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A Street Broadcast Reduction Scheme (SBR) to Mitigate the Broadcast Storm Problem in VANETs

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Abstract In urban vehicular wireless environments, several vehicles can send warning messages and so every vehicle within the transmission range will receive the broadcast transmission, possibly rebroadcasting these messages to other vehicles. This increases the number of vehicles receiving the traffic warning messages. Hence, redundancy, contention, and packet collisions due to simultaneous forwarding (usually known as the broadcast storm problem), can occur. In the past, several approaches have been proposed to solve the broadcast storm problem in wireless networks such as *Mobile ad hoc Networks* (MANETs). In this paper, we present *Street Broadcast Reduction* (SBR), a novel scheme that mitigates the broadcast storm problem in VANETs. SBR also reduces the warning message notification time and increases the number of vehicles that are informed about the alert.

Keywords Vehicular ad hoc networks · Warning message dissemination · Broadcast storm · Inter-vehicular communication

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1 Introduction

Vehicular ad hoc networks (VANETs) are wireless communication networks that do not require any fixed infrastructures. Vehicles function as communication nodes and relays, forming dynamic networks with other near-by vehicles on the road and highways. 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. Technology advances in the wireless networking field have contributed to supporting new services and applications for vehicular passenger safety and driver assistance. Wireless technologies such as *Dedicated Short Range Communication* (DSRC) and IEEE 802.11p *Wireless Access for Vehicular Environment* (WAVE) enable peer-to-peer mobile communication among vehicles. IEEE 802.11p is a draft amendment to the IEEE 802.11 standard that defines enhancements to support *Intelligent Transportation Systems* (ITS) applications. This includes data exchange between moving vehicles and between vehicles and roadside infrastructure in the licensed ITS band at 5.9 GHz (5.85–5.925 GHz).

In urban vehicular wireless environment, an accident can cause many vehicles to send warning messages, and all vehicles within the transmission range will receive the broadcast transmissions and rebroadcast these messages. Hence, a broadcast storm (serious redundancy, contention and massive packet collisions due to simultaneous forwarding) will occur, and this must be reduced [9]. In this paper, we present a new scheme called *Street Broadcast Reduction* (SBR), which uses location and street information to facilitate the dissemination of warning messages so as to mitigate the broadcast storm problem found in 802.11p based VANETs.

Although several schemes has been previously proposed to mitigate the well-known broadcast storm problem in other wireless networks such as MANETs, the special characteristics of VANETs make it necessary to propose new schemes to cope with broadcast storm issues in these networks. This paper is organized as follows: Section 2 presents some related work on the broadcast storm problem and on warning message dissemination in VANETs. Section 3 presents our proposed SBR scheme. Section 4 presents the simulation environment. Simulation results are then discussed in Section 5. Finally, Sect. 6 concludes this paper.

2 Related Work

In VANETs, intermediate vehicles act as message relays to support end-to-end vehicular communications. For applications such as route planning, traffic congestion control, and traffic safety, flooding of broadcast messages commonly occurs. However, flooding can result in many redundant rebroadcasts, heavy channel contention, and long-lasting message collisions [9].

2.1 Work on Broadcast Storm

Over the years, several schemes have been proposed to address the broadcast storm problem in wireless networks, particularly in MANETs. They are:

1. The *Counter-based scheme* [9]. To mitigate broadcast storm, this scheme uses a threshold C, and a counter c to keep track of the number of times the broadcast message is received. Whenever $c \geq C$, rebroadcast is inhibited.

2. The *Distance-based scheme* [9]. In this scheme, the authors use the relative distance d between vehicles to decide whether to rebroadcast or not. It is demonstrated that when the distance d between two vehicles is short, the *additional coverage* (AC) of the new rebroadcast is lower, and so rebroadcasting the warning message is not recommended. If d is larger, the additional coverage will be larger.
3. The *Location-based scheme* presented in [9] is very similar to the distance-based scheme, though requiring more precise locations for the broadcasting vehicles to achieve an accurate geometrical estimation (with convex polygons) of the AC of a warning message. The main drawback for using this scheme is the high computational cost of calculating the AC, which is related to calculating many intersection areas among several circles.
4. The *weighted p-persistence*, the *slotted 1-persistence*, and the *slotted p-persistence* techniques presented in [10] are some of the few proposed rebroadcast schemes for VANETs. 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. These schemes are specifically designed for use in highway scenarios.

