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Lightweight intersection-based traffic aware routing in Urban vehicular networks

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ABSTRACT

One of the important characteristics of VANETs is the multi-hop communications, which provides Vehicle-to-Vehicle(V2V) communication for many applications. In order to adapt to mobility in high speeds and limited-time communication links, traffic aware routing was proposed in many research works. As a type of position based routing protocols, traffic aware routing utilizes vehicles' positions and traffic status as two main routing parameters. However, providing real-time measurements for traffic status on each road generates high network overhead. In addition, to make such measurement always updated and available for routing purposes, the measurement process has to be applied frequently. This paper introduces a Lightweight Intersection-based Traffic Aware Routing (LITAR) protocol for V2V communication in urban vehicular networks. LITAR introduces two new algorithms to reduce the network overhead generated by the traffic status measurement process while preserving the accuracy of measurement. Moreover, LITAR make routing decisions based on vehicular directional density, Road Network Connectivity (RNC) and distance towards destination. The evaluation of the proposed LITAR protocol shows significant performance improvements in terms of packet delivery ratio, while reducing communication overhead as compared to existing routing approaches.

1. Introduction

Vehicular Ad Hoc Networks (VANETs) provided the required environment for intelligent transportation systems development. Although most of VANETs early applications were to improve traffic safety, the number of third-party providers offering non-safety applications is increasing recently [1]. For instance, VANETs can be utilized for real-time data collection in traffic control and roads maintenance systems [2,3], automated toll payment, enhanced navigation, location-based services [4], infotainment applications and Internet access [5]. Thus, in the near future the demand for reliable and efficient communication, among vehicles (V2V) and between vehicles and infrastructure (V2I), will rise dramatically.

To enable geographically separated vehicles to communicate, VANETs employ multi-hop communications by relying on intermediate vehicles for packets forwarding. However, the high speed mobility of vehicles causes rapid changes in vehicles density and intermittent inter-vehicle communication. Therefore, delivering data packets through multi-hop communications in VANETs environment requires reliable and efficient routing protocol. In general, there are two types of routing protocols designed purposely for VANETs: topology based routing and position based routing, also called geographical routing [6]. Topology based protocols require high route maintenance, specially with frequent topology changes in VANETs dynamic environment. In contrast, geographical routing protocols forward packets in a dynamic way based on vehicles positions. Accordingly, geographic routing was considered a more promising routing approach for dynamic environments, as it provides scalability and robustness against frequent topology changes [7].

Greedy Perimeter Stateless Routing (GSPR) is the basic geographical routing protocol proposed for ad hoc networks [8]. As GSPR forwards packets greedily based on vehicles positions only, and it has no consideration for network and traffic status, packets might be forwarded through roads with low vehicular density or high level of network disconnections. In VANETs, vehicular density has a significant impact on inter-vehicle communication links stability [9]. In order to eliminate conventional geographical routing protocols limitations, new metrics have been introduced by recent routing protocols, which involve network and traffic status in routing decisions. In particular, integrating geographic routing with traffic awareness results in traffic aware routing protocols, which adapt to variable traffic conditions. A comparison for the existing traffic aware routing protocols and a discussion for their limitations

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Annex

AP	Access Point
APs	Access Points
CBR	Constant Bit Rate
CF	Current Forwarder
CP	Collector Packet
CPR	Collector Packet Reply
CPRs	Collector Packet Replies
CPs	Collector Packets
EVPC	Enhanced Validity Period Calculation
GeoSVR	Geographic Stateless VANET Routing
GPSR	Greedy Perimeter Stateless Routing
ICS Factor	Inter-vehicle Communication Stability Factor
IVD	Indirection Vehicular Density
LITAR	Lightweight Intersection-based Traffic Aware Routing
LLT	Link Lifetime
MP	Measurement Process
MVD	Measured Vehicular Density
NF	Next Forwarder
OVD	Opposite direction Vehicular Density
PD	Progressive Distance
PDD	Packet Delivery Delay
PDR	Packet Delivery Ratio
RCPR	Restricted Collector Packet Reply
RNC	Road Network Connectivity
RS	Road Status
RSSI	Received Signal Strength Indication
RTNSM	Real-time Traffic and Network Status Measurement
RVD	Road Vehicular Density
TAR	Traffic aware routing
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VANETs	Vehicular Ad Hoc Networks
VDVR	Vehicular Density Variation Rate
VP	Validity Period
VPV	Validity Period Value

has been published in [10]. Section 1.1 elaborates the concepts and limitations of traffic aware routing in brief.

1.1. Traffic aware routing: concepts and limitations

Traffic aware routing (TAR) protocols utilize new routing metrics, such as vehicular density and inter-vehicle connectivity, in order to make routing decisions based on network and traffic status. A comprehensive review was published in [10], which investigates the shortcomings of different categories of TAR protocols based on: routing process, routing metrics measurement process, forwarding mechanisms and recovery techniques. Although there is a variety of TAR protocols, intersection-based TAR protocols are considered the most adaptable to VANETs dynamic environment [10]. While forwarding a packet, intersection-based TAR protocols make routing decisions at each intersection after giving each adjacent road a weighted score, which is calculated based on road's traffic and network status as well as distance towards destination. Subsequently, the road with the highest score is chosen for packet forwarding.

Basically, to get information about traffic status for intersection-based Traffic aware routing routing purposes there exist many processes, which are discussed in [11]. However, real-time road evaluation processes are preferred, as they adapt more to the dynamic environment of VANETs. The real-time road evaluation processes are based on generating and forwarding Collector Packets (CPs) from one road end to another as shown in Fig. 1. While forwarding a CP through road R, it collects traffic and network information (e.g., vehicular density, inter-vehicle communication link lifetime and transmission delay) from each forwarder vehicle. Thus, by reaching intersection I_j, the CP can provide real-time measurements for traffic and network status of road R. In addition, a Collector Packet Reply (CPR) might be sent to intersection I_i to announce the measurement results their. However, in order to keep the road evaluation results available and updated at intersection areas, the evaluation process has to be executed continuously. As a result, a high number of CPs and CPRs are generated which increases network overhead and degrades intersection-based TAR protocols performance.

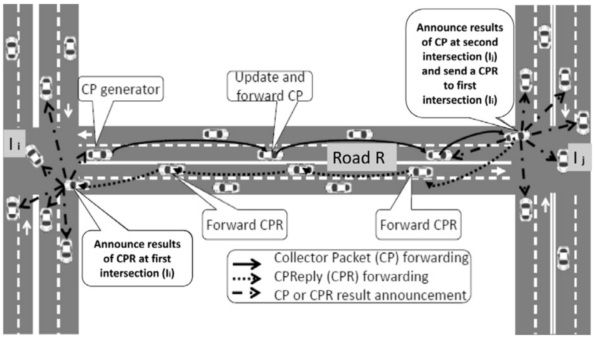

Fig. 1. Collecting and announcing road's evaluation results utilizing CPs.

Accordingly, a Lightweight Intersection-based Traffic Aware Routing (LITAR) is proposed in this paper. LITAR introduces the Real-time Traffic and Network Status Measurement (RTNSM) process, which enhances the road evaluation process by proposing two algorithms to reduce the generated network overhead. The first algorithm is the Enhanced Validity Period Calculation (EVPC), which eliminates the unnecessary generation of CPs. The second algorithm is the Restricted Collector Packet Reply (RCPR) which generates CPRs in certain cases only. In addition, LITAR improves routing decisions by introducing a new routing metric called Road Network Connectivity (RNC).

This paper is structured as follows: Section 2 discusses several TAR approaches proposed in the context of VANETs and details the motivations of this paper. Section 3, introduces LITAR functionality, design and components. Section 4 presents and discusses the performance evaluation of LITAR. Finally, Section 5 concludes the paper.

2. Motivations and related work

In urban VANETs environment, destination and source vehicles might be geographically separated. In addition, intersections, buildings and vehicles may affect or obstruct signal propagation. Hence, multi-hop communication in urban areas is essential, in order to address the long transmission distance and frequent obstacles problems, which makes vehicles direct communication impossible in many cases [12]. On the other hand, a study of the impact of multi-hop communication on the performance of a modelled vehicular content downloading system is carried out in [13]. The study revealed the significant role that multi-hop communications play in improving the network throughput while accessing infrastructure Access Points (APs). Precisely, the study showed that 80% of the data was downloaded through relay vehicles even when the considered area is fully covered by APs. This is due to preferring the high-rate multi-hop paths to low-rate single-hop direct V2I communications, even within AP coverage area. In addition, in case of spars deployment of APs, multi-hop communication is important to provide access to infrastructure networks. Accordingly, providing efficient multi-hop communication via reliable routing protocols is vital in VANETs environment.

This section introduces our motivations for carrying out this research study and highlights the novelty of our protocol. To this end, the following review focuses on inspecting the most recent and relevant VANETs routing protocols to our work. Our proposed LITAR protocol has two main components: the RTNSM process that provides routing metrics; and the intersection-based data packet routing. Therefore, the existing solutions are studied in terms of their routing mechanisms and utilized route or road evaluation processes, which provide their TAR metrics. In particular, the existing road or route evaluation processes are reviewed from two aspects: the way of representing or reflecting traffic and network status; and their generated network overhead.

