiving join requests, provisional cluster heads finalize their status as official cluster heads. Cluster heads confirm the membership of their cluster members and broadcast a cluster formation message.

Algorithm 1: Cluster Head Selection

M=Number of contestants for Cluster Head
N=Number of Criteria
X=Initial Matrix
W=weight Matrix

for each column j =1 to N
        S ← 0
    for each row i=1 to M
        S←S+Xij* Xij
    end for
    D[j] ← sqrt(S)
end for
for each column j =1 to N

```
        for each row i=1 to M
            R[i,j] ← X[i,j]/D[j]
        end for
    end for
    for each column j =1 to N
    for each row i=1 to M
    V[i,j] ← W[j] *R[i,j]
    end for
    end for
    for each column j =1 to N
        V*[j] ← findmin(V,M)
    end for
    for each column j =1 to N
        V_minus-[j] ← findmax(V,M)
    end for
    for each row i =1 to M
        S1 ← 0; S2 ← 0
    for each column j=1 to N
        x← (V[i,j] -V*[j])
        y← (V[i,j] -V_minus[j])
        S1←S1+ x* x
        S2←S2+ y* y
     end for
     A+[i] ← sqrt(S1)
     A-[i] ← sqrt(S2)
     Final[i]= A-[i]/( A+[i]+ A-[i])
    end for
    return max(Final)
```

Cluster heads periodically broadcast messages to ensure stability and connectivity within the cluster. Cluster members regularly update their status to the cluster head. If a member moves out of range or changes its state significantly, it may leave the cluster. If a cluster head detects a significant change in the network, like a high number of new nodes or a change in vehicle density, it initiates a cluster re-evaluation.

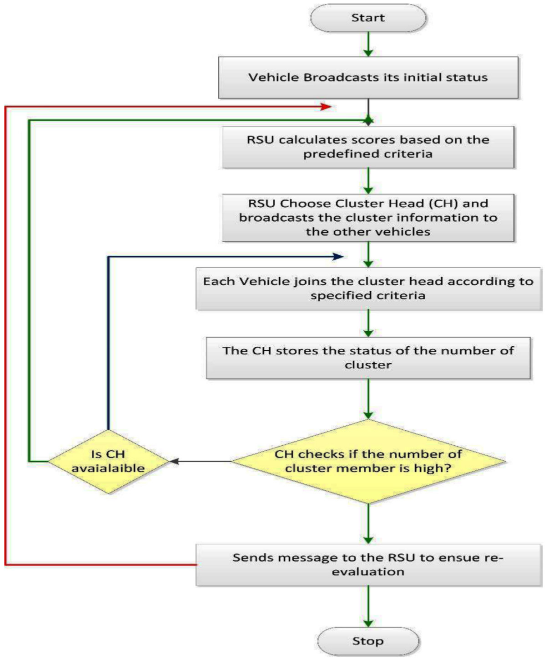

Figure 3

Cluster Head Selection and Maintenance

Clusters may be merged or split based on vehicle density, cluster size, and the overall network stability requirements. In case the current cluster head becomes unsuitable, due to moving out of range, low resources, etc., a new cluster head is elected from the existing cluster members based on the initial election criteria.

Cluster heads periodically update the SDN controller with the network status, including cluster member information and performance metrics. The SDN controller can make global network decisions and suggest adjustments to clusters for optimal performance. When a vehicle leaves the network or no longer needs to be part of a cluster, it sends a departure message to its cluster head and exits the cluster. Figure 3 Illustrates all processes.

VI. Results & Discussion

Two softwares have been used in order to simulate the roads of Delhi, India as shown in figure 4(a) and 4(b), which are namely, OpenStreetMap[25] and SUMO [26]. The intersection of Connaught Place in Delhi is being simulated as the centre, the area of 1,024,000,000 square meters is used as the simulation environment. NS-3[27] is being used to simulate actual driving and packet delivery, which uses parameters mentioned in table 2. Figure 4 illustrate the sample maps used for simulation. The proposed routing protocol is evaluated based on two categories. First the performance of proposed protocol is evaluated based on routing parameters with GPCR and IDVR. The clustering performances are evaluated with two cluster based protocols, High Connectivity Clustering (HCC) and Maximum Packet Collection (MPC).