2.2 Dissemination of Warning Messages for VANETs

Previous research work on dissemination of warning messages for VANETs had focused on two issues: (a) message dissemination protocols, and (b) collision prevention mechanisms.

Korkmaz et al. [4] proposed a new efficient IEEE 802.11 based *Urban Multi-hop Broadcast protocol* (UMB) which was designed to avoid hidden node and reliability problems of multi-hop broadcast in urban areas. They showed that this protocol had a very high success rate and efficient channel utilization when compared with other flooding based protocols. Torrent-Moreno et al. [8] studied the situation that arises when the number of nodes sending periodic safety messages in a specific area is too high. To achieve good performance, they proposed to limit the channel load by using a strict fairness criterion among nodes. Fasolo et al. [3] proposed a distributed position-based broadcast protocol, named *Smart Broadcast* (SB), that aims at maximizing the progress of the message along the propagation line, as well as minimizing the rebroadcast delay.

Yang et al. [11] investigated ways to achieve low-latency in delivering emergency warnings under various road situations. They designed an effective protocol, comprising congestion control policies, service differentiation mechanisms and methods for emergency warning message dissemination. More recently, Zang et al. [13] studied the performance of the *Emergency Electronic Brake Light with Forwarding* (EEBL-F) application as an example safety application in congested scenarios.

3 The Street Broadcast Reduction (SBR) Scheme

In this section, we present the *Street Broadcast Reduction scheme* (SBR)—our novel proposal to reduce the broadcast storm problem in urban scenarios. In urban scenarios, and at the frequency of 5.9 GHz (i.e., the frequency band of the 802.11p standard), radio signals are highly directional and will experience a very low depth of penetration. Hence, in most cases, buildings will absorb radio waves at this frequency, making communication only possible when the vehicles are in line-of-sight.

In our simulations, vehicles operate in two modes: (a) warning, and (b) normal. Warning mode vehicles inform other vehicles about their status by sending warning messages periodically (every T_w seconds). These messages have the highest priority at the MAC layer. Normal mode vehicles enable the diffusion of these warning packets and, periodically (every T_b seconds), 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.

Algorithms 1 and 2 describe our SBR scheme. In the warning message dissemination mechanism, $vehicle_i$ indicates each vehicle in the scenario; m indicates each message sent or received by each vehicle; $warning$ represents a warning message generated by a warning mode vehicle; *beacon* represents a normal message generated by an normal vehicle; T_w is the interval between two consecutive warning messages; T_b is the interval between two consecutive normal messages; P_w indicates the priority of the warning messages and P_b indicates the priority of the normal messages.

When a $vehicle_i$ starts the broadcast of a message, it sends m to all its neighbors. When another vehicle receives m for the first time, it rebroadcasts it to the surrounding vehicles only when the distance d between sender and receiver is higher than a distance threshold D, or the receiver is in a different street than the sender. We consider that two vehicles are in a different street when: (1) both are indeed in different roads (this information is obtained

Algorithm 1: Send()

```
Pw = AC3;   // set the highest priority
Pb = AC1;   // set default priority
ID = 0;     // initialize sequence number of messages
while (1) do
    if (vehicle_i is in warning mode) then
        create message m;
        set m.priority = Pw;
        set m.seq_num = ID++;
        broadcast warning message (m);
        sleep (Tw);
    else
        create message m;
        set m.priority = Pb;
        broadcast beacon (m);
        sleep (Tb);
```

