Simulation-based Study of Common Issues in VANET Routing Protocols

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Abstract—Vehicular communications have been one of the hottest research topics for the last few years. Many routing protocols have been proposed for such kind of networks. Most of them try to exploit the information which may be available at the vehicle by the time that a routing decision must be made. In addition, some solutions are designed taking into account the particular, highly partitioned, network connectivity in vehicular settings. To do so, they embrace the store-carry-forward paradigm of delay-tolerant networks.

Despite the great variety of approaches which have been proposed, we found that there is a set of issues which are common to many vehicular ad hoc routing protocols in the literature. In this paper, we perform a simulation-based analysis of five of those protocols, which are representative of the various categories of vehicular routing. We describe in detail every problem and show simulation results which support our reasonings. Moreover, solutions to solve every presented problem are outlined. The paper is concluded with some guidelines which may be helpful to prospective VANET routing protocol designers.

I. INTRODUCTION AND MOTIVATION

Recent advances in wireless communication technologies are enabling new vehicular networking scenarios. In Vehicular Ad hoc Networks (VANET), vehicles can communicate wirelessly through multihop paths. That is, vehicles use other intermediate vehicles as relays to reach the final destination of data messages. The routing protocol has the responsibility of finding a path between the source and the destination. Thus, many research efforts have been devoted during the last years to design VANET-specific routing protocols which take advantage of additional information available to vehicles (e.g. geographic positions, digital maps or planned routes). Additionally, some protocols address the inherent dis connectivity problem of vehicular scenarios. Since vehicles tend to travel forming groups, the VANET actually consists of disconnected clusters of vehicles. In order to route data messages between clusters, the store-carry-forward paradigm typical of delay-tolerant networks (DTN) is adopted by some vehicular routing protocols.

In this paper, we have simulated five different routing protocols specifically designed for vehicular networks. They are representative of the main types of VANET routing which we found in the literature. By means of this thorough study, we have detected several problems which are common to the protocols and which cause unnecessary message drops and temporary loops. So, we show that VANET protocols based on geographic routing are prone to message losses because they usually assume ideal transmission ranges, which is not applicable in real vehicular setups. When geographic routing does not incorporate the store-carry-forward approach, it also loses data messages in the advent of beacon losses and when stale neighbors’ positions are handled. In case the protocol is DTN-enabled, it is shown that temporary loops which affect the routing efficiency, and may exhaust the time-to-live (TTL) of the data message, are created. On the other hand, we find that trajectory-based routing must carefully choose the criterion employed to forward a data message, since it could get stuck or move away from the final destination, reducing the chances of successful delivery.

We describe in detail every issue and support our conclusions with simulation results. Moreover, we propose solutions for each problem and draw some guidelines which should be taken into account when designing effective VANET routing protocols. In the authors’ opinion, this article may help prospective protocol designers to avoid common past errors, in order to develop new routing protocols more effective for the vehicular environment.

This paper is divided into the following sections. Section II summarizes the different routing approaches which have been proposed in VANET routing. The simulation environment employed for our analysis is described in Section III. The transmission range assumption problem, which affect geographic routing protocols, is presented in Section IV. Section V analyzes the use of stale information in geographic protocols with and without DTN support. In Section VI, it is discussed how trajectory-based protocols must carefully choose the criterion to optimize, since it could lead to message losses. Finally, we conclude the paper and depict some guidelines for routing protocol designers in Section VII.

II. ROUTING IN VEHICULAR AD HOC NETWORKS

Vehicular ad hoc networks exhibit different characteristics from classical ad hoc networks. First, the mobility of vehicles is restricted by the road layout, other vehicles’ movements and traffic rules. It is also affected by external factors like weather conditions or the timeframe under consideration. In addition, different scenarios such as cities or highways lead to distinct distributions of vehicles. Maybe the most salient feature derived from vehicular mobility patterns, is the fact that
vehicles tend to move in groups forming clusters. Thus, the network becomes highly partitioned and an end-to-end path between source and destination might not exist at the time of sending a data message. All these factors make traditional ad hoc routing not to be a very appropriate solution for vehicular settings. Thus, specific protocols have been proposed accordingly.

Because of the great number of vehicles which may participate on a VANET, routing protocols need to be localized to ensure their scalability. That is, vehicles make routing decisions solely based on information locally available in their close vicinity. Therefore, exchanging information with neighboring vehicles via beacon messages is a fundamental part of routing protocols in the literature.

Usually, vehicles can obtain position information from systems like GPS and Galileo. Hence, many protocol designers have employed geographic routing as the basis for VANET-specific solutions. By using greedy heuristics, the protocols choose as next hop the neighbor which provides greater advance towards the destination’s position (i.e., the one which is closer to the destination). However, there are known problems associated to geographic routing protocols in VANET scenarios. Several authors have adapted traditional geographic routing to the singularities of vehicular scenarios. GPCR [1] and CAR [2] are examples of these approaches.

