Multi-Copy Intersection-Based Routing Protocol for VANET in Urban Areas

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***Abstract*—In this paper, we propose a new routing protocol called multi-copy intersection-based routing (MCIR) for vehicular ad-hoc networks (VANETs) in urban areas. MCIR is an intersection-based routing protocol that forwards multiple copies of the packets in different road segments. Moreover, it is a beacon-less routing protocol with a carry-and-forward strategy. We show via simulation that MCIR protocol is superior to other existing routing protocols, especially in low vehicular density scenarios. The results show that MCIR achieves a shorter end-to-end delay and a higher packet delivery ratio in urban VANET communications.**

I. Introduction

Vehicular ad-hoc network (VANET) technology enables communication between vehicles, or vehicles and road-side units (RSU) through wireless communication devices installed on the vehicles. One of the most important goals of VANET is providing safety applications for passengers. In addition, VANET provides comfort applications to the users (e.g., mobile e-commerce, weather information, Internet access, and other many multimedia applications). Routing is a fundamental process for vehicular communications to select a source-to-destination path. The important goal of unicast routing protocols in VANET communications is to transmit data from the source to the destination via a multi-hop path. Some VANET applications have an end-to-end delay constraint. Consequently, end-to-end delay is a very important issue in VANET routing design.

VANET connectivity often changes, especially when the vehicular density is low. Therefore, regular ad-hoc routing protocols with complete path discovery mechanisms are not feasible since the routing path is usually disconnected due to the intermittent nature of the network links. Scenarios with low vehicular density have a higher probability of network disconnection [1]. As a result, packets suffer from long end-to-end delay due to queuing in the buffer and this increases the packet loss probability caused by timeout or overflow in the queues [2]. To overcome this problem, vehicles can be used as carriers to deliver messages via a carry-and-forward strategy whenever forwarding option via wireless transmission is not available. Therefore, most of the existing routing protocols for VANET use the carry-and-forward strategy as one of its routing strategies to face the network disconnection.

Many papers proposed routing protocols for VANET routing in urban areas. Most of routing protocols in urban areas are position-based protocols that depend on the greedy perimeter stateless routing protocol (GPSR) [3]. GPSR protocol uses greedy forwarding to forward packets from a source to a destination. In greedy forwarding, GPSR tries to bring packets closer to the destination in each hop using geographic information. However, in many cases, greedy forwarding can lead to areas where there is no neighbor closer to the destination vehicle except for the current forwarding vehicle.

Greedy traffic-aware routing (GyTAR) protocol [4] uses digital maps to identify the position of intersections and location service to get the destination location. It selects a forwarding path with the highest vehicular density and the shortest distance. The protocol consists of two parts, namely dynamic junction selection procedure and forwarding strategy between two involved intersections. For each intersection, the protocol calculates a score for each road segment candidate that depends on the vehicular density and the Euclidean distance to the destination. A road segment is an area between two adjacent intersections such as the region that is between the intersections I_1 and I_2 in Fig. 1. The candidate road segment with the highest score is selected. After the next road segment is selected, the protocol uses greedy forwarding to forward the packets. Moreover, GyTAR uses carry-and-forward as one of its routing strategies.

On the other hand, backbone assisted hop greedy routing (BHAG) [5] selects the forwarding path with the minimum number of intersections. This is because the shortest path, or the path with the highest connectivity, may include numerous intermediate intersections. As a result, this yields a routing path with a higher hop count. Moreover, it ranks the connectivity of the streets based on the number of lanes.

Street-centric routing protocol-based on micro topology (SRPMT) [6] represents the city on a transfer graph, where each edge represents micro topology, while the vertex represents an intersection. Micro topology consists of vehicles and wireless links among vehicles along a street. The edge weights depend on the vehicles mobility, signal fading, wireless channel contention, and existing data traffic. Multi-path for video streaming proposed in [7], distributes the traffic into a set of two or three paths for load balancing.

"Adaptive Multi-copy Routing (AMR) [8] adaptively selects between single-copy and multi-copy routing at the intersections depending the difference between estimated end-to-end delay for the single-copy and the multi-copy. If the difference is greater than threshold, AMR selects multi-copy routing. However, AMR assume that the average vehicle density and the real-time delay cost of every road section in the network are available for each vehicle. In addition, AMR does not eliminate the unneeded copies of the packets".

