Actas de las XXIV Jornadas de Paralelismo, Madrid (Madrid), 17-20 Septiembre 2013

Broadcast Schemes for Disseminating Safety Messages in VANETs

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Abstract—**In Vehicular ad hoc Networks (VANETs), the efficient dissemination of messages is a key factor to speed up the development of useful services and applications. In this paper, we present the Optimal Broadcast Selection algorithm, a novel proposal that automatically chooses the best broadcast scheme trying to fit the warning message delivery policy to the current characteristics of each specific vehicular scenario. Our mechanism uses as input parameters the vehicular density and the topological characteristics of the environment where the vehicles are located, in order to decide which dissemination scheme to use. Simulation results demonstrate the feasibility of our approach, which is able to support more efficient warning message dissemination in vehicular environments.**

Keywords— **Vehicular ad hoc networks, warning message dissemination, adaptive systems.**

I. Introduction

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

In a VANET, any vehicle detecting an abnormal situation (e.g., accident, slippery road, etc.) rapidly starts notifying the anomaly to nearby vehicles to spread the alert information in a short period of time. Thus, broadcasting warning messages can be useful 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) a reduced message delivery effectiveness due to serious redundancy, contention, and massive packet collisions provoked by simultaneous forwarding, usually known as broadcast storm (prone to occur in highly congested areas) [9]. Therefore, knowing the density of vehicles and the characteristics of the area where the vehicles are moving (e.g., in terms of topological complexity) in a vehicular communications environment is important, as better opportunities for message delivery can show up.

In this paper, we propose an adaptive algorithm that automatically chooses the best dissemination scheme to adapt the warning message delivery policy to each specific scenario. Our mechanism uses as input parameters the vehicular density and the topological characteristics of the environment where the vehicles are located, using them to decide which dissemination scheme to use. The main goal is to maximize the message delivery effectiveness while generating a reduced number of messages and, thus, avoiding or mitigating broadcast storms. In addition, we also propose the Nearest Junction Located (NJL), our novel warning message dissemination scheme specially designed for being used in highly congested urban areas.

The paper is organized as follows: in Section II we introduce our novel NJL scheme, and the optimal broadcast selection algorithm. Section III shows the simulation environment used to validate our proposal. Section IV presents and discusses the obtained results. In Section V we review previous works closely related to our proposal. Finally, Section VI concludes this paper.

II. Selecting the Optimal Broadcast Scheme in VANETs

Over the years, several dissemination schemes have been proposed to address the broadcast storm problem in vehicular networks. Some of the most representative ones are presented in detail below.

A. Broadcast Schemes

- The *Counter-based scheme* [9]. 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 *Distance-based scheme* [9]. 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 (AC) area of the new rebroadcast is lower, and so rebroadcasting the warning message is not recommended.
- 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 ($> d_{min}$), or

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if the vehicles are located in different streets, giving access to new areas of the scenario.

- The *enhanced Message Dissemination for Roadmaps* (eMDR) [2]. 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 geopositioning system, is allowed to forward the messages received.

B. Nearest Junction Located: our Novel Broadcast Scheme

The eMDR and eSBR schemes proved to be specially effective in sparse urban environments. However, the number of messages produced may become excessive in scenarios with a high vehicle density. To cope with this deficiency, in this paper we proposed a novel dissemination scheme called *Nearest Junction Located* (NJL) that is completely based on the topology of the roadmap, 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. Although the performance of this algorithm is not optimal in sparse environments, it performs quite well 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 and eSBR schemes, while requiring only a fraction of the messages.

C. Optimal Broadcast Selection Algorithm

During a warning message dissemination process, the most important objective to accomplish consists on informing the highest possible number of vehicles in the shortest time. Hence, a critical metric to be used is the percentage of informed vehicles at different time instants (Inf_T). We propose to measure the percentage of vehicles receiving warning messages after 10, 30, and 120 seconds since the time when the dangerous situation started being notified, providing information about both the speed and completeness of the dissemination process. The first 10 seconds provide a good reference of the dissemination speed, the second period (30 seconds) offers a balance between dissemination speed and the completeness, and the state of the scenario after 120 seconds shows the stationary value when no evolution is observed.

These three values were combined using a weighted average, thereby obtaining a single value representing the efficiency of the dissemination process (P_{inf}). In our results, the weights applied to the values collected during the different time intervals are 0.5 (10 seconds), 0.3 (30 seconds), and 0.2 (120 seconds), respectively, since the stationary values of the different broadcast schemes do not tend to vary significantly, and the most noticeable differences occur during the first seconds of the process.

