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RESEARCH ARTICLE

Multi-Constraints Clustering Driven QoS-Centric VANET Routing Protocol: MCCQVR

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Abstract – In the last few years, Vehicle Ad-Hoc Network (VANET) has emerged as a potential wireless technology to serve different communication purposes including intelligent transportation, vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V), internet-of-vehicular-things (IOVT) etc. Despite significances, the characteristics like high mobility, topological-dynamism, link-vulnerability, iterative congestion make routing more challenging, especially in urban ecosystem. The existing routing protocols use standalone node parameter to perform routing decision; yet, its efficacy over dense deployed IOVT yields compromised performance due to the iterative link-outage, retransmission cost and delay. Consequently, it impacts Quality-of-Service (QoS) aspects. Cluster-based routing protocols have performed better in densely deployed VOIT; however, ensuring stable clustering, optimal cluster-head (CH) selection and best-forwarding path formation remains the key to success. Ironically, the state-of-arts being developed over standalone feature driven solution could not meet IOVT demands. With this inference, this research paper proposes a robust multi-constraint (multi-metric) clustering-based QoS-centric VANET routing protocol (MCCQVR) for IOVT communication. The MCCQVR protocol makes use of the multiple cross-layer parameters including node's topology, packet velocity, link quality, and congestion information to perform CH selection. Additionally, it contributes service differentiation and adaptive resource allocation (SDARA) to guarantee optimally sufficient resource for real-time-traffic (RTD) transmission. Being a cross-layer protocol, MCCQVR exploits traffic details from the application layer, packet velocity or injection rate and congestion probability from the medium access control (MAC) layer, dynamic link quality from the data-link layer and neighborhood information from the network layer to perform CH selection followed by the best forwarding path estimation, which cumulatively guarantees transmission reliability over IOVT conditions. The SDARA on the other hand applied dual-buffer concept to retain reliable RTD transmission while guaranteeing optimally large resource for the non-real-time traffic (NRT). The simulation results over the different network conditions like payload, density, velocity etc. revealed that the proposed MCCQVR model achieved average PDR of 96.55% and 96% for the RTD and NRT traffic, respectively over the different payloads, speed and network density.

Index Terms – VANET, Clustering-Based Routing, Multi-Metric CH Selection, Cross-Layer Protocol, Resource Scheduling, Load Balancing in VANET, Quality-of-Service.

1. INTRODUCTION

The recent years have witnessed exponential rise in wireless communication systems serving numerous purposes like industries, science and technologies, civic purposes as well as defense etc. increasing urban population has alarmed industries to achieve improved wireless communication network which could support timely, reliable and QoS centric data transmission for real-time decisions [1]. Among the major wireless networks, the decentralized and infrastructure-less nature of mobile Ad-Hoc network (MANET) makes it suitable for varied real-time communication systems. It has been playing decisive role in internet-of-things (IoTs), machine-to-machine (M2M), human-machine interface (HMI), IOVT etc. [1]. Despite this, the inherent characteristics like mobility, link-vulnerability, congestion etc. over dense deployed network makes overall efficiency debatable, especially when not addressed effectively [1-3]. To cope with the urban V2V, V2I, IOVT and intelligent transportation systems (ITS), VANET [1][2], which is a subset of MANET can be vital. In VANET, the moving vehicles are considered to be the nodes responsible for communication and allied data dissemination [3]. These networks are designed to serve specific communications like V2V, V2I, IOVT etc. In real-world realization, it requires communicating to the road side units (RSUs) and V2V transmission. However, unlike MANETs, VANETs can undergo challenges like high mobility, topological changes, link-vulnerability, congestion, etc., which makes communication more difficult [1-3]. Due to mobility the vehicles undergo short connection time, which is more frequent over large relative speed in the difference directions that can impact link stability and hence transmission reliability [4][5]. The unpredictable pattern (direction) can cause frequent link-outage [5], as the two vehicles moving in the same direction with the same speed can have the stable link for a few seconds; however, the link-duration for the vehicles moving in opposite direction with relatively different speed and direction can have poor link stability [3-5]. It can be visualized in Figure 1. In this case, with the short-time node information, identifying the best forwarding path remains a challenge, especially in multi-hop transmission [6]. The traditional methods employing iterative or frequent node discovery and link-maintenance can cause huge computational and signaling overheads, delay and energy exhaustion [4-6], and hence can impact real-world scalability [7]. In ITS, V2V, V2I, IOVT and varied other M2M communications ensuring reliable and time-efficient data dissemination is inevitable. Such applications demand VANET having high PDR with no latency [7-10]. It requires QoS for both RTD as well as NRT traffics [7][10]. In RTD traffic there can be the critical data like vehicle alarms, fire systems, accident alarms etc., while in NRT traffic there can be the multimedia data for log or other entertainment. In real-time communication, guaranteeing optimal transmission of RTD is inevitable, while supporting near optimal resource to the NRD traffic [10]. Yet, fulfilling these objectives over aforesaid network complexities is a challenge [10-13].

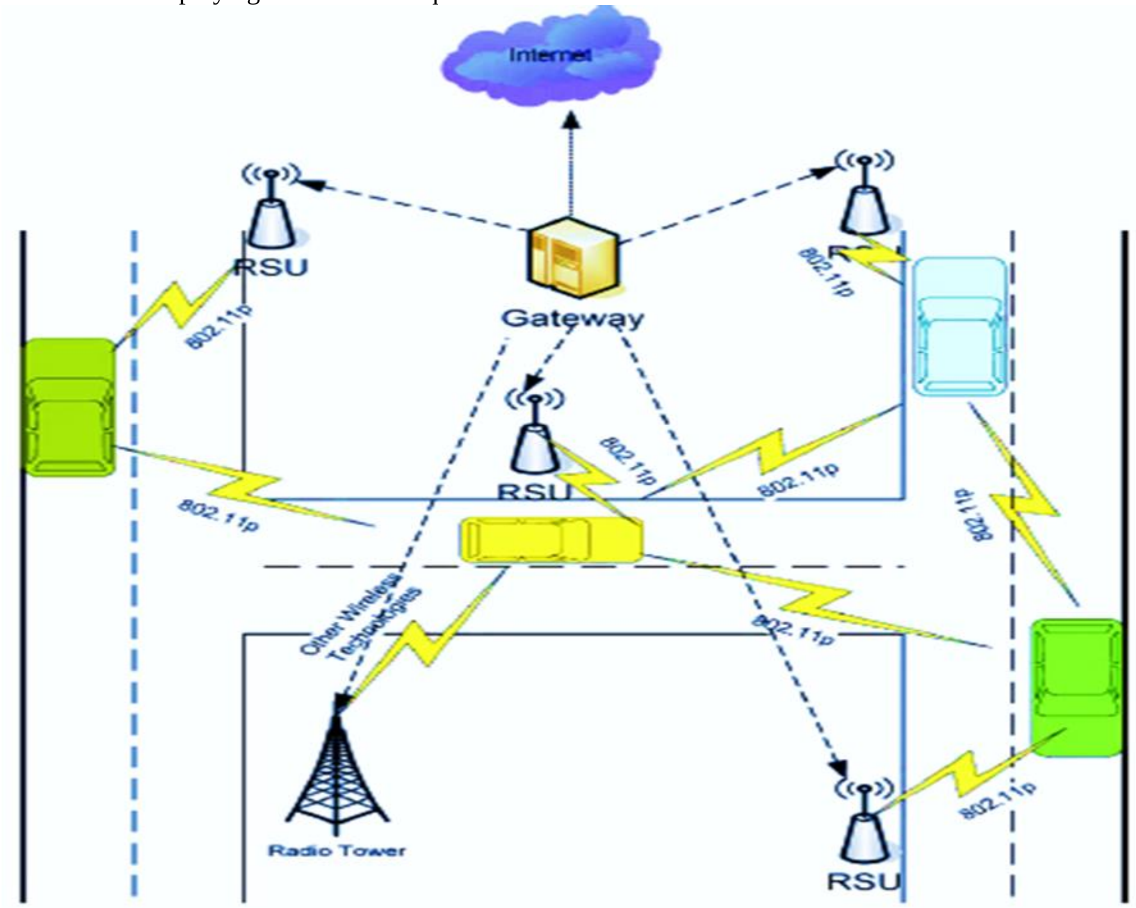

Figure 1 A typical Operating Environment of VANET

Unlike traditional routing models which requires iterative link search and maintenance between the source and destination nodes, especially over unpredictable trajectory and moving speed, clustering-based protocols have performed better in VANETs [4][5][6][7]. Cluster-based routing split network into multiple groups (say, clusters) that enables task subdivision and hence provides communication with the minimum demand of (iterative) link-outage estimations and link-discovery. Clustering splits the network into multiple sub-groups where the vehicles within cluster requires communicating through an optimally selected CH to complete transmission [7]. Here, CH becomes responsible for successful data dissemination between the source and the destination nodes. Unlike classical routing protocols where each node requires identifying the best forwarding node and allied path, cluster-based routing methods reduces aforesaid mechanism and connects vehicles to the CH that eventually forwards data to the destination vehicle in single or multi-hop transmissions [4][14]. It improves link reliability, signaling overheads, energy consumption and delay [14]. Though, VANET clustering methods have been used applied for load-balancing, QoS support and timely data-dissemination [14]; yet, their efficacy depends on CH selection and its appropriateness. In major existing VANET clustering methods, CH selection is done by using parameters like mobility information or trajectory [14-18], delay [19], relative position [20][21], relative speed, location and speed [22]. Though, a few methods applied multi-metric solutions with speed and distance information for clustering; yet, they failed in addressing optimal CH selection under dynamic topology and link-vulnerability [22]. A few methods applied distance, link probability values for CH selection; however, those were highly reliant on the accurate vehicle positioning, direction and speed information. Estimating delay information too needs accurate synchronization amongst the moving vehicles, which is nearly impossible in real-world dense networks. This problem becomes challenging in VANET due to the random-access protocol considered by IEEE 802.11p standard. In this case, VANET clustering undergoes re-clustering [15][20] which requires iterative reactive clustering [22] during link-outage [21][22]. In VANET due to random movement pattern the likelihood of congestion (it is often triggered due to greedy nature of wireless transponders and frequent change in the radio range) can’t be ruled out, which can create hotspot and hence packet drop, retransmission and delay [90]. It can impact QoS decisively. To address iterative CH selection and improve cluster stability the use of multi-metric cross-layer information can be vital [22]. Unlike single parameter-based CH selection methods, the use of cross-layer information embodying the dynamic parameters from application layer, MAC layer, network layer and data-link layer can make CH selection more effective. This hypothesis is based on the fact that despite a CH selection model designed on the basis of PDR, mobility and topology can’t yield reliable communication until it doesn’t select the node with minimum link-outage probability. Additionally, a CH node with minimum source-destination distance can’t guarantee QoS until it doesn’t ensure that it transmits connected node’s data with high velocity. In addition to the link quality information, packet velocity and topology details, the use of congestion information can achieve more reliable transmission to meet QoS demands in VANET.