Table 2

Parameters for simulation

Parameter	Setting value
Simulated environment size	3200m * 3200m
MAC protocol	IEEE 802.11p
Transmission range	300m
Transmission rate	2Mbps
Maximum number of CM	15
Invitation packet cycle	50ms
Invitation packet size	64Bytes
Driving information packet cycle	500ms
Packet size of driving information	10kb

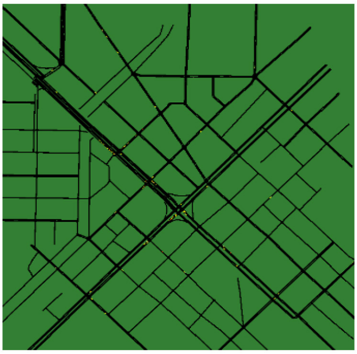

Figure 4(a)

Map used for simulation

Figure 4(b)

Map used for simulation

A. *Routing Performance Comparison*

The figure 5 presents the throughput performance across varying numbers of nodes (20, 40, 60, and 80). GPCR demonstrates low throughput across various node densities. The IDVR outperforms GPCR, however, its effectiveness reduces as network size increases, because of scalability challenges. The better stability of cluster heads gives the longevity of connection during the data transfer; therefore, the proposed protocol demonstrates better throughput at all node densities. The system exhibits a robust throughput at the beginning, even with an increasing number of nodes, yet there is a minor decline as the network grows further. This indicates that the proposed protocol exhibits greater efficiency in managing larger network sizes when compared to GPCR and IDVR.

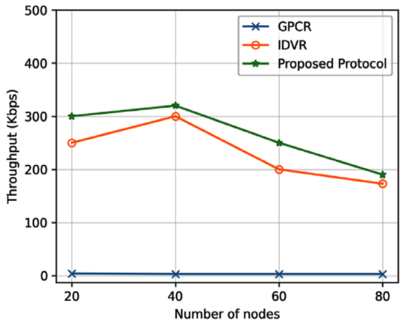

Figure 5

Throughput vs Number of nodes

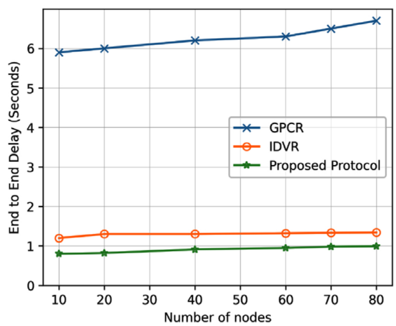

Figure 6

End to End Delay vs Number of nodes

The end-to-end delay denotes the time taken for data to traverse from its source to its destination. The figure 6 presents the end-to-end delay analysis for proposed protocol. The increasing delay denotes that GPCR performs poorly when network density increases. However, the IDVR exhibits a stable end-to-end delay compared to GPCR. The cluster heads in MC^{2}R is relatively stable hence, the proposed protocol shows consistently low end-to-end delay. This performance demonstrates the effectiveness of the proposed protocol in managing end-to-end delay, even as the number of nodes increases. Therefore, the proposed algorithm exhibits scalability while maintaining low latency across different network sizes.

B. *Clustering Performance Comparison*

The figure 7 illustrates the average cluster survival time (in seconds). The analysis has been performed on various time intervals ranging from 25 to 150 seconds. The proposed protocol consistently demonstrates the highest average cluster survival time. This indicates the good stability and longevity of VANET connection. The use of AHP and TOPSIS aims to find the best cluster head according to the predefined criteria. Hence, the proposed protocol performs better than MPC and HCC.

