Using Roadmap Profiling to Enhance the Warning Message Dissemination in Vehicular Environments

Manuel Fogue, Piedad Garrido, Francisco J. Martinez
University of Zaragoza, Spain
Email: {m.fogue, piedad, f.martinez}@unizar.es

Juan-Carlos Cano, Carlos T. Calafate, Pietro Manzoni
Universitat Politècnica de València, Spain
Email: {jucano, calafate, pmanzoni}@disca.upv.es

Abstract— **In recent years, new applications, architectures and technologies have been proposed for Vehicular ad hoc networks (VANETs). Regarding traffic safety applications for VANETs, warning messages have to be quickly disseminated in order to reduce the required dissemination time and to increase the number of vehicles receiving the traffic warning information. In the past, several approaches have been proposed to improve the alert dissemination process in multi-hop wireless networks, but none of them is adapted to the propagation features of the scenario. In this paper, we present an adaptive algorithm designed to improve the warning message dissemination process. With respect to previous proposals, our proposed scheme uses a mapping technique based on adapting the dissemination strategy according to the characteristics of the street area where the vehicles are moving. Our algorithm reported a noticeable improvement in the performance of alert dissemination processes in simulated scenarios based on real city maps.**

I. INTRODUCTION

A. Motivation

Vehicular ad hoc networks (VANETs) are wireless networks that do not require any fixed infrastructure. These networks are considered essential for cooperative driving among cars on the road. VANETs are characterized by: (a) a constrained but highly variable network topology, (b) a great number of nodes with very specific speed patterns, (c) variable communication conditions (e.g., signal transmissions can be blocked by buildings), (d) road-constrained mobility patterns, and (d) no significant power constraints. Such features make standard networking protocols inefficient or unusable in VANETs; hence, there is a growing effort in the development of specific communication protocols and methodologies for vehicular networks. The development of VANETs is backed by strong economical interests since vehicle-to-vehicle (V2V) communication allows the sharing of wireless channels for mobile applications, thereby increasing the passengers' comfort, improving route planning, controlling traffic congestion, and improving traffic safety.

In this work we focus on efficient warning message dissemination to be used in traffic safety applications. The main goal is to reduce the latency and to increase the accuracy of the information received by nearby vehicles when a dangerous situation occurs.

In a VANET, any vehicle detecting an abnormal situation (i.e. accident, slippery road, etc.) should notify the anomaly to nearby vehicles that could face this problem in a short period of time. Hence, broadcasting warning messages can be useful to alert nearby vehicles. However, a simple retransmission of warning messages yields an exponential growth of messages over time, and broadcast storm (serious redundancy, contention and massive packet collisions due to simultaneous forwarding) will occur, which must be avoided or reduced [1].

B. State of the art

In the networking literature, we can find several works that proposed either broadcast storm reduction techniques or adaptive mechanisms to enhance message dissemination. In this section we present some of the most representative works.

Tseng et al. [1] proposed different schemes to mitigate broadcast storms. The *Counter-based scheme* uses a counter to keep track of the number of times the broadcast message is received, inhibiting rebroadcast when it exceeds a threshold. The *Distance-based scheme* calculates the distance between the sender and the receiver and only allows retransmission when the additional coverage area is large enough. The *Location-based scheme* is similar to the previous one, though requiring more precise locations for the broadcasting vehicles to achieve an accurate geometrical estimation (with convex polygons) of the additional coverage of a warning message.

Wisitpongphan et al. [2] developed the *weighted p-persistence*, the *slotted 1-persistence*, and the *slotted p-persistence* techniques. These three probabilistic and timer-based broadcast suppression techniques are not designed to solve the broadcast storm problem, but they can mitigate the severity of the storm by allowing nodes with higher priority to access the channel as quickly as possible. Unlike our proposal, these schemes are specifically designed for use in highway scenarios.

The Last One (TLO) scheme, presented in [3], tries to reduce the broadcast storm problem by finding the most distant vehicle from the warning message sender; this vehicle will be the only allowed to retransmit the message. Although it brings a better performance than simple broadcast, this scheme is only effective in highway scenarios because it does not take into account the effect of obstacles (e.g. buildings) in radio signal propagation. The TLO approach was extended using a protocol which utilizes adaptive wait-windows and adaptive probability to transmit, named *Adaptive Probability Alert Protocol* (APAL) [4]. This scheme shows even better

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performance than the TLO scheme, but it is also only validated in highway scenarios.

