iCARII: Intersection-based Connectivity Aware Routing in Vehicular Networks

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Abstract—Vehicular Ad hoc Network (VANET) has been gaining the attention from the academic and industry communities due to the promising applications in road safety, traffic management and passenger comfort. However, the short vehicle-to-vehicle (V2V) communication range and the nature of vehicle mobility impose many challenges in packet routing and, accordingly, infrastructure-based applications, e.g., Internet access. For more reliable communication, automobile manufacturers have started the investigation to deploy cellular networks, such as LTE, to support in-car Internet access. In addition to the high communication cost to the end-user, using centric cellular networks for vehicular communication applications causes data explosion and network overload. A feasible solution is using VANETs for mobile data offloading when connectivity to infrastructure is guaranteed, which requires an efficient routing protocol with global connectivity awareness. In this paper, we propose a novel infrastructure-based, dynamic, and connectivity-aware routing protocol, iCARII, to enable infotainment applications and Internet access in an urban environment. iCARII aims to improve VANETs routing performance by enabling selecting roads with guaranteed connectivity and reduced delivery delay. Detailed analysis and simulation-based evaluations of iCARII demonstrate the significant improvement of VANET performance in terms of packet delivery ratio and end-to-end delay with a negligible cost of routing overhead.

I. INTRODUCTION

Enabling vehicular communication is an important goal of governments, standardization organizations, researchers and automotive industries, in order to achieve many social, environmental, and economic benefits expected from Intelligent Transportation Systems (ITS) applications. These applications support road safety, traffic management and passenger comfort through vehicle-to-vehicle (V2V) or vehicle-to-infrastructure (V2I) communication. Safety applications require direct updates to nearby vehicles to avoid accidents, while traffic management applications include sending updates to traffic centers via infrastructure. Passengers can also enjoy infotainment applications and Internet access via V2I communication [1].

In VANETs model, vehicles are equipped with on-board communication units (OBUs) to enable direct communication with other vehicles, and with roadside units (RSUs) installed along the roads as gateways to infrastructure. VANET has low cost deployment, and supports direct V2V communication. However, its short communication range and the nature of vehicle mobility result in an intermitted and short-lived V2I communication. Enabling multi-hop routing, by designing efficient routing protocols, can expand the network coverage. Nevertheless, the performance of the network highly rely on the existence of vehicles, which leads to unreliable networks. Thus, stakeholders investigate the deployment of Long Term Evolution (LTE) [2], [3] for V2I applications.

LTE is a promising cellular network that can support vehicular applications due to its large coverage, high data rate and low latency to mobile vehicles [2]. However, in dense areas with high vehicular traffic, and with respect to the expected huge spread of smartphones and data applications, data explosion is anticipated and centric cellular networks can be easily overloaded. Using hybrid networking can benefit from the reliable communication of LTE, low deployment cost and low communication cost for users of VANETs, by using distributed VANETs for mobile data offloading [4].

Routing is a major challenge in VANET deployment due to the highly dynamic topology of VANETs. Traditional topology-based routing protocols depend on link information between nodes and fail in the large scale VANETs due to the frequent path finding and maintenance flooding [5]. Position-Based Routing (PBR), or geographic routing, is an alternative routing paradigm that uses position information of nearby and destination nodes instead of existent links between nodes from the source to the destination. In VANETs, vehicles are able to determine their positions using Global Positioning System (GPS) receivers, and can share the location information with neighbouring vehicles using the periodic beacon messages, which are required by safety applications. PBR protocols design the method of obtaining destination location, called Location Service (LS), and selecting the next forwarding hop to forward a packet toward its destination location. Thus, prior determination of packet paths or topology-awareness are not required in PBR making it a more suitable and stable routing paradigm in VANETs [5].

