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Two-Level Cluster Based Routing Scheme for 5G V2X Communication

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ABSTRACT Efficient data dissemination is a big challenge for both IEEE 802.11p (MAC contentions problem) and cellular vehicle-to-everything communications (limited bandwidth in the high dense network). In this paper, a two-level clustering scheme is proposed for efficient data dissemination in 5G V2X communications. In the proposed protocol, level-1 cluster heads (L1CHs) are selected by a fuzzy logic algorithm using three factors, i.e., relative velocity factor, *k*-connectivity factor, and link reliability factor. The slide link vehicle-to-vehicle (V2V) or the Third Generation Partnership Project V2V overcomes the MAC contention problem in L1CHs selections. Next, the level-2 cluster heads are selected by an improved Q-learning aiming to reduce the number of iterations in the gateway selection to LTE base station. The proposed scheme is evaluated under different network conditions showing that our protocol achieves good results compared to the existing schemes.

INDEX TERMS Two level clustering, cluster head, connectivity, link reliability, efficient data dissemination.

I. INTRODUCTION

The rapid advancement of computation and communication technologies changed the conventional vehicular ad-hoc networks (VANETs) to the Internet of Vehicles (IoVs) [1], [2]. Apart from safety and user applications, IoV also provides a platform for the vehicle to cloud communication. The exponential increase in vehicles population is a big challenge to contents distribution [3]. Vehicle to cloud communication is an attractive application of recent years. A pure vehicle-to-vehicle (V2V) communication faces many problems such as network disconnection, broadcast storm, and MAC protocol contention problem, etc. [4], [5]. In literature, the vehicle to cloud communication is done by combining V2V with vehicle-to-infrastructure (V2I) communication [6]–[8], where roadside units (RSUs) provide Internet access to the vehicles. Due to the high mobility, the performance of contents downloading degrades because of the limited link lifetime (LLT) between the vehicle and RSU.

There is a trade-off between IEEE 802.11p and cellular networks. The deployment of pure IEEE 802.11p based communication has many challenges as mentioned above. Similarly, for cellular network, it is difficult to support all sorts of communications. For example, in an urban area network, the spectrum efficiency of cellular will drop drastically with the increase of vehicular density. Secondly, in rural areas, cellular will not perform well due to the less number of users terminals. To get control over the limitations of IEEE 802.11p with short coverage, non-supportability of highly-dense vehicular network, signal congestion, erratic broadcast services, and connectivity interruptions, an emerging technology cellular vehicle-to-everything (C-V2X) communications have been introduced for vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-pedestrian (V2P) services [9], [10]. The initial C-V2X technology has defined by the Third Generation Partnership Project (3GPP) group in Release 14. Seo *et al.* [11] addressed all the open challenges towards the V2X services in high mobility and dense environment. The authors proposed that to get the guaranteed V2X services in vehicular communication, new solutions are required to achieve the goals, such as latency and reliability. Their main concern was to target the design requirements related to the different communication types. The channel structure of the side link (SL) device-to-device (D2D) [12] communications was suggested for 3GPP specifications, which were expected for 5G interface design. Similarly, Uhlemann [13] also discussed the importance of interface PC5 (based on SL D2D communications) toward the open challenges of V2X services. PC5 interface will enable V2V communications under in-coverage and out-of-coverage application scenarios. We can conclude from the above discussion that 5G and SL D2D communication is a key enabling technology towards the enhanced 5G V2X services [14]. Here in this work, a new cluster based routing scheme is proposed for 5G V2X communications.

Different routing schemes in VANETs are designed to cope with the problem of V2V communications such as opportunistic routing [6], QoS-aware routing [15], street-centric approach [16], RSU controlled approach [17], and clustering [18]–[20] for content distributions. Similarly, some hybrid architectures of cellular and IEEE 802.11p [21], [22] are also proposed to cope with traditional routing schemes. In a high-density vehicular network, the performance of the schemes as mentioned earlier are ignored and will be costly in case of cellular technology. In a high congested vehicular network, the intensity of channel contention increases significantly among vehicles which causes considerable degradation of the IEEE 802.11p performance, due to a high transmission collision rate and a large channel access delay. To cope with MAC contention problem, the formation of manageable groups (clustering) is an excellent solution to reduce the contention among vehicles.

In [23], a reliable and low latency clustering protocol called Multi-hop Moving Zone (MMZ) was proposed by combining IEEE 802.11p with cellular technology. In MMZ, nodes were grouped up-to 3-hops using DSRC based V2V communications aiming to reduce cellular hand-off cost. Whereas the cluster heads (CHs) were selected by C-V2X technology by multi-metrics, i.e. relative velocity, distance and link lifetime (LLT). The proposed MMZ formed stable clusters with high packet delivery and low latency.

A novel V2V-enabled resource allocation scheme [24] was proposed by Abbas *et al.* [25] based on C-V2X technology aiming to improve the reliability and latency of VANETs. The proposed scheme was hybrid, where the V2V communications were performed by eNodeB in the overlay scheme. Every vehicle in the scheme mentioned above periodically monitors its packet lifetime and requests the cellular eNodeB to control V2V links. Furthermore, cellular eNodeB performed optimum resource allocation to assign optimal receiver vehicles to determine V2V links and allocate suitable channels to minimize the total latency. The authors proposed resource allocation problem is NP-hard and is similar to the maximum weighted independent set problem (MWIS-AW) with associated weights. The V2V-enabled resource allocation scheme significantly improved the latency, packet delivery, and throughput.

Wu *et al.* [4] examined the integration of LTE with DSRC (Dedicated Short Range Communication) for content dissemination in VANETs and proposed a two-level clustering scheme, where cluster heads (CHs) in the first-level aim to overcome V2V MAC layer contentions problem, and CHs within the second-level are accountable for providing an optimal gateway between V2V and LTE. The first and second level clusterings were done by Fuzzy logic and Classical Q-learning algorithm [26] respectively.

The introduction of the two-level approach in clustering is useful to improve the performance of data dissemination. In the first level, CHs are selected using a Fuzzy-logic algorithm based on three factors such as velocity, leadership, and signal quality factor. The term leadership refers to a group of vehicles moving in the same direction. Generally, in a given cluster, all vehicles follow the same direction; therefore leadership factor is not an appropriate metric to consider in CH selection. Similarly, the signal quality factor is related to the number of successful received hello messages, which not only depends on signal quality but also depends on buffer sizes. To improve the stability and performance of first level clustering using fuzzy logic, it is necessary to use alternate factors of leadership and signal quality. Apart from the CH selection parameters, the Classical Q-Learning (CQL) [26] has a computational issue due to the excessive iterations in gateway selection. To cope with computational issue, Improved Q-Learning (IQL) [27] is an optimal choice to use as a substitute of CQL. Since in IQL, the Q-values are updated only in case of the best action availability. Therefore, the time and space complexity will reduce significantly.

Vehicles position and strength of connectivity concerning cluster size and transmission ranges are essential arguments of vehicular connectivity [28]. Since connectivity is a good factor, hence it can be used as an alternate to leadership factor. Connectivity not only considers the strength of transmission range and neighborhood degree but also considers the direction of vehicles as well. Similarly, reliability [15] defines the quality of link better [29] than signal quality factor [4], that's why we used link reliability instead of signal quality.

In this paper, a novel two-level cluster based routing scheme is proposed for 5G V2X communications by extending the existing two-layer clustering scheme [4]. The major contributions of this paper are listed below.

- The hybrid architecture of LTE and DSRC [4], [23] is examined and proposed a new 5G-V2X architecture using SL-V2V as a substitute of DSRC based V2V.
- An efficient data dissemination cluster based routing scheme is designed for 5G V2X communications, where Level-1 Cluster Heads (L1CHs) are selected based on 3GPP V2V by using three metrics, i.e. relative velocity, k-connectivity, and link reliability. In literature, different protocols use different selection criteria for cluster head selection such as ID, degree, propagation delay, velocity, travel time, average relative velocity, mean connection time, trust level, number of following vehicles, etc. [19]. Herein proposed scheme, L1CHs used k-connectivity and link reliability for the first time as a metrics for CH selection.
- On the other hand, IQL algorithm selects Level-2 Cluster Heads (L2CHs) aiming to find an optimal gateway to the 5G cellular base station (BS).