Algorithm 2: OnRecv()

```
for (every received message) do
    if (m is is a warning and m.seq_num received for the first time) then
        if (distance between sender and receiver > D or both vehicles are in different streets) then
            rebroadcast(m);
        else
            discard(m);
            /* warnings are only rebroadcasted when additional coverage area is high or they can be
            propagated to different streets */
    else
        discard(m);
        // duplicated warnings and beacons are not rebroadcasted
```

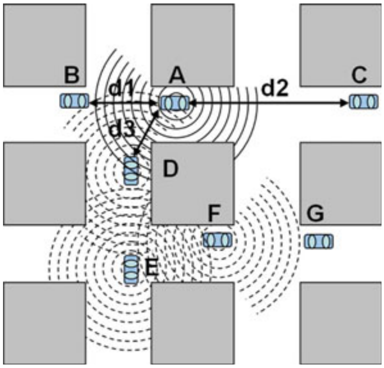

Fig. 1 The street broadcast reduction scheme: example scenario

by on-board GPS systems with integrated street maps), or (2) the receiver, in spite of being in the same street, is near an intersection. Hence, warnings can be rebroadcasted to vehicles which are traveling on other streets. If the message is a *beacon*, it is simply discarded since we are not interested in the dissemination of beacons.

Figure 1 shows an example where shaded rectangles represent buildings. When vehicle A broadcasts a warning message, it is only received by neighboring vehicles B, C, and D because buildings interfere with the radio signal propagation. In this situation, if we use distance or location-based schemes, vehicles B, C, and D will rebroadcast the message only if distances $d1$, $d2$ and $d3$, respectively, are large enough (i.e., the distance is larger than a distance threshold D), or its additional coverage areas are wide enough (i.e., the AC is larger than a coverage threshold A). So, suppose that only vehicle C meets this condition, the warning message could still not be propagated to the rest of vehicles (i.e., E, F, and G).

Our SBR scheme tries to solve this problem. In SBR, vehicle D will rebroadcast the warning message since vehicle D is in a different street than vehicle A. In this way, the warning message will arrive to all the vehicles represented in only four hops. In modern *Intelligent Transportation Systems* (ITS), vehicles are equipped with on-board GPS systems containing integrated street maps. Hence, location and street information can be readily used by SBR to facilitate dissemination of warning messages.

Note that distance and location schemes can be very restrictive, especially when buildings interfere with radio signal propagation. Without SBR, warning messages will not arrive at vehicles E, F and G due to the presence of buildings. Also, SBR can be combined with the location based scheme. When the additional coverage area is wide enough, vehicles will rebroadcast the received warning message. However, when the additional coverage area is very low, vehicles will rebroadcast warning messages only if they are in a different road.

4 Simulation Environment

In this section, we present our VANET simulation setup. Simulation results presented in this paper were obtained using the ns-2 simulator [2]. We modified the simulator to follow the upcoming WAVE standard closely. Achieving this requires extending the ns-2 simulator to implement IEEE 802.11p. In terms of the physical layer, the data rate used for packet broadcasting was fixed at 6 Mbit/s, i.e., the maximum rate for broadcasting in 802.11p. The MAC layer is based on the IEEE 802.11e *Enhanced Distributed Channel Access* (EDCA) *Quality of Service* (QoS) extensions. Therefore, application messages are categorized into different *Access Categories* (ACs), where AC0 has the lowest and AC3 the highest priority. The contention parameters used for the *Control Channel* (CCH) are shown in [1]. Thus, in our warning message dissemination mechanism, warning messages have the highest priority (AC3) at the MAC layer, while *beacons* have lower priority (AC1).

Moreover, the Radio propagation model used was the *Building and Distance Attenuation Model* (BDAM) [5]. BDAM considers the signal attenuation due to the distance between vehicles by using a probabilistic model (with a maximum transmission range of 250 meters), and the presence of buildings (i.e., communication among vehicles is only possible when they are within line-of-sight). The impact of the priority and the radio propagation model used was previously studied in [7].