Another important metric for the dissemination schemes is the number of messages produced (M_{recv}). If the wireless channel is saturated with packets, the high contention and the occurrence of collisions will reduce the performance of the process, producing broadcast storms. Thus, the number of messages must remain as low as possible without compromising the efficiency of the dissemination.

Our Optimal Broadcast Selection Algorithm makes use of these two metrics (P_{inf} and M_{recv}) to select the scheme to be used on each particular situation. Specifically, it works following a three step process, as shown in Algorithm 1:

- *Step 1*: For each considered broadcast scheme, the first metric (P_{inf}) is computed, and the schemes with the highest percentage of informed vehicles are selected. Due to the importance of this metric, only the dissemination schemes with a deviation lower than 10% with respect to the best one are considered for the second step of the algorithm, and they are stored in set $\mathbb{C}$.
- *Step 2*: Considering only the broadcast schemes in $\mathbb{C}$, the scheme producing the lowest number of messages received per vehicle (M_{recv}) is obtained, in order to reduce the probability of broadcast storms, and the percentage variation with respect to this value is computed for each scheme.
- *Step 3*: The optimal scheme will be selected as the one minimizing the deviation with respect to both the maximal P_{inf} and the minimal M_{recv}. Depending on the vehicle density, it may become more important to minimize the number of messages for high densities, and in that case our algorithm varies the degree of importance of the two metrics by using the K value, calculated as follows:

$$K = \frac{100}{density\ of\ vehicles} \tag{1}$$

In particular, we used the value of reference 100 to compute K, since our experiments showed that the differences in terms of informed vehicles decrease noticeably for densities above 100 vehicles/km^2 (see Figure 1), and, hence, a higher weight is assigned to the number of messages received when this density is exceeded.

III. SIMULATION ENVIRONMENT

Our optimal broadcast selection algorithm was tested using the ns-2 simulator, modified to consider the IEEE 802.11p standard[1]. In terms of the physical layer, the data rate used for packet broadcasting is 6 Mbit/s, as this is the maximum rate for broadcasting in 802.11p.

The simulator was also modified to make use of our *Real Attenuation and Visibility* (RAV) scheme

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[1] All these improvements and modifications are available in http://www.grc.upv.es/software/

Algorithm 1: Optimal Broadcast Selection

```
input  : $\mathbb{B}$: set of broadcast schemes
input  : $Inf_{10}(b), Inf_{30}(b), Inf_{120}(b)$: percentage of
         informed nodes after 10, 30, and 120 seconds
input  : $M_{recv}(b)$: number of messages received per
         vehicle
output : $Optimal_{bcast}$: optimal scheme in terms of
         informed vehicles and messages received

/* Step 1:  Maximize percentage of informed vehicles   */
forall $b \in \mathbb{B}$ do
    $P_{inf}(b) = Inf_{10}(b) \cdot 0.5 + Inf_{30}(b) \cdot 0.3 + Inf_{120}(b) \cdot 0.2$;
$max_{inf} = max(P_{inf}(b)) \ \forall \ b \ \in \mathbb{B}$
$\mathbb{C} = \{\}$
forall $b \in \mathbb{B}$ do
    if $(max_{inf} - P_{inf}(b)) < 10\%$ then $\mathbb{C} = \mathbb{C} \cup \{\mathrm{b}\}$
/* Step 2:  Minimize received messages                 */
$min_{recv} = min(M_{recv}(b)) \ \forall \ b \ \in \mathbb{C}$
forall $b \in \mathbb{C}$ do
    $dev_{inf}(b) = max_{inf} - P_{inf}(b)$
    $dev_{recv}(b) = \frac{M_{recv}(b) - min_{recv}}{min_{recv}}$
/* Step 3:  Selection of the optimal broadcast scheme  */
$Optimal_{bcast} = \arg\min_{b \in \mathbb{C}} (dev_{inf}(b) \cdot K + dev_{recv}(b)) \ \forall \ b \ \in \mathbb{B}$
```

TABLE I

Parameter settings in the simulations.

Parameter	Value
roadmaps	Rome, Valencia, Sydney, Amsterdam, Los Angeles, San Francisco, Madrid
number of vehicles per km^2	$[25, 50, 100, 150, 200, 250]$
number of collided vehicles	3
roadmap size	$2000m \times 2000m$
warning message size	$256B$
beacon message size	$512B$
interval between messages	1 second
MAC/PHY	802.11p
radio propagation model	*RAV* [5]
mobility model	*Krauss* [3]
channel bandwidth	$6Mbps$
max. transmission range	$400m$
d_{min} (used in distance-based, eSBR, and eMDR schemes)	$200m$

TABLE II

Map features.

