Safety Message Dissemination in VANETs: Flooding or Trajectory-Based?

Nedal Ababneh and Houda Labiod

TELECOM ParisTech
46 rue Barrault
75013 Paris, France

Email: {firstname.lastname}@telecom-paristech.fr

Abstract—In this paper, we address the reliable alarm message dissemination in Vehicular Ad hoc NETworks (VANETs) environment. We study various techniques to disseminate emergency data, after a car crash, within a group of vehicles. We consider a trajectory-based data dissemination technique to perform broadcast flooding task optimization, and compare it with a pure flooding scheme. For the evaluation, we examine various parameters such as inter-vehicle distance, transmission radio range and traffic load. Experimental results, obtained by several simulations implemented on VanetMobiSim/NS-2 platform, show the effectiveness of trajectory-based solutions for efficient dissemination of emergency messages in VANETs. We also conclude that a simple flooding technique is not always considered harmful, and can outperform more complicated schemes in high density VANETs environment.

Keywords—VANETs; dissemination; trajectory-based broadcasting; flooding; performance evaluation.

I. INTRODUCTION

Vehicular Ad-hoc NETworks (VANETs) have recently become a popular research topic in both academia and industry. The main objective of VANETs research is to develop an inexpensive vehicular communication system to enable efficient dissemination of data for the benefit of passengers’ safety and comfort. Various efforts (e.g., ComeSafety [1], VII [2], VSC-A [3], C2C-CC [4] and InternetITS [5]), and standardization bodies (e.g., IEEE [6], and more generally ISO TC204 [7]) are currently developing technologies for inter-vehicle communications. While safety is the main focus, mobile infotainment applications are expected to enhance the comfort of driving and travelling. Many infotainment applications require access to the Internet, whereas safety applications typically use direct and local communication among neighboring vehicles [8]. Although dense deployment is desirable in many vehicular networks applications scenarios, it also causes problem with the radio broadcast communication. When a vehicle broadcasts a message, all the nodes within its communication range will immediately attempt to relay the message further by rebroadcasting. This mechanism is clearly not scalable due to the large number of messages flooded over the network, especially in high traffic density scenarios causing excessive radio communication within the region. This not only wastes system resources but also causes network congestion, leading to what so-called broadcast storm problem [9].

The goal of this study is to investigate strategies to alleviate broadcast storm in VANETs. An efficient broadcast protocol should provide fast dissemination by limiting the number of retransmissions. The dissemination mechanism can either broadcast information to vehicles in all directions, or perform a directed broadcast restricting information about a critical event to vehicles coming from the rear. The protocol presented in this paper, termed SIFT: Simple Forwarding over Trajectory; requires the source node to encode a geographical curve, referred to as a trajectory, into the packet header. Since the sequence of forwarding nodes is not specified, packets are routed towards their destination hop-by-hop according to nodes’ positions with respect to the trajectory and the last transmitter. In contrast to the previously proposed trajectory-based forwarding (TBF) protocols such as [10-12], SIFT is based on broadcast instead of point-to-point transmissions, and it does not require any neighbors’ information to be maintained at each node since forwarding decisions are shifted from the transmitter to the receiver. It provides reachability to all one-hop neighbors, and supports the dissemination of packets to all nodes in a given geographic region in a natural way. Upon receiving a data packet each node makes a decision on whether to forward it or not based, merely, on node’s own position, the last transmitter’s position and the trajectory. In SIFT, we define a new routing protocol category: Timed Trajectory-Based Forwarding (TTBF) protocols. Based on timers, we allow the most-suitable node to forward the packet and to suppress other potential forwards. The principle is to assign shorter retransmission timers to better relays. Hence, the best relay’s retransmission timer will expire before all other possible relays and it will retransmit the packet first. This retransmission will be overheard by the other potential relays which will stop the retransmission timers and give up retransmission. This process will continue until the destination is reached. In this paper, we compared the performance of SIFT against two well known flooding techniques:

The first technique studied is simple flooding. Once a packet is generated and transmitted by a vehicle, it is relayed once by all the receivers (i.e., vehicles within sender’s transmission range). All the vehicles must maintain a duplicate table containing all the IDs of the packets received, in order to avoid multiple processing and relaying.

The second technique is randomized-backoff flooding. Here, in order to reduce contention when multiple nodes try to
Some of the related work followed by a detailed description of time between zero and the maximum randomization interval. Upon receiving a packet, the flood module will wait for a random time between zero and the maximum randomization interval.

