QoS-enabled Group Communication in Integrated VANET-LTE Heterogeneous Wireless Networks

Rajarajan Sivaraj*, Aravind Kota Gopalakrishna†, M. Girish Chandra‡, P. Balamuralidhar§

Embedded Systems Innovation Lab,
Tata Consultancy Services,
Bangalore, India.
rsivaraj@ucdavis.edu*, get.aravindkg@gmail.com†, {m.gchandra‡,balamurali.p§}@tcs.com

***Abstract*—Ubiquitous integration of high-speed WLANs with wide-range 3GPP systems results in the service extension of the backbone cellular network. This paper envisions such heterogeneous wireless network architecture by integrating IEEE 802.11p VANETs with 3GPP LTE to achieve seamless data connectivity for uninterrupted multimedia sessions amongst spatially-apart vehicular clusters. Issues on cluster head-based multicasting and QoS are explored in this paper. An adaptive multi-metric Cluster Head (CH) election mechanism is proposed to manage the VANET sub-clusters. In addition to this, construction of a 2-hop virtual overlay mesh-based shared multicast tree for lower-level multicasting within VANETs is discussed. Following this, the process of VANET-LTE upper-level communication is detailed, addressing the issues of CH and gateway handover, and resource allocation of the LTE eNB. The envisioned architecture enables the LTE to effectively schedule multimedia sessions based on the service requirements of the VANET gateways, thus satisfying QoS. Requisite simulation results are presented to evaluate the integrated network.**

***Keywords*-VANET; LTE; Group Communication; Gateway Candidates; Cluster Head; Mesh topology; Shared tree; QoS;**

I. Introduction

Recent research in wireless networking has been focusing upon the heterogeneous integration of IEEE 802.11-based wireless ad hoc networks with 3GPP cellular networks, as in [1], [2]. One such example is integrating Universal Mobile Telecommunication Systems (UMTS) with Vehicular Ad hoc Networks (VANET), as discussed in [1]. It provides anytime, anywhere seamless data access to vehicles due to the service extension of the 3G network. It, thereby, aims to cater to the next-generation group communication service applications such as video conferencing, mobile TV etc. over vehicles. Vehicular communication has been gaining a great momentum in the academic and industrial fronts. Toyota has come forward with the design of an LTE-connected car and Intel, with a WiMax-connected car, for deploying cloud-based and monitoring applications, respectively.

IEEE 802.11p, an enhanced version of the IEEE 802.11 family for Wireless Access in Vehicular Environments (WAVE), providing 5.9 GHz bandwidth with data rates between 6 Mbps and 27 Mbps, is used in VANETs. The Federal Communications Commission has allocated spectrum for Inter-Vehicle Communications (IVC). Though the rates of the VANET-UMTS integrated network are higher, they still pose significant challenges for deploying delay-sensitive multimedia applications, requiring high bandwidth. On the other hand, 3GPP Long Term Evolution (LTE) provides uplink and downlink data rates of atleast 50 Mbps and 100 Mbps respectively, and a round-trip time interval of around 10 ms.

A. *Existing issues in heterogeneous wireless networks*

The prominent issue in such integrated networks revolves around the selection and management of vehicular gateway nodes, which act as liaisons between the IEEE 802.11p-based VANETs and 3GPP LTE. But, the vehicles do not exhibit identical characteristics(Eg. Vehicles could travel in different directions), and so, it is challenging for the gateways to reach out to them. One of the approaches used to address this issue is to form clusters of vehicles, based on similar vehicular characteristics and choose Cluster Heads (CH) for each cluster, which could eventually become gateways [1]. Though clustering is a good mechanism to address this problem, the cluster head election process was based only on the geographic position of the vehicles for a lower TTL value, in [1]. This could result in the cluster heads not possessing the essential credentials to manage the VANET clusters and to enable them communicate with the LTE backhaul, especially when it comes to group communication.

The common modes of multicasting include a mesh-based and a tree-based multicasting. While mesh-based multicasting is more scalable, it always yields to significant overhead affecting the performance of the VANET. Whereas a tree could

Manuscript created June 10, 2011, revised August 4, 2011. This work was fully supported by TCS Innovation Labs, research division of Tata Consultancy Services Ltd., and was carried out in TCS Embedded Systems Innovation Lab, Bangalore, India.

Mr. Rajarajan Sivaraj* was a researcher at TCS Innovation lab, Bangalore, India. He currently is a Ph.D student in Computer Science at the University of California, Davis, USA.

Mr. Aravind Kota Gopalakrishna† was a researcher at TCS Innovation Lab, Bangalore, India. He is currently a Ph.D Candidate at Eindhoven University of Technology, the Netherlands.

Dr. M. Girish Chandra‡ is a senior scientist at TCS Innovation Lab, Bangalore, India.

Mr. P. Balamuralidhar§ is the head of TCS Innovation Lab, Bangalore, India

reduce the amount of overhead, it is not robust as a mesh. In a dynamic scenario, both robustness as well as limited overhead are essential requisites because of the need to sustain the inter-connectivity with the LTE backhaul, in spite of the network dynamics. Identifying the traffic profiles of different VANET groups for service and scheduling prioritization by the LTE for end-to-end group communication is another relevant issue.

