Assessing the Feasibility of a VANET Driver Warning System

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ABSTRACT

In this work we evaluate the feasibility of a VANET Warning System in which damaged vehicles send vehicle safety messages with high reliability and low delay.

We performed a sensitivity study to evaluate the impact of varying some parameters in the proposed system. We varied the number of damaged vehicles, the total number of vehicles, as well as the priority and periodicity of the messages sent to study the impact on the time required to propagate the warning messages, the number of blind vehicles (i.e., vehicles that do not receive these packets) and the number of packets received per vehicle, in order to study the viability of our system.

We show that the warning notification time is lower when vehicle density increases and the percentage of blind vehicles highly depends on this factor. Finally, the results demonstrated that, to obtain the lowest possible warning notification time in our system, the best solution is that messages have different priorities depending on their characteristics.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*

General Terms

Experimentation, Performance

Keywords

Vehicular ad hoc networks, performance evaluation, inter-vehicular communication, 802.11p

1. INTRODUCTION

Ad hoc networking is regarded as the adequate solution to cooperative driving between communicating cars on the road. Such networks, named *Vehicular Ad-hoc Networks* (VANETs), represent a rapidly emerging research field [1].

VANETs have particular features such as distributed processing and organized networking, a great number of vehicles, the distribution and the speed of these vehicles, constrained but highly variable network topology, communication conditions and mobility patterns, signal transmissions blocked by buildings, frequent partition due to the high mobility, and finally there are no significant power constraints.

Emerging wireless technologies for *vehicle-to-vehicle* (V2V) and *vehicle-to-roadside* (V2R) communications, such as *Dedicated Short Range Communications* (DSRC), are promising to dramatically reduce the number of fatal roadway accidents by providing early warnings [2].

In traffic safety, it is important to ensure a reliable broadcasting of warning messages, as well as a low delivery delay. Road safety applications require fast and reliable propagation of alert messages throughout the network, especially to nearby and approaching vehicles. Due to potentially large distances and shadowing, the delivery protocol must forward messages over multiple hops, thereby increasing network congestion and packet collisions. In *Inter-Vehicular Communication* (IVC) systems, broadcast is a frequently used method. Possible applications relying on broadcast include sharing emergency, traffic, weather, and road data among vehicles, and delivering advertisements. These applications generate packets of various lengths at different rates.

In this paper, we evaluate the feasibility of a Driver Warning System based on the use of 802.11p standard and a flooding based protocol. The objective is to measure the viability and delay of warning data packets. We evaluated the performance of our proposed system, and we also concentrated on several important issues related to traffic safety such as the warning notification time of warning messages in an urban environment, the number of blind vehicles that do not receive these messages, and the total number of warning messages received by each vehicle. We varied some parameters of the model to study the variation of these metrics.

This paper is organized as follows: Section 2 describes the related work with regard to warning messages in VANETs. Section 3 presents our proposed advertisement system in 802.11p-based VANETs. Section 4 presents the details of the simulation tools, the experimental environment and the methodology we followed to perform the simulations. Section 5 presents the obtained results. Finally, Section 6 presents some concluding remarks.

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2. RELATED WORK

In this section we reflect the previous research work regarding warning messages that focused on collision prevention mechanisms.

Xu et al. [2] studied the design of layer-2 protocols for a vehicle to send safety messages to other vehicles. The target is to send vehicle safety messages with high reliability and low delay. They also explored the feasibility of sending safety messages from vehicle to vehicle in the DSRC control channel. Since safety messages are time sensitive, when vehicles send safety messages to each other while traveling at high speed, they must be received with small delay and high probability.

Sengupta et al. [3] focused on *Cooperative Collision Warning* (CCW) systems and presented experimental results showing the performance of a first prototype CCW system. The CCW concept provides warnings or situation awareness displays to drivers based on information about the motions of neighboring vehicles obtained by wireless communications from those vehicles.

More recently, Zang et al. [4] studied the performance of the *Emergency Electronic Brake Light with Forwarding* (EEBL-F) application as an example of the safety application in congested scenarios, and proposed a congestion control architecture for VANETs.