This paper is structured as follows. In Section II, we recall some of the related work followed by a detailed description of SIFT in Section III. In Section IV, we describe the mobility model used in this paper. Finally, we wrap up our analysis in Section V.

II. RELATED WORK

There are several international consortium and research group addressing the problem of data dissemination using short-range vehicle-to-vehicle communication for safety-related applications [1-7]. The general strategy is to determine a minimum set of forwards from one-hop or two-hop neighbors to rebroadcast the packets and at the same time guarantee that all nodes in the network can receive the packets by preserving adequate network capacity. It is been said before, flooding is the most common approach for broadcasting without explicit neighbor information exchange in MANETs. Forwarding is more suited for applications with reliable delivery requirements than for delay-sensitive safety application. In the latter, flooding is the preferred message dissemination mechanism.

Several forwarding-based protocols for data dissemination and comparison studies have been proposed recently for VANETs applications. In [13], the authors proposed a solution based on a combination of opportunistic forwarding and a trajectory-based approach, while specifically addressing vehicle mobility. Wherein [14], the authors explored the performance of opportunistic routing for different node densities, channel quality and traffic rates and compared it to geographic routing. They tried to understand when it becomes profitable to move from geographic to opportunistic routing. In terms of node densities for a moderate channel, it was found that opportunistic routing was suitable only for higher node densities like more than 9-10 neighbors per node. Even so, the gains were modest — about 40 % improvements in delay. However, opportunistic routing was definitely superior when the channel quality worsens. On the other hand, if the channel was very good and the node density low, then it was found to be best to stick with geographical routing. Geographical routing also becomes more efficient for higher traffic scenarios. Jerome et al. [15], evaluated AODV and OLSR under realistic urban traffic environment in different velocities, densities and data traffic rates. In order to model realistic vehicular motion patterns, they made use of the Vehicular Mobility Model (VMM). They showed that the clustering effect obtained at intersection has a major effect on the effective average velocity during the simulation. Also, they found that OLSR has a better performance than AODV in terms of routing overhead, end-to-end delay and route length.

The most comprehensive studies have been performed in [16, 17]. In the first study [16], authors compared AODV, DSR, FSR and TORA on highway scenario, while [17] compared the same protocols in city traffic scenario. They have found that AODV and FSR are the two best suited protocols, and that TORA and DSR are completely unsuitable for VANET. In [18], the authors used GPSR to compare its performance to DSR in a highway scenario. It is argued that geographic routing achieves better results because there are fewer obstacles compared to city conditions and is fairly suited to network requirements.

In [19], the authors studied dissemination of emergency messages in the VANETs. Mainly three techniques (i.e., pure flooding, the multipoint relay (MPR) diffusion mechanism of OLSR [20] and geographic aware flooding technique (GAF) [21]) were simulated under realistic scenarios, and the effects of changing vehicle density and background traffic on emergency packet delivery delay were analyzed. They found that the simple MPR technique has the least bandwidth consumption, but it has the largest delivery delay. They also improved the MPR technique, and showed that it is more suitable for VANETs use because it has comparable delays to flooding and GAF as well as low network traffic overhead.

In [22], the authors considered location-aware protocols for delivering emergency warning messages with improved reliability to nearby and approaching vehicles. They proposed a new hybrid method of location-based and counter based method, and studied several variants through simulations. The proposed hybrid method was evaluated through simulation and proved that it operates more efficiently and achieves higher message reception rates than conventional random delay techniques.

To our knowledge, there are no comparison studies between trajectory-based and flooding techniques in VANETs environment available in the literature. Thus, we are motivated to conduct this performance comparison study to show the strengths and weaknesses in those two approaches.

III. SIFT: SIMPLE FORWARDING OVER TRAJECTORY

Different from previously proposed trajectory based forwarding schemes, SIFT [23] uses broadcast instead of point-to-point transmissions. Wireless transmissions are broadcast in nature and allow reaching possibly all active neighbors at the same time. Moreover, the forwarding decision is shifted from the transmitter to the receiver. Each node that receives the packet takes the decision whether to forward it or not based only on its own position, the transmitter position and the trajectory. This greatly reduces control overhead introduced by the protocol and energy consumption.

To support its functions, SIFT includes two phases:

- The trajectory computation phase: The first phase is implemented by the COMPUTE_TRAJECTORY procedure, and it is only executed by the source node before sending a new packet for the first time. This procedure cannot be invoked by intermediate nodes since SIFT is source-based and thus trajectories are established only by the source node. The intention behind this phase is to compute the trajectories and to send the messages for the first time triggering the multi hop forwarding process.

- The packet forwarding phase: The second phase is implemented by the FORWARD procedure, which is invoked by each intermediate node when receiving a
data packet that passes through the networks on its way towards its destination. The intention behind this phase is to decide, at each intermediate node, on whether to forward the packet or not.

Once received a packet, each node sets a timer according to its position with respect to the trajectory and the transmitter. If a copy of the packet, forwarded by another node, is received before the timer expires, the timer is stopped and the packet is deleted from the forwarding queue. Otherwise, the packet is passed to the Medium Access Control (MAC) layer for transmission when the timer expires. Therefore, the node with the minimum timeout value will forward the packet. It is the node in the best position since it is far from the last node and close to the trajectory. Packets include into the header the trajectory and the coordinates of the last node that forwarded the packet. The original source identifier, a sequence number, and a hop count are included as well. Each node maintains a list of recently received packets (i.e., source ID and sequence number) to avoid cycles.

IV. THE VEHICULAR MOBILITY MODEL

Mobility model clearly affects the simulation results. Thus, it is important to use a realistic mobility model so that results from the simulation correctly reflect the real-world performance of a VANET. Mobility models proposed for vehicular networks have been largely studied and surveyed in literature [24-27]. In this paper, we use Intelligent Driver Model with Intersection Management (IDM-IM). This model is a macroscopic car-following model that adapts a vehicle speed according to other vehicles driving ahead, thus falling into what so-called car following models category. IDM-IM model uses a quite small set of parameters, which can be evaluated with the help of real traffic measurements. This model extends the IDM model [28], in order to include the management of intersections regulated by traffic lights and of roads with multiple lanes [29]. It borrows the car-to-car interaction description of the IDM model and provides intersection handling capabilities to vehicles driven by the IDM model. It can manage crossroads regulated by both stop signs and traffic lights. In both cases, IDM-IM only acts on the first vehicle on each road, as IDM automatically adapts the behavior of vehicles following the leading one. Every time a vehicle finds no intermediate vehicle between itself and an intersection regulated by stop signs, the following variables are used by IDM-IM:

\[ S = \sigma - S \]
\[ \Delta v = v \]

where \( \sigma \) the current distance to the intersection and \( S \) is a safety margin, accounting for the gap between the center of the intersection and the point the vehicle would actually stop at. Thus, compared to the IDM model, the distance from preceding vehicle is substituted by the distance to the point the vehicle has to stop at. On the other hand, the speed difference is set to the current speed of the vehicle \( v \), so that the stop sign is seen as an obstacle. This allows vehicles to accelerate when far from the next intersection, and then to smoothly decelerate as they approach a stop sign. Once a vehicle is halted at a stop sign, it is informed by the macroscopic level description of the number of vehicles already waiting to cross the intersection from any of the incoming roads. If there are no other vehicles, the vehicle may pass. Otherwise, it has to wait until its turn in a first-arrived-first-passed and right hand rule policy. Furthermore, each time a vehicle moves towards a traffic light intersection, it is informed by the macroscopic description about the state of the semaphore. If the color is red, passage is granted and the vehicle maintains its current speed through the intersection. If the color is red, crossing is denied and the vehicle is forced to decelerate and stop at the road junction. Afterwards, the vehicle may drive ahead or change its direction at a specific probability.

In real world, traffic lights are used to regulate traffic flow moving in different directions. The existence of traffic lights tends to create a clustering effect as vehicles queue in the road junctions. In other words, places where there is a traffic light are likely to have a higher node density since vehicles are forced to stop at the traffic light to wait for the light to turn green. Naturally, a high node density might improve the network connectivity. On the other hand, a higher node density might also suggest a higher chance for packet collision since more nodes might be transmitting at the same time. The higher concentration of vehicles around intersections also has the side-effect of reducing the number of vehicles on the other roads of the topology, which, records lower vehicular densities as illustrated in Fig. 1, which, as a result, incurs a drop in the number of delivered packets.

![Figure 1. Traffic lights clustering effect in VANETs.](image)

A realistic effect of smooth vehicular density increasing towards the congested crossroads, is obtained with this model. It is apparent that density increases when the vehicles’ speed increases. In addition, the distance between two adjacent traffic lights can have a significant effect on the network connectivity. Specifically, the network can be fragmented by the traffic lights when the radio transmission range is smaller than the distance between two adjacent clusters. In other words, a link breakage can happen when the inter-cluster distance is larger than the radio coverage. Here, we set the distance between two adjacent intersections to 500 m, which is double the radio range.

V. PERFORMANCE EVALUATION

In this section, we study the emergency message relaying in case of emergency event (e.g., car accident, traffic jam, etc.). We simulate different vehicle density, communication range and traffic load scenarios. Their effects on the performance of the techniques under study are examined.

In the following, we describe the simulated scenarios, then we present the simulation setup, and we end by a discussion of
the results. For simplicity reasons, we do not distinguish between different types of vehicles like cars or trucks in the following evaluations.

A. Scenario Description

The simulated city scenario considered in this paper is based on the road network topology shown in Fig. 2. In our simulated scenario, vehicles travel in a 3 km² city section over a set of urban roads, which include several road intersections regulated by traffic lights or stop signs. The roads created in the simulation have two lanes and vehicular movement occurs on a single direction in each lane.

![Figure 2. City section topology, each line representing a single-lane road. Vehicular movement occurs on the direction shown by the arrows.](image)

We focus on the immediate consequences of a crash. The crashed car starts generating and transmitting emergency messages after the collision in order to inform the neighboring vehicles coming from the rear of the incident, which must cooperate in a distributed fashion in order to relay this information as quickly as possible using a relaying technique to the vehicles behind. When an accident occurs, the crashed vehicle(s) starts sending emergency messages to warn the cars behind. The vehicles positions are denoted by \((x,y)\). The source vehicle is located in \((500,50)\) and the destination vehicle is in \((2500,53)\).

B. Simulation Setup

In this paper, we have used VanetMobiSim/NS-2 [30] simulation environment in order to conduct our performance evaluation study. In all simulations, the source and destination nodes are static. The mean distance between two vehicles is 10 m. The propagation model employed in our simulation is the TwoRayGround model. All nodes use IEEE 802.11 MAC operating at 2 Mbps. The transmission range is 150 m. The source node sends one CBR packet per second to the destination node. In our experiments, the randomization interval is set to 50 s, and the simulation lasts for 1000 s. For all simulation results in this paper, each experiment is repeated ten times on different network topologies. Unless otherwise stated, the parameters settings appear in Table 1 are adopted for these set of experiments.

![Table 1. Simulation Parameters Settings](image)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulator</td>
<td>NS-2</td>
</tr>
<tr>
<td>Mobility simulator</td>
<td>VanetMobiSim</td>
</tr>
<tr>
<td>Simulation time</td>
<td>1000 s</td>
</tr>
<tr>
<td>Simulation runs</td>
<td>10</td>
</tr>
<tr>
<td>Simulation area</td>
<td>3000 x 1000 m²</td>
</tr>
<tr>
<td>Transmission Range</td>
<td>150 m</td>
</tr>
<tr>
<td>Vehicle speed</td>
<td>10 m/s</td>
</tr>
<tr>
<td>Packet generation rate</td>
<td>1 packet/s</td>
</tr>
<tr>
<td>Node density</td>
<td>30 vehicle/km</td>
</tr>
<tr>
<td>Mobility model</td>
<td>IDM-IM</td>
</tr>
</tbody>
</table>

C. Simulation results and discussions

In this section, we present our main findings. We discuss results from an extensive performance evaluation. For analyzing the performance of the three broadcast techniques we considered the following performance metrics:

- **Packet Delivery Ratio**: is the ratio between the number of packets received at the destination to the number of packets sent by the source.
- **Data Throughput**: is the total received number of bits at the destination node divided by the simulation time.
- **Average Latency**: it represents the average end-to-end transmission delay by taking into account, only, the correctly received packets. It can be defined as the time interval between the start of the transmission of the packet from the source node and the end of its reception at the destination node.
- **Average Number of Hops (i.e., hop count)**: it represents the number of hops a packet takes to travel from the source to the destination.

In the following results an emergency message is generated and relayed according to SIFT, FLOOD (pure flooding) and FLOOD+ (randomized-backoff flooding). Actually, we ran three sets of different simulations:

1) **Effect of Vehicle Density**

Each two successive cars are separated by an inter-vehicle distance (IVD). We vary the IVD in order to increase and decrease node density. To see the impact of vehicle density on the network performance, we simulated traffic densities between 30 and 50 vehicle/km. to achieve this, we varied inter-vehicle distance from 10-30 m. Here, we define vehicle density as the number of vehicles per km. Figures 3 and 4 depict the packet delivery ratio and network throughput, respectively, for each of the techniques for different vehicle densities. As can be seen from the graphs, as the vehicle density increases, all protocols clearly experience a drop in the number of successfully delivered packets. It is clear that randomized-backoff flooding delivers more packets to the destination than pure flooding and this comes at the cost of high end-to-end delay. SIFT performs worse as the packet is broadcasted once at each hop comparing to flooding technique, resulting in less robust dissemination of the emergency packet.
Figures 5 and 6 depict the end-to-end delay and average hops, respectively. From the graphs, we can notice that the results are not much affected by inter-vehicle distance. However, pure flooding depicts the best performance followed by SIFT. On the other hand, randomized-backoff flooding experience a high end-to-end delay, and this is because the backoff delay policy used in this technique.

2) Effect of Radio Transmission Range

The second experiment set involves the investigation of the impact of communication range on broadcast protocols. We varied the vehicles’ radio range from 50 to 250 m. Figure 7 shows the emergency packet delivery ratio as a function of radio range. It is apparent that for all techniques the delivery ratio actually increases as the radio range increases. It is worthwhile to say that the delivery ratio for the three techniques is zero when the radio range is set to 50 m. This is because decreases in radio range will result in path length increases (i.e., in terms of hop count), and this increases the probability to lose packets. This effect is due to the fact that the probability of finding a low-connectivity zone in the network is proportional to the number of intermediate nodes that forward the data packet. This is consistent with the average throughput depicted in Fig. 8. However, pure flooding and randomized-backoff flooding techniques provide more reliable packet dissemination than SIFT as they allow each node within sender’s transmission range that captured the packet to retransmit it.
Figures 9 and 10 show the average end-to-end delay and average hops, respectively, incur by the three techniques. From the graphs, it appears clear that all the techniques experience an increase in the delay when vehicles’ radio range decreases as the number of hops in the path also increases resulting in more delays to deliver packets to their destination. SIFT incurs higher delay than pure flooding due its timer-based broadcast mechanism. While randomized-backoff flooding performs worse in terms of end-to-end delay as it gives a backoff time for the retransmission of the received packet at each relay node. The performance of the three techniques is almost the same in terms of hop counts, this is because they allow packets to travel through the shortest path and thus reach their destination faster.

3) Effect of Emergency Packet Generating Rate

In this experiment we study the impact of traffic load on the studied techniques performance. We varied the emergency packet generating rate from 2-10 packets/second. Figure 11 present packet delivery ratio as a function of emergency packet generating rate. We can say that SIFT depicts the best performance in high traffic load scenarios. Its mechanism of dynamic selection of relays causes the lowest overhead. Moreover, it has the highest throughput as illustrated in Fig. 12, and is able to deliver packets quite fast.

Figures 13 and 14 show the end-to-end delay and average hops, respectively. We notice that the results are not much affected by emergency packet generating rate. We observe that for randomized-backoff flooding technique the increase in packet generating rate significantly increases its average end-to-end delay. SIFT incurs lower average hops as depicted in Fig. 14. This is because SIFT produce low routing overhead comparing to pure flooding and randomized-backoff flooding, and thus the number of collisions and retransmission is lower.
In this paper we studied dissemination of emergency messages in VANETs. Three techniques were simulated under mobility scenarios, and the effects of changing vehicle density, communication range and traffic load on emergency packet dissemination were analyzed. In pure flooding and randomized-backoff flooding techniques, all vehicles participate in the broadcasting task. Our simulation results and analysis show that broadcast by a subset of vehicles using trajectory-based technique is enough to achieve good message dissemination through the network. However, we have seen that a broadcast technique as simple as flooding outperforms SIFT scheme in case of high vehicle densities, while generating a significant large amount of network traffic overhead. SIFT reduces this overhead while showing an acceptable end-to-end delivery delay. SIFT performs better than pure flooding in high traffic load scenarios. It is able to deliver more emergency packets through shorter paths comparing to the other two flooding techniques.

VI. CONCLUSIONS

REFERENCES

on modeling, analysis, and simulation of wireless and mobile systems (MSWiM ’07), 2007.


