Hybrid Geo-Routing in Urban Vehicular Networks

Aisling O’ Driscoll and Dirk Pesch
NIMBUS Centre for Embedded Systems Research
Cork Institute of Technology
Cork, Ireland
aisling.odriscoll@cit.ie, dirk.pesch@cit.ie

Abstract— It is expected that future vehicular networks will consist of a combination of ad-hoc network and infrastructure components. Road Side Units (RSUs) will form part of the infrastructure element. However, it is anticipated that a fully deployed RSU infrastructure may not be economically feasible in the short term, therefore, a partial infrastructure in urban environments is more likely, at least initially while vehicular networks are being adopted. It is further likely that low vehicle penetration rates will exist while 802.11p On-Board Unit (OBU) technology is being rolled out, thus routing schemes should exploit infrastructure where available to improve packet delivery. This paper presents a hybrid vehicular routing protocol that facilitates unicast routing by dynamically changing its routing decisions in the presence of RSU infrastructure in order to maximise packet delivery rate. A quantitative evaluation of the proposed Infrastructure Enhanced Geographic Routing Protocol (IEGRP) is provided as a function of varied source to destination distances, vehicular densities, infrastructure availability and application QoS characteristics. It exhibits much improved delivery rates with partial and full infrastructure compared to related protocols.

Keywords—geo-routing; VANET; Road-Side Units (RSUs);

I. INTRODUCTION

Intelligent Vehicular Communication (IVC) networks have gained considerable attention in recent years, with advanced vehicular application and technology development driven through global Intelligent Transportation Systems (ITS) standardisation and academic research efforts, in collaboration with major automobile manufacturers. Such applications include safety and warning systems, traffic efficiency and management applications as well as multi-hop V2X enabled communications such as on-board infotainment services [1-3]. Infotainment services include, but are not limited to, file sharing e.g. music or movie files or the utilisation of location-based content such as travel related information, news items etc. As a Vehicular Ad-hoc NETwork (VANET) is comprised of multi-hop connections between mobile nodes that are fleeting and may incur frequent disconnections, end to end delivery performance decreases significantly. Thus the success of V2X applications is only feasible if connectivity can be provided. Such connectivity is reliant on either high vehicular density to sustain multi-hop communications or the availability of fixed infrastructure such as Road-Side Units (RSUs). The utilisation of infrastructure extends multi-hop routing capabilities to facilitate robust wide area communications as it can be assumed that RSUs are connected via high bandwidth links. This can also overcome voids in the network connectivity to improve the packet delivery rate.

Existing routing protocols only consider fully distributed solutions or alternatively they assume the existence of full infrastructure. Infrastructureless solutions are not equipped to avail of road-side infrastructure, if available, in order to maximise delivery and ignore the consequences of frequent disconnections. Very importantly, it was noted in [4] that a hybridisation of the afore-mentioned approaches has yet to be addressed and remains a vital area for future work. The use of RSUs is an important area of expansion as current routing schemes do not adapt to operate in fully distributed, partially equipped or fully infrastructure based topologies. As a fully deployed RSU network is not feasible in the short term, partial infrastructure in urban environments is a more imminent reality. The ability to adapt and exploit infrastructure, where available, will accommodate robust routing, without which packet delivery is not maximised, rendering all other protocol optimisations such as overhead optimisations pointless. Thus the success of V2X applications is only feasible if connectivity can be provided and packet delivery is maximised where possible. Therefore this paper presents the Infrastructure Enhanced Geo-Routing Protocol (IEGRP), a hybrid routing protocol designed to maximise packet delivery in vehicular networks by adapting the routing algorithm to exploit fixed infrastructure where available.

II. RELATED WORK

As previously stated, current vehicular routing schemes are either completely distributed such as those described in [5-8] or are reliant on a fully deployed infrastructure located at prescribed locations. As distributed routing protocols are not designed to exploit available infrastructure, the routing algorithm will choose a RSU as the forwarding node only if it is the node that makes the greatest greedy progress towards the destination. Furthermore these protocols are not optimised to prioritise the transmission of packets over the wired network, rather than via the VANET, if available.

Subsequently, a number of infrastructure-based schemes have been proposed. Roadside-Aided Routing (RAR) [9], TrafRoute [10] SADV [11] and ROAMER [12] require a fixed number of RSUs in fixed positions as a prerequisite to the correct operation of the routing scheme. Specifically, RAR assumes dense RSU deployment with the RSUs dictating the start and end of sectors and with multiple RSUs managing each sector. Similarly TrafRoute requires a fixed number of RSUs (although not as many as RAR), distributed uniformly with one RSU per sector, although the sector partitioning scheme is not described. SADV requires a RSU to be located at every intersection and, in the case of partial deployment, that they are located uniformly. It does not consider that these RSUs may be connected over a wired
network or Internet connection. ROAMER also assumes widespread RSU deployment. Therefore RAR, TrafRoute, SADV and ROAMER cannot simply adapt with the network topology. Furthermore, RAR, TrafRoute and ROAMER implement their own proprietary route discovery mechanisms to identify the location of the destination and to establish the route. Their approaches present tightly coupled routing and location service solutions. Furthermore, packets must follow this pre-determined route towards the destination. In TrafRoute, the route is established before packet transmission and does not change. In ROAMER the path is reassessed at every intersection. SADV does not specify how it determines the destination node’s location.

The proposed routing protocol, described in Section III, can adjust dynamically to the network topology under consideration. Such methods are not considered by current infrastructure assisted schemes. RAR predominantly relies on V2I2V routing, although vehicles within the same sector can use standard multi-hop greedy routing. It does not outline a recovery scheme as it is based on the assumption of widespread infrastructure deployment. SADV, specifically designed for sparse networks, buffers or greedily routes packets to the closest intersection where it assumes a RSU exists. Importantly, SADV does not consider that static RSUs are interconnected via a backbone network or via the Internet. A basic greedy/buffering algorithm is assumed with no method for finding a preferred or alternative forwarding mechanism using the infrastructure network. In TrafRoute, intra-sector communications is facilitated via multi-hop V2V routing with inter-sector routing via the RSU network. A densely connected ad-hoc network is assumed and alternative routing techniques to overcome the shortcoming of standard buffering or the default greedy algorithm are not considered. Borsetti et. al [13] similarly pre-determine a route to the destination, following the GSR scheme, assuming the basic greedy routing algorithm and a connected network. ROAMER does not implement a greedy unicast algorithm but rather utilises multicast for redundancy when utilising ad-hoc V2I or I2V routing, as well as bounded geo-casts when in range of the destination node. High density is assumed as is widespread RSU coverage to resolve the location of the destination.

Thus, all of the afore-mentioned schemes are designed to work well for particular network configurations e.g. specific vehicle or RSU densities, but do not generalise well.

III. INFRASTRUCTURE ENHANCED GEOGRAPHIC ROUTING PROTOCOL (IEGRP)

IEGRP is a geographic routing protocol designed to operate over a fully distributed or a partially/fully infrastructure based network and extends our previous work in [14]. Unlike recently proposed infrastructure-reliant approaches described in the previous section, it does not demand particular network conditions with respect to RSU availability in order to operate and allows routing algorithms to be dynamically overridden to exploit infrastructure where available.

For fully distributed routing, IEGRP exhibits many characteristics that, in isolation, have been used as part of other vehicular routing protocols. A set of generic guidelines for improved VANET routing were recommended in [15] including the use of a store and forward paradigm to cope with temporary disconnections, extended beacon messages (though the content is not specified) and careful selection of forwarding criteria. IEGRP uses store and forwarding buffering to overcome temporary disconnections in the vehicular ad-hoc network. Extended beacons are periodically transmitted between one hop neighbour vehicles, including motion and position vectors. The position vector contains the current and previous position of a node, with the motion vector describing a nodes velocity. These extended beacons are used to predict if a vehicle has moved out of the radio range since the timestamp of the last beacon and also to determine the next hop neighbour that will be chosen by the advanced greedy algorithm. In IEGRP, rather than the basic method of choosing the vehicle that will make the greatest greedy progress towards the destination, IEGRP also accounts for the direction in which the vehicle is travelling and so may choose a vehicle that achieves slightly less progress but is travelling in the direction of the destination. Such an approach has been discussed in the GeoNet final project deliverable [16] as being a possibility for a future extension in the GeoNet specification. In these ways, IEGRP fulfils the optimum criteria for routing in a fully distributed vehicular network. However the primary distinguishing factor of IEGRP is that it exhibits a number of hybrid characteristics, now described and illustrated in Fig. 1:

- IEGRP allows a vehicle’s default greedy algorithm to be dynamically over-ridden so that unlike other schemes that choose a neighbour vehicle that makes the greatest geographic distance towards the destination, IEGRP favours a RSU that makes less forward progress to the destination but has a wired link to another RSU that can achieve a greater gain in geographical distance over the infrastructure based backbone. This ultimately offers a better geographical routing gain for packet delivery.
- Similarly, a RSU that may incur a geographic loss in forward progress towards the destination can be chosen if it can route the packet to another RSU geographically closer to the destination over the backbone. Thus in scenarios where the store-and-forward recovery technique would typically buffer a packet or greedy forwarding would be used, it instead “back-tracks” the packet to a RSU that can route over the wired network.
- RSU neighbours are advertised in periodic vehicle beacons so that indirect neighbour nodes may learn about infrastructure based two hop neighbours. Thus the previous two points consider not only one hop neighbours but also two-hop infrastructure neighbours.

In Fig. 1(a), the blue vehicle wishes to route a packet to the red vehicle. As the blue vehicle has reached the local maxima, a geo-routing protocol would ordinarily buffer the packet until a new vehicle is encountered that can make greater geographic progress towards the destination. However IEGRP exploits topology knowledge of RSU neighbours acquired indirectly via two hop beaconing to select an alternative node towards the packet will be forwarded i.e. dynamically overriding the default buffering
mechanisms. The routing algorithm operating on the blue vehicle determines that it should multi-hop the packet via the black vehicle to the two-hop RSU. While this will not make a temporary gain towards the destination (it achieves lesser forward progress in the short term), it can route over the wired backbone network (or Internet) to another RSU that will achieve greater physical proximity to the target red vehicle. Similarly in Fig. 1(b), the blue vehicle wishes to route a packet to the red vehicle but the IEGRP routing algorithm will not simply choose the neighbour that achieves the greatest physical progress towards the destination i.e. the black vehicle, as per typical greedy behaviour, but rather forwards the packet to the RSU does not make the best progress to the destination in the short term, but will the best progress to the destination overall.

In contrast to the infrastructure based schemes discussed in Section II, IEGRP does not dictate a mandatory minimum availability of RSUs. Furthermore, it does not require mandatory RSU placement in order to correctly operate (though uniform distribution may improve delivery rates), as it acknowledges that RSUs may be located where there is existing infrastructure and thus it can adapt to varied network topologies. It operates with any location service protocol and most importantly specifies stateless greedy and recovery routing schemes that can dynamically adjust to best accommodate network conditions on a per packet basis to maximise the possibility of packet delivery. This allows IEGRP to adjust dynamically in conjunction with the network topology under consideration.

![Image](image-url)

**Figure 1**: IEGRP routing protocol to favour RSU connectivity (a) Overriding Store and Forward Mode (b) Overriding Greedy Mode

IV. SIMULATION ENVIRONMENT

A. Vehicular Topology & Traffic Modelling

A 2.5Km² Open Street Map (OSM) sub section of Cork City, Ireland, is considered as shown in Fig. 2(a). SUMO [17] is used to generate traffic flows. It is necessary for the OSM map to be manipulated to reflect real vehicular conditions i.e. one way streets, accurate speed limits etc., via Java OSM [18], as shown in Fig. 2(b) with the derived road network subsequently imported into SUMO in Fig. 2(c). Buildings (polygons) are specified as they are employed in an obstacle model for realistic wireless channel transmission modelling as shown in Fig. 2(d). Varied vehicular traffic densities are generated with vehicles travelling at a maximum speed of 50kph with the traces subsequently imported into OPNET as shown in Fig. 2(f).

B. Network Simulation Environment

A prevalent unicast geo-routing protocol has yet to emerge. As such, comparative vehicular routing protocols were chosen in accordance with EU standardisation best practice and specification. IEGRP is compared against C2CNET/GPSR and ISO/ETSI GeoUnicast. C2CNET/GPSR [19] specifies the use of the Greedy Perimeter Stateless Routing (GPSR) protocol, utilising the ‘perimeter routing’ recovery scheme. ISO/ETSI GeoUnicast is specified as part of the ISO/ETSI vehicular communications framework [20]. Its greedy algorithm operates in the same way as that of C2CNET/GPSR but it employs delay tolerant packet buffering. Three IEGRP derivatives are compared, labelled as IEGRP, IEGRP + OGS (Override Greedy Scheme) and IEGRP + ORS (Override Recovery Scheme). IEGRP does not prioritise infrastructure amongst a vehicle’s neighbours however if the default greedy algorithm chooses a RSU as the forwarding node, it ensures that the RSU forwards the packet over the available wired backbone network rather than solely using the wireless VANET. IEGRP + OGS allows the default greedy algorithm to be overridden to favour a RSU one hop neighbour that makes less forward greedy progress can exploit geographical gain over the backbone. IEGRP + ORS allows a temporary geographic loss to occur in favour of infrastructure. V2I schemes, as outlined in Section II, are not directly comparable as they require full infrastructure, often dictating specific RSU locations and a pre-defined route. The Sommer et al channel model is used [21] that differentiates between Line of Sight (LOS) and Non-LOS between the transceivers. A shadowing component is used. This model is specific to the topology under consideration utilising traces of the JOSM buildings as, importantly, the authors of this paper have extended the channel model to include small-scale characteristics modelled via the Nakagami-\(m\) distribution. As a result, the channel is subject to errors in information exchange for routing control information and data. UDP application traffic is transmitted from 10 randomly chosen vehicle pairs with a new pair chosen on application session completion.

C. Contextual Network Description

Current simulation tools do not provide the information that is necessary for the context of the topological characteristics and dynamics of the mobile vehicular traffic to be understood, thus ensuring the validity and subsequent interpretation of the results to be benchmarked. Custom Python scripts have been employed to visualise network oriented and link level metrics. Specifically, the following metrics are considered:
Vehicular Node Degree: The number of vehicles within radio range of a given vehicle, reflective of the wireless network connectivity.

Link Duration: The time duration of a wireless communication link between a pair of vehicles.

Vehicular densities have been chosen to consider a range of sparsely, freely moving and densely populated traffic scenarios and are in keeping with the densities considered in comparable vehicular quantitative routing protocols evaluations (discussed further in Section V). Histograms depicting the node degree are shown in Fig. 3(a-b) with (c-d) depicting vehicular link durations. Fig. 3(e-f) illustrates mean vehicular density over the considered road topology. Table 1 summarises the mean, minimum and maximum node degree and link durations for all considered vehicular densities. Fig. 3(a-b) depicts the 90 vehicle (approximately 4 veh/km) and 520 vehicle (approx. 9 veh/km) scenarios.

It can be observed that the 90 vehicle scenario is significantly more sparsely connected with a mean of 8.8 and ~46 neighbouring vehicles respectively, as shown in Table 2(a). It can be further observed that the 90 vehicles scenario incurs over 7500 occurrences of isolated vehicles at a given time, in contrast to less than 2000 occurrences for 520 vehicles. Fig. 3(c-d) graphs the link durations in seconds for the vehicles in the network, with the mean, minimum and maximum link durations summarised in Table 2(b).

In the higher density scenario, the network becomes well-connected with significantly more vehicles connected for approximately 3.5 minutes or less than the 90 vehicle equivalent. Furthermore, the mean vehicular road density in the form of heat-maps over 2 densities (156 vehicle (approximately 5 veh/km) and 520 vehicles is shown in Fig. 3(e-f) with green representing less densely populated areas and red representing the converse.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation Duration</td>
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</tr>
<tr>
<td>Application Duration</td>
<td>Exponential (90s)</td>
</tr>
<tr>
<td>Number of Sender Pairs</td>
<td>10 (constant)- chosen randomly</td>
</tr>
<tr>
<td>Inter-Packet Arrival Rate</td>
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</tr>
<tr>
<td>Packet Payload Size</td>
<td>Uniform(100B) with std.dev ±15B</td>
</tr>
<tr>
<td>Vehicle Densities</td>
<td>~4-9 veh/km²</td>
</tr>
<tr>
<td>Channel Model</td>
<td>Sommer et. al obstacle based model with Shadowing + Nakagami small scale fading</td>
</tr>
<tr>
<td>Maximum transmission range</td>
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</tr>
<tr>
<td>Transmit Power</td>
<td>8 dBm</td>
</tr>
<tr>
<td>Receiver Sensitivity Threshold</td>
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<tr>
<td>Antenna heights</td>
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<td>PHY and MAC</td>
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<tr>
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<tr>
<td>Buffer Timeout</td>
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</tr>
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</table>

Table 1: Simulation Parameters

V. PERFORMANCE ANALYSIS

IEGRP is evaluated with respect to the following metrics:

1. **Packet Delivery Rate (PDR):** The PDR is the ratio between the generated data packets to those successfully delivered to the destination vehicle.

2. **End to End Data Packet Delay:** The latency from when a data packet is generated at the source vehicle to when it is successfully delivered to the destination vehicle application, including WAVE MAC and routing delays.

3. **Path Length:** The number of wireless and wired hops incurred between the source and destination vehicles.

PDR is the most important metric when highlighting the improved performance of the proposed protocol, IEGRP. It must be noted however, that while improved delivery rates are vital to sustain communications, the timeliness of packet delivery is also important if particular application types are to be supported.
A. Impact of Source Destination Distance Ranges

Fig 4(a-b) illustrates the impact of data packets destined for a target vehicle within a particular radius of the source vehicle, on the PDR for a fully infrastructure-equipped network topology and a completely infrastructureless VANET respectively. Ranges in multiples of 210m are considered (maximum theoretical radio range) with ranges less than 210m disregarded as in such cases, packets can be delivered based on single hop neighbour table information populated through periodic beacons.

It can be observed from Fig. 4(a) that IEGRP and its derivatives out perform comparative schemes and achieves the best delivery ratio when infrastructure is available. However, this improved PDR is particularly notable as the distance range increases with IEGRP derivatives making better use of available infrastructure. IEGRP + OGR incurs approximately 34% and 23% improvement over C2CNET/GPSR and ISO/ETSI GeoUnicast respectively for the 630m-840m (approx. 4-6 hops), 840m-1050m (approx. 5-7 hops) and 1050-1260m (approx. 6-8 hops) ranges. This large improvement occurs for two reasons. Firstly, RSUs route packets over the backbone network in order to make greater greedy progress towards the destination vehicle. Secondly, the greedy routing algorithm can be overridden in a RSU as a neighbour as the algorithm recognises that it may not be located to make the greatest temporary greedy progress in the first instance but can make greater gains over the backbone network with respect to the overall delivery. It can be observed that IEGRP + ORS further outperforms IEGRP + OGS by allowing the greedy scheme to be overridden to choose a node that makes a temporary loss in progress but can route closer to the destination over the backbone. Furthermore IEGRP + ORS incorporates an alternative to the store and forward scheme where packets can be routed ‘backwards’ to a RSU (potentially two hop).

In contrast, the PDRs of C2CNET/GPSR and the ISO/ETSI GeoUnicast protocol are highly dependent on the distance between the transmitting and receiving vehicles with an almost exponential decrease in successful packet deliveries noted as distance increases, rendering them essentially inoperable. The sharp decrease in the performance of C2CNET/GPSR is as a result of its recovery scheme which is not suitable for highly dynamic environment i.e. the challenges in forming and maintaining a planar graph in vehicular networks, given high vehicle mobility, negatively impacts such a routing scheme leading to routing loops and poor delivery rates. By employing store and forward buffering techniques, the ISO/ETSI GeoUnicast protocol while incurring slightly improved PDRs is highly susceptible to increased distance ranges. Fig. 4(b) shows the incurred PDRs over a completely infrastructureless network. As the distinguishing factor of IEGRP is that it exploits infrastructure where available, it incurs minor PDR improvements in a completely ad-hoc network. However as it incorporates an additional advanced forwarding characteristic in that it selects forwarding vehicles not only based on distance, but also based on their direction of travel in order to maximise delivery, a marginal improvement in PDR is still noted (approx. 3%). However, as with all completely distributed routing solutions designed for vehicular networks, it is susceptible to impacted delivery rates when density is decreased and the network is partitioned i.e. when a path does not exist to the destination.

B. Impact of Vehicular Density

In order to evaluate the impact of vehicular density on the routing protocol performance, traffic densities between 4 and 10 vehicles/km were simulated across three distance ranges as shown in Fig. 5(a-c). Lower densities are representative of either periods of non-peak traffic or lower penetration rates, rising to 520 vehicles representing densely connected yet free flowing traffic conditions. It can be observed that as the vehicle density increases, all protocols experience an increase in the PDR resultant from increased network connectivity in the VANET. At the lower traffic density of 4 vehicles/km (90 vehicles), it may not be possible, to establish a communication path between the source and destination vehicles due to the lack of multi-hop connectivity.

Overall, it can be observed from Fig. 5, that IEGRP clearly outperforms comparative protocols, demonstrating much improved delivery rates, especially with higher vehicle densities. At lower densities of 90 vehicles, for a distance range of 630m-840m, as shown in Fig. 5(b), IEGRP + ORS achieves a PDR of 75.7%, a considerable improvement over C2CNET/GPSR (27%) and GeoUnicast (~42%) as well as a notable improvement over it derivatives of its own scheme, IEGRP (66.1%) and IEGRP + OGS (66.6%).
As the vehicular density is increased to 520 vehicles, the PDR of IEGRP + ORS grows to 89.19%, which is 38.9% and 25.22% greater than C2CNET/GPSR and GeoUnicast as well as 14.43% and 4.75% better than its own derivatives. When the distance range increases, as shown in Fig. 5(a), an increase in vehicular density lends negligible improvement in delivery rates for C2CNET GPSR and ISO/ETSI GeoUnicast, due to the lack of a path through the multi-hop network. C2CNET GPSR and GeoUnicast achieve a PDR of only 9.8% and 23% respectively over a 90 vehicle network, increasing to only 24.48% and 34.47% respectively for 520 vehicles. For C2CNET/GPSR, these performance issues exist because of the absence of a suitable recovery scheme leaving the protocol susceptible to temporary disconnections in the network. GeoUnicast does not suffer degradation for this reason as increased density enables it to overcome voids in the network, increasing the change of offloading the packet to a neighbour, however at larger distances this improvement does not sustain adequate delivery rates. It can be further observed in Fig. 5(c) that IEGRP offers minor performance benefits for the 210m-420m distance for the same reason as outlined in the previous section i.e. proximity of vehicle, negating use of infrastructure.

C. Impact of RSU Density

In order to discount the possibility of biased evaluation as a consequence of the random RSU placement over partial infrastructure, the presented evaluation provides the mean across a subset of permutations. It is assumed that RSUs are located where there is existing infrastructure such as traffic lights at intersections, with all possible locations marked in red and shown in Fig. 6(a). RSUS are connected over a high speed wired backbone network. As it was not computationally feasible to evaluate every possible permutation, a diverse subset was chosen to cover:

- RSUS distributed uniformly throughout the network
- RSUs clustered in a particular part of the network
- RSUS located around the perimeter of the network.

Four RSU clusters were considered as highlighted in Fig. 6(b), labelled Cluster 1 (Blue, Cluster 2 (Green), Cluster 3 (Red) and Cluster 4 (Purple). It can be observed from Fig. 7 that RSU placement has a significant impact on the PDR of all protocols. Research into optimal and cost effective RSU placement has increased significantly in the last year [22-24] and it can be expected that this will continue as research in infrastructure assisted vehicular networks continues to attract increased attention. The benefits associated with clustered RSUs and RSUs located around the perimeter of the network can be observed to be negligible and are actually comparable in performance to an infrastructureless VANET. This is particularly the case over longer distances with a range of 1050m-1260m considered in Fig. 7. However for uniformly distributed partial RSU infrastructure, IEGRP notes a significant improvement as noted in Fig. 7(a), Fig. 7(b) further examines the performance of IEGRP and comparative protocols over decreasing density of uniformly distributed RSUs. It can be noted that with even as little as 4 RSUs in a 2.5km² area an improvement of ~22% can be observed.

D. Implications for Application Performance

IEGRP performance has thus far been discussed with respect to the PDR metric and has demonstrated that it out performs other protocols in partially and fully equipped vehicular networks across a wide range of conditions. However application performance metrics must also be considered, as even though a packet may be delivered, this delivery may be rendered meaningless if it does not meet the delay requirements of the application. Table 3 summarises the distribution characteristics of the packet latencies experienced by IEGRP and comparative protocols for two source-destination distance ranges assuming 520 vehicles and full infrastructure.

The mean, minimum, maximum, standard deviation and 90th/95th percentiles are shown in seconds. It can be noted that despite incurring noteworthy improvements in PDR (see % Improvement (Imp) column over C2CNET/GPSR for full infrastructure), IEGRP schemes incur comparable maximum delays and significantly reduced minimum delays over C2CNET/GPSR and ISO/ETSI GeoUnicast. C2CNET/GPSR incurs much lower delays than other schemes but with considerably worse delivery rates as it does not employ buffering techniques. Significantly, it must be observed that IEGRP derivatives incurs a lower mean delay than ISO/ETSI GeoUnicast despite both schemes employing delay tolerant store and forward buffering. In particular, for the IEGRP + ORS derivative, it can be noted that 90% of packets incur a delay of 5ms or less and 95% of packets incur a delay of ~3.9s by making better use of available infrastructure. While 5ms is tolerable for infotainment applications such as fast paced gaming applications (<200ms is satisfactory), delays in the region of seconds are not suitable.
However the delays of ~3.9s or less would be tolerable for applications such as a delay tolerant file transfer application or a puzzle based challenge gaming application. Some vehicular delay tolerant applications and projects include CarTel [25] and Drive-Thru [26] amongst others.

Fig. 8(a-b) shows the mean, minimum and maximum hop counts incurred for successfully delivered packets across varied source destination distance ranges. The number of hops is a commonly examined metric as it can often impact the end to end delay. However it can be noted that C2CNET/GPSR has the highest path length (typically due to the face routing recovery scheme) yet buffering schemes may intuitively incur lower path lengths in terms of hops yet incur higher delays. IEGRP + ORS prioritise the wired network, resulting in slightly lower path lengths with a greatly improved PDR.

VI. CONCLUSION

This paper describe a hybrid routing protocol, IEGRP that maximises delivery in vehicular networks with partial or fully deployed RSU infrastructure. Simulation analysis indicates that IEGRP incurs improved delivery rates on comparative routing techniques with similar and, in some cases, improved end to end delays noted.

References

Table 3: Distribution characteristics for the packet delivery latencies (s) experienced over increasing source destination distance ranges with full infrastructure

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Min (x 10^{-3})</th>
<th>Max (x 10^{-3})</th>
<th>Mean</th>
<th>Std. dev</th>
<th>Percentile 0.90</th>
<th>Percentile 0.95</th>
<th>% Imp</th>
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<td>630m-840m</td>
<td>C2CNET/GPSR</td>
<td>17.78</td>
<td>0.1719</td>
<td>0.0029</td>
<td>0.0013</td>
<td>0.0043</td>
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<td>IEGRP + OGS</td>
<td>9.9</td>
<td>29.985</td>
<td>1.2515</td>
<td>4.1769</td>
<td>0.37704</td>
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<td>IEGRP + ORS</td>
<td>9.9</td>
<td>24.131</td>
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<td>3.407</td>
<td>0.0048</td>
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<tr>
<td>1050m-1260m</td>
<td>C2CNET/GPSR</td>
<td>28.2</td>
<td>0.2086</td>
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<td>3.389</td>
<td>61.47</td>
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Figure 8: Path Length as a function of varied source-destination distance ranges for (a) full infrastructure and (b) infrastructureless VANET