Full path traffic aware routing protocols:

In [14], a multi-hop routing and gateway selection scheme was proposed, which selects the routes with the best inter-vehicle link lifetime. Routes lifetime was measured by gateway advertisement messages, which are broadcasted by each gateway in a specified geographical area. Vehicles motion parameters (e.g., speed, position and direction) were used to estimate inter-vehicle Link Lifetime (LLT) between each consecutive vehicles along the routes, then the lowest LLT is considered the route lifetime. However, vehicular density was not consider as a routing metric even though it has a huge impact on inter-vehicle LLT. In addition, this approach might forward data through congested routes as network load on routes was not considered as a routing metric.

Similarly, a connectivity-aware with minimum-delay geographic routing protocol was introduced in [9], whereas routes with good connectivity are selected. The connectivity evaluation was computed based on node local density, density changing rate and transmission delay time. Route discovery messages are broadcasted from a vehicle towards gateways, which measures the density and delay parameters while being forwarded. Afterwards, the destination vehicle chooses the most stable route with the highest density and lowest network congestion, as transmission delay gives an indication for network load. Although, the author utilized density change rate as an indication for route stability, it does not give an accurate estimation for route lifetime.

In [15], a routing protocol based on QoS was proposed, which utilizes route request broadcasting for route discovery and route reply messages for collecting route status information. However, upon receiving a route request message, the carried QoS information is evaluated and if the current node satisfies the required QoS, it forwards the route request message. Once a route request is received by the destination vehicle, a route reply message is sent back which collects links expiration time, expected transmission time and local neighboring density. Afterwards, the source vehicle chooses the best route based on the collected information. A similar QoS-based routing protocol was introduced in [16], whereas routes are discovered by sending route requests. However, the author assumed that vehicles at intersection areas have information about the QoS of adjacent roads, thereby route requests are propagated through roads that fulfil QoS requirements. The evaluation of routes was done based on LLT, degree of link failure and hop count. Accordingly, as vehicular density and network load was not considered in the evaluation process, the routing process may not adapt smoothly to network and traffic changes.

Unlike LITAR, the measured vehicular density in [9,15] does not consider vehicles direction, thus packets might be sent through routes with high vehicular density moving in the opposite direction of packet forwarding, which reduces network throughput as stated in [17]. Although, some of the aforementioned protocols consider LLT as a routing metric [14–16], such protocols have no consideration for alternative links which can be used when a link of the constructed route is broken.

In terms of generated network overhead, the work in [14] depends on broadcasting gateway advertismnet messages, which contributes to high network overhead that is proportional to broadcast area. In addition, broadcasting gateway messages might result in broadcast storms that degrades network performance. As the TAR protocols in [9,15,16] utilize route discovery/reply messages to obtain the real-time values of routing parameters, a significant amount of network overhead is generated, which is directly proportional to the number of communicating vehicles, route length and broadcast area. Therefore, such approach is not suitable for high vehicular density scenarios with high network load, due to its high network overhead that degrades routing performance.

Statistical vehicular density information is exploited as a routing metric in [18,19]. However, depending on statistical traffic information for evaluating roads status is not efficient in the highly dynamic and unpredictable VANETs environment [11]. In [20], the Geographic Stateless VANET Routing (GeoSVR) was proposed. GeoSVR calculates the full path based on a digital map and considers roads width as an indication for high vehicular density. Nevertheless, roads width is not accurate indication for the real-time traffic status [10]. Moreover, high vehicular density does not guarantee sufficient network connectivity, as link stability and network load are two main factors affecting transmission quality [21].

In fact, full path TAR protocols construct a full path from source to destination and insert the full path information in the packet header before forwarding. Thus, the selected path can not be modified or adjusted while forwarding a packet, which makes such routing strategy less adaptable to network and traffic changes. In addition, as routes tend to be unstable due to vehicles high mobility, route maintenance and discovery has to be executed frequently, which results in extra network overhead [10]. Therefore, the full path routing strategy is not preferable for VANETs.

Intersection-based traffic aware routing protocols:

In general, intersection-based routing has less overhead compared to full path routing, as no need for route discovery messages and packets carry the position of destination and next-intersection only. In addition, it adapts more efficiently to variable VANETs conditions, as routing decision is done sequentially at each intersection based on the evaluation of adjacent roads [10]. However, providing traffic aware routing metrics at intersections by road evaluation process generates high network overhead, which increases transmission interference and reduces data packet delivery ratio. Moreover, to keep routing metrics measurements updated and always available for routing decisions, the road evaluation process has to be done so frequently, which worsen the problem and increases the generated network overhead.

The intersection-based TAR protocols proposed in [22–24], dissect roads into fixed location cells, whereas the closest vehicle to the cell center (i.e., cell leader) collects the cell's vehicular density information. Afterwards, each former cell leader leaving the road, generates a CP and forwards it through the previous road to collect vehicular density information form cell leaders. Next, the collected density information is announced at the second intersection to be used for routing purposes. Although, allowing only former leaders to generate CPs suppresses the generation process, it does not guarantee the generation of a new CP once road status changes. In addition, no reply packets are generated; thus, for a one way road no road evaluation results are provided at the first intersection (I_i in Fig. 1). Furthermore, depending on vehicular density and distance as routing metrics for selecting the best road for packet forwarding, does not necessarily provide sufficient routing performance, since high vehicular density may increase signal interference and network load [21]. Moreover, not considering link stability or lifetime metrics may result in forwarding data through roads with high level of intermittent communications.

Unlike the three aforementioned protocols that has no consideration for roads' network status, the protocols proposed in [25,26] utilize Road Vehicular Density (RVD), transmission delay and progressive distance towards destination, in order to compute a rank for each adjacent road. The road evaluation is carried out by sending CPs and CPRs between consecutive intersections without forming fixed cells. CPs are generated by vehicles entering the road and do not have valid evaluation results for the entered road. While forwarding a CP, each visited vehicle attaches its local vehicular density information, and the validity period of the carried results is updated. The validity period of the road evaluation results is the period after which the first network disconnection may occur. By reaching the second intersection the collected RVD, evaluation results validity period and CP transmission time are announced at the intersection area.

Unlike LITAR, the validity period in [25,26] was not used as a routing metric for evaluating communication link stability, instead it is used to avoid exploiting expired road evaluation results. Similar to LITAR, the validity period is used to suppress the generation of CPs, as it prevents vehicles from generating new CPs as long as they have valid road evaluation results. However, the proposed validity period calculation in [25,26] does not consider the availability of alternative links among vehicles, which emerge due to vehicles movement and can replace broken links. As a result, the calculated validity period is short and does not adapt to changes in the road status in an accurate way, which may lead to generating high number of unnecessary CPs and increasing the network overhead. Moreover, the used link lifetime estimation for calculating the validity period is based on neighbours motion information, which are obtained through beacon messages. Nevertheless, such mobility information are instantaneous values that might lead to inaccurate link duration estimation. In contrast with other existing protocols, LITAR calculates a more accurate validity period, which reflects the real state of the road and adapts CP generation based on changes in road's traffic or link stability status. Accordingly, LITAR generates new CPs only when it is necessary to detect and represent the changes in roads status.

Similarly, in [27], the roads' vehicular density and network load is measured using CPs and CPRs. For estimating road's network load the number of packets stored in each CP forwarder's buffer queue is considered. However, communication link stability is not evaluated, and the road evaluation process does not adopt the concept of calculating a validity period for evaluation results. Likewise, the author in [28], employed CPs forwarding to get roads' network load status by measuring CP forwarding delay. Thereafter, roads are ranked based on their progressive distance and transmission delay. However, relying on roads' forwarding delay to select the best road is not sufficient. This is because roads' forwarding delay represents only the network load status of the evaluated road, and it can not be an indication for the road's communication stability and traffic density status.

An important point distinguishing LITAR from the four protocols in [25–28], is that such protocols generate a CPR after each CP to be sent back to the first intersection regardless of the replying necessity, which increases the road evaluation process network overhead. In contrast, LITAR generates CPRs in certain necessary cases, which contributes to huge reductions in network overhead as explained in the following sections.

As a matter of fact, high vehicular density in the packet forwarding direction (i.e., indirection density) contributes to higher delivery ratio [17]. On the other hand, vehicles moving in the opposite direction of packet forwarding (i.e., opposite direction density) are not preferred for forwarding; however, such vehicles can improve the connectivity of the road network [10]. Although, indirection vehicular density was exploited in [23], unlike LITAR the opposite direction vehicular density was completely neglected. In [24], the non-directional vehicular density is exploited when there is no traffic moving in the packet forwarding direction. However, when indirection vehicular traffic is available, the opposite direction vehicular density is ignored, which results in underestimating the road traffic status. Despite of the importance of vehicles direction in forwarding packets, the rest of the existing TAR protocols have no consideration for directional density. Distinctively, LITAR utilizes both directions vehicular density as routing metrics, whereas opposite direction vehicular density is given a lower weight compared to indirection density.

A different approach is introduced in [29], whereas routing decisions are made in intersection zone. The proposed road evaluation process considers only the parts of roads which are located within 30 m from the center of the intersection center. The evaluation is carried out by counting the number of vehicles located within the considered area and sent a beacon message within the last 100msec, while the average channel busy time to MAC queue size ratio of the counted vehicles is calculated as well. However, such approach may give unrealistic road evaluation as it considers only 30 m of the road for evaluation. For instance, data packets might be forwarded through a road that has high vehicular density near intersection area due to traffic lights, while the rest of the road has no network connectivity.

