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Sanguesa, JA.; Fogue, M.; Garrido, P.; Martínez, FJ.; Cano Escribá, JC.; Tavares De Araujo Cesariny Calafate, CM. (2014). Topology-based broadcast schemes for urban scenarios targeting adverse density conditions. En 2014 IEEE Wireless Communications and Networking Conference (WCNC). IEEE. 2564-2569. doi:10.1109/WCNC.2014.6952786



The final publication is available at

<http://dx.doi.org/10.1109/WCNC.2014.6952786>

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# Novel Topology-based Broadcast Schemes for Hostile Urban Scenarios

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**Abstract**—Research works regarding vehicular communications usually obviate assessing the proposals in scenarios including adverse vehicle densities, despite such scenarios are quite common in real urban environments. In this paper, we study the effect of these hostile conditions on the performance of different schemes providing warning message dissemination. We then propose the *Junction Store and Forward (JSF)* and the *Nearest Junction Located (NJL)* schemes, which were specially designed to be used in very low and very high density scenarios, respectively. Simulation results using real maps demonstrate how our proposed schemes are able to outperform existing warning message dissemination schemes in urban environments under hostile vehicle density conditions.

**Index Terms**—Vehicular ad hoc networks, warning message dissemination, extreme density conditions, VANETs

## I. INTRODUCTION

Vehicular ad hoc Networks (VANETs) are wireless communication networks which support cooperative driving among vehicles on the road. Vehicles act as communication nodes and relays, forming dynamic vehicular networks together with other nearby vehicles [1].

The specific characteristics of VANETs favor the development of attractive and challenging services and applications, including road safety, traffic flow management, road status monitoring, environmental protection, and mobile infotainment [2]. In this work we focus on traffic safety and efficient warning message dissemination, where the main goal is to reduce the latency while increasing the accuracy of the information received by nearby vehicles when a dangerous situation occurs.

In a VANET, any vehicle detecting an abnormal situation on the road (i.e. accident, slippery road, etc.) starts notifying the anomaly to nearby vehicles to rapidly spread the information in a short period of time. Hence, broadcasting warning messages is of utmost importance to alert nearby vehicles. However, this dissemination is strongly affected by: (i) the signal attenuation due to the distance between the sender and receiver (especially in low vehicular density areas), (ii) the effect of obstacles in signal transmission (very usual in urban areas, e.g., due to buildings), and (iii) the instantaneous vehicle density. Regarding (i) and (ii), the topology of the roadmap is an important factor that affects the average distance between the sender and the receiver, as well as the different obstacles present in the scenario. As for (iii), the warning

message propagation scheme should be aware of the vehicle density, since lower densities can provoke message losses due to reduced communication capabilities, whereas higher densities can provoke a reduced message delivery effectiveness due to serious redundancy, contention, and massive packet collisions caused by simultaneous forwarding, usually known as broadcast storm [3].

In this paper, we study the performance of typical broadcast dissemination schemes under hostile density conditions, i.e., vehicle densities far from the average values in vehicular environments and especially adverse for message dissemination. Based on this analysis, we propose the *Junction Store and Forward (JSF)* and the *Nearest Junction Located (NJL)*, our two novel dissemination schemes to be used under low and high density conditions, respectively. Our main goal is to maximize the message delivery effectiveness, something difficult to achieve, especially in adverse conditions.

The paper is organized as follows: in Section II we review existing dissemination schemes related to our proposal. In Section III we introduce our proposed schemes, i.e., the JSF, and the NJL approaches. Section IV shows the simulation environment used to validate our proposal. Section V presents and discusses the obtained results. Finally, Section VI concludes this paper.

## II. EXISTING DISSEMINATION SCHEMES FOR EXTREME DENSITY CONDITIONS

Current research on vehicular networks usually focuses on analyzing scenarios representing common situations with average densities. However, situations with very low or very high vehicle densities are often ignored, whereas they are very common in real vehicular environments. For example, outskirts or suburban areas usually present density values below 25 vehicles/km<sup>2</sup>, whereas traffic jams that appear in large cities present densities above 300 vehicles/km<sup>2</sup>. We consider these scenarios as hostile conditions for vehicular networks, since they are really adverse for the correct communication between vehicles.

In this paper we analyze the performance of existing broadcast schemes for VANETs under adverse density conditions, accounting for both low and high vehicle densities. We then propose new dissemination schemes especially suitable for these situations.

### A. Low Density Conditions

Vehicular scenarios presenting very low vehicle densities are frequently found, especially in residential, rural, and outskirts traffic areas. The main goal when developing an emergency message dissemination system is to inform as many vehicles as possible in the shortest time. In these situations, the relative importance of the number of messages received per vehicle is lower, since the number of vehicles is reduced and the probability of overloading the channel is minimal. Suitable schemes for these situations should focus on forwarding warning messages even when the probability of informing new vehicles is low. Schemes that can be used under these conditions are the following:

- *Flooding*. This strategy is the simplest broadcast scheme, in which vehicles blindly rebroadcast every message they receive without applying additional control mechanisms. In low density scenarios where the probability of broadcast storms is reduced, flooding represents a good candidate scheme.
- The *Counter-based scheme* [3]. Initially proposed for Mobile Ad Hoc Networks (MANETs), this scheme aims at mitigating broadcast storms by using a threshold  $C$  and a counter  $c$  to keep track of the number of times a broadcast message is received. Whenever  $c \geq C$ , rebroadcast is inhibited.
- The *enhanced Street Broadcast Reduction (eSBR)* [4]. This scheme is specially designed to be used in VANETs, taking advantage of the information provided by maps and built-in positioning systems, such as the GPS. Vehicles are only allowed to rebroadcast messages if they are located far from their source, or if the vehicles are located in different streets, giving access to new areas of the scenario. The eSBR scheme uses information about the roadmap to avoid blind areas due to the presence of urban structures blocking the radio signal.

### B. High Density Conditions

Another typical hostile scenario occurs when the vehicle density is enough to produce traffic jams, or considerably reduce the speed of vehicles. This effect leads to an increase of the number of vehicles sending warning messages and beacons in a specific area, generating a likely scenario for channel contention and message collisions. These situations require more restrictive dissemination schemes that allow reducing the number of messages sent in order to mitigate broadcast storms. Among these schemes we highlight the following:

- The *Distance-based scheme* [3]. This scheme accounts for the relative distance  $d$  between vehicles to decide whether to rebroadcast or not. When the distance  $d$  between two vehicles is short, the additional coverage area of the new rebroadcast is low, and so rebroadcasting the warning message is not recommended. Forwarding is only beneficial when the additional coverage is significant.
- The *enhanced Message Dissemination for Roadmaps (eMDR)* [5]. As an improvement to the eSBR scheme,

eMDR increases the efficiency of the system by avoiding multiple forwardings of the same message if nearby vehicles are located in different streets. Specifically, vehicles use the information about the junctions of the roadmap, and only the vehicle closest to the geographic center of the junction, according to the ge positioning system, is allowed to forward the messages received. This strategy aims at reducing the number of broadcasted messages while maintaining a high percentage of vehicles informed.

## III. NOVEL SCHEMES PROPOSED

Due to the lack of dissemination schemes specifically designed for hostile density conditions, in this work we propose two different approaches suitable for each adverse situation. The main objective is to achieve the highest percentage of informed vehicles in the shortest time possible. On the one hand, in environments with low vehicle densities, frequent network partitioning is a huge problem causing message losses and misinformation. On the other hand, in environments with high vehicle densities, the number of messages in the channel is a problem since they can provoke the well-known broadcast storm problem.

### A. Junction Store and Forward Scheme

After receiving a new warning message, the formerly presented dissemination algorithms only decide whether to rebroadcast a message or not depending on the conditions of the vehicle with respect to its surroundings. However, instead of simply forwarding a message when it is received, it might be beneficial to store it until an optimal situation is found. Using this premise, we developed the *Junction Store and Forward (JSF)* scheme. Since vehicles located near junctions have a higher probability of reaching new vehicles within line-of-sight, the JSF scheme is designed to exploit the road topology by considering that vehicles in junctions are in an optimal position to rebroadcast warning messages.

The operation of the JSF scheme is summarized in the flowchart shown in Figure 1. This scheme requires the presence of a neighbor list in each vehicle, built using the one-hop *beacons* periodically interchanged by the vehicles with information about their position and speed. After the reception of a new warning message, the vehicle checks the presence of additional neighbors apart from the sender of the message, hence avoiding sending useless messages in case there are no additional neighbors. A timer is used to dispose old stored messages. Once the message is stored, the vehicle uses the location provided by the integrated GPS system to determine if the vehicle is near a junction.

Vehicles using JSF upon reaching a new junction forward the stored message a finite number of times ( $N$ ); the latter value is determined by the value of a counter updated whenever a new junction is reached. In our simulations, we considered three different JSF configurations:

- JSF-1: the message is only rebroadcasted within the first junction.

TABLE I  
PERFORMANCE OF THE JSF VARIATIONS UNDER LOW DENSITY CONDITIONS

| Density                     | JSF-1     |                   |            | JSF-3     |                   |            | JSF-U     |                   |            |
|-----------------------------|-----------|-------------------|------------|-----------|-------------------|------------|-----------|-------------------|------------|
|                             | % Inform. | Notif. time (60%) | Mess./veh. | % Inform. | Notif. time (60%) | Mess./veh. | % Inform. | Notif. time (60%) | Mess./veh. |
| 10 vehicles/km <sup>2</sup> | 47.2%     | -                 | 17.2       | 48.4%     | -                 | 17.6       | 46.2%     | 111 s             | 22.6       |
| 20 vehicles/km <sup>2</sup> | 61.1%     | 105 s             | 57.1       | 64.8%     | 69 s              | 59.5       | 80.4%     | 43 s              | 72.8       |
| 30 vehicles/km <sup>2</sup> | 83.6%     | 41 s              | 129.0      | 85.7%     | 35 s              | 135.6      | 91.8%     | 29 s              | 158.4      |

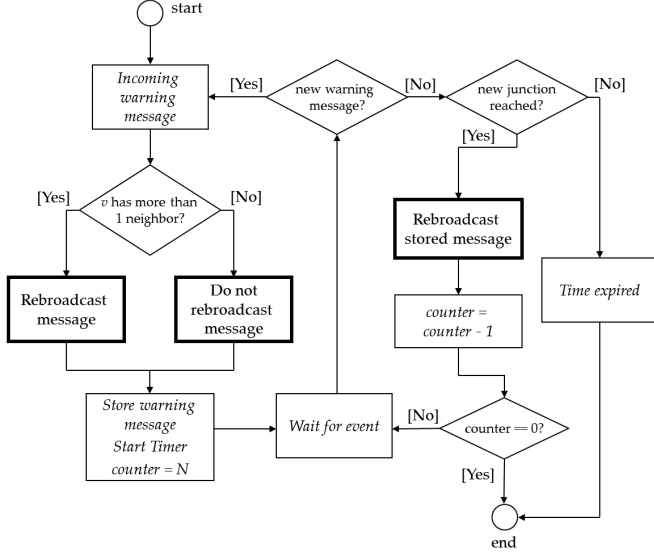


Fig. 1. JSF dissemination scheme working flowchart.

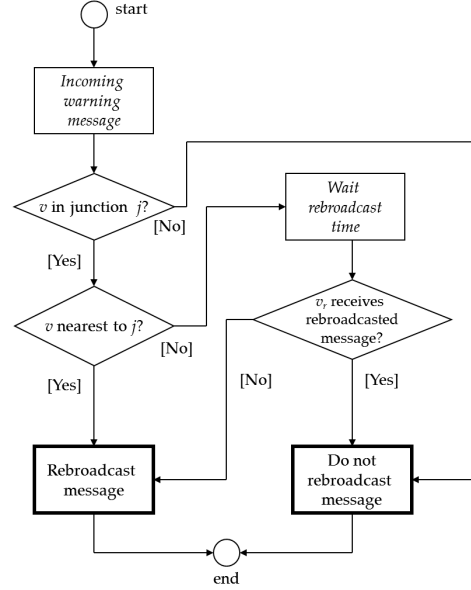


Fig. 2. NJL scheme working flowchart.

- JSF-3: the vehicle rebroadcasts the message in the next three junctions after the message arrival.
- JSF-Unlimited (JSF-U): Junction Store and Forward without limitations, the vehicle rebroadcasts the message every time it arrives at a new junction until the message timer expires.

Table I shows the preliminary results obtained when using the low density simulation environment presented in Section IV, comparing the variations of our JSF scheme. We observe that the differences in the number of messages received per vehicle are minimal, whereas JSF-U is able to increase the percentage of vehicles receiving warning messages and reduce the time required to inform 60% of the vehicles in the scenario. Hence, this variant is the most effective one in low density scenarios, and we will use the term JSF to refer to the JSF-U variant in the rest of the paper.

### B. Nearest Junction Located

Some dissemination schemes, such as the eMDR, have proved to be effective at reducing broadcast storms in typical urban environments. However, the number of messages produced may become excessive in scenarios with high vehicle densities. On the other side, the distance-based scheme offers a reduced number of messages but does not achieve optimal results in terms of informed vehicles in most scenarios. In addition, Store and Forward schemes are not usually necessary, due to the lower frequency of partitions in highly congested networks [5].

To cope with these deficiencies, we propose a dissemination scheme called *Nearest Junction Located* (NJL) that, unlike existing approaches, is completely based on the topology of the roadmap where the vehicles are located, allowing vehicles to rebroadcast a message only if they are the nearest vehicle to the geographical coordinates of any junction obtained from the integrated maps. This scheme also requires maintaining a neighbor list in each of the vehicles that allows determining the relative position of the surrounding vehicles.

The NJL follows a procedure similar to the eMDR algorithm, although ignoring the distance between sender and receiver; thus, it only focuses on the location of the receiving vehicle. Figure 2 shows the working flowchart of NJL. Whenever a vehicle receives a warning message, it checks the position of its neighbors to determine whether it is the nearest to any junction of the road layout. The scheme includes a security mechanism to avoid malfunction due to the radio interface or GPS errors, waiting for a rebroadcast backoff time before forwarding the message when ever a better positioned vehicle is expected (right side part of the flow chart).

Although the performance of this approach is not optimal in sparse environments, since it is very restrictive, it performs efficiently in high density scenarios where the dominant factor to improve the dissemination process is the position of the vehicles, achieving results similar to those obtained by the eMDR, while requiring only a fraction of the messages.



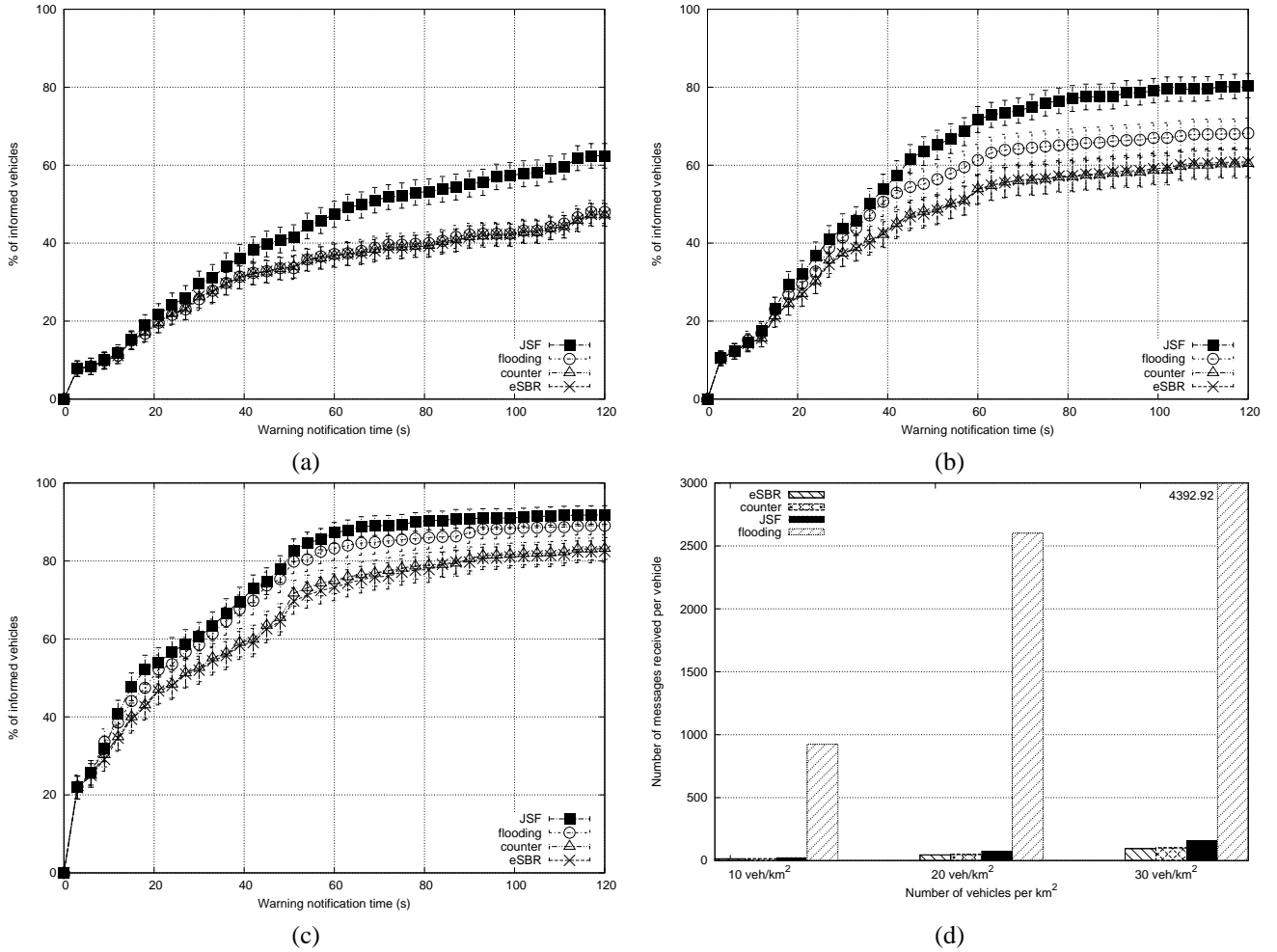


Fig. 4. Percentage of informed vehicles in Valencia with: (a) 10, (b) 20, (c) 30 vehicles/km<sup>2</sup>, and (d) number of messages received per vehicle.

TABLE III  
AVERAGE TIME NECESSARY TO INFORM 60% OF THE VEHICLES

| Density                 | JSF   | Counter         | eSBR            | Flooding      |
|-------------------------|-------|-----------------|-----------------|---------------|
| 10 veh./km <sup>2</sup> | 111 s | -               | -               | -             |
| 20 veh./km <sup>2</sup> | 43 s  | 108 s (+151.2%) | 105 s (+144.2%) | 58 s (+34.9%) |
| 30 veh./km <sup>2</sup> | 29 s  | 43 s (+48.3%)   | 43 s (+48.3%)   | 32 s (+10.3%) |

JSF, in spite of the low differences in terms of number of messages received per vehicle.

Finally, it is noticeable how our JSF scheme is able to outperform the flooding scheme concerning percentage of informed vehicles, while drastically reducing the number of messages received per vehicle. Hence, using Store and Forward strategies and exploiting the topology of the roadmap allow achieving better performance compared to existing dissemination schemes.

### B. NJL Evaluation in High Vehicle Density Scenarios

Figure 5 shows the results obtained in Valencia when simulating very high vehicle densities, i.e., 300, 400, and 500 vehicles/km<sup>2</sup>. As shown, the distance-based scheme offers a poor performance in terms of percentage of informed vehicles when compared to both NJL and eMDR. Hence, it is not

suitable to be used in highly congested urban scenarios. Note that the NJL and the eMDR schemes basically present the same results in terms of notification time and percentage of informed vehicles, whereas the number of messages received per vehicle when using the NJL scheme is reduced up to 30% compared to eMDR, therefore making NJL the most suitable dissemination scheme in this kind of scenarios.

## VI. CONCLUSIONS

In this paper we studied the performance of different warning message dissemination schemes for VANETs under adverse situations classified as hostile due to the very low or very high density of vehicles in the scenario. We also proposed two dissemination approaches especially designed for these situations: the *Junction Store and Forward* (JSF) scheme for very low vehicle densities, and the *Nearest Junction Located* (NJL) scheme for very high vehicle densities.

Simulation results showed that the proposed schemes outperform the existing dissemination algorithms. The variant of the JSF algorithm that sends messages in an unlimited number of junctions provided better results than other versions that limit the number of junctions. Comparing its performance with the counter-based and eMDR schemes, JSF allowed

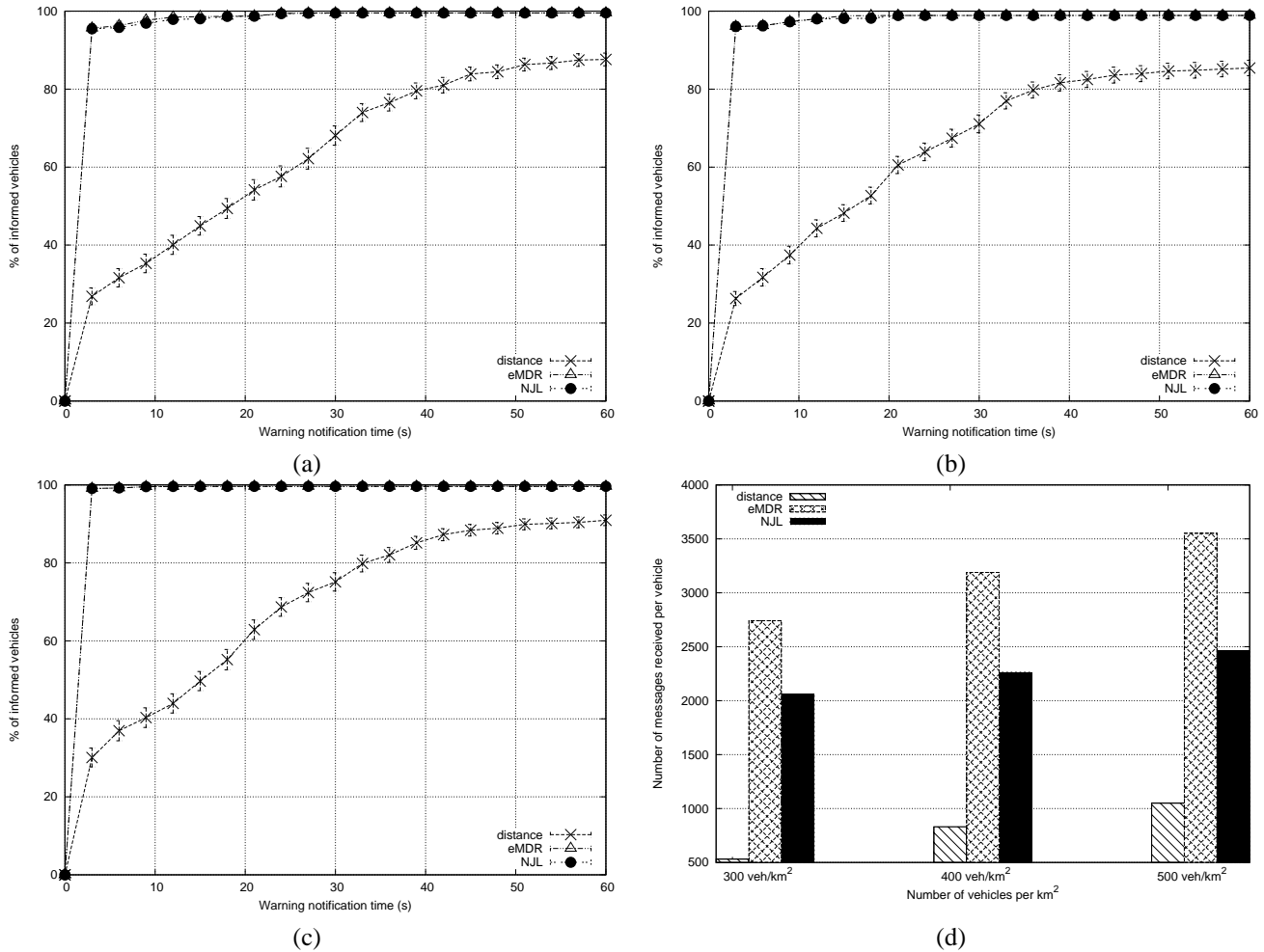


Fig. 5. Percentage of informed vehicles in Valencia for: (a) 300, (b) 400, (c) 500 vehicles/km<sup>2</sup>, and (d) number of messages received per vehicle.

reducing the warning notification time up to 40% in low density scenarios. Under high density conditions, NJL proved to be the most efficient of the tested schemes, informing almost the same percentage of vehicles, while reducing the number of messages up to 30% when compared to eMDR.

## VII. ACKNOWLEDGMENTS

This work was partially supported by the *Ministerio de Ciencia e Innovación*, Spain, under Grant TIN2011-27543-C03-01, as well as by the *Fundación Universitaria Antonio Gargallo* and the *Obra Social de Ibercaja*, under Grant 2013/B010.

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