Improved Multi-hop Routing in Integrated VANET-LTE Hybrid Vehicular Networks

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ABSTRACT

The VANET-LTE integration offers many potential advantages for vehicular networks such as high data rates, low latency and extended communication range. However, utilizing these advantages requires novel protocols and algorithms at each layer of the networking protocol stack. In this paper, we propose a location-based routing scheme for hybrid vehicular networks that exploits availability of multiple radio access technologies i.e., IEEE 802.11p supported ad hoc and LTE enabled cellular connectivity. Each vehicle periodically transmits link update information to the neighboring vehicles and remote routing server through both interfaces while maintaining forwarding information towards the reachable destinations. For non-reachable destinations route requests are send to the remote routing server which then calculates the route and send route updates to all the intermediate vehicles on the path. The simulation based study shows that the proposed routing scheme considerably improves the packet delivery ratio and achieves lower delay while significantly reducing the communication overhead.

Categories and Subject Descriptors
C.2.2 [Computer Communication Networks]: Network Protocols, Routing protocols

General Terms
Algorithms, Design, Performance

Keywords
VANET, LTE, IEEE 802.11p, Routing

1. INTRODUCTION

In Vehicular Ad hoc Networks (VANETs) multi-hop communications is performed by several intermediate vehicles which relay messages between the source-destination pairs. This can be achieved by employing different routing and forwarding approaches such as Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I) or hybrid communication [1]. The challenging task is to deliver data reliably with lower delay and control message overhead. Moreover, VANETs are large-scale networks deployed over metropolitan-wide area, thus scalability of communication scheme should also be considered. Since, reliability, scalability, delay and communication efficiency are often considered conflicting in nature, existing algorithms cater for only subset of these requirements [2].

While IEEE 802.11p [3] is considered the de facto standard for VANET communications, many endorsed the idea of incorporating different communication technologies like LTE by 3GPP [4] for performance improvements. Following the widespread support by research consortium like C2C-CC [5] and standardization bodies such as ETSI [6] a number of feasibility studies have been conducted to evaluate the performance of HSUPA [7], UMTS [8], Mobile WiMAX [9] [10] and LTE [11] [12] [13] [14] [15] [16] [17] in vehicular networks. Most of these studies concluded to combine the best from IEEE 802.11p and cellular network standards. To this end, a number of communication protocols have been proposed. These include 3G cellular network enabled data delivery [18] and smartphone based data dissemination [19] [20]. LTE and 3G assisted clustering algorithms [21] [22] [23] [24], hybrid approach for providing location services [25], topology control [26] for efficient broadcasting [27] and routing protocol [28] in vehicular ad hoc networks.

In Mobile-Gateway routing protocol (MGRP) [28] the data messages are delivered to the nearest mobile gateway which then transfers the data to the gateway controller over the cellular network. The gateway controller relays the data to another mobile gateway closer to the destination. Finally, the mobile gateway vehicle transmits the data to the destinations via IEEE 802.11p enabled links. To achieve higher...
delivery ratio, a large number of mobile gateway vehicles has to be present in the network. Route discovery and maintenance overhead increases as the mobile gateways moves at higher speed throughout the network. Moreover, all routes are requested from the gateway controllers.

In this paper, a location-based routing scheme for VANET-LTE integrated hybrid vehicular networks is proposed. It is assumed that each vehicle is equipped with a dual-interface On-Board Unit (OBU) which is capable of switching between multiple radio access technologies (RAT) [29]. Each vehicle periodically sends Neighbor Link Metric (NLM) information and its location updates to the immediate neighboring vehicles and remote routing server using the cellular network infrastructure. Depending on the availability, the assistance from infrastructure can be in the form of Roadside Units (RSUs) or base station (eNodeB in LTE) connected to the internet either through RSU gateway or LTE Radio Access Network (RAN), respectively. Upon receiving the data message, each vehicle first checks whether the destination is reachable through local neighbor table and forwarding table lookups. If the destination is not reachable, then a route request is generated to the remote routing server. The remote routing server calculates the route on-the-fly and updates the forwarding tables at each vehicle on the routing path. Availability of multiple radio access technologies (RAT) in vehicle’s communication system takes the control packet overhead for route construction and maintenance off the ad hoc networks. Moreover vehicles are required to maintain the local forwarding information only while the extended routing information is located at a remote server and shared with the vehicle in on-demand fashion. The scheme is also particular useful because most of the Cooperative Awareness (CA) applications require messages to be transmitted in close proximity of the source vehicles. Moreover, sharing link delay and mobility contextual information with a remote routing server results in better/near-optimal routing decisions. Finally, the forwarding technique can be implemented independent of the routing strategy.