Each simulation lasted for 450 s. In order to achieve a stable state before gathering data traffic, we only started to collect data after the first 60 s. Since performance results are highly related to the specific scenarios used, and due to the random nature of the mobility model, we performed several simulations to obtain reasonable confidence intervals. All the results shown have a 90% confidence interval. Moreover, since Random Waypoint Model is considered unrealistic [12], in our simulations, vehicles moved according to the *Downtown Model* (DM). This is a mobility model that we had earlier proposed and validated [6] for use in VANETs. In this model, streets are arranged in a Manhattan style grid, with a uniform block size across the simulation area. All streets are two-way, with lanes in both directions. Vehicles will move with a random speed, but lower than the permitted speed limits.

Our model also simulates semaphores at random positions (not only at crossings), and with different delays. Moreover, our model uses a traffic density scenario similar to a real town, where traffic is not uniformly distributed. Hence, there will be zones with a higher vehicle density. These zones are usually in the downtown, and vehicles must move more slowly than those in the outskirts. CityMob version 2, the mobility generator that we use, has also the following capabilities: (1) multiple lanes in both directions for every street, (2) vehicle queues due to traffic jams, and (3) the possibility of having more than one downtown.

5 Performance Evaluation

In this section, we perform a detailed analysis to evaluate the impact of the proposed SBR scheme on the overall system performance. We compare the impact of our scheme with respect to a flooding scheme without limitation of broadcasts, and a location-based broadcast scheme.

We evaluated the following performance metrics: (a) percentage of blind vehicles, (b) warning notification time, and (c) number of packets received per vehicle. The percentage of blind vehicles is the percentage of vehicles that do not receive the warning messages sent by accident vehicles. These vehicles remain blind because of their positions, due to packet collisions, or due to signal propagation limitations. The warning notification time is the time required by normal vehicles to receive a warning message sent by a "warning mode" vehicle (a vehicle that broadcasts warning messages). Table 1 shows the simulation parameters used.

5.1 Evaluating the Impact of the Vehicle Density

We now proceed to evaluate the impact of vehicle density (without using any scheme to reduce the broadcast storm problem). Figure 2 shows the simulation results when varying the number of vehicles while keeping the rest of parameters unaltered.

Table 1 Parameter values for the different scenarios

Parameter	Value
Maximum speed	50 km/h
Map area size	2500 × 2500 m
Distance between streets	100 m
Number of warning mode vehicles	3
Downtown size	1000 × 1000 m
Downtown speed (min–max)	5–30 km/h
Downtown probability	0.6
Warning packet size	256 bytes
Normal packet size	512 bytes
Packets sent by vehicles	1 per s
Warning message priority	AC3
Normal message priority	AC1
MAC/PHY	802.11p
Radio Propagation Model	BDAM [5]
Maximum transmission range	250 m
SBR distance threshold (D)	200 m

