Towards Efficient Routing in Vehicular Ad Hoc Networks

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Abstract— **Multi-hop data delivery through Vehicular Ad-hoc Networks is challenging since it must efficiently handle rapid topology changes and a fragmented network. This paper proposes a new intersection-based geographical routing protocol called GyTAR (improved Greedy Traffic Aware Routing protocol) and capable to find robust routes within city environments. GyTAR consists of two modules: (i) dynamic selection of the junctions through which a packet must pass to reach its destination, and (ii) an improved greedy strategy used to forward packets between two junctions. GyTAR assumes the existence of an accurate traffic-information system that it requires to select paths with high connectivity. To address this issue, we also propose a completely decentralized mechanism for the estimation of traffic density in city-roads called IFTIS for Infrastructure-Free Traffic Information System. The proposed routing protocol shows significant performance improvement in a comparative simulation study with other routing approaches.**

Index Terms— **Vehicular Ad hoc Network, Greedy Routing, Vehicular Traffic Estimation, Performance Measurements**

I. INTRODUCTION

Inter-vehicle communication is a fast growing research topic in the academic sector and industry. Through this kind of communication, vehicles are able to communicate with each other by using wireless technology like WLAN. As a result, they can be organized in vehicular ad hoc networks (VANETs). VANETs are an instantiation of mobile ad hoc networks (MANETs). MANETs have no fixed infrastructure and instead rely on ordinary nodes to perform routing of messages and network management functions. However, vehicular ad hoc networks behave in different ways than conventional MANETs. Driver behavior, mobility constraints, and high speeds create unique characteristics of VANETs. These characteristics have important implications for designing decisions in these networks. Thus, numerous research challenges need to be addressed for inter-vehicule communications to be widely deployed. For example, routing in conventional mobile ad hoc networks is a challenging task because of the network's dynamic topology changes. Numerous studies and proposals of routing protocols have been conducted to relay data in such a context; however these solutions can not be applied to the vehicular environment due to the specific constraints and characteristics of VANETs.

In this work, we present a novel geographical routing protocol for vehicular networks in city environments called GyTAR: improved Greedy Traffic Aware Routing protocol. Based on a localization system like the GPS (Global Positioning System), our solution aims to efficiently relay data in the network considering the real time road traffic variation and the characteristics of city environments. GyTAR assumes then the existence of an accurate traffic-information system that it requires. To this end, we also propose in this work a completely decentralized mechanism for the estimation of traffic density in city-roads called IFTIS for Infrastructure-Free Traffic Information System. Note that, although it has been designed to operate with GyTAR, IFTIS is a completelty independent component which could be used for any other purpose requiring road density estimation. Indeed, IFTIS could be adopted, for instance, to be used in real-time traffic congestion warning systems, leveraging on the proposed distributed mechanism that provides updated traffic information to drivers.

The rest of the paper is structured as follows. Section 2 presents existing approaches on routing in VANET and details the principles of GyTAR. Section 3 describes the mechanism used in IFTIS to provide the information about vehicular traffic between two junctions. Section 4 presents simulation setting and results. Finally, conclusion and future work are summarized in Section 5.

II. IMPROVED GREEDY TRAFFIC AWARE ROUTING PROTOCOL

A. *Routing in VANET*

Recently, some routing protocols specific to VANETs have been proposed. In the following, we present the most important ones: GSR, A-STAR, and GPCR.

'GSR' [1] (Geographic Source Routing) has been recently proposed as a promising routing strategy for vehicular ad hoc networks in city environments. It combines position-based routing with topological knowledge. The simulation results, with the use of realistic vehicular traffic in city environments, show that GSR outperforms topology-based approaches (DSR and AODV) with respect to delivery rate and latency. In another study [2], the same authors have shown, for highway scenarios, that routing approaches using position information, e.g., obtained from on-board GPS receivers, can very well deal with the mobility of the vehicles.

'A-STAR'[3] (Anchor-based Street and Traffic Aware Routing) is a position-based routing scheme designed specifically for IVC in city environments. It features the novel use of city bus route information to identify anchor paths of higher connectivity so that more packets can be delivered to their destinations successfully. A new recovery strategy for packets routed to a local optimum[1] was also proposed, consisting of the computation of a new anchor path from the local maximum to which the packet is routed.

The Greedy Perimeter Coordinator Routing (GPCR) protocol [4] has been designed to deal with the challenges of city scenarios. It does not require any global or external information such as a static street map. The main idea of GPCR is to forward data packets using a restricted greedy forwarding procedure. That means when choosing the next hop, a coordinator node (a node on a junction) is preferred to a non-coordinator node, even if it is not the closest node to destination.

In summary, existing data delivery schemes use a position-based routing strategy, which scales better in a highly dynamic and fragmented network as VANET. In addition, most of the current routing proposals are spatial aware since spatial information such us streets map of a city is utilized to assist in making routing decisions.

In the following sub-sections, we give detailed description of our approach and present its added value compared to other existing vehicular routing protocols.

B. GyTAR Assumptions

GyTAR considers that each vehicle in the network knows its own position thanks to the use of GPS[2]. Furthermore, a sending node needs to know the current geographical position of the destination in order to make the routing decision. This information is assumed to be provided by a location service like GLS (Grid Location Service) [7]. Moreover, we consider that each vehicle can determine the position of its neighboring junctions[3] through pre-loaded digital maps, which provides a street-level map. The presence of such kind of maps is a valid assumption when vehicles are equipped with on-board navigation system. We also assume that every vehicle is aware of the vehicular traffic (number of vehicles between two junctions). This information can be provided by IFTIS: a completely decentralized mechanism for the estimation of traffic density in a road traffic network which will be described in section III.

C. GyTAR Overview

GyTAR is a new intersection-based geographical routing protocol capable to find robust routes within city environments. It consists of two modules:

1) Junction selection

In GyTAR, the different junctions the packet has to traverse in order to reach the destination are chosen dynamically and one by one, considering both vehicular traffic variation and distance to destination: when selecting the next destination junction, a node (the sending vehicle or an intermediate vehicle in a junction) looks for the position of the neighboring junctions using the map. A score is given to each junction considering the traffic density and the curvemetric[4] distance to the destination. The best destination junction (the junction with the highest score) is the geographically closest junction to the destination vehicle having the highest vehicular traffic. To formally define this score, we need the following notations:

- J: the next candidate junction.
- I: the current junction
- D_j: the curvemetric distance from the candidate junction J to the destination.
- D_i: the curvemetric distance from the current junction to the destination.
- $D_p = D_j/D_i$ (D_p determines the closeness of the candidate junction to the destination point)
- Between junction I and junction J:
  - N_v : total number of vehicles between I and J,
  - N_c : number of cells[5] between I and J,
  - N_{avg}: average number of vehicles per cell ($N_{avg} = N_v/N_c$),
  - N_{con}: constant which represents the ideal connectivity degree we can have within a cell.
- α, β: used as weighting factors for the distance and vehicular traffic respectively (with $\alpha + \beta = 1$).

Hence, score $(J) = \alpha \times [\, 1 - D_p] + \beta \times [\, \min(N_{avg}/N_{con}, 1)\,]$

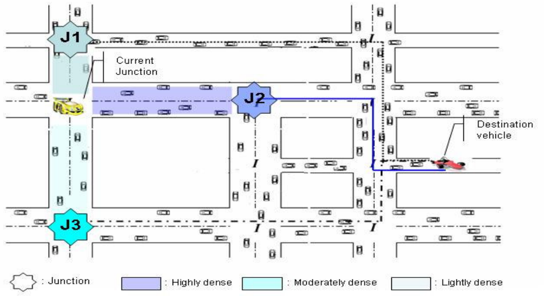

Figure 1. Selecting junctions in GyTAR.

Figure 1 shows an example of how the next junction is selected on a street. Once vehicle *A* receives a packet, it computes the score of each neighboring junction. Considering its curvemetric distance to the destination and the traffic density, junction (2) will have the highest score. Then, it will be chosen as the next anchor.

2) Forwarding data between two junctions

Once the destination junction is determined, the improved greedy strategy is used to forward packets towards the selected junctions. For that, all data packets are marked by the location of this junction. Each vehicle maintains a neighbor table in which, the position, velocity and direction of each neighbor vehicle are recorded. This table is updated through hello messages exchanged periodically by all vehicles. Thus, when a packet is received, the forwarding vehicle computes the new predicted position of each neighbor using the recorded information (velocity, direction and the latest known position), and then selects the next hop neighbor (i.e. the closest to the destination junction).

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[1] Situation where there is no neighbor of the forwarding node s, which is closer to destination than s itself.

[2] The popularity of GPS on vehicles in today's world makes this assumption acceptable.

[3] A place where two or more roads join or meet.

[4] This term describes the distance measured when following the geometric shape of a road.

[5] The cell is determined based on the wireless transmission range of vehicles.

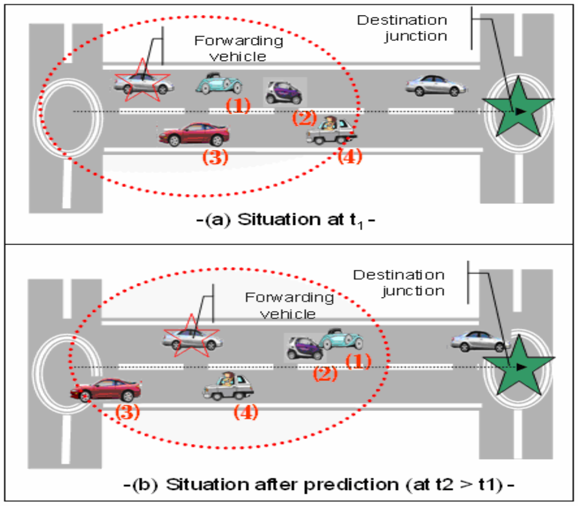

Figure 2. Forwarding data between two junctions using improved greedy strategy.

This approach is illustrated in Figure 2, where vehicle (1), which is moving in the same direction as the forwarding vehicle with a speed greater than vehicle (2), will receive the forwarded packet since at time (*t*2), it is the closest to the next junction. However, without using prediction, the forwarding vehicle would choose vehicle (4) as the next hop instead of vehicle (1) since it was the closest to the destination junction at time *t1* (last time the neighbors table was updated).

3) *Recovery strategy*

Despite the improved greedy routing strategy, the risk remains that a packet gets stuck in a local optimum. Hence, a recovery strategy is required. The repair strategy of GyTAR is based on the idea of "carry and forward": the forwarding vehicle of the packet in a recovery mode will carry the packet until the next junction or until another vehicle, closer to the destination junction, enters/reaches its transmission range.

III. INFRASTRUCTURE-FREE TRAFFIC INFORMATION SYSTEM

IFTIS is a completely decentralized mechanism for the estimation of traffic density in a road traffic network. This decentralized approach revolves around the core idea of information relaying between groups of vehicles rather than individual vehicles. More precisely, vehicles are arranged into location-based groups. Local density information is then relayed between groups using Cells' Density Packet (CDP).

A. *Group Formation*

Each road (section of street between two intersections) is dissected into small fixed area cells, each defining a group. Note that the cell size depends on the transmission range of vehicles (around 300m) and the cell ID depends on the road ID. Cells, and hence groups, overlap in such a way that any vehicle moving from one cell to the next belongs at least to one group. The closest vehicle to the cell center is considered as group leader for a given duration. This is illustrated in Figure 3 where group leaders are vehicles which are within the small circle around the cell center.

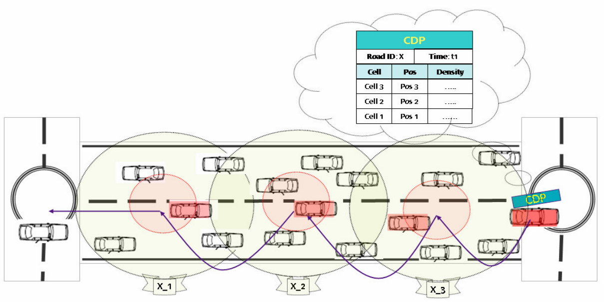

Figure 3 –Relaying Local Density Information between groups.

In the following sub-section, we introduce the distributed mechanism for the estimation of road-traffic density.

B. *Generating, Forwarding & Analysing CDP*

1) *What is a CDP?*

The Cells' Density[6] data Packet (CDP) provides the cell density of a given road. As illustrated in Fig. 4, CDP also contains fields identifying the road ID, transmission time[7], and the list of route anchors (position of cells center).

Cells Data Packet (CDP)		
Road ID	*Time*	
Cell ID	*Cell 's Center (Position)*	*Cell's Density*

Figure 4 - CDP message format –

2) *Who generates the CDP?*

The CDP is generated by vehicles which have already been group leaders. In other words, only a vehicle which has already updated a CDP message will generate the new CDP. It only does so when it reaches a road intersection (i.e. before leaving the road). This is to control the generation of CDP messages, avoiding scalability issues. When initiating the CDP, such vehicle records the road ID, the transmission time and a list of anchors through which the packet has to pass while traveling to the other intersection. Then, it sends it backward..

3) *How the CDP is forwarded backward and who updates it?*

The CDP header includes a limited list of anchors corresponding to the position of the cells' centers. Then, the CDP is forwarded towards the first anchor on the basis of greedy forwarding (the forwarding vehicle selects among all its neighbors the closest vehicle to the next anchor). When it is reached, the group leader (closest vehicle to the cell center) updates the CDP by including the density of the corresponding cell (the number of its neighbors which belong to the corresponding road[8]) and then forwards it towards the next anchor, and so on. When the last anchor (the destination intersection) is reached, the CDP is propagated to vehicles which are around the intersection. The IFTIS algorithm is illustrated in Fig 5.

Arriving at the traffic junction, the CDP packet contains the information of the cell-density of all the traffic groups in the road. Having this information is advantageous for determining if the cell is over-populated, for example, due to a traffic jam

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[6] By density, we mean the number of vehicles within the cell.

[7] Note that all the vehicles are synchronized by GPS.

[8] This information is already available in the neighbor table (built and updated thanks to the periodic exchange of hello messages by all vehicles)

or accident. Perhaps, the overall traffic density will not be high for the road, but for a particular cell, the density level maybe very high, indicating some traffic problem.

Notation:
CDP: the CDP packet to forward
fv: the forwarding vehicle,
Ibegin: intersection at the beginning of the road section
Iend: intersection at the end of the road section
Ni1:number of vehicles on cell i moving from ***Ibegin*** to ***Iend,***
Ni2:number of vehicles on cell i moving from ***Iend*** to ***Ibegin,***

Algorithm:

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A vehicle fv receives the packet CDP:
if fv is not around Ibegin
then
    if fv is a group leader // fv is in the red zone of Cell i
    then
        Update CDP
            - Fill the density of cell i Ni = Ni1 + Ni2;
            - NextAnchor = center of cell i+1
    End if
    Select next Hop & forward CDP
        - fv selects neighbors (N)moving towards Ibegin
        - if ∃ v ∈ N closer to NextAnchor
        - then
            fv forwards CDP to v
        else // fv is the closest vehicle to NextAnchor
            Store CDP and carry it
else //the CDP reaches Ibegin
Broadcast CDP around Ibegin
end if
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Figure 5 **- Algorithm: Forwarding CDP Packet –**

4) *Analyzing CDP*

The CDP packets are received by the vehicles traversing through the junctions. These vehicles analyze the CDP packet and calculate the density for the respective road from which the CDP was received. The CDP packet is analyzed with respect to the group density information recorded in the packet by each group leader. The analysis of the information from each group (for example, the mean and variance of the cells density) will provide the overall density of the road.

Hence, when using GyTAR as routing protocol, vehicles around a junction receive CDP and based on the analysis of its content, they calculate the score corresponding to the road density.

IV. SIMULATION RESULTS

To evaluate the performance of our proposed protocol, we used the Qualnet simulator [5]. We implemented two versions: B-GyTAR (Basic GyTAR without local recovery: a packet is simply dropped when it encounters a local maximum situation), and GyTAR with the recovery method. We also implemented a version of the position-based vehicular routing protocol GSR [1] since there is not any publicly available implementation of the protocol. B-GYTAR and GyTAR are then compared to GSR and LAR [6]. All the key parameters of our simulation are summarized in the following table:

Table 1: **Simulation setup**

SIMULATION / SCENARIO		**MAC / ROUTING**	
Simulation Time	200s	MAC protocol	802.11 DCF
Map Size	2500 x 2000 m2	Channel Capacity	2 Mbps
Mobility Model	Our own realistic mobility model	Trans. Range	~266 m
Number of intersections	16	Traffic Model	15 CBR connections
Number of roads	26	Packet sending rate	0.1 – 1 second
Number of vehicles	100-300	Weighting factors (α ; β)	(0.5;0.5)
Vehicle velocity (city)	30-50±5 Km/h	Data packet size	128 bytes

The algorithms are compared under various data transmission rates and various vehicle densities. Detailed analysis of the simulation results are given in the following.

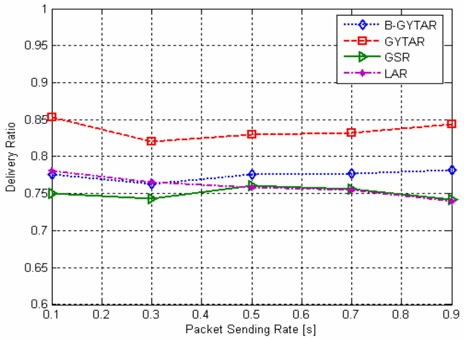

Figure 6 –Delivery ratio Vs Packet Sending Rate (300 nodes).

In Fig. 6, we present the obtained packet delivery ratio of the four studied protocols. Figure 6 shows that GyTAR achieves the highest packet delivery ratio for the different CBR rates (a relative improvement of over 9% than GSR).

This is mainly because in GyTAR, the path is determined progressively following road traffic density and urban environment characteristics. Hence, a packet will move successively closer towards the destination along streets where there are enough vehicles to provide connectivity. While in GSR, a complete sequence of waypoints is computed before the packet is originally transmitted by the source and without considering the vehicular traffic. Consequently, some data packets can not reach their destination due to a problem of connectivity on some sections of streets.

LAR achieves a lower delivery ratio than GyTAR because it uses a route discovery mechanism. Consequently, some data packets can not reach their destination because it is very difficult to maintain an end-to-end connection in the vehicular environment (frequent topology change and network fragmentation).

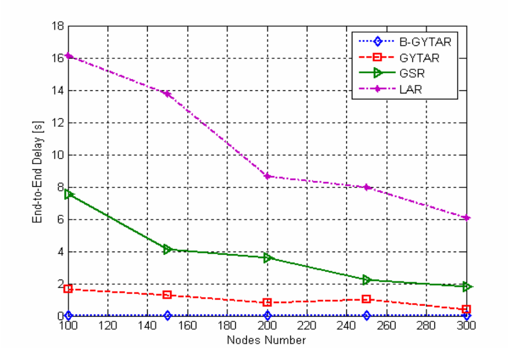

Figure 7 –End-to-End Delay Vs Nodes Number (5 packets/ second).

As shown in Figure 7, GyTAR and B-GyTAR achieve a much lower end–to-end delay than LAR and GSR in all configurations. This is because in GyTAR, the number of hops involved to deliver packets is reduced due to the improved greedy strategy used to forward packets between two junctions, and also because GyTAR does not need to keep track of an end-to-end route before sending data packets: the route is discovered progressively when relaying data packets from source to destination. In contrast, the geographical routing protocol LAR uses a route discovery mechanism which causes longer delays.

Delay of GSR is higher than GyTAR because packets whose delivery was suspended are stored in the buffer for longer time than in GyTAR's suspension buffer.

V. CONCLUSION AND FUTURE WORK

In this paper, we proposed GyTAR, a novel routing algorithm for vehicular ad hoc networks, and we measured its performance in comparison to other algorithms existing in the literature. Simulation results show significant performance improvement in terms of packet delivery ratio, end-to-end delay.

We also proposed IFTIS, a completely distributed traffic information system, capable to monitor the city traffic condition and distribute such information to vehicles around junctions.

We are currently studying the impact of IFTIS approach in vehicular ad hoc routing protocols like GyTAR to analyze the performance gains.

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