B. Contributions of the paper

Our paper addresses the above-identified issues by the following key contributions:

1) **Devising a QoS-enabled VANET-LTE integrated architecture** : For end-to-end communication between spatially-apart VANET groups through the LTE, we devise a VANET-LTE heterogeneous network architecture, incorporating the relevant QoS components.
2) **Proposing a multi-metric CH election mechanism** : Here, we identify the essential metrics from the perspectives of both the VANET and LTE for a vehicle within a cluster to act as the CH.
3) **Incorporating a dynamic mesh-based multicast tree** : To incorporate a dynamic mesh-based multicast tree, combining the robustness of a mesh and the scalability of a tree, for lower-level communication amongst VANET groups.

The remainder of the paper is structured as follows. The envisioned VANET-LTE integrated network architecture is described in Section II. Section III delineates the methodology of dynamic clustering for grouping vehicles and proposes a Cluster Head (CH) election mechanism. Section IV discusses multicasting in the integrated network and addresses the related QoS issues. The performance of the proposed mechanisms is evaluated in Section V. The paper concludes in Section VI with a brief on the future research directions.

II. Proposed VANET-LTE Heterogeneous Wireless Network Architecture

The envisioned QoS-based VANET-LTE integrated network architecture is shown in Fig 1. The topology depicts two spatially-apart roads with a VANET existing in each of them. The vehicles in the VANETs are equipped with IEEE 802.11p radio interfaces. Further, each road has two different tracks, corresponding to the direction of movement of vehicles. An LTE Evolved Node B (eNB) base station transceiver is deployed alongside each road, and the two VANETs are assumed to be under the coverage region of different eNBs. The Evolved Universal Terrestrial Radio Access Network (E-UTRAN) interface enables the vehicles communicate to the eNB so as to access the core components of the LTE [3].

The main purpose of our paper is to perform an effective group communication between the spatially-apart VANETs through the backhaul LTE network, making the best use of E-UTRAN and eNB resources. Optimal end-to-end group communication requires effective lower-level multicasting within VANETs and upper-level communication with the LTE eNB. The architecture focuses on dynamic clustering and cluster head election mechanisms to achieve this. Referring to the architecture shown in Fig 1, the region within the LTE eNB's coverage, where the LTE received signal strength is intense, is termed as the 4G active region. Vehicles in the VANET, which are lying in or moving into the 4G active region and equipped with the E-UTRAN interface , are termed as the Gateway Candidates (GWCs). The E-UTRAN interface is enabled on the GWCs. Rest of the vehicles that are either not instantaneously present in the 4G active region or unequipped with LTE E-UTRAN interfaces are termed as Ordinary Vehicles (OVs). The E-UTRAN interface is either absent or disabled on them. Dynamic clustering is performed on the GWCs, resulting in individual GWC sub-clusters with a Cluster Head (CH), present in each of them. In group communication scenarios, multi-casting within VANETs is controlled and co-ordinated by the CHs. A minimum number of gateways (GWs) are adequately elected out of them. Only the GWs are activated with their E-UTRAN interfaces to communicate with the LTE eNB. The QoS requirements of the multicast sessions are handled by the four modules: SACM, PPM, GWMM and SCMM, detailed in Section IV. Based on these requirements, the LTE eNB multicasts data to more than one GW, which shall further multicast data to the intended destination vehicles. It is to be noted that the 4G active region is only a portion of the entire coverage boundary of the LTE eNB.

III. Proposed Cluster Head Election Mechanism

For group communication to be carried out, it is essential for the vehicles to be dynamically clustered, according to different relevant metrics, as discussed in [1]. The metrics used here include the vehicular direction of movement, LTE Received Signal Strength and IEEE 802.11p wireless transmission range. Dynamic clustering is performed using the above metrics, in order. Clustering is followed by the process of election of a Cluster Head (CH) for each sub-cluster. But, the CH election, proposed here, involves the IEEE 802.11p transmission rate, the LTE Uplink/Downlink Channel Quality Indication (CQI) and the relative distance metrics of the GWCs, unlike in [1], where the GWC closest to the center of the sub-cluster deems itself as the CH.

The transmission rate, which is the net bit rate of the GWC at the link with the minimum channel capacity, is a critical factor for the CH in team multicasting. A good transmission rate indicates a higher link capacity across the channel. Similarly, the CQI value in the LTE E-UTRAN channel is a reflection of the Signal-to-Interference-plus-Noise Ratio (SINR) across the communication channel. By this, both the topological as well as physical layer paradigms are involved in the CH election process. As stated in [1], in each sub-cluster, the leading edge GWC is identified by the absence of GWC neighbors behind it and the trailing edge GWC is identified by the absence of GWC neighbors before it. The total number of hops between these border edge GWCs' is termed as the hop length of the sub-cluster. A HELLO packet broadcast is initiated by the leading-edge GWC within the sub-cluster and after the broadcast, the GWC possessing the