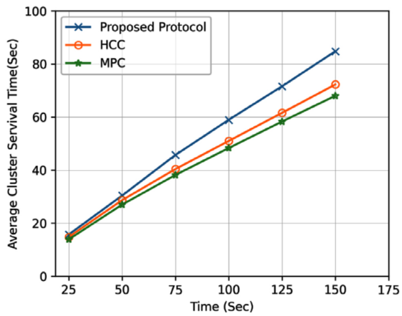

Figure 7

Average cluster time vs simulation time

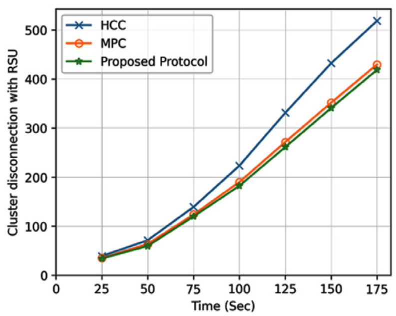

Figure 8

Cluster disconnection with RSU vs Time

Assessing the frequency of cluster head disconnections is crucial for analyzing the stability of the network. Figure 8 examines the frequency of cluster disconnection. The graph clearly indicates that the proposed protocol demonstrates superior performance. Stability and communication range are among the criteria for selecting the cluster. To determine the cluster, the weightage is 34.4% and 14.9% respectively. Consequently, the disconnection of the cluster head decreases throughout the simulation

C. *Analysis of Load on RSU*

The figure 8 illustrates the analysis of load on the RSU The proposed protocol demonstrates a consistently reduced load on the RSU in comparison to RC-LAHR. The RC-LAHR calculates all route on RSU itself, hence, the load on RSU increases in RC-LAHR. The Proposed Protocol utilises the cluster-based routing that divides the route calculation load on cluster heads. Therefore, the load on RSU decreases by 10% to 40%.

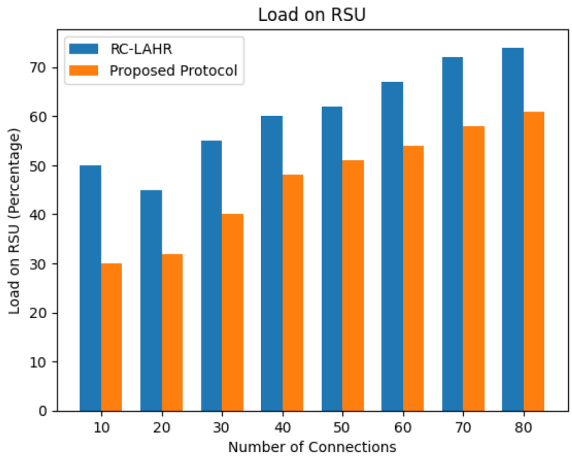

Figure 8

Load on RSU vs Number of Connection

VII. Conclusion

In this study, a cluster based routing for SD-VANET has been proposed. The AHP has been used to calculate the weightage of selection criteria to select the cluster head. The proposed protocol uses TOPSIS select the best cluster head node based on the criteria. The proposed protocol has been analysed on three basic parameters i.e. routing parameter (e2e delay and throughput), clustering parameter and load on RSU. The proposed protocol has been compared to GPCR and IDVR. The end-to-end delay analysis shows the lowest and most stable performance, indicating its efficiency and reliability. Also, the proposed protocol shows superior performance with respect to HCC and MPC in cluster survival time by providing the most durable clusters which further enhances the network stability and minimizing overhead. Finally, the proposed protocol exhibits considerably lower load on RSU in comparison of RC-LAHR. The minimisation of load on RSU provides the viability to SD-VANET even in dense networks. Hence, the proposed protocol demonstrates robustness and scalability for VANETs, providing improved performance regarding throughput, delay, cluster stability, and RSU load management, thereby making it suitable for dynamic vehicular networks. The proposed protocol gives the promising result but still processing load on RSU can be minimised. The combination of machine learning and edge computing can be used to distribute the load of the RSUs. In future, the combination of edge computing and clustering can be used to reduce the load of RSUs and provide better network performances.

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