PAWDS: A Roadmap Profile-driven Adaptive System for Alert Dissemination in VANETs

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 traffic safety applications for Vehicular Ad hoc Networks (VANETs), warning messages have to be disseminated whenever a dangerous situation occurs to alert nearby vehicles. Using inefficient broadcast schemes may lead to ineffective dissemination of warning messages causing broadcast storm problems. In the past, several approaches have been proposed to reduce the so called broadcast storm in multi-hop wireless networks, but none of them is adapted to the features of the propagation scenario. In this paper, we present the Profile-driven Adaptive Warning Dissemination Scheme (PAWDS) to improve the warning message dissemination process. With respect to previous proposals, our PAWDS scheme uses an adaptive technique based on tuning the operation of the dissemination scheme 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

Vehicular ad hoc networks (VANETs) are wireless communication networks that do not require any sort of fixed infrastructure, offering a novel networking paradigm to support cooperative driving applications on the road. VANETs are characterized by: (a) constrained but highly variable network topology, (b) specific speed patterns, (c) time and space varying communication conditions (e.g., signal transmissions can be blocked by buildings), (d) road-constrained mobility patterns, and (e) no significant power constraints.

VANETs have many possible applications, ranging from inter-vehicle communication and file sharing to obtaining real-time traffic information (such as jams and blocked streets). In this work we focus on traffic safety and efficient warning message dissemination, where 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 any 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].

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. In this paper we propose PAWDS, a *Profile-driven Adaptive Warning Dissemination System* 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.

The rest of the paper is organized as follows: Section II reviews the related work on the broadcast storm problem and adaptive schemes in VANETs. Section III justifies our scheme and presents the simulation environment. Section IV shows a classification of urban environments depending on their density of streets and junctions. Section V defines and tests our proposed profile-driven adaptive scheme (PAWDS). Finally, Section VI concludes this paper.

II. RELATED WORK

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.

A. Broadcast storm reduction techniques

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,

(a) (b) (c)

Fig. 1. Scenarios used in our simulations as street graphs in SUMO: (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).

these schemes are specifically designed for use in highway scenarios.

Finally, a stochastic broadcast scheme is proposed in [3] 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.

B. Adaptive mechanisms to enhance message dissemination

With respect to adaptive schemes for message dissemination in VANETs, not much research can be found in the literature. Mariyasagayam et al. [4] 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 [5] 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) [6], a reactive position-based routing protocol that estimates the vehicle density of the available paths to be taken to send a message, also accounting for the direction and speed of traveling nodes 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.

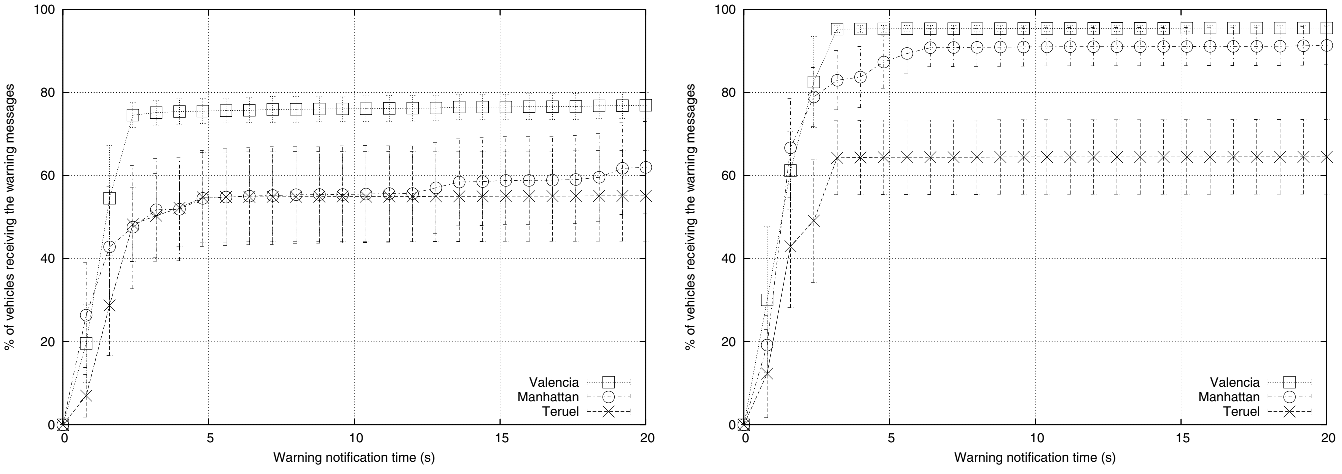
III. JUSTIFYING THE NEED FOR ANOTHER APPROACH

Since deploying and testing VANETs involves high cost and intensive labor, simulation is a useful alternative prior to actual implementation [7]. 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 [8]. 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 [9], 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. Simulation Environment

To test our experiments, simulations were done using the ns-2 simulator [10], which was modified to include the IEEE 802.11p [11] standard so as to follow the upcoming WAVE standard closely. In terms of the physical layer, the data rate used for message 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 [12], 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 [13], which employs a minimum distance under which



(a) (b)

Fig. 2. Warning notification time in different scenarios simulating (a) 100 vehicles (25 vehicles/km^2) and (b) 400 vehicles (100 vehicles/km^2).

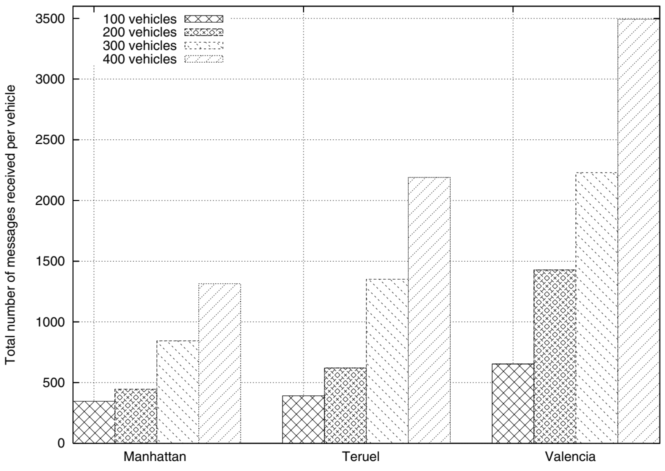


Fig. 3. Number of messages received per vehicle simulating different scenarios and vehicle densities.

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 messages 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 The Simulation of Urban MObility (SUMO) mobility generator [14], an open source traffic simulation package which can import maps directly from map databases such as OpenStreetMap [9] and TIGER [15]. In our simulations we use the Krauss mobility model [16] with some modifications to account for areas with different vehicle densities since, in a real town, traffic is not uniformly distributed [17]. Simulated vehicles move at a maximum speed of 23 $m/sec.$ ($\approx$ 83 km/h), and the size of warning messages and beacons is 256B and 512B, respectively. All results represent an average over several executions with different random scenarios, presenting all of them a maximum error of 10% with 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.

B. *Obtained results*

Figures 2 and 3 show the differences in both warning notification time (the time required by normal vehicles to receive a warning message) and messages received per vehicle (including beacons and warning messages) when varying the density of vehicles in these scenarios. All the simulations used the same base configuration: 2 seconds between messages, 200 meters for minimum rebroadcast distance, and the broadcast scheme used is 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 density of vehicles. In the other two scenarios, increasing the density of vehicles yields better performance in 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 Figure 3, 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 rebroadcasting. Thus, in these environments, the dissemination process should be tuned to use operation

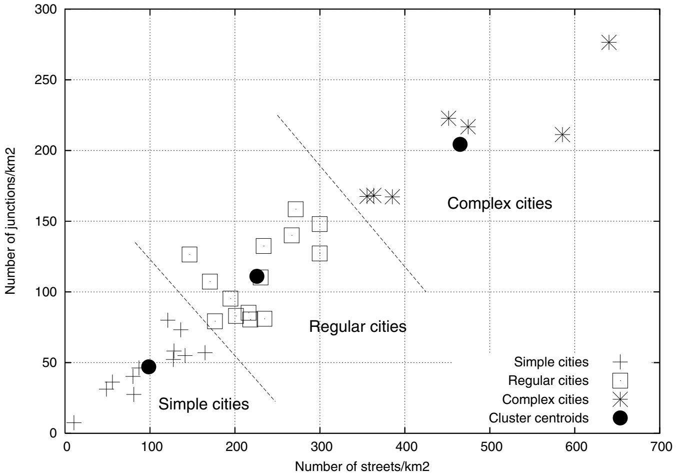


Fig. 4. Classification of different cities based on the density of streets and junctions.

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.

IV. CITY PROFILE CLASSIFICATION

Aiming at using the specific features of the scenarios to improve performance, maps from several existing cities have been tested to obtain a classification that allows warning dissemination to dynamically adapt its parameters based on the scenario type. The chosen area tries to represent the overall layout of the streets in each city, and is usually taken from the downtown. We selected cities from Europe (Berlin, London, Milan, Moscow, Paris, Rome, Seville, Teruel, Valencia), Asia (Beijing, Hong Kong, Istanbul, Kuala Lumpur, New Delhi, Seoul, Shanghai, Taipei, Tokio), North America (Boston, Chicago, Los Angeles, Manhattan, Mexico City, New York, San Francisco, Washington DC), South America (Buenos Aires, Montevideo, Rio de Janeiro), and Africa (Cape Town, Casablanca, El Cairo, Rabat).

Figure 4 shows the number of streets and junctions present in a 4 km^2 square area in these cities. As shown, the relationship between the number of streets and the number of junctions is almost linear, in an approximate ratio of 2 streets per junction. Since three different groups of cities can be distinguished in the figure, the well-known *k-means* clustering algorithm [18] was used with a number of clusters $k = 3$ to obtain a precise classification of the cities. By using the results of the clustering process in Figure 4, we can classify a new city according to the cluster whose centroid is the nearest (using the Euclidean distance as a measure). We can classify existing cities by their street profiles into:

- *Simple*: maps with low density of streets and junctions. Examples of these cities are Manhattan (USA), Moscow (Russia) and Seoul (South Korea).
- *Regular*: maps with medium density of streets and junctions. Some cities in this group are Teruel (Spain), Washington DC (USA) and Paris (France).
- *Complex*: maps with high density of streets and junctions. Cities which belong to this group are Valencia (Spain), Rome (Italy) and Tokio (Japan).

Table I summarizes the classification process of the studied cities, and shows the location of the centroid of the cluster assigned to each profile. It also shows the maximum vehicular density accepted in our simulations before the number of received messages grows excessively (see Figure 3), thereby provoking broadcast storm problems with the base configuration used in the previous section. Results show that the roadmap which serves as scenario for the warning dissemination has a considerable influence in the effectiveness of the process. Moreover, we can differentiate three groups of city profiles in which the propagation process is likely to behave in a similar way. This is the basis for our proposal, the *Profile-driven Adaptive Warning Dissemination Scheme* (PAWDS): the effectiveness of the alert dissemination can be increased if vehicles determine the city profile of their current area.

V. PROFILE-DRIVEN ADAPTIVE WARNING DISSEMINATION SYSTEM (PAWDS)

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, PAWDS 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 more restrictive dissemination schemes 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. This estimation is done in our system using the beacons interchanged periodically amongst 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 in the proximities.

Initial simulations showed that the values of three of the parameters of the dissemination process have a notable influence in both warning notification time and the number of messages received. These parameters are: (a) interval between consecutive messages, (b) broadcast scheme used and (c) minimum rebroadcast distance. If we vary their values, we can 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

TABLE I

MAP PROFILES CLASSIFICATION

Roadmap profile	**Street and junction density**	**Cluster centroid**		**Max. acceptable vehicle density**
		Streets	**Junctions**	
Simple	Low	98.50	47.06	75 veh./km^2
Regular	Medium	225.72	111.04	50 veh./km^2
Complex	High	465.14	204.32	25 veh./km^2

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 street map 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 II 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 diverse situations.

PAWDS is 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 provokes an excessive growth on the number of messages. Hence, the *Standard performance* is more suitable in this situation.

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.

Algorithm 1 summarizes the PAWDS algorithm, where the values of vehicle density are obtained from Table I, and T_r is the interval between reconfigurations of the system (30 seconds).

A. PAWDS performance testing

In this section we show the result of a wide set of experiments whose goal is to prove the effectiveness of our proposed PAWDS algorithm when disseminating warning messages. The proposed technique consists of determining the adequate selection of working modes in every possible situation. Figure 5 shows the warning notification time using the three configurations in diverse scenarios, and Figure 6 depicts the average number of messages received per vehicle.

Algorithm 1: PAWDS() pseudo-code

```
use standard performance mode
while (1) do
    obtain street-profile from the current map
    estimate vehicle-density from messages sent by neighbor vehicles
    if (street-profile is Simple) then
        if (vehicle-density $>$ 75 vehicles/km$^2$) then
            use standard performance mode
        else
            use full performance mode
    else if (street-profile is Regular) then
        if (vehicle-density $>$ 50 vehicles/km$^2$) then
            use standard performance mode
        else
            use full performance mode
    else if (street-profile is Complex) then
        if (vehicle-density $>$ 25 vehicles/km$^2$) then
            use reduced performance mode
        else
            use standard performance mode
    sleep($T_r$);
```

Focusing on Simple profile cities like Manhattan, the *Full performance* mode (used in the PAWDS 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 be indeed 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 notable reduction of notification time and blind vehicles,

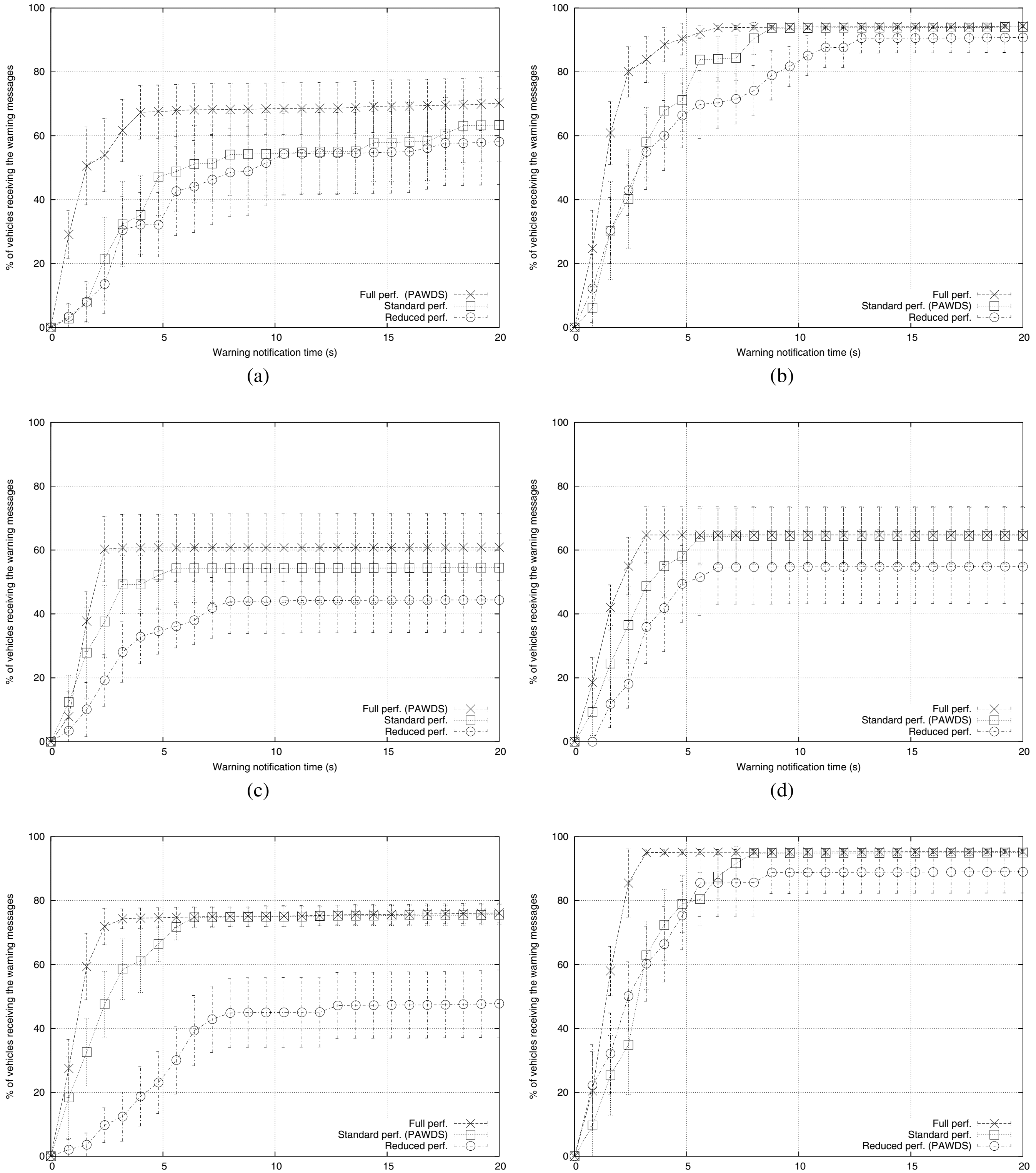
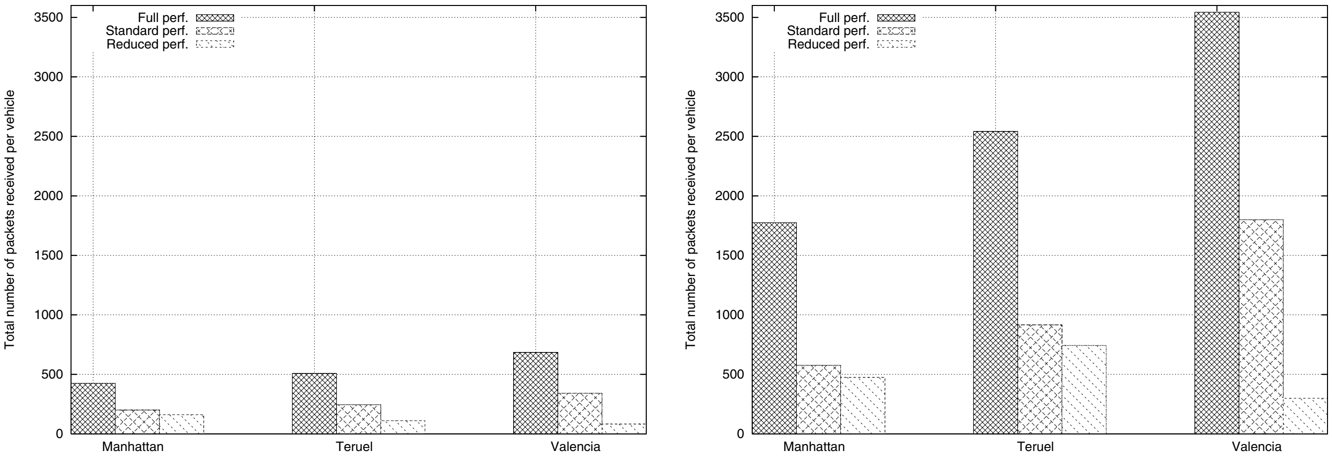


Fig. 5. Warning notification time with the different PAWDS working modes in different cities: Manhattan with (a) 100 and (b) 400 vehicles, Teruel with (c) 100 and (d) 400 vehicles, and Valencia with (e) 100 and (f) 400 vehicles.

TABLE II
PAWDS WORKING MODES

Working mode	**Interval between consec. messages**	**Broadcast scheme**	**Min. rebroadcast distance**
Full performance	2 seconds	Counter-based [1]	—
Standard performance	4 seconds	eSBR [13]	200 m.
Reduced performance	5 seconds	Distance-based [1]	250 m.



(a) (b)

Fig. 6. Number of messages received per vehicle with the different PAWDS working modes simulating (a) 100 and (b) 400 vehicles.

without requiring a big 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 and it is not suitable at all. 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 using the *Standard performance* mode, which is more balanced and more suitable for this situation. However, 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.

Table III summarizes the average results and presents the warning notification time (WNT) to inform at least 40% of the vehicles, the percentage of blind vehicles (BV) and the number of messages received (MR) per vehicle in the different studied situations. The most balanced configurations are highlighted, matching with the specific operation mode used in our proposed PAWDS.

VI. CONCLUSIONS

In this paper we introduced PAWDS, 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, PAWDS 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, thus three different working modes (*Full*, *Standard* and *Reduced* performance) were proposed to be selected depending on their efficiency in each situation.

The PAWDS 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

TABLE III

AVERAGE SIMULATION RESULTS AFTER 30 RUNS. THE WORKING MODES SELECTED BY PAWDS ARE IN BOLDFACE.

		Working Mode		
Map	**Veh. density**	Full perf.	Standard perf.	Reduced perf.
Manhattan (Simple profile)	Low (25 veh./km^2)	***WNT: 1.2 s*** ***BV: 29.8%*** ***MR: 424.97***	WNT: 4.32 s BV: 36.67% MR: 199.6	WNT: 5.4 s BV: 41.87% MR: 160.33
	High (100 veh./km^2)	WNT: 1.14 s BV: 5.59% MR: 1774.77	***WNT: 2.35 s*** ***BV: 5.87%*** ***MR: 576.33***	WNT: 2.31 s BV: 9.24% MR: 473.93
Teruel (Regular profile)	Low (25 veh./km^2)	***WNT: 1.68 s*** ***BV: 39.1%*** ***MR: 507.37***	WNT: 2.56 s BV: 45.53% MR: 244.9	WNT: 6.81 s BV: 55.63% MR: 110.53
	High (100 veh./km^2)	WNT: 1.53 s BV: 35.23% MR: 2540.47	***WNT: 2.63 s*** ***BV: 35.55%*** ***MR: 915.57***	WNT: 3.75 s BV: 45.17% MR: 742.53
Valencia (Complex profile)	Low (25 veh./km^2)	WNT: 1.11 s BV: 23.87% MR: 683.93	***WNT: 1.98 s*** ***BV: 24.4%*** ***MR: 341.87***	WNT: 6.55 s BV: 52.23% MR: 82.43
	High (100 veh./km^2)	WNT: 1.21 s BV: 4.63% MR: 3543.47	WNT: 2.54 s BV: 4.97% MR: 1799.07	***WNT: 1.95 s*** ***BV: 9.69%*** ***MR: 299.43***

without concentrating on reducing the number of messages involved in the process.

Simulation results show that reducing the interval between messages increases the convergence speed of the system, but it also notably rises the number of messages received per vehicle. Hence, as a future idea, we plan to modify our approach to adapt the time between messages depending on the time elapsed since the last dangerous situation was detected. This way, during the first few seconds after the detection, the system will work on full performance, and then the time interval should increase to reduce the amount of messages involved.

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