To the best of our knowledge, none of the research works currently available has studied the most important parameters in a VANET when warning messages are used to improve traffic safety, including a detailed performance evaluation.

3. THE DRIVER WARNING SYSTEM

In this section we describe how the Driver Warning System operates, as well as the technologies and protocols involved. In our system, each vehicle periodically broadcasts information about itself. When a vehicle receives a broadcast message, it processes it and, in case it is a warning message, it immediately forwards it by re-broadcasting the message. Warning messages should be propagated to all neighbors up to a certain number of hops, and so a flooding-based routing protocol fits our requirements adequately.

We pretend that the warning packets sent by damaged vehicles can be received by all the vehicles in the nearby area, and so this protocol offers the best reliability in terms of coverage.

The 802.11p is a draft amendment to the IEEE 802.11 standard for vehicular communications. It has been adopted by *Wireless Access in Vehicular Environments* (WAVE), which defines an architecture to support *Intelligent Transportation Systems* (ITS) [5]. This includes data exchange between high-speed vehicles and between the vehicles and the roadside infrastructure in the licensed ITS band of 5.9 GHz (5.85-5.925 GHz) and broadcasting data rates from 3 to 6 Mbps. The purpose of this standard is to provide the minimum set of specifications required to ensure interoperability between wireless devices attempting to communicate in potentially rapidly changing communications environments, as well as in situations where transactions must be completed within time periods much shorter than the minimum allowed with infrastructure or ad hoc 802.11 networks.

For our Driver Warning System we picked IEEE 802.11p technology because it is expected to by widely adopted by the industry, as occurred with other IEEE 802.11 standard extensions. Moreover, we consider that this technology is able to offer good performance in environments where the physical layer properties are rapidly changing and where very short-duration communications exchanges are required.

The proposed Driver Warning System is composed by damaged vehicles that send warning messages periodically to inform about their situation to the rest of the vehicles. These messages have the highest priority (AC3). Undamaged vehicles make the diffusion of these warning packets and periodically send other normal messages with information such as their position, their speed, etc. These periodic messages have less priority (AC1) than warning messages and are not propagated by other vehicles. With respect to warning messages, each vehicle is only allowed to propagate them once for each sequence number, being that older messages are dropped.

Algorithms 1 and 2 describe our considered Driver Warning System, where $node_i$ indicates each vehicle in the scenario; m indicates each message sent or received by each vehicle; *warning* represents a warning message generated by a damaged vehicle; *beacon* represents a normal message generated by a normal vehicle; T_w is the interval between two consecutive warning messages; T_b is the interval between two consecutive normal messages; P_w indicates the priority that warning messages have and P_b indicates the priority that normal messages have. Furthermore, we consider that a vehicle is a *neighbor* of another when the Euclidean distance between both vehicles is lower than the wireless transmission range, so that communication between them is possible.

When a $node_i$ starts the broadcast of a message, it sends m to all its neighbors. Whenever a node receives m for the first time, it rebroadcasts by relaying m to its neighbors. Depending on their characteristics, every node repeats *send*(*warning*) or *send*(*beacon*) operations periodically with different periods (T_w and T_b, respectively). When a new message m is received, the receptor tests if m has already been received. To achieve this, each node maintains a list of message IDs. An incoming warning message ID is inserted in the list if m is received for the first time (i.e. its ID is not present in the list). Then m is broadcasted to the surrounding nodes. If the message is a *beacon*, it is simply discarded since we are not interested in the dissemination of beacons.

Algorithm 1: Send()

```
P_w = AC3;    // set the highest priority
P_b = AC1;    // set default priority
ID = 0;       // initialize sequence number of messages
while (1) do
    if (node_i is in warning mode) then
        create message m;
        set m.priority = P_w;
        set m.seq_num = ID++;
        send(warning) to all neighbors;
        sleep (T_w);
    else
        create message m;
        set m.priority = P_b;
        send(beacon) to all neighbors;
        sleep (T_b);
```

Algorithm 2: OnRecv()

```
for (every received message) do
    if (m is a warning message and m.seq_num
    received for the first time) then
        broadcast(m);
    else
        discard(m);
        // duplicated warnings and beacons are not
        rebroadcasted
```