The key contribution in this paper is given as follows:

This research proposes a robust multi-Constraints (multi-metric) Clustering Driven QoS-Centric VANET Routing Protocol (MCCQVR) for IOVT systems. Unlike traditional standalone feature driven clustering protocol, MCCQVR exploits cross-layer information from the application layer, MAC layer, network layer and the data link layer. More specifically, this is the first of its kind solution in which the cross-layer details including the traffic details from the application layer, packet velocity or injection rate and congestion probability from the MAC layer, dynamic link quality from the data-link layer and neighborhood information from the network layer, were applied altogether to perform CH selection which can make overall routing decision more reliable under dynamic network conditions. It also helps to identify the best forwarding path for the QoS-centric data dissemination in IOVT. Moreover, relative-distance and speed information enabled stable clustering. In sync with real-time VANET and IOVT communications, MCCQVR armored CHs with the SDARA ability by assigning two buffers each for RTD and NRT. In case of 100% resource consumption by RTD traffic, to guarantee reliable and timely data dissemination, SDARA allots resource from the NRT buffer to accommodate RTD traffic, while ensuring maximum possible resource for the NRT traffic. The dual-buffer provision with first-in-first-out queue model ensured QoS delivery. The depth simulation assessment revealed that the MCCQVR achieved average PDR of 96.55% and 96% for the RTD and NRT traffic, respectively over the different payloads, speed and network density. This is the first of its kind solution that contributes cross-layer parameter driven CH selection with traffic sensitive load balancing which makes overall transmission reliable and QoS-adaptive. It makes the proposed protocol suitable for the run-time significance.

The other sections of the presented manuscript are given as follows. Section 2 discusses the related work, which is followed by problem definition in section 3. Section 4 presents the problem formulation, which is followed by the research question and the proposed method in Section 5 and Section 6, respectively. The conclusion is given in Section 7, while the references used are given at the end of the manuscript.

2. RELATED WORK

VANET (and derived IOVT technology) being a special kind of MANET network technology is found to have decisive significance for ITSs [21]. In this reference, to meet real-time transmission over mobile topology and dynamic link cluster-based routing methods can be vital [22]. To improve stability, the authors proposed a clustering based VANET routing protocol [22]. To improve cluster-stability they applied speed difference information. Though, later the authors found that the multi-metric approaches can improve link-stability better, especially over dynamic topology [23]. In this reference, the authors [23] applied topology information, node mobility, road scenario and node density, relative speed and communication overheads to perform clustering-based routing. Though, other methods [24-27] have used topology information, weight-oriented clustering, neighbor-based clustering etc. for VANET routing [24-27]. Cheng and Huang [28] proposed a stable cluster-based routing protocol by using direction vector and CH location to perform CH selection for routing decision. Ren et al. [29] proposed a mobility- and stability-driven clustering algorithm (MSCA). To achieve stable clustering, it applied the direction of vehicle's movement and inter-vehicle position information with link-span for clustering. Zhu et al. [30] proposed multilevel greedy opportunity routing protocol (MGOR), by using node-connectivity probability information to perform routing decision in VANET. Chen et al. [31] used relative mobility information, historical following information for multihop clustering and CH selection in VANET. Vodopivec et al. [32] used redundant connections between nodes to perform clustering-based multi-hop routing protocol. Similarly, Zhang et al. [33] exploited inter-vehicle distance information to perform routing decision. Yet, it failed addressing key issues including link-dynamism and mission critical communication. Node mobility information was applied by Hassanabadi et al. [34] to perform stable CH selection and clustering for VANET communication. Ucar et al. [35], on the other hand applied the mean relative speed of the moving vehicles traversing in the same direction to perform multi-hop clustering-based routing protocol. Dror et al. [36] developed a hierarchical clustering model that performs randomized clustering for transmission scheduling. However, they performed clustering with a definite radius obtained as a diameter of at most four hops. Ni et al. [37] proposed a prediction-based clustering model for wireless ad-hoc networks, where CH selection was done based on the node mobility information. Clustering was done based on the relative speed information, while to measure average connection time an analytical model was designed which helped estimating the lower and upper threshold to perform CH selection. Despite the fact that CH selection can help achieving stable routing [38], it suffers huge overheads over dynamic topology [39]. Literatures indicate that the use of mobility features including vehicle's speed, direction and node position can enable more efficient CH selection and routing model [40]. Though, these approaches consider the assumption that each vehicle possesses same velocity, which seems impractical in real-world VANETs. Chen et al. [41] used distance information to perform clustering-based routing. It also applied a central server or base station to perform clustering and allied decisions including cluster merging and splitting. Shea et al. [42] used position and mobility information for distributed mobility-based clustering in VANET. Wang et al. [43] proposed priority-based clustering for routing decision. Mohammad et al. [44] performed CH selection by applying traffic flow, relative speed, and relative position of the vehicle to perform CH selection. Zhang et al. [23] performed multi-hop clustering with priority-based CH selection method. Morales et al. [45] used vehicle's destination information to perform clustering decision. Those vehicles having similar destination were considered to form cluster. Link reliability-based CH selection was done by Khan et al. [46], where cluster-based VANET oriented evolving graph (CVoEG) mode was proposed. They applied Eigen gap heuristic to perform clustering decision, which can impose computational cost and latency.

Wolny [47] developed MDMAC that performed k-hop clusters by using TTL (time-to-live) information for routing decision. Zhang et al. [48] used relative mobility information and multi-hop inter-node distance to perform clustering based routing in VANET. Ucar et al. [49] proposed VMaSC where CH selection was done by using inter-node mobility details. Ziagham and Noorimehr [50] designed a single-hop clustering method named MOSIC by using vehicular relative mobility information for the CH selection. It also applied the Gauss–Markov mobility (GMM) model to perform mobility predication to improve link reliability. Zhang et al. [51] exploited inter-vehicle link information to perform routing. Lin et al. [52] proposed a moving-zone-based protocol for VANETs. The vehicles with the similar movement pattern were used to perform (self-organized) clustering. Rivoirard et al. [53] designed the chain-branch-leaf (CBL) clustering by using road side information, link quality and vehicle mobility information. Song et al. [54] developed a cluster-based directional routing protocol for VANETs, where they used direction of the moving vehicle for CH selection. Ohta et al. [55] performed CH selection by using node position and direction. The authors applied link reliability information as supplementary information to perform CH selection. They applied LLT-based neighbor sampling method to remove unstable neighbor nodes to reduce unexpected message transmission. In [56] vehicle's movement details and link quality were used for stable CH selection in VANET. Song et al. [57] designed a Cluster-Based Directional Routing Protocol (CBDRP) where vehicle's direction was used to perform clustering. The vehicle nearest to the center coordination of the cluster was labelled as CH to perform further transmission decision. Louazani et al. [58] performed CH selection based on the nearest actual velocity of the nodes present within the cluster. Ramakishnan [59] used the minimum velocity information to perform CH selection. Zhao et al. [60] applied traffic density and load condition with source-to-destination distance information to perform routing in VANET. A similar effort named IRTIV was made in [61]; however, the iterative signaling overhead and costs might limit its significance for real-time VANETs [62]. To improve stability over clustering-based routing in VANET, in [63] a lane-based clustering model was proposed. In [64] speed-difference was applied to perform CH selection. Lin et al. [65]

proposed a MOving-ZOne-based (MoZo) model that possessed multiple moving zones to cluster vehicles by using movement similarity. Sun et al. [66] proposed an environmentally-aware clustering method for wireless ad hoc networks. The authors applied the probability of link-failure to perform clustering. In [67], a distance-based clustering model named the affinity propagation (AP) was proposed. Yet, it underwent repeating CHs over high-speed movement. In [68], a modified distributed mobility adaptive clustering method was proposed. Ji et al. [69] too focused on link-based clustering where link reliability-based clustering approach (LRCA) for CH selection. They designed link-lifetime driven neighbor sampling method to identify and remove unstable neighbors. Abbas et al. [70] applied link-reliability information to perform CH selection. Being mobility adaptive, it used traffic direction information to perform clustering; yet, frequently changing clustering can not only impose redundant cost but also can increase delay in VANETs. Ardakani [71] assigned vehicle ID address for each moving vehicle, while respective location and mobility information were applied to perform clustering. Despite their claim to have better clustering stability in distributed network by using hamming distance, it failed in addressing major network complexities. Hamedani et al. [72] suggested to use link-information, distance and velocity for clustering-based routing in VANETs. Benkerdagh et al. [73] and Sophy et al. [24] failed in addressing latency and high-dynamic network conditions. Sachdev et al. [74] applied heuristic-based routing in VANET for warning message transmission among the cars. Radhika et al. [75] bagging ensemble x-means based clustering model which splits network into multiple groups based on density, velocities, directions, and distances to perform routing amongst vehicles. To address delay and throughput issues in VANETs, Abushour et al. [76] proposed cluster-based routing where link-lifetime was applied to perform stable clustering and CH selection. Bhaumik et al. [77] split VANET into multiple clusters of the different sizes where the forwarding path was selected on the basis of the lowest time and overhead information. Farooq et al. [78] on the other hand applied mobility speed and the cluster threshold value to perform CH selection and multi-cast transmission in urban traffic. Despite the efforts by applying relative speed as parameter for routing [79], merely depending on one parameter can cause frequent link-outage [80].

