International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
IJISAE
ISSN:2147-6799 www.ijisae.org Original Research Paper

Cellular-Aided Greedy Routing with Junction Oriented Recovery as an Offloading approach in VANETs

B. Vasumathi[1], **Amit Kumar Bhore**[*2], **Pradeepa D.**[3], **D. Sridhar**[4], **Mugunthan S. R.**[5], **D. Sangeetha**[6]

Submitted: 29/01/2024 **Revised**: 07/03/2024 **Accepted**: 15/03/2024

Abstract: The exponential growth of mobile data has put the existing cellular networks under a tremendous performance pressure. This alarming picture calls for newer wireless technologies to aid cellular networks for data communication. Over the last few years, vehicles as mobile routers have gained a lot of importance. Using a network of such ad hoc routers, we can offload mobile data traffic from cellular networks onto a vehicle based ad hoc network so as to reach destination road side units. But, one of the major concerns in offloading data is routing. Greedy routing in vehicle based ad hoc networks has been a very popular approach, but it faces the problem of local maximum. By incorporating greedy approach into routing the intention is to maximize the percentage of packet offloading as well as minimize the latency of packets. The proposed routing approach Cellular-Aided Greedy Routing with Junction Oriented Recovery (CAGRJOR) takes the help of Inviting Road Side Units in order to attract packets away from local maximum regions as well as recover packets which get generated in such regions. Taking a scenario, this work compares the performance of CAGRJOR with an existing greedy routing algorithm for crowd sensing vehicular networks, Greedy Forwarding with Virtual Roadside units (GFVIR). Undergoing simulations, the observations register a noticeable 60% decrease in latency as well as a 20% increase in packet offloading in the case of CAGRJOR over GFVIR.

Keywords: *Cellular Offloading, VANET, Greedy Routing, Local Maximum Problem.*

1. Introduction

Going into future as the world steadily embraces the concept of smart cities [3], data connectivity is going to undergo a major paradigm shift. As the need for hassle freeness and efficiency increases, the current established order will either become redundant or will need complementing. Cellular networks as is known are dependent on a careful usage of their resources like radio-frequency spectrum, infrastructure, and energy [4]. And given the sharp rise in the users being heavily dependent on it, there is a perceived degradation in the performance of cellular networks being able to provide infotainment services to the users. The cellular technologies that are in place now are already over-burdened. According to CISCO, the mobile data traffic will increase globally sevenfold leading up to the year 2021 [5]. And with the predicted data explosion, these existing technologies will be unable to satiate the users' need. This ever-increasing data hungry population is a major motivation in looking towards newer advanced wireless technologies [6] in order to provide better on-the-move experience to the users.

Talking about the future of data communication, smart vehicles [7] equipped with short range communication systems forming an inter-connected network of vehicles are taking center stage. Wireless technologies such as WAVE/IEEE 802.11p [8] have been proposed to make this possible in a vehicular environment. Vehicular Ad hoc Networks (VANETs) as these networks are called, present an altogether different set of challenges to master as viewed in comparison to Mobile Ad hoc Networks (MANETs) [9]. On-Board Units (OBUs) [10] will be equipped on each such smart vehicle in order to make them act as routers. So, with such vehicle-turned-routers in place we could route the data traffic to Road Side Units (RSUs) [11] which are road side contact points connected to the backbone infrastructure network. These RSUs connect the VANET to the infrastructure. In VANETs, RSUs are strategically placed in order to cover up for link breakdowns and to collect data from the vehicular nodes. Fig. 1 shows a combination of VANET as well as cellular networking scenario. A lot of work has already been carried out regarding RSU placement optimization [12][13][14] in VANETs. But, the RSUs can be utilized fruitfully only if proper routing protocols are there to take their advantage of, which the proposed work mainly deals with.

The smart city concept mainly revolves around utilizing available or collected data in order to provide better informed decisions to people. Floating Car Data (FCD) [15][16] related to vehicular traffic, weather etc. which are almost exclusively dependent on cellular networks for

---

[1,2] *Computational Sciences, Brainware University, West Bengal, India*
[3] *School of CSA, REVA University,Bangalore, Karnataka,India*
[4,5,6] *Department of Computer Science and Applications, Dr. Vishwanath Karad MIT World Peace University, Pune, Maharashtra, India.*
** Corresponding Author Email: bhore.amit@gmail.com@email.com*

delivery to target points can now be thought of being offloaded into much cheaper and readily available VANETs. With this tremendous growth of sensor based data, VANETs provide a lucrative method to ease off the pressure on cellular networks which can now focus on providing bandwidth consuming infotainment services to the users. Data which are delay tolerant [17] or even moderately delay sensitive like weather data need to be forwarded over vehicles in the VANET. Therefore, there needs to be suitable routing procedures in VANETs to be able to route such data through multi-hops in order to reach RSUs.

One of the more popular approaches of routing in VANETs is the greedy approach [18] [19] [20]. In this approach, packets are routed based on the position of the vehicles. This greedy approach also called as, position-based routing in which the neighbor which is nearest in position to the destination is chosen as the next hop. If there is no greedy next hop to forward to then, i.e., the sender vehicle is the closest node to the destination as compared to its neighbors, then the vehicle is said to be in a local maximum.

Fig. 2 shows an example of greedy routing. The data generated by all the vehicles need to be delivered to the RSU A. The region bounded by dashed lines represent a local maximum region with vehicle D clearly in a local maximum position. As a visual aid, Fig. 2 also provides supposed data flows using free-form yellow arrows. Data flows A1, A2, A3, and A4 follow greedy hops to reach the destination RSU A. Whereas, data flows A5 and A6 after following greedy hops end up in a local maximum region. This is a serious problem in greedy forwarding leading to increase in delay and fall in performance. Now, either the vehicle has to store and carry until it is no more in a local maximum position or needs to follow some recovery strategy to route the packets out of that local maximum position.

This work takes the help of greedy routing and mainly focuses on trying to offload maximum number of packets over to VANET as well as reducing the latency or average transmission delay of the packets. This work also tries to address the issue of local maximum in greedy routing by recovering packets which tend to get stuck in such forbidden areas which are the Local maximums. The proposed work on greedy routing revolves around dynamically placing Inviting RSUs (IRSUs) which are virtual RSUs in order to redirect the flow of packets. The authors in [21] have also taken the help of virtual RSUs in order to tackle local maximum problem in Greedy Forwarding with Virtual RSUs (GFVIR) position-based routing. Their approach is a centralized approach which assumes that area on which GFVIR is to be implemented has already been well identified for local maximum regions. The proposed algorithm is compared with GFVIR for parameters like Delivery ratio and latency in section VII.

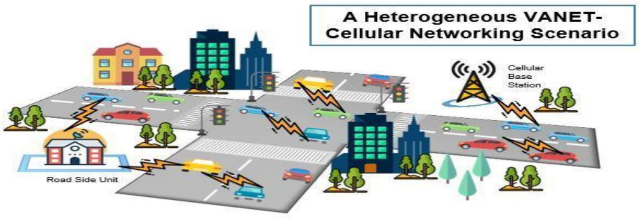


Fig.1. System model

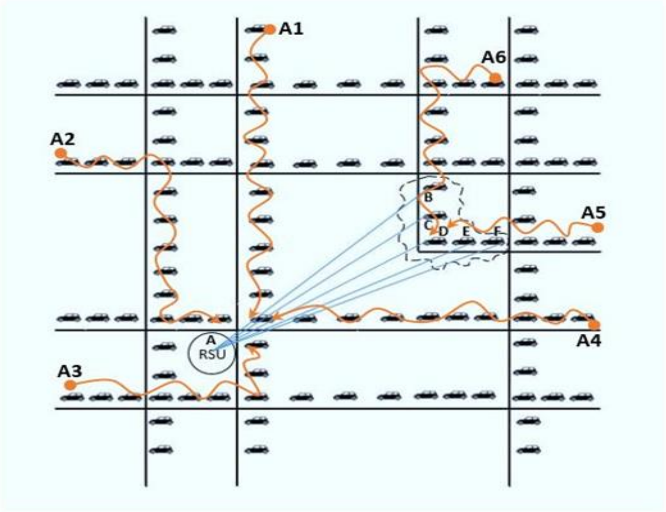


Fig.2. Greedy routing picture explaining LMP

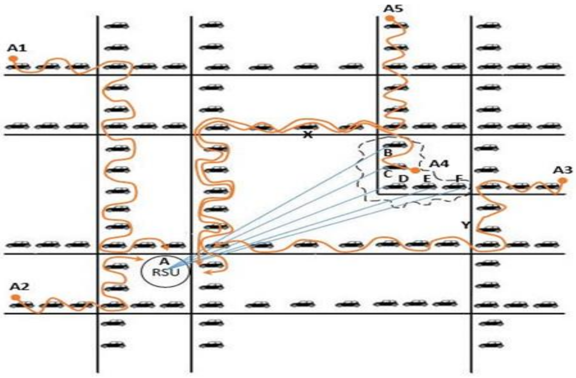


Fig.3. Overcoming LMP using IRSUs

2. Review Work

The review work comprises of a study of cellular offloading and routing in VANETs. Finally, the findings obtained after going through the existing works are noted at the end in this section.

The rapid growth of vehicles in the cities has been a major push towards realizing the concept of networking among vehicles. It was only a matter of time before smart vehicles equipped with the necessary technologies such as IEEE 802.11p made vehicular networking a possible reality. The authors in [22] have provided a detailed survey on VANETs – the framework, features, applications, and challenges. Several wireless access technologies like cellular, Wi-Fi, DSRC/WAVE have also been discussed in their work showing the versatility of VANETs in the domain of data communication. But, citing a lack of proper literature study related to VANET performance, and in order to get more insight into the VANETs, the authors in [23] have undertaken field experiments using IEEE 802.11p. In their experiment, they have measured performance metrics such as throughput, delay, jitter, loss rate, and association time. Through their work they aim to improve future studies on VANETs.

[1] Explore VANET technology, its integral role within intelligent transportation systems, recent advancements in the field, and the anticipated timeline for system implementation. [2] It furnishes trajectory-based forwarding and redirection forwarding using data caching to manage alterations in the destination vehicle's trajectory caused by changes in its speed and direction. VANETs in combination with cellular networks have also been explored as a possibility [24] [25]. This kind of heterogeneous network provides a very feasible approach for wireless data communication on the move, as this section notes down some of recent works that have been carried out in the field of cellular offloading. The authors in [26] have proposed a novel framework defining a set of decision rules in order to exploit network diversity in a heterogeneous vehicular network. Their approach allows different types of paths of the same application to venture through the most favorable network in terms of throughput and delay. [27] Proposes a fully distributed Floating Car Data (FCD) collection protocol that is suited to a heterogeneous network provided by DSRC and LTE. Their objective is to reduce the number of concurrently active LTE channels by collecting FCD only through specifically designated nodes. These designated nodes are chosen by starting an election process in the VANET. Device-to-Device (D2D) communication has also picked up in recent years. The proposed solutions which aim to integrate D2D in cellular network demand added functionalities on the network resources, especially at time of discovery process. The work in [28] and [29] focuses mainly on offloading Device-to-Device (D2D) discovery process onto VANETs. The authors in [28] have presented a multitier heterogeneous adaptive vehicular network integrating cellular network with DSRC. Their work incorporates High Tier Nodes (HTN) and Low Tier Nodes (LTN) in order to balance the load between LTE/DSRC networks. The authors in [31] have stressed a lot of importance on big data collection in VANETs. They have developed an intelligent network recommendation system supported by traffic big data analysis. The traffic model for network recommendation is built through big data analysis and vehicles are recommended to access the appropriate Cellular/Vehicular network by employing an analytic framework which takes traffic status, user preferences, service applications and network conditions into account. According to them, this ensures the ubiquitous connectivity of vehicles using cellular network and VANET without overloading problem. The work in [32] provides an analytical study based on an optimization problem formulation where the aim is to select a maximum target set of flows to route through the VANET. The offloading decision in it considers link availability, channel load, V2V link quality and the maximum volume that could be offloaded from RSU to the vehicular nodes. After performing simulations, the authors concluded that the offloading fraction is highly related to the traffic flow volume. The authors in [33] 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 routing performance by selecting roads with guaranteed connectivity and reduced delivery delay. But, the heavy usage of cellular network in order to update locations of all the nodes to get an idea of the network can be too demanding in case of iCARII.

In order to have an offloading approach it is quite imperative to devise a routing scheme that suits well to VANETs. A detailed survey of the various kinds of routing approaches proposed till date in the field of VANETs has been provided in [34] [35]. In [36], the authors survey the existing data dissemination techniques and their performance modelling approaches in VANETs, along with optimization strategies under two basic models: the push model, and the pull model. But, according to [37], routing protocols based on the node’s positions have been suggested to be most adequate to VANETs due to their resilience to handling the nodes position variation. The authors have surveyed the existing position-based routing protocols with an emphasis on their applicability to different environments. A systematic classification of different position-based routing protocols into infrastructure-based and infrastructure-less categories has been provided in [39]. The authors also provide a comparative study of each protocol by taking different quality parameters. But, one of the major issues in position-based routing also called greedy routing, is the problem of local maximum [39] [40] [41]. A node is said to be in a local maximum if it has no greedy next hop to forward packets to. Once packets get stuck in a local maximum, there is a need for recovery. The authors in [21] have followed greedy approach for routing in crowd sensing vehicular networks. They propose two routing protocols - Greedy Forwarding with Available Relays (GFAVR) and Greedy Forwarding with Virtual RSUs (GFVIR). GFVIR is a centralized approach and has been concluded by them to perform better than GFAVR in most scenarios. But, neither of the protocols have any recovery procedure for packets stuck in local maximum regions other than to follow store-and-carry, which tends to increase in the packet delivery latency.

After undergoing literature survey of the existing works, it is found that there are two major areas which need improvement. The cellular overhead while data forwarding in the heterogeneous VANET-cellular network needs to be reduced. Also, the latency of packets needs to be reduced in order to further enhance the degree of cellular offloading.

3. Basic System Model

The network architecture as suggested in Fig. 1 is based on an urban city road establishment that tries to mimic a VANET. The major components of the network are:

A. On Board Unit (OBU):

An OBU consists of an assemblage of technologies needed for a vehicle to communicate with each other or the road side contact points connected to the infrastructure network. In particular, DSRC/WAVE (Dedicated Short Range Communications/ Wireless Access in Vehicular Environment) for short range wireless communication is to be used for automotive purposes. OBUs are the most essential part the system model that helps in realizing a VANET.

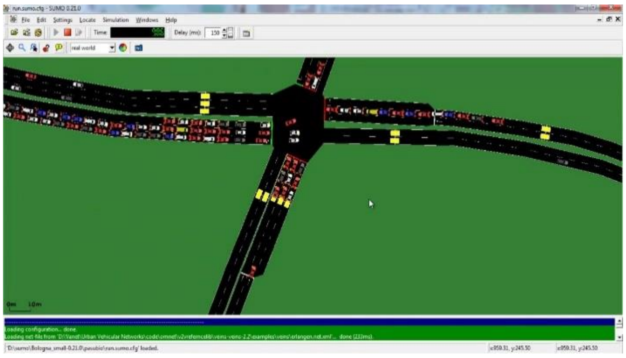
B. Road Side Unit (RSU):

RSUs play the role of destination nodes for all the data that is offloaded into VANET. The RSU is also equipped with the necessary technologies needed to communicate with the OBUs.

Communication in VANETs can be broadly categorized under the following three forms:

- V2V: V2V, also known as Vehicle-to-Vehicle communication, in which the OBUs communicate with each other using DSRC/WAVE technology. This kind of communication can be undertaken over multi-hops.
- V2I: Whenever an OBU is within proximity or in range of an RSU, this one-hop communication is termed as V2I i.e., Vehicle-to-Infrastructure. The communication between an OBU and an RSU can take place over Wi-Fi or DSRC/WAVE.
- V2C: The data which cannot be offloaded into VANET needs to be transferred to cellular network which is carried over Vehicle-to-Cellular communication also known as V2C.

The vehicles get to know about their immediate neighbors through a beaconing service. Through the beacons, information regarding a vehicle's position, speed, and direction can be known. Such information is kept in the neighbor table of every vehicle.



```
Loading configuration... done.
Loading net-file from 'D:\Vanet\Urban Vehicular Networks\code\omnet\v2vreferncelib\veins-veins-2.2\examples\veins\erlangen.net.xml'... done (233ms).
'D:\sumo\Bologna_small-0.21.0\pasubio\run.sumo.cfg' loaded.
```

Fig.4. Simulation for Traffic (Roadmap with Vehicles)

4. Data Model

Applications, that deal with moderately time-sensitive data like sensor data are the target applications. Data which is delay tolerant, is considered to be a trivial case, i.e., they will always be offloaded into VANET.

5. Problem Definition

In dense city regions huge amounts of sensor-based data are ordinarily transferred over cellular network. In order to reduce the load over cellular network, wherever possible, the objective is to offload packets into VANET in a maximum way possible, reducing the dependency on V2C. The generated packets though have a time limit defined by the timeout parameter of each packet which when expires, then those packets are forcibly sent over V2C.

6. Proposed Work

A. Introduction

Since OBUs which need to transfer packets are not always in proximity of RSU, a routing technique needs to be applied in order to make the packets travel in a multi-hopped manner to the RSU. The Cellular-Aided Greedy Routing with Junction Oriented Recovery (CAGRJOR) technique takes a greedy approach to route packets. But, with greedy approach there is an issue of local maximum which needs to be tackled.

Since, in greedy approach, the routing decisions are taken locally, some packets may unwantedly get stuck up in local maximum regions. So, in order to provide a global view of VANET, there needs to be a provision for a central knowledge base which would store information related to local maximum regions. Such a knowledge base can be accessed by every node over V2C, in order to make the routing decision an informed one. The nodes do not need to access the central knowledge base all the time. Only when a node needs to forward data in VANET, it will refer the database over V2C to get information related to local maximums so as to take informed routing decisions. In dense vehicular regions it is an unnecessary overhead to constantly keep a positional track of all the vehicles over V2C. So by using a central knowledge base which only stores local maximum related information there is a great reduction in V2C overhead. In order to avoid local maximums, the proposal takes the help of virtual RSUs whose positional information is stored in the prior mentioned central knowledge base. These virtual RSUs attract packets away from local maximum regions.

In CAGRJOR along with avoiding local maximum regions in the first place, there is also a recovery strategy for packets generated in local maximum regions to pull them out of those regions. This recovery strategy helps in reducing the latency of packets and therefore in turn the percentage of offloaded packets increases.

One more point that is worth noting is that although each vehicle maintains a neighbor table, it will not be used in the process of deciding which next hop to forward to. This is because on implementing routing using neighbor table, it was found out that stale entries are getting selected especially around corners at junction points because they are no more in line of sight. Reducing beacon interval to keep the latest information in the neighbor table is also not feasible as that would affect the performance of beaconing. Therefore, if a vehicle has packets to forward to, and if it receives a beacon from any neighbor, it decides depending upon the location parameter whether to forward or not. This way packet loss due to stale entry selection in the neighbor table can be eliminated. The role of the neighbor table is only to help in finding out Junction Nodes which is explained in JN (Junction Node) and IRSU Determination in sub section D in the Proposed Work section.

B. Assumptions

All the vehicles have an OBU on it. Each OBU has sufficient processing power, data buffer and is equipped with Global Positioning System (GPS), DSRC/WAVE, and LTE for cellular connectivity. The term OBU can be interchangeably used for vehicle or node.

The proposal assumes that in dense city regions, the vehicles are always connected. The vehicular density will only decrease if smaller transmission ranges are employed. Hence, the idea is to overcome genuine local maximum regions due to position constraints and not due to sparse vehicular density.

C. Terminologies used in the Proposed Work

1) Local Maximum Position (LMP):

While greedy forwarding to the destination, if a sender node has no greedy next hop to forward to, then the sender node is said to be in an LMP. The immediate region surrounding an LMP is considered a Local Maximum Region (LMR).

2) Inviting RSU (IRSU):

IRSU is a virtual RSU whose aim is to aid in the process of routing. It has no additional implementation cost. The role of IRSU is two-fold:

- IRSU is used to keep packets away from entering LMRs. That is, the LMRs are avoided from being traversed at all cost.
- The packets generated in LMRs need to be recovered from those regions. This is only possible if an IRSU is defined for that LMR. The packets are then forwarded to that IRSU in order to overcome the LMR. In the case of more than one IRSU being defined for an LMR, the one nearest to the RSU is chosen for forwarding.

3) IRSU Set (IS):

It is a set of location of IRSUs defined for a particular LMR.

4) Safe Path (SP):

The path that is chosen as an alternative to the path that would have otherwise lead to an LMR during the process of greedy forwarding. (Finding an SP is explained in JN and IRSU determination in sub section D of this section.)

5) Junction Discovery Query (JDQ):

This is a restricted broadcast started by the node which faced the LMP. The purpose of JDQ is to identify the nearest JNs. Effectively, JDQ identifies a Local Maximum Region (LMR)

6) Junction Node (JN):

A node is said to be a JN corresponding to an LMR, if:

- When that node makes at least a near-straight angle and a near-right angle with any two of its neighbors. The neighbor table which stores the current neighbors of a node is used to arrive at this decision.
- There is an SP available corresponding to that LMR for the node.

7) Junction Set (JS):

It is a set of location of JNs for a particular LMR. The elements of JS give us the location of junctions at which we need to find an IRSU so as to avoid falling into an LMR. In short, JS comprises of the end points of an LMR.

8) Central Knowledge Repository (CKR):

The problem with employing greedy forwarding is its localized routing behavior which is dependent only on the location of neighbors. This is the reason why sometimes packets may end up in an LMR. Therefore, we need to have an overall view of the positional constraints in an area. CKR is a global database that consists of information relating to LMRs. The structure of the CKR is shown in Table 1.

- Every LMR entry has a unique LMP attribute that acts as the focal point of that LMR.
- For each LMR entry, the corresponding JS is formed during the process of routing.

- And, for each element in the JS, a location of an IRSU is added into the IS for that LMR entry.
- Any LMP detected within a threshold range of 100m from an already defined LMP attribute of any LMR entry is not considered as a new case.

The structure of CKR is:

Sl. No.	Local Maximum Position (LMP)	Junction Set encompassing the local maximum region. (JS)	IRSU Set for the LMP (IS)
1.	A(x1,y1)	A = {A1, A2, A3…}	X = {X1, X2, }
2.	B(x2,y2)	B = {B1, B2, B3….}	Y = {Y1, Y2,}
….	….	….	….
….	….	….	….

Table 1: Structure of CKR

All the vehicles have access to the CKR over V2C as and when required during the process of routing. The CKR is empty before the routing is applied to any new region.

Δx	Generic OBU x
RΔx	Nearest RSU to OBU x
TB	Beacon time interval
Rj(IR)	Generic IRSU j
R(IR)	Set of IRSUs
P	Maximum number of consecutive beacons received by the receiver node from neighbours which are not greedy w.r.t. itself towards the destination node, after which the node is said to be in a local minimum.
C	Number of consecutive beacons received by the receiver node from neighbours which are not greedy w.r.t. itself towards the destination node.
(LMR)u	The Local Maximum Region corresponding to LMP u.
(JS)u	The Junction Set corresponding to LMP u.
(IS)u	The IRSU Set corresponding to LMP u.
(JDQ)u	Junction Discovery Query for LMP u.
(P-JDQ)x	A table for Δx that stores the LMPs for which it has processed a JDQ.
Q	A chosen range in order to restrict a JDQ to the local maximum region only.
dist(x, y)	Euclidean distance between locations x and y.
K	Exclusion distance of Rj(IR)

Table 2: Notations

D. The CAGRJOR Approach

A brief outlook of the CAGRJOR process is provided below:

1. Initially before CAGRJOR is applied to a dense vehicular region, the CKR is empty. The nodes have no knowledge of the local maximum regions. Here, the data forwarding takes place as usual in a greedy manner.
2. Gradually with time, some packet after being routed over multiple hops finds itself with a node that has a no greedy neighbor to forward to. At this point the below steps are followed:
    - The node starts a JDQ in order to locate the nearest JNs. This process is explained in Local Maximum Junction Discovery Phase in the current sub section D.
    - Once a JN is found by the JDQ, the position of IRSU is dynamically located. The JN and IRSU determination is explained in detail in the current sub section D.
    - The CKR is then updated with this information. It is important to note here that this JDQ takes place only once for a particular LMR because that LMR information is already updated in the CKR. The CKR eventually enables the nodes to a global view of the network which was earlier impossible in simple greedy routing.

3. Now, the nodes trying to forward packets can access the CKR to get information about the IRSUs. Cellular Aided greedy forwarding with Inviting RSUs takes place in the following way:

- The approach uses IRSUs to attract packets away from LMRs, i.e., the primary objective is to avoid LMRs at any cost. This process is explained in the Greedy Forwarding Phase in this sub section D.
- But if the packets are generated in an LMR, then the packets need to be recovered from that region using IRSUs. The recovery process is explained in this sub section D.

Therefore, the CAGRJOR approach can be broadly divided into 3 major phases. The 3 phases are:

- Greedy Forwarding Phase (GFP)
- Local Maximum Junction Discovery Phase (LMJDP)
- Recovery Phase (RP)

Additionally, there is a need of two new fields in the header of the data packets in order to accommodate this approach. These are:

- RF: It stands for Recovery Flag needed to indicate Recovery Phase.
- (LMP)u: The Local Maximum Position u due to which recovery is being done.

The OBU which starts the RP for the first time, it sets the RF and inserts the Local Maximum Position u in the data packet header, and greedy forwards it to the appropriate neighbor. Any OBU on receiving a packet that has RF set, realizes that the packet is in Recovery Phase and hence retrieves the LMP from the (LMP)u field and goes into RP itself. If RF of the packet is not set, then the OBU on receiving it follows GFP. By default all OBUs are assumed to be in GFP.

An Abstract view of the Data Packet Header is provided in Fig. 4.

Fig.4. An Abstract view of the Data Packet Header

The components of CAGRJOR are provided in detail below:

1) The Greedy Forwarding Phase (GFP)

This is the phase in which the vehicle forwards data packets following greedy routing approach. If RSU is a one-hop neighbor, then the vehicle forwards the packets to the RSU.

When RSU is not a neighbor to Δx,

- The nodes in GFP utilize IRSUs to stay clear of LMRs. Initially though, Δx which has packets to deliver, has to find out the RΔx.
- Then, Δx needs to get the list of IRSUs from the CKR and find the available IRSUs towards RΔx. The definition of an IRSU being available for Δx towards RΔx.
- Then, the nearest IRSU is selected as the addressed RSU from the set of available IRSUs. If the set of available IRSUs is empty, then the addressed RSU is set to RΔx. The addressed RSU is the destination node to deliver packets to.
- Upon receiving beacon from a neighbor Δy, the OBU Δx decides whether Δy is a greedy neighbor w.r.t. itself towards the addressed RSU.
- If Δy is not a greedy next hop, then increment c by 1. Otherwise, Δy is selected as the next greedy hop and c is reset to 0.
- If c > p, then Δx is in a local maximum. Then Δx switches to LMJDP. The functioning of LMJDP is explained in the later sections.

The proposal assumes p=20 depending upon the average vehicular density of the scenario.

2) The Local Maximum Junction Discovery Phase (LMJDP)

This is the phase, in which JNs are found for an LMR and thereby, the IRSUs are found out for that LMR. This is a one-time process for every LMR. Once IRSUs for an LMR is located, the packets that are generated in that LMR can be easily routed out of that region. Also, vehicles outside of that LMR avoid transferring packets into the LMR taking the help of information present in the CKR.

If Δx is in LMP u,

- Δx then checks the LMP j of all the entries in CKR. If u lies in q=100m range of any j, i.e., u is not a new entry and hence find (IS)j. If (IS)j is empty, then Δx waits till time out of the packets. If before that, Δx finds (IS)j as-non empty, then it switches to RP.
- If u is a new entry, then start Junction Discovery Query (JDQ) for u. The query includes within itself the LMP u position and direction of Δx and broadcasts it. Every OBU maintains a history of processed JDQs by storing the LMP from the query in the Processed-JDQ (P-JDQ) table. Δx then enters u into its P-JDQ.

  If Δx wants to relay a (JDQ)u,

    - o It first checks whether u is already present in its P-JDQ. (This is to avoid rebroadcasts.)
    - o If yes, then Δx has already processed (JDQ)u.
    - o Else, Δx checks the CKR to see if any element of (JS)u is within q=100m range of within itself. (A nearby JN has already been defined and so, this is to limit the JDQ to the LMR.)

o If there is no such element, then Δx checks whether it is a JN. If it is not a JN, it broadcasts the (JDQ)u by inserting in it u and its direction. Δx then enters u into P-JDQ. If it is a JN, it checks whether it is in q=100m range of any element of (JS)u (This is to avoid redundant junctions.). If not, then Δx adds its position to (JS)u.

3) The Recovery Phase (RP)

A vehicle in this phase tries to route the packets out of the local maximum region it is in. Utilizing the information present in the CKR, the packets are routed to the proximity of an IRSU, the details of which are explained below.

- If a Δx is in RP, then it has information regarding the LMP, say (LMP)u, due to which it is in a recovery phase.
- Initially, Δx which has packets to deliver, has to find out the RΔx. It selects the Rj(IR) in (IS)u, which is at the least distance from the RΔx. If Δx finds itself in the proximity of Rj(IR), i.e., there is no IRSU available, it then switches to GFP and RΔx becomes the addressed RSU. Otherwise, Rj(IR) becomes the addressed RSU.
- Upon receiving beacon from a neighbor Δy, the OBU Δx decides whether Δy is a greedy neighbor w.r.t. itself towards the addressed RSU.
- Δx waits until the time out of the packets before which if it gets a beacon from a greedy neighbor Δy, it then forwards to Δy. Otherwise, send packets over V2C after time out.

4) JN and IRSU Determination

1. Δx uses its neighbor table to find out whether there is:

   a. At least one pair of its neighbors with which it makes a near straight angle.

   b. At least one pair of its neighbors with which it makes a near right angle.

   Both the conditions are necessary to be met in order for Δx to be a JN.

2. If the above two sub-conditions are met, then Δx uses the direction information received from (JDQ)u in order to check if there is an SP.

   a. First, Δx calculates RΔx.

   b. From the neighbor table excluding all the neighbors which are in the direction retrieved from the (JDQ)u, Δx finds if there is a greedy next hop Δy w.r.t. itself towards RΔx.

   c. If there exists a Δy then, there is an SP. Therefore, Δx is a JN and its position is added to (JS)u. The location of Δy is now taken as the new IRSU position which is added to (IS)u.

5) IRSU Availability

An IRSU Rj(IR) is said to be available for Δx towards RSU RΔx if:

- dist(Rj(IR), RΔx) < dist(Δx , RΔx) : This condition ensures that Rj(IR) doesn't deviate the data away from RΔx.
- dist(Rj(IR), Δx) < dist(Δx , RΔx) : This condition ensures that Rj(IR) is not farther from Δx than RΔx.
- dist(Rj(IR), Δx) < k : The condition is to ensure that extremely nearby Rj(IR) are avoided to be considered as available because they won't prove to be any more useful.

Fig. 3 is an example of overcoming the problem of Local Maximum Region using IRSUs. The CAGRJOR approach is applied in Fig. 3 as a contrast to the simple greedy routing approach applied in Fig. 2. CAGRJOR over the period of its execution, would roughly compute X and Y as the two IRSUs for the LMR denoted by the dashed lines. Like in Fig. 2, the vehicles need to transfer the packets to the destination RSU A. As a visual aid, the supposed data flows are indicated by free-form yellow arrows. Data flow A4 which is initiated inside the LMR which earlier in greedy routing would not have been possible, is now able find its existence due to the presence of IRSU X. Even data flows A5 and A3 by utilizing IRSUs X and Y respectively, are able to route around the LMR to reach RSU A, which would have instead ended up in the LMR when only greedy routing would have been used. Quite clearly, CAGRJOR helps in maximizing data packet offloading into the VANET.

7. Simulation Settings

Both CAGRJOR as well as GFVIR were simulated using the VEINS framework which works upon OMNET++ discrete event network simulator and SUMO road traffic simulator. Fig. 5 shows the scenario that covers an area of nearly 1Km2 over which the simulations were run. There is clearly a local maximum region in the scenario marked by the dashed curve, where greedy forwarding fails. As can be seen, point B is the local maximum position which is nearest to the RSU other than any of its neighbors C and D. GFVIR algorithm takes the help of virtual RSUs in order to route packets. Attractive Virtual RSUs (AVRSU) are used to attract packets away from local maximum regions and Stopping Virtual RSUs (SVRSU) are used to select greedy hops in such a way that the packets don't end up in a local maximum region. In order to simulate GFVIR, strategically an SVRSU and an AVRSU were placed which are shown with the help of dashed circles in Fig. 6. The SVRSU intentionally covers the local maximum region. Obstacles area also placed in order to make the scenario more realistic by taking the help of Simple Obstacle Shadowing model present in VEINS. The points X and Y are the IRSUs that CAGRJOR dynamically computes over the time of simulation as shown in Fig. 7.

PARAMETERS	VALUES
Number of vehicles	200
Maximum Speed of vehicles	50 Km/hr
Transmission Range	[50,500]
Receiver sensitivity	-89dBm
Thermal noise	-110dBm
Beacon interval	3secs

Table 3: Simulation parameters and their values

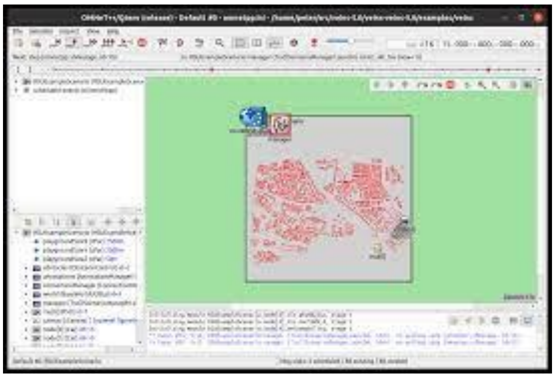


Fig.5. Actual Simulation environment with vehicles

SYMBOL	MEANING
DR	Delivery Rate per 100 packets that were delivered through VANET to RSU.
TR	Average Transmission Delay or Latency of packet delivery.
TO	Time out time for after which packets will be delivered through V2C.

Table 4: Notations used for observations

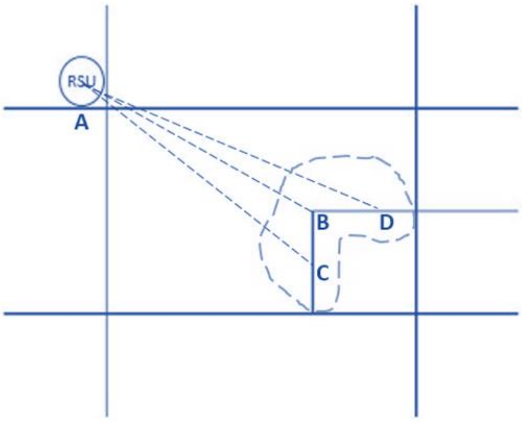


Fig.6. Scenario explained

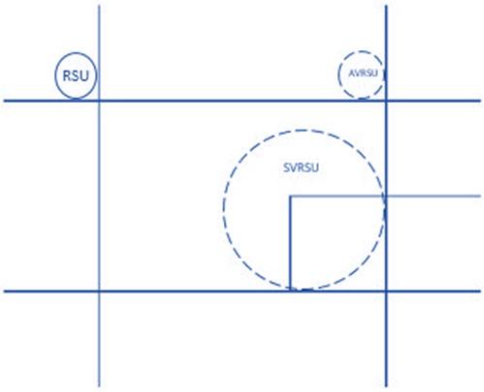


Fig.7. Scenario with AVRSU and SVRSU

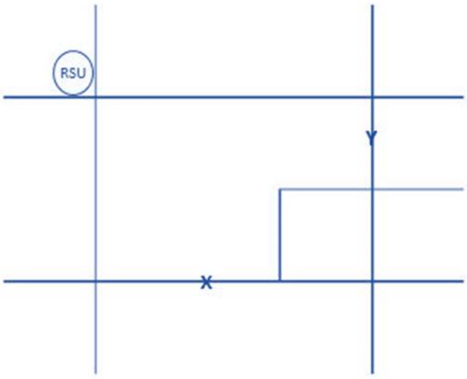


Fig.8. Scenario with IRSUs

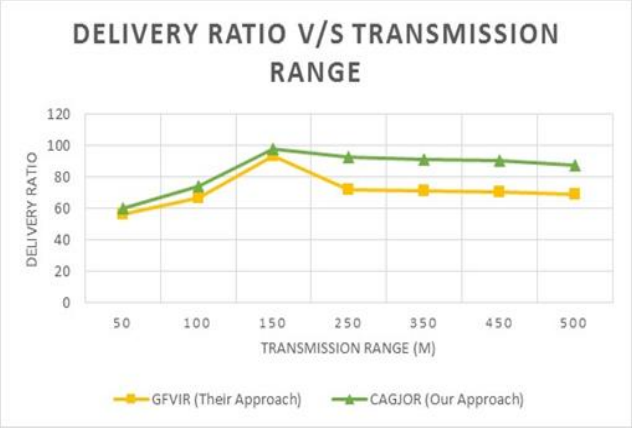


Fig.9. Plot1: Delivery Ratio v/s Transmission Range

The plot of Fig. 8 is between Delivery Ratio and Transmission Range for TO = 100sec. The average performance of CAGRJOR in the graph for all the transmission ranges, shows nearly a 20% jump over GFVIR in terms of offloading packets through VANET. As a matter of fact, the graph presents a very intuitive take on how wireless communication in VANETs work. For lower transmission ranges, the delivery ratio is pretty dismal due to packets being multi hopped over a lot of vehicles. This results in a hefty penalty of queuing and processing delay which otherwise would have been negligible for greater-distance transmissions. At a transmission range of 150m both CAGRJOR as well as GFVIR achieve their best packet delivery results i.e., 98.17% and 93.29% of the packets were offloaded through VANET by CAGRJOR and GFVIR respectively. But, beyond the transmission range of 150m, there is fall in the delivery ratio. This is primarily due to loss of packets due to collision as there might be unnecessary interference between distant generated signals even though there is multi-channel operation in IEEE 802.11p.

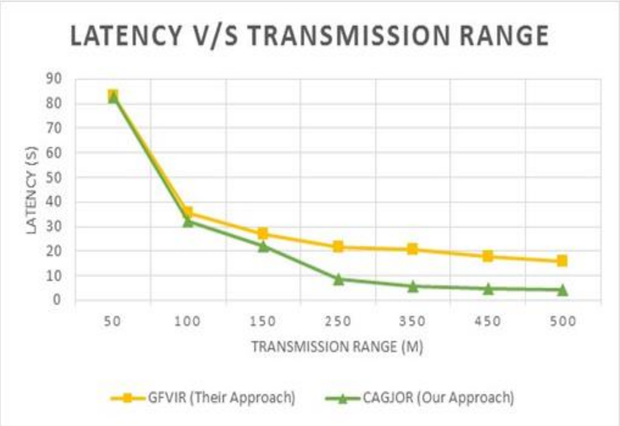


Fig.10. Plot2: Latency v/s Transmission Range.

Over a transmission range of (100-250)m where the delivery ratio seems to be higher in Fig.8 there is a corresponding stark decrease of 60% in the Average Transmission Delay or Latency of CAGRJOR over GFVIR as inferred through Fig. 9. This is majorly due to the fact that packets which are generated in local maximum regions are stored and forwarded in GFVIR leading to an increase in latency. Whereas in CAGRJOR, packets have the ability to recover from local maximum regions using IRSUs. This leads to a much lower latency. Also, as the transmission range is increased, the latency values decrease considerably for both CAGRJOR as well as GFVIR. But the tradeoff for this is already seen in Fig. 8 as explained before, i.e., a reduction in delivery ratio.

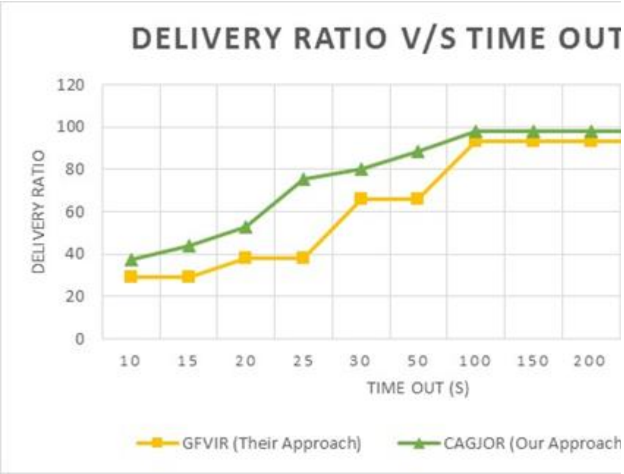


Fig.11. Plot3: Delivery Ratio v/s Time out

Fig. 10 gives an idea about a steady increase in the percentage of packets that get delivered through VANET as the timeout time increases for both the approaches. The TR is set at 150m which produces the best packet delivery results as seen from Fig. 8. CAGJOR though performs much better as compared to GFVIR as is evident from the fact that there is nearly a two-fold increase in DR at TO = 25sec. This is a clear indication that CAGJOR can be an attractive choice for moderately time-sensitive data. One more point that is worth noting is that beyond TO = 100sec, DR reaches a saturation value. This saturation region represents the percentage of packets that were sent over V2C which couldn't be offloaded.

8. Conclusion

Analyzing the previous observations, we have therefore built a strong case for CAGRJOR as a data forwarding approach in VANETs which in turn will help us achieve the objective of cellular offloading in VANETs. CAGRJOR approach will prove fruitful for applications that deal with huge amounts of data that are moderately delay-sensitive especially in the field of smart city scenario, IoT, and ITS.

9. Future Work And Extensions

Although, there is no doubt that VANETs, sooner or later will become an impeding reality but, this is also needed to be kept in consideration that there will be a gradual growth in the penetration ratio of n/w enabled vehicles. So, the future extensions to the proposed work includes a gateway based VANET scenario where only the gateways would have the capability to take part in data forwarding. And since there is an introduction of gateways into VANET, there would be an essential need for load balancing.

Conflicts of interest: Authors have no conflict of interest to declare

References

[1] Ishtiaq Wahid 1 , Sadaf Tanvir 2 , Masood Ahmad 1 , Fasee Ullah 3,*, Ahmed S. AlGhamdi 4 , Murad Khan 5 and Sultan S. Alshamrani 6 , "Vehicular Ad Hoc Networks Routing Strategies for Intelligent Transportation System", Electronics 2022, 11, 2298. https://doi.org/10.3390/electronics11152298

[2] Yongje Shin, Hyunseok Choi, Youngju Nam, Euisin Lee, "Data delivery protocol using the trajectory information on a road map in VANETs, Ad Hoc Networks, Volume 107, 1 October 2020, 102260, https://doi.org/10.1016/j.adhoc.2020.102260

[3] S. M. Wu, T. chun Chen, Y. J. Wu, and M. Lytras, "Smart cities in Taiwan: A perspective on big data applications," Sustain., vol. 10, no. 1, pp. 1–14, 2018.

[4] Jorswieck, L. Badia, T. Fahldieck, E. Karipidis, and J. Luo, "Spectrum sharing improves the network efficiency for cellular operators," IEEE Commun. Mag., vol. 52, no. 3, pp. 129–136, 2014.

[5] Summary, "Cisco Visual Networking Index : Global Mobile Data Traffic Forecast Update , 2016 – 2021," pp. 2016–2021, 2017.

[6] E. Hossain and M. Hasan, "IEEE Instrumentation & Measurement Magazine 5G Cellular: Key Enabling Technologies and Research Challenges," no. June, pp. 11–21, 2015.

[7] K. Abboud, H. A. Omar, and W. Zhuang, "Interworking of DSRC and Cellular Network Technologies for V2X Communications: A Survey," IEEE Trans. Veh. Technol., vol. 65, no. 12, pp. 9457–9470, 2016.

[8] Transportation, S. Committee, I. Vehicular, and T. Society, IEEE Guide for Wireless Access in Vehicular Environments (WAVE) Architecture IEEE Vehicular Technology Society, vol. 2010, no. February. 2013.

[9] Domingos, D. Cunha, L. Villas, A. Boukerche, G. Maia, A. C. Viana, R. A. F. Mini, and A. A. F. Loureiro, "Data Communication in VANETs: Survey, Applications and Challenges," vol. 44, pp. 90–103, 2016.

[10] Q. Yang, L. Wang, W. Xia, Y. Wu, and L. Shen, "Development of on-board unit in vehicular ad-hoc network for highways," 2014 Int. Conf. Connect. Veh. Expo, ICCVE 2014 - Proc., pp. 457–462, 2014.

[11] S. Zeadally, R. Hunt, Y.-S. Chen, A. Irwin, and A. Hassan, "Vehicular ad hoc networks (VANETS): status, results, and challenges," Telecommun. Syst., vol. 50, no. 4, pp. 217–241, 2012.

[12] Aslam, F. Amjad, and C. C. Zou, "Optimal roadside units placement in urban areas for vehicular networks," Proc. - IEEE Symp. Comput. Commun., vol. 1, pp. 000423–000429, 2012.

[13] Y. Liang, H. Liu, and D. Rajan, "Optimal placement and configuration of roadside units in vehicular networks," IEEE Veh. Technol. Conf., 2012.

[14] S. Mehar, S. M. Senouci, A. Kies, and M. M. Zoulikha, "An Optimized Roadside Units (RSU) placement for delay-sensitive applications in vehicular networks," 2015 12th Annu. IEEE Consum. Commun. Netw. Conf. CCNC 2015, pp. 121–127, 2015.

[15] O. Briante, C. Campolo, A. Iera, A. Molinaro, S. Y. Paratore, and G. Ruggeri, "Supporting augmented floating car data through smartphone-based crowd-sensing," Veh. Commun., vol. 1, no. 4, pp. 181–196, 2014.

[16] X. Kong, Z. Xu, G. Shen, J. Wang, Q. Yang, and B. Zhang, "Urban traffic congestion estimation and prediction based on floating car trajectory data," Futur. Gener. Comput. Syst., vol. 61, pp. 97–107, 2016.

[17] V. N. G. J. Soares, J. J. P. C. Rodrigues, and F. Farahmand, "GeoSpray: A geographic routing protocol for vehicular delay-tolerant networks," Inf. Fusion, vol. 15, no. 1, pp. 102–113, 2014.

[18] I. Abdalla Ahmed, A. Gani, S. H. Ab Hamid, S. Khan, N. Guizani, and K. Ko, "Intersection-based Distance and Traffic-Aware Routing (IDTAR) protocol for smart vehicular communication," 2017 13th Int. Wirel. Commun. Mob. Comput. Conf. IWCMC 2017, pp. 489–493, 2017.

[19] Walker and M. Radenkovic, "GPSR-TARS: Congestion aware geographically targeted remote surveillance for VANETs," 2017 Int. Conf. Sel. Top. Mob. Wirel. Networking, MoWNeT 2017, 2017.

[20] Mukunthan, C. Cooper, F. Safaei, D. Franklin, and M. Abolhasan, "Leveraging the Propagation Model to Make Greedy Routing Decisions in Urban Environments," IEEE Veh. Technol. Conf., vol. 2017–June, 2017.

[21] Bazzi and A. Zanella, "Position Based Routing in Crowd Sensing Vehicular Networks PT," Ad Hoc Networks, vol. 36, no. JUNE 2015, pp. 409–424, 2015.

[22] S. Al-sultan, M. M. Al-doori, A. H. Al-bayatti, and H. Zedan, "Journal of Network and Computer Applications A comprehensive survey on vehicular Ad Hoc network," J. Netw. Comput. Appl., vol. 37, pp. 380–392, 2014.

[23] F. Teixeira, V. Silva, J. Leoni, D. Macedo, and J. M. S. Nogueira, "'Vehicular networks using the IEEE 802.11p standard: An experimental analysis,'" Veh. Commun., vol. 1, no. 2, pp. 91–96, 2014.

[24] Z. H. Mir and F. Filali, "LTE and IEEE 802_11p for vehicular networking," pp. 1–15, 2014.

[25] Bazzi, B. M. Masini, A. Zanella, and G. Pasolini, "IEEE 802 . 11p for cellular offloading in vehicular

sensor networks q," Comput. Commun., vol. 60, no. February, pp. 97–108, 2015.

[26] F. Valle and S. Cespedes, "Improving vehicular applications through network diversity," 2016 8th IEEE Latin-American Conf. Commun. LATINCOM 2016, 2016.

[27] P. Salvo, I. Turcanu, F. Cuomo, A. Baiocchi, and I. Rubin, "Heterogeneous cellular and DSRC networking for Floating Car Data collection in urban areas," Veh. Commun., vol. 8, pp. 21–34, 2017.

[28] Chour, Y. Nasser, H. Artail, and A. Kachouh, "FREDDY: A framework for VANET aided D2D discovery," IEEE Wirel. Commun. Netw. Conf. WCNC, vol. 2016–Septe, no. Wcnc, 2016.

[29] Chour, Y. Nasser, H. Artail, A. Kachouh, and A. Al-Dubai, "VANET Aided D2D Discovery: Delay Analysis and Performance," IEEE Trans. Veh. Technol., vol. 66, no. 9, pp. 8059–8071, 2017.

[30] S. Ansari, T. Boutaleb, S. Sinanovic, C. Gamio, and I. Krikidis, "MHAV: Multitier Heterogeneous Adaptive Vehicular Network with LTE and DSRC," ICT Express, vol. 3, no. 4, pp. 199–203, 2017.

[31] Y. Liu, X. Chen, C. Chen, and X. Guan, "Traffic big data analysis supporting vehicular network access recommendation," 2016 IEEE Int. Conf. Commun. ICC 2016, 2016.

[32] G. E. M. Zhioua, H. Labiod, N. Tabbane, and S. Tabbane, "VANET inherent capacity for offloading wireless cellular infrastructure: An analytical study," 2014 6th Int. Conf. New Technol. Mobil. Secur. - Proc. NTMS 2014 Conf. Work., pp. 0–4, 2014.

[33] N. Alsharif and X. Shen, "ICAR-II: Infrastructure-based connectivity aware routing in vehicular networks," IEEE Trans. Veh. Technol., vol. 66, no. 5, pp. 4231–4244, 2017.

[34] Dua, N. Kumar, and S. Bawa, "A systematic review on routing protocols for Vehicular Ad Hoc Networks," Veh. Commun., vol. 1, no. 1, pp. 33–52, 2014.

[35] Of and N. Applications, "Vehicular communication ad hoc routing protocols : A survey," vol. 40, no. APRIL, pp. 363–396, 2014.

[36] V. Communications, "Equation Chapter 1 Section 1A Survey on Data Dissemination in Vehicular Ad hoc Networks," vol. 1, no. October, pp. 214–225, 2014.

[37] Fonseca and T. Vazão, "Applicability of position-based routing for VANET in highways and urban environment," J. Netw. Comput. Appl., vol. 36, no. 3, pp. 961–973, 2013.

[38] S. Kumar and A. K. Verma, "Position Based Routing Protocols in VANET: A Survey," Wirel. Pers. Commun., vol. 83, no. 4, pp. 2747–2772, 2015.

[39] Karp and H. Kung, "GPSR: Greedy Perimeter Stateless Routing for wireless networks," ACM MobiCom, no. MobiCom, pp. 243–254, 2000.

[40] Lochert, M. Mauve, H. Füßler, and H. Hartenstein, "Geographic routing in city scenarios," ACM SIGMOBILE Mob. Comput. Commun. Rev., vol. 9, no. 1, p. 69, 2005.

[41] C. Lee, J. Häerri, U. Lee, and M. Gerla, "Enhanced perimeter routing for geographic forwarding protocols in urban vehicular scenarios," GLOBECOM - IEEE Glob. Telecommun. Conf., no. 01, 2007.