Hybrid traffic aware routing protocols:

The hybrid TAR protocols attempt to enhance the performance of full path TAR protocols by allowing route adjustments at intersections. The protocols proposed in [30,31], first construct a full path towards destination using Dijkstra algorithm. Afterwards, the forwarding path is dynamically adjusted at intersections based on updated traffic information. At each intersection a vehicle is appointed to collect vehicular traffic information from adjacent roads by utilizing CPs in a similar way to [22], and then it disseminates the collected information to adjacent intersections. However, electing the appointed vehicle and continuously maintaining this role at intersections is a critical issue, which generates extra routing overhead. In addition, [30,31] utilized vehicular density and network load as routing metrics for routing packets at intersections; however, not considering link stability my result in forwarding packets through roads with intermittent connectivity.

A similar approach is introduced in [32,33], where static nodes are placed at each intersection, in order to collect real-time traffic information from adjacent roads by forwarding CPs. In [32], a transmission delay estimation model is utilized to evaluate roads, while roads are evaluated based on vehicular density and traffic load in [33]. However, the applicability of such solution is restricted to areas where the static nodes are fixed which reduces the network scalability and increases deployment cost. Despite of utilizing insufficient routing metrics that do not reflect the real traffic and network state of roads, the authors in [30–33] did not introduce a mechanism for controlling CP generation or adapting it to changes in road conditions.

3. Lightweight intersection-based traffic-aware routing protocol

This section explains in details the proposed LITAR protocol for V2V multi-hop communication. Delivering data packets from source to destination using LITAR comprises two processes working in parallel. The first process is the RTNSM process for road evaluations, which is applied continuously on each road to provide at each intersection the adjacent roads evaluation results. The second process is the data packet routing, which utilizes RTNSM results as routing metrics to make routing decisions at intersections. Accordingly, data packets are forwarded through the best road in terms of vehicular density, network connectivity and progressive distance towards destination. Unlike existing intersection-based TAR protocols, LITAR considers the directional density for both directions as a routing metric (i.e. indirection and opposite direction with respect to packet forwarding direction). However, lower weight is given to opposite direction vehicular density, in order to improve the packet delivery performance. Moreover, the network connectivity utilized in LITAR is calculated by considering communication links stability (i.e., LLT) and network load.

LITAR aims at reducing the network overhead generated by RTNSM process while preserving the measurement results accuracy. To this end, LITAR eliminates the unnecessary CPs generated by the RTNSM process by introducing the Enhanced Validity Period Calculation (EVPC) algorithm. Basically, EVPC considers calculating a Validity Period (VP) for the RTNSM results, to suppress the generation of new CPs as long as the road traffic and network status is not changing. Although, the concept of calculating a VP for road evaluation results was in introduced in [25]. However, the existing VP calculation suffers of the following problems. First, it was based on calculating the LLT with the furthest neighbour, and the alternative links which can be utilized when such a link is broken were ignored. As a result, the calculated VP is short and results in generating many unnecessary CPs, even when the road status is not changing. Second, the existing LLT calculation depends on the neighbours instantaneous mobility information received by beacon messages, which might lead to inaccurate LLT estimation. In order to address the previously mentioned problems of VP calculation, LITAR's EVPC anticipates when the next change in road status is going to occur based on three factors: the average LLT with all available neighbours, vehicular density and vehicular density change rate. Thus, EVPC considers the alternative links that can be used instead of the furthest neighbour link. In addition, to reduce the effect of instantaneous mobility information, a higher level view for traffic status was considered by utilizing vehicular density and its variation rate. Consequently, by adapting the generation of CPs based on changes in road traffic or network status, the obtained routing metrics (i.e. RTNSM results) accurately reflect the real state of the road without generating unnecessary CPs.

Basically, LITAR utilizes the calculated VP for three purposes. First, VP value indicates when it is required to generate a new CP, which eliminates unnecessary CP generation. Second, vehicles can avoid using out of date RTNSM results for adjacent roads, while routing data packets at intersections. Third, as higher VP value indicates more stable road's status, the calculated VP is used to choose the most stable road for packet forwarding as explained in Section 3.1.5.

As generating CPRs highly contributes in increasing the network overhead. Unlike the existing protocols which generates a CPR after each CP results announcement, LITAR introduces the RCPR algorithm which generates CPRs in certain cases only. In fact, as CPs are also generated by vehicles entering from the second road end (i.e. I_j in Fig. 1), generating a CPR after each CP becomes unnecessary in some cases as explained in Section 3.1.4 and Fig. 6.

Similar to existing TAR protocols, LITAR considers that each vehicle is required to maintain a neighbor table where the position, speed, and direction of each neighbouring vehicle are recorded. Such table is built and maintained based on the information received through exchanging beacon messages between vehicles. In addition, destination vehicle position can be obtained using location services such as [34]. Finally, each vehicle needs to maintain a roads table where it can record the received RTNSM results for routing decisions at intersections.

Section 3.1 explains the phases of LITAR RTNSM process and introduces the proposed algorithms. Afterwards, Section 3.2 elaborates LITAR improved data packet routing.

<table>
<tr><th>Current Forwarder Address</th><th colspan="2">Next Forwarder Address</th></tr>
<tr><td>In Direction Vehicular Density</td><td colspan="2">Opposite Direction Vehicular Density</td></tr>
<tr><td>Road ID</td><td colspan="2">Validity Period Value (VPV)</td></tr>
<tr><td>No. of Hops</td><td>Originality flag</td><td>Time Stamp</td></tr>
</table>

Fig. 2. Collector packet structure.

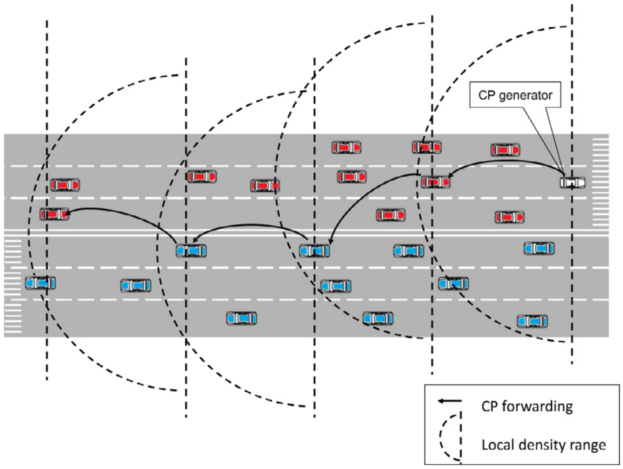

Fig. 3. Counting indirection (blue) and opposite direction (red) vehicles while forwarding CP. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.1. LITAR RTNSM process

The purpose of the measurement process is to provide feedback data about the traffic and network status, which is utilized by the routing process. The following section explains the structure of a CP. Afterwards, the RTNSM process phases are explained in Section 3.1.2.

3.1.1. Collector packet structure

The Collector Packet (CP) is used to collect data about traffic and network status from the road it passes through. The CP structure consists of nine fields as shown in Fig. 2. The content of each field and how it is updated, while forwarding the CP towards the road end, is explained in the following points:

- *Current Forwarder (CF) Address*: is the address of the vehicle holding the CP currently.
- *Next Forwarder (NF) Address*: is the address of the next forwarder, which is assigned by the CF in the forwarding phase.
- *Indirection Vehicular Density (IVD)*: is the accumulative number of vehicles located in each CF vicinity and moving in the same direction as the CP forwarding direction. However, in order to avoid over counting neighbours, only neighbours located within the area between the CF and NF are counted, as explained in Section 3.1.2 and Fig. 3.
- *Opposite direction Vehicular Density (OVD)*: is measured in the same way as the "In Direction Vehicular Density" field; however, it counts opposite direction vehicles.
- *Road ID*: is the ID of the road where the CP was generated. The road ID can be obtained from the digital map based on vehicle's position as stated in [35]. The value of road ID field is assigned by the vehicle that generated the CP. Afterwards, any vehicle receives the CP can use the value of road ID to obtain road information from the digital map system such as road location, driving direction, number of lanes and road structure.
- *Validity Period Value (VPV)*: is the estimated period of time after which a network disconnection is expected to happen in

that road. The algorithm of calculating VPV is explained in Section 3.1.3.

- *No. of Hops*: is the number of participating nodes in forwarding the CP so far.
- *Originality flag*: to differentiate between original CP and CPR.
- *Time Stamp*: to register the generation time of the CP or CPR.

3.1.2. LITAR RTNSM process phases

In intersection-based TAR protocols, the road evaluation process generates high network overhead. This is due to forwarding CPs between each two consecutive intersections to measure the traffic or network status along the road. Afterwards, the measurement results are announced at intersection areas to be used as routing metrics while making routing decisions. In addition, some of the existing routing protocols generate a CPR after announcing the CP results, which increases the network overhead. The RTNSM process of LITAR aims at reducing the road evaluation network overhead by introducing the EVPC and RCPR algorithms.