More recently, a stochastic broadcast scheme was proposed in [5] to achieve an anonymous and scalable protocol where relay nodes rebroadcast messages according to a retransmission probability. The performance of the system depends on the vehicle density, and these probabilities must be tuned to adapt to different scenarios. However, the authors only test this scheme in an obstacle-free environment, thus not considering urban scenarios where the presence of buildings could interfere with the radio signal.

With respect to adaptive schemes for message dissemination in VANETs, not much research can be found in the literature. Mariyasagayam et al. [6] proposed an adaptive forwarding mechanism to improve message dissemination in VANETs. Vehicles compute the density of neighbor nodes to calculate a forwarding sector in which vehicles are not allowed to rebroadcast the message.

The *Adaptive-ADHOC* (A-ADHOC) protocol [7] uses a variable frame length to increase channel utilization and to reduce response time. Another adaptive algorithm is the *Junction-based Adaptive Reactive Routing* (JARR) [8], a reactive position-based routing protocol that estimates the vehicle density of the available paths to be taken when sending a message, also accounting for the direction and traveling speed of vehicles in order to choose the optimal path.

Existing VANET adaptive systems only consider features related to the vehicles in the scenario such as density, speed and position to adapt the performance of the dissemination process. Moreover, most authors only evaluate their schemes using very simple scenarios and topologies that are not constrained by any obstacles, and where all the vehicles are in line-of-sight with each other. Unlike our proposal, these scenarios are not realistic enough to conclude that the proposed protocols and schemes could work efficiently in real VANET scenarios.

C. Our proposal

In this paper we present an adaptive algorithm for warning message dissemination that dynamically modifies some of the key parameters of the propagation process, such as the interval between notifications and the selected broadcast scheme, to achieve an optimal performance depending on the features of the roadmap in which the propagation takes place.

Adapting to the specific environment where the vehicles are located can be beneficial in order to reduce broadcast storm related problems, and also to increase the efficiency of the warning message dissemination process. Existing adaptive techniques for VANETs only make use of the vehicle density to adapt the process; however, this information in not enough in many situations to determine the most effective configuration.

Our proposal is combined with a previously presented broadcast storm reduction technique, the *enhanced Street Broadcast Reduction* (eSBR) [9], to achieve better performance in warning message dissemination by reducing the notification time.

D. Paper organization

The rest of the paper is organized as follows: Section II presents our proposed adaptive scheme. Section III shows the simulation environment used to validate our proposal. Section IV presents and discusses the obtained results. Finally, Section V concludes this paper.

II. AN ADAPTIVE ALGORITHM TO ENHANCE WARNING MESSAGE DISSEMINATION

In previous works, we identified the most representative factors to be taken into account in VANETs [10], [11]. We showed that the roadmap, which serves as scenario for the warning dissemination, has a considerable influence in the effectiveness of the process. The roadmap (road topology) is an important factor accounting for mobility since the topology constrains the cars' movements. Roughly described, an urban topology is a graph where vertices and edges represent, respectively, junction and road elements.

Aiming at using the specific scenario topology features to improve the warning message dissemination process, we can classify existing cities by their street profiles into:

- *Simple layouts*: maps with low density of streets and junctions that are usually arranged orthogonally like a Manhattan style grid. Examples of these cities are New York (USA), Moscow (Russia) and Seoul (South Korea).
- *Regular layouts*: maps with medium density of streets and junctions. Some cities in this group are San Francisco (USA), Washington DC (USA) and Paris (France).
- *Complex layouts*: maps with high density of streets and junctions. Cities which belong to this group are Rome (Italy), Valencia (Spain), and Tokyo (Japan).

In [11] we demonstrated that the propagation process is likely to behave in a similar way when vehicles are moving in different cities as long as they belong to a same roadmap profile group (i.e., dissemination processes behave similarly in New York and Moscow, but differently than in San Francisco, Paris, or Tokyo). This is the basis for our proposal: the effectiveness of the alert dissemination can be increased if vehicles determine the city profile of their current area, and adapt their dissemination schemes accordingly.

