Towards Provisioning Vehicle-Based Rural Information Services

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Abstract—**Rural areas often lack extensive technological support and usually do not have a high priority in governmental investments due to economic reasons. As the scale of information service provisioning – with data sensing and delivery as primary elements – grows national, there is a matching need to extend these services to rural areas. Smart Vehicular networks present cost-effective, mobile coverage for rural areas. The sensing and buffering resources of vehicles can be utilized in collecting and relaying data. Being delay-tolerant in nature, the data need for some information services, such as environmental monitoring applications, can be sensed by on-vehicle sensors and delivered by vehicles to the collecting destination/sink. In traditional store-carry-and-forward data delivery techniques, a vehicle can continue to carry data even if it is heading away from the destination direction. Such cases may lead to excessive delays and eventual packet dropping. As a part of the vehicular network, road side units (RSUs) are deployed at intersections with no/limited backbone communication at rural areas. By utilizing these RSUs, we propose an infrastructure-assisted data delivery (IADD) scheme that utilizes vehicles headings to enhance delay-tolerant rural information services and improve data delivery ratio and packet delay. Our scheme is evaluated via extensive simulations, carried on NS-2. Our experiments show that IADD achieves significant performance improvements in terms of delivery ratio and delay bounds compared to the traditional store-carry-and-forward technique.**

Keywords-vehicular networks; delay-tolerant networks; rural services; vehicular infrastructure; data delivery

I. INTRODUCTION

Rural areas around the globe suffer from being deprived of high investments for technological advances and services. Often, services provided for urban/suburban environments are not supported by governments for rural areas because of the low population of these areas, which does not always translate to a good ROI. Although this state of affairs remains dominant for economic reasons, the interest in rural services is progressively increasing in order to achieve a degree of fairness in service provisioning for such areas. Instead of increasing the level of financial support for these areas, governments are trying to find solutions and approaches for utilizing the resources already available in rural areas to enhance the services provided for rural residents.

One of the key enablers of many of the urban services is the availability of IT infrastructure that can be used to provide direct access to information/services for residents or passers-by, to collect data that can be used later for service provisioning, or to relay data among service publishers and subscribers. Rural areas suffer from lack of infrastructure because of the high level of investment they require and this is one of the main reasons for the limited number of rural services compared to those available for urban areas. Even if a rural area may have limited infrastructure deployment, use of such infrastructure will be expensive and very restricted. This all makes rural areas a challenging environment for providing services with the available, limited resources, and calls for additional flexible elements to compliment the limited available infrastructure with no or little extra deployment costs.

Resource-rich vehicles can play a pivotal role in service provisioning and are currently the focus of novel solutions for many of the data/service delivery challenges and obstacles. Equipped with many in-vehicle sensors and an on-board unit and mounted with a communication module, a vehicle can be considered as a mobile service provider for other vehicles and third parties [1][2][3].

In the context of rural services, a vehicle can serve as a flexible and available element to communicate and provide many of the services that are hindered because of lack or restricted use of infrastructure. Some of these services are those related to environmental monitoring, including road and weather conditions. In urban environments, data needed by such environmental monitoring services are collected by means of on-road sensors that report the sensed data to sinks/base stations connected to the Internet via a backbone network. Such a reporting paradigm cannot be deployed in rural areas because of the high investments needed to deploy on-road sensors and reporting sinks. Instead of depriving rural areas of such services, vehicle-based paradigms can be utilized with no/very low cost. With its on-vehicle sensors, a vehicle can be considered a cost-effective replacement for on-road sensors, and with its communication capabilities, it can be considered a standalone, mobile sensing and reporting resource [4]. In other words, a vehicle, on the move, can monitor the surrounding environment, sense related-data, and report such sensed data to the designated data center/collecting point.

We remark that sensing and delivery of environmental monitoring data are considered delay-tolerant, as they allow for bounded delivery delay without affecting the quality of the provided services. Hence, in rural areas, delay-tolerant services can be supported by vehicles in spite of the sparse nature of rural traffic and the resulting intermittent connectivity. For delivery of such data, a number of delay-tolerant routing and

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data delivery schemes have become available for vehicular networks. These schemes adopt the well-known paradigm of store-carry-and forward for storing data when there are no neighbors in the vehicle's vicinity, storing and carrying them on the move, and forwarding them when another vehicle comes in contact. Most such schemes depend solely on vehicles and vehicle-to-vehicle (V2V) communication for data relaying and delivery. As a part of the vehicular network, road-side units (RSUs) will be deployed for enhancing the operation of the vehicular network by providing some sorts of vehicle-to-infrastructure (V2I) and infrastructure-to-vehicle (I2V) communication. Although they are an important part of the vehicular network, RSUs are ignored by most of the delay-tolerant schemes which, as mentioned earlier, depend only on V2V communication. Such ignoring of the utilization of RSUs leads to some missed opportunities that, if taken into consideration, can enhance the performance and operation of the data delivery scheme.

Despite the lack of infrastructure in rural areas, it is envisaged that RSUs will be deployed at selected road intersections for enhancing the Intelligent Transportation System (ITS) services. Compared to the wide services provided by RSUs in urban areas that are enhanced by the backbone connectivity of RSUs amongst one another and to the Internet, RSUs in rural areas will have no wide backbone network connecting them to one another and to the Internet for saving the deployment cost of such a network, but they, when urgently needed, will depend on the broadband connectivity available there which, in most cases, will be in the form of cellular communication. As an expensive broadband network, the cellular network available to RSUs in the rural areas will be restricted and allowed only for critical data and not for delay-tolerant data. Therefore, the store-carry-and-forward data delivery mechanism will be the dominant one for supporting the environment monitoring services in rural areas.

In the traditional store-carry-and-forward mechanism for delay-tolerant data delivery, a vehicle continues to carry the data even if the vehicle is heading away from the destination's direction [5]. This will lead to eventual packet dropping because data packets are being moved far from the destination with such direction-agnostic delivery scheme.

This paper proposes an infrastructure-assisted data delivery (IADD) scheme for enhancing and provisioning delay-tolerant services for rural areas. IADD utilizes the availability of RSUs at intersections without depending on the expensive broadband backbone network. It follows the store-carry-and-forward mechanism for data delivery with the assistance of RSUs to handle cases where vehicles are moving away from the data destination. IADD is a direction-aware data delivery mechanism that combines V2V, V2I, and I2V communication for the sake of reporting delay-tolerant data with significant improvements to the data-delivery ratio compared to the traditional store-carry-and-forward mechanism that ignores vehicles' headings. Vehicles are the primary data forwarder, due to their more extensive coverage of the geographic terrain. RSUs will be used for relaying only when there are no viable peer vehicles for the data packets. Priority in storing the packet therefore will be given to vehicles, provided they are heading towards the same general direction of the destination of a packet.

To the best of our knowledge, IADD is the first delay-tolerant, infrastructure-assisted data delivery scheme that takes vehicles' headings into consideration in order to improve data delivery ratios and to lower end-to-end delays.

The rest of the paper is organized as follows. Section II discusses some related work about delay-tolerant data delivery schemes and covers the few infrastructure-assisted data delivery schemes for vehicular networks. In Section III, the proposed infrastructure-assisted data delivery (IADD) scheme is introduced along with its detailed functionalities. Section IV presents the performance evaluation of the proposed scheme via simulation. Finally, Section V concludes the paper and discusses our future work.

II. RELATED WORK

Several data delivery schemes have been proposed for vehicular networks. In this section, we highlight some of relevant protocols and discuss their suitability for use in rural areas and for delay-tolerant services.

A. Delay-Tolerant Data Delivery Schemes

Many delay-tolerant routing and data delivery schemes are available in the literature for use by vehicular ad-hoc networks (VANETs) [6][5]. As mentioned earlier, these protocols depend on the store-carry-and-forward mechanism for handling the intermittent connectivity of vehicles in sparse environments such as rural areas. We categorize the unicast VANET delay-tolerant data delivery schemes into two categories; *a)* anchor-based, and *b)* trajectory-based.

The most well-known VANET delay-tolerant delivery scheme is the Vehicle-Assisted Data Delivery (VADD) scheme [7]. VADD adopts the idea of carry-and-forward but in an anchor-based fashion where packets stop at junctions for determining the next road segment to go through. At intersections, VADD chooses the segment with the least delivery delay computed using a set of linear system equations that takes into consideration the segment's density, average vehicle velocity, and length. After determining the next road segment, VADD has four options for choosing the next forwarding vehicle: 1) L-VADD: selects the closest node to the selected outgoing road regardless of its direction, 2) D-VADD: selects a node going toward the selected outgoing road regardless of its distance to it, 3) MD-VADD: selects multiple nodes going toward the selected outgoing road, and 4) H-VADD: combines both L-VADD and D-VADD to reduce the delay incurred in D-VADD and avoid the potential loops of L-VADD. In VADD, if a vehicle does not find a forwarding vehicle at the selected segment, it loops on the other segments in a prioritized way as long as their delivery delay is lower than the vehicle's current one, and if no possible hop is found, the packet holder decides to keep carrying the packet till a neighbor comes in contact. While carrying the packets, vehicles do not pay attention to their movement direction relative to the packets' destination; therefore, in many cases, packets will be eventually dropped if they expire before reaching their destination.

The Geographical Opportunistic (GeOpps) routing scheme [8] is an example of a trajectory-based scheme. GeOpps assumes that each vehicle is equipped with a navigation system from which it can obtain its complete trajectory to the destination. In GeOpps, vehicles compute the closest point on their trajectory to the packet destination. Given this point and the map obtained from the navigation system, vehicles estimate the minimum time required to reach the destination (METD). Vehicles periodically broadcast messages carrying information about the destinations of the buffered packets. Each 1-hop neighbor computes its METD for each destination and replies to the packets holder which chooses the neighbor with the smallest METD for each destination, or keeps carrying the packet if it has the smallest METD to the packet destination.

Another example of a trajectory-based scheme is the Motion Vector (MoVe) scheme [9] which depends on knowledge of a neighboring node's relative velocity. In MoVe, when a vehicle has a packet to forward, it broadcasts a periodic HELLO message. When a neighbor receives the beacon, it replies with a RESPONSE message to the packet holder. Both the HELLO and RESPONSE messages are piggybacked with the velocity information and the packet is sent to the neighbor that is predicted to get closer to the destination. The packet holder keeps carrying it if it is on the most promising trajectory to the destination.

Other trajectory-based delivery schemes can be found in [10] and [11]. Although in trajectory-based schemes, vehicles depend on their neighbor vehicles' headings in forwarding decisions – while keeping the packet in cases of no better advancing neighbor – vehicles do not consider their own headings; hence, packets still might be moved away from their destinations.

Some other delay-tolerant data delivery schemes depend on flooding to deliver data to destinations and they can be considered suitable candidates for rural areas with their sparse nature. Examples of these schemes are the Epidemic routing scheme [12] and the Border Node-Based Routing (BBR) scheme [13] that improves on Epidemic routing by the use of controlled flooding. Such flooding-based schemes are not preferable for sending unicast data because they do not efficiently use the network bandwidth and node buffer space.

B. *Infrastructure-Assisted Data Delivery Schemes*

A number of data delivery schemes have been proposed to make use of already deployed RSUs for purposes of better QoS; e.g., lower delay. We categorize them into *a)* non delay-tolerant, and *b)* delay-tolerant schemes.

The Infrastructure-Assisted Geo-Routing scheme [14] is an example of the non delay-tolerant category but with no strict delay considerations. It assumes that RSUs are partially connected and exploits that reliable interconnection to improve the end-to-end performance. This scheme depends on modifying a traditional topology-aware protocol by taking the connectivity of RSUs into consideration when relaying data. As RSUs are connected through the internet, the scheme ignores the distance among these RSUs in calculating the shortest path and represents them as a unique graph node referred to as a backbone gate. Making use of RSUs and their backbone interconnection saves a number of hops and this, in turn, reduces the end-to-end delay and enhances reliability. Following the same approach, the Infrastructure-Assisted Routing scheme proposed in [15] utilizes the interconnectivity of RSUs for relaying data with the focus on buffer allocation and management challenges for RSUs. Despite the performance improvements achieved, because of the reliance on the backbone connectivity of the RSUs these two delivery schemes are not suitable for use in rural areas due to the limited backbone connectivity in such areas.

One of the early schemes utilizing RSUs is the Roadside-Aided Routing (RAR) scheme [16]. RAR is a non delay-tolerant scheme that depends on partitioning the geographical area of interest into closed sectors formed by RSUs at the borders of each sector. A routing protocol is proposed to manage exchanging packets among vehicles in different sectors through RSUs. One of the drawbacks of RAR is that it requires deployment of a large number of RSUs to form sectors, which is not feasible in rural areas and even in urban areas at the early stage of deployment. In addition, RAR requires hierarchical addressing with an affiliation protocol which increases its complexity.

As an infrastructure-assisted, delay-tolerant scheme, the Static-Node Assisted Adaptive routing protocol (SADV) utilizes RSUs deployed at intersections for data relaying and reduced data delivery delay. In SADV, a packet can be buffered at the RSU available at an intersection until a vehicle is encountered on the best delivery path to further forward the packet. This improves on VADD where, when there is no forwarding opportunity on the best path, the data may have to be forwarded on an available, detoured path. For determining the best forwarding path at intersections, SADV depends on real-time measurements in contrast to VADD which depends on some statistical data. In this way, by having packets go only through the best path, SADV improves the data delivery performance.

Some other schemes utilize RSUs to provide internet access to vehicles. In such schemes, RSUs are used as gateways to the internet and not as data relays. Examples can be found in [17] and [18]. These schemes are not suitable for deployment in rural areas.

All of the aforementioned delay-tolerant data delivery schemes, whether infrastructure-assisted or not, do not take vehicles' headings into account, which may lead to a low data delivery ratio and longer delays, as discussed earlier. Our proposed data delivery scheme improves on these schemes by being direction-aware while carrying packets to save them from going away from their destination, which is expected to reduce delivery delay and improve delivery ratio.

III. INFRASTRUCURE-ASSISTED DATA DELIVERY (IADD)

The main goal of the proposed IADD scheme is to improve the delivery rate of data packets associated with services that need to be provided to rural areas, subject to bounded delay requirements. In order to achieve this goal, IADD depends on both vehicles and RSUs for its operation. Vehicles are the primary forwarders of data packets, and RSUs will be used only when there is no suitable forwarder for data. The major forwarding decisions will be made at intersections, where a vehicle will not relay data to a RSU unless neither it nor its peer neighbors are heading towards the destination. This implies that a vehicle will always estimate its heading compared to the destination at an intersection before it makes a forwarding decision to a RSU, and will keep the packet further if it decides that it is still going in the general direction towards the destination. On the other hand, once a vehicle chooses a road segment to forward the packet along, it will attach the address of the next RSU along that segment as a temporary anchor for the packet. This way, a packet is not just sent to another vehicle that is geographically closer to the destination, but is kept along a path that is optimized at each intersection.

IADD requires RSUs to be already installed at intersections. However, no inter-RSU connectivity is needed, which makes IADD suitable for the challenges of rural areas. The details of IADD are explained in the following two subsections, and are better understood by way of example as illustrated in Fig.1 and explained in the following paragraphs, where a source vehicle S needs to deliver data to destination D, with S's route as shown in the dashed arrow.

In a pure vehicular ad hoc delivery mechanism, only vehicles are responsible for forwarding and delivering data packets. As can be seen in Fig. 1a, this mechanism may result in a higher rate of dropped data packets in the sparse scenario that is prevalent in rural areas. As shown, the source S does not find a possible forwarder and has to keep carrying the packet. At intersection I_3, it will move farther from the destination while carrying the packet which will lead to eventual dropping.

In the proposed IADD scheme however and as shown in Fig. 1b, when S encounters the RSU on I_3, it will find that it has no neighbors in the vicinity to which it can forward the data, and since it is not heading towards D, it decides to forward the data to the RSU on I_3. As can be seen in Fig. 1c, the RSU on I_3 will check to see if it has encountered neighbor vehicles leaving the intersection. In this case it will find M, which is on a segment with high directional priority, so it will forward the data to M. M, upon reaching intersection I_4, will find that it has no neighbors of its own. Before it decides to forward the data to I_4, it checks first if it is heading towards the destination. As it is indeed heading towards D, it decides to keep the data further. At the end, the information reaches its designated destination via the final intersection point, I_5.

As the purpose of IADD is to enhance rural information services such as environmental monitoring by efficiently delivering the vehicle's sensed data, vehicles using IADD will deliver data to a designated data collector/sink which is D in the example. For utilizing the collected data, D can aggregate the collected data from all vehicles, filter them, and send them periodically through the available broadband network to the data center responsible for analyzing the data and providing the service. We assume that we have a single sink/destination that will be deployed at the intersection with the highest traffic load in the area for the best delivery opportunities. Having a single data collector with data aggregation and filtering capabilities reduces the amount of data to be transferred to the data center; hence, reduce the cost of using the broadband network.

A. IADD at the Vehicle on the Road

In IADD, vehicles keep basic information about their peer vehicle neighbors, and use this information whenever a data packet needs to be forwarded. Assuming the availability of a road map, it is possible for a vehicle to determine the road segment on which another peer vehicle resides, given its location information. The logic a vehicle follows in order to forward a data packet is illustrated in Algorithm **IADD Forward by Vehicle**. A vehicle can be in one of two modes of operation; segment mode or intersection mode. In *segment mode* (lines 28-36), the vehicle is traveling along a road and not near any RSUs, and thus when it receives a data packet that needs to be forwarded it will depend solely on the existence of peer vehicles along that road segment. Greedy forwarding will be used by the vehicle to find the closest peer neighbor to the next RSU at the end of the current road segment, thus

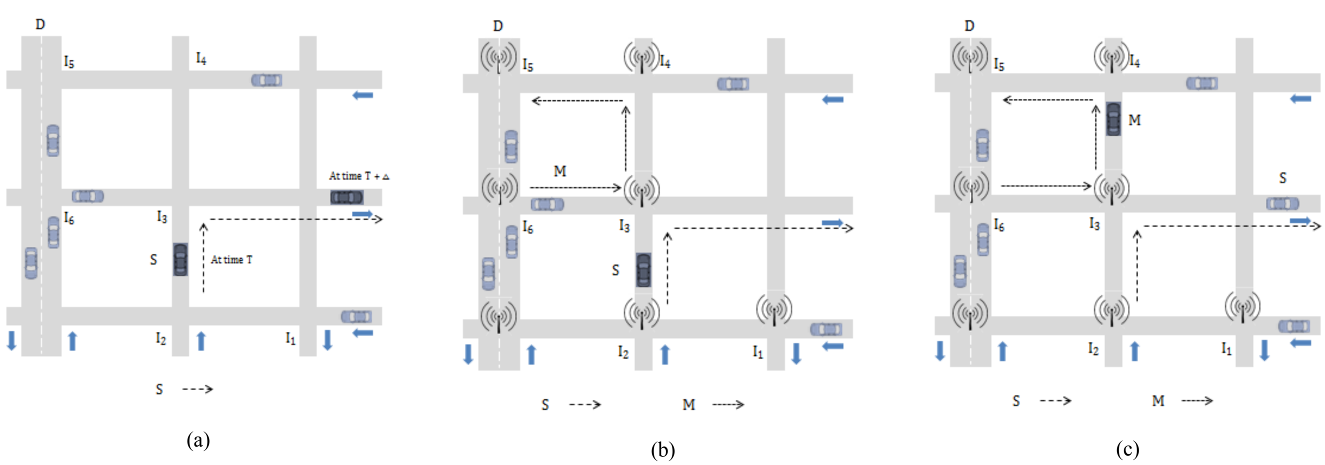

Figure 1. IADD illustrative scenario. Source vehicle S is carrying data that needs to be delivered to destination D, and its path is shown as seen in the dashed lines. The dark vehicles are the data carrying ones. In (a), there is no infrastructure to relay data to in a sparse traffic scenario, so a source vehicle S will continue to carry the data that will be dropped eventually as it is moving away from the destination. Parts (b) and (c) show the potential improvement offered by IADD by utilizing RSUs. In (b), source vehicle S will encounter the RSU at intersection I_3 where it will forward the data to since it estimates that it is going away from D. In (c), RSU_3 will forward the data to M, since it is located on the segment closest to D. At I_4, M will decide to keep storing the data since there are no neighbors and M is heading towards D anyway. M delivers the data finally to D.

anchoring the packet to the next intersection for subsequent forwarding decisions. If there is a better neighbor along the road segment, the vehicle will forward the packet to that neighbor. Otherwise it will keep holding the packet further, until new neighbors are encountered or it approaches the next intersection.

When a vehicle receives a beacon from an RSU announcing its presence, and if the vehicle has data packets to forward, the *intersection mode* is activated (lines 9-27). An RSU announcement beacon will include the RSU's assessment of its linked segments in a prioritized list that carries each segment's weighted priority computed based on the real-time traffic density information it collected and the segments' directional priorities to the sink. The segments' weighted priority is computed as

$$weighted\_priority(S_i) = \alpha \times direction\_priority(S_i) + \beta \times density(S_i) \quad (1)$$

where α and β are tunable parameters that can be adjusted according to the desired delay bound and traffic density, *direction_priority*(S_i) is the priority of a road segment in terms of its general direction towards the destination, and *density*(S_i) is a normalized density estimation of that road segment based on the volume of traffic a RSU encounters because of its observation of traffic at the intersection.

Algorithm 1: **IADD Forward by Vehicle**

```
1.  Input:
2.  Data packet p.
3.  List of road segments RS, ordered by density, sent from RSU.
4.  Neighborhood list N.
5.  begin
6.  if V is close to destination do
7.      send packet to destination
8.  else
9.      if Intersection_Mode = true do
10.         rd_lst[] ← weighted priorities for segments in RS,
            according to (1);
11.         foreach RD_i in rd_lst[] do
12.             RD_next ← RD_i;
13.             VonS ← list of neighbor vehicles on RD_next from N;
14.             if VonS is not empty do
15.                 V_next ← vehicle furthest on segment;
16.                 send p to V_next;
17.                 packet_relayed ← true;
18.                 break;
19.             endif
20.         endfor
21.         if packet_relayed = false do
22.             if V is heading close to destination do
23.                 keep holding p;
24.             else
25.                 send p to RSU_next;
26.             endif
27.         endif
28.     else // RoadSegment_Mode
29.         if N is empty do
30.             keep holding p;
31.         else
32.             V_next ← neighbor closest to RSU_next from N;
33.             send p to V_next
34.         endif
35.     endif
36. endif
```

A vehicle uses the prioritized list announced by the RSU at the intersection where the vehicle is making the decision for choosing the best available road segment. The vehicle proceeds to check if it has neighbor vehicles along the best chosen segment, and if it does, it chooses the next forwarder along that best segment in a greedy way. If it does not find a possible forwarder along the best segment, it searches for a forwarder on the other possible segments in a prioritized way. If a vehicle does not find a proper peer forwarder, it checks if its current heading indicates that it is going towards the destination. If that is the case, the vehicle continues to hold the packet, in the hopes of finding a better forwarder later. If, on the other hand, the vehicle is not heading towards destination, it sends the packet to the RSU, which then initiates its own forwarding procedure. The RSU forwarding procedure is explained in the following subsection.

B. IADD at the Intersection RSU

RSUs periodically scan their corresponding intersection area for vehicle neighbors, and periodically update the densities of the road segments linked to their intersection. Accordingly, each road segment will be associated with a real-time traffic density. This traffic density is averaged over a tunable time interval Δτ, which is a time interval used to control freshness of density information and average the overall long-term density estimation, according to

$$average\_density(S_i) = \frac{density(S_i)}{\Delta\tau} \quad (2)$$

Whenever a packet requiring forwarding arrives, an RSU will depend in its forwarding decision on the road segments' weighted priorities computed based on both the real-time density and the directional priority for each of the linked segments according to (1).

The data delivery logic carried out at the RSU is illustrated in Algorithm **IADD Forward by RSU**. The RSU will search for appropriate vehicle neighbors on the corresponding road segments in the order of their weighted priorities (lines 5-8). If it finds an appropriate forwarding vehicle on one of the segments, it forwards the packet to that vehicle, along with the address of the next RSU along that road segment as a temporary destination used for anchoring the vehicle in its overall path towards the destination (lines 9-16). If the RSU cannot find a forwarder, it continues to store the packet (lines 17-19). As long as there are packets to be forwarded at the RSU's buffer, it continues to periodically check if there is a suitable neighboring vehicle for the packet to be forwarded to.

IV. Performance Evaluation

In this section, the details of the simulation model and environment used for implementing the IADD scheme are detailed. To enable accessible benchmarking, and to allow for

Algorithm 2: **IADD Forward by RSU**

```
Input:
Data packet p.
Ordered weighted road segments RS.
Neighborhood list N.
begin
found_forwarder ← false;
foreach RD_i in RS do
    VonS ← list of neighbor vehicles on RD_i from N;
    if VonS is not empty do
        V_next ← vehicle furthest on segment;
        Send p to V_next;
        found_forwarder ← true;
    endif
    if found_forwarder = true do
    break;
endfor
if found_forwarder = false do
    keep holding p;
endif
```

potential further extensions, we carried out our simulations in NS-2.

The objective of the simulation analysis encompasses analyzing the performance of IADD in terms of *packet delivery ratio* and *packet delivery delay* and comparing it to a data-delivery scheme that does not involve the assistance of RSUs.

A. Simulation Setup

The proposed IADD scheme was implemented using the NS-2 network simulator [19]. The NS-2 simulation parameters and network configurations are shown in Table I. Data packets were sent using the UDP transport protocol with the traffic rate set to constant bit rate. Simulations are conducted for a period of 1000 seconds.

Experiments were performed over five different scenarios with different numbers of nodes (25, 50, 75, 100, and 125 nodes) to represent various levels of traffic density within a $1000m^2$ area. To generate a realistic vehicular topology and traffic movement, we used MOVE (MObility model generator for VEhicular networks) [20] in conjunction with the SUMO (Simulation of Urban MObility) vehicular simulator [21]. We divide simulated vehicles into 10 different traffic flows each following a different path on the topology. Fig. 2 shows the schematic topology of the simulated vehicular scenario as taken from SUMO.

TABLE 1: SIMULATION PARAMETERS AND CONFIGURATIONS

Simulation Parameter/Configuration	Value
Number of vehicles	25, 50, 75, 100, 125
Max. Node Velocity (*Km/h*)	40
Average Road Length (*m*)	300
Number of Lanes/Road	2
Beaconing Interval	0.5*sec*
Data Packet Size	50 *bytes*
Antenna Type	Omni directional
Propagation Model	Two-ray Ground
Transmission Range	250*m*
Link-/MAC Layer	802.11
Topography Dimensions(*m*)	1000 × 1000

In each of the scenarios, 10 vehicles have data packets to send to the designated destination that is the end point of collection. These vehicles are chosen randomly for each scenario. Two main metrics will be used to assess the performance of the IADD scheme; *packet delivery ratio* and *packet delivery delay*. IADD targets an improved delivery ratio while bounding the incurred delay to a limit that should be application-specific. Based on preliminary results, we have set the α and β weights to be 0.8 and 0.2 respectively. This gives a higher weight at each RSU to the linked segments whose direction brings a packet closer to the destination.

B. Simulation Results and Analysis

We compare IADD to a store-carry-and-forward scheme that has no assistance from RSUs. We compare the two schemes in terms of the *packet delivery ratio* and *packet delivery delay* as shown in Fig.3 and Fig.4.

As shown in Fig.3, IADD has significantly improved the *packet delivery ratio* compared to the scheme that has no RSUs assistance. This improvement comes from the fact that IADD saves many packets from eventual dropping by preventing packet holders from keeping the packets when moving away from the destination. In such cases, vehicles leave the packets at the nearest RSU, which will attempt to find the best available forwarder going towards the destination, and thus will give those packets a chance to reach the destination instead of being dropped. As the number of vehicles increases, the delivery ratio of IADD increases too due to having more potential forwarders and forwarding opportunities.

We notice a decrease in the delivery ratio of the scheme

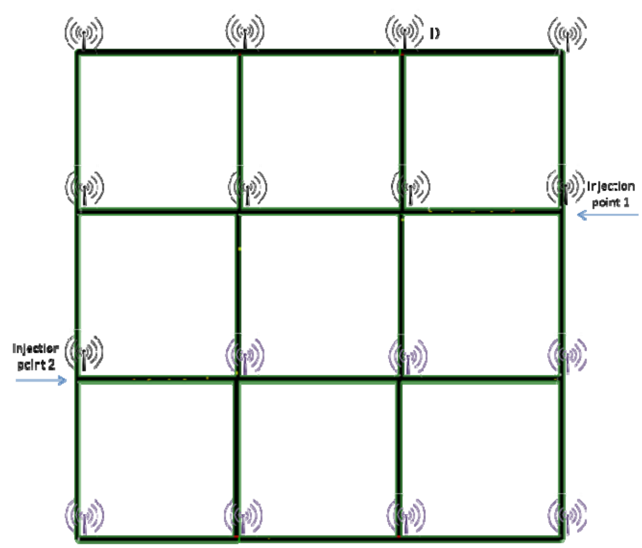

Figure 2. Simulation topology, with the RSUs placed at different junctions. Vehicle points of entry are at injection points 1 and 2.

that has no RSU assistance as the number of vehicles increases. We found this decrease to be mainly attributed to the increase in the number of packet collisions. Depending solely on vehicles for data delivery increases the collision probabilities of the packets exchanged among vehicles. This is not the case with IADD as with engaging RSUs in data delivery, some of the data forwarding load done by vehicles is offloaded to RSUs which decreases the packet collision opportunities compared to the scheme with no RSU assistance and load sharing.

In Fig.4, we compare the two schemes in terms of the *packet delivery delay*. In this comparison, we only consider the packets that are actually delivered by both schemes. Depending on the paths taken by the random vehicles sending the data, the delivery delay of IADD can either be the same as the one that has no RSUs assistance (if the vehicles are going closer to the destination), or much lower (if the random vehicles' paths were getting them farther from the destination in a part of their paths). As shown in Fig.4, for different number of nodes, the *packet delivery delay* of IADD is lower than the other scheme. This is because some of the random vehicles sending packets were moving away from the destination for a part of their path, so IADD has saved the packets carried by these vehicles from going around in the topology and kept them for other forwarders going directly closer to the destination.

For the packets saved by IADD from being dropped, we plotted the average *packet delivery delay* for each scenario. As shown in Fig.5, the *packet delivery delay* decreases as the number of nodes increases because, by having more possible forwarders, the period of time that a packet has to wait at an RSU to be sent to a possible forwarder decreases.

As shown in the simulation results, IADD has achieved significant improvements for both the *packet delivery ratio* and *packet delivery delay* compared to a scheme that receives no assistance from RSUs.

V. CONCLUSIONS AND FUTURE WORK

Vehicular networks are poised to provide a myriad of 3rd-party services aside from the typical safety and infotainment applications. The abundance and mobility of vehicles provide for a cost effective service a provisioning opportunity for rural areas that will compliment public infrastructure deployments that may be in place.

In this paper, an infrastructure-assisted data delivery scheme (IADD) has been proposed. IADD depends on a delay-tolerant, store-carry and forward mechanism in which vehicles either forward packets to peer neighbors that are going closer to the destination or continue to carry data packets as long as they are heading towards the destination. A vehicle relays data packets to an RSU only when there are no suitable neighbors to forward to and the vehicle is heading away from the destination. RSUs continue to search for suitable neighbor vehicles from the ones passing by the intersection and moving along road segments prioritized according to direction and real-time density. Simulations demonstrate that the proposed scheme has a very high delivery ratio, while still keeping packet delay rates within a bounded

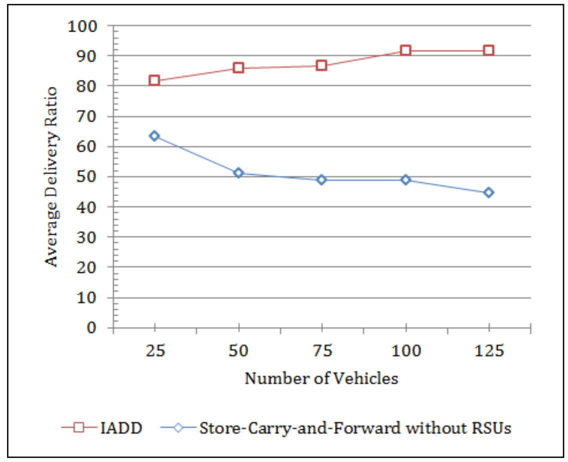

Figure 3. Avergae delivery ratio vs. number of vehicles

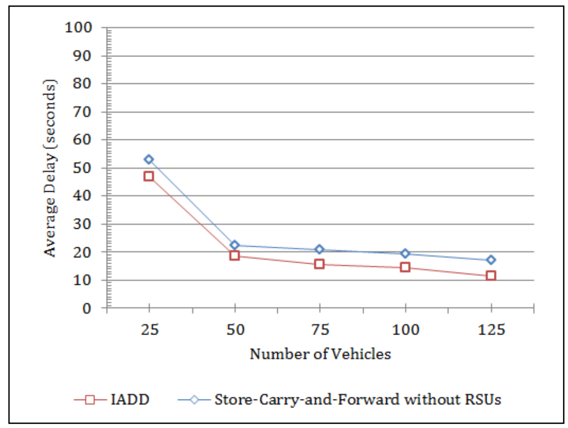

Figure 4. Average delay vs. number of vehicles.

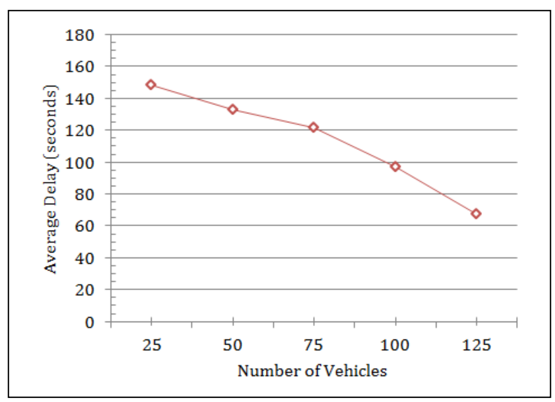

Figure 5. Average delay vs. number of vehicles for saved packets by IADD.

threshold that can be tuned according to the service that needs to be provided.

In our future work, we will consider having multiple destinations each reserved for serving/assisting a certain service. Moreover, a buffer elimination method will be deployed to help in managing RSU buffers based on service priorities. As well, we will consider having a target packet delivery ratio and study the number and locations of RSUs needed to achieve this targeted ratio.

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