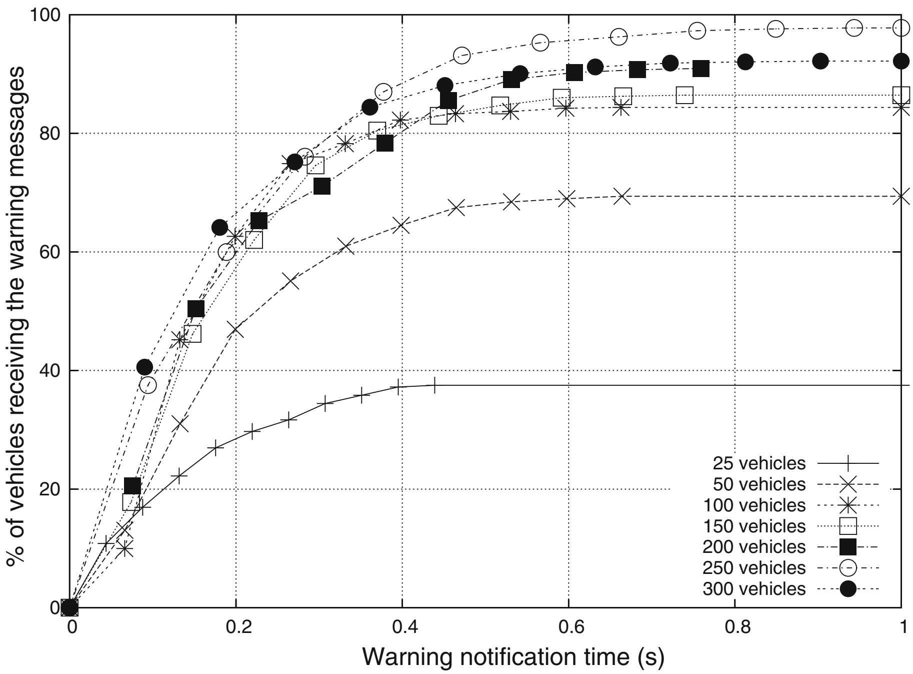

Fig. 2 Average propagation delay when varying the number of vehicles

As expected, when vehicle density increases, the warning notification time decreases and the message reaches more vehicles. Warning notification reaches about 60% of the vehicles in less than 0.21 s (except for scenarios with 25 and 50 vehicles, where very low density does

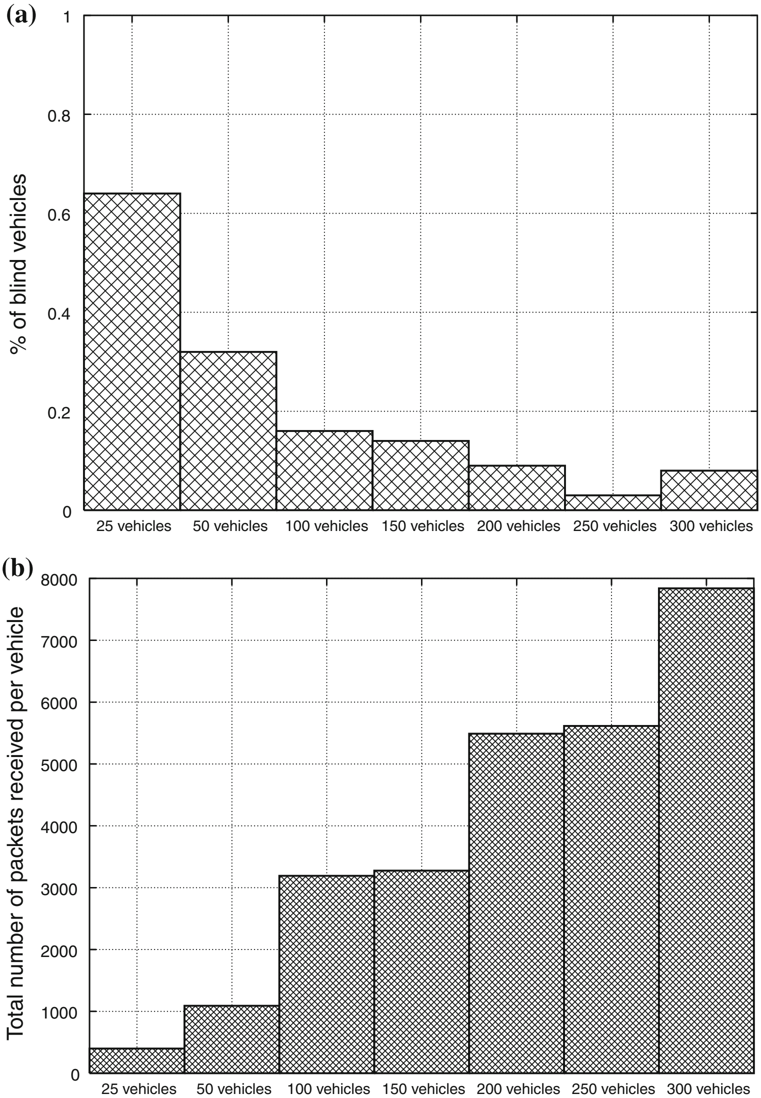

Fig. 3 **a** Percentage of blind vehicles versus number of vehicles and **b** total number of packets received at each vehicle versus number of vehicles

not allow reaching 60% of vehicles), and the propagation process is completed in less than 1 s. Note that, for 300 nodes, information reaches 60% of the vehicles in less than 0.16 s. However, the percentage of vehicles receiving the warning messages for 300 vehicles is lower than that of 250 vehicles. This demonstrates the presence of a broadcast storm. The massive rebroadcasting of messages provokes heavy channel contention and message collisions, thus causing warning messages to arrive to a fewer number of vehicles.