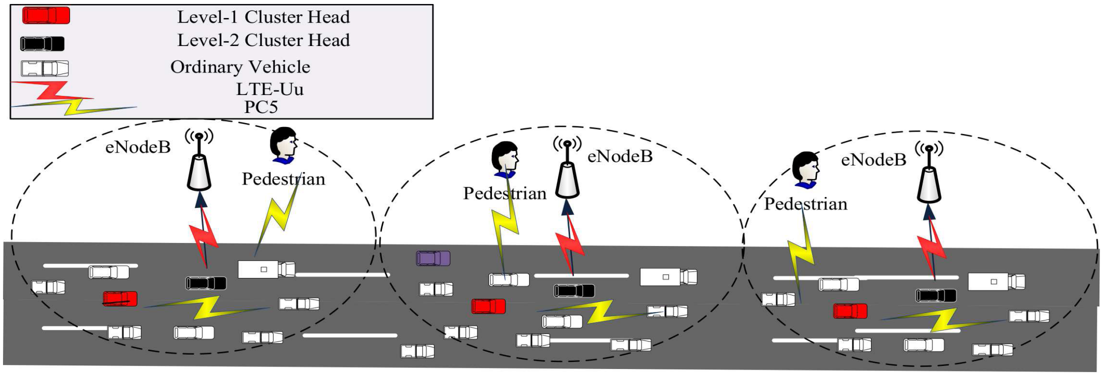

FIGURE 1. Two level cluster based routing scheme V2X scenario.

- The proposed scheme reduced both the communication and computational cost. The stable and consistent CH selection improved the throughput under various network conditions. In level-1 clustering, the SL-V2V reduced the intensity of channel contention among vehicles. The time complexity of L1CHs selection is calculated to be $O(pcd)$, where p is the number of patterns, c is the number of clusters and d is the dimension of the data points. On the other hand, the complexity of IQL for optimal gateway discovery is $O(n(m-2))$, where n is the number of states and m is the number of taken actions.

The rest of the paper is organized as follows; Section II describes the system model, Section III maintains the proposed two-level clustering algorithm formulation, Section IV deliberates the discovery of the route for data dissemination. Section V discusses the theoretical analysis. Section VI explains the experimental study along with discussion and VII concludes the paper based on simulation results.

II. SYSTEM MODEL

Herein this work, we considered a highway road model with a random distribution of V2X vehicular nodes. Each vehicular node uses LTE-V standard supporting side link or V2V communications using the $PC5$ interface in LTE. According to 3GPP Rel.15, 5G V2X supports two modes (Mode 3 and 4) for direct V2V communications, but the difference is the allocation of the radio resources. In Mode 3, Resources are allocated by the cellular network whereas in Mode 4 cellular coverage does'nt require, vehicles autonomously select their radio resources using a distributed scheduling scheme. Here, Mode 4 is considered the baseline model and represents an alternative to 802.11p or DSRC [30]. Each vehicle's speed follows Normal distribution [31], [32]. The vehicles are exchanging necessary information reactively with each other. It is assumed that vehicles disseminate contents with each other using Mode 4 V2V communications (PC5 interface). While contents from/to network will distribute through gateway vehicle using cellular Uu interface as shown in Figure 1.

III. PROPOSED TWO-LEVEL CLUSTER BASED ROUTING SCHEME FORMULATION

Considering the issues of pure V2V and cellular setup, we proposed a novel two-level cluster based routing scheme for 5G V2X, where vehicles are grouped into two-layers. In the first layer, L1CHs are elected by considering prominent factors, i.e. relative velocity, vehicular k-connectivity, and link reliability.

A. CLUSTER FORMATION AND LEVEL-1 CLUSTER HEAD (L1CH) SELECTION

Every vehicle gets information from disseminated Hello messages and calculates three important factors, i.e. relative velocity factor (RVF), k-connectivity factor (KCF), and link reliability factor (LRF). Next, each vehicle calculates leadership value (LV) for itself and one-hop neighbors by using a fuzzy logic approach. The vehicle having the largest LV in its neighborhood declares itself as an L1CH using hello message aims to form a stable cluster of vehicles. The LV calculation for neighbors' vehicles is done within the range of 1/2R, but L1CH is selected within 1/4R range with maximum LV.

1) LEADERSHIP VALUE (LV) CALCULATION USING FUZZY LOGIC ALGORITHM

The three factors RVF, KCF, and LRF are calculated first for one-hop neighbors within the range 1/2 R. Next, the selected factors are converted to fuzzy-values using fuzzy rules by predefined fuzzy member functions. Lastly, the fuzzy values are converted to numerical values, i.e. LVs based on fuzzy output membership function. The RVF, KCF, and LRF are calculated from neighbor's beacon messages.

a: RELATIVE VELOCITY FACTOR (RVF)

The velocity of vehicle v_i with respect to vehicle v_j is called relative velocity. Upon the reception of hello messages from one-hop neighbors N, vehicle calculates its RVF concerning neighbors set by Eqn(1) as given below.

$$RVF = \frac{\sum_{i=1}^{N} |\mu - v_i|}{N} \tag{1}$$

Here μ represents the mean velocity of a given vehicle. A smaller RVF represents less variation in velocity concerning neighbors' vehicles. RVF is updated periodically and also reactively in case of sudden change in speed.

b: K-CONNECTIVITY FACTOR (KCF):

A network is said to be k-connected if the extraction of any (k − 1) intermediate nodes does not disconnect the network connectivity [33]. Vehicular connectivity depends on transmission range R and spatial density of neighborhood vehicles.

The connectivity probability P_c, that at-least k vehicles are connected on a road segment s is given as [28]

$$P_c(k) = P(N \geq k) = \sum_{i=k}^{\infty} P(N = i) = \sum_{i=k}^{\infty} (F_s(R))^i = (1 - e^{-\rho R})^{k-1} \quad (2)$$

In Eqn(2), $F_s(.)$ is the distribution function of inter-vehicle spacing. N is the total number of vehicles and k represents connected vehicles at time t. The parameter ρ represents the spatial density of vehicles in sub segment s. A large value of KCF represents strong connectivity and stability of a node.

c: LINK RELIABILITY FACTOR (LRF)

Link reliability refers to the probability that a direct communication link will be available between two vehicles V_i and V_j over a particular time t.

Vehicle's velocity is an important metric, which measures network dynamicity and expected communication duration between two vehicles. That's why here velocity is used to measure link reliability. It is assumed that velocity v of vehicles follows the Gaussian distribution $N(\mu, \alpha^2)$ [31], having probability density function (pdf) is

$$f(v) = \frac{1}{\sigma.\sqrt{2\pi}} e^{-\frac{(v-\mu)^2}{2\sigma^2}} \quad (3)$$

where μ and σ^2 represent the mean and variance of velocity v respectively. The probability density function (pdf) of link duration T of V_i and V_j is given as

$$f(T) = \frac{R_{ij}}{\sigma_{\Delta v_{ij}}.\sqrt{2\pi}T^2} e^{-\frac{(\frac{R_{ij}}{T} - X_{\Delta v_{ij}})^2}{(2\sigma_{\Delta v_{ij}})^2}} \quad (4)$$

The parameter $X_{\Delta v_{ij}}$ is the expected mean of velocity v. $\sigma_{\Delta v_{ij}}$ represents the deviation of both vehicles, i.e. $\sigma_{\Delta v_i} + \sigma_{\Delta v_j}$. R_{ij} represents the relative transmission range. The probability that a link l will be available for T duration is

$$r_t(l) = \int_t^{t+T_{est}} f(T)dt \text{ if } T_{est} > 0 \quad (5)$$

Here $r_t(l)$ is the reliability of link l at time t.