Most of the above mentioned routing protocols use a single-copy of the generated packets. Moreover, they select the route with the highest vehicular density to avoid network disconnection. However, this single-copy may face disconnected road segments due to low vehicular density. Therefore, most of the previous protocols focus on VANET with high vehicular density or in a small area on their simulation. For example, BHAG protocol obtains their results with 600 vehicles in an area of 3 km x 3 km. On the other hand, SRPMT performs the simulation with 100 to 300 vehicles in an area of 2 km x 1.5 km. Moreover, GyTAR conducts the simulation with 100 to 350 vehicles in an area of 2.5 km x 2 km. Nevertheless, one of VANET characteristics is that vehicular density fluctuates between low and high. Therefore, we need to consider low vehicular density scenarios in the simulation. In addition, it is challenging to estimate the vehicular density and make this information available accurately to all vehicles in the network as in AMR. Moreover, the beacon packets add much overhead to VANET.

This paper focuses on developing multi-copy intersection-based routing (MCIR) protocol for urban VANET communications. MCIR is a beacon-less routing protocol with a carry-and-forward strategy. In addition, MCIR does not need vehicular density estimation. The proposed protocol deals with low vehicular density by forwarding either one or two copies of each packet at the intersections towards the destination depending on the forwarding vehicle position with respect to the destination position. At each intersection, MCIR finds out which one or two of the four main directions will bring the packets closer to the destination. Next, MCIR forwards the packet in these selected directions. For instance, as shown in Fig. 1, at intersection I_1, MCIR forwards the packet up and right, while at intersection I_4, MCIR forwards the packet right only. Meanwhile, the proposed protocol eliminates the unneeded copies of the packets at the intersections to minimize the routing overhead. The proposed protocol improves the packet delivery ratio and reduces the end-to-end delay. Moreover, on the straight road segments, the protocol greedily forwards packets to the next intersection.

The main contributions of this paper are as follows: 1) It proposes a new routing protocol for VANET in urban areas. 2) It analyzes the proposed protocol at low vehicular density and its impact on the routing performance. 3) It compares the proposed protocol with two of the most commonly-used protocols in the literature. The rest of this paper is organized as follows. Section II introduces the system model. Section III provides MCIR protocol design with a detailed example. Section IV presents the performance evaluation for MCIR in terms of packet delivery rate, average end-to-end delay, and routing overhead. Finally, the conclusions and future work are presented in Section V.

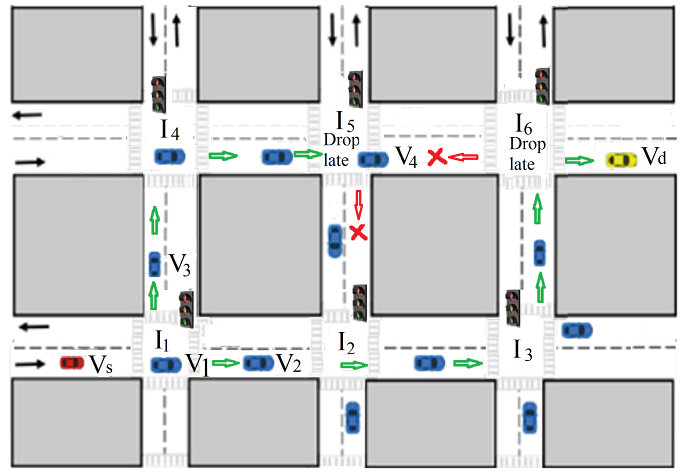

Fig. 1. Urban grid model

II. System Model

We assume that each vehicle has the capability to obtain digital maps and its position information, which we consider as a valid assumption since nowadays most of the vehicles have a GPS device [9]. In addition, it is assumed that the source vehicle acquires the destination's location via a location service such as hierarchical location service (HLS) [10] or grid location service (GLS) [11].

Once the destination vehicle's location is obtained, it is included in the packet header. Therefore, the intermediate vehicles do not have to use the location service. However, due to the dynamic nature of the VANET, the destination vehicle may change its location by the time packets arrive at the initial location. In this case, the packet carrier obtains the new location of the destination vehicle via location service and forwards the packet towards the new location [12]. Further, we presume the use of location service is limited only to acquiring the destination vehicle location.