To enhance the performance of the alert dissemination, we propose to tune the warning dissemination system using the information provided by the on-board GPS system (with integrated street maps from the city that is being evaluated) to determine the profile of the city and select the most effective parameters to achieve a proper warning message dissemination. Previously proposed schemes use a fixed set of parameter values, or they only consider the vehicle density to adapt the system. Instead, our algorithm can obtain a preliminary estimation of the parameters to use just by checking the map of the area where the vehicle is located in. It is also beneficial to use a more restrictive dissemination scheme when the vehicle density is high to avoid broadcast storm problems. Hence, it is helpful to estimate the vehicle density in the surrounding area to maximize the effectiveness of the dissemination scheme.

TABLE I

WORKING MODES IN THE ADAPTIVE ALGORITHM

Working mode	**Interval between consec. messages**	**Broadcast scheme**	**Min. rebroadcast distance**
Full performance	2 seconds	counter-based [1]	—
Standard performance	4 seconds	eSBR [9]	200 m.
Reduced performance	5 seconds	distance-based [1]	250 m.

This estimation is done in our system using the beacons periodically sent among the vehicles with information about their position and speed. Moving vehicles use this information to compute the predicted position of nearby vehicles in order to determine how many vehicles are there in their proximities.

We observed that three parameters have a notable influence in both warning notification time and the number of messages received in the dissemination process. They are: (a) the interval between consecutive messages, (b) the broadcast scheme used, and (c) the minimum rebroadcast distance. If we vary their values, we see that the target requirements of our scheme are mutually exclusive, i.e. we cannot increase the percentage of notified vehicles and decrease the notification time at the same time if we do not increase the number of messages involved, and vice versa. Hence, our scheme must be able to find a balance among all these metrics. To facilitate the selection of the parameters, we have defined three adaptive working modes oriented to different situations. The dissemination scheme will select the most suitable one depending on the profile of the roadmap and the estimated vehicle density. The defined operation modes are:

- *Full performance*: vehicles move in low density areas, and hence they can send a high number of messages with little danger of provoking broadcast storm problems.
- *Standard performance*: vehicles try to achieve a balance between the number of informed vehicles and the number of messages received.
- *Reduced performance*: vehicles send as few messages as possible due to the high density of vehicles detected in the area that could easily lead to broadcast storm problems.

Table I contains the parameter values used in each working mode. Several preliminary simulations representing different environments were performed in order to select the sets of values with an optimal behavior in different situations. Our proposed algorithm can be summarized as follows (T_r is the interval between reconfigurations of the system, set to 30 seconds):

1) Set *Standard performance* as default working mode.
2) Every T_r seconds, Check *street profile* and Estimate *vehicle density*.
    a) If *street profile* is *Simple*:
        - If *vehicle density* > 75 vehicles/km^2: Set *Standard performance* as current working mode.
        - If *vehicle density* ≤ 75 vehicles/km^2: Set *Full performance* as current working mode.
    b) If *street profile* is *Regular*:
        - If *vehicle density* > 50 vehicles/km^2: Set *Standard performance* as current working mode.
        - If *vehicle density* ≤ 50 vehicles/km^2: Set *Full performance* as current working mode.
    c) If *street profile* is *Complex*:
        - If *vehicle density* > 25 vehicles/km^2: Set *Reduced performance* as current working mode.
        - If *vehicle density* ≤ 25 vehicles/km^2: Set *Standard performance* as current working mode.

According to this scheme, the system will be configured to use the *Full performance* mode in low vehicle density scenarios to inform as many vehicles as possible, except when the density of streets and junctions is high (Complex profile cities), which causes the number of messages to grow excessively. In this situation, the *Standard performance* is more suitable.

When the vehicle density is high, the *Full performance* mode should not be used, as it could easily yield broadcast storms. The *Standard performance* mode can be appropriate in most of cases, but the number of messages received when the street density is too high (Complex profile cities) may be excessive. In these cases, the *Reduced performance* mode is the most suitable.

III. SIMULATION ENVIRONMENT

Since deploying and testing VANETs involves high cost and intensive labor, simulation is a useful alternative prior to actual implementation [12]. Simulation experiments have shown that different dissemination strategies are associated with a different behavior in an urban environment, but also showed that the features of each specific scenario determine the efficiency of the process. To illustrate this effect, we selected three different cities in an attempt to represent diverse environments, as shown in Figure 1. The scenarios were obtained from OpenStreetMap [13], each one representing 4 km^2 of square area.