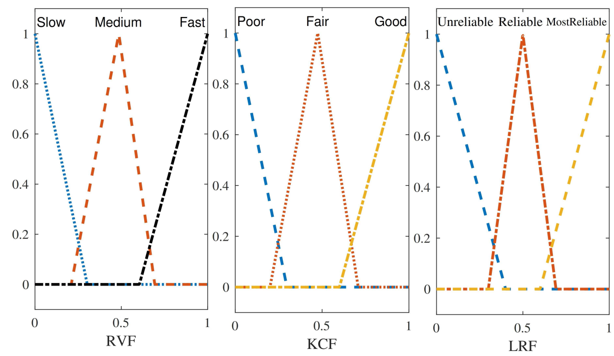

FIGURE 2. Fuzzy member functions of selected factors.

2) FUZZY MEMBER FUNCTION AND FUZZY RULES

The defined fuzzy member functions of all three factors are shown in Figure 2. All factors are converted to their corresponding linguistic variables. The linguistic variables of RVF are {Low, Medium, Fast}. Next, the linguistic variables for KCF and LRF are constructed as {Good, Fair, Poor} and {Unreliable, Reliable, Most-reliable} respectively. Each vehicle calculates the leadership value (LV) for being a CH election using IF/THEN rules as given in Table 1. The rules are constructed from our selected factors based on [4].

Our fuzzy inference system adaptively calculates LV by using the proposed parameters (RVF, KCF, and LRF). The output is obtained by Mamdani's fuzzy inference method. The frequent outputs show that, LV increases when the value of RVF is in the interval (0 to 0.2) and KCF is (0.5 to 1) as shown in Figure 3. Similarly, LV increases with respect to RVF and LRF having boundaries between 0 to 0.6 and 0.4 to 1 respectively as shown in Figure 4. The correlation of LRF and KCF with LV is also shown in Figure 5, which shows that LV increases with the given intervals 0.4 to 1 for both KCF and RLF.

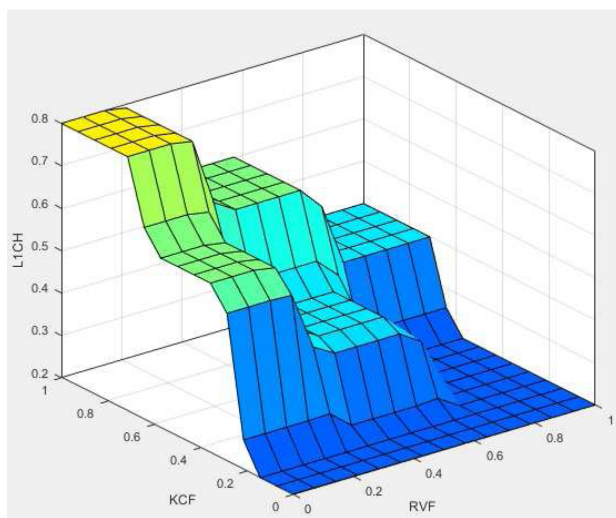

FIGURE 3. Correlation between inputs (RVF, KCF) and output (L1CH).

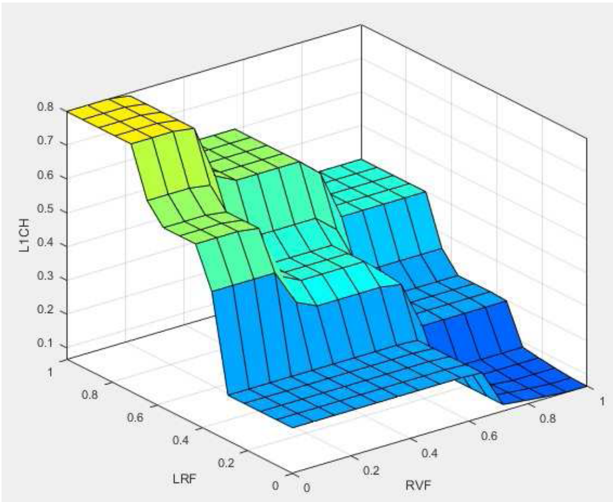

FIGURE 4. Correlation between inputs (RVF, LRF) and output (L1CH).

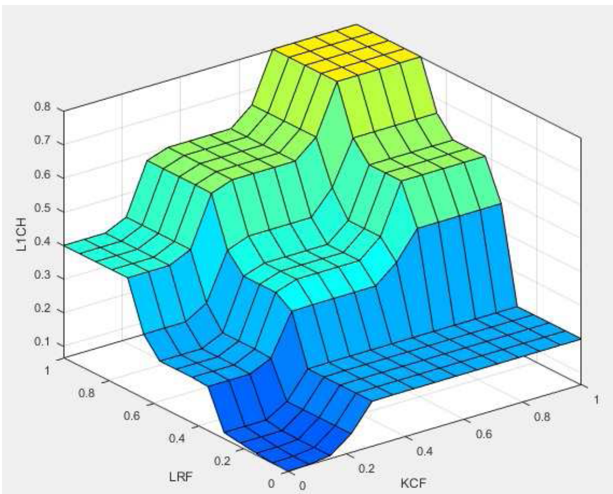

FIGURE 5. Correlation between inputs (KCF, LRF) and output (L1CH).

To evaluate the LV, the final rank is also categorized into linguistic variables as {Perfect, Good, Acceptable, Unacceptable, Bad, Very Bad} shown in Figure 6. A rule can be expressed as *IF the relative velocity is Low, K-connectivity is Good, and Link Reliability is Most Reliable THEN rank is perfect.* In the case of multiple rules, Min-Max method is used to calculate their net results.

3) DEFUZZIFICATION

To convert the fuzzy output value, i.e. (Leadership Value) to numerical value, we used output membership function as defined in (Figure 2 and 6) and defuzzification method. In this work, Center of Gravity (COG) method is used for defuzzification.

B. LEVEL-2 CLUSTER HEAD (L2CH) SELECTION USING IMPROVED Q-LEARNING (IQL)

To select an optimal gateway for contents distribution, an appropriate level-2 cluster head (L2CH) is chosen from L1CHs or other cluster members. Wu *et al.* [4] used classical Q-learning for gateway selection, which uses excessive iterations to reach the desired goal. To consider this issue, we used an Improved Q-learning (IQL) [27] instead of classical Q-learning (CQL). The IQL is an optimized form, where only the best actions values are stored in Q-Table. Thus for n states, n values require to store in Q-Table. Aside from the Q-values storage, n Boolean Lock variables B_i need for state S_i, $i = 1$ to n, representing the status of available states. A Q-value will be updated if the state of Lock variable is set to 1. The step by step explanation of IQL is given in Algorithm 1.

Algorithm 1 Improved Q-Learning (IQL) Gateway Discovery to LTE BS

Result: Gateway to LTE BS
Input : Agents and Actions
Output: Return L2CH

$B_G \longleftarrow 1$
$Q_G \longleftarrow 100$
$\gamma \longleftarrow [0, 1]$
$S_c \longleftarrow InitialState$
$i \longleftarrow 1$
foreach $S_i \neq S_G$ **do**
  $a_i \longleftarrow A$
  $Q_i \longleftarrow 0$
  $calculate(d_{ng}, d_{cg})$
  if $d_{ng} < d_{cg}$ **then**
    if $B_n == 1$ **then**
      if $B_c == 0$ **then**
        $Q_c \longleftarrow Q_n \times \gamma$
        $B_c \longleftarrow 1$
      else if $B_c == 1$ **then**
        $Q_n \longleftarrow Q_c/\gamma$
        $B_n \longleftarrow 1$
    else if $B_c == 1$ **then**
      if $B_n == 0$ **then**
        $Q_n \longleftarrow Q_c \times \gamma$
        $B_n \longleftarrow 1$
      else if $B_n == 1$ **then**
        $Q_c \longleftarrow Q_n/\gamma$
        $B_p \longleftarrow 1$
  end
end

In Algorithm 1, it is shown that on every node, IQL checks the depth to LTE BS, where four properties [27] are further analyzed to whether update the Q-value or not. A vehicle will be selected as a gateway or L2CH if it has the largest Q-value in the iterative discovery of LTE BS. In CQL, the Q-Table keeps track of all n states and m actions information with $(m \times n)$ memory consumption. Since IQL maintains only the best actions records, hence its space complexity reduced to $n(m - 2)$.