The performance of the proposed routing scheme is compared against GPSR [30] and AODV [31] routing protocols. The simulation results show that the proposed routing scheme delivers 13% and 25% more data messages in comparison with GPSR and AODV, respectively with significantly lower delay and communication overhead.

The rest of the paper is organized as follows. Section 2, describes the proposed routing scheme over the VANET-LTE integrated architecture. In Section 3, performance of the proposed routing scheme is evaluated using simulations and compared against GPSR and AODV routing protocols. Finally, Section 4 concludes the paper.

2. MULTI-HOP ROUTING OVER VANET-LTE INTEGRATED VEHICULAR NETWORK

The VANET-LTE integrated reference architecture combines both IEEE 802.11p enabled vehicular ad hoc network and the infrastructure-based LTE cellular network. Each vehicle is equipped with a dual-interface On-Board Units (OBU) which allows both Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communications. Whereas Road-side Units (RSU) are deployed V2I communication can be performed over IEEE 802.11p interface. Alternatively, existing mobile network infrastructure such LTE/4G cellular network is used to connect to the internet and to the remote routing server. For this purpose the OBU must be capable of selecting appropriate radio access technology. It is also assumed that each vehicle is capable obtaining its GPS location and estimate movement contextual information such as velocity, direction etc. In addition all vehicles are required to be time synchronized using GPS.

2.1 Link Discovery and Neighbor Table Construction

During the network operational lifetime, Neighbor Link Metric (NLM) messages are transmitted at both interfaces. Each vehicle exchanges the NLM messages among its one-hop neighboring vehicles by broadcasting in V2V fashion whereas NLM packets are delivered to a remote routing server via LTE or RSU gateway infrastructure in V2I manner. The NLM message format consists of following information, \{Address, GPS Location, Neighbor List \{Address, ULDelay, GPS Location\}\}.

On receiving the NLM messages each vehicle stores and updates a local neighbor table. The local neighbor table stores information on immediate neighboring vehicles and the information on neighbor’s neighbor. Similarly, remote routing server also maintains the information provided within the NLM messages at the global or multi-cell scale and later uses this information for route path calculation and selection. While exchanging the NLM messages, link delay metric information is also estimated and stored locally and shared globally with the routing server. The link delay metric information is directional i.e., both uplink and downlink delays i.e., ULDelay and DLDelay are stored separately. This information can be exchanged among neighboring vehicles without the need of a direct response. On receiving the NLM message from vehicle \(i\), vehicle \(j\) extracts the uplink delay metric information \(ULDelay_{ij}\) from the NLM message, whereas the downlink delay metric \(DLDelay_{ij}\) is calculated using the following equation.

\[
DLDelay_{ij} = interval - (recvTime_j - currentTime) \tag{1}
\]

The local neighbor table holds the following information. \{Address, GPS Location, ReachableNeighborList \{Address, DLDelay, GPS Location\}, ULDelay, DLDelay\}.

2.2 Forwarding Table Construction

The integrated VANET-LTE network configuration enables functional split between routing and forwarding. This in turn helps in optimizing and implementing the routing decisions independent of the forwarding strategy. In addition to the neighbor table each vehicle also maintains a forwarding table with a single forwarding entry for each reachable destination. The entries in the forwarding table are of the format \{Destination Network Address, Nexthop Address, Expiration Time\}.
The procedure for route discovery and dissemination consists of the following steps.

1. **Destination Network Address:** Network address of a vehicle to which the data messages are finally delivered. (also the destination address).

2. **Nexthop address:** Address of the next vehicle in the routing path towards the final destination.

3. **Expiration Time:** Time duration after which the forwarding entry is considered stale and discarded from the forwarding table.

The forwarding table is dynamically updated either when the forwarding entry expires or by the remote routing server when there is a change in the routing path. When a vehicle has data message to send, it looks up the forwarding table to determine the next hop towards the final destination.

### 2.3 Route Discovery and Dissemination

The procedure for route discovery and dissemination consists of the following steps.