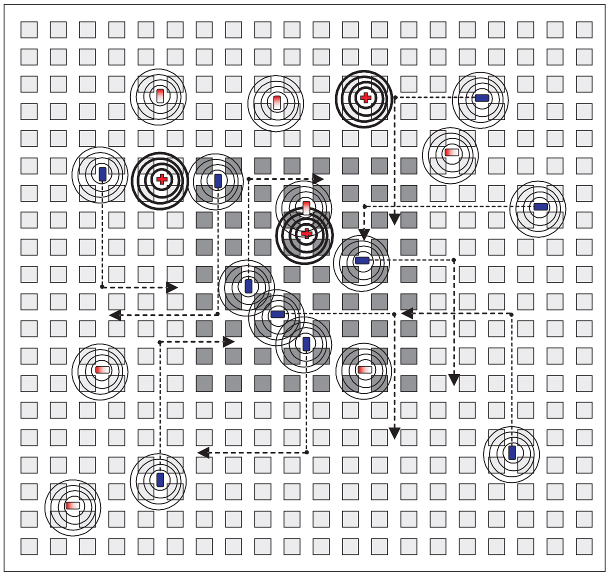

Figure 1: Typical simulation environment using the proposed warning advertisement system in a Downtown scenario.

Figure 1 shows an example of the advertisement system. Notice that the darker buildings area represents the downtown. Dark rectangles represent vehicles, shadowed rectangles represent vehicles stopped at semaphores, and crosses represent damaged cars sending warning packets (darker circles).

4. SIMULATION ENVIRONMENT AND METHODOLOGY

In this section we present our simulation environment. Simulations were done using the ns-2 simulator [6]. Our simulated system follows the upcoming WAVE standard closely. Achieving this required extending the ns-2 simulator to implement IEEE 802.11p. In terms of the physical layer, the data rate used for packet broadcasting was fixed at 6 Mbit/s, i.e., the maximum rate for broadcasting in 802.11p. The MAC layer is based on the IEEE 802.11e *Enhanced Distributed Channel Access* (EDCA) *Quality of Service* (QoS) extensions [7], but adapted to 802.11p timing changes, frequency differences, etc. Therefore, application messages are categorized into different *Access Classes* (ACs), where AC0 has the lowest and AC3 the highest priority. All these improvements and modifications of the simulator are available at http://www.grc.upv.es/software/default.htm.

Our methodologies consisted of first selecting the most representative parameters for VANETs, then defining a reference scenario and, finally, varying the selected parameters, thereby generating and evaluating a large number of different scenarios. The selected parameters were: 1) the number of damaged vehicles, 2) the total number of vehicles, 3) the scenario size, 4) the priority of these messages and 5) their periodicity. Each simulation lasted for 450 seconds. In order to achieve a stable state, we only collect data after the first 60 seconds.

Since the Random Waypoint Model is considered unrealistic [8], in the simulation vehicles moved according to a mobility model called *Downtown Model* (DM) [9], a model included in the CityMob [10] mobility generator that we have proposed and validated to be used in VANETs. In this model streets are arranged in a Manhattan style grid, with a uniform building size across the simulation area. All streets are two-way, with lanes in both directions. Car movements are constrained by these lanes. Vehicles move with a random speed, lower than the maximum one defined by the user. Damaged vehicles will remain stopped during the entire simulation time. This model also simulates semaphores at random positions (not only at crossings), and with different delays. When a vehicle meets a semaphore, it will remain stopped until the semaphore turns to green. Moreover, this model adds traffic density like in a real town, where traffic is not uniformly distributed; so, there are zones with a higher vehicle density. These zones are usually in the downtown, and vehicles must move more slowly than in the outskirts. The Downtown area is defined by the coordinates ($start\_x$, end_x, $start\_y$, end_y). Parameter p is used to establish the probability of a vehicle being initially located inside the downtown area, and also the probability that vehicles on the outskirts move into the downtown.