In addition, we use a grid model for the city environment as shown in Fig. 1. This model is based on Manhattan grid mobility model [13]. In this model, each vehicle is able to adjust its speed based on the movement of the neighboring vehicles and change the lane to overtake other vehicles in multi-lane roads. This model also supports smart intersection management, where vehicles slow down and stop at intersections, or they act accordingly at traffic lights. Moreover, wrap-around pattern is used such that when a vehicle reaches the border or its destination position, it starts moving towards a new destination position. For instance, as shown in Fig. 1, when a vehicle V_1 reaches its destination location at I_3, it starts moving towards a new destination location.

Moreover, we assume that the speed of the vehicles is uniformly distributed within the interval $[V_{min}, V_{max}]$ [14], while the inter-vehicle distance is exponentially distributed [15]. The medium access control (MAC) layer protocol is the distributed coordination function (DCF) of the IEEE 802.11. In addition, the radio channel propagation model is assumed to be Nakagami-m distrbution [16]. Packet traffic model follows

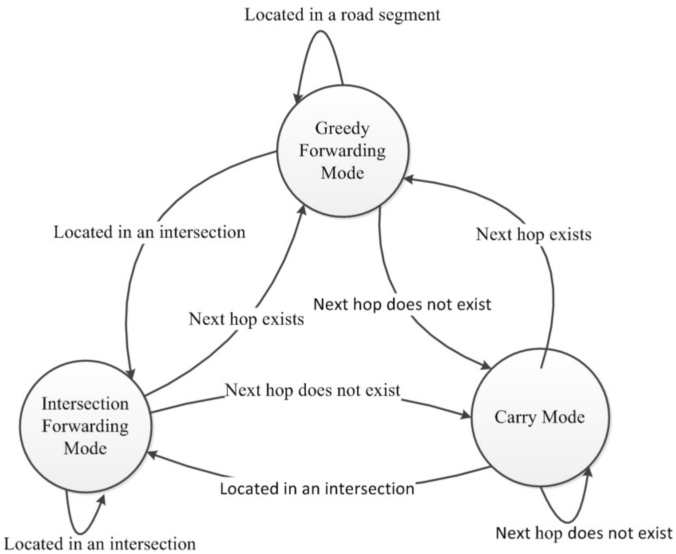

Fig. 2. MICR Modes

the constant bit rate (CBR) pattern between a source and a destination that are randomly selected.

III. Proposed routing protocol

MCIR protocol has three modes that depend on the location of the forwarding vehicle (the vehicle that has a packet or a flow of packets and wants to forward it towards the destination) and the vehicular density as shown in Fig. 2. Algorithm 1 explains the three modes in detail. The three modes are defined as follows.

Greedy Forwarding Mode: In this mode, the current location of the forwarding vehicle and the destination location are stored in the packet header to enable the neighbors to calculate their progress towards the destination. All neighbors check if they are closer to the destination than the forwarding vehicle. If this condition is true, each neighbor vehicle starts a timer with an interval as follows

$$Timer\ Interval = \frac{R-D}{R}, \qquad (1)$$

where R is the communication range and D is the Euclidean distance from the neighbor vehicle to the forwarding vehicle. Therefore, the closest neighbor vehicle to the destination vehicle starts the forwarding first. Consequently, it achieves more progress towards the destination, decreases the hop count, and reduces the end-to-end delay. When one neighbor vehicle forwards the packet, all other neighbors vehicles which overhear the packet transmission will drop the packet. On the other hand, the forwarding vehicle must overhear one neighbor forwarding the packet. Otherwise, the forwarding vehicle switches to Carry Mode.

Carry Mode: MCIR switches to Carry Mode when a forwarding vehicle is located at a forwarding area with no neighbors. When a carry timer (a timer during its period the forwarding vehicle must overhear one neighbor forwards the packet) expires, the forwarding vehicle rebroadcasts the packets and starts the overhearing. Consequently, if one neighbor

Algorithm 1 MCIR Algorithm

procedure Receive–Packet(Packet P)
    $Src \leftarrow Packet - Source$
    $D \leftarrow Packet - Destination$
    $MyID \leftarrow Node - ID$
    $Mydis \leftarrow Distance(MyID, Source)$
    $Frdis \leftarrow Distance(Source, Destination)$
    if $D = MyID$ **then**
        Received-packet(success)
    end if
    if $MyID = P.Previous.node$ **then**
        Drop-packet(P)
        Delete-packet-overhearing-list(P)
    end if
    if $P = Timer - packet$ and $Src.road = Myroad$ **then**
        Drop-packet(P)
        Cancel-Forwarding-Timer(P)
    end if
    if $P \in copy - table$ **then**
        Drop-packet(P)
    end if
    if $Distance(MyID, Destination) \leq Frdis$ **then**
        Delay= (R-D)/R
        Start-Forwarding-Timer((R-D)/R,P)
        Add-copy-table(P)
    end if
end procedure

exists in the forwarding area and is closer to the destination than the forwarding vehicle, this neighbor will be the next hop for the packet. As a result, the forwarding vehicle switches to the Greedy Forwarding Mode and drops the packet after overhearing the neighbor forwarding the packet.