1. The source vehicle first searches for the destination in its local neighbor table. The local neighbor table contains information on all the reachable vehicles at two-hop distance. If the destination is found then it calculates the shortest path towards the destination. In scenarios where there are multiple next hop candidate vehicles, then the neighboring vehicle with minimum uplink delay is selected.

2. If the destination is not found in the neighbor table then the forwarding table is checked for a valid entry. Once a route to the destination vehicle is found, it simple starts forwarding the messages to the next hop towards the final destination.

3. For the scenario where the destination lies beyond the reachable neighborhood with no valid entry in the forwarding table, the vehicle initiates the route request to the remote routing server.

4. On receiving the route request message, the routing server calculates the shortest path based on location between the source and the destination. The routing server transmits the route update messages to the source, destination and all the other intermediate vehicles on the selected path.

5. Once the route update message is received, vehicles on the path maintain a soft forwarding state. Each vehicle adds an entry into its forwarding table with the updated list of reachable destinations. Moreover, the route expiration time is set to some predefined constant value.

Algorithm 1 Routing over VANET-LTE Integrated Architecture

**Steps:**

1. **Step: Link update V → I, V → V** @ Vehicle
2. **if timerExpire = TRUE then**
3. **SENDLinkUpdate(address, location, neighborList)**
4. **end if**
5. **procedure** RECEVLINKUPDATE(address, location, neighborList)
6. **nbr.Address ← msg.address**
7. **nbr.Location ← msg.location**
8. **nbr.ReachableList ← msg.neighborList**
10. **nbr.ULDelayji ← msg.neighborList(j).DLDelayji**
11. **nbrTable.Update(nbr)**
12. **end procedure**

13. **Step: Forwarding and Route Request** @ Vehicle
14. **procedure** RECEVMESSAGE(addressDest, payload)
15. **if addressDest ∈ reachableNeighbors then**
16. **nextHop ← shortestPath(addressDest, delay)**
17. **else if addressDest ∈ forwardTable then**
18. **nextHop ← fwdTable.nextHop(addressDest)**
19. **sendMessage(nextHop)**
20. **else**
21. **SENDROUTEREQUEST(addressDest)**
22. **end if**
23. **end procedure**

24. **Step: Route Selection and Dissemination** @ Vehicle
25. **procedure** RECEVROUTEREQUEST(addressDest)
26. **intermediateList ← shortestPath(addressDest, loc)**
27. **SENDROUETUPDATE(intermediateList, addressDest)**
28. **end procedure**

29. **Step: Forwarding table update** @ Vehicle
30. **RECEVROUTEUPDATE(intermediateList, addressDest)**
31. **if myAddress ∈ intermediateList then**
32. **fwd.Destination ← msg.addressDest**
33. **fwd.nextHop ← msg.intermediateList.next()**
34. **fwdTable.Update(fwd)**
35. **end if**

Fig. 1, shows the VANET-LTE integrated reference architecture along with its constituent components and exemplifies the link discovery and route request/update, path construction and the data forwarding procedures among a source and the destination. A formal representation of the proposed routing scheme is given in Algorithm 1. In algorithm the route expiration time ($\alpha$) is set to 5 seconds.
Table 1: Simulation parameters and values for integrated VANET-LTE vehicular network.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Vehicles</td>
<td>200</td>
</tr>
<tr>
<td>Vehicle Average Speed</td>
<td>20 km/h</td>
</tr>
<tr>
<td>CAM Transmission Rate</td>
<td>10 packets/seconds</td>
</tr>
<tr>
<td>Transmission Power</td>
<td>22 dBm</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>175 m</td>
</tr>
<tr>
<td>Antenna Type</td>
<td>Omni-Directional</td>
</tr>
<tr>
<td>Simulation Area</td>
<td>2000m x 2000m</td>
</tr>
<tr>
<td>Road Network Layout</td>
<td>5 x 5 Manhattan grid</td>
</tr>
<tr>
<td>Simulation Duration</td>
<td>100 seconds</td>
</tr>
<tr>
<td>Packet Size</td>
<td>500 bytes</td>
</tr>
<tr>
<td>Number of eNodeB</td>
<td>1 eNodeB</td>
</tr>
<tr>
<td>MAC/PHY protocol</td>
<td>IEEE 802.11p, 18Mbps</td>
</tr>
<tr>
<td>LTE scheduler</td>
<td>Proportional Fairness</td>
</tr>
<tr>
<td>RB allocation</td>
<td>50 UL / 50 DL</td>
</tr>
<tr>
<td>Link update interval</td>
<td>1 seconds</td>
</tr>
<tr>
<td>Route expiration (α)</td>
<td>5 seconds</td>
</tr>
</tbody>
</table>