In the path planning, the whole vehicular topology is considered as an environment, where L1CHs are agents and their neighbors are the possible actions. In the planning phase,

Algorithm 2 Path Planning

Result: Shortest Path
Input : Agents and Actions
Output: Return Next Best Hop to LTE
Current ⟵ S_c
foreach $S_i \neq S_G$ **do**
  if $Q_n > Q_c$ **then**
    GotoNext
    Current ⟵ *Next*
  end
end

TABLE 1. Fuzzy rules.

Rules	RCF	KCF	LRF	LV
1	Low	Good	Most-Reliable	Perfect
2	Low	Good	Reliable	Good
3	Low	Good	Un-Reliable	UnPreferable
4	Low	Fair	Most-Reliable	Good
5	Low	Fair	Reliable	Accept
6	Low	Fair	Un-Reliable	Bad
7	Low	Bad	Most-Reliable	UnPreferable
8	Low	Bad	Reliable	Bad
9	Low	Bad	Un-Reliable	Very Bad
10	Medium	Good	Most-Reliable	Good
11	Medium	Good	Reliable	Acceptable
12	Medium	Good	Un-Reliable	Bad
13	Medium	Fair	Most-Reliable	Acceptable
14	Medium	Fair	Reliable	UnPreferable
15	Medium	Fair	Un-Reliable	Bad
16	Medium	Bad	Most-Reliable	UnPreferable
17	Medium	Bad	Reliable	Bad
18	Medium	Bad	Un-Reliable	Very Bad
19	Fast	Good	Most-Reliable	Acceptable
20	Fast	Good	Reliable	UnPreferable
21	Fast	Good	Un-Reliable	Bad
22	Fast	Fair	Most-Reliable	UnPreferable
23	Fast	Fair	Reliable	Bad
24	Fast	Fair	Un-Reliable	Very Bad
25	Fast	Bad	Most-Reliable	UnPreferable
26	Fast	Bad	Reliable	Bad
27	Fast	Bad	Un-Reliable	Very Bad

the agent node (L1CH) examined the neighboring states in Q-Table. The agent node followed the best action to move from current state S_c to next best state S_n. IQL has two main steps, i.e. Initialization and Q-Table update. The variables are set to zeros for all states $S = \{S_1, S_2, ...S_G\}$ except S_G in the initialization step. The immediate reward r is set to 100 from the neighboring state to BS LTE. The other initial states and discounting factor γ are kept constant. In the update phase, if $B_c(B_n)$ value is 1, then $B_n(B_c)$ also set to 1. The value of B_G is set to 1 in the initialization phase. Algorithm 2 shows path planning in details. If an agent current or next state is BS LTE, then no update will happen in Q-value. After all iterations, any node having largest Q-value in the Q-Table will be considered as L2CH. The convergence time is an important

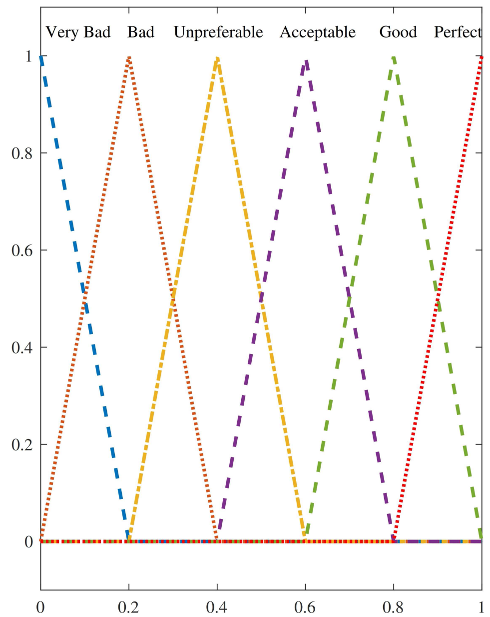

FIGURE 6. Fuzzy member functions of leadership value (LV) ranking.

metric to measure the reliability of a learning algorithm. The convergence of IQL refers to the total time taken to discover an appropriate gateway/L2CH. Since the proposed IQL followed only best actions, hence the convergence time reduced significantly as compared to CQL.

IV. ROUTE DISCOVERY PROCESS IN PROPOSED CLUSTERING SCHEME

In the proposed two-level clustering scheme, contents can be routed in either inter-cluster or intra-cluster mechanism. In intra-cluster, route discovery is simple, which is limited to level-1 clustering only. While on the other hand, contents distribution to cloud or vehicle belongs to other cluster is different and require two-level clustering (L2CH to LTE BS).

A. INTRA-CLUSTER ROUTE DISCOVERY

The information of L1CH is disseminated to all cluster members. All ordinary vehicles keep information of selected L1CH. Suppose a source vehicle s sends contents to the destination vehicle de. In case of 1-hop neighborhood clustering, the source vehicle will send the contents directly to L1CH using SL-V2V, which will further forward to the destination de. Since L1CH is selected dynamically by adaptive execution of fuzzy logic approach, hence the MAC contention problem will not be too much in case of multiple concurrent senders. Secondly, in the case of multi-hop clustering for multiple concurrent requests, we proposed to use EG-Dijkstra [29] for route discovery to L1CH aims to load balance on multiple links. The EG-Dijkstra will select various alternate routes to L1CH to decrease the MAC contention problem. The L1CH will further disseminate the contents to the required destination.

B. INTER-CLUSTER ROUTE DISCOVERY

The contents distribution to the cloud or another cluster (outside transmission range) uses Mode 3 based V2X communication [30]. In the discovery process, the source node directly accesses the L1CH as discussed in the intra-cluster route discovery process. Once L1CH receives the route request (RR), it checks the Q-Table to explore the L2CH for outside contents dissemination. L1CH selects the largest Q-value inside the Q-Table calculated by the IQL for L2CH gateway selection. Once the gateway to LTE BS discovers, the contents are transferred to eNodeB. In LTE, the evolved packet core (EPC) handles the received contents. If the contents belong to the cloud or pedestrians, the server gateway (SGW) assumes the responsibility for its delivery. On the other hand, if it belongs to other vehicles, the packet data gateway (PGW) takes the responsibility for its delivery.

V. THEORETICAL ANALYSIS

A. IMPACT OF VEHICLE SPEED ON L1CH SELECTION

Let $L(L = 2R)$ be the length of the contents distribution region, then $\frac{L}{v}$ be the maximum data transfer interval, where v is the vehicle velocity. The content distribution interval is closely related to the speed of vehicles as shown in Figure 7. We can observe that a vehicle with low speed (or less variant with respect to others) is an essential factor to reduce data transfer frequency. Hence the selection of RVF in L1CH election is an optimal choice to increase CH lifetime and minimize data transfer frequency.

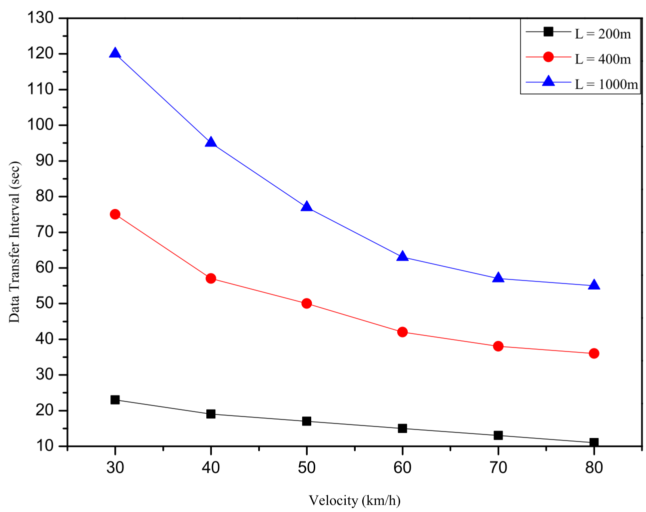

FIGURE 7. Impact of velocity on data transfer interval.