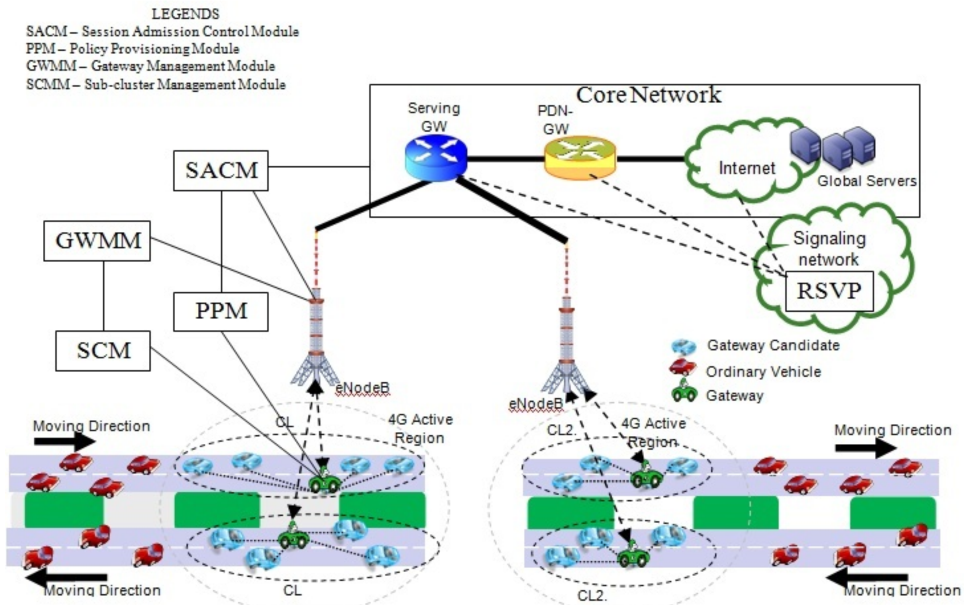

Fig. 1. Envisioned QoS-enabled VANET-LTE integrated network architecture

maximum weight, computed as detailed in [4], is notified and elected as the CH. Following are the fields in the HELLO packet:

- TS : Current Time stamp of the broadcast packet
- ID : Relative identity of the GWC within the sub-cluster. The leading and trailing edge GWCs are identified as GWC_1 and GWC_n , where n denotes the size of the sub-cluster.
- W : Net weight of the GWC
- DEG : One-hop neighborhood degree of the GWC
- GWC_{max} : Structure of the GWC with the maximum weight within the sub-cluster (till the current time stamp)
  - GWC_{id} :Relative identity of the GWC_{max}
  - D_r :Relative hop Distance from the leading-edge GWC
  - T_x_Rate :IEEE 802.11p transmission rate of GWC_{max}
  - CQI_{eNB} :Uplink / Downlink Channel Quality Indication value of the LTE eNB in the GWC_{max}
  - W_{id} : Net weight of the GWC_{max}
  - Hop dist: Hop distance from GWC_{max} to the GWC
- Link State: Structure of the one-hop neighbors to the GWC, with total number matching value in DEG field
  - NB_{id} - Relative ID of the neighbor GWC
  - W_{id} : Net weight of the neighbor GWC

The procedure for the CH election is given in Algorithm 1. The ACK packet piggybacked from each GWC_i comprises the following fields in addition to the TS, ID and GWC_{max} fields as in HELLO packet.

- GWC_{disc} - List of discarded GWCs within the sub-cluster
  - GWC_{id} - Relative identity of the GWC discarded
  - W_{id} - Weight of the GWC discarded
  - Hop dist - Hop distance from the current GWC_i
- Position - Location information of the current GWC_i
  - GPS co-ordinates (x, y, z)
  - Angle of Inclination with respect to Cartesian Space (Θ)
  - Velocity of the current GWC_i (ν)
  - Link Expiration Time (LET) with the sender

The elected CHs periodically broadcast CH Advertisement (CHADV) within the sub-cluster. The list of discarded GWCs in the ACK packet is to prevent re-transmission of control packets by these GWCs, reduce computational complexity in comparing the weights and thereby forbidding these GWCs from contesting the CH election.

The packet structures for the HELLO is in Fig. 2 (a). Here, basically, each GWC, within the sub-cluster, starting from the leading-edge GWC (GWC_1) broadcasts its parameters, and computes its weight based on the parameters. It also keeps track of the GWC with the maximum weight (GWC_{max})and indicates its metrics in the HELLO packet. Initially, GWC_{max}=GWC_1. So as to enable every GWC maintain its two-hop information, the HELLO packet also includes information of the one-hop neighbors of the source, to which it sends an ACK packet, and forwards it to the next-hop. This maintenance of two-hop information is essential for the construction of the virtual mesh as indicated in the next section. When the HELLO packet reaches the trailing-edge GWC and after its metric comparisons are carried out, the CH is elected as the GWC with the maximum weight. A notification NOTIFY_{CH} is sent out, starting from the trailing-edge GWC. Once the GWC with the maximum weight receives it, it deems itself to be the CH of that sub-cluster. Following this, it computes the TTL and broadcasts the CHADV within the sub-cluster.