Other protocols try to improve the performance obtained with geographic routing by means of using digital maps. In this way, the map provides information about topology of streets. This is employed by the source node to compute a list of junctions which the data message must traverse to get to the destination. In order to reach each junction, the protocols apply geographic routing along each street. GSR [3] and A-STAR [4] are examples of geographic-based VANET routing protocols that employ map information.

The aforementioned solutions assume that an end-to-end path between the source and the destination exists at the moment of issuing a data message. However, this is not the common case in VANET scenarios, since vehicular networks are formed by disconnected groups of vehicles. In order to solve this problem, the store-carry-forward paradigm can be employed. It consists of storing the message when there is no neighbor which provides advance towards the destination. When a suitable neighbor is found, the forwarding takes place. SAR [5] and VADD [6] lie on this kind of routing.

On the other hand, some protocols are based on the planned trajectories of vehicles instead of on geographic routing. Vehicles forward the data message to those neighbors whose trajectory is more useful than the one followed by the current holder. The usefulness of a trajectory depends on the protocol under consideration. Hence, protocols like GeOpps [7] try to get to the destination as fast as possible, while others like MoVe [8] look for the greatest advance towards the destination according to current velocity vectors.

In the remainder of the paper, we detail the problems we found in each of the aforementioned routing techniques.

### III. Simulation setup

In order to evaluate the strengths and weaknesses of VANET routing, we have implemented the GPCR, GSR, A-STAR, SAR and GeOpps protocols within The Network Simulator ns-2\(^1\), version 2.33. These protocols cover the variety of routing approaches depicted in the previous section. In order to generate the simulation scenario (street map) and the vehicular mobility patterns, the SUMO tool\(^2\) has been employed. In this way, we have been able to simulate realistic vehicular movements such as traffic jams and stops at intersections. Moreover, we consider a broad spectrum of traffic densities. So, we have defined several routes which are followed by the vehicles. SUMO injects cars into each route at a given traffic rate that we have varied from 1/30 to 1/5 vehicles per second. The maximum speed of the vehicles is limited to 50 km/h.

Since our objective is to obtain insight onto the routing protocols and their associated problems, we must carefully design the simulation scenario. It must be simple enough to analyze the behavior of vehicles, but representative of common vehicular setups. So, we employed a square grid (2x2) in which each edge is 500 meters long (1000 m\(^2\)). Vehicles communicate via IEEE 802.11p interfaces (the implementation is described in [9]), and wireless signals propagate according to the two-ray-ground model. The transmission range is fixed at 250 meters.

Data messages are sent when the first vehicle completes its trajectory, in order to run simulations with vehicles distributed throughout the whole network. Once the network reaches the steady state, the simulation lasts 150 seconds. Twenty data messages are issued from one source to the destination, at a rate of one message per second.

### IV. The Transmission Range Assumption

All the reviewed routing protocols assume an ideal transmission range of radius \(r\), in a way that two vehicles \(u, v\) can directly communicate with each other iff \(\text{distance}(u, v) \leq r\). However, in real scenarios, even static networks do not reveal such notion of transmission range because of different factors which affect the propagation and decoding of wireless signals (fading, interference, collisions, etc.). In fact, the probability of reception decreases as the distance from the transmitter to the receiver increases. In this section, we analyze the implications of the ideal transmission range assumption.

The geographic-based routing protocols under consideration use greedy heuristics to select the next hop for a given message. So, they choose the farthest neighbor as next hop, which usually has low probability of reception. This problem occurs more often when traffic density increases, because it is more likely to find a neighbor near the theoretic limit of the transmission range. Simulation results corroborate this trend. Hence, Figure 1(a) shows how the average distance to the next hop increases in GSR as the traffic density gets higher. The problem is common to the other geographic protocols under

\(^1\)http://www.isi.edu/nsnam/ns/
\(^2\)http://sumo.sourceforge.net/
evaluation (GPCR, SAR and A-STAR). In order to measure the effect that this issue has onto the protocol performance, Figure 1(b) shows the number of messages which are dropped because the receiver cannot correctly decode them.

Traditionally, it has been assumed that greedy geographic routing performs better as the density increases. While this is true if ideal transmission ranges are assumed, our results show the situation changes dramatically when realistic environments are considered. In fact, the number of drops due to incorrect reception actually increases.

**Solution.** We propose two different schemes to deal with this issue. First, receiver-based next hop selection solves this problem because no transmission range is assumed. This on-demand technique consists of sending the data message without pre-selecting any next hop. Among those neighbors which actually receive the message, one is selected to forward it [10].