Intersection Forwarding Mode: At the intersection points that are defined by the digital map, MCIR operates in Intersection Forwarding Mode. MCIR forwards multiple copies of the packets in the candidate road segments towards the destination vehicle and eliminates unneeded copies at the next intersections to reduce the overhead. All the vehicles in the candidate road segments must be closer to the destination than the forwarding node. At the intersections, MCIR forwards the packet if it is the first time the packet reaches this intersection. Otherwise, the packet is dropped. Next, each neighbor vehicle in this intersection checks if it is located in one of the four main directions bringing the packet closer to the destination. This can be achieved by using the digital map and the destination location from the packet header. If this condition is true, the neighbor starts the Greedy Forwarding Mode as mentioned before. In addition, the neighbor vehicle drops the packet and stops the forwarding if one neighbor in the same road segment forwarded the same packet. Before dropping the packet, the neighbor vehicle ensures that it is located in the same road segment of the forwarding neighbor vehicle. For instance, as shown in Fig. 1, if V_2 overhears V_3 forwarding the same packet, V_2 does not stop forwarding because V_3 is in a different road segments and MCIR forwards the packets in both road segments. This condition is added because the neighbor vehicle may overhear one vehicle forwarding the packet but in another road segment and MCIR forwards the same packet in one or two road segments. Finally, the forwarding vehicle drops the packet after it ensures that there is one neighbor forwarding the packet. Otherwise, the forwarding vehicle switches to the Carry Mode.

As illustrated in Fig. 2, MCIR switches from the Greedy Forwarding Mode or the Intersection Mode to the Carry Mode if the forwarding vehicle does not find a next hop for the packet. In addition, MCIR switches from the Greedy Forwarding Mode or the Carry Mode to the Intersection Mode when the vehicle moves from a road segment to an intersection. The Carry Mode and the Greedy Forwarding Mode are timer-based as MCIR is a beacon-less routing protocol. MCIR has two timers; one operates on the neighbor vehicles to forwards the packet in the Greedy Forwarding Mode. The second timer operates on the forwarding vehicle to carry the packet in the Carry Mode until one neighbor exists.

A. Detailed Example for MCIR

In this sub-section, we present an example to show the multi-copy forwarding algorithm, which is the main component of MCIR protocol. In Fig. 1, we assume that a source vehicle V_s wants to send a flow of packets to a destination vehicle V_d. Therefore, V_s broadcasts the packet and the intermediate vehicle V_1 will receive it. After V_1 receives the packet from V_s at the intersection I_1 and ensures that this packet has never been replicated and forwarded at I_1, V_1 switches to the Greedy Forwarding Mode.

Since MCIR does not know the vehicular density of the road segments towards the destination, MCIR sends the packet in both directions of the road segments I_1-I_4 and I_1-I_2. Therefore, V_1 switches to the Intersection Forwarding Mode. V_1 broadcasts the packet and starts the overhearing. Each neighbor vehicle ensures that it is located at a candidate road segment. This condition is added to reduce the overhead by forwarding the packet towards the destination only. In this example, I_1-I_4 and I_1-I_2 are candidate road segments for the packet forwarding.

Next, V_2 and V_3 ensure that their distances to the destination V_d is less than the distance between V_1 and the destination V_d. Therefore, V_2 and V_3 start their forwarding timer to forward this packet. After the timer expires, V_2 and V_3 forward the packet in the road segments I_1-I_4 and I_1-I_2, respectively. If V_2 overhears V_3 forwarding the packet, V_2 does not stop forwarding because V_3 and V_2 are not in the same road segment. Simultaneously, V_1 drops the packet after overhearing the packet. Otherwise, V_1 switches to the Carry Mode. This process is then repeated once the packet reaches intersections I_2 and I_4. At intersection I_4, there is only one candidate road segment for the packet which is I_4-I_5. On the other hand, at intersection I_2, there are two candidate road segments which are I_2-I_5 and I_2-I_3. In this example, we assume the packet arrives first at intersection I_5 via I_2; and the current forwarding vehicle V_4 switches to the Intersection Forwarding Mode at I_5.