Algorithm 1 CH_ELECTION: Cluster Head Election Procedure

Initiate HELLO packet broadcast by GWC_1.
Assign the hop dist field of the GWC_{max} structure to 0 and the remaining fields to the corresponding values of GWC_1.
Assign NB_{id} and W_{id} to NULL.
for all one-hop neighbor GWC_i receiving HELLO **do**
    Compare D_r, T_x Rate and CQI_{eNB} metrics of GWC_{max} with those of GWC_i (X_{ij}) and determine maximum of each metric as max(D_r), max(T_x_Rate) and max(CQI_{eNB}), where $1 \leq j \leq 3$
    Compute the scaled value (Y_{ij}) of each metric as (D_r/max(D_r), T_x_Rate/max(T_x_Rate), CQI_{eNB}/max(CQI_{eNB})).
    Determine weight (W_i) of each GWC_i as

$$W_{ij} = \sum_{j=1}^{3} (Y_{ij} * PRIORITY\_FACTOR_j) \quad (1)$$

    Assign W_i to field W of the current GWC_i
    if $W_i > W_{id}$ of GWC_{max} **then**
        Assign the GWC_{id}, D_r, T_x_Rate, CQI_{eNB} and W_{id} fields of GWC_{max} with the respective values of GWC_i.
        Assign hop dist field value of GWC_{max} to 0.
    else
        Increment hop dist field value of GWC_{max} by 1
    end if
    Assign NB_{id} and W_{id} of Link State field to the sender of the current GWC_i
    Piggyback ACK to the sender GWC and notify the list of discarded GWCs.
    Update the Link State field of the previous relaying neighbor with the corresponding ID and W values of the current GWC_i
    Forward HELLO packet with updated metric information to the one-hop neighbor(s) of GWC_i
    if ACK is received **then**
        Forward neighbor ACK packet to sender GWC.
    end if
    if GWC_i is the trailing edge GWC **then**
        Send $NOTIFY_{CH}$ packet to GWC_{max} using the Time-To-Live (TTL) value, equal to the value in hop dist field.
        exit for
    end if
end for
if GWC_{max} receives $NOTIFY_{CH}$ **then**
    Compute the TTL value of the CH as in [1]
    Broadcast Cluster Head Advertisement (CHADV) within the sub-cluster
end if

As every GWC relays the HELLO packet, it also acknowledges receipt of the HELLO packet back to its sender. The ACK comprises the set of GWCs, discarded from the GW election, which could include the senders as well, if their weight is not the maximum at that point of time. This is to forbid them from participating in the CH election, which reduces the overhead from these GWCs. The ACK packet also contains information of the current GWC_{max}. Its packet structure is shown in Fig. 2 (b).

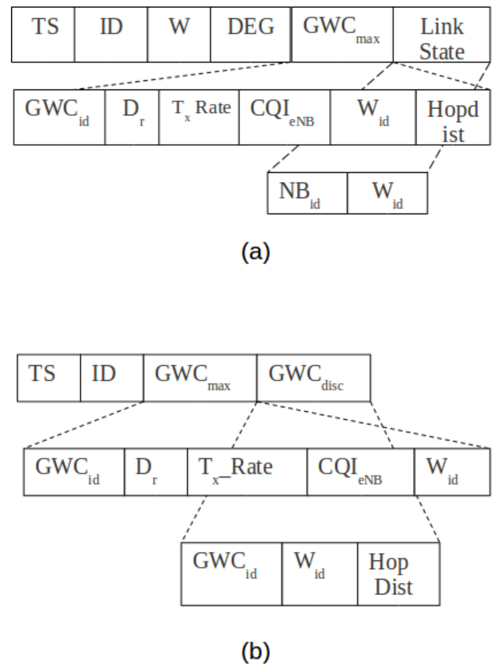

Fig. 2. HELLO and ACK packet structures

IV. Multicasting and QoS in the Integrated Network

Referring to the architecture in Fig 1, end-to-end multicasting in the integrated network takes place at two levels: upper-level communication between LTE eNB and VANET CHs, and lower-level multicast within VANET sub-clusters.

A. Low-level Multicasting

For intra-cluster group communication, this paper discusses a mechanism to construct a virtual overlay 2-hop mesh within each sub-cluster and build a shared multicast tree using it. Construction of a multicast tree is centralized and results in good efficiency with low overhead. On the other hand, a distributed mesh is more robust and scalable with alternate routes for managing link failures. The advantages of both these procedures are clubbed in the proposed mechanism. The virtual mesh is constructed during the process of CH election, discussed earlier. When a HELLO packet is relayed by a GWC, it encapsulates the link state information of its sender GWCs within the packet. So, the next receiving GWC deciphers information about the current GWC's senders. On receiving the ACK packet, the current GWC pads information about the receiver to the ACK and transmits it back to the sender. Thus, a two-hop link state information is available for each GWC, from which, it maintains a partial mesh view of the sub-cluster, using its unicast tunnels.