Another solution is based on monitoring the link status with the neighboring vehicles, and make intelligent forwarding decisions accordingly. The transmitter checks the status of the links with its neighbors and selects as next hop a vehicle with high probability of reception which provides advance towards the destination.

V. USE OF STALE INFORMATION

Geographic routing protocols for VANET highly depend on the knowledge of the neighbors’ positions. This information is updated periodically via beacon messages. When beacons get lost due to temporary transmissions errors, some vehicles become unaware of the existence of nearby neighbors. In addition, positions get outdated because of the mobility of the vehicles. This provokes some routing problems which are related to the interval at which beacons are issued, and to the holding time that the information is considered useful (usually, from one to three times the beacon interval). We analyze these derived issues below.

A. Beacon Losses

When a vehicle does not receive beacon messages from one of its neighbors for a given amount of time, it removes the information about such vehicle and does not take it into account for the forwarding task. However, there are cases in which beacon messages sent by a vehicle are lost due to temporary interferences. As a result, its neighbors think, wrongly, that it is no longer reachable when it is indeed.

This situation is a problem for geographic routing protocols which do not incorporate DTN-support, like GSR, GPCR and A-STAR. Figure 2 shows an example. There, vehicle B broadcasts a beacon message which is received by vehicle A. At the next beacon interval, B issues another beacon but this time it is lost. Let us assume that the information that A has about vehicle B expires (holding time equals the beacon interval). Afterwards, A tries to send a data message but it is discarded because A thinks that it has no neighbors. However, B is still reachable from A.

B. Stale Positions

Due to beacon losses and the interval between consecutive beacons, routing protocols work with outdated information and therefore stale positions. In this section we analyze two problems which arise because of this.

On the one hand, there is an issue which affects all geographic routing protocols with greedy heuristics, even if we assume an ideal transmission range. In Section IV we explained that even in static scenarios, when realistic transmissions are modeled, there exists a problem with geographic protocols. This worsens in vehicular scenarios with mobile nodes, which is the usual case. However, even if ideal transmission ranges are assumed, the protocol may drop messages because of the stale neighbors’ positions it handles. So, in Figure 3(a), A knows the position of B which lies on the limit of A’s transmission range. In Figure 3(b), a little bit of time ahead, vehicle A generates a data message and selects B as next hop. However, B is currently outside the transmission range of A and the message is lost.

On the other hand, outdated information may cause a temporary loop between two vehicles if a geographic routing protocol of the store-carry-forward paradigm is employed (e.g. SAR). Figure 4 illustrates this issue. In Figure 4(a) each vehicle knows the current position of all its neighbors. Vehicle A generates a data message to be routed and applies greedy forwarding towards the destination. B is closer to the

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**Fig. 1.** Transmission range assumption problem.

**Fig. 2.** Example of beacon losses.

**Fig. 3.** Mobile vehicles and the outdated position problem (ideal transmission range).
destination than A, so the message is forwarded to B. Since B has no neighbors closer to the destination than itself, it buffers the data message. A is moving towards the next destination while vehicle B gets away from it. In Figure 4(b), vehicles just crossed their paths and B receives a new beacon message from A. Then B knows the updated position of A, but not vice versa. A thinks that B remains in the position of virtual vehicle B'. A is closer to the destination than vehicle B (see Figure 4(c)), so B forwards the message to A. A should store the data message because there is no vehicle closer to the destination than itself. However, since A still thinks that B is in its old position B', a new forwarding occurs and the loop is created (both A and B think that the other is closer to destination than itself). Until vehicle A receives a new beacon from B, the message gets stuck in a temporary loop. If this situation continues the message could be eventually dropped if the time to live (TTL) expires.

Temporary loops have been detected thanks to our simulation-based analysis. Unfortunately, varying the beacon interval and the neighbor holding time does not solve this issue. To evaluate the impact of this issue, we define the forwarding loop ratio (FLR) as the ratio between the number of hops that a data message has taken and the number of different vehicles which actually forwarded the message, $FLR = \frac{N_{hops}}{N_{veh}}$. So, it indicates the average number of transmissions of a same message by a same vehicle. Ideally, $FLR = 1$ means that no loop has occurred. Tables I, II show the FLR obtained in SAR for a variety of beacon intervals and neighbor holding times. $FLR > 1$ regardless the beacon interval and the holding time employed. Although Table II shows a descending tendency of FLR as the holding time increases, we can see that the number of messages dropped because the packet is not decoded (DPND) gets higher. Then, fewer loops occur because the messages are prematurely dropped by the problem showed at the beginning of this section, not because this problem gets solved.