" Therefore, V_4 starts forwarding the data packet on the road segment I_5-I_6. On the same time, V_4 forwards alarm packet (packet includes only the data packet id, the source id, the destination id) in the road segment I_5-I_2 to inform all the vehicles in this road segment to drop any received data packet with the same information (id, source id, destination id). This process is added to prevent forwarding the same packet from the intersection I_2 to the intersection I_5". Finally, the same process will be repeated at I_6. In this example, we assume the packet arrives first at intersection I_6 via I_3; and the alarm packet is forwarded in the road segment I_6-I_5". As a result, the destination gets the packet that arrives first.

IV. Simulation Results

This section presents the performance evaluation of MCIR to investigate the performance impact of multi-copy on routing protocols. We implement our proposed MCIR protocol in NS-2 (V-2.34). For comparison, we implement GPSR and SRPMT explained in the introduction section. We make two modifications on GPSR to be more suited for VANET and for fair comparison with MCIR. The first modification is the addition of the location service on GPSR to get the location of the destination vehicle, while the second modification is the addition of the carry-and-forward strategy.

The simulation scenarios are configured in a 3 km x 3 km urban grid model with different vehicular densities ranging from 5 vehicles/km to 30 vehicles/km. We use VanetMobiSim [17] to generate realistic vehicle mobility. Table 1 summarizes the configuration parameters used in the simulation.

Table I
Simulation parameters

Simulation Parameter	Value
Area	3 km x 3 km
Vehicular density (vehicles/km)	5,10, 15, 20, 25, 30
Speed (m/sec)	5 to 15
Simulation time (seconds)	600
Traffic model	CBR Traffic
CBR rate (packets/second)	2
Transmission range (m)	250
Channel date rate (Mbps)	2
Packet size (bytes)	256
Number of sessions	1
beacon interval (seconds)	2

Four main important performance metrics are considered. The first metric is the end-to-end delay defined as the difference between the time a data packet arrives at its destination and the time the same packet is originated by the source. This time includes all possible delays as follows

$$Delay = Queue_{\text{delay}} + Carry_{\text{delay}} + Prop_{\text{delay}} + Tr_{\text{delay}}, \quad (2)$$

where $Queue_{\text{delay}}$ is the queuing delay, $\text{Carry}_{\text{delay}}$ is the Carry Mode delay, $Prop_{\text{delay}}$ is the propagation delay over the wireless channel, and Tr_{delay} is transmission delay. The second metric is the packet delivery ratio (PDR) defined as the ratio of the total number of the data packets received by the destination to the the total number of the data packets sent by the traffic sources. Finally, the third metric is the routing overhead defined as follows

$$(Overhead)_{\text{packets}} = \frac{Number\ of\ transmitted\ packets}{Number\ of\ received\ data\ packets}. \quad (3)$$

However, the routing overhead in MCIR represents data and the alarm packets, while the overhead in modified-GPSR and SRPMT represents beacon and data packets. Therefore, for fair comparison with MCIR, we consider the fourth metric that represents the routing overhead in the number of transmitted bits as in [6] . It is defined as follows

$$(Overhead)_{\text{bits}} = \frac{Number\ of\ transmitted\ bits}{Number\ of\ received\ data\ bits}. \quad (4)$$

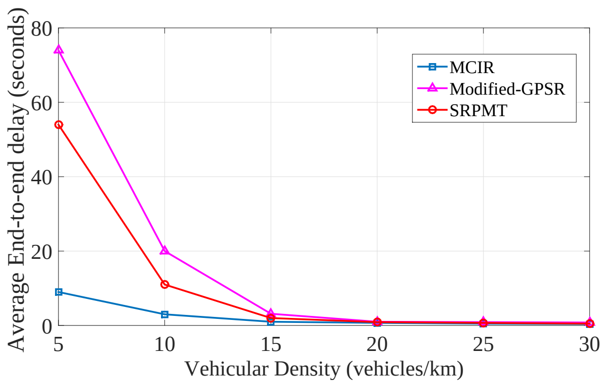

Fig. 3. Average End-to-end Delay.

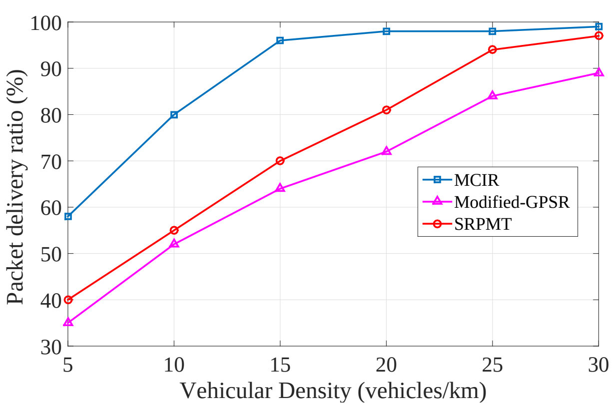

Fig. 4. Packet delivery Ratio.

Fig. 3 shows the average end-to-end delay against the vehicular density for MCIR, SRPMT, and modified-GPSR protocols. Results show that there is a significant decrease in the average end-to-end delay of MCIR compared with modified-GPSR and SRPMT especially at low vehicular density. For instance, at vehicular density of 5 vehicles/km, the average end-to-end delay of MCIR is reduced by 87% and

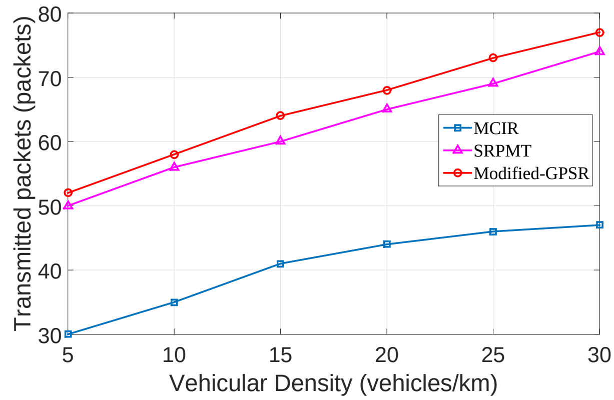

Fig. 5. Routing overhead represented in transmitted packets.

83% compared with modified-GPSR and SRPMT, respectively. However, this improvement decreases to 50% and 2% at vehicular density of 30 vehicles/km due to the increase of the vehicular density that increases the connectivity of the network. In addition, at vehicular density of 15 vehicles/km, the average end-to-end delay of MCIR is reduced by 66% and 50% compared with modified-GPSR and SRPMT, respectively. The reason behind this behavior is that low vehicular density leads to disconnected road segment. As a result, the three routing protocols switch to the Carry Mode. Consequently, the packets suffer from a higher end-to-end delay. Also, the results show that the vehicular density highly impacts the end-to-end delay. With decreasing the vehicular density, the average end-to-end delay increases for all values of the vehicular density for the three routing protocol. On the other hand, SRPMT has a slightly shorter end-to-end delay than modified-GPSR due to micro topology consideration in the routing metric, especially at low vehicular density. For instance, at vehicular density of 5 vehicles/km, the average end-to-end delay of SRPMT is reduced by 27% compared with modified-GPSR.

Fig. 4 shows the PDR against the vehicular density for MCIR, SRPMT, and modified-GPSR protocols. It is noticed that there is a significant increase in the PDR of MCIR compared with modified-GPSR and SRPMT for all values of the vehicular density. For instance, at vehicular density of 5 vehicles/km, the PDR of MCIR is increased by 63% and 45% compared with modified-GPSR and SRPMT, respectively. However, this improvement decreases to 11% and 2% at vehicular density of 30 vehicles/km due to the increase of the vehicular density that enhances the connectivity of the network. Three reasons are behind this behavior. Firstly, in SRPMT and modified-GPSR, packets are more likely to collide with the beacon packets. On the contrary, MCIR is a beacon-less protocol. Secondly, in case of SRPMT and modified-GPSR, the single-copy of the packet may be dropped after time out in the queue due to switching to carry-and-forward strategy in the disconnected road segments. Thirdly, modified-GPSR depends on the neighbor table to select the next hop. However, the neighbor table may contain outdated information. Consequently, the packet is dropped after for-

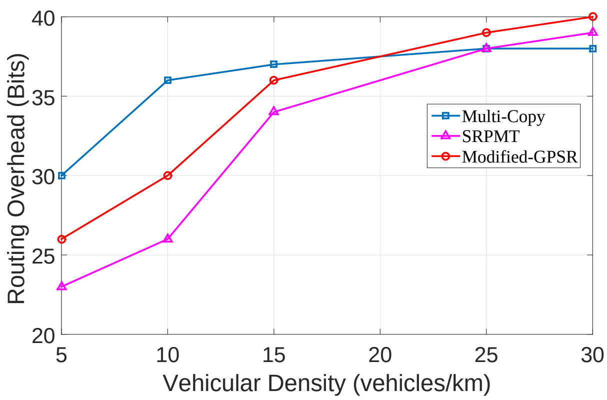

Fig. 6. Routing overhead represented in transmitted bits.

warding to a non-existing neighbor. On the other hand, MCIR does not suffer from the three previous problems as it sends muti-copy from the same packet. Therefore, if one copy of the packet is dropped, another copy arrives at the destination. As a result, the PDR of MCIR remains the highest of all of them for all values of the vehicular density. SRPMT appears to have a slightly higher PDR than modified-GPSR due to micro topology consideration in the routing metric, especially at low vehicular density. For instance, at vehicular density of 5 vehicles/km, the PDR of SRPMT is increased by 14% compared with that modified-GPSR.

Fig. 5 shows the routing overhead represented in the number of transmitted packets against the vehicular density for MCIR, SRPMT, and modified-GPSR protocols. It is noticed that MCIR has less routing overhead than SRPMT and modified-GPSR for all values of the vehicular density. For instance, at vehicular density of 5 vehicles/km, the routing overhead of MCIR is decreased by 40% and 42% compared with modified-GPSR and SRPMT, respectively. There are two reasons for this behavior. Firstly, MCIR is a beacon-less routing protocol. Secondly, MCIR has the highest number of successfully received data packets compared with SRPMT and modified-GPSR. The results confirm that the increase of the vehicular density causes an increase in the routing overhead for all three routing protocols. This is expected because increasing vehicular density leads to an increase in the hop count for the packets. Moreover, the number of transmitted beacon packets increase in case of SRPMT and modified-GPSR with the increase of the vehicular density. SRPMT appears to have a marginally higher routing overhead than modified-GPSR due to the beacon packets to collect vehicle information in local micro topology. For instance, at vehicular density of 5 vehicles/km, the routing overhead of SRPMT is increased by 4% compared with modified-GPSR.

Fig. 6 shows the routing overhead represented in the number of transmitted bits against the vehicular density for MCIR, SRPMT, and modified-GPSR protocols. It is noticed that MCIR has a higher routing overhead than SRPMT and modified-GPSR in low vehicular density. For instance, at vehicular density of 5 vehicles/km, the routing overhead of MCIR is increased by 11% and 30% compared with modified-GPSR and SRPMT, respectively. The reason behind this behavior is that MCIR is multi-copy routing protocol, while SRPMT and modified-GPSR are single-copy protocols. In addition, the data packets are larger in size than the beacon packets. On the other hand, the results confirm that MCIR overhead remains constant after reaching its peak. However, Modified-GPSR and SRPMT overhead increases with the increasing of the vehicular density. For instance, at vehicular density of 30 vehicles/km, the routing overhead of MCIR is decreased by 12% and 8% compared with modified-GPSR and SRPMT, respectively. This is expected because increasing vehicular density leads to an increase in the number of beacon packets in case of SRPMT and modified-GPSR. On the contrary, MCIR is beacon-less routing protocol. Finally, modified-GPSR appears to have a marginally higher routing overhead than SRPMT due to the larger size of the beacon packets at modified-GPSR.

V. Conclusion

In this paper, we proposed multi-copy routing protocol that aims to reduce the end-to-end delay and increase the packet delivery ratio. MCIR is a beacon-less routing protocol that forwards multiple copies of the packets and eliminates unneeded copies at the intersections. We have investigated the vehicular density impact on the VANET routing protocols performance. Simulation results confirm that the vehicular density highly impacts the routing performance in urban VANET communications. In addition, results show that MCIR outperforms SRPMT and modified-GPSR in terms of the end-to-end delay and packet delivery ratio with a slight increase in the routing overhead. In our future work, we will consider an adaptive beacon-less routing protocol that switches between mutli-copy and single-copy based on the vehicular density to reduce the routing overhead.

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