3. PERFORMANCE EVALUATION

In this section, performance evaluation of the proposed routing technique over VANET-LTE integrated hybrid network architecture is described. For this purpose the proposed routing protocol is evaluated against Greedy Perimeter Stateless Routing (GPSR) and Ad hoc On-Demand Vector (AODV) routing protocols. The simulation based study is conducted using ns-3 (Version 3.23) [32] network simulator. The simulation study explains the impact of number of sessions between randomly selected source-destination pairs on the communication performance. The performance is measured in terms of Packet Delivery Ratio (PDR), delay, and control message overhead.

3.1 Simulation Environment

The simulation setup consists of 200 vehicles moving within the simulation area of 2000m x 2000m. The simulation area is divided into 5 x 5 Manhattan grid road network topology where each grid is of 400m in length and width. The Simulation of Urban Mobility (SUMO) [33] is used to generate vehicular mobility traces which generates vehicular trips between randomly selected origins and destinations. Fig. 2 shows the road network layout and vehicular mobility used for creating the simulation scenario. To simulate VANET scenario IEEE 802.11p MAC/PHY is utilized with 22 dBm transmission power or 175m of communication range. Each vehicle transmits 500 bytes message using UDP based application. In order to simulate the LTE communication technology, the LENA [34] module in ns-3 is utilized. The Radio Access Network (RAN) consisted of a single eNodeB connected to the routing server or Remote Host (RH) via Evolved Packet Core (EPC) network with a single Serving Gateway/PDN Gateway (SGW/PGW) element. Table 1 summarizes the simulation parameter and their values used during the experiments.

3.2 Simulation Results

Fig. 3 shows the impact of number of sessions on packet delivery ratio. For all the routing schemes, as the number of session increases, the PDR decreases. Without assistance from the LTE infrastructure, GPSR and AODV protocol reliability decreases significantly as the number of communicating pairs are increased. As compared with GPSR and AODV, on average the proposed routing protocol delivers 13% and 25% more data messages. In the proposed protocol and GPSR, higher frequency of neighbor discovery messages also contributed towards attaining better performance.

Fig. 4 shows the delay as the number of sessions increases for all three routing schemes. The reason lies well in the way no-route to the destination scenario is handled by each of the evaluated routing scheme. In GPSR, this situation is handled by applying the right-hand rule which often results in path lengths longer than the optimal path length. Similarly in AODV the route acquisition latency increases as the number of generated session increases. In proposed scheme, the facts that the route requests are only send when the destinations lies beyond the local reachable neighborhood and that the assistance from the infrastructure which calculates near optimal paths results in significantly lower delays.

Fig. 5 shows the control message overhead in log-scale. While the proposed scheme and GPSR used same frequency to disseminate neighbor discovery messages in the local neighborhood, the neighbor link metric (NLM) updates and route requests to the remote routing server via cellular infrastructure results in excessive number of control messages like route request and reply to establish paths among the sources and the destinations. The communication overhead increases significantly as the number of generated sessions are increased along with network sizes.

4. CONCLUSION

In this paper, a location based routing scheme is proposed for integrated VANET-LTE hybrid vehicular networks. The
hybrid architecture enables functional split between routing decision and forwarding strategy so that both can be implemented and optimized independent of each other. In the proposed routing scheme maintaining local neighbor information and forwarding state results in fewer route request to be sent towards the remote routing server. This is very helpful in most of cooperative awareness applications where messages are destined within close proximity of the source vehicles. For this reason, links with minimum delays are selected to reach the near-by neighboring vehicles. For scenarios where route to destination is not available locally, remote routing server calculates the shortest path by taking into account current topology state. Finally, routing server transmits route updates to all vehicles on the path between the source and the destination. Simulation results shows that the proposed scheme performed significantly better in terms of packet delivery ratio, delay and control message overhead as compared with GPSR and AODV routing protocols.

5. ACKNOWLEDGMENTS
This work was made possible by NPRP Grant No.: 5-1080-1-186 from the Qatar National Research Fund (a member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

6. REFERENCES