The behavior in terms of percentage of blind vehicles highly depends on vehicle density (see Fig. 3a). In fact, when vehicle density increases, the percentage of blind vehicles decreases. This is because the flooding of messages is more effective at higher vehicle

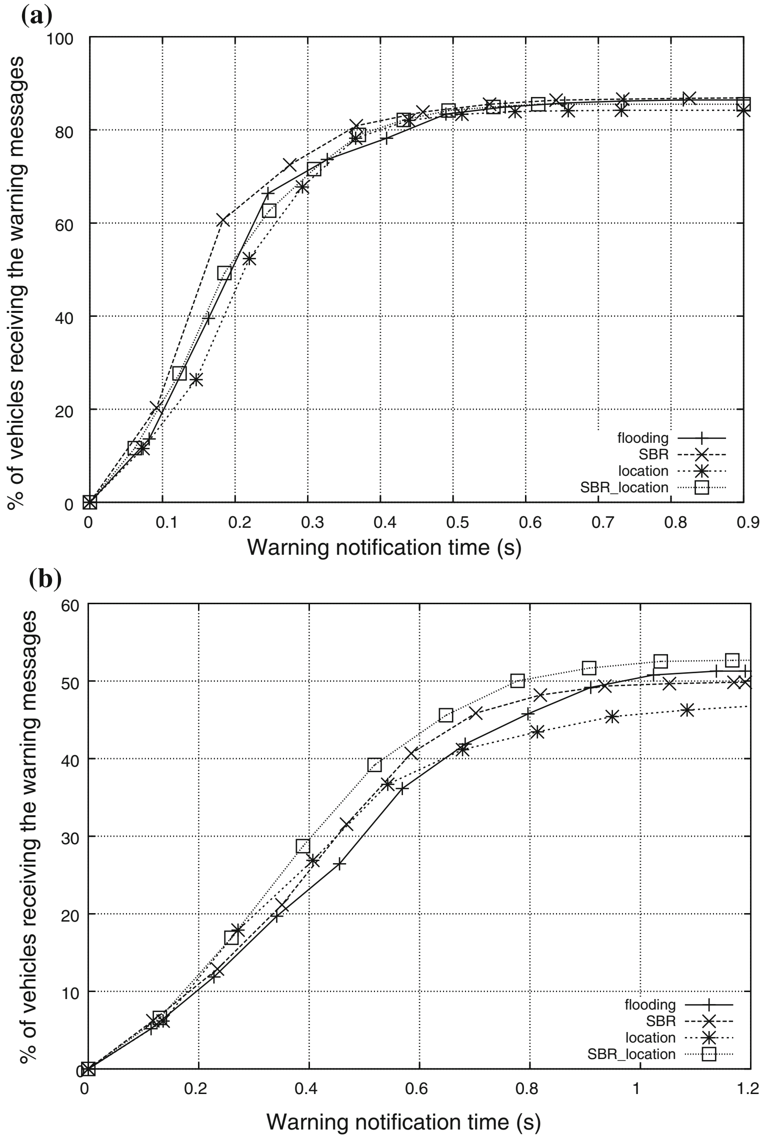

Fig. 4 Average propagation delay when varying the dissemination scheme (**a**) without obstacles (**b**) with obstacles

densities. However, the percentage of blind vehicles increases with 300 vehicles due to the presence of broadcast storm.