5. SIMULATION RESULTS

The overall goal of this work was to evaluate the feasibility of the Driver Warning System presented in section 3, as well as measuring and comparing the behavior of some important metrics: (a) average percentage of blind vehicles, (b) warning notification time and (c) average number of packets received per vehicle when modifying the different parameters of a VANET scenario. The percentage of blind vehicles is the percentage of vehicles that do not receive the warning messages sent by the accident vehicles. These vehicles can remain blind because of their positions, due to collisions, or due to signal propagation limitations. The warning notification time is the time required by normal vehicles to receive a warning message sent by a warning mode vehicle (a vehicle that broadcasts warning messages).

We first obtain reference results using the reference scenario, and then we test a wide number of scenarios by varying one of the selected parameters. The results shown in this section represent an average over several simulation runs with different randomly generated mobility scenarios and with warning mode vehicles placed randomly. Since the performance results are highly related to the scenarios, and due to the random nature of the mobility model used, we repeated the simulations to obtain reasonable confidence intervals. All results present a maximum error of 10% with a degree of confidence of 90%.

5.1 The reference scenario

Table 1 shows the parameter values used in as the refer-

Table 1: Parameter values for the reference scenario

Parameter	Value
number of vehicles	100
maximum speed	23 $meters/sec.$ $\approx$ 83 km/h
map area size	$2000m \times 2000m$
distance between streets	$50m$
number of damaged vehicles	3
downtown size	$500m \times 500m$
downtown speed (min.-max.)	$3-14$ $meters/sec.$ $\approx$ $11-50$ km/h
downtown probability	0.7
warning packet size	$256bytes$
normal packet size	$512bytes$
packets sent by vehicles	1 *per second*
warning message priority	$AC3$
normal message priority	$AC1$
MAC/PHY	802.11p
transmission range	$250m$

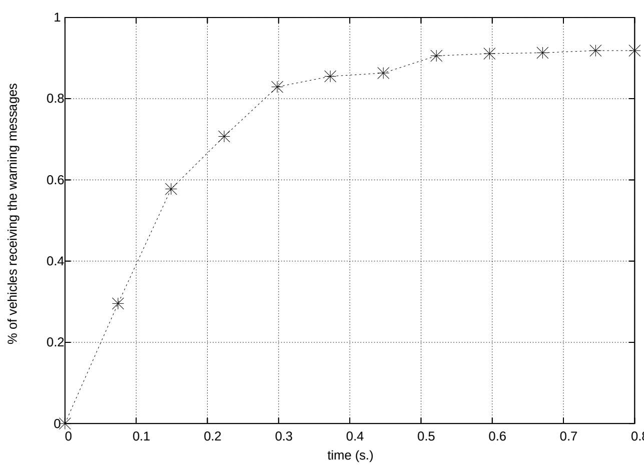

Figure 2: Cumulative histogram for the time evolution of disseminated warning messages in the reference scenario.

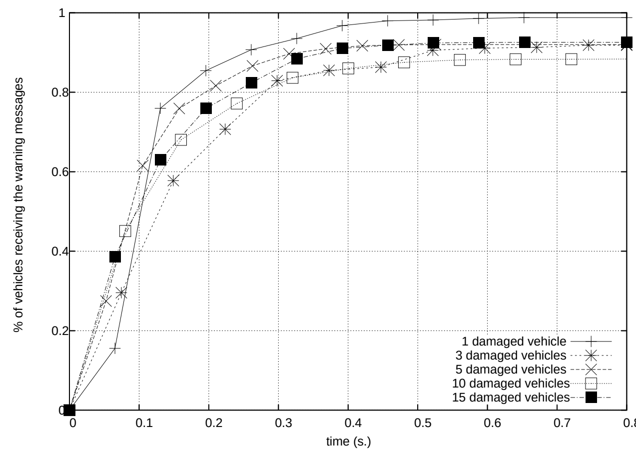

Figure 3: Cumulative histogram for the time evolution of disseminated warning messages when varying the number of damaged vehicles.

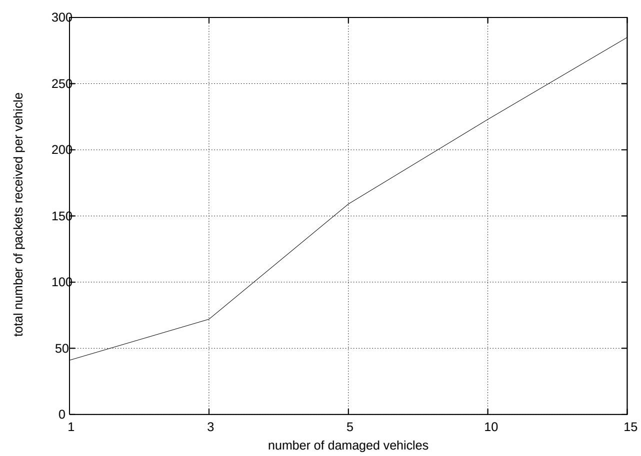

Figure 4: Total number of packets received per vehicle when varying the number of damaged vehicles.

ence scenario. The results obtained for the measured metrics when simulating the reference scenario were: 9.07% blind vehicles and 72.18 packets received per vehicle, on average. Figure 2 depicts the average warning notification time of the warning messages and also the percentage of blind nodes (% of nodes that not received the warning messages). As shown, information does not reach all vehicles, but in only 0.15 seconds about 60% of the vehicles received the warning message, and in less than 0.3 seconds the information reached 80% of the vehicles. From now on we will use as reference the time it takes to reach 80% of the vehicles (or 60%, in case there are too many blind vehicles). For our reference scenario the propagation process finished after 0.8 seconds.

5.2 Varying the number of damaged vehicles

We now study the effect of varying the number of damaged vehicles. The selected values were: 1, 3 (reference scenario), 5, 10 and 15. Varying the number of damaged vehicles affects the percentage of vehicles that receive the warning messages. The percentage of informed vehicles increases when the number of damaged vehicles decreases, since when there are more damaged vehicles, the probability that some damaged vehicle becomes isolated also increases. Most important, we observed that although the number of damaged vehicles fluctuates between 2 and 11%, the system needed less than 0.3 seconds to inform 80% of the vehicles in all cases (see Figure 3). As can be expected, the total number of packets received per vehicle increases when the number of damaged vehicles increases (see Figure 4), though not in the same proportion due to packet collisions (41.62, 72.18, 159.05, 223.50 and $285, 26$ respectively).

5.3 Varying the number of vehicles

Figure 5 show the simulation results when varying the number of vehicles and maintaining the rest of parameters unaltered. We selected 25, 50, 100 (reference scenario), 150

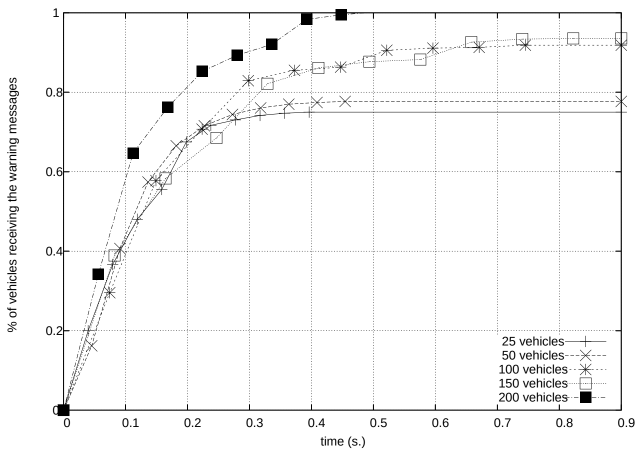

Figure 5: Cumulative histogram for the time evolution of disseminated warning messages when varying the number of vehicles.

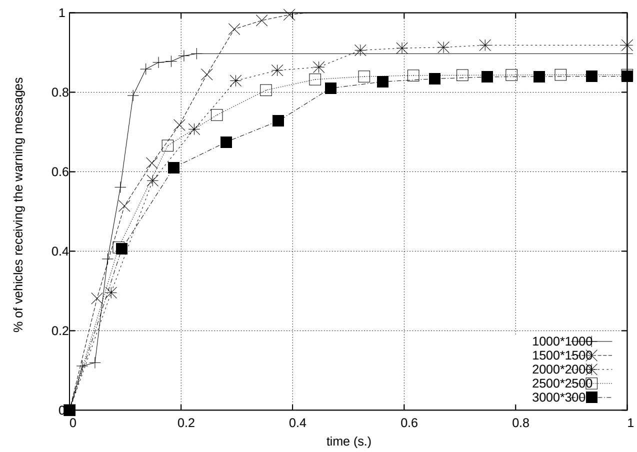

Figure 7: Cumulative histogram for the time evolution of disseminated warning messages when varying the size of the area.

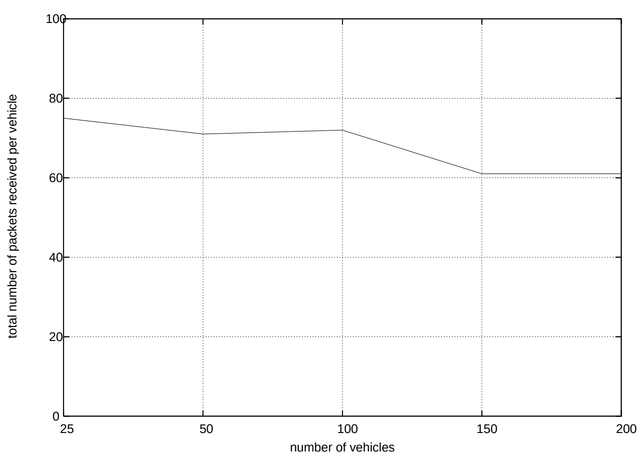

Figure 6: Total number of packets received per vehicle when varying the number of vehicles.

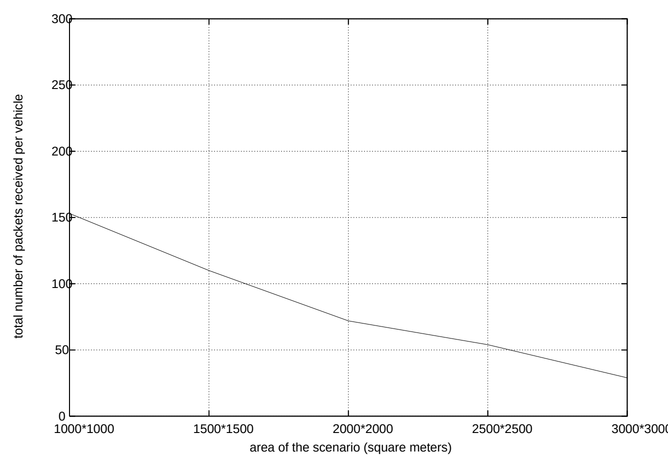

Figure 8: Total number of packets received per vehicle when varying the size of the area.

and 200 vehicles. As expected, the warning notification time is lower when the vehicle density increases. Information reaches about 60% of the vehicles in less than 0.2 seconds, and propagation is completed in less than 0.9 seconds. When simulating with 200 vehicles, propagation was completed in only 0.5 seconds.

The behavior in terms of percentage of blind vehicles highly depends on this factor. In fact, when vehicle density is high, there are no blind vehicles. This characteristic is explained because the flooding propagation of the messages works better with higher vehicle densities. Due to collisions, the number of packets received per vehicle slightly decreases when the number of vehicles increases (75.43, 71.43, 72.18, 61.43 and 61.79, respectively), as shown in Figure 6.

5.4 Varying the scenario size

In this section we show the simulation results when varying the size of the area while maintaining unaltered the density of vehicles as well as the rest of parameters. We selected scenario areas of 1000×1000m, 1500×1500m, 2000×2000m (reference scenario), 2500×2500m and 3000×3000m, with a vehicle density fixed at 25 vehicles per square kilometer.

Figure 7 depicts the average warning notification time. As can be seen, when the area increases, the system needs more time to inform 80% of the vehicles (approximately 0.12, 0.25, 0.30, 0.35 and 0.45 seconds respectively). The percentage of blind vehicles highly depends on this factor. In fact, when the area is very small, the percentage of blind vehicles is also very small. Likewise, when the size of the area increases, the number of blind vehicles also increases. Nevertheless, the total number of packets received per vehicle decreases since the distances are greater (152.66, 109.80, 72.18, 53.89 and 29.23, respectively), as shown in Figure 8.

5.5 Varying the message priority

In traffic safety it is important to ensure a reliable broadcasting of warning messages with low delivery delay. Road safety applications require fast and reliable propagation of

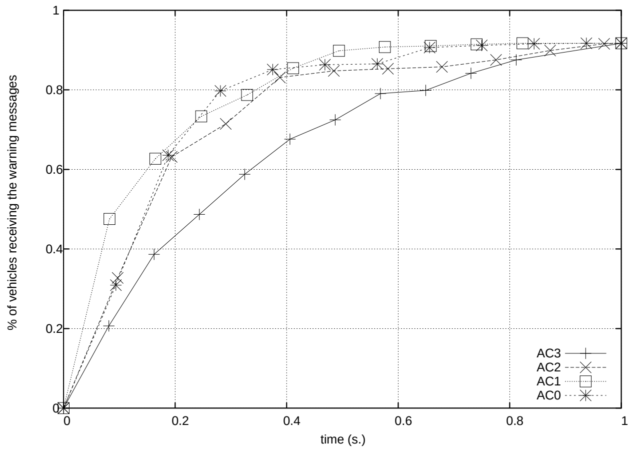

Figure 9: Cumulative histogram for the time evolution of disseminated warning messages when varying the priority of the messages sent by the undamaged vehicles.

alert messages throughout the network, since vehicle safety applications require reliable delivery of warning messages to nearby and approaching vehicles. Therefore, in this section we vary the priority of regular (background) traffic to assess the impact in terms of warning messages' effectiveness.

Figure 9 show the simulation results when varying the priority of the messages sent by undamaged vehicles when maintaining the rest of parameters unaltered. We selected AC3 (highest priority in our simulation system), AC2, AC1 (reference scenario) and AC0 (lowest priority).

The results demonstrated that, to obtain the lowest possible warning notification time in our system, the best solution is to give the less priority to the background traffic, while the warning messages must have the highest priority. In that case, about 80% of the vehicles are informed in only 0.28 seconds. If we increment the priority of the normal messages, the system needs more time to inform 80% of the vehicles (0.34 and 0.36 seconds).

The worst case scenario arrives when all the messages (warning and normal) have the same priority, since the system needs 50% more time to inform 80% of the vehicles. The priority does not affect the percentage of blind vehicles and the total number of messages received (9.07% blind vehicles and 72.18 packets received per vehicle in all the experiments).

5.6 Varying the periodicity of messages

In this last experiment we studied the impact of varying the periodicity of the messages sent in two different situations: first, when the priority of all the messages is the same and second, when the priority of the normal messages is lower than the priority of the warning messages.

Figure 10 shows the warning notification time when varying the data rate considering that all the messages have the same priority. Figure 11 shows the warning notification time when varying the data rate considering that the priority of normal messages is lower than the priority of warning messages.

As can be seen by comparing both figures, when the mes-

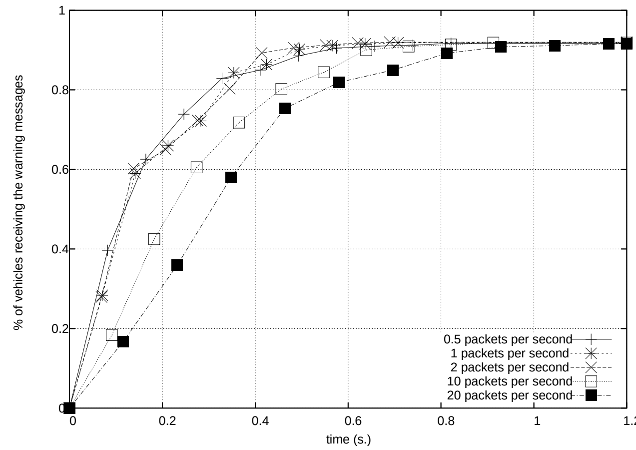

Figure 10: Cumulative histogram for the time evolution of disseminated warning messages when varying the data rate (same priority for messages).

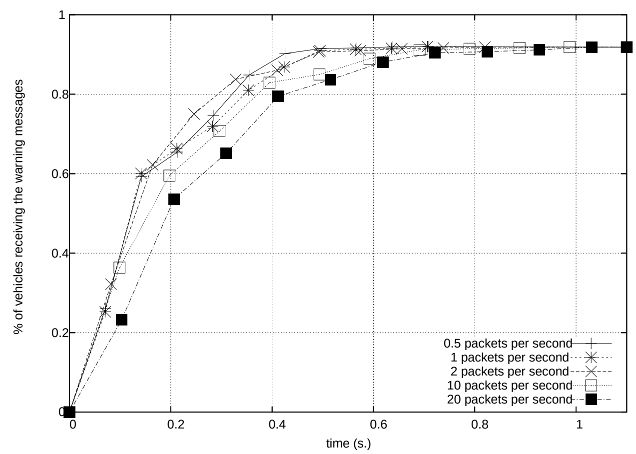

Figure 11: Cumulative histogram for the time evolution of disseminated warning messages when varying the data rate (different priority for messages).

sage priority differs the system's behavior is improved since it requires less time to inform 80% of the vehicles. In both cases, when data rate increases, the system requires more time to inform vehicles. Therefore, to achieve optimum performance, we must find a trade-off between message generation intervals and system responsiveness. Besides, we must make sure that message priority is handled adequately to avoid that warning messages compete with other traffic.

The periodicity does not affect the percentage of blind vehicles (9.07% for all the experiments). Figure 12 shows the number of packets received when considering that all the messages have the same and different priorities. As shown, the behavior is very similar in both cases. The number of packets received is slightly higher when using the same priority for messages at lower data rates, but when periodicity increases, the number of packets received is lower when using the same priority for all messages, due to contention and packet collisions caused by simultaneous forwarding.

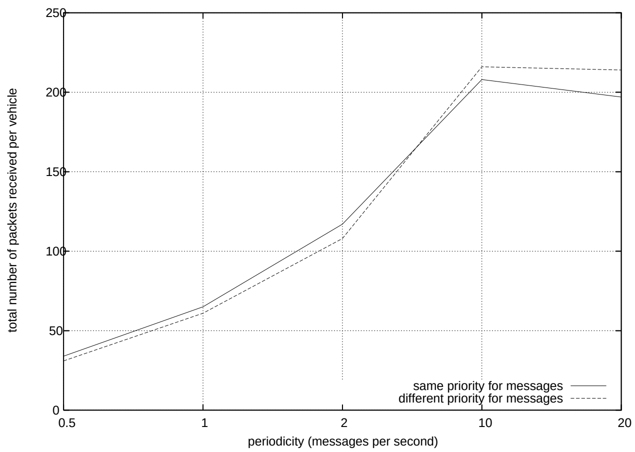

Figure 12: Total number of packets received per vehicle when varying the periodicity of messages.

6. CONCLUSIONS

In this paper we presented a Driver Warning System for IEEE 802.11p-based VANETs. To evaluate our system we proposed a vehicle mobility model and we enhanced the ns-2 simulator to support the novel IEEE 802.11p technology. We selected the most representative parameters for VANETs, and then we defined and simulated a reference scenario. Finally, by varying the selected parameters, we performed a sensibility study.

The results obtained from the simulations allowed us to draw some important conclusions.

The number of damaged vehicles has an impact on the warning notification time of messages. It also affects the percentage of blind vehicles, which is increased when the number of damaged vehicles increases.

As we expected, the warning notification time is lower when vehicle density increases. Besides, the percentage of blind vehicles highly depends on this factor. In fact, when vehicle density surpasses a certain threshold, there are no blind vehicles. This occurs because the flooding propagation of messages is more effective with a higher density of vehicles. Finally, the number of packets received slightly decreases when the number of vehicles increases due to collisions.

Thus, an increase in the simulation area causes the number of blind vehicles to increase, despite the number of packets received per vehicle decreases due to greater distances.

When varying the priority of the packets sent by the undamaged vehicles, the warning notification time of the system changes.

The results showed that to obtain the lowest possible warning notification time in our system, the best solution is to give less priority to background traffic, while warning messages must have the highest priority. We have a worst case scenario when all the messages (warning and normal) have the same priority. However, packet priority does not affect the percentage of blind vehicles nor the total number of packets received. The system's behavior decays when increasing the data rate of messages, especially if both warning and regular messages are assigned the same priority.

Acknowledgments

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