Numerous PBR protocols are proposed or adopted for VANETs, e.g., [6]–[12]. The majority of PBR protocol have not considered a realistic Location Service in their evaluation and assumed the availability of destination location. Destination location can be obtained via the pure ad hoc network or another network such as cellular or sensor networks which can affect protocols performance and communication cost. In the route selection process, protocols deploy different methods such as pure geographic [6], anchor-based [7]–[9], [11], static information such as map [10] and bus routes [11], statistics...
information and real-time information [8], [9], [12]. The vast majority of protocols give priority to dense roads for better network connectivity which causes data traffic congestions. Vehicles can also act as communication obstacles which increase the number of packet retransmissions as well as packet retransmissions. Moreover, it is common in city scenarios to have vehicles clustered around traffic lights, while the VANET is intermitted at the middle of the roads. Thus, selecting dense areas in the routing process is not an accurate criterion.

We present a novel intersection-based connectivity-aware routing protocol (iCARII) designed for inter-vehicle communications in a city scenario. iCARII integrates real-time locations and mobility information to estimate a minimum network connectivity lifetime and average delivery delay per road using a distributed algorithm, and updates location centers using LTE channel. Thus, location centers will have a global network view and near real-time topology, and dynamically suggest the best route together with the destination location. Vehicular applications can obtain immediate information about VANETs connectivity and expected network performance, enabling mobile data offloading and low cost Internet access.

This paper is organized as follows: in section II we describe the system model. We introduce iCARII protocol in Section III, followed by simulation-based evaluation and discussion of iCARII performance. Section V concludes the paper.

II. NETWORK MODEL

We consider a hybrid network consisting of VANET and LTE cellular network in an urban area with roads and intersections as shown in Figure 1. VANET consists of vehicles equipped with OBUs and limited number of RSUs that provide access to infrastructure and Internet. Vehicles are also equipped with GPS receivers to obtain accurate locations and velocity vectors, and with LTE interfaces for cellular communication and synchronization within the network. All vehicles have access to identical digital maps with well-defined roads and intersections. Both RSUs and LTE eNBs have access to location centers. While safety applications use direct V2V communication, traffic management and infotainment applications as well as Internet access can use LTE communication or packet routing to a suitable RSU. The objective of this paper is to develop routing protocol for VANETs under these considerations to improve network performance in terms of packet delivery ratio and end-to-end delay.

III. iCARII- INTERSECTION-BASED CONNECTIVITY AWARE ROUTING

iCARII is an infrastructure-based routing scheme designed for vehicular infotainment applications and Internet access in the city scenario. As a PBR protocol, iCARII requires vehicles to update their locations periodically to location centers. These updates are sent when vehicles enter new roads via LTE channel. Vehicles are required, by safety applications, to report road and driving conditions periodically [2]. This is achieved via VANETs one hop V2V beacon messages which include the current locations and mobility vectors.

In a probabilistic manner, a vehicle entering a road segment, a road between two major intersections, initiates a measuring procedure called Road Segment Evaluation (RSE) by sending a unicast packet that traverses the road to the other end and collects information. The packet is dropped when failing to reach the other end due to local network disconnectivity; otherwise, a vehicle at the other end reports the collected information to the location centers via LTE channels. The information includes the experienced delivery delay of the packet in addition to the minimum expected lifetime of the local network connectivity at that road. Location centers construct a network graph that has nodes to represent road intersections and weighted edges to represent connected roads and the associated experienced delivery delay.

When a vehicle attempts to contact a non-neighbouring vehicle or access an infrastructure gateway, it has to send an inquiry message to location centers via LTE. Location centers locate the target destination, run a shortest-path algorithm, (e.g., Dijkstra) on part of the graph that includes both the source and destination, and send back a message to the source. The message includes information about the network connectivity status, the routing path by means of intersection IDs, and the expiry time of the suggested path. If there is no connected path from the source to the destination, the source vehicle either selects mobile data communication through LTE, or reschedules the attempt. Otherwise, it starts the low cost VANETs communication for the specified period of time, and refresh path information before the expiry time of the current path if needed.

iCARII can be further described by its four components: RSE, path lifetime calculation (LTC), next-junction selection, and next-hop selection.

A. Road Segment Evaluation (RSE)

RSE is a heuristic procedure used to dynamically sense the different parts of the network in order to obtain near real-time awareness of its conditions. Light-weight control packets (CPs) are sent probabilistically and distributedly from
intersections to other adjacent intersections traversing road segments. \( v_i \), a vehicle leaving intersection \( A \) and entering the road segment \( AB \), starts RSE with a probability \( P \), and sends a \( CP \) to the other intersection, \( B \). \( CP \) is a unicast packet forwarded hop-by-hop using greedy routing (i.e., the next hop is the geographically closest neighbour to \( B \)). Each forwarder estimates the first possible network disconnectivity in its vicinity according to LTC algorithm (which will be described later in Section III-B), updates \( CP \) and resumes forwarding.

When \( CP \) reaches a vehicle \( v_j \) that is less than \( R/2 \) m away from the center of the target intersection \( B \), where \( R \) is the transmission range, it runs LTC like other forwarders, calculates the experienced packet delay \( D_{AB} \), and sends a response packet \( CP_{rea} \) that includes \( D_{AB} \), as well as the minimum predicted lifetime of \( AB \) network connectivity, \( TE_{AB} \) to the location centers via LTE, and to \( v_i \) via VANET. \( D_{AB} \) is the difference between the time of receiving \( CP \) by \( v_j \) and the \( CP \) generation time by \( v_i \).

When \( v_i \) enters a road segment \( AB \), it triggers RSE with a probability \( P \). \( P \) is designed to enable local network conditions refreshment before the expiry time \( TE_{AB} \). Moreover, \( P \) should maintain a refreshing possibility during the lifetime of the local network in order to update location centers with major increase or decrease in delivery delay, for more accurate route calculations. In (1) and (2), we present one way to design \( P \), where \( P \) is a function of the remaining time in \( TE_{AB} \) \( (t_{rem}) \) and the length of the road segment \( (l) \). \( t_{max} \) and \( \epsilon \) are design constant parameters representing the maximum acceptable delay per forwarder, including average transmission delay and queuing delay, and a small protection time, respectively.

\[
P = \begin{cases} \frac{e^{-t_{rem}-C}}{1}, & t_{rem} \geq C \\ 1, & t_{rem} < C \end{cases} \quad (1)
\]

\[
C = 2 \cdot t_{max} \cdot \lceil l/R \rceil + \epsilon \quad (2)
\]

B. Lifetime Calculation (LTC)

LTC aims to find the time for the first disconnection that might occur at a certain road, in order to enable location centers to determine path lifetime. In PBR, routing path does not depend on the existent links between vehicles, due to the short lifetime of these links; instead the routing decision is taken based on the location of one-hop neighbouring vehicles. Then, the link can be established to a particular forwarder. \( iCARII \) takes advantage of the frequent heartbeats safety messages, or beacons, and piggybacks the mobility information of vehicles. With simple mobility prediction equations, a vehicle can support its routing tables with the expected time for each neighbouring vehicle to move out of its transmission range, and update these information with each beacon processing operation.

As \( CP \) is forwarded using greedy routing, road segments can be further divided into smaller variable length areas of interest (AoIs). Each AoI falls between two successive \( CP \) forwarders. When a forwarder \( v_i \) selects \( v_j \) to be the next \( CP \) forwarder, it attaches the set of expected link lifetime for vehicles in AoI between \( v_i \) and \( v_j \), \( L_{v_j} = \{ t_i,1, t_i,2, t_i,3, ... t_i,j \} \). This information can be found in \( v_i \)'s routing table. When \( v_j \) receives \( CP \), it extracts a similar set \( L_{v_j} \) for the same set of vehicles. Intuitively, time for the first expected disconnectivity in that AoI can be described as the time where there is no possible link between any two vehicles in that area, and can be found as in (3) and (4) where \( S_{max} \) is the maximum speed on that road.

\[
LLT(i) = \min(\max(L_{v_i}), \max(L_{v_j}), l_{max}) \quad (3)
\]

\[
l_{max} = \frac{R}{S_{max}} \quad (4)
\]

Each forwarder updates \( CP \) in such a way that \( CP \) maintains the minimum \( LLT \) for all AoIs. Thus, the last \( CP \) receiver can get the smallest \( LLT \) value, which represents road connectivity expiry time. When location centers find a path, the path expiry time is the minimum expiry time of the road local networks performing that path.

C. Next-junction selection

Unlike the traditional PBR protocols, \( iCARII \) has a global view of the network at location centers which can determine in advance the existence of a path from the source to the destination. Thus, \( iCARII \) deploys source routing where intersections IDs involved in the route are attached to the header of each packet. This will reduce the cost and delay of multiple route inquiries via LTE.

In most cases, packets are delivered within the given lifetime of the path. Packets source renew path information before the expiry time of the current one. However, for different reasons packets might reach to a disconnected road. This can occur due to unexpected delay in delivery, exceeding the path lifetime, or unexpected disconnection in the network within the path lifetime. In this case, the current data packet forwarder sends a new path request to location centers in order to select a new path. Destination information is always included in the packet’s header. If there is no path available to the destination, the packet is dropped.

D. Next-hop selection

As in \( iCAR \) [9], \( iCARII \) deploys a greedy-based next-hop selection algorithm that mainly depends on the expected position of neighbouring vehicles and RSSI. Pure greedy forwarding between junctions has been widely used by PBR protocols; however, vehicles that are further from a sender are more likely to leave the communication range during the inter-beacon interval, and have worse link-quality than other neighbours. Thus, next-hop is selected, after position prediction, to be the closest to the next junction among vehicles have RSSI above a certain threshold. RSSI is initially recorded in the routing table and updated via the received beacon messages. RTS, CTS and data packets can also refresh RSSI information.
IV. PERFORMANCE EVALUATION

In this section, we present simulation-based validation for the heuristic LTC algorithm based on real vehicle movement traces, in addition to network simulation to evaluate the performance of iCARII. The evaluation metrics include packet delivery ratio, end-to-end (E2E) delivery delay, control packet overhead in VANETs, and LTE control messages overhead.

A. LTC Validation

LTC algorithm is validated using real data traces provided by the Next Generation Simulation (NGSIM) project [13]. Vehicle trajectories used in this study represent data collected from road segments of Peachtree Street in Atlanta, Georgia, between 4:00 p.m. and 4:15 p.m. on November 8, 2006. By applying LTC, recording the expected network lifetime of each connected road segment, and comparing these recordings to the actual disconnections occur after LTC, we found that LTC succeeded in 93% of the total recordings to predict a disconnection before it actually happens. In most cases, vehicles move to other AoIs and prevent expected link breakage. Thus, the observation is that the actual link lifetime is larger than the expected ETs. LTC fails in 7% of cases which are related to the randomness of the driver’s behaviour of a critical vehicle such as stopping or turning at a minor intersection. Critical vehicles are vehicles that have effective contribution in eq (3).

Figure 2 shows some random samples of LTC validation results for cases that has a road disconnection status after less than 20 S from running an LTC algorithm. The figure compares the actual disconnection time with the expected one.

B. Network Simulation Setting

City scenario VANET has been implemented in MATLAB to represent 7000m x 7000m grid area with bidirectional roads. Roads vary in terms of length, width and vehicle density to represent main roads and residential areas. The grid has a total of 165 intersections with 45 of them being major controlled intersections (i.e., with traffic lights). After the initial vehicle placement, the vehicles flow and mobility follow Greenshield’s model; vehicles obey traffic lights, turn with probability and do not leave the grid.

System and simulation parameters for iCARII are listed in Table I, while GyTAR and GPSR parameters follow [8] and [6] respectively. In iCARII and GyTAR, vehicles update their locations to location centers when they enter new road segments, while in GPSR vehicles update their location every 200 m. This is because GPSR is not an intersection-based protocol. Nodes implement a FIFO packet queue, such as the AC queues designed for WAVE’s MAC layer, to buffer packets pending for transmission, and DCF MAC is applied for MAC contention. For RSSI estimation, a free space model with urban area path loss exponent is deployed. We simulate VANETs and location centers, LTE channels are assumed to have ideal communication with fixed one-way communication delay of 100 ms. Simulation scenarios have been repeated several times for more accurate results, with random sources and destinations selected in each run. Sources vehicles are 10% of the total number of vehicles.

C. Simulation Results and Analysis

1) Packet Delivery Ratio: In iCARII, a source will start sending packets only when there is a connected path to the destination. Therefore, we define PDR as the average ratio of packets received to packets that are ready to send. iCARII has significantly higher PDR than GyTAR and GPSR as it has full path connectivity awareness. For the portion of PDR that packets are not delivered using iCARII, it is more likely that there are no path from the source to destination. In this case, source saves the network bandwidth and reschedule transmission or use LTE for data transmission. On the other hand, GyTAR and GPSR are not aware of the absence of connected path, and packets traverse the network until eventually reach their expiry time. Figure (3a) shows that packet generation rate (PGR) has a minor effect on iCARII as iCARII selects paths dynamically to avoid data traffic congestions, while GyTAR and GPSR do not take in consideration data congestions. Similarly, with high vehicular traffic, GyTAR routes converge to dense roads which cause data traffic congestions and high queuing delay. Delay

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Scenario Duration</td>
<td>40 S</td>
</tr>
<tr>
<td>Routing Protocols</td>
<td>iCARII, GyTAR, GPSR</td>
</tr>
<tr>
<td>Transmission Range (R)</td>
<td>250 m</td>
</tr>
<tr>
<td>Packet Generation</td>
<td>CBR</td>
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<tr>
<td>Packet Size</td>
<td>512 byte</td>
</tr>
<tr>
<td>Transmission Rate</td>
<td>12 Mbps</td>
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<tr>
<td>Packet Lifetime</td>
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</tr>
<tr>
<td>$S_{min}$</td>
<td>60 kbps</td>
</tr>
<tr>
<td>$t_{max}$</td>
<td>200 ms</td>
</tr>
<tr>
<td>Inter-Beacon Period</td>
<td>500 ms</td>
</tr>
<tr>
<td>Random Backoff Period</td>
<td>1-5 S</td>
</tr>
<tr>
<td>$e$</td>
<td>200 ms</td>
</tr>
<tr>
<td>$RSSI_{th}$</td>
<td>0.6 x RSSI$_{min}$</td>
</tr>
</tbody>
</table>

**TABLE I**

Simulation Parameters
is associated with PDR as packets with high delivery delay can reach their expiry time and be dropped. With taking the experienced delay in consideration as well as the deterministic LTC, route calculation in iCARII takes advantage of the higher vehicular density to find new routes with less delay for more efficient dynamic routing.

2) Packet Delivery Delay: Figure (3b) shows that iCARII has significantly reduces the average E2E packet delivery delay. This is mainly because iCARII selects routes with minimum expected delay and connected paths. Notice that with sparse VANETs, iCARII achieves higher PDR on the cost of higher delivery delay as it selects connected paths even with long trajectories. Moreover, iCARII reduces the queuing delay by using dynamic routing, and eliminates the store-carry-forward strategy used by GyTAR, by using deterministic calculation of LTC and more frequent RSE triggers.

3) Routing Overhead: The routing control packets can be divided into three categories: 1) broadcast periodic safety messages (beacons), 2) LTE routing messages, and 3) unicast routing control packets. Beacons are the main overhead introduced to the network by PBR; however, it is required by safety applications. Protocols under consideration use the same inter-beacon interval and beacons effects are equal for all protocols. LTE overhead includes location updates and inquiry messages in addition to road condition information updates introduced by iCARII. Figure (3c) shows that iCARII introduces slightly higher overhead than GyTAR, and the number of messages per vehicle is negligible. The high LTE overhead by GPSR is due to the frequent location updates, which indicates the effect of location updates frequency comparing to routing control messages. For the unicast VANETs overhead, we found that iCARII introduces about double the overhead of GyTAR, however, this overhead is distributed, unicast, and on average it is less than two packets per road segment every second, i.e., it can be neglected.

V. CONCLUSIONS

We have proposed a framework of infrastructure-based VANETs routing protocol, iCARII, to enable mobile data offloading from LTE cellular network to VANETs, in addition to infotainment and multi-hop V2V applications, with minimum deployment of RSUs. The deployment of such framework can provide end users with connectivity information prior to use VANETs. Users can enjoy the target applications at significantly low cost comparing to pure LTE data services. For our future work, we will focus on sensitivity analysis to adjust the different system parameters of iCARII in order to optimize its performance.

REFERENCES