3. PROBLEM FORMULATION

Amongst the different wireless networks serving scalable communication demands, the IOVT (Internet-of-Vehicular-Things) have been playing decisive role towards swift routing and transmission in urban setups. The evolution of internet of Vehicular Things (IOVT) has gained widespread attention towards inter-vehicular and vehicle to the road-side units (RSU) communication demands. Its purposes and scalability have been found more efficient in urban ecosystem; however, the same application environment makes its realization more complex and difficult. The key reason behind the challenges in IOVT implementation is its exceedingly high mobility, link fluctuations, etc. The rapid mobility of vehicles makes the link between nodes less reliable in cluster. A slight change in the speed of cluster head nodes has a great influence on the cluster members and even causes the cluster head to switch frequently. It makes the classical clustering methods limited to ensure reliability and QoS transmission, especially over higher dynamic topological changes and load variations. The vehicles require communicating to the peers and RSU at the different movement conditions, such as the speed and direction. It causes topological changes that might even vary significantly fast over urban setups. The dynamics in inter-node distance often impacts the received signal strength indicator (RSSI) and hence influences link quality between the nodes. It makes link-reliability a challenge. On the contrary, routing over highly dynamic link-quality can impact transmission reliability due to the increased packet loss, retransmission probability, power consumption and delay. It can also cause congestion and hence can impact overall network performance. In addition to the link-quality (dynamics) challenges, resource allocation remains a trivial task to meet QoS demands.

In real-world transmission environment, the IOVTs can have the large network size with heterogenous nodes and hence ensuring transmission reliability with higher PDR, minimal PLR, optimal resource utilization and other QoS aspects is must. To meet such network demands, clustering-based routing can be of great significance. It can not only reduce the signalling overheads, iterative transmission, delay but can also make effective realization over large densely deployed VANET network. This is the matter of fact that the majority of the state-of-art clustering-based routing protocols have applied standalone node’s parameter such as the residual energy, PDR, link quality or congestion to perform CH selection. However, the dynamics over non-linear topology can impact their efficiency as merely applying single node parameter can’t guarantee successful transmission probability. Undeniably, in the past numerous efforts have been made for clustering-based routing in mobile ad-hoc networks, yet, the majority of the state-of-arts apply standalone network parameters such as the residual energy, congestion, buffer availability, inter-node distance information, link-quality, buffer space or resource availability, transmission probability, life-time, average throughput, node mobility awareness (say, topology), network degree and average speed, region-based (topology) clustering, etc. However, node cluster’s instability makes most of these at hand approaches vulnerable due to the likelihood of link-outage over exceedingly high topological changes. Unfortunately, merely applying single or limited network parameters for CH selection and allied routing decision impact’s long-term reliability of the network. To alleviate it the use of cross-layer information driven multi-constraint CH selection can be of great significance. In other words, the use of multiple parameters such as the network topology and hop counts, the dynamic link-quality from the network layer, network congestion, packet velocity at the MAC layer, traffic type at the application layer etc. can be applied altogether to make CH selection. Unlike traditional single parameter driven CH selection the use of multi-constraints cross layer information (since the above stated node information are obtained from the different layers of the OSI structure) can be more effective towards optimal forwarding decisions that eventually can improve QoS aspects.

Considering above inferences, this research proposes a multi-constraint (multi-metric) clustering driven QoS-centric IOVT routing protocol (MCCQVR). As the name indicates the proposed MCCQVR protocol performs multi-metric clustering followed by cross-layer information driven optimal CH selection and service differentiation and adaptive resource allocation (SDARA). To achieve it, the MCCQVR protocol exploits cross-layer information from each node's OSI protocol stack (IEEE 801.11). To achieve it, at first the node initiates the hello message as multi-cast, which is followed by ACK response as the unicast response. Thus, exploiting ACK response, the MCCQVR extracts the cross-layer information including the nodes topological details from the application layer, packet velocity or injection rate and congestion probability from the MAC layer, dynamic link quality from the data-link layer and neighborhood information from the network layer. These cross-layer details are applied in conjunction with the moving average method to derive multi-constraints node score based on which the node with the highest score is selected as the CH node that acts as an anchor node to transmit the connected node's data in multi-hop scenario. Thus, the use of the multi-constraints CH selection method functions as a best forwarding path selection measure that makes overall transmission reliable and swift that eventually can support QoS aspects for IOVTs. In addition to the routing decisions, the proposed protocol also makes use of the dual-buffer technology where each CH was armored with two buffers, each dedicated for the real-time traffic (RTD) and non-real-time traffic (NRT). Functionally, identifying the traffic nature or type (i.e., RTD or NRT), the proposed model executes SDARA that schedules resources to cope up RTD demands, while ensuring that the NRT traffic receives optimally sufficient (say, minimum resource required to retain transmission in FIFO manner). In the proposed load-balancing or resource allocation strategy, the proposed SDARA model schedules resources in such manner that in case the 100% resource of the RTD buffer is consumed, then to guarantee QoS aspects (for run-time RTD traffic), it borrows or allots resource from the NRT buffer retain continuous data transmission, while ensuring maximum possible resource for the NRT traffic. The dual-buffer provision with first-in-first-out queue model ensured QoS delivery, while maintaining sufficiently large resource to the RTD traffic, while maintaining minimum loss to the NRT. The overall proposed routing protocol is developed by using MATLAB tool, where nodes are deployed with the different node characteristics (say, heterogeneous nodes), while each node was deployed as a mobile node with random speed. The simulations were made over the different payload conditions, node density etc. The efficiency was measured in term of the packet delivery ratio (PDR), packet loss rate (PLR) etc. The detailed discussion of the proposed model is given in the subsequent section.

4. RESEARCH QUESTIONS

In sync with the overall research intends, scopes and allied methodological paradigms, we define certain questions, which are given as follows:

RQ1: Can the strategic amalgamation of cross-layer information driven multi-metric clustering and CH selection model be effective towards QoS-centric VANET routing?

RQ2: Can the amalgamation of cross-layer information including service differentiation and adaptive resource allocation (SDARA) information from application layer, packet velocity and congestion information from MAC layer, dynamic link quality from the data-link layer and neighborhood information from the network layer be effective towards reliable CH selection for QoS-centric routing in VANETs?

RQ3: Can the strategic amalgamation of SDARA with dual-buffer provision enable the proposed MCCQVR protocol achieving optimal resource allocation and load balancing in VANETs for QoS-communication?

RQ4: Can the strategic amalgamation of aforesaid cross-layer information driven multi-metric parameters-based CH selection and best forward routing with SDARA be effective towards QoS-centric VANET communication?

RQ5: Can the proposed MCCQVR protocol be superior over other state-of-arts protocols to meet real-time network demands?

5. SYSTEM MODEL

The detailed discussion of the overall proposed MCCVQR routing protocol is given in the subsequent sections.

5.1. Network Clustering

The network model considered in this work employs a large number of vehicle nodes deployed randomly over the network space, where each node possesses its distinct characteristics including energy, radio range, NodeID etc. In case the inter-node distance (say, the distance d_{ij} between the vehicle i and j), as defined in equation (1) is less than the radio range R_{DSRC} (i.e., $d_{ij} < R_{DSRC}$), the nodes are labelled as the neighbor node.

$$d_{ij} = \sqrt{(x_i - x_j) + (y_i - y_j)} \tag{1}$$

The connectivity between the neighboring vehicle node is measured by means of the number of vehicle nodes which are directly connected to it. The neighboring nodes of a moving vehicle i at certain instant t is obtained as per the equation (2).

$$\sum_{j=1}^{n} \mathrm{dis}(i,j,t) < \text{Transmission Range} * (\text{Node } i) \tag{2}$$

In (2), the distance value $\mathrm{dis}(i,j,t)$ is measured only when the connection is established between the vehicle i and j, at certain time t. The mobile vehicles can move randomly across the network region with distinct speed, their speed can be a decisive factor deciding link probability, link duration and eventually the packet delivery ratio. In this reference, in the proposed network, free flow traffic state (FFTS) model was considered that follows a normal node distribution. Thus, the probability density function (PDF) can be obtained as per the equation (3).

$$\mathrm{PDF} = \frac{1}{\sqrt{2 * \pi * \sigma^2}} e^{\frac{-(V-\mu)^2}{2\sigma^2}} \tag{3}$$

In (3), σ^2 states the standard deviation of the vehicle's speed, while μ be the average speed of the vehicle. In this manner, the vehicle node with the nearest distance and speed would be the cluster member and would be processed for further CH selection. The proposed method measures the average speed of the neighboring nodes by using function defined in the equation (4).

$$\mu_{\text{Neighbour}} = \sum_{i=0}^{n} \frac{\text{Distance}}{\text{time}} \tag{4}$$

The location of a specific moving vehicle can be obtained as per the equation (4), where x_t and y_t be the position coordinate of the moving vehicle at certain instant time.

$$L_T = (x_t, y_t) \tag{5}$$

The average speed of a vehicle node is measured as per the equation (5).

$$\mu_{\text{Speed}} = \frac{1}{T} \sum_{t=1}^{T} \sqrt{(x_t - x_{t-1})^2 + (y_t - y_{t-1})^2} \tag{6}$$

In equation (5), T and t state the real-time (period) and the instant real-time values, correspondingly. Thus, applying above derived average speed parameter, the normalized speed is measured as per the equation (6). Mathematically,

$$\mu_n = \frac{v_i - \mu_{\text{Speed}}}{\sigma} \tag{7}$$

In equation (7), v_i states the speed of a mobile vehicle speed. Here, each moving node measures its weight to become the cluster member (CN). In this manner, estimating the values of average vehicle speed and the sum of the adjacent vehicle nodes. Mathematically,

$$\mathrm{CN}(i) = \beta_1 \mu_n + \beta_2 \mathrm{Neigh}(i) \tag{8}$$

In equation (8) $\mathrm{Neigh}(i)$ refers the total adjacent vehicles having radio range more than the inter-CH-Vehicle distance. Being a multi-metric cluster model, we applied weight factors β_1 and β_2, where $\beta_1 + \beta_2 = 1$. We applied this method to cluster the network. This approach enabled initial clustering, where the connected vehicles identified the optimal CH, with reference to which the distance method as defined in equation (2) is applied to re-confiure the cluster for further transmission. Once performing clustering, MCCQVR performs CH selection for transmission. The detailed discussion of the proposed cross-layer information driven CH selection and proactive routing decision is given in the subsequent sections.

5.2. Cross-layer information driven Multi-Metric CH Selection

The proposed MCCQVR protocol perform clustering and allied CH selection in such manner that it ensures stable clustering with QoS-sensitive routing and allied data forwarding decision. To achieve it, MCCQVR model considered cross-layer information from the application layer, MAC layer, network layer and data link layer. To achieve stable and QoS-centric routing the focus was made on using multiple network parameters to perform optimal CH selection. To achieve it, MCCQVR obtained traffic type details from the application layer, while congestion degree and packet velocity information were obtained from the MAC layer. The dynamic link quality information was obtained from the link layer, while network layer provided network topology and inter-vehicle distance information (i.e., hops, node relative distance). The selection of cumulative congestion degree as CH selection criteria ensures that the node with the minimum cumulative congestion degree with sufficient resource gets selected as the CH to assist reliable data dissemination. On the other hand, packet velocity information which is obtained from the MAC layer guarantees that only a node with high-speed transmission capability with the minimum buffer time or holding period is selected as CH. It can help achieving delay-resilient transmission in MCC to cope up with RTD data dissemination amongst the vehicles. Similarly, the network layer provides topological details with inter-node distance and hops information which helps improving both clustering as well as CH selection. A node with the minimum inter-node distance (i.e., each neighboring vehicle is within its radio range and remains connected for long time) is considered as the candidate node to become CH. The dynamic link quality information which is obtained from the data link layer guarantees that a specific node with the highest link-quality and stability gets selected as CH. Thus, the use of the multiple dynamic parameters obtained from the different layers of the IEEE 802.11p protocol stack can enable optimal CH selection and allied best forwarding path decision to achieve QoS support in VANET. MCCQVR protocol addresses almost major challenges of the VANET routing problem and thus serves a robust routing approach to meet QoS demands. Additionally, MCCQVR applies SDARA concept that ensures that the MCC data or RTD traffic gets successful transmission or dissemination within deadline time, while guaranteeing maximum possible resource to the NRT traffic to meet QoS demands in real-time VANETs. A snippet of the cross-layer information obtained is given in Figure 2. As depicted in Figure 2, the proposed MCCQVR model applies the different cross-layer information to perform CH selection and allied run-time resource allocation decision. The multi-metric parameters are given as follows:

1. Neighborhood (Mobile Topology) Manager,
2. Adaptive Congestion Detection,
3. Packet Injection Rate,
4. Adaptive Link Quality, and
5. Service Differentiation and Adaptive Resource Allocation.

The detailed discussion of these key parameters and their run-time estimation is given in the subsequent sections.

5.2.1. Neighborhood (Mobile Topology) Manager

In real-time urban traffic the non-linearity of traffic density, congestion, and trajectory changes etc., require the use of neighborhood information and adaptive clustering, CH selection and multi-metric condition aware forwarding decision. With this reference, MCCQVR protocol exploits network's topological information to achieve stable clustering and allied CH selection. It hypothesizes that a CH with minimum inter-node distance and minimum hops counts (between the source and the destination vehicle) can provide more stable routing decision for QoS-centric data dissemination. Therefore, MCCQVR intends to perform CH selection in such manner that it could have a node with the minimum hops for reliable and time-efficient routing decision. Retaining minimum hops can not only help reducing link-vulnerability impact but can also reduce signaling overheads and delay, which can be inevitable over large hop counts. In sync with these facts, the proposed routing model performs proactive network management where the dynamic topological information and allied node (i.e., vehicle's) parameters are updated proactively after a predefined interval (here, 10 seconds). In this method the network table is updated dynamically after 10 ms and therefore the network condition aware cross-layer information becomes available to make proactive CH selection and forwarding routing decision. The VANET contained the network with the different density with heterogenous node features. Noticeably, here, heterogeneity states the difference in node characteristics including buffer capacity, data types, traffics, loads, speed and movement trajectory. The deployed nodes function in such way that each node maintains the information of one-hop distant vehicle by performing interval-based beaconing method. More specifically, in this method each node multicasts a beacon message and receives response message encompassing vehicle's NodeID, vehicle location in the network, relative distance information and other cross-layer information (i.e., packet velocity, signal to noise ratio and/or packet delivery ratio (PDR), buffer capacity and availability etc.). We received message (say, ACK) contains the information pertaining to the packet transmitted and received that helps estimating the PDR for that specific vehicle node. In the proposed MCCQVR protocol the control packets was configured with 512-byte size which encompassed the aforesaid dynamic network parameters (i.e., node position, packet velocity, NodeID, location vector). Collecting one-hop distant node information the MCCQVR protocol updates the network table to perform CH selection and allied best forwarding routing decision. It enables a vehicle to multicast beacon message to its neighbor vehicles based on an offset timer, which is decided on the basis of the classical uniform distribution approach. Once receiving the beacon message from a moving vehicle (say, transmitter), a receiver node or vehicle resets its timer and, in this manner, avoids any likelihood of retransmission or congestion. It avoided signal congestion and hence reduces redundant transmissions.

Being proactive in nature MCCQVR maintains network table for each moving node. Let $\mathrm{N_j}$ be a one-hop vehicle and $\mathrm{CH_i}$ be the cluster head candidate. Thus, the proactive node table is defined as per the equation (9).

$$\mathrm{N_T} = \left\{\mathrm{CH_{i\in N_j}} \mid \mathrm{D_{Euclidiand}} - \mathrm{D_{Euclidianf}} \geq 0\right\} \tag{9}$$

In (9), $\mathrm{D_{Euclidiand}}$ and $\mathrm{D_{Euclidianf}}$ represents the Euclidean distance in between the source vehicle to the nearest destination node (in both V2V as well as V2I communication) and the distance between source vehicle and the nearest CH node, respectively. Thus, obtaining the aforesaid distance estimation MCCQVR model performs clustering. Here, hop information is also applied as decision variable to perform CH selection.

5.2.2. Adaptive Congestion Detection

In VANET under the different network density and topological changes, the non-linearity in load patterns, resource demands and thus eventual congestion can't be ruled out. The abrupt change in topology and allied vehicles density can give rise to the network congestion iteratively. Due to aforesaid network dynamism the likelihood of congestion can be severe over dense network and hence can undergo iterative packet loss. It can eventually increase retransmission cost, resource consumption and allied delay. MCCQVR exploits dynamic resource information to perform congestion probability. MCCQVR protocol applies buffer information including the present buffer availability and the maximum buffer capacity to measure the congestion probability at a node. In this work, the model derived in equation (10) was applied to perform congestion probability P_{CON}estimation for each moving vehicle in the network. Let, B_{NRT} and B_{NRT_Max} be the (NRT) buffer available and the maximum (NRT) buffer capacity, respectively for a node. Similarly, let B_{RTD} and B_{RTD_Max} be the available (RTD) buffer at a node and its maximum buffer capacity, correspondingly. Thus, with aforesaid buffer information, MCCQVR protocol estimates cumulative congestion as per the equation (10).

$$P_{CON_r} = \frac{B_{NRT} + B_{RTD}}{B_{NRT\_Max} + B_{RTD\_Max}} + \sum_{i=1}^{\mathbb{N}} P_{CON_{ri}} \tag{10}$$

In equation (10), P_{CON_r} states the cumulative congestion probability at a vehicle node r, while $P_{CON_{ri}}$ be the congestion caused due to the neighboring nodes. Thus, the overall congestion on a node is estimated as the sum of buffer-sensitive congestion and the congestion caused due to the connected nodes. Once estimating the value of the equation (10), the node with the minimum P_{CON_r} is considered as the CH candidate for further decision.

5.2.3. Packet Injection Rate or Velocity

VANETs always demand timely transmission to serve V2V as well as V2I communication. A node requires disseminating data (packets) within a predefined time and therefore the only node with the appropriate transmission ability (say, the rate with which a node can transmit the data swiftly) can be potential to become CH node. In this reference, we define a mechanism or node feature called packet velocity or injection rate signifying the ability of a node to transmit the data swiftly. This estimation was found decisive as there can be a node with sufficient buffer, low congestion and even better link, but due to certain hardware or processing inabilities it might not be capable to deliver data within a predefined time to meet QoS demands. In this reference, MCCQVR protocol estimated packet injection rate or packet velocity for each node to assess its suitability to become CH node. To achieve it, it measured the distance between the neighboring node and the nearest destination node, round trip time (RTT) and the velocity of light in air. It estimated the Euclidian distance between the nodes (with reference to the destination node), average RTT (RTT_{Ti}) to calculate the packet injection rate. The MCCQVR protocol measured average RTT as the time-difference between the transmitted and received signal. Mathematically, we applied equation (11) to perform average RTT time.

$$RTT_{Ti} = \frac{\sum_{i=0}^{N} R_{At}^{i} - V_{Pt}^{i}}{N} \tag{11}$$

In equation (11), R_{At}^{i} refers the time when a node receives the acknowledgement (ACK) message. V_{pt}^{i} signifies the time when a node transmitted packet i. Let, N be the total received packets. The proposed MCCQVR model measures Euclidian (relative) distance between source and the nearest destination node. Thus, applying aforesaid relative distance vector information along with the average RTT information, we measured a velocity factor V_{t}, which was measured as per the equation (12).

$$V_{t} = \left(\frac{D_{ESD}^{i} - D_{ENS}^{i}}{RTT_{Ti}}\right) \tag{12}$$

In equation (12), D_{ESD}^{i} states the Euclidean distance between the transmitter node i and the destination node. D_{ENS}^{i} presents the distance between the transmitter and the nearest destination node. In reference to the predefined transmission power, MCCQVR applied maximum speed of the radio signals in open air (S_{Max}) to measure packet velocity (V_{PKT_i}).

$$V_{PKT\_i} = \left(\frac{V_{t}}{S_{Max}}\right) \tag{13}$$

where $S_{Max} = 3 \times 10^{-8}\ m/s$.

In this manner, MCCQVR protocol measured the packet injection rate or velocity V_{PKT} for each node, signifying the speed with which that specific node can transmit the data for timely dissemination. MCCQVR protocol considered it as unit parameter for multi-metric CH selection decision.

5.2.4. Adaptive Link Quality Estimation

The topological change in VANET results into frequent link disruption when the vehicles move with the different speed and in the different directions. Consequently, the nodes might suffer frequent link outage and data drop, and therefore can undergo frequent retransmission and delay. MCCQVR protocol exploits the number of transmitted data packets and received packets at MAC layer to measure adaptive link quality by using equation (15). It used the PDR information obtained as per the equation (14) to further measure the adaptive link quality.

$$PDR_{ij} = \frac{N_{rx\_ji}}{N_{tx\_ij}} \tag{14}$$

$$\eta_{ij} = \alpha * \eta_{ij} + (1-\alpha) * \left(PDR_{ij}\right) \tag{15}$$

In equation (14), PDR_{ij} represents the packet delivery rate between the two nodes i and j. The parameters N_{rx_ji} and N_{tx_ij} states the received packets and the transmitted packets, respectively. Here, i and j be the source and the destination nodes, respectively. The parameters η_{ij} be the adaptive link quality between the source i and destination j, while α represents the network coefficient, which is selected in between the range of 0 to 1. Since, the proposed routing protocol is designed towards VANET protocol, which is characterized as a network with high topology and mobility, we assigned network coefficient α as 0.6. Thus, for the considered network model we measured adaptive link quality between each node pair, which is subsequently applied to perform CH selection.

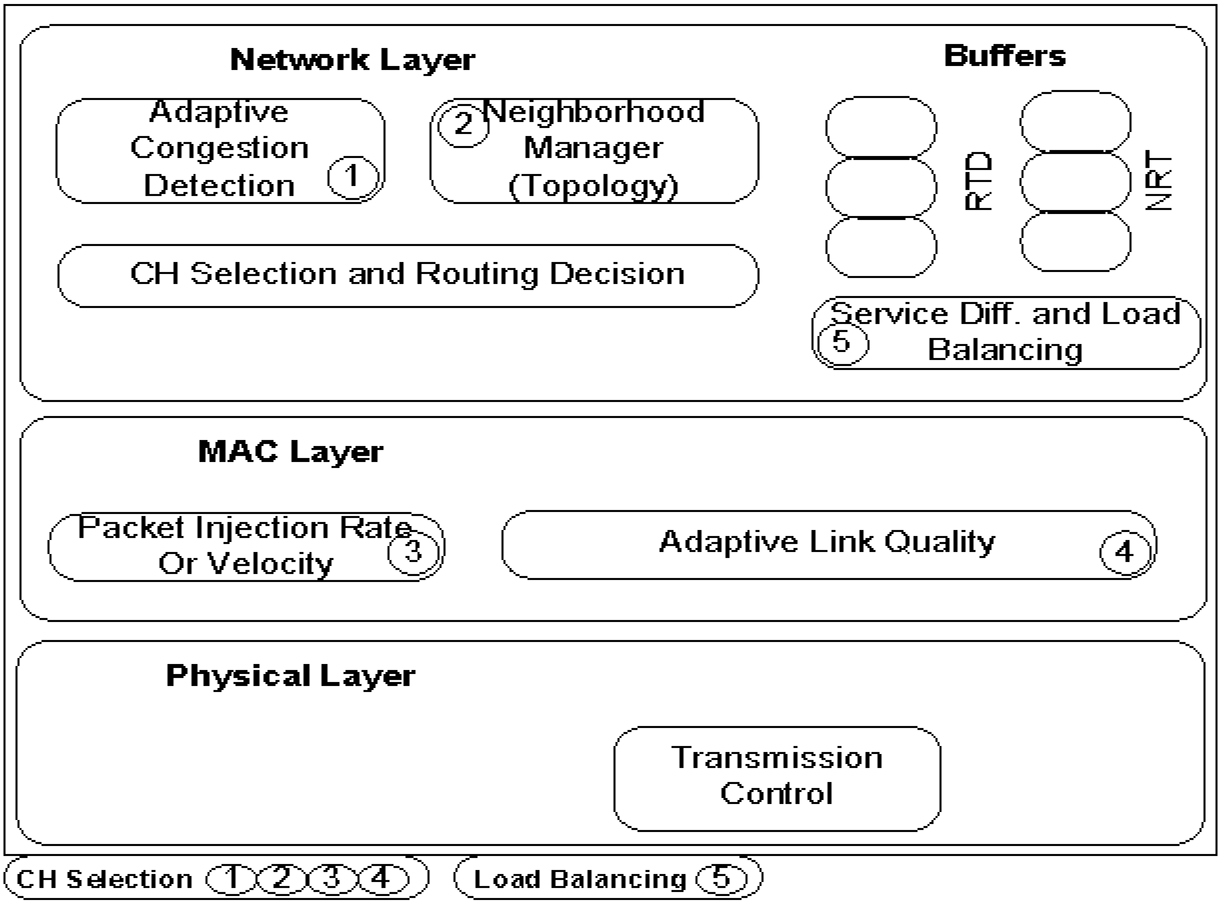

Figure 2 Proposed MCCQVR Routing Protocol

5.2.5. Traffic Prioritization and SDARA Scheduling

In sync with real-time VANET applications, MCCQVR protocol intends to ensure QoS delivery by applying dual-buffer concept (i.e., RTD and NRT buffer) and allied SDARA mechanism. Recalling the fact that in real-time VANETs, each MCC data packet used to have definite life-time in which a packet requires reaching to the respective destination node within the deadline time. To achieve it, MCCQVR protocol requires performing deadline-sensitive resource allocation to meet QoS demands. It can help assessing congestion probability to ensure optimal CH selection for the reliable transmission. Once estimating the topological details and allied distance information, MCCQVR protocol estimates the inter-node (say, source and the destination node) distance. In sync with RTD/NRT traffic prioritization and adaptive congestion estimation, the proposed method identifies the data with the maximum priority. We measured traffic priority by using equation (16). In sync with the formulation defined in equation (16), the traffic data (packet) with the minimum T_{Factor} is considered to have high priority for resource allocation by using SDARA mechanism.

$$T_{Factor} = \frac{R_{time\_i}}{d_i^j} \tag{16}$$

In equation (16), R_{time_i} represents the residual deadline time, while d_i^j refers the inter-node (i.e., source i and the destination

j) Euclidian distance. Here, the residual time R_{time_i} is measured by using the time of arrival (TOA) information of each data packet. R_{time_i} information is updated for each data packets (queued in the FIFO manner). An RTD packet with minimum T_{Factor} is assigned more priority and accordingly the resource allocation is done by using SDARA method.

In VANET-based services, a node can have different purposes including V2V and V2I data dissemination and allied communication tasks. To meet QoS demands, a node can be required to serve varied real-time services including MCC data dissemination and NRT (multimedia or less significant data logs) transmission. Thus, there can be certain traffic which is required to be delivered within the deadline time (say, RTD traffic). On the contrary, there can be certain traffic data, which is required to be communication but doesn't have any deadline time or MCC constraints. In this manner, these varied data traffic can have the different priority and therefore MCCQVR protocol requires prioritizing data transmission in such manner that it fulfils QoS demands. Unlike traditional approaches, where to accommodate RTD traffic demands, especially during 100% buffer utilization the researchers have dropped complete NRT traffic that eventually impacts QoS provision. This is because dropping the NRT traffic can not only force a network to undergo retransmission but can also impose retransmission cost, delay and hence resource exhaustion. To alleviate it, MCCQVR protocol applies dual-buffer concept in which each CH node is assigned two distinct buffers each dedicated for the RTD and NRT traffic, distinctly. Though, in the classical geographical routing protocols the aforesaid dual-buffer is required to be assigned to each node; however, MCCQVR requires assigning dual-buffer only to the CH node. It is because each connected node needs to first transmit data to the respective CH node, which is responsible to transmit the data to the destination node in single or multi-hop transmissions. In MCCQVR protocol if CH node undergoes 100% resource or buffer exhaustion MCCQVR protocol doesn't drop RTD traffic rather borrows resource from the NRT buffer to ensure its transmission within its deadline time. To accommodate additional RTD traffic (under 100% resource exhaustion), the proposed protocol drops recently connected or attached NRT packets. Thus, MCCQVR protocol doesn't require dropping complete NRT traffic, rather it drops recently added packets arranged in FIFO queue (in NRT buffer). It helps ensuring optimal resource provision to the RTD traffic, while ensuring near-optimal resource availability to the NRT data. It achieves QoS provision to both RTD as well as NRT traffic in VANET.

5.3. Multi-Constraints CH Selection

To ensure stable clustering and allied reliable transmission in VANET, our proposed MCCQVR protocol applied above discussed different node parameters (i.e., topology information, packet velocity (or injection rate), adaptive link quality and congestion information. More specifically, we applied equation (17) to derive CH probability CH_{Score_i} for each node i.

$$\mathrm{CH}_{Score\_i} = \varphi_1 * \mathrm{Hop}_{ij} + \varphi_2 * P_{CON_r} + \varphi_3 * \eta_{ij} + \varphi_4 * V_{PKT\_i} \tag{17}$$

In above equation (17), φ states the weight parameter which is decided on the basis of the network condition or probable condition. In the proposed VANET network the mobility can be more and hence link quality can be more dynamic and therefore we assigned φ_1 and φ_3 as 0.3 each. While φ_2 and φ_4 was assigned 0.2 value, each. As stated above, the selection of these network parameter has been done based on network characteristics, where the node or the vehicles can have high mobility and hence more dynamic link change. Additionally, considering one hop (distant) node information for CH selection, we assigned φ_1 as 0.2, as defined in equation (17). Noticeably, the addition of these weight parameters used to be unit value (i.e., 1), which follows the condition given in equation (18).

$$\sum_{i=1}^{N=4} \varphi_i = 1 \tag{18}$$

Thus, applying the CH probability value for each node, MCCQVR protocol performed CH selection. The algorithm used for the CH selection mechanism is given in Algorithm 1.

```
MCCQVR-driven CH selection
Input: Nodes, One-hop distant node information, Cross Layer information, Link Quality, Congestion degree, packet injection rate or packet velocity.
Output: Selected Optimal CH Node.
Step-1 Deploy Nodes
Step-2 Initiate Beacon Multicast
Step-3 Receive ACK Message as unicast from each neighbouring node.
Step-4 Estimate $\mathrm{Hop}_{ij}$, $P_{CON_r}$, $\eta_{ij}$ and $V_{PKT\_i}$.
Step-5 Initiate Node (Vehicle) score $\mathrm{CH}_{Max} = -1$;
Foreach connected node or vehicle node (within cluster) i
Calculate CH probability matrix by using equation (17).
Step-6 Assess each node's CH probability as:
    If $\mathrm{CH}_{Max} \leq \mathrm{CH}_{Score_i}$, then
Select $i-$th node or vehicle as the CH node (i.e., CH=$\mathrm{CH}_i$)
Step-7 Collect data from the connected node
Step-8 Perform data dissemination.
```

Step-9 Continue the process till all packets of the connected node is transmitted to the corresponding destination node.

*Continues till packet reaches the Destination Node.