Map	Streets	Junctions	SJ Ratio
Rome	1655	1193	1.387
Valencia	2829	2233	1.267
Sydney	872	814	1.071
Amsterdam	1494	1449	1.031
Los Angeles	287	306	0.938
San Francisco	725	818	0.886
Madrid	628	715	0.878

TABLE III

Simulation Results in San Francisco after 120 seconds.

	25 veh./km^2		250 veh./km^2	
	% inform.	mess./veh.	% inform.	mess./veh.
eSBR	89.9%	345	99.9%	4661
eMDR	89.5%	301	99.9%	4275
NJL	83.9%	174	99.9%	2184

[5], which proved to increase the level of realism in VANET simulations using real urban roadmaps in the presence of obstacles. As for vehicular mobility, it has been obtained with CityMob for Roadmaps (C4R) [1], a mobility generator able to import maps directly from OpenStreetMaps, and make them available for being used by the ns-2 simulator. All the results represent an average of over 50 repetitions with different random scenarios, obtaining for all of them a degree of confidence of 90%; each simulation run lasted for 120 seconds. Table I shows the parameters used for the simulations.

The roadmaps used in the simulations were selected in order to have different profile scenarios (i.e., with different topology characteristics). Table II shows the main features of the cities simulated. Note that we added a column labeled as *SJ Ratio*, which represents the result of dividing the number of streets between the number of junctions.

IV. Simulation Results

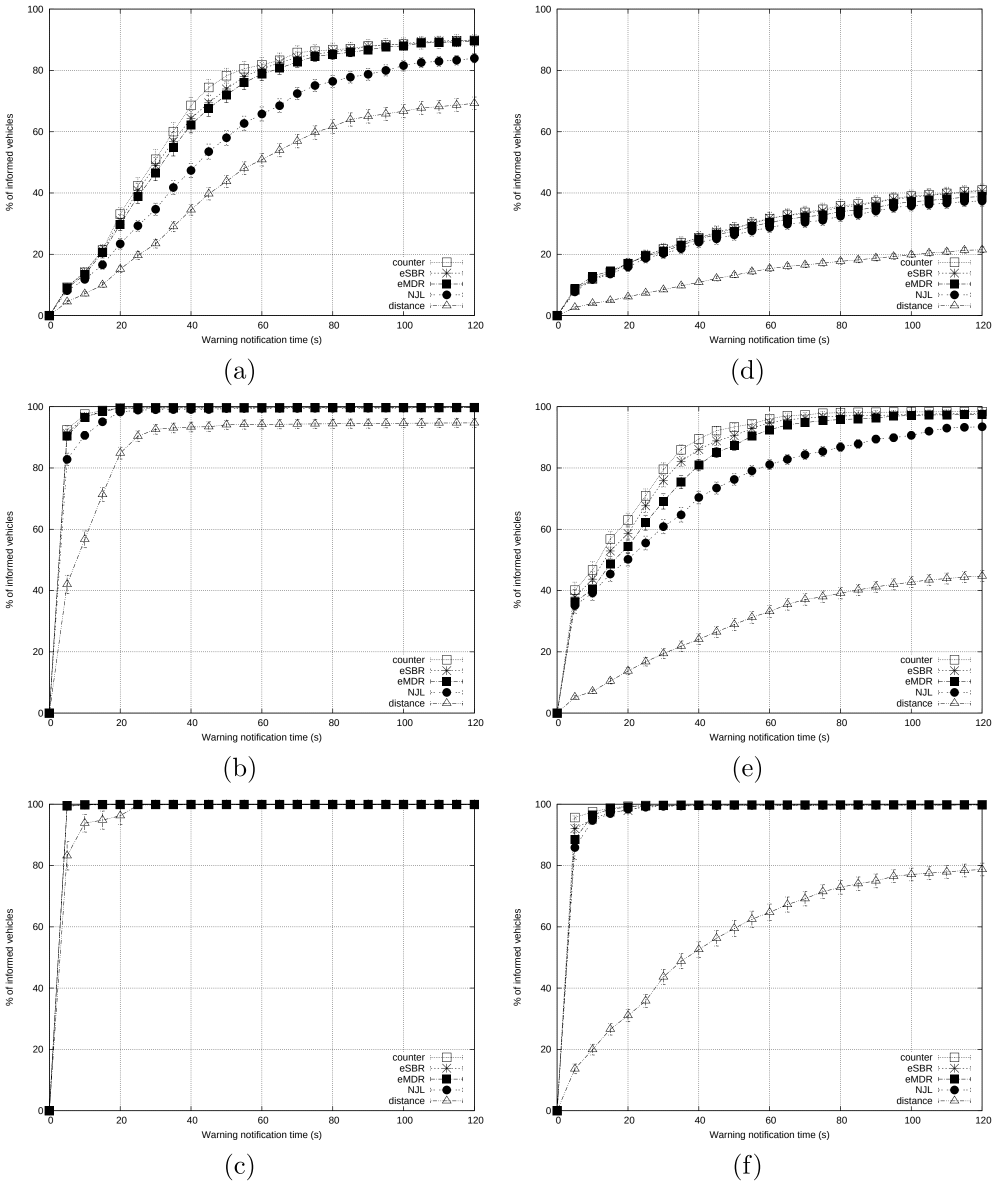
In this work we performed a total of 10,500 experiments. Due to space restrictions, it is not possible to present the results of all of the cities simulated, so in some cases we only included the results obtained for San Francisco and Valencia since, according to our previous work [6], the simulation results obtained in these roadmaps are closer to the average ones.