The virtual mesh topology is shown in Fig 3. It precisely shows the ID, weight and hop distance values of the link state neighbors of each GWC. Thus, an adequate TTL value of 2 is configured for every GWC within the sub-cluster, so as to be communicable up to its 2-hop mesh members. For every pre-defined time stamp interval, the topological changes, if any, are updated in the mesh table. Once the underlying mesh is constructed, by then, the HELLO packet would have been broadcast within the entire sub-cluster and the GWC with the maximum weight would have been determined. The trailing edge GW candidate transmits notification to the GWC with the maximum weight, electing it as the CH. A core-based multicast shared tree [5], [6] is constructed, rooted at the CH, such that the communication between the GWCs and CH is bidirectional. The CH is designated as the rendezvous point, and controls and co-ordinates group communication within the sub-cluster. Using the unicast tunnels of the underlying mesh with high LET, the shared tree connects all the members of the multicast group with the CH. The CH is configured with a TTL value, equal to the maximum number of hops between the leading and trailing edge GWCs with the CH, as in [1], so that the CH is communicable with all the GWCs within the sub-cluster.

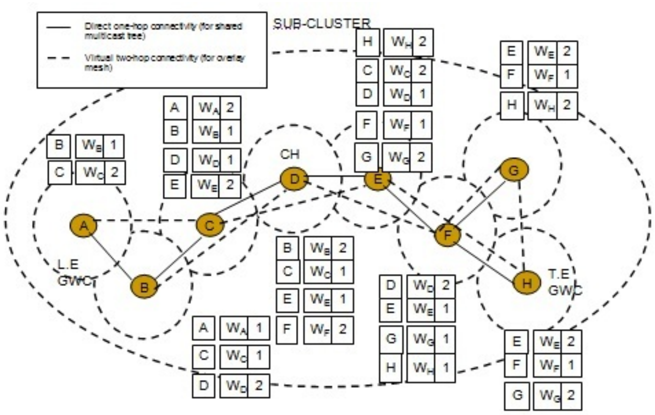

Fig. 3. 2-hop link state information for virtual mesh topology

Let $V_1(i)$ and $T_1(i)$ denote the 1-hop neighborhood set for GWC_i in the underlying virtual mesh and the shared tree. Let $V_2(i,j)$ denote the 2-hop mesh neighborhood set for GWC_i via GWC_j. Let $\chi_{in}(x)$ denote the incoming one-hop tree neighborhood set of a GWC, say x. Once the CH is selected, the CH initiates the construction of tree using the virtual mesh. For the CH, initially, $T_1 = V_1$. The procedure for the establishment of links in the shared multicast tree from the underlying mesh is described in Algorithm 2. The idea behind the algorithm is that a GWC should determine with which GWCs, its one-hop tree neighbors should establish an edge, from its 2-hop mesh view. That is, if j and m, neighbors of i, are at one-hop with x, then i determines which GWC, between j and m, should have an edge with x, by comparing Link Expiration Time between j and x; LET_{jx} with LET_{mx}. It follows a Breadth First Search (BFS) strategy by means of which all edges are established for each GWC in the sub-cluster. This results in the construction of the shared tree. The time complexity taken by a GWC to directly determine its tree neighbors and establish an edge with them is $O(n^2)$.

Algorithm 2 CONSTRUCT_EDGE: Establishment of edges for construction of shared multicast tree

for all $j \in T_1(i)$ **do**
  for all $x \in V_2(i,j)$, where $\chi_{in}(x) = \emptyset$ **do**
    if $x \in V_2(i,m)$, where $m \in T_1(i)$ **then**
      if $LET_{jx} \geq LET_{mx}$ **then**
        Construct an edge (j,x) in the multicast tree.
        $T_1(j) = T_1(j) \bigcup \{x\}$
      end if
    else
      Construct an edge (j,x) in the multicast tree.
      $T_1(j) = T_1(j) \bigcup \{x\}$
    end if
  end for
  Forward $T_1(j)$ to j.
end for

B. QoS-enabled Upper-level VANET-LTE communication

After the CHs of different sub-clusters are elected, each vehicular source elects its respective Gateway (GW) from the available CHs using the GW selection mechanism, discussed in [1]. However, the metrics used here include IEEE 802.11p transmission rate and CQI_{eNB} of the CHs, along with their mobility speed and Route Expiration Time (RET) with the sources. The Hybrid Gateway Discovery mechanism, detailed in [1], notifies the sources about the elected GWs. The E-UTRAN interfaces of the GWs are activated to enable communication with the LTE eNB. This section addresses critical issues of CH/GW handover and LTE resource allocation to schedule GWs.

As a first step, a domain-level hierarchical multicasting approach, as discussed in [7], is followed in which, the GWs serve as the sub-roots for communication between the source and destination VANET sub-clusters. When the existing gateway loses its optimality, a gateway handover mechanism as proposed in [1] is initiated. But here, the optimality check is performed for the IEEE 802.11p transmission rate, CQI_{eNB} and RET metrics. The E-UTRAN interface of the serving GW is de-activated and the newly-elected GW registers with the LTE eNB. A similar handover is subjected to CH by checking its optimality for CQI_{eNB}, IEEE 802.11p T_x rate and D_r metrics. If the vehicles in the destination group are GWCs, they are identified by their respective CHs, designated as their serving GWs. But, if the destination vehicles are OVs, there are a few cases to be observed, based on service level agreements.