Algorithm 1 Pseudocode for MCCQVR-Based CH Selection

Noticeably, in MCCQVR protocol, the network table is updated proactively at the interval of 10 ms, which was decided in such manner that the MCC criteria remains fulfilled. Thus, if it identifies link-outage at certain node or CH, it reinitiates the network discovery to identify optimal CH node for data dissemination. Interestingly, in the MCCQVR protocol, the multi-metric CH selection serves dual purposes, first it helps identifying the optimal CH for reliable vehicle-to-CH node transmission and second it performs best forwarding CH selection to cope with the multi-hop transmission. In other words, in addition to the CH selection task, the proposed multi-metric CH selection (17) is applied to identify the best forwarding node for QoS-centric communication. It helps achieving time-efficiency and computational efficacy to serve delay-resilient transmission in VANETs. The simulation results and allied inferences are discussed in the subsequent section.

6. RESULTS AND DISCUSSION

Unlike traditional proactive and geographical routing approaches, which require performing iterative forwarding node discovery and maintenance, MCCQVR was designed based on cluster routing model. The traditional geographic and/or proactive routing protocols undergo decisive change in topology, link quality change and outage, the proposed MCCQVR protocol was designed as a cluster-based approach in which participating vehicle node doesn't require exploring best forwarding node, rather transmits its data through an optimally decided CH node, which is responsible to disseminate the collected data (from the participating nodes). This as a result reduces the probability of frequent link-outage and data drop and hence optimizes overall performance. However, the efficacy of any cluster-based VANET routing protocols primarily depends on two factors; first, stable cluster formation and second, optimal CH selection. In the past though a few efforts have been made towards VANET routing; however, their efficacy has remained constrained due to low PDR and reliability over highly dynamic (and dense) network conditions. Moreover, the state-of-arts have merely applied standalone network parameters such as mobility pattern or trajectory, vehicle speed, delay to perform CH selection. Unfortunately, despite selecting a node as CH based on standalone parameter like trajectory, the sudden increased congestion and hence packet drop might impact overall routing efficiency. Similarly, despite the use of delay as a performance parameter, the vulnerable link, especially over the dynamic network condition might impact overall network performance and its reliability (say, QoS performance). It infers that merely applying standalone network parameter for CH selection can't yield optimal performance and hence multi-metric CH selection can be a viable approach. Considering it as motivation, in this paper we designed MCCQVR protocol in which four distinct network (cross-layer) parameters were applied to perform CH selection. The MCCQVR protocol applied cross-layer information from the different layers of the IEEE 802.11p protocol stacks including application layer, MAC layer, data link layer, and network layer. More specifically, our proposed MCCQVR protocol obtained traffic type and priority information from the application layer, congestion degree and packet injection rate (packet velocity) from MAC layer, adaptive link quality from link layer and topological information from the network layer. Thus, MCCQVR protocol exploits aforesaid four parameters including number of hops between source to the destination node (Hop_{ij}), congestion degree $\left(P_{CON_r}\right)$, adaptive link quality (η_{ij}) and packet velocity or packet injection rate (V_{PKT_i}) to perform CH selection. In MCCQVR protocol we applied weighted moving average method to derive node score parameters $\varphi_1 * Hop_{ij} + \varphi_2 * P_{CON_r} + \varphi_3 * \eta_{ij} + \varphi_4 * V_{PKT_i}$ to assess suitability of a node to become CH node. Here, $\sum_{i=1}^{N=4} \varphi_i = 1$, where φ_1, φ_2, φ_3 and φ_4 values were assigned as 0.3, 0.3, 02 and 0.2, respectively. Thus, applying aforesaid cross-layer performance parameters CH selection was performed. Noticeably, in addition to the aforesaid CH selection method, our proposed MCCQVR protocol performed cluster formation where distance and mean speed information were applied to perform clustering. Thus, applying above stated clustering and CH selection process, we performed data dissemination to meet QoS demands. To cope up with real-time VANET communication, MCCQVR applied dual-buffer concept with service differential and adaptive resource allocation (SDARA) mechanism. Each cluster head node was assigned two distinct buffers NRT and RTD buffer, where NRT traffic was arranged or connected in FIFO queue. In this case, during real-time network condition, if RTD buffer is completely exhausted (i.e., 100% buffer used) then the proposed SDARA model dropped most recently connected NRT packets in NRT buffer to accommodate the RTD traffic. In this manner, the proposed model intended to achieve optimal QoS deliver for the RTD traffic, while guaranteeing near-optimal NRT resource allocation and QoS. To assess efficacy of the proposed model, the simulations were made over the different vehicle densities and velocity, and corresponding packet delivery ratio (PDR), packet loss rate (PLR) were measured. The proposed MCCQVR routing protocol was developed and simulated on Windows 2010 Operating System, armored with 8 GB RAM, and Intel i5 processor with 3.2 GHz frequency. The proposed model is developed and simulated on MATLAB 2020b software. The simulation parameters used in this work are given in Table 1.

Table 1 Simulation Parameters

Parameter	Specification
Number of Vehicles	50, 100, 150, 200 and 250
Network Region	500 × 500 m
Payload (kB)	250, 500, 750, 1000, 1500, 2000, 2500, 3000
Physical	IEEE 802.11 PHY
MAC	IEEE 802.11 MAC
Protocol	MCCQVR
Link-layer	CSMA-CD
Packet Size	512 Bytes
Radio Range	250 meter
Packet deadline time	8 Sec.
Traffic	CBR
Mobility	Athelete Running Competition
Clustering	Inter-CH-connected node distance, average speed of the neighbouring nodes.
CH estimation weight parameters	$\varphi_1 = 0.3, \varphi_2$ =0.2, $\varphi_3 = 0.3,$ and $\varphi_4 = 0.2.$
Simulation Period	800 Sec.
Traffic Payload	Real-time traffic (RTD) and Non-real-time traffic (NRT)
Vehicle Speed	5 m/s, 10 m/s and 25 m/s.
Transmitter Power	100 mW
Message Type	Unicast, Multicast
Simulation Tool	MATLAB

To assess efficacy, we measured performance in terms of PDR and PLR for both RTD as well as NRT traffics. Here, PDR was measured as the ratio of the number of successful data packets (transmitted by the transmitter) to the total number of packets generated. Let, R_i and T_i be the received packets and the transmitted packets, respectively, then the PDR information for both NRT as well as RTD was measured as per the equation (19).

$$PDR = \frac{\sum_{i=1}^{n} R_i}{\sum_{i=1}^{n} T_i} \times 100\% \qquad (19)$$

Thus, the PLR performance (in percentile) for both RTD and NRT traffic was measured as per the equation (20).

$$PLR\ (\%) = (1 - PDR)\% \qquad (20)$$

6.1. Intra-Model Assessment

This is the matter of fact that in real-world scenario, especially in VANETs the vehicle node might require transmitting data with the different sizes, depending on the application size. For instance, a real-time inter-vehicular communication for alarm (say, V2V communication) might consume relatively smaller data size. On the contrary, data logs, multimedia data etc. might demand more resources (i.e., high payload). Similarly, a CH node with the greater numbers of the connected vehicle node (or CNs) might sometime require more resources so as to accommodate multiple data packets to disseminate across the network (to the CN's destinations). And the allied traffic nature can be of both RTD as well as NRT types. In this case, it becomes inevitable for the proposed MCCQVR protocol to ensure high PDR to accommodate RTD, while retaining maximum possible PDR for NRT traffic. As discussed earlier, in traditional routing protocols, where to accommodate additional data packets, the models require dropping NRT packets and hence undergoes almost 100% data loss. Unlike such approaches, in MCCQVR protocol the use of SDARA module which helped accommodating RTD traffic (or packets) under 100% RTD buffer utilization, drops the last (or recently) connected NRT data (which is connected in FIFO queue in NRT buffer). This approach not helps achieving optimal PDR and hence QoS for RTD traffic but also guarantees minimum packet loss to the NRT traffic while maintaining maximum possible PDR for the same (i.e., NRT traffic). In this manner, we mainly focused on ensuring optimal PDR for the RTD as well as NRT traffic in VANET to meet QoS demands. Now, in this reference, to characterize the robustness of the proposed MCCQVR routing protocol, we quantified the performance in terms of intra-model assessment and inter-model assessment. Here, intra-model assessment performs performance characterization over the different payload conditions (i.e., data packets), speed (m/s) and vehicle density. Noticeably, here, vehicle density represents the number of vehicles within the radio range of CH node, which is selected as 250 meters. In other words, we measured vehicle density as the number of vehicles within the circumference (or radio range) of 250 meters. Here, the key purpose of intra-model assessment is to assess whether the proposed MCCQVR routing protocol achieves expected (high) performance over the different operating conditions such as with high payload condition (it is common in dense and congested network), high speed and denser network environment. In this reference, we performed simulations over the different network conditions, and the resulting (simulation) outputs are discussed as follows:

6.1.1. Performance with the Different Payloads

As stated above, in sync with dynamic load conditions, which is highly probable in VANETs with more connected vehicle nodes and dense network, we simulated our proposed MCCQVR routing protocol with the different payload conditions including 250, 500, 1000, 1500, 2000 and 2500 packets. Noticeably, each data packet encompasses 512 bytes of information.

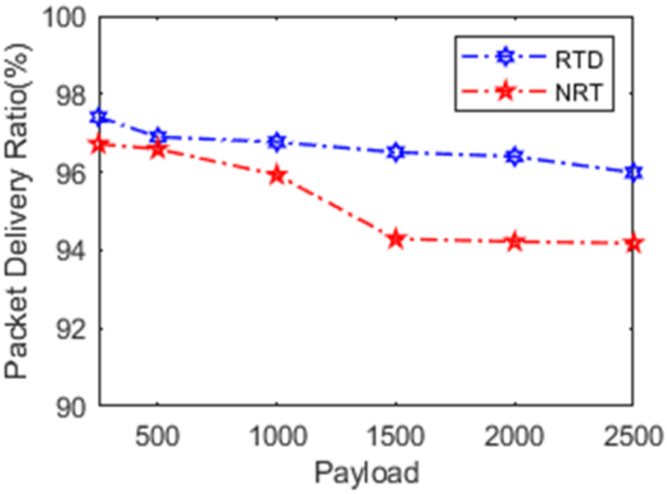

Figure 2 Packet Delivery Ratio (%) Over Varying Payloads

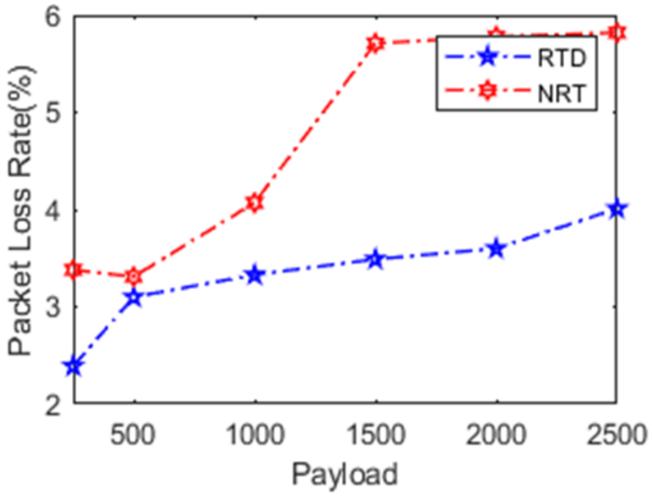

Figure 3 Packet Loss Ratio (%) Over Varying Payloads

The simulation results reveal that the proposed MCCQVR protocol exhibits PDR of 97.4%, 97%, 96.7%, 96.4% and 96% over the payload of 250, 500, 1000, 1500, 2000 and 2500 packets, correspondingly (Figure 2). The average PDR over aforesaid payload condition(s) for the RTD traffic was measured as 96.66%. Interestingly, for NRT traffic as well the proposed routing protocol retained the PDR of 96.7%, 96.6%, 95.9%, 94.3%, 94.2% and 94.2% for the payload of 250, 500, 1000, 1500, 2000 and 2500 packets, respectively. The average PDR performance for the NRT traffic was measured as 95.32%. Considering packet loss rate (PLR) performance, the proposed MCCQVR protocol exhibited the average PLR of 3.32% for RTD and 4.67% for NRT traffic (Figure 3). It clearly indicates robustness of the proposed routing protocol towards high data rate dissemination tasks. It also confirms that the proposed VANET routing protocol is capable to accommodate high-rate dissemination tasks for both RTD as well as NRT data packets.

6.1.2. Performance with the Different Speed

VANET network is often characterized in terms of its high and random mobility, where each moving vehicle can have the different speed and hence corresponding link-stability. High speed, especially over heterogenous nodes can result frequent link-outage and hence reduced PDR performance. The resulting (high) PLR can also impose retransmission costs including resource and delay and hence can impact QoS performance. In this reference, we simulated the proposed routing protocol with the nodes moving with the different speed. Specifically, the simulation has done with the speed of 5 m/s, 10 m/s, 15 m/s, 20 m/s and 25 m/s, and corresponding PDR and PLR performance over the RTD and NRT traffic has been obtained. The PDR performance over the different vehicle speeds for the RTD and NRT traffic is depicted in Figure 4, while the respective packet loss rate (PLR) is given in Figure 5.

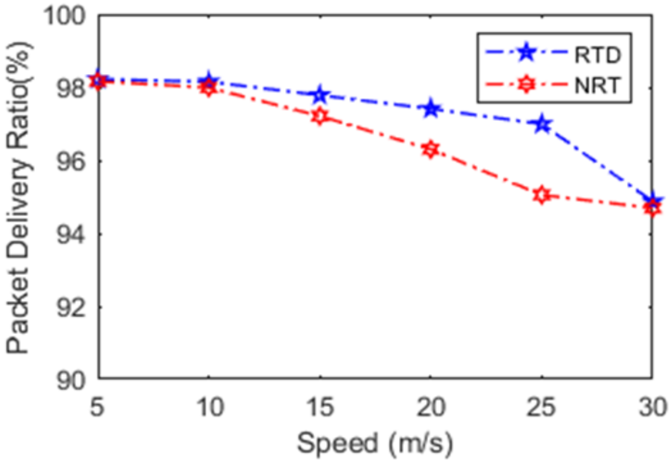

Figure 4 Packet Delivery Ratio (%) Over Varying Speed (m/s)

As depicted in Figure 4, the proposed MCCQVR routing protocol exhibits the PDR of 98.2%, 98.15%, 97.8%, 97.4%, 97% and 94.9% for the RTD traffic over the vehicles' speed of 5 m/s, 10 m/s, 15 m/s, 20 m/s and 25 m/s, respectively. The average PDR at the different speed is obtained as 97.23%. Similarly, it exhibited the PDR of 98.16%, 98%, 97.2%, 96.3%, 95.0%, 94.7% for the NRT traffic over the speed of 5 m/s, 10 m/s, 15 m/s, 20 m/s and 25 m/s. The average PDR for the NRT traffic was obtained as 96.56%. Quantifying the relative PDR performance for the RTD and NRT traffic, it can be found that the proposed MCCQVR routing protocol exhibits the average PDR of 97.23% and 96.56% for RTD and NRT traffic, respectively. It clearly indicates that the inclusion of SDARA strategy and allied load balancing measure helps MCCQVR achieving better PDR performance for both RTD as well as NRT traffic. It makes proposed routing protocol suitable for the real-time VANET communication.

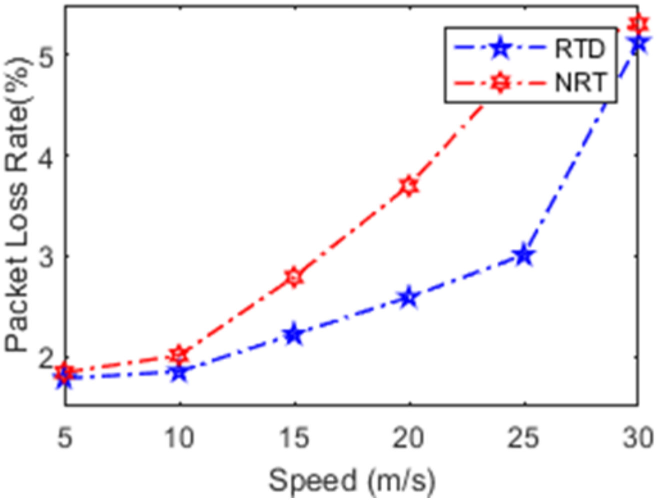

Figure 5 Packet Loss Ratio (%) Over Varying Speed (m/s)

The average PLR performance too was found 2.76% and 3.43% for the RTD and NRT traffic, correspondingly, even over the high-speed node transition. Observing the results (Figure 4 and Figure 5), it can be found that undeniably with the high-speed movement the PDR reduces; however, the reduction is very small and hence doesn't impact overall efficacy decisively. It confirms robustness of the proposed routing protocol over the high-speed topological changes and hence makes it potential towards VANETs.

6.1.3. Performance with the Different Vehicle Density

In VANETs the density of moving vehicle can be dynamic. In other words, in urban road networks or transportation systems, the pattern of vehicle density often remains non-linear and hence there can be dynamic node density or vehicle density. In this case, the number of nodes participating a cluster can also be dynamic that consequently would impose their respective load on the CH and hence can undergo congestion at the same. Similarly, performing dynamic link formation and allied data dissemination requires timely and swift link-formation and transmission decision. It can have the impact on PDR performance. Considering these inferences, we assessed efficacy of the proposed MCCQVR protocol with the different vehicles (say, vehicle density). To be noted, here we define vehicle density as the number of vehicles present within the radio range of the vehicles (i.e., 250 meters). The simulated results and allied PDR and PLR outputs are given in Figure 6 and Figure 7. As depicted in Figure 6, the MCCQVR routing protocol performs PDR (%) of 98.3%, 97.5%, 97.2%, 96.2%, 95.8% and 94.2% over the vehicle density of 50, 100, 200, 300, 400 and 500 vehicles for the RTD traffic. For the NRT traffic, MCCQVR protocol achieved the PDR of 98%, 97.18%, 98.7%, 95.96%, 95% and 93.9% for 50, 100, 200, 300, 400 and 500 vehicles.

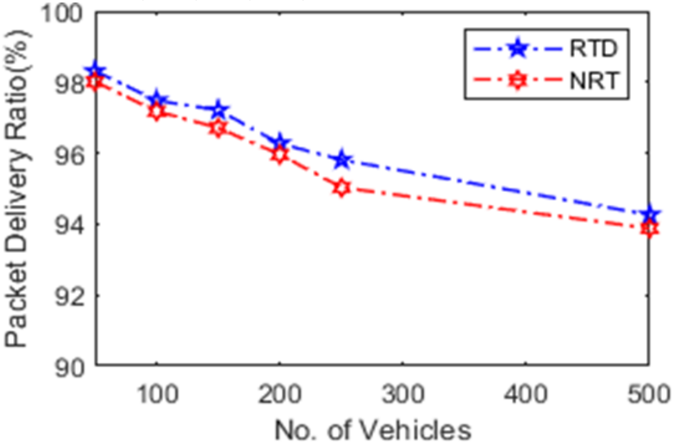

Figure 6 Packet Delivery Ratio (%) Over Varying Vehicle Density

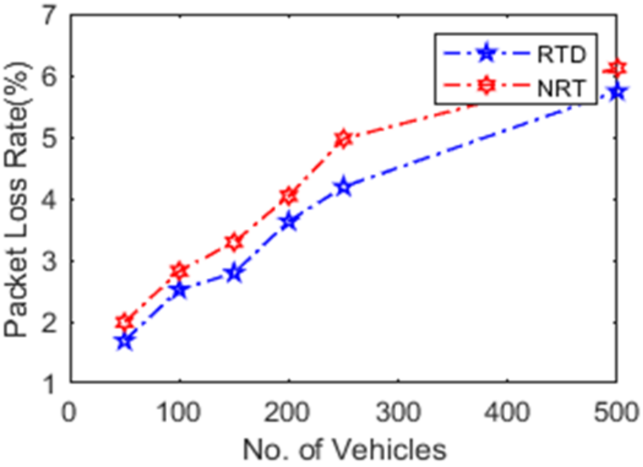

Figure 7 Packet Loss Ratio (%) Over Varying Vehicle Density

Table 2 Average Performance

Parameters	RTD		NRT	
	PDR (%)	PLR (%)	PDR (%)	PLR (%)
Payload	95.32	4.67	95.32	4.67
Speed	97.23	2.76	96.56	3.43
Density	96.55	3.42	96.12	3.87
Cumulative Average	96.36	3.61	96.00	3.99

Observing the average performance (Table 2), it can be found that the proposed MCCQVR routing protocol achieves average PDR of 96.36%, and 96% for the RTD traffic. Similarly, the average PLR was found as 3.6% and 4% for the RTD and NRT traffic, respectively. The overall performance confirms that the proposed model can be effective towards the real-time VANET communication. The results confirm robustness of the proposed model exhibiting effective over the different network conditions such as payloads, speed and density. It affirms its suitability towards real-time applications.