Tables III and IV compare the simulation results after 120 seconds in two different maps (San Francisco and Valencia). The values of the *percentage of informed vehicles* and the *number of messages received per vehicle* are shown. As can be seen, the NJL scheme allows informing about 3-6% less vehicles under low densities (25 veh./km^2) in both maps, but the percentage of informed vehicles when the vehicle density is high is the same. However, the number of messages received per vehicle is reduced by half in all the scenarios tested using the NJL scheme. This makes the NJL scheme specially suitable for scenarios with a high density of vehicles where broadcast storms are prone to occur.

A. Comparison in Terms of Percentage of Informed Vehicles

Figure 1 presents the evolution of the dissemination process in terms of notified vehicles for the maps of San Francisco and Valencia under three different vehicle densities: 25, 100, and 250 vehicles/km^2. It is noticeable how the topology of the area and the number of vehicles are determinant factors affecting the performance of the broadcast scheme. The dissemination process develops faster in every situation when the vehicle density increases. For sparse networks, the counter-based scheme provides the best results in terms of informed vehicles, whereas for densities above 150 vehicles/km^2, the process presents a very similar behavior for all the selected schemes. The exception is the distance-based scheme in the map of Valencia, which proved to be very inefficient due to the high amount of obstacles interfering with the radio signal.

In addition, we corroborated that simple and regular city profiles like San Francisco allow an easier propagation of the radio signal, increasing the number of informed vehicles at a given time. The most restrictive schemes, such as the NJL, require a very high density of vehicles to achieve an efficiency similar to other dissemination schemes.



(a) (d)

(b) (e)

(c) (f)

Fig. 1. Percentage of informed vehicles in San Francisco for: (a) 25, (b) 100, and (c) 250 vehicles/km^2, as well as in Valencia for: (d) 25, (e) 100, and (f) 250 vehicles/km^2.

TABLE IV

Simulation Results in Valencia after 120 seconds.

	25 veh./km^2		**250 veh./km^2**	
	% inform.	mess./veh.	% inform.	mess./veh.
eSBR	40.6%	55	99.7%	3360
eMDR	38.8%	48	99.7%	2451
NJL	37.4%	41	99.7%	1521

B. *Comparison in Terms of Messages Received per Vehicle*

The number of messages produced by a given dissemination scheme may become very important in VANETs due to the high number messages sent and received by the vehicles involved. This could increase channel contention and the frequency of collisions.

Figure 2 shows the number of messages received per vehicle in two of the maps under study. As shown, the selected dissemination scheme presents a determinant influence over the amount of messages produced; some of them produce only a fraction of the messages required by other schemes. In general, the counter-based scheme produces the highest number of messages, whereas the distance-based is the most restrictive one. The NJL scheme produces the smallest amount of messages of all the schemes which used the information topology of the map to select the forwarding nodes. Again, the features of the map are determinant for the performance of the system. Simple maps allow a faster dissemination at the cost of noticeably increasing the number of messages received per vehicle, thereby increasing the probability of broadcast storms. Thus, more restrictive schemes are recommended for this kind of roadmaps.

C. *Optimal Broadcast Scheme Selection*

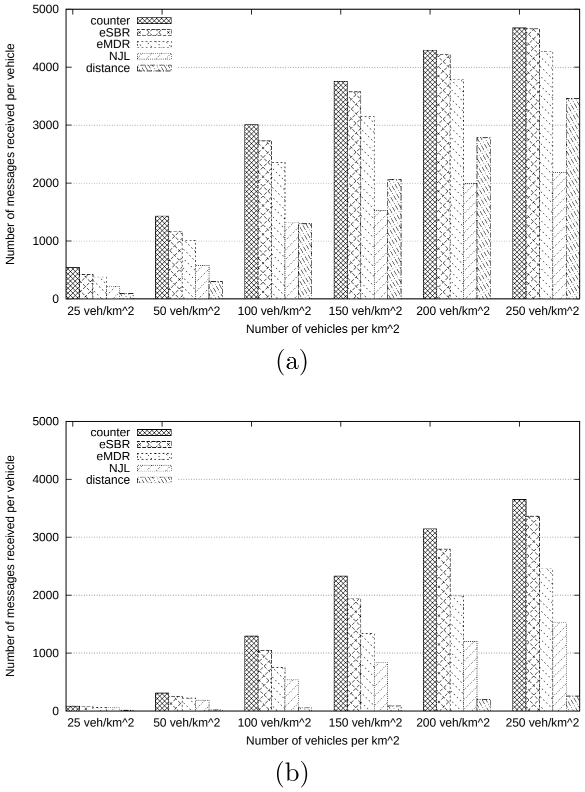
Table V contains an example of the performance of our broadcast scheme selection algorithm presented in Section II-C. Specifically, it shows the results obtained for Valencia when simulating 100 vehicles/km^2. All the values are obtained as the average of 50 repetitions for each configuration. It is noticeable how only three of the available schemes

TABLE V
SIMULATION RESULTS FOR 100 VEHICLES/KM^2 IN VALENCIA.

Broadcast	Inf_{10}	Inf_{30}	Inf_{120}	P_{inf}	dev_{inf}	$\mathbb{C}$ (Step 1)	M_{recv}	dev_{recv} (Step 2)	dev_{Tot}	**Optimal** (Step 3)
Counter	46.6%	79.5%	98.3%	66.81%	**0%**	✔	1196	**77.9%**	**75.55%**	✘
Distance	7.10%	19.4%	44.7%	18.31%	**72.59%**	✘	-	-	-	-
eSBR	43.7%	75.8%	97.7%	64.13%	**4.01%**	✔	940	**39.87%**	**43.89%**	✘
eMDR	40.4%	69%	97.4%	60.38%	**9.62%**	✔	672	**0%**	**9.62%**	✔
NJL	39.2%	60.8%	93.4%	56.52%	**15.4%**	✘	-	-	-	-

TABLE VI
BROADCAST SCHEME SELECTED ACCORDING TO OUR OPTIMAL BROADCAST SELECTION ALGORITHM.

City	**SJ Ratio**	**Vehicle Density (veh./km^2)**					
		25	50	100	150	200	250
Rome	1.387	eSBR	eSBR	eSBR	eSBR	NJL	NJL
Valencia	1.267	eMDR	eMDR	eMDR	eMDR	NJL	NJL
Sydney	1.071	eMDR	eMDR	eMDR	NJL	NJL	NJL
Amsterdam	1.031	eMDR	eMDR	NJL	NJL	NJL	NJL
Los Angeles	0.938	eMDR	eMDR	NJL	NJL	NJL	NJL
San Francisco	0.886	eMDR	eMDR	NJL	NJL	NJL	NJL
Madrid	0.878	Counter	eMDR	NJL	NJL	NJL	NJL



(a)

(b)

Fig. 2. Number of messages received per vehicle when varying the broadcast scheme and the vehicular density in: (a) San Francisco and (b) Valencia.

are considered after the first step of the algorithm: i.e., the counter-based, the eSBR, and the eMDR broadcast schemes. Since the eMDR produces the lowest number of messages while maintaining a high percentage of informed vehicles in a small time period, our algorithm considers it as the optimal broadcast scheme for this specific situation.

Table VI shows the selected broadcast scheme for each of the simulated scenarios according to our proposed Optimal Broadcast Selection Algorithm. Notice that the proposed NJL scheme is selected as the optimal one in most cases, especially under high vehicle densities or simple maps with a small SJ ratio, where the radio signal can reach long distances and broadcast storms are prone to occur. On the contrary, eMDR and eSBR schemes offer better results in scenarios where broadcast storms are not a problem, and the main objective is informing as many vehicles as soon as possible.