Case 1: When the destination OVs are already aware of their participation in the multicast sessions

In this case, the OVs identify the instantaneous CHs using the hybrid discovery mechanism by broadcasting CH solicitation messages.

Case 2: When the destination OVs are unaware of their participation in the multicast sessions

Here, the CH discovery is purely pro-active as the CHs periodically broadcast their advertisement messages with appropriate metrics within the destination VANET.

In both these cases, when the destination OVs receive metrics simultaneously from more than one CHs, they select their respective gateways out of these CHs, as discussed above. After selection, they communicate to the respective GWs, which add them to their multicast group. A virtual mesh view of the multicast group, as discussed above, is maintained by the CH to facilitate effective group communication with the destination vehicles. However, the OVs are not a part of the sub-cluster. Then, the elected GWs will have their E-UTRAN interface activated to communicate with the backhaul LTE network. The Multicast Broadcast Multimedia Services (MBMS) is a feature of the 3GPP LTE [8], the subscription of which could be activated by the GWs. The MBMS enables the same multimedia content to be transmitted to different GWs on a point-to-multipoint (p-t-m) basis, if the vehicles of the same destination group are handled by more than one GW by sprawling over more than one sub-cluster. LTE scheduling for the purposes of resource allocation to GWs is another concerned issue because the number of GWs keeps varying across different time instances. So, the bandwidth for each GW should be dynamically, yet effectively, allocated. In view of the same, this paper proposes a DiffServ-based QoS framework, as discussed in [9]. The framework, as in Fig 1, comprises 4 modules:

1. Policy Provisioning Module (PPM) - Handles priority requirement of the multicast sessions on the GW side
2. Session Admission Control Module (SACM) - Decides session admission/drop based on the requirements of the GW.
3. Sub-Cluster Management Module (SCMM)-Manages vehicular mobility, multicast mesh maintenance and resources within the VANET sub-cluster.
4. GW Management Module (GWMM) - Reserves and manages resource for GWs on the LTE eNB side.

The LTE-SAE traffic classes include Conversation Voice, Conversational, Streaming, Interactive and Background, as detailed in [8]. The GW decides the QoS requirements for the multicast session. Based on the requirements, the PPM sets the subscription profile of the sub-cluster. The QoS metrics include delay, jitter, packet error rate and loss ratio, and throughput and are decided by the LTE eNB by differentiating its services based on the priority of the following parameters:

- Number of destination vehicles to be served (n_d)
- Net Bandwidth required for each GWC (β)
- Number of multimedia sessions to be served (n_s)

The SACM module on the side of the LTE eNB is interfaced with the PPM to schedule sessions. If n_d is to be given more priority for the LTE, then the SACM module prioritizes session admission for the GW with the maximum cluster size or multicast group size. This requirement could serve for Interactive and Background classes. If β is given more priority, then the SACM module admits session for that GW, which serves less number of vehicles, so that the available net bandwidth for an individual vehicle is more. The traffic classes served as a result include Conversation and Streaming, as they are delay-sensitive, requiring higher individual bandwidth. On the other hand, if n_s should be prioritized, then the appropriate traffic class is Streaming and the GW having the highest downlink CQI_{eNB} and IEEE 802.11p transmission rate will be prioritized, since these parameters reflect good end-to-end group communication.

V. Results and Discussions

The simulations of the proposed mechanisms in an integrated VANET-LTE network environment have been carried out in Network Simulator NS2.34. A source and destination VANET, each comprising of 50 vehicles, along with the LTE E-UTRAN and core network are considered in topographical area of 8000x1000m^2, for a simulation time of 200s. The standards of IEEE 802.11p-based Wireless Access for Vehicular Environments (WAVE), discussed in [10], are utilized for vehicular communication amongst vehicles (V2V) or between vehicles and internet gateways (V2I). The Manhattan mobility model is considered to model the vehicular traffic. Protocol for Unified Multicasting through Announcements (PUMA), detailed in [11], is used for multicasting over VANETs. Packet size of 1 KB, suited for multimedia data transfer, is used. Simulation of LTE Access and Core Networks, and its integration with IEEE 802.11p network interface is carried out using Multi-Interface Cross Layer Extension for NS2 (NS-MIRACLE), as discussed in [12]. Configuration of the LTE E-UTRAN and core network is referred from [3], [8], [13]. The performance of the integrated network for Group Communication purposes is evaluated in terms of Data Packet Delivery Ratio (DPDR), Packet Error Rate (PER), Delay and Throughput metrics. The DPDR and throughput metrics generally decrease, whereas the PER and delay metrics increase with the increase in the number of multicast sessions and participating vehicles. The dynamic clustering, reflecting the CH and GW management mechanisms, is iteratively carried out every second. The mechanism proposed in this paper is dubbed as Clustered Virtual Mesh-based Tree (CMVT). PUMA routing protocol is used to evaluate the performance of CVMT and it is compared with the standard PUMA multicasting (without CVMT) and simultaneous AODV unicasting over CMGM [1] in VANETs. Equal priorities are given for all the concerned metrics for the CH election as well as CH/GW management functionalities.