6.2. Inter-Model Assessment

The performance characterization in the previous section exhibited that the proposed MCCQVR routing protocol exhibits efficiently for both RTD as well as NRT traffic. However, to assess whether the proposed model performs superior than the other state-of-arts, we compared the performance with other recent cluster-based VANET routing protocols. Noticeably, none of the VANET routing protocols have considered QoS problem with RTD and NRT traffic. Most of the state-of-arts have applied standalone (Ex. Link probability, delay information) or multiple parameters such as vehicle trajectory, average speed. However, such approaches have failed contributing a robust solution which could exploit dynamic cross-layer information to perform real-time clustering, CH selection and best forwarding routing decision. Moreover, none of the state-of-arts in VANET could address real-time resource allocation and load-balancing decision to meet QoS demands. Interestingly, MCCQVR used cross-layer information including topological information (hops), congestion probability, adaptive link quality and packet velocity features to perform CH selection. It helped to ensure optimal CH selection as well as improved best forwarding routing decision to achieve QoS performance. SDARA helped the MCCQVR achieving resource allocation and allied load balancing for QoS-centric RTD and NRT data dissemination. The results revealed that the average PDR performance for the RTD data was 96.36%, while for NRT traffic it retained average PDR of 96%.

Sharma et al. [81] developed weight-based clustering model for military vehicle communication in VANET. They applied average speed information and distance to perform clustering and allied CH selection decision. However, the highest PDR obtained was almost 90%, which is lower than the proposed model. The other state-of-arts such as [82-85] too were found inferior in terms of PDR performance. Despite being cluster-based destination-aware context based VANET routing protocol the authors [82] could achieve the highest PDR of 53%, which is almost 43% lower than our proposed MCCQVR routing model. The authors in [83] designed secure hashish with K-Means cluster-based VANET protocol; however, it underwent significantly reduced PDR performance which was measured as 80%. An agglomerative CH selection model was proposed in [84] for VANET routing, yet, the highest PDR obtained was merely 30%. Here, it clearly indicated that merely applying network parameters on random instant can't guarantee successful data dissemination and therefore requires proactive multiple parameters with dynamic routing decision to retain high PDR. In this reference, our proposed model is found more efficient and robust to meet real-time VANET communication demands. In [85], AODV was used for VANET; yet, the highest PDR observed for multicast transmission was 80%, which is still lower than the proposed MCCQVR routing protocol. The authors [86] applied different heuristic models named Harris Hawks optimization algorithm (HHO) and Artificial Bee Colony algorithm (ABC) to perform clustering and best routing in VANET. Despite their claim to have achieved 94% of maximum PDR, the authors failed in addressing delay problem, especially caused due to iterative computations over the large iterations. It can confine their scalability over real-time network problems. They applied aforesaid heuristic methods to optimize a minimization function which intended to reduce distance and speed of the node to identify an optimal CH node. However, its practical significance over dynamic topology with heterogenous nodes seems unrealistic. In [49] multi-hop clustering based VANET routing protocol (VMaSC-LTE) was developed for Long Term Evolution (LTE) driven solutions.

This approach performed CH selection based on the relative mobility pattern (i.e., average relative speed of the vehicles) and minimum overhead of the nodes. Interestingly, over the different speeds (in the range of 10-35 m/s) the authors achieved the average PDR of almost 94%, which is still lower than the proposed MCCQVR protocol. The authors assessed PDR performance with 1, 2 and 3 hop details. They found that exploiting multi-hop (precisely 2 or 3 hop information) can help achieving almost 97% of PDR performance. Unfortunately, the authors failed to clarify whether the use of multi-hop information which often require performing multiple handshaking, route-request (RREQ), acknowledgement (ACK) signaling etc. might force the model to undergo increased delay. That over high-speed moving vehicle might cause frequent link-outage and therefore can impact overall performance. Considering such limitations in this paper, we designed MCCQVR routing protocol with single hop proactive (cross-layer) information which helped exploiting more node's intrinsic features to ensure CH optimality as well as best forwarding node (CH node) decision.

In this manner, our proposed MCCQVR routing protocol achieves relatively superior performance than the existing VMaSC-LTE protocol [49]. To be noted, VMaSC-LTE could achieve the average PDR of 96% for one-hop information-based clustering, which is still lower than our proposed

MCCQVR protocol. While varying vehicle density, VMaSC-LTE protocol with 1-hop clustering achieved average PDR of 91.5%, which is almost 5.05% lower than our proposed MCCQVR routing protocol which exhibited average PDR of 96.55% for RTD traffic. To be noted, none of these state-of-arts could address traffic sensitive load-balancing or resource allocation problem which is quite frequent problem in real-time VANETs, especially LTE-supported VANETs [49]. The authors [87] developed load-balanced clustering based VANET protocol with genetic algorithm (GA)-based clustering. Same as [86], the large number of generations in GA evolutionary computing and CH optimization can make it limited to serve real-time VANETs. The authors used GA and dynamic programming to perform load-balanced clustering; however, its efficacy over dense and heterogenous network seems unjustifiable. They applied velocity and angle to perform load-balanced clustering. Though, they claimed to have achieved 97.5% PDR; yet, their efficacy over rising velocity reduced. The average PDR over the different vehicles speed was found to be 93.4%, which is lower than the proposed MCCQVR protocol.

The authors [69] made a significant contribution where a reliable cluster-based VANET routing protocol was designed. More specifically, they proposed a link-reliability based clustering algorithm (LRCA). Before executing LRCA, the authors performed link-lifetime based neighbor sampling to improve cluster formation. Undeniably, the use of LRCA helped optimizing link-reliability and hence data dissemination in VANET; however, the average PDR obtained for the vehicle velocity of 10-35 m/s was found almost 90%, which is nearly 6.5% lower than the proposed MCCQVR routing protocol. The authors [88] designed a clustering based VANET routing protocol, where the average PDR performance assessment with the different vehicle density was obtained as 93%. In [89] water wave optimization-based clustering was proposed, which was followed by multi-metric feature-based CH selection; yet the highest PDR observed was 94%, which is lower than our proposed MCCQVR protocol (PDR 96.55% for RTD traffic). A cluster-based VANET routing protocol (CBVRP) was proposed.

The authors assessed efficacy over both intra-cluster as well as inter-cluster communication. Despite their claim to have higher efficiency over AODV, DSR, CBRP, their average PDR was found near 91%, which is decisively lower than the MCCQVR protocol. Moreover, none of the above stated VANET routing protocols could consider QoS-centric traffic aware resource allocation, which is inevitable in modern communication systems serving V2V, V2I or other M2M or IoVT communications. A snippet of the relative PDR performance by the different state-of-arts and the proposed routing protocol is given in Table 3. The graphical depiction of the performance is given in Figure. 8.

Table 3 Relative Performance Comparison

Reference	Packet Delivery Ratio (PDR %)
[49]	91.50
[65]	91.00
[69]	90.00
[81]	90.00
[82]	53.00
[83]	80.00
[84]	30.00
[85]	80.00
[86]	94.00
[87]	93.40
[88]	93.00
[89]	94.00
MCCQVR	96.55

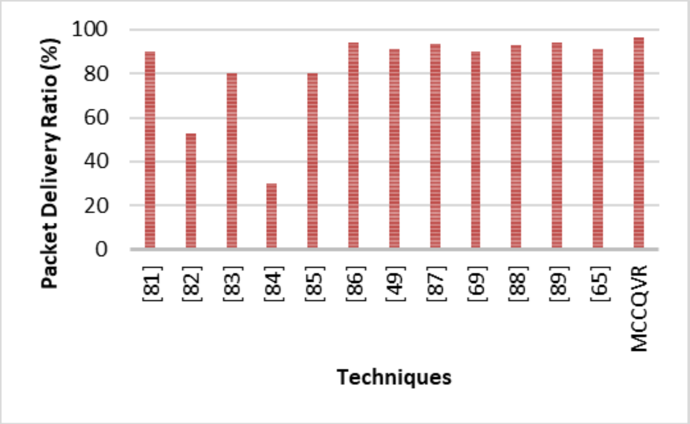

Figure 8 Relative (PDR) Performance Comparison

The overall results obtained confirms affirmative answers for the research questions defined in Section 4.

7. CONCLUSION

This paper proposed a novel Multi-Constraints Clustering Driven QoS-Centric VANET Routing Protocol (MCCQVR) is proposed. As the name indicates the proposed MCCQVR protocol exploits multiple metrics obtained as the cross-layer dynamic information to perform stable CH selection and allied clustering task. Being a cross-layer driven clustering model, MCCQVR exploits service differentiation and adaptive resource allocation information from the application layer, packet velocity and congestion probability information from the MAC layer, dynamic link quality from the data-link layer and neighborhood information from the network layer. Thus, applying aforesaid dynamic parameters the proposed MCCQVR protocol performs CH selection, which is then followed by best forwarding path decision to ensure reliable communication over VANETs. The use of packet velocity as CH selection criteria ensured that the cluster head guarantees successful transmission of the data packet within the deadline time. Congestion probability which estimated cumulative congestion degree on a node helped MCCQVR to avoid any probable vehicle node to become CH that eventually could have impacted transmission reliability and hence packet loss. The dynamic link quality too helped identifying the best vehicle node with most stable link quality to ensure reliable data transmission. MCCQVR ensures reliable transmission without undergoing frequent link-outage or congestion caused data drop. Thus, it alleviated any likelihood of data retransmission and hence energy exhaustion. Additionally, the avoidance of retransmission improved time-efficiency that with packet velocity sensitive CH selection achieved timely data transmission. It can be of great significance for real-time communication over VANETs under complex network conditions like high density with non-linear load and topological change conditions. In addition to the aforesaid contributions, the proposed MCCQVR protocol applied dual-buffer concept where each node was assigned two distinct buffers, each for RTD traffic and NRT traffic. In case of 100% resource utilization of the RTD buffer, the MCCQVR protocol borrows resource from the NRT buffer in which the packets are queued in FIFO manner. The proposed service differentiation and dynamic resource allocation (SDARA) model dropped recently connected packet (i.e., last packet) to accommodate RTD and achieved delay-resilient transmission. The simulation results confirmed that MCCQVR routing protocol achieved high PDR of (96.5%) for RTD traffic, while retaining PDR of (96.0%) for NRT traffic.

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