B. IMPACT OF CONNECTIVITY FACTOR ON L1CH SELECTION

Link connectivity directly impacts the performance of contents distribution. Let R be the transmission range of vehicle's antennas (LTE-V standard) and d be the distance between two vehicles. Since contents distribution will be successful only when all the vehicles are connected. The probability of link breakage $P_{LB}(N)$ can be calculated as

$$P_{LB}(N) = \begin{cases} 1, & \text{if } 2d \geq R \\ 1-(1-e^{-\rho R}), & \text{Otherwise} \end{cases} \tag{6}$$

where N is the number of vehicles selected for content distribution. Since a packet can be lost due to either collisions or link breakage. Thus packet loss probability can be calculated as

$$P(N) = P_{LB}(N) + P_L(N) - P_{LB}(N) * P_L(N) \tag{7}$$

where $P_L(N)$ is the packet loss probability due to link breakage. Figure 8 shows the packet loss probability with different link loss probability. It is shown that packet loss probability increases with link loss probability. Hence link connectivity is an excellent factor to define the performance of contents distribution.

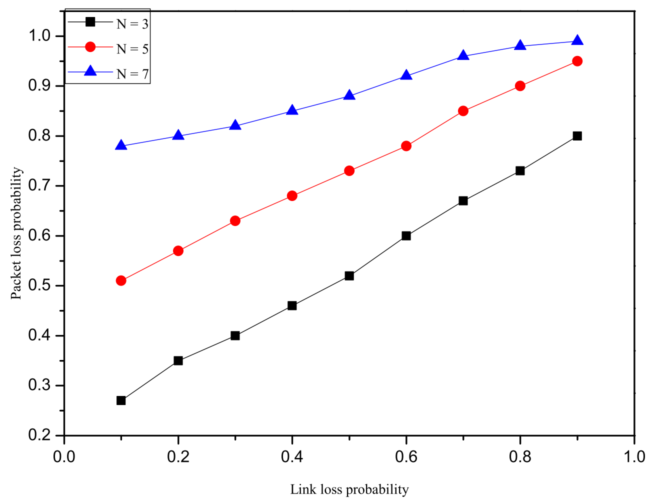

FIGURE 8. Impact of link connectivity loss probability over packet loss probability.

C. IMPACT OF LINK RELIABILITY (PROBABILITY OF V2V LINK DURATION) ON L1CH SELECTION

Let d_0 be the initial distance between two vehicles, then V2V link duration will be

$$f(\Delta v\tau) = \frac{1}{\sigma\tau.\sqrt{2\pi}} e^{-\frac{(\Delta v\tau - \mu\tau)^2}{2\sigma^2\tau}} \tag{8}$$

where $\Delta v\tau \approx N(\mu\tau, \sigma^2\tau)$, $\mu = \mu_A - \mu_B$ and $\sigma^2 \approx \sigma_A^2 + \sigma_B^2$. Let the vehicles are in straight line, where the inter-vehicle distance is divided into $2n+1$ regions, and state $D_i(i = 1, 2, \ldots 2n+1)$ is defined as the i^{th} region. The first 2n states $D_i(i = 1, 2, \ldots 2n)$ are of the same length $\varepsilon(\varepsilon = \frac{R}{n})$. Therefore the probability of communication duration can be calculated as

$$Pro\{d_k \epsilon D_j | d_{k-1} \epsilon D_i, X = x\} = p_{ij} = \int_{(j-i)\varepsilon - x}^{(j-i+1)\varepsilon - x} f(x)dx \tag{9}$$

The probability of V2V link disconnection duration will be

$$Pro\{T_{LLD}^{A-B} \geq p_{ij}\} = 1 - \int_{(j-i)\varepsilon-x}^{(j-i+1)\varepsilon-x} f(x)dx \quad (10)$$

where T_{LLD}^{A-B} is the link disconnection duration between vehicle A and B. The analytical and Monti Carlo simulation results are shown in Figure 9, which shows that link duration decreases with the increase of initial inter-vehicle distance. Hence we can say that the probability of link duration, i.e link reliability depends on initial inter-vehicle distance. Figure 9 also depicts that our theoretical model accurately defines the relationship between link duration and inter-vehicle distance.

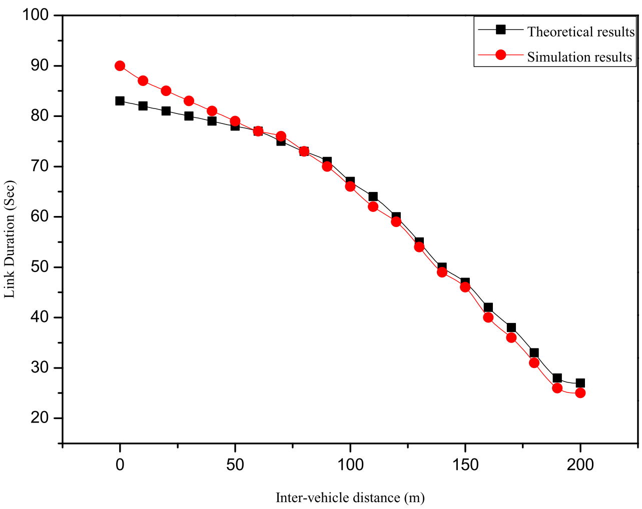

FIGURE 9. Impact of initial inter-vehicle distance on link duration.

VI. SIMULATION RESULTS AND DISCUSSION

In the simulation scheme, a freeway road of length 2km with three lanes is considered with random arrival of vehicles. The illustration of freeway scenario with 100-500 nodes is done with the help of traffic simulators, i.e. Simulation of Urban MObility [34] (SUMO 0.25.0, SUMO 0.12.0), and MObility model generator for VEhicular networks (MOVE (v2.9)) [35]. Next, the SUMO traffic traces are passed as an input to the proposed two-layer cluster scheme in MATLAB(R2015b). The Nakagami propagation model is used with the same parameters as used by Wu *et al.* [4]. The numbers of LTE BSs are set to 3. The detailed V2X and 5G LTE parameters are given in Table 1 and Table 2.

In the simulation, two types of experiments are performed.

1) *Experiment A:* The proposed two-level clustering scheme is computationally analyzed with CQL and IQL.
2) *Experiment B:* The proposed scheme performance is evaluated under the various number of vehicles, speeds, and LTE bandwidth.

In Experiment A, two performance metrics, i.e. No of iterations and Route Request Messages (RRMs) are used to measure the computational overhead.

TABLE 2. V2X simulation parameters.

Neighbor ID	Information
Simulation Time	300s
Number of Vehicles	100-500
Number of Pedestrians	3
SL V2V range	500m
No's of Hops	3
Vehicle's Speed	40-100 km/h
Pedestrian's Speed	3 km/h
Uplink packet size	20 bytes
Downloading packet size	50 bytes
Vehicle Mobility Model	V2X Mobility Model
Pedestrians Mobility Model	Random Walk 2d Mobility Model

TABLE 3. 5G LTE simulation paramentes.

Neighbor ID	Information
eNodeB Scheduler Type	PfFfMacScheduler (default)
eNodeB Transmission Range	7 km
Pathloss Model	Friis Propagation Model
LTE Mobility Model	Constant Position Mobility Model

No. of iterations (Convergence time): refers to the number of repetitions in the discovery of an appropriate L2CH. The iterations in the discovery of gateway also refers to the convergence of learning algorithm.

Route Request Messages (RRMs): refers to the number of request messages in the discovery of a route to L2CH.

In Experiment B, the proposed clustering scheme is compared with two others schemes [4], [23]. The schemes as mentioned above are closely related to our proposed scheme. The detail description of both schemes are described in section I. Three performance metrics are used in experiment B, i.e. throughput, the number of gateways and number of V2V routes changes to CH.

Throughput: It represents the amount of data successfully transferred from source vehicle to destination vehicle in a given period which is typically measured in Megabits per second (Mb/s).

The number of gateways/L2CHs: It represents the number of gateways to LTE BS in a given cluster under different number of vehicles. The MMZ [23] protocol is not evaluated with this metric due to the absence of gateways concept.

The number of V2V route changes to CH: refers to the number of V2V route changes due to the instability of selected CH.