It is remarkable that almost all the schemes selected by our proposed algorithm rely on topology information to select the most appropriate forwarding vehicle, highlighting the importance of this factor in the warning dissemination process. In fact, broadcast schemes that only make use of the distance between the sender and the receiver, or which only focus on avoiding repeated messages, present a worse trade-off between performance and the amount of messages required. We also observed an anomaly in the results obtained in Table VI corresponding to the map of Madrid. The selected scheme when simulating 25 vehicles/km^2 is the counter-based one, while the overall trend indicates that the chosen one should be the eMDR scheme. This is due to the thresholds selected for Step 1 of the algorithm, where only those schemes with less than 10% variation with respect to the maximum value are considered. The eSBR and eMDR schemes achieve a value of 10.2% and 10.51% variation, respectively, which causes them to be ignored after the first step of the selection algorithm. This indicates that the use of fixed thresholds may lead to inaccurate decisions in some specific cases. We consider that a possible improvement of the broadcast selection algorithm could be using fuzzy logic to decide upon protocol adequacy, thereby avoiding those cases where values close to the threshold are completely ignored.

V. RELATED WORK

In the networking literature we can find several works that present adaptive mechanisms specially designed to enhance message dissemination in vehicular communications. In this section we present some of the most representative works.

Xue-wen et al. [10] proposed the Transmission Range Adaptive Broadcast (TRAB) algorithm for VANETs. Considering the transmission ranges of vehicles together with the inter-vehicle distances, TRAB calculates the waiting time to select the relay vehicles in accordance with the additional coverage area of adjacent vehicles to ensure that fewer relay vehicles will be used to forward the emergency packets. However, this scheme is designed to obtain efficient propagation of warning messages in highway scenarios alone, making it unsuitable for scenarios with complex topologies where we would want to disseminate warning messages in all directions surrounding the critical area.

Slavik et al. [8] proposed the Rate-Adaptive Broadcast (RAB) protocol for information dissemination in VANETs. RAB adapts to the network conditions, although it does not require any knowledge of network topology. By assuming a VANET dissemination application with fixed periodic updates, RAB is able to use a decision threshold control algorithm based on the rate of both messages. If the new message rate dips below its long-run average, the decision threshold is adjusted to improve message propagation. Otherwise, RAB adjusts the decision threshold to keep the duplicate message rate within an efficient range. Unlike the TRAB scheme, the use of RAB is not restricted to highways; nevertheless, the roadmap layout is not used to select the vehicles to forward the messages.

Schwartz et al. [7] proposed a data dissemination protocol for VANETs that distributes data utility fairly over vehicles while adaptively controlling the network load. The protocol relies only on local knowledge to achieve fairness with concepts of Nash Bargaining from game theory. Simulation results show that their algorithm presents a higher fairness index, and it maintains a high level of bandwidth utilization efficiency compared to other approaches. However, the vehicular density of the scenarios where their proposal was tested was very low (i.e., only 20 $vehicles/km^2$). Additionally, it is not clearly explained if their simulations accounted for the effect of obstacles in wireless signal propagation, and the benefits of their proposal in terms of vehicles informed.

As shown, existing adaptive dissemination techniques for VANETs usually consider features related to vehicles in the scenario, such as their density, speed, and location, to adapt the performance of the dissemination process. However, most of the works in the literature are designed for highway scenarios where messages are only propagated in one direction, or focused on end-to-end routing. Additionally, most of them do not account for the effect of buildings and other obstacles during the dissemination of messages, which may lead to wrong conclusions.

VI. CONCLUSIONS

In this paper we proposed an adaptive algorithm that allows selecting the optimal broadcast scheme in a VANET scenario depending on two different metrics: (i) the percentage of informed vehicles, a particularly determinant factor in warning message dissemination, and (ii) the number of messages received by each vehicle, an important factor which indicates the channel contention and the possibility of broadcast storms during the dissemination of alert messages. In addition, we presented a new broadcast scheme called Nearest Junction Located (NJL), which was specially designed for scenarios presenting high vehicular densities or simple topologies, where broadcast storms are prone to occur. The NJL scheme reduces the number of messages received per vehicle without noticeably affecting the percentage of informed vehicles.

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, and by the Government of Aragon and the European Social Fund (T91 Research Group).

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