The city of Manhattan (KS, USA) has a very regular street layout where the simulations should have a very similar behavior compared to simulations performed using synthetic Manhattan-grid layouts. The city of Teruel (Spain) is an example of a town with medium density of streets and junctions, arranged in a complex layout different from typical Manhattan-grid layouts. The city of Valencia (Spain) represents a city with an extremely high density of streets and junctions. These scenarios will be used to show that the warning dissemination process behaves differently when the same configuration is used in different environments.

(a) (b) (c)

Fig. 1. Scenarios used in our simulations: (a) fragment of the city of Manhattan (KS, USA), (b) fragment of the city of Teruel (Spain), (c) fragment of the city of Valencia (Spain).

Simulations to test our experiments were done using the ns-2 simulator [14], modified to include the IEEE 802.11p [15] standard so as to follow the upcoming WAVE standard closely. In terms of the physical layer, the data rate used for packet broadcasting is of 6 Mbit/s, as this is the maximum rate for broadcasting in 802.11p. The MAC layer was also extended to include four different priorities for channel access. Therefore, application messages are categorized into four different *Access Categories* (ACs), where AC0 has the lowest and AC3 the highest priority.

The simulator was also modified to make use of our *Real Attenuation and Visibility* (RAV) scheme [16], which proved to increase the level of realism in VANET simulations using real urban roadmaps in presence of obstacles. In order to mitigate the broadcast storm problem, our simulations use: (a) the counter-based scheme [1], (b) the distance-based scheme [1], and (c) the *enhanced Street Broadcast Reduction* (eSBR) scheme [9], which employs a minimum distance under which vehicles are refrained from forwarding, except if they are close enough to a junction.

With regard to data traffic, vehicles operate in two modes: (a) warning mode, and (b) normal mode. Warning mode vehicles inform other vehicles about their status by sending warning messages periodically with the highest priority at the MAC layer; each vehicle is only allowed to propagate them once for each sequence number. Normal mode vehicles enable the diffusion of these warning packets and, periodically, they also send *beacons* with information such as their positions, speed, etc. These periodic messages have lower priority than warning messages and are not propagated by other vehicles.

Mobility is performed with CityMob for Roadmaps (C4R)[1], a mobility generator which can import maps directly from OpenStreetMap [13]. C4R is based on SUMO [17], an open source traffic simulation package. All results represent an average over several executions with different random scenarios, presenting all of them a degree of confidence of 90%. Each simulation run lasted for 450 seconds, and we only collect data after the first 60 seconds in order to achieve a stable state.

TABLE II
PARAMETER VALUES USED FOR THE SIMULATIONS

Parameter	**Value**
number of vehicles	$100, 400$
maximum speed of vehicles	$23\ m/sec. \approx\ 83\ km/h$
simulated area	$2000m \times 2000m$
number of warning mode vehicles	3
warning message size	$256B$
normal message size	$512B$
warning message priority	$AC3$
normal message priority	$AC1$
MAC/PHY	802.11p
maximum transmission range	$400m$
mobility generator	C4R
mobility models	Krauss [18] and Downtown model [10]

We are interested in the following performance metrics: (a) warning notification time, (b) percentage of blind vehicles, and (c) number of packets received per vehicle. The warning notification time is the time required by normal vehicles to receive a warning message sent by a warning mode vehicle. The percentage of blind vehicles is the percentage of vehicles that do not receive the warning messages sent by warning mode vehicles. The number of packets received per vehicle (including beacons and warning messages) gives an estimation of channel contention. Table II shows the parameter values used in our simulations.

IV. SIMULATION RESULTS

In this section, we first present the impact of the roadmap and vehicle density in warning message dissemination performance and, afterward, we evaluate and demonstrate the benefits of using our proposed adaptive scheme.