Solution. In order to avoid problems with outdated or wrong information, we propose to employ the store-carry-forward paradigm and position estimates.

Being the protocol DTN-enabled, it can buffer the data message when appropriate neighbors to which forward it are not available. As soon as temporary interferences disappear, the vehicle will become aware of their neighbors and the forwarding will take place.

To eliminate the formation of loops, vehicles can piggyback their current velocity vectors within the periodic beacons. Then, at the time the forwarding decision has to be made, the vehicle can estimate the position of its neighbors and avoid the ping-pong effect described in Figure 4(c).

<table>
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<th>Beacon Interval</th>
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<th>1</th>
<th>1.5</th>
<th>2</th>
<th>2.5</th>
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<td>2.33</td>
<td>2.05</td>
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<table>
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<tr>
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<th>4</th>
<th>5</th>
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<tr>
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<tr>
<td>DPND</td>
<td>93</td>
<td>84</td>
<td>98</td>
<td>105</td>
<td>126</td>
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</tbody>
</table>

VI. OBJECTIVE FUNCTION IN TRAJECTORY-BASED ROUTING

Trajectory-based routing protocols make the forwarding decision depending on the expected trajectories of the neighboring vehicles. The objective is to deliver the message near the destination, according to the trajectory of each vehicle. These protocols inherently use the store-carry-forward paradigm, since the message is buffered and held by the current vehicle if its trajectory is more promising than those of its neighbors.

In this section we focus on GeOpps, since it has been shown to outperform other trajectory-based protocols like MoVe [7]. However, it presents an issue which has shown up in our simulation study.

In order to evaluate the usefulness of a trajectory for a given data message, GeOpps employs a function which estimates the expected time of delivery from the vehicle to the destination. It consists of the time that the vehicle would take to travel from its current position to the closest point to the destination, according to the trajectory of each vehicle. These protocols inherently use the store-carry-forward paradigm, since the message is buffered and held by the current vehicle if its trajectory is more promising than those of its neighbors.

This criterion is not always the most appropriate to use. Let us see the example in Figure 5. Vehicle B holds a data message and, therefore, its neighbors A and C calculate their minimum expected time of delivery. In the case of A, the closest point to the destination D is its current position. Then, the estimation $METD_A$ is the time to go from the current position to D. On the other hand, the nearest point from C’s trajectory to the destination is the destination itself. So, the expected delivery time $METD_C$ corresponds to the time that C takes to arrive.
at $D$. Since the distance traversed is longer than in the case of $A$’s estimation, then $METD_C > METD_A$ and, accordingly, $B$ selects $A$ as the next hop.

Given the scenario above, note that if more vehicles appear following $A$’s trajectory, the message get stuck around that position until its expiration. On the other hand, if no more vehicles appear, $A$ would hold the message and carry it farther away from the destination. This is the opposite of the objective of the protocol.

Continuing with the same example, $C$ would have been a more suitable next hop because it had delivered the message to $D$. The key is that the message had approached the destination at each step.

Solution. We propose to attribute more usefulness to those vehicles whose trajectory carry them near the destination, rather than those that (presumably) provide quick advance. In case that more than one neighbor have the same closest point to the destination, the one which arrives first is chosen as next hop. To assess the validity of our approach, we have simulated a scenario like the one in Figure 5. While GeOpps is not able to deliver any of the issued messages, the proposed solution achieves a 75% of successful delivery ratio.

VII. CONCLUSION

In this paper we have presented a comprehensive list of common problems in VANET routing literature. They have been detected by means of a simulation-based study subject to vehicular mobility patterns. Since the problems are not bound to specific protocols, but are inherent to the sort of routing which is employed, we suggest some guidelines which could improve the performance of VANET routing:

- Store-carry-forward paradigm. In order to cope with temporary disconnections in vehicular networks, the protocol must incorporate DTN-support if such kind of delay-tolerant data traffic is to be routed.
- Beacons dependency. Avoid, as much as possible, that the protocol performance highly depends on the information received via beacons. This can lead to message losses, lost forwarding opportunities and routing loops. Receiver-based next hop selection approaches can be more effective, since the data message is directly forwarded and the retransmitter is selected among those neighbors which actually received the message. This immediately gets rid of any problem derived from assuming an ideal transmission range.
- Add useful information. Since beacons are periodic messages issued by every vehicle, they can not incorporate much information. Otherwise, the protocol overhead would be high and lower bandwidth would be available to data messages. However, some lightweight information like velocity vectors can be included to make more intelligent forwarding decisions.
- Careful selection of forwarding criteria. Especially when dealing with the trajectories of vehicles, it should be guaranteed that the forwarding function carries the data message closer to the destination than the current data holder. Otherwise, messages are more prone to get lost.

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