A. COMPUTATIONAL OVERHEAD ANALYSIS

Here IQL (Proposed Scheme) and CQL based clustering schemes are analyzed with respect to the number of iterations (convergence time) and route request messages (RRMs). In both cases, the numbers of iterations are measured in the discovery of L2CHs under the different number of vehicles. The performance in Figure 10 shows that IQL is performing very well in appropriate L2CH discovery. Due to the Boolean locks variables, the convergence time of IQL reduced significantly as compared to CQL. Since the updates are done only in case of best actions only, that's why the computational overhead reduced in IQL based clustering scheme.

The line graph in Figure 10 also shows that convergence increases with the increased number of vehicles. In case of large number of vehicles, the number of possible actions also increase, which causes a large number of iterations. In IQL, with the increasing number of vehicles, the number of Boolean locks also increases.

Secondly, IQL based RRMs are measured under the different number of agents and compared with CQL RRMs as shown in Figure 11. It is shown in Figure 11, that IQL has less number of discovery messages because of the Boolean locks. In IQL, actions are taken only in best available choices in Q-Table.

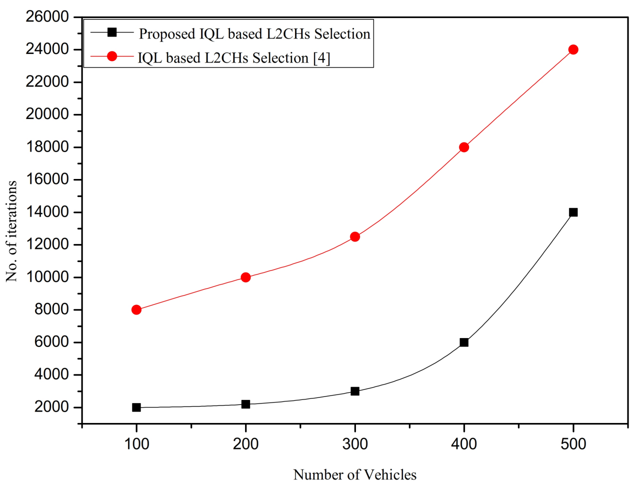

FIGURE 10. Number of iterations (Convergence) with respect to various number of vehicles.

B. PERFORMANCE UNDER DIFFERENT NUMBER OF VEHICLES

In this part, the throughput and number of gateways/L2CHs are analyzed under the various number of vehicles.

First, throughput is analyzed with respect to various vehicle densities. The LTE bandwidth is set to 100 Mbps for the entire vehicular topology. It is shown in Figure 12, that the throughput has an inverse relation with the number of vehicles for all schemes. The increasing number of vehicles cause a throughput decrease. With the increasing number of nodes, the number of L2CHs are also increased on available

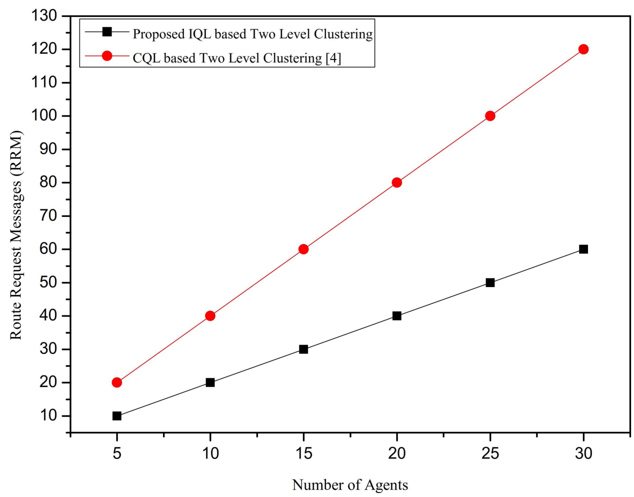

FIGURE 11. Number of route discovery messages under various number of agents (number of states n = 4).

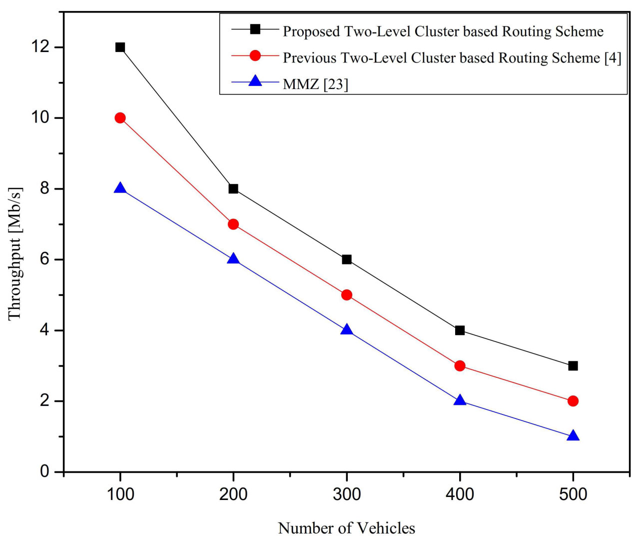

FIGURE 12. Throughput with respect to various number of vehicles (Vehicles speed 80km/h).

LTE's bandwidth. It is shown that when the vehicle density is large, LTE can not achieve good throughput due to the small bandwidth allocation. Which explains the importance of 3GPP V2V communications. Our proposed clustering scheme outperforms than previous schemes [4], [23] because of the IQL [27], optimum L1CHs selection based on novel factors (Relative Velocity, K-connectivity, Link Reliability) and the adaptation of 3GPP V2V interfaces. MMZ and previous two-level clustering schemes use the hybrid architecture of DSRC and LTE. Where IEEE 802.11p MAC contention issue reduced the throughput significantly as compared to SL V2V/3GPP V2V connections (used in the proposed scheme).

Secondly, the association between the number of vehicles and the number of gateways/L2CHs is also analyzed and shown in Figure 13. Normally with the increase of the gateways/L2CHs, the available LTE's bandwidth decreases.

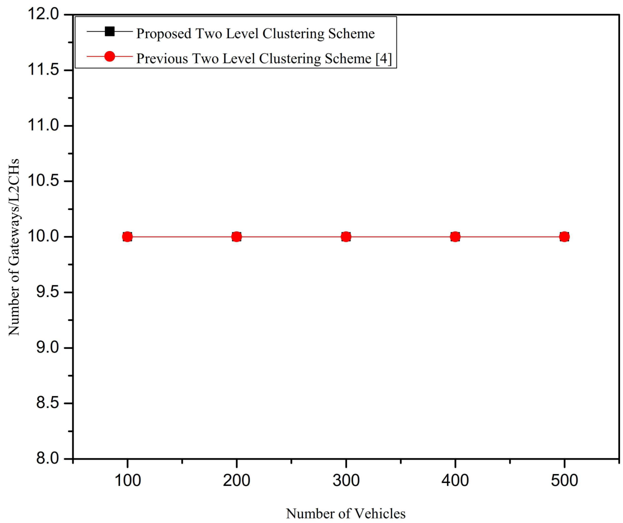

FIGURE 13. Number of gateways/L2CHs with respect to various number of vehicles (Vehicles speed 80km/h, Proposed and Previous [4] overlapped).

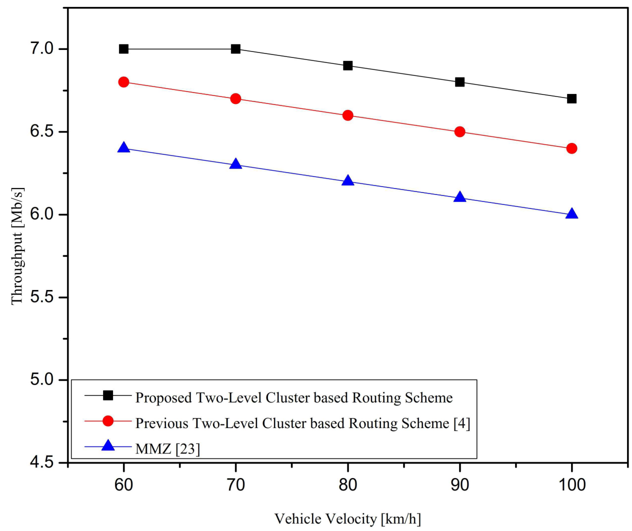

FIGURE 14. Throughput with respect to various speeds (Number of vehicles = 200).

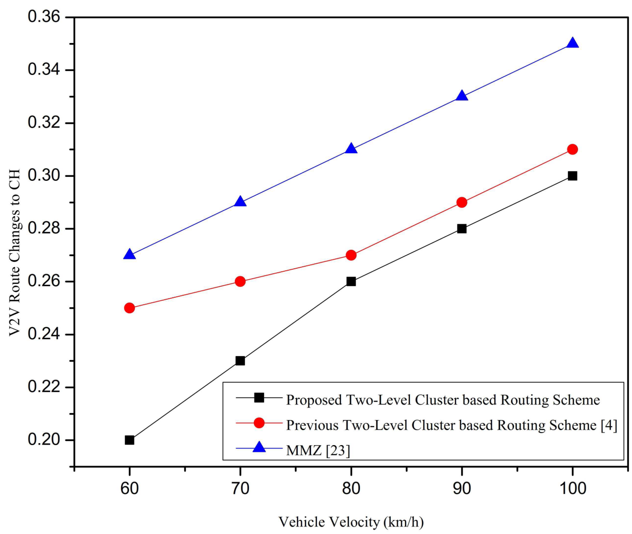

FIGURE 15. Number of route changes with respect to various speeds.

But on the other hand, the route quality between non-gateway and gateway/L2CH (V2V link) increases. In Figure 13, the proposed and previous schemes are overlapped with each other. Since both the schemes are using the same deep learning approach (Q-Learning), that's why the results are the same. The only difference in gateway selection in our proposed scheme is the use of improved Q-learning, which reduces the iterations in L2CH selection. Since only one LTE BS is considered among three LTEs, that's why the number of gateways/L2CHs are fixed even in very high vehicular traffic. In a large number of vehicles, the V2V communications will cause bottleneck problem in previous two-level clustering scheme. The MMZ protocol is not considered here due to the absence of the gateways factor.

C. PERFORMANCE UNDER DIFFERENT SPEEDS

Figure 14 shows the throughput of proposed, previous [4] and MMZ schemes [23] under various speeds. The results show the importance of IQL [27], SL V2V/3GPP V2V and proposed new factors as compare to previous two-level clustering scheme [4] and MMZ [23]. From results, we can say that connectivity and link reliability are the core parameters in the selection of consistent and stable CH selection. The connectivity factor selects a stronger connected node among the vehicular topology's members. Similarly, the reliability factor selects a robust CH to the vehicle's speed. Also, the IQL reduces the iterations and performs the re-selection of L2CH quickly in case of large mobile topology. Since 3GPP V2V outperforms than IEEE 802.11p [36]. That's why our proposed scheme outperforms than DSRC based MMZ and previous two-level clustering scheme.

Secondly, Figure 15 shows V2V route changes under various speeds. Since we considered vehicle speed, link connectivity and link reliability (probability of link duration) in L1CH selection, hence all the cluster members are quite similar to each other, and the probability of V2V route changes significantly reduced. Since we used SL V2V links, whose reliability and connectivity are far better than conventional DSRC based V2V, that's why the probability of route variation in our proposed scheme is quite less than MMZ and previous two-level clustering scheme.

D. PERFORMANCE UNDER VARIOUS LTE BANDWIDTHS

In this subpart, throughput is analyzed under various LTE bandwidths. Here 500 vehicles are considered. Since both previous [4] and proposed schemes are using Q-Learning approach, hence both are efficiently utilizing the LTE bandwidth by tuning an appropriate number of gateways.

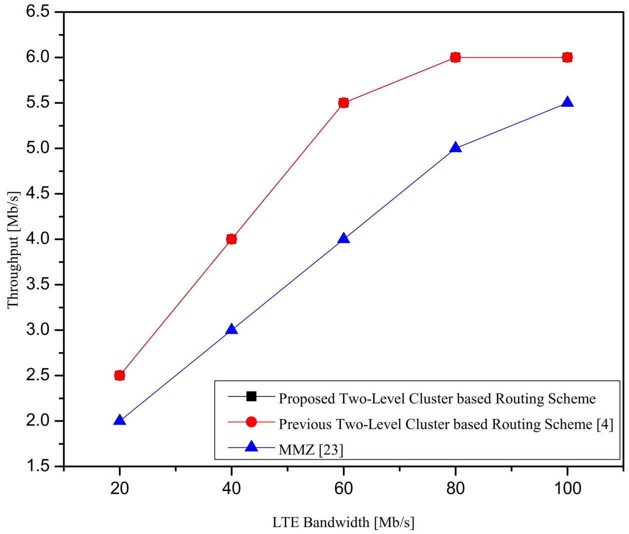

FIGURE 16. Throughput with respect to various LTE bandwidth (previous [4] and proposed schemes overlapped).

In Figure 16, it is shown that both of the schemes having the same throughput, it is because of the same number of gateways in both schemes. Our proposed scheme selects L2CHs from stable and consistent L1CHs; hence it efficiently utilizes both V2V and V2I bandwidth. Since MMZ is different than our proposed scheme in the context of CH selection and V2V interfaces, that's why its throughput is less than our proposed scheme. MMZ has no feature to tune the number of gateways for LTE's bandwidth utilization.

VII. CONCLUSION

In this paper, a two-level cluster based routing scheme is proposed for efficient data dissemination in a vehicular network. The first layer is done with the help of Fuzzy logic approach, where three well-known metrics (Relative Velocity Factor (RVF), K-Connectivity Factor (KCF) and Link Reliability Factor (LRF)) are passed to select a stable and consistent cluster head. The connectivity factor selects a stronger connected node among the vehicular topology's members. Similarly, the reliability factor selects a robust CH to the vehicle's speed. Secondly, Improved Q-Learning is used in the second layer clustering, which not only reduces the computational cost but also tunes the number of gateways to LTE BS to achieve good performance. Through simulations, we concluded, that proposed clustering scheme achieves good performance than previous schemes in various scenarios, especially achieving good throughput in high-density vehicular network scenarios. The proposed scheme performed very well in many dimensions, but in case of high dense topology, there will be many agents and actions for IQL, which will lead to excessive iterations in gateway discovery. Secondly, we also paid a cost in the form of time complexity by calculating temporal connectivity, and reliability.

REFERENCES

[1] J. Wang, C. Jiang, Z. Han, Y. Ren, and L. Hanzo, "Internet of vehicles: Sensing-aided transportation information collection and diffusion," *IEEE Trans. Veh. Technol.*, vol. 67, no. 5, pp. 3813–3825, May 2018.

[2] C. Wu, Z. Liu, D. Zhang, T. Yoshinaga, and Y. Ji, "Spatial intelligence toward trustworthy vehicular IOT," *IEEE Commun. Mag.*, vol. 56, no. 10, pp. 22–27, Oct. 2018.

[3] J. Wang, C. Jiang, L. Gao, S. Yu, Z. Han, and Y. Ren, "Complex network theoretical analysis on information dissemination over vehicular networks," in *Proc. IEEE Int. Conf. Commun. (ICC)*, May 2016, pp. 1–6.

[4] C. Wu, T. Yoshinaga, X. Chen, L. Zhang, and Y. Ji, "Cluster-based content distribution integrating LTE and IEEE 802.11p with fuzzy logic and Q-learning," *IEEE Comput. Intell. Mag.*, vol. 13, no. 1, pp. 41–50, Feb. 2018.

[5] K. Abboud, H. A. Omar, and W. Zhuang, "Interworking of DSRC and cellular network technologies for V2X communications: A survey," *IEEE Trans. Veh. Technol.*, vol. 65, no. 12, pp. 9457–9470, Dec. 2016.

[6] X. Zhang, X. Cao, L. Yan, and D. K. Sung, "A street-centric opportunistic routing protocol based on link correlation for urban vanets," *IEEE Trans. Mobile Comput.*, vol. 15, no. 7, pp. 1586–1599, Jul. 2016.

[7] L. Zhu, C. Li, B. Li, X. Wang, and G. Mao, "Geographic routing in multilevel scenarios of vehicular ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 65, no. 9, pp. 7740–7753, Jun. 2016.

[8] J. Cheng, J. Cheng, M. Zhou, F. Liu, S. Gao, and C. Liu, "Routing in Internet of vehicles: A review," *IEEE Trans. Intell. Transp. Syst.*, vol. 16, no. 5, pp. 2339–2352, Oct. 2015.

[9] B. Masini, A. Bazzi, and A. Zanella, "A survey on the roadmap to mandate on board connectivity and enable V2V-based vehicular sensor networks," *Sensors*, vol. 18, no. 7, p. E2207, 2018.

[10] J. Wang, C. Jiang, K. Zhang, T. Q. Quek, Y. Ren, and L. Hanzo, "Vehicular sensing networks in a smart city: Principles, technologies and applications," *IEEE Wireless Commun.*, vol. 25, no. 1, pp. 122–132, Feb. 2018.

[11] H. Seo, K.-D. Lee, S. Yasukawa, Y. Peng, and P. Sartori, "LTE evolution for vehicle-to-everything services," *IEEE Commun. Mag.*, vol. 54, no. 6, pp. 22–28, Jun. 2016.

[12] Y. Ren, F. Liu, Z. Liu, C. Wang, and Y. Ji, "Power control in D2D-based vehicular communication networks," *IEEE Trans. Veh. Technol.*, vol. 64, no. 12, pp. 5547–5562, Dec. 2015.

[13] E. Uhlemann, "Initial steps toward a cellular vehicle-to-everything standard [connected vehicles]," *IEEE Veh. Technol. Mag.*, vol. 12, no. 1, pp. 14–19, May 2017.

[14] N. Bonjorn, F. Foukalas, and P. Pop, "Enhanced 5G V2X services using sidelink device-to-device communications," in *Proc. 17th Annu. Medit. Ad Hoc Netw. Workshop (Med-Hoc-Net)*, Jun. 2018, pp. 1–7.

[15] M. H. Eiza, T. Owens, and Q. Ni, "Secure and robust multi-constrained QoS aware routing algorithm for VANETs," *IEEE Trans. Depend. Sec. Comput.*, vol. 13, no. 1, pp. 32–45, Jan. 2016.

[16] X. M. Zhang, K. H. Chen, X. L. Cao, and K. S. Dan, "A street-centric routing protocol based on microtopology in vehicular ad hoc networks," *IEEE Trans. Veh. Technol.*, vol. 65, no. 7, pp. 5680–5694, Jul. 2016.

[17] K. Liu, J. K. Y. Ng, V. C. S. Lee, S. H. Son, and I. Stojmenovic, "Cooperative data scheduling in hybrid vehicular ad hoc networks: VANET as a software defined network," *IEEE/ACM Trans. Netw.*, vol. 24, no. 3, pp. 1759–1773, Jun. 2016.

[18] D. Lin, J. Kang, A. Squicciarini, Y. Wu, S. Gurung, and O. Tonguz, "MoZo: A moving zone based routing protocol using pure V2V communication in VANETs," *IEEE Trans. Mobile Comput.*, vol. 16, no. 5, pp. 1357–1370, May 2017.

[19] C. Cooper, D. Franklin, M. Ros, F. Safaei, and M. Abolhasan, "A comparative survey of VANET clustering techniques," *IEEE Commun. Surveys Tuts.*, vol. 19, no. 1, pp. 657–681, 1st Quart., 2017.

[20] A. A. Khan, M. Abolhasan, and W. Ni, "An evolutionary game theoretic approach for stable and optimized clustering in VANETs," *IEEE Trans. Veh. Technol.*, vol. 67, no. 5, pp. 4501–4513, May 2018.

[21] S. Ucar, S. Ergen, and O. Ozkasap, "Multihop-cluster-based IEEE 802.11p and LTE hybrid architecture for VANET safety message dissemination," *IEEE Trans. Veh. Technol.*, vol. 65, no. 4, pp. 2621–2636, Apr. 2016.

[22] M. F. Feteiha and H. S. Hassanein, "Enabling cooperative relaying VANET clouds over LTE-A networks," *IEEE Trans. Veh. Technol.*, vol. 64, no. 4, pp. 1468–1479, Apr. 2015.

[23] Z. Khan and P. Fan, "A multi-hop moving zone (MMZ) clustering scheme based on cellular-V2X," *China Commun.*, vol. 15, no. 7, pp. 55–66, Jul. 2018.

[24] H. Zhou, X. Wang, Z. Liu, Y. Ji, and S. Yamada, "Resource allocation for SVC streaming over cooperative vehicular networks," *IEEE Trans. Veh. Technol.*, vol. 67, no. 9, pp. 7924–7936, Sep. 2018.
[25] F. Abbas, P. Fan, and Z. Khan, "A novel low-latency V2V resource allocation scheme based on cellular V2X communications," *IEEE Trans. Intell. Transp. Syst.*, to be published, doi: 10.1109/TITS.2018.2865173.
[26] S. M. Shah and V. S. Borkar, "Q-learning for Markov decision processes with a satisfiability criterion," *Syst. Control Lett.*, vol. 113, pp. 45–51, Mar. 2018.
[27] A. Konar, I. G. Chakraborty, S. J. Singh, L. C. Jain, and A. K. Nagar, "A deterministic improved Q-learning for path planning of a mobile robot," *IEEE Trans. Syst., Man, Cybern. Syst.*, vol. 43, no. 5, pp. 1141–1153, Sep. 2013.
[28] Z. Khan, P. Fan, and S. Fang, "On the connectivity of vehicular ad hoc network under various mobility scenarios," *IEEE Access*, vol. 5, pp. 22559–22565, 2017.
[29] M. H. Eiza and Q. Ni, "An evolving graph-based reliable routing scheme for VANETs," *IEEE Trans. Veh. Technol.*, vol. 62, no. 4, pp. 1493–1504, May 2013.
[30] R. Molina-Masegosa and J. Gozalvez, "LTE-V for sidelink 5G V2X vehicular communications: A new 5G technology for short-range vehicle-to-everything communications," *IEEE Veh. Technol. Mag.*, vol. 12, no. 4, pp. 30–39, Dec. 2017.
[31] S. B. Cruz, T. E. Abrudan, Z. Xiao, N. Trigoni, and J. Barros, "Neighbor-aided localization in vehicular networks," *IEEE Trans. Intell. Transp. Syst.*, vol. 18, no. 10, pp. 2693–2702, Oct. 2017.
[32] H. Zhou, S. Xu, D. Ren, C. Huang, and H. Zhang, "Analysis of event-driven warning message propagation in vehicular ad hoc networks," *Ad Hoc Netw.*, vol. 55, pp. 87–96, Feb. 2017.
[33] C. Shao, S. Leng, Y. Zhang, A. Vinel, and M. Jonsson, "Analysis of connectivity probability in platoon-based vehicular ad hoc networks," in *Proc. Int. Wireless Commun. Mobile Comput. Conf. (IWCMC)*, Aug. 2014, pp. 706–711.
[34] M. Behrisch, L. Bieker, J. Erdmann, and D. Krajzewicz, "Sumo–simulation of urban mobility: An overview," in *Proc. 3rd Int. Conf. Adv. Syst. Simulation (SIMUL)*, vol. 14, 2011, pp. 63–68.
[35] F. J. Martinez, C. K. Toh, J.-C. Cano, C. T. Calafate, and P. Manzoni, "A survey and comparative study of simulators for vehicular *ad hoc* networks (VANETs)," *Wireless Commun. Mobile Comput.*, vol. 11, no. 7, pp. 813–828, 2011.
[36] G. Cecchini, A. Bazzi, B. M. Masini, and A. Zanella, "Performance comparison between IEEE 802.11p and LTE-V2V in-coverage and out-of-coverage for cooperative awareness," in *Proc. IEEE Veh. Netw. Conf. (VNC)*, Nov. 2017, pp. 109–114.

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