A. Evaluating the Impact of the Roadmap and Vehicle Density

Figure 2 and Table III show the differences in terms of both warning notification time and messages received per vehicle when varying the density of vehicles in the aforementioned city scenarios. In all these simulations we used the same base configuration: 2 seconds between messages, 200 meters for

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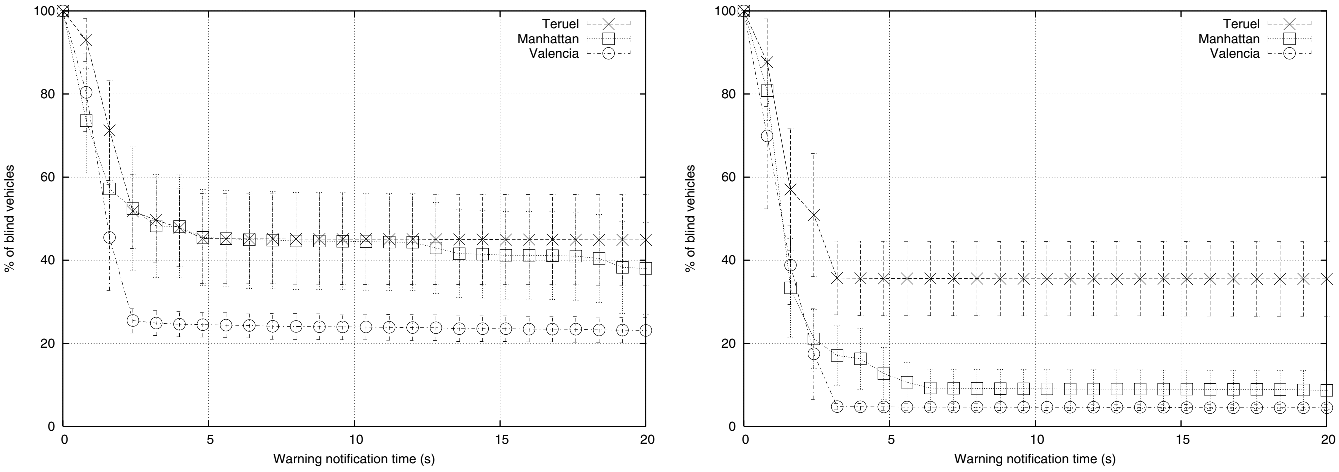
[1] `C4R` is available at http://www.grc.upv.es/software/



(a) (b)

Fig. 2. Evolution of the percentage of blind nodes in different scenarios simulating (a) 100 vehicles (25 vehicles/km^2) and (b) 400 vehicles (100 vehicles/km^2).

TABLE III

AVERAGE NUMBER OF MESSAGES RECEIVED PER VEHICLE SIMULATING DIFFERENT SCENARIOS AND VEHICLE DENSITIES

	Vehicle density			
Map	**100 veh.**	**200 veh.**	**300 veh.**	**400 veh.**
Manhattan	346.80	445.93	843.17	1314.73
Teruel	391.30	620.40	1351.67	2189.67
Valencia	652.93	1427.50	2229.27	3493.50

TABLE IV

AVERAGE NUMBER OF MESSAGES RECEIVED PER VEHICLE WITH THE DIFFERENT WORKING MODES SIMULATING 100 VEHICLES

	Working mode		
Map	**Full perf.**	**Standard perf.**	**Reduced perf.**
Manhattan	424.97	199.60	160.33
Teruel	507.37	244.90	110.53
Valencia	683.93	341.87	82.43

minimum rebroadcast distance, and the broadcast scheme used was eSBR.

Results in Figure 2 show that the selected scenario notably affects the efficiency of the dissemination process. Simulations performed using scenarios like Teruel present similar results with independence of the vehicle density.

In the other two scenarios, increasing the density of vehicles yields better performance in terms of both warning notification time and percentage of blind vehicles (i.e. not receiving warning messages), especially in roadmaps like Manhattan where the streets are the longest and vehicles may be too far away to communicate when the density of vehicles is low.

As shown in Table III, urban scenarios with high density of streets and junctions greatly increase the number of messages received per vehicle because of the higher number of vehicles allowed to rebroadcast. Thus, in these environments, the dissemination process should be tuned to use operation modes with low message generation rates.

Moreover, it is very important to reduce the amount of messages generated when the density of vehicles is high, but with low densities it is a good idea to produce enough messages to reach as many vehicles as possible, as the probability of broadcast storms becomes small.

B. Performance Testing

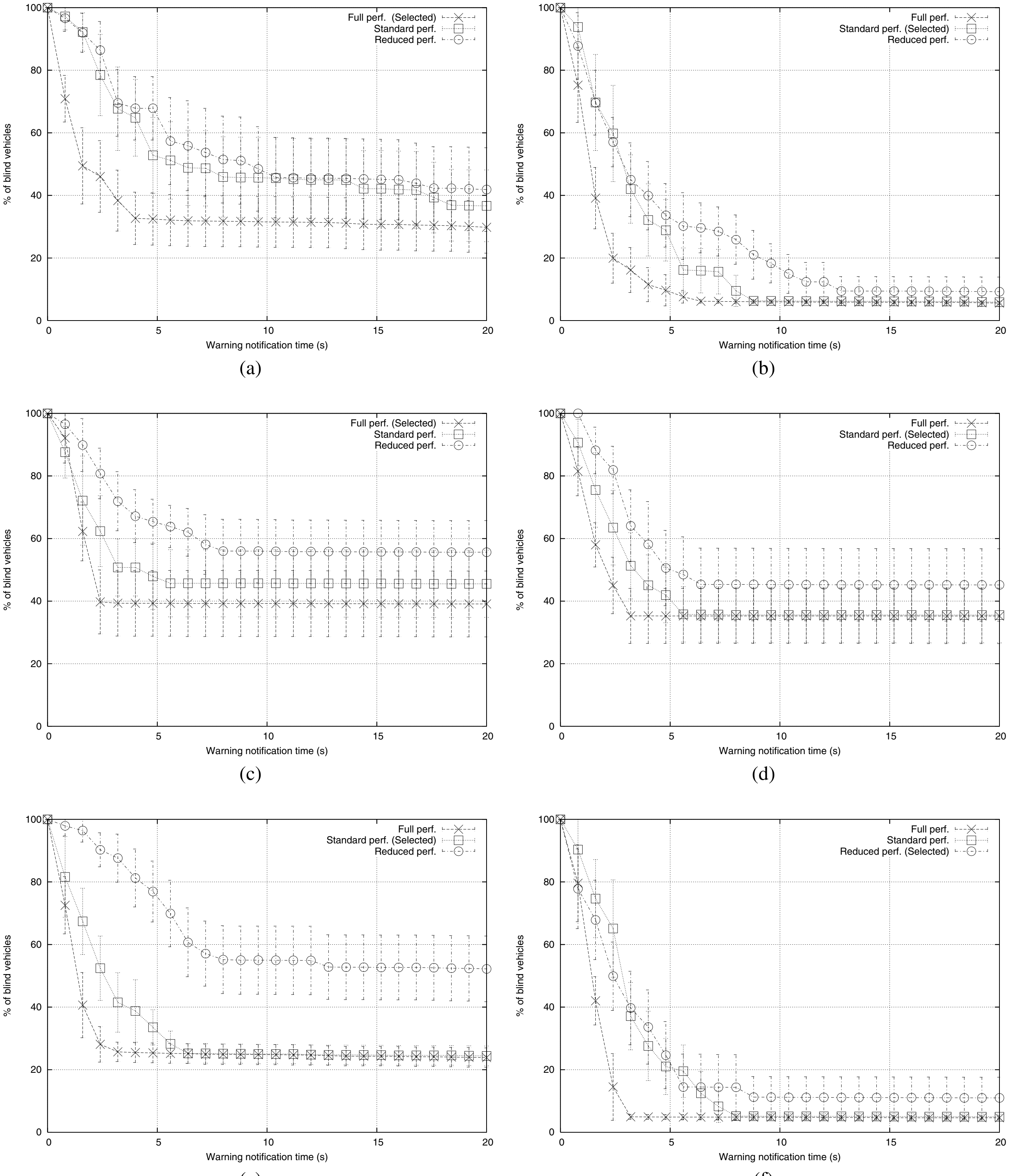
In this subsection we show the result of a wide set of experiments whose goal is to prove the effectiveness of our proposed adaptive algorithm when disseminating warning messages. The proposed technique consists of determining the adequate selection of working modes in every possible situation.

Figure 3 shows the warning notification time using the three configurations in diverse scenarios, and Tables IV and V depict the average number of messages received per vehicle.

Focusing on Simple profile cities like Manhattan, the *Full performance* mode (used in our algorithm) clearly outperforms the rest of the modes in terms of blind vehicles and warning notification time when only 100 vehicles are involved. In addition, the number of messages received is not very high (below 500 messages per vehicle), meaning that this mode would indeed be suitable for this environment.

When the number of vehicles increases to 400, this mode produces three times as many messages per vehicle than the other two modes with a similar warning notification time. *Standard* and *Reduced* modes achieve a similar performance in terms of blind vehicles and received messages, but the *Standard performance* mode is chosen because it allows notifying 80% of the vehicles in just 5 seconds, while the *Reduced performance* mode needs 9 seconds.

In Regular cities (e.g. Teruel), the *Reduced performance* mode does not obtain a good performance in terms of notification time and blind vehicles (about 30%-40% more blind nodes with respect to the rest of modes). In low vehicle density scenarios, using the *Full performance* mode yields



(a) (b) (c) (d) (e) (f)

Fig. 3. Evolution of the percentage of blind nodes with the different working modes in different cities: Manhattan with (a) 100 and (b) 400 vehicles, Teruel with (c) 100 and (d) 400 vehicles, and Valencia with (e) 100 and (f) 400 vehicles. The legend indicates the working mode selected by our algorithm in each scenario.

TABLE V

AVERAGE NUMBER OF MESSAGES RECEIVED PER VEHICLE WITH THE DIFFERENT WORKING MODES SIMULATING 400 VEHICLES

	Working mode		
Map	**Full perf.**	**Standard perf.**	**Reduced perf.**
Manhattan	1774.77	576.33	473.93
Teruel	2540.47	915.57	742.53
Valencia	3543.47	1799.07	299.43

a notable reduction of notification time and blind vehicles, without requiring a large amount of messages. Nevertheless, if the vehicular density is high, the number of messages grows excessively, and using the *Standard performance* mode allows reducing them to the third part with similar values for the rest of metrics. Hence, the most appropriate scheme would use the *Full performance* mode when there are few vehicles, and the *Standard* mode when their density increases.

Finally, in Complex profile cities (e.g. Valencia), the *Full performance* mode produces a very high number of messages, thus being unsuitable for this environment. When the density of vehicles is low, the *Reduced performance* mode allows reducing the total amount of messages disseminated; however, the notification time and the percentage of blind vehicles is far greater than for the *Standard performance* mode, which is more balanced and more suitable for this situation. In high density scenarios, the differences in performance between these two modes diminish: the *Standard* mode only informs about 6% more vehicles, while the number of messages involved is minimized to merely 20% with the *Reduced performance* mode. This effect confirms its selection as the most suitable mode for this environment.

Figure 4 summarizes the average results after 30 runs in terms of: (i) warning notification time to inform at least 40% of the vehicles, (ii) percentage of blind vehicles, and (iii) number of messages received per vehicle in the different studied situations. As shown, all the results are normalized, i.e., divided by the highest value for each metric in each scenario, and thus the presented results vary between 0 and 1. The most balanced configurations are highlighted, matching with the specific operation mode used in our proposed scheme. When the vehicle density is low, the number of received messages is not critical, whereas in high density scenarios the scheme tends to reduce messages by slightly increasing the other metrics.

V. CONCLUSIONS

In this paper we introduced a new adaptive approach that allows to increase the efficiency of warning message dissemination processes using the information about the urban environment where the vehicles are moving. Our solution requires vehicles to make use of the information contained in their integrated maps to determine the profile type. Additionally, the beacons exchanged with neighbors are used to estimate the density of vehicles in the area. By combining these two inputs, our algorithm is able to tune the parameters of the dissemination process and mitigate broadcast storm related problems. The objective is to find a balance among different performance metrics. With this aim, three different working modes (*Full*, *Standard* and *Reduced* performance) were proposed to be selected depending on their efficiency in each situation.

The proposed system has proven to be extremely effective when the density of vehicles is high, especially in maps with very high density of streets and junctions. In those cases, selecting a balanced working mode allows to maintain an acceptable level of performance in terms of notification time and percentage of blind vehicles, while reducing the number of messages by more than 90% compared to other base configurations. In the rest of the maps, using the most suitable mode allows reducing message duplicates by about 60%. The effectiveness of the proposed system in scenarios with low density of vehicles becomes less meaningful as it is unlikely to find broadcast storm problems in such environments. Instead, the system is configured to reach as many vehicles as possible without concentrating on reducing the number of messages involved in the process.

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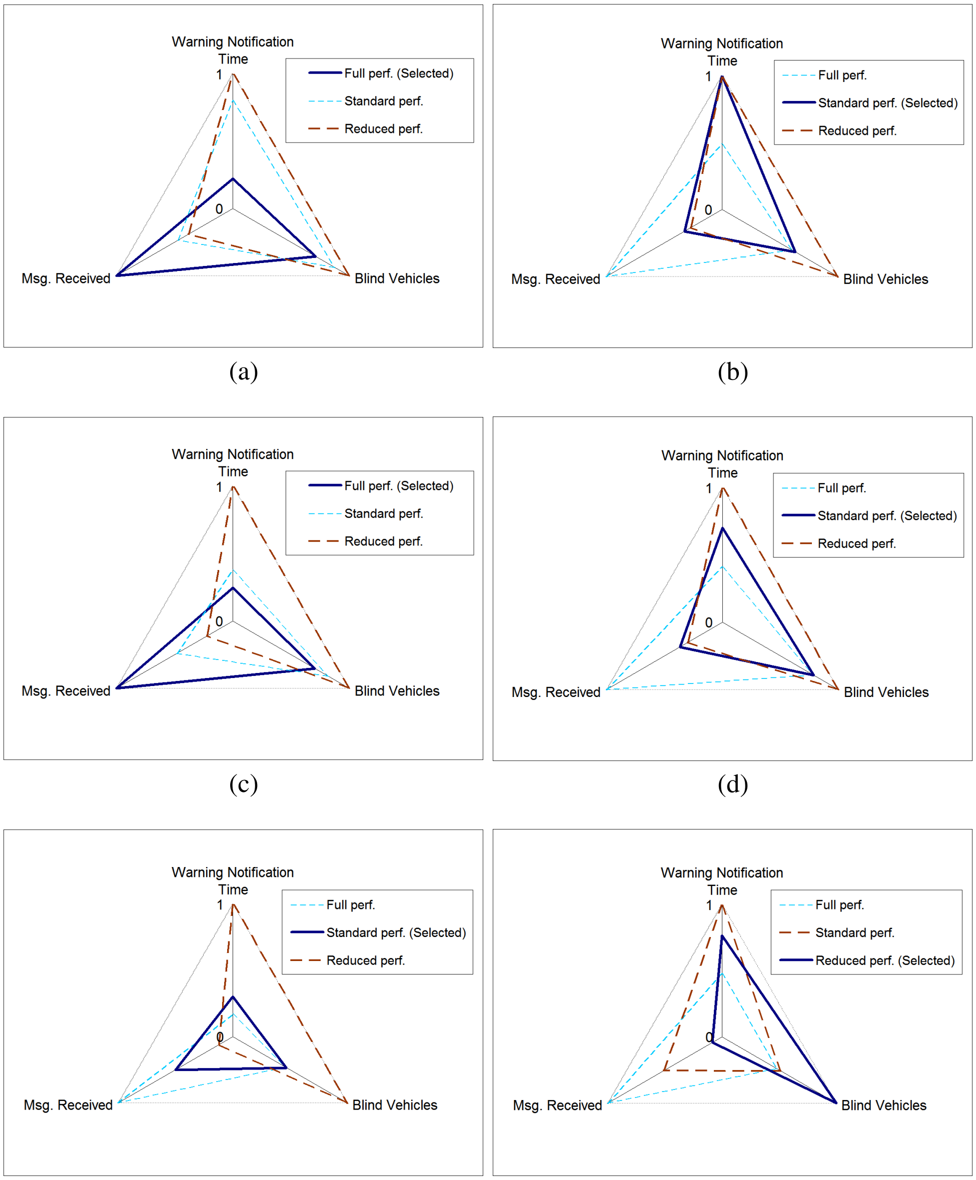

(a) (b)

(c) (d)

(e) (f)

Fig. 4. Average simulation results after 30 runs in: Manhattan with (a) 100 and (b) 400 vehicles, Teruel with (c) 100 and (d) 400 vehicles, and Valencia with (e) 100 and (f) 400 vehicles. The working modes selected by our algorithm are represented using solid lines.

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