In Fig 4, the DPDR for the three protocols is evaluated against the number of on-going multicast sessions in the integrated network. Each multicast session is considered to compose of a maximum of two vehicular sources. DPDR for PUMA over our proposed CVMT shows an average of 6.49% increase over DPDR for standard PUMA and 16.91% increase over DPDR for simultaneous AODV unicasts using CMGM. The good performance of PUMA over CVMT is attributed to the effective management of sub-clusters by the respective CHs. Further, the CVMT is scalable as well as efficient in handling dynamic topologies and the CH/GW handovers sustain inter-connectivity with the backbone LTE network. Fig 5 shows the PERs of the three routing protocols as against the IEEE 802.11p wireless transmission range of vehicles. PER is taken as the fraction of the net data rates (max. 27 Mbps) of the vehicles, due to packet errors, measured in Mbps. On an average, PUMA over CVMT shows a 4% decrease in PER compared to the standard PUMA and around 20.32% decrease, compared to simultaneous AODV unicasts using CMGM. Shorter transmission ranges result in more number of VANET sub-clusters and the subsequent generation of larger number of control packets results in the unwanted consumption of the available bandwidth. Packet drops and hence, the error rates increase. Lower PER values in PUMA over CVMT is also attributed to the robustness of the virtual mesh and the lower overhead of the shared multicast tree.

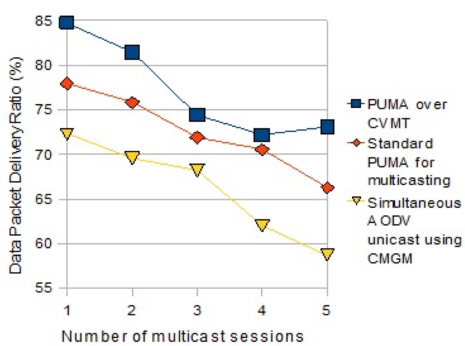

Fig. 4. Performance of the three protocols in terms of DPDR for varying number of multicast sessions.

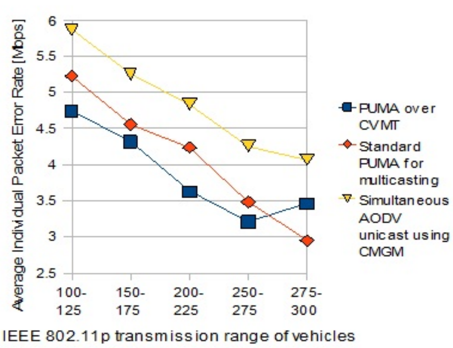

Fig. 5. Packet Error Rates for different average IEEE 802.11p wireless transmission ranges.

In Fig 6, the time elapsed since the broadcast of GWSOL/GWADV messages till the point of establishment of a path from the vehicular sources to the gateways is plotted for varying number of VANET sub-clusters. PUMA over CVMT shows 10.45% more delay than AODV over CMGM and around 8.95% less delay compared to standard PUMA multicasting. This is because of the higher amount of delay accounted for multicasting due to communication with more than one vehicle within the group. However, by dynamic and stable connectivity, CVMT reduces the latency for PUMA, compared to the standard PUMA for VANET multicasting.

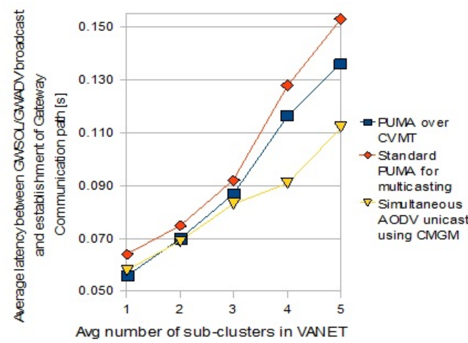

Fig. 6. Delay involved in establishment of communication path from the vehicular sources to the elected gateways after broadcast of GWSOL/GWADV.

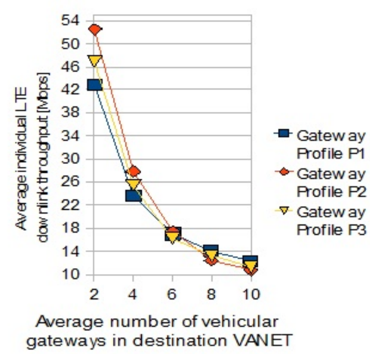

Fig. 7. Performance of the average downlink LTE throughput for varying number of vehicular gateways in destination VANET.

In Fig 7, the average LTE downlink throughput is measured against the number of vehicular gateways in the destination VANET, by varying the session priorities of the gateway. Profiles P1, P2 and P3 indicate the priority requirements of the gateway and these profiles are mapped on to the QoS classes of the LTE for scheduling purposes. Referring to section IV, the following are the policy requirements of the profiles.

Profile P1 : (n_d = 0.5, β = 0.3, n_s = 0.2),

Profile P2 : (n_d = 0.2, β = 0.5, n_s = 0.3) and

Profile P3 : (n_d = 0.3, β = 0.2, n_s = 0.5)

Mapping the gateway's priorities to the QoS profiles of the LTE eNB, P2 indicates an improvement of 3.65% over P1 and 3.71% over P3, indicating the emphasis given to bandwidth (Conversational and Streaming classes) requirement of the vehicular gateways. From the graphs, different priority policies of the gateways are effectively handled, thereby giving a good

QoS guarantee. Further, the total delay in the LTE uplink and downlink communication with VANET gateways is also determined and is practically found to be around 15 ms, which is an acceptable round trip latency value for delay-sensitive multimedia applications.

VI. Conclusion and Future Research Directions

This paper envisioned a novel VANET-LTE integrated architecture to provide multimedia communication services over spatially-apart vehicular groups. An effective cluster head election mechanism is proposed to effectively manage VANET sub-clusters. Following this, a virtual 2-hop overlay mesh-based shared tree for lower-level VANET multicasting is proposed. Upper-level multicasting dealt with concepts of CH/GW handover and discussed a QoS framework for the LTE eNB to schedule and serve the VANET gateways. The simulation results demonstrated that the integrated system shows acceptable values in terms of LTE throughput and end-to-end delay, thereby indicating an improved performance. As future work, further research is in progress towards exploring the capabilities of the MBMS feature of the LTE and incorporation of appropriate Erasure Correction Codes, as the latter are very useful candidates for robust multicasting to arrive at an enhanced scheme to support QoS.

References

[1] A. Benslimane, T. Taleb, and R. Sivaraj, "Dynamic clustering-based adaptive mobile gateway management in integrated VANET - 3G heterogeneous wireless networks." *IEEE Journal on Selected Areas in Communications*, vol. 29, no. 3, pp. 559–570, March 2011.

[2] R. Manoharan, R. Sivaraj, S. Sashtinathan, and K. Sriram, "A novel multi-hop B3G architecture for adaptive gateway management in heterogeneous wireless networks," in *Proc. 5th IEEE WiMob 2009*, Marrakech, Morocco, October 2009.

[3] D.M-Sacristan, J.F.Monserrat, J.C-Penuelas, D.Calabuig, S.Garrigas, and N.Cardona, "On the way towards fourth-generation mobile: 3GPP LTE and LTE-Advanced," *EURASIP Journal on Wireless Communications and Networking*, vol. 2009, p. 10, 2009.

[4] F. Setiawan, S. Bouk, and I. Sasase, "An optimum multiple metrics gateway selection mechanism in MANET and infrastructured networks integration," in *Proc. IEEE WCNC 2009*, Las Vegas, NV, March 2009.

[5] C. Gui and P. Mohapatra, "Overlay multicast for MANETs using dynamic virtual mesh," *Wireless Networks*, vol. 13, no. 1, pp. 77–91, May 2006.

[6] A.Benslimane and O.Moussaoui, *Hierarchical Multicast Protocols with Quality of Service*. WILEY, January 2010, ch. 2.

[7] C. Gui and P. Mohapatra, "Scalable multicasting in mobile ad hoc networks," in *Proc. IEEE INFOCOM 2004*, Hong Kong, March 2004.

[8] E.Dahlman, S.Parkvall, J.Skold, and P.Beming, *3G Evolution - HSPA and LTE for Mobile Broadband*. Academic Press, 2008.

[9] X.G.Wang, G.Min, J.E.Mellor, K.Al-Begain, and L.Guan, "An adaptive QoS framework for integrated cellular and WLAN networks," *Computer Networks*, vol. 47, no. 2, pp. 167–183, August 2004.

[10] T. Murray, M. Cojocari, and H.Fu, "Measuring the performance of IEEE 802.11p using ns-2 simulator for vehicular networks," in *Proc. IEEE Int'l Conf. on Electro/Information Technology (EIT)*, Ames, IA, May 2008.

[11] R.Vaishampayan and J.J.Garcia-Luna-Aceves, "Efficient and robust multicast routing in mobile ad hoc networks," in *Proc. IEEE Int'l Conf. on Mobile Ad-hoc and Sensor Networks*, Florida, USA, October 2004, pp. 304–313.

[12] N. Baldo, F. Maguolo, M. Miozzo, M. Rossi, and M. Zorzi, "ns2-MIRACLE: a modular framework for multi-technology and cross-layer support in network simulator 2," in *Proc. 2nd International Conference on Performance Evaluation Methodologies and tools*, Nantes, France, October 2007, pp. 1–8.

[13] Q. Qiu, J.Chen, L. Ping, Q. Zhang, and X. Pan, "LTE/SAE model and its implementation in NS2," in *Proc. 5th IEEE Int'l Conf. on Mobile Ad-hoc and Sensor Networks 2009*, Fujiyan, China, December 2009, pp. 299–303.