LITAR's RTNSM process is initiated when a vehicle moving on road R generates a CP upon reaching the intersection area (I_i). The CP is forwarded from the first road intersection to the second (i.e., from I_i to I_j), as shown in Fig 1. Each vehicle on road R receives the CP updates its fields, based on its local traffic and network status information, then forwards the CP towards I_j. Once the CP reaches I_j the collected traffic and network status measurement is processed then announced at the intersection area. In addition, a CPR might be sent to the original intersection I_i based on Algorithm 2. Basically, the RTNSM process consists of four phases as explained in the following points:

- **Collector packet generation phase**: There are two conditions the leaving vehicle has to satisfy, in order to generate a CP, unless it has no previous measurement for the current road. First, the vehicle must have updated a previous CP while moving in that road. Second, the measurement which was previously received from the current road must be expired. Such conditions are applied to reduce the number of generated CPs. The generator vehicle attaches a time stamp and its current road ID to the generated CP. Afterwards, the rest of the generated CP's fields are updated as described in the updating and forwarding phase.
- **Collector packet updating and forwarding phase**: The number of hops is incremented by one at each subsequent forwarder. The vehicular density fields are incremented based on the number of neighbour vehicles located in the area between CF and NF. Basically, each CF counts the number of vehicles between itself and NF, while considering their directions as shown in Fig. 3. Afterwards, the number of indirection vehicles (i.e., blue vehicles in Fig. 3) is added to IVD field, whereas the same procedure is applied to update the OVD field. In addition, the generator vehicle calculates and assigns the initial value of VPV field based on Algorithm 1. Subsequently, each forwarder calculates its VP value, and then if the calculated value is less than the received VPV, the calculated value is assigned to the VPV field. Thereby, the lowest VP value will be delivered by the forwarded CP to the road end. Moreover, by reaching the road end, the CP's vehicular density fields have the total number of neighbours for all visited nodes, which represent the density of vehicles along the evaluated road. In case the CF vehicle is not at an intersection area a NF has to be selected. The NF is the neighbour which has the highest Received Signal Strength Indication (RSSI), and shortest distance towards next intersection. Next, the NF address is assigned to the CP's "next forwarder address" field, then updated CP is unicasted to NF. This phase is applied repeatedly until the CP is delivered to next intersection area, where the carried RTNSM results can be processed and announced.

Algorithm 1 Enhanced Validity Period Calculation (EVPC)

```
Require: Current forwarder's neighbour table and CP
Ensure: Validity period (VP) value
$CF = CurrentForwarder$
$TotalLLT = numberOfNeighbour = calculatedVPV = 0$
for $i = 1; i \le NeighbourTable.Length; i++$ do
    $n = NeighbourTable[i]$
    $NeighbourPosition = PredictNeighbourPosition(n)$
    $NeighbourRoadID = n.RoadID$
    $d = distance(NeighbourPosition, CF.Position)$
    if $d < TransmissionRange$ then
        if $CF.RoadID = NeighbourRoadID$ then
            $calculatedLLT = calculateLLT(n)$
            $TotalLLT = TotalLLT + calculatedLLT$
            $numberOfNeighbour++$
        Endif
    Endif
Endfor
if $numberOfNeighbour! = 0$ then
    $ICSFactor = exp[\frac{-1 * (VDVR)}{(VehicularDensity)}]$    (1)
    $calculatedVPV = ICSFactor * (TotalLLT/numberOfNeighbour)$    (2)
Endif
if $(CP.VPV > calculatedVPV)$ then
    $CP.VPV = calculatedVPV$    $//updatetheCP'sVPVfield$
Endif

calculateLLT(n)
{
if $CF.direction == n.direction$ then
    Return $TransmissionRange/n.Speed$    (3)
else
    if $CFisApproaching(n)$ then
        Return $\frac{TransmissionRange + d}{n.Speed + CF.Speed}$    (4)
    else
        Return $\frac{TransmissionRange - d}{n.Speed + CF.Speed}$    (5)
    Endif
Endif
}
```

- **Collector packet results announcement phase**: When a vehicle at intersection receives a CP, it will process the carried RTNSM measurement. Afterwards, the processed results are attached to the next beacon message, in order to be broadcasted at the intersection area. In addition,the announcer vehicle generates a CPR based on Algorithm 2.
- **Collector packet reply phase**: if the conditions of replying are satisfied based on Algorithm 2 then, the announcer vehicle generates a CPR. Afterwards, the CPR is updated and forwarded to the origin intersection of the received CP (i.e., I_i). In LITAR, a CPR is not to carry the results of the announced CP. Instead, new measurement is carried out while forwarding the CPR

Algorithm 2 Restricted Collector Packet Reply (RCPR)

```
Require: Current forwarder's roads table and received CP
Ensure: Restricted generation of CPReply
$CF = CurrentForwarder$
$CFRoad = CF.roadID$
if ($CFannounced(CP)$) then
    if ($CFisLeavingRoad(CFRoad)\&!(CFgeneratedCP(CFRoad))$) then
        if ($!(CFhasPreviousMeasurement(CFRoad))$) then
            if ($CP.VPV \geq CP.travelTime$) then
                $generateCPReply()$
        else
            if ($CFhasPreviousMeasurementFromCP(CFRoad)$) then
                $PreviousCP = CFgetPreviousMeasurement(CFRoad)$
                $CPfrequency = CP.timeStamp - PreviousCP.timeStamp$
                if ($CP.VPV \geq CPfrequency - CP.travelTime$) then
                    $generateCPReply()$
                Endif
            Endif
        Endif
    Endif
Endif
```

to origin intersection, which makes the carried results more updated.

3.1.3. The Enhanced Validity Period Calculation (EVPC) Algorithm

In order to reduce the frequency of RTNSM process execution and control CPs generation, a VP value can be calculated for each CP. By applying such a mechanism, a vehicle can not generate a new CP as long as the received CP's VPV has not expired yet. The VPV of a road's CP is the estimated period of time after which the road status has to be re-evaluated, by initiating a new cycle of the RTNSM process. Accordingly, a road with high VPV has more stable traffic and network status than roads with lower values.

Unlike the existing validity period calculation proposed in [25], EVPC calculates more accurate validity period, which provides right timing for CPs generation to detect changes in road status without generating unnecessary CPs. The existing VP value calculation algorithm [25] utilizes mobility information received through beacons, in order to predict neighbours' positions and estimate their LLT. However, the received mobility information has instantaneous values, which might change rapidly in VANETs dynamic environment. In particular, with the frequent and difficult to predict changes in VANETs, utilizing instantaneous mobility values does not accurately indicate the level of stability of such links. Therefore, considering LLT values (calculated based on neighbourhood instantaneous mobility information), as an estimation for the network connectivity (i.e., VP value) in the CF vicinity, is not accurate. In addition, the existing algorithm [25] has no consideration for the alternative links available with neighbours. Accordingly, EVPC introduced two enhancements to improve the calculation of VP value:

- The first enhancement is that EVPC considers all alternative links while calculating the average LLT. In fact, calculating the VP value based on the LLT of the link that will break soon between CF and NF results in short VP; and it does not reflect the real connectivity state as it ignores the alternative links between CF and alternative NF. Therefore, EVPC calculates the average LLT between the CF and all the potential NF as the first step for calculating the VP value.
- The second enhancement that EVPC introduced is the utilization of Vehicular Density Variation Rate (VDVR) and local vehicular density, in order to alleviate the effect of using instantaneous mobility information in calculating LLT. Basically, as communication link stability between vehicles is affected by vehicular density and its changing rate, EVPC utilizes those two parameters to calculate the Inter-vehicle Communication Stability Factor (ICS Factor). The ICS Factor is exploited in the second step of VP calculation, whereas the link duration and stability are combined to estimate the validity period of network connectivity.

EVPC algorithm is applied by each vehicle in charge of updating a CP. Algorithm 1, explains the details of EVPC. First, for each neighbour registered in the neighbour table the current position is predicted (line 5) based on its mobility information (i.e., speed, direction and latest known position). Afterwards, for the neighbours that are still within transmission range and belong to same road (lines 6,7,8), the total LLT is calculated, which is the summation of LLTs between CF and the neighbours. For calculating LLT, Equations (3–5) of function "calculateLLT" are utilized (lines 24 to 32). Equation (3) is used if CF and its neighbour are moving in the same direction. Equations. (4,5) are utilized if CF and its neighbour are moving in opposite directions, whereas Equation (4) is used if both vehicles are approaching each other and Eq. (5) when vehicles already passed each other. Second, the ICS Factor is calculated based on Equation (1) (line 17). Next, the VP value is calculated based on Equation (2) (line 18), which uses two parameters: the ICS Factor and the average LLT (derived from the total llt). Subsequently, the calculated VP value is compared to the carried value in the received CP's VPV field, if the later is greater then the calculated VP value is assigned to the VPV field (lines 20 and 21). Thereby, when a CP reaches the evaluated road end, its VPV field has the lowest calculated VP value among all forwarder vehicles on that road.

Calculating ICS factor

In order to mitigate the effect of instantaneous mobility information on the VP value calculation, the average LLT is multiplied by a stability factor (i.e., ICS Factor). In fact, ICS Factor is an indication for the stability level of communication links among vehicles in the CF neighbourhood. Although, high local vehicular density was considered as an indication for higher connectivity and more stable communications in a vehicles neighbourhood [25], such approach does not take into account that vehicular density is highly variable and can change over time. According to Taleb [36], communication links among vehicles with relatively similar speeds are more stable as they move as a group. Obviously, each vehicle belongs to such a group has a low local density variation rate in its neighbourhood. Accordingly, vehicular density and VDVR are both affecting the stability of communication links in the CF's neighbourhood. For instance, a CF with high local vehicular density has more alternative communication links to forward a packet, which results in higher network connectivity in the CF vicinity. However, in such a case, having a high VDVR will result in less stable communication links.

Fig. 4 summarizes in four different cases the vehicular density and VDVR effects on communication link stability. Obviously, inter-vehicle communication links stability is inversely proportional to VDVR and directly proportional to vehicular density. Thus, the relationship between ICS, vehicular density and VDVR can be formulated by Eq. (6), where C is a constant. To give a more specific evaluation for the communication link stability level, the values of ICS, which are in the range (0, ∞], are mapped to the range (0, 1] whereas 1 indicates the highest stability and 0 is for totally unstable links. For this purpose the exponential function in Equation (1) is used, where the constant C is assigned the value of -1.

$$ICS = \frac{C * VehicularDensity}{VDVR} \tag{6}$$

Fig. 5, shows the graph of the ICS Factor as a function of vehicular density and VDVR based on Equation (1). Obviously, high vehicular density with low VDVR represents the most stable

Vehicular Density	Vehicular Density Variation	Inter-vehicle link stability
High	Low	Highest
High	High	↓
Low	Low	
Low	High	Lowest

Fig. 4. Inter-vehicle communication stability in different traffic situation.

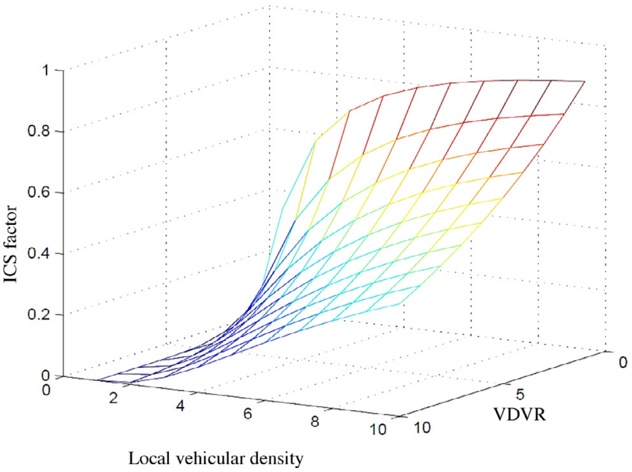

Fig. 5. Inter-vehicle communication stability function.

traffic and network state. Therefore, the effect of using neighbours instantaneous mobility information is neglected, as the probability of rapid changes in traffic conditions is low. Consequently, ICS Factor value should be approximately one in such a case. On the other hand, when vehicular density is low and VDVR is high, which represent the most unstable situation in VANETs, there is a high probability for rapid and unpredictable changes. In such a case ICS Factor has low values (close to zero), which will reduce the effect of instantaneous mobility information on calculating VP values. Thus, the ICS Factor adjusts the calculated average LLT based on vehicular density and VDVR status. As a result, Algorithm 1 calculates the VP value based on the average LLT of CF neighbours, CF's local vehicular density and its VDVR.

3.1.4. The Restricted Collector Packet Reply (RCPR) Algorithm

Once a CP reaches its target intersection (intersection I_j in Fig. 1), the CF will process then announce the collected results. In addition, a CPR is sent to the origin intersection (intersection I_i in Fig. 1). The purpose of generating LITAR CPRs is to increase the availability of RTNSM measurement results at intersections and to suppress unnecessary generation of CPs. Moreover, when vehicular traffic is moving in one direction, CPR is necessary to provide RTNSM results for the first intersection (e.g., I_i), as CPs carry and announce results at the second intersection only (e.g., I_j). However, restricting the generation of CPRs to certain necessary cases contributes to the RTNSM network overhead reduction. LITAR eliminates the number of unnecessary CPRs by employing the RCPR algorithm. Based on Fig. 1, when a vehicle at intersection I_j receives a CP generated at intersection I_i, it announces the results at intersection I_j. Afterwards, a CPR is generated and sent back to intersection I_i in case the vehicle, which announced the results, satisfies the conditions of RCPR algorithm (Algorithm 2). Firstly, the announcer vehicle must be at the road end and has not generated any CP for the current road (line 4). Secondly, the announcer vehicle makes the decision of generating a CPR based on the following cases, which are depicted in Fig. 6 as well:

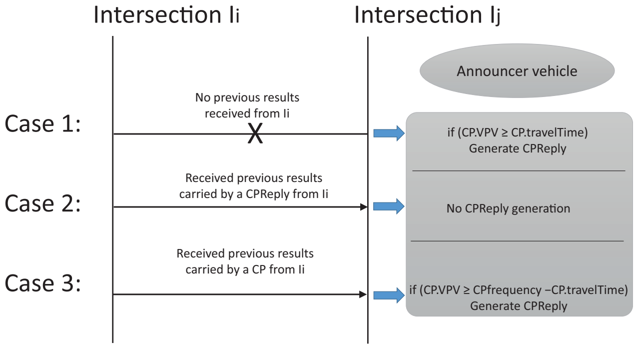

Fig. 6. The three cases an announcer vehicle may encounter

- **Case 1:** the announcer vehicle has not received any previous RTNSM results through a CP or CPR generated at intersection I_i (line 5). This situation means that there has been no generation for CP or CPR before the currently received CP, while driving from intersection I_i to I_j. In this case, if the RTNSM results can reach I_i while it is still valid ($CP.VPV \geq CP.travelTime$), then the announcer vehicle will generate and forward a CPR to intersection I_i (lines 6 and 7).
- **Case 2:** the announcer vehicle has previous valid RTNSM results carried by a CPR generated at intersection I_i. This situation means that there was a RTNSM result announcement at intersection I_i followed by sending a CPR to intersection I_j. Therefore, there is no need to send back a CPR to provide RTNSM results at intersection I_i.
- **Case 3:** the announcer vehicle has previous RTNSM results carried by a CP generated at intersection I_i (line 9). This situation means that at intersection I_i there were two consecutive generations of CPs. Thus, the announcer vehicle will generate and send a CPR if the reply packet can suppress the generation of a new CPR at intersection I_i. To suppress the generation of a new CP, the CPR has to reach intersection I_i before generating a new CP, provided that the CPR's VPV is still valid upon reaching ($CP.VPV \geq CPfrequency - CP.travelTime$ (line 12)), whereas *CPfrequency* is the time period between the two successive generations of CP (lines 10 and 11). Otherwise, no CPR is generated as its going to be useless and replaced by a new CP or CPR soon.

3.1.5. RTNSM results processing

As mentioned in Section 3.1.2, once a vehicle at an intersection receives a CP or CPR, it processes the carried RTNSM results to calculate the Road Status (RS) parameter. Eq. (7), calculates the RS parameter based on the RVD and RNC parameters, where $\alpha_1$and α_2 are weighting factors for RVD and RNC parameters respectively. The RS parameter value is in the range (0.0, 1.0), as $\alpha_1 = \alpha_2 = 0.5$ and both RVD and RNC are scaled to be in the range (0.0, 1.0).

$$RS = \alpha_1 \cdot RVD + \alpha_2 \cdot RNC \tag{7}$$

Road vehicular density (RVD)

The CP and CPR have two fields for collecting vehicular density information: IVD and OVD, which represent density of vehicles leaving and entering the road from announcement intersection, respectively. Before announcing the RTNSM results at an intersection area, the received values of density fields are utilized to calculate the road's RVD parameter using Eqs. (8), (9).

$$Density_{score} = \frac{2 * IVD + OVD}{3 * No.\ of\ Hops * N_{con}} \tag{8}$$

$$RVD = \begin{cases} 1 & Density_{score} > 1 \\ Density_{score} & otherwise \end{cases} \tag{9}$$

Forwarding packets through roads, which have higher vehicular density of vehicles moving in packet forwarding direction (i.e. indirection vehicular density), results in higher delivery ratio and lower packet delivery delay [23]. Therefore, higher weighting factor, equals to $\frac{2}{3}$ is given to *IVD*, while *OVD* weighting factor is $\frac{1}{3}$. Thus, Eq. (8) guarantees that roads with higher vehicular densities in packet forwarding direction are given more density score than roads with equal density but different direction. N_{con} is a constant that represents the ideal connectivity degree in a vehicle transmission range [22]. In case the $Density_{score}$ is higher than required density for full connectivity (i.e. $2 * IVD + OVD \geq 3 * No.\ of\ Hops * N_{con}$), the *RVD* parameter is scaled to 1, otherwise, *RVD* value is in the range (0.0, 1.0) based on Eq. (9).

***Road network connectivity* (RNC)**

Road network connectivity is a metric which measures the status of the communication between vehicles moving in the evaluated road. Vehicular density is an indication for the availability of vehicles in a road. However, roads with high vehicular density does not guarantee high packet delivery ratio. This is due to variant vehicles distribution, limited communication LLT between vehicles and high network load.

LITAR evaluates a road network connectivity by calculating how many CP packets a vehicle can process and transmit (*ProcessedPackets*) before the traffic status in its neighbourhood changes. As VPV is the time after which traffic status might change on the corresponding road, it is utilized in Eq. (11), to calculate *ProcessedPackets*, where $Delay_{hop}$ is the processing and transmission delay per hop. Afterwards, the number of *ProcessedPackets* is mapped from the range (0, ∞) to the range (0, 1) based on Eq. (12). Thus, if *RNC* has a value close to one, then the evaluated road has high connectivity. On the other hand, if *RNC* value is approaching zero, then the road connectivity is poor.

$$Delay_{hop} = \frac{travelTime}{No.\ of\ Hops} \tag{10}$$

$$ProcessedPackets = \frac{VPV}{Delay_{hop}} \tag{11}$$

$$RNC = exp\left(\frac{-1.0}{ProcessedPackets}\right) \tag{12}$$

3.2. LITAR data packets routing

LITAR has two routing modes: road routing and intersection routing. Road routing is for packet forwarding between intersections, whereas a next forwarder located in the same road as the CF is selected. Although applying greedy-based forwarding reduces the number of hops, it has higher packet loss ratio. In fact, the distance between the current and next forwarder is related inversely to their communication link quality. In order to avoid losing data packets due to low quality communication links, LITAR utilizes the improved greedy forwarding [25]. The improved greedy forwarding depends on two parameters to choose a next forwarder: progressive distance to destination and RSSI.

Once a data packet reaches an intersection, LITAR switches to intersection routing mode, in order to choose the best adjacent road for data packets forwarding. First, a score is calculated for each adjacent road (except the previous road). A road's score is calculated based on the announced road's status (*RS* parameter) and progressive distance towards destination (*PD*).

Progressive distance towards destination is an essential metric in geographical routing. The PD metric measures how close a data packet will be to destination, in case it is forwarded through the evaluated road. In other words, it measures the progress in distance that the evaluated road will contribute in the process of delivering a data packet to destination. Thus, roads which make data packets closer to destination are given higher scores.

In LITAR, the PD parameter is calculated in the same way as in [24,25] using Eq. (13), where $Distance_{fromNext}$ and $Distance_{fromCurrent}$ are the distance from candidate intersection to destination, and distance from current intersection to destination, respectively. The candidate intersection is where the data packet will reach in case it is forwarded through the evaluated road.

$$PD = 1.0 - \frac{Distance_{fromNext}}{Distance_{fromCurrent}} \tag{13}$$

A road's score is calculated, utilizing Eq. (14), based on the announced road's status (*RS* parameter) and progressive distance towards destination (*PD*).

$$RoadScore = \beta_1 \cdot RS + \beta_2 \cdot PD \tag{14}$$

Where β_1 and β_2 are weighting factors for the two road evaluation parameters. As the summation of all weighting factors must equal one, $\beta_1 = \beta_2 = 0.5$. The calculated road score value is in the range (0.0, 1.0) as both *PD* and *RS* have values in the same range.

Based on the calculated score for each of the adjacent roads, the road with the highest score is selected to forward the data packet through. Afterwards, LITAR switches to road mode routing to deliver the data packet to next intersection, where intersection routing is executed again. Subsequently, LITAR continues routing the data packet using road and intersection routing modes until it reaches the destination vehicle.

4. LITAR performance evaluation

In geographic routing each node can obtain its position by using a GPS device, which is available in most vehicles nowadays [37]. Destination vehicles' position can be obtained by utilizing a location service system such as HLS or GLS [38]. To provide mobility information for direct neighbours (e.g. geographical position, speed and direction), vehicles exchange periodic beacon messages [4].

To evaluate the performance of the proposed LITAR protocol, simulation scenarios are created using OMNET++ [39] as a network simulator and SUMO [40] for vehicular traffic simulation. The simulation scenarios are applied on part of Manhattan city map (latitude: 39.1912 to 39.1839 and longitude: −96.5737 to −96.5629). The map data and structure is obtained from OpenStreetMap contributions and used as an input for SUMO traffic simulation. Afterwards, map and traffic related information (e.g., road ID, number of lanes, traffic direction and vehicles positions) is obtained from SUMO to be used in the network simulator OMNET++. The area of simulation map is 2000 *m* × 2000 *m* with 84 bidirectional roads and 49 intersections. In addition, the real traffic regulations (e.g., traffic lights, speed limits and traffic priorities), which are applied in that part of Manhattan city, are also considered in the vehicular traffic simulation.

Table 1 demonstrates the simulation parameters utilized to evaluate LITAR performance. The parameters values are assigned based on the values used in [23,25]. The simulation was carried out in high density (40-50 vehicle/km/lane), average density (13–16 vehicle/km/lane) and low density (6–8 vehicle/km/lane) scenarios. The maximum vehicle speed is 60 km/h, however, speed drops

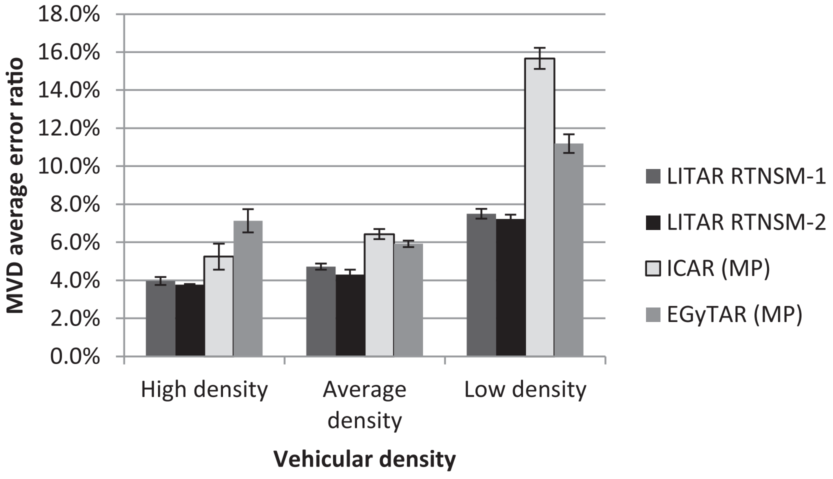

Fig. 7. MVD average error ratio for LITAR, ICAR and EGyTAR.

Table 1
Simulation parameters.

Parameters	Value
Simulation time	400 s
Simulation area	2000 m × 2000 m
Mobility model	car following model
Vehicular Density	high density (40-50 vehicle/km/lane), average density (13–16 vehicle/km/lane), low density (6–8 vehicle/km/lane)
Maximum vehicle speed	60 km/h
Transmission range	300 m
Data packet size	512 bytes
Channel bandwidth	18 Mbps
MAC protocol	IEEE 802.11p
Beacon interval	1 s
Data packet sending rate	0.1 s
Data traffic model	1-16 CBR connections
N_{con}	12

to zero when vehicles are stopping for traffic lights regulations or to give priority to other vehicles to cross intersections.

For the purpose of benchmarking iCAR [25] and EGyTAR [23] protocols are simulated in the same simulation environment as LITAR. The performance evaluation of LITAR is conducted through two main stages. First, the RTNSM process performance is evaluated based on two metrics: Measured Vehicular Density (MVD) average error ratio and the generated communication overhead. Second, the routing protocol performance is evaluated in terms of packet delivery ratio and packet delivery delay. The confidence intervals are calculated based on the values of 10 simulation repetitions and included in all graphs, whereas 95% confidence level is considered.

4.1. LITAR's RTNSM process performance evaluation

The impact of applying EVPC algorithm (i.e., LITAR RTNSM-1) on the RTNSM process performance is discussed in the following subsections. In addition, the effect of applying both EVPC and RCPR algorithms (i.e., LITAR RTNSM-2) is studied as well. The evaluation is carried out in the simulation environment described previously. However, in this stage of evaluation, vehicles generate and forward CPs and CPRs only, no data packets are sent between vehicles. The following two sub-sections evaluate the RTNSM process in terms of the MVD average error ratio and the generated communication overhead.

4.1.1. Measured vehicular density average error ratio

The purpose of calculating the MVD average error ratio is to evaluate the accuracy of the RTNSM process. In other words, it shows to which level the RTNSM process is reflecting and detecting changes in vehicular traffic status. Therefore, the MVD is compared to the real vehicular density, which is calculated by counting the number of vehicles available in each road within the map area. In the carried simulation, every time a vehicle is leaving or entering a road the real vehicular density and MVD values are recorded. The MVD is the summation of the vehicular density measurement announced at intersections. Afterwards, the average error ratio is calculated based on the recorded results of real vehicular density and MVD.

Fig. 7, presents the MVD average error ratio for LITAR RTNSM-1, LITAR RTNSM-2, iCAR Measurement Process (MP) and EGyTAR MP, in high, average and low vehicular density scenarios. It can be observed that LITAR RTNSM-2 has the lowest MVD average error ratio, which equals to 3.7%, 4.3% and 7.2% in high, average and low scenarios, respectively. This is because LITAR generates CPs and CPRs based on road status changes and its CPRs provide more updated measurements at the origin intersection. On the other hand, LITAR RTNSM-1 has higher average error ratios (3.9% in high, 4.7% in average and 7.5% in low density scenarios) compared to LITAR RTNSM-2, this is due to the absence of CPRs and depending only on original CPs to provide RTNSM results at intersections.

In general, MVD average error ratio of iCAR, EGyTAR and LITAR measurement processes increases in sparse scenario, this is due to the high variation rates in vehicular density and network intermittent connectivity. However, LITAR has lower MVD average error ratio than iCAR and EGyTAR in all three scenarios. In particular, LITAR has lower error ratio as CPs generation is more adapted to changes in vehicular traffic status through utilizing the EVPC algorithm. In addition, employing the RCPR reduces the number of unnecessary CPRs, which results in lower network load and less communication interference. In fact, as traffic aware routing protocols depend on beacon messages to collect neighbourhood information, less interference results in more accurate neighbourhood information collection.

4.1.2. Communication overhead

As mentioned previously, the purpose of LITAR is to enhance traffic aware routing by reducing the RTNSM process communication overhead. In fact, reduction in measurement process overhead leads to reduction in network load and transmission interference, which results in higher data delivery ratio with less delivery delay.

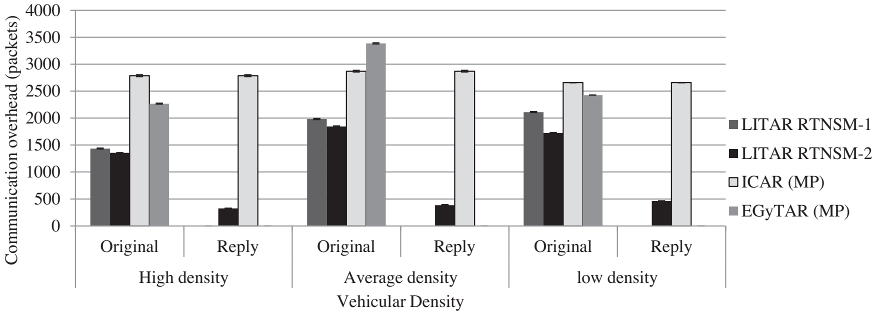

Fig. 8. Communication overhead for LITAR, iCAR and EGyTAR

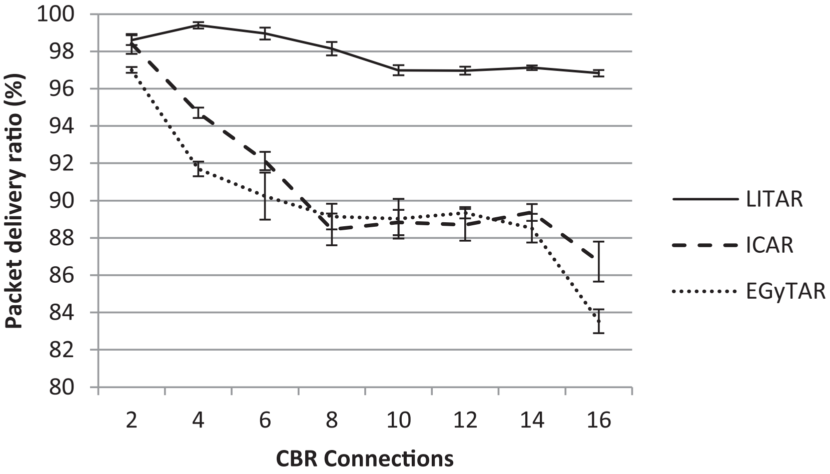

Fig. 9. PDR for different number of CBR connections in average vehicular density.

Communication overhead is measured by counting the number of CPs and CPRs generated while applying the RTNSM process.

Fig. 8, describes how LITAR RTNSM-1 and LITAR RTNSM-2 contributed significantly to the reduction of measurement process communication overhead. Although RTNSM-1 does not implement a CP reply mechanism, it generates 1435, 1983 and 2112 CPs in high, average and low vehicular density scenarios, respectively. However, generating CPRs is important in order to guarantee the availability of results at both road's ends. Accordingly, RTNSM-2 employs the RCPR which generates CPRs in certain cases and suppresses CPs generation. Obviously, RTNSM-2 reduces the number of CPs to 1356, 1846 and 1724 while generating 326, 386 and 464 CPRs in high, average and low density scenarios respectively.

For the purpose of benchmarking, RTNSM-1 is compared to EGyTAR MP as both processes do not employ a reply mechanism. Based on Fig. 8, it can be observed that RTNSM-1 has significant reduction in communication overhead in comparison with EGyTAR MP, which reaches 36.7% and 41.45% in high and average density scenarios. However, the reduction in communication overhead is less (12.97%) in case of sparse scenario. This is because RTNSM-1 generates more CPs in sparse scenarios than in dense scenarios, in order to reduce MVD average error ratio.

On the other hand, RTNSM-2 is compared to iCAR MP, in order to evaluate the communication overhead while utilizing reply mechanisms. Fig. 8 shows the number of original CPs and CPRs, generated by RTNSM-2 and iCAR MP, in the three considered scenarios. RTNSM-2 generates 51.3%, 35.65% less original CPs and 88.3%, 86.54% less CPRs in high and average density scenario, which contributes to 69.8% and 61.10% reduction in the total communication overhead. For the sparse scenario, RTNSM-2 reduces the communication overhead by 58.84%, which is a result of 35.51% and 82.54% reduction in original CPs and CPRs, respectively. Obviously, the RCPR algorithm implemented in RTNSM-2 has a tremendous effect on reducing measurement process communication overhead.

4.2. LITAR data packet routing performance evaluation

LITAR data packet routing process is evaluated in this section in terms of Packet Delivery Delay (PDD) and Packet Delivery Ratio (PDR). The evaluation is carried out in the simulation environment described previously. In this evaluation, LITAR RTNSM process employs both EVPC and RCPR algorithms. The impact of increasing the number of Constant Bit Rate (CBR) connections on the performance of LITAR, EGYTAR and iCAR is studied in the following sub-sections, whereas high, average and low vehicular density scenarios are considered. A CBR connection is established when a source vehicle starts sending data packets (in constant bit rate) to a destination vehicle through multi-hop communication.

4.2.1. Packet delivery ratio

Fig. 9, illustrates the packet delivery ratio of the three protocols, where various number of CBR connections (i.e., 2–16 CBR connections) in average vehicular density scenario are considered. It can be observed that LITAR has the highest packet delivery ratio compared to iCAR and EGyTAR. More precisely, for 2 CBR connections LITAR delivered 99.3% percent of sent packets, while iCAR and EGyTAR achieved 98.2% and 97% packet delivery ratio, respectively. However, when the number of CBR connections increased to 16, LITAR packet delivery ratio decreased slightly to 96.8%. In contrast, packet delivery ratio of 16 CBR connections dropped sharply for iCAR and EGyTAR to reach 86.7% and 83.52%, respectively. Thus, LITAR has achieved 11.6% and 15.9% higher packet delivery ratio,

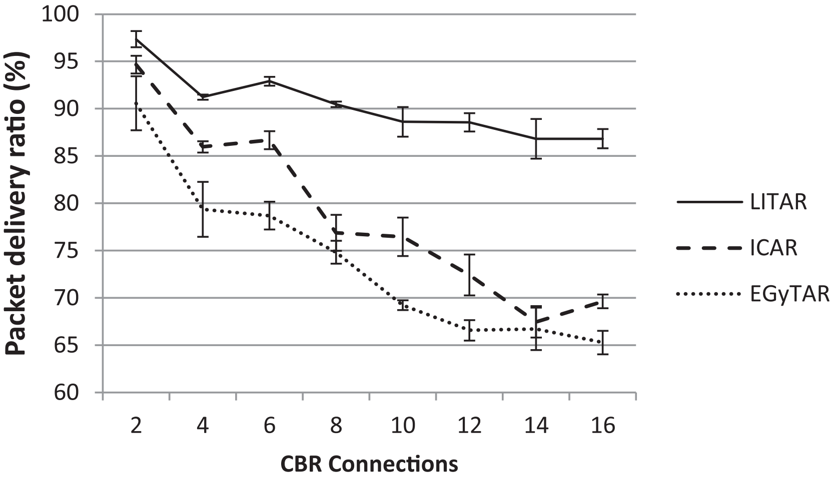

Fig. 10. PDR for different number of CBR connections in high vehicular density.

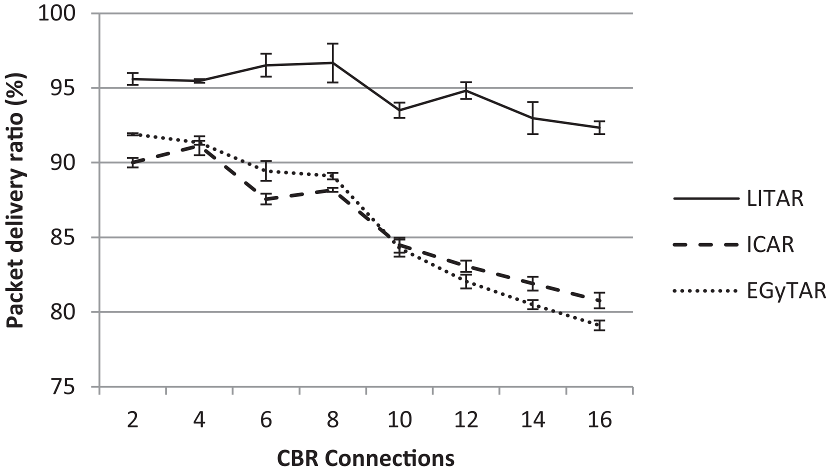

Fig. 11. PDR for different number of CBR connections in low vehicular density.

compared to iCAR and EGyTAR, in the case of 16 CBR connections in average vehicular density scenario. This is due to the reduction of LITAR's RTNSM process communication overhead, which is achieved by eliminating the generation of unnecessary CPs and CPRs.

Fig. 10, depicts the packet delivery ratio of the three protocols, while varying number of CBR connections (i.e., 2 to 16 CBR connections) in high vehicular density scenario. Obviously, LITAR has the highest packet delivery ratio compared to iCAR and EGyTAR. More precisely, for 2 CBR connections LITAR delivered 97.0% percent of sent packets, while iCAR and EGyTAR achieved 94.6% and 90.5% packet delivery ratio, respectively. However, by increasing the number of CBR connections to 16, LITAR packet delivery ratio decreased to 86.8%. In contrast, packet delivery ratio of 16 CBR connections dropped sharply for iCAR and EGyTAR to reach 69.6% and 65.3%, respectively. Thus, LITAR has achieved 24.7% and 32.9% higher packet delivery ratio, compared to iCAR and EGyTAR, in the case of 16 CBR connections in high vehicular density scenario. It is clear that eliminating the generation of unnecessary CPs and CPRs, contributed to significant reductions of LITAR's RTNSM process communication overhead. Due to the effect of high signal interference that results in collisions and packet losses, the three protocols have lower performance in high density compared to average density scenario. However, LITAR was less affected by the signal interference and contention on transmission channels, as its RTNSM process reduces the routing overhead.

For the low vehicular density scenario, Fig. 11 describes the performance of LITAR, iCAR and EGyTAR while increasing the number of CBR connections from 2 to 16. Obviously, LITAR has the highest packet delivery ratio in all cases compared to iCAR and EGyTAR. In particular, LITAR achieved 95.6% in the case of 2 CBR connections, whereas a PDR of 92.3% is achieved when 16 CBR connections are considered. On the other hand, the graphs of iCAR and EGyTAR, which started at 90.0% and 91.9% of PDR for 2 CBR connections, dropped incrementally to reach a PDR of 80.7% and 79.1% for iCAR and EGyTAR, respectively. From Fig, 11, it is clear that LITAR performs better than iCAR and EGyTAR specially in high number of CBR connections. Precisely, LITAR achieved a PDR which is higher by 14.37% compared to iCAR and 20.8% compared to EGyTAR, while considering 16 CBR connections.

4.2.2. Packet delivery delay

Packet delivery delay is an evaluation metric which shows the effect of LITAR on the average end-to-end delay for delivering a packet from source to destination. The values of packet delivery delay for LITAR, iCAR and EGyTAR are presented in the graphs of Figs. 12–14, as a function of CBR connections number.

For the average vehicular density scenario, LITAR PDD is slightly higher than iCAR and EGyTAR specially for low number of CBR connections, as depicted in Fig. 12. More precisely, PDD of LITAR for 2 CBR connections is 0.028 seconds, while iCAR and EGyTAR started with 0.035 and 0.025, respectively. Afterwards, LITAR PDD

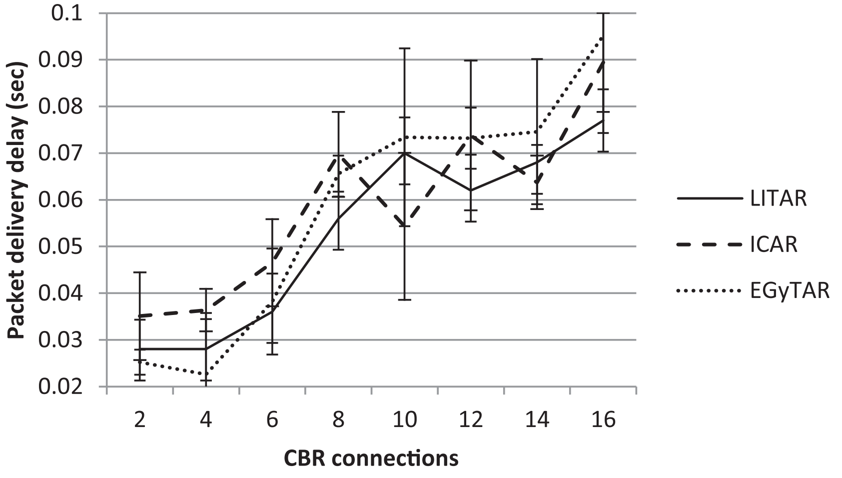

Fig. 12. PDD for different number of CBR connections in average vehicular density.

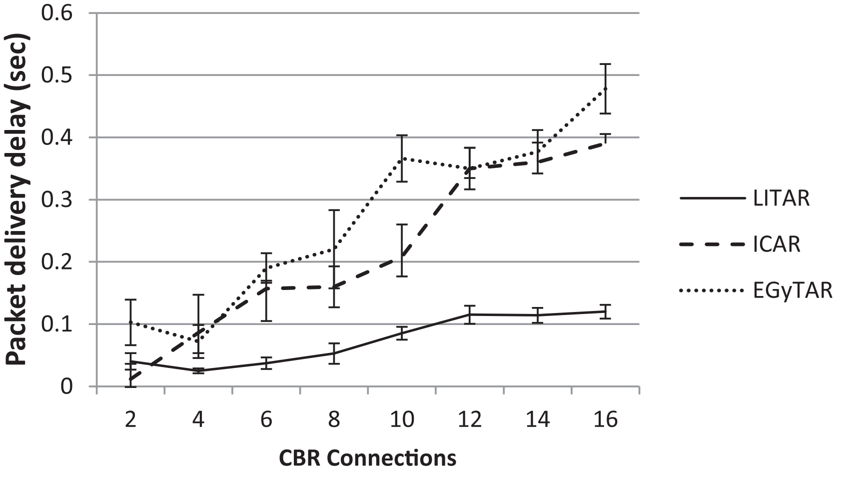

Fig. 13. PDD for different number of CBR connections in high vehicular density.

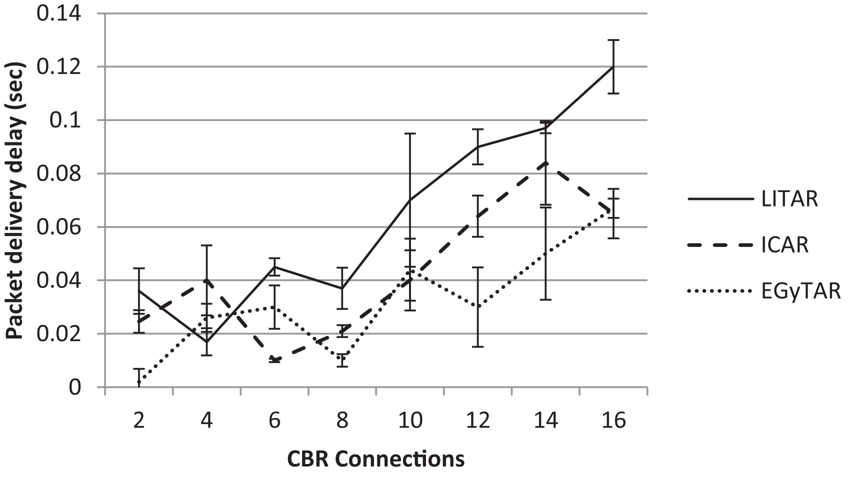

Fig. 14. PDD for different number of CBR connections in low vehicular density.

increases to 0.056 seconds for 8 CBR connections, where iCAR and EGyTAR has a higher PDD equals to 0.069 and 0.065 seconds, consecutively. However, for higher number of CBR (i.e., 14 and 16 CBR connections), the effect of the high network overhead generated by iCAR and EGyTAR becomes more clear and results in high PDD with low PDR. On the other hand, LITAR PDD does not grow fast for high number of CBR connections as its RTNSM process generates less network overhead. In particular, LITAR PDD reached 0.077 seconds for 16 CBR. In contrast, iCAR and EGyTAR PDD increased dramatically to reach 0.089 and 0.095 seconds.

In the high vehicular density scenario, LITAR PDD achieved significant decrements compared to iCAR and EGyTAR specially for high number of CBR connections, as depicted in Fig. 13. More precisely, PDD of LITAR for 2 CBR connections is 0.04 seconds, while iCAR and EGyTAR started with 0.012 and 0.10, respectively. However, for higher number of CBR (i.e., 14 and 16 CBR connections), the effect of the high network overhead generated by iCAR and EGyTAR becomes more clear and increases the PDD dramatically while providing low PDR. On the other hand, LITAR PDD does not grow fast for high number of CBR connections as its RTNSM process generates less network overhead. In particular, LITAR PDD reached 0.12 seconds for 16 CBR. In contrast, iCAR and EGyTAR PDD increased dramatically to reach 0.39 and 0.48 seconds. This is due to the high contention on transmission channels that causes high delays while sending packets.

As can be observed from Fig. 14, LITAR has slightly higher PDD, in the low vehicular density scenario, compared to ICAR and EGyTAR. In more details, LITAR PDD reached 0.12 seconds for 16 CBR connections, while ICAR and EGyTAR PDD values are below 0.0.067 seconds. This is because LITAR tends to choose roads with higher connectivity to deliver data packets, even though the distance towards destination might be longer and consumes a longer delivery time. Accordingly, the slightly higher delivery delay of LITAR results in higher packet delivery ratio as show in Fig. 11.

Obviously, employing the EVPC algorithm, which eliminates the unnecessary generation of CPs while maintaining the accuracy of RTNSM results, has contributed to the reduction of network overhead. In addition, reducing the number of unnecessary CPRs by applying the RCPR algorithm, leads to magnificent reduction in the network traffic generated through CPRs. Accordingly, the enhanced RTNSM process of LITAR, which combined both EVPC and RCPR has a significant impact on improving the routing performance of TAR protocols.

5. Conclusions

Intersection-based Traffic aware routing protocols have the ability to adapt to VANETs dynamic environment, as routing decisions are made based on traffic and network conditions. However, employing a real-time measurement process for the traffic and network status generates high network overhead, which degrades routing protocol performance.

LITAR protocol introduced two algorithms for reducing the network overhead generated by the real-time traffic and network status measurement process. The first algorithm (EVPC algorithm) eliminated the number of unnecessary generated collector packets, which are used by the real-time measurement process. The second algorithm (RCPR algorithm) restricted the number of collector packet replies. In addition, LITAR route data packets based on three metrics; directional vehicular density, road network connectivity and distance towards destination. Simulation results show that LITAR performs better than iCAR and EGyTAR in terms of packet delivery ratio, end-to-end delay, real-time measurement accuracy and routing overhead. Accordingly, LITAR should be able to provide stable and efficient V2V communication in urban environment.

For future work LITAR will be tested on more complicated city maps. In addition, a research will be carried out to investigate how LITAR can be utilized to provide V2I communication based on traffic conditions.

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