As shown in Fig. 3b, the number of packets received per vehicle increases highly when the density of vehicles also increases. So, we demonstrated that the broadcast storm problem is likely to appear in vehicular urban scenarios with a high density of vehicles. Also, although the number of packets received per vehicle increases when the number of vehicles increases, the percentage of blind vehicles can also increase. For example, for 300 vehicles, the number of packets received per vehicle increases by +40.81% (with respect to 200 vehicles);

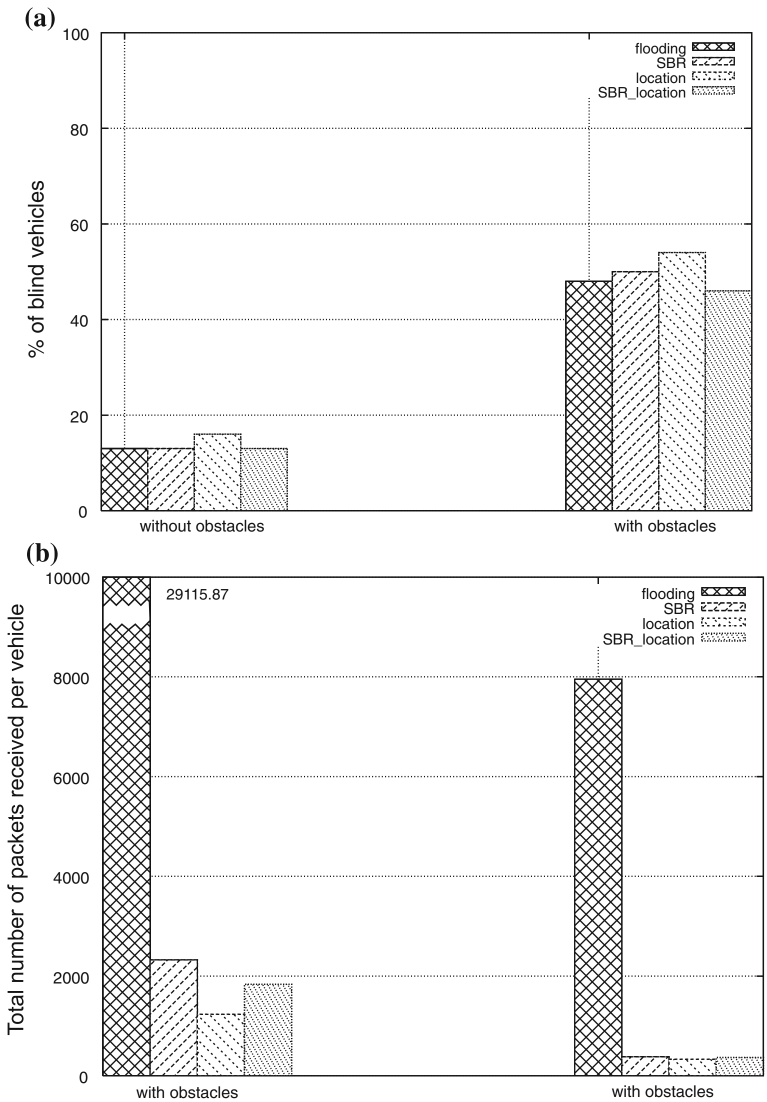

Fig. 5 **a** Percentage of blind vehicles versus dissemination scheme and **b** total number of packets received per vehicle versus dissemination scheme, both accounting for no obstacles and the presence of obstacles

nevertheless, the percent increased in terms of blind vehicles is almost the same due to heavy channel contention and message collisions.

5.2 Evaluating the Performance of Our SBR Scheme

Authors in [9] had demonstrated that the location-based scheme is preferred, since it reduces redundancy without compromising the number of vehicles receiving the warning message. We evaluate the performance of our proposed scheme (SBR) with respect to: (1) a flooding scheme without limitation of rebroadcasts, (2) a location-based scheme, and (3) a combination of our SBR with the location-based scheme. Moreover, we have modified the ns-2 simulator to model the impact of distance and obstacles in signal propagation (i.e. direct communication between vehicles is only possible when in line-of-sight) [5]. Figure 4 shows the warning notification time obtained when simulating 150 vehicles. As shown, when the effect of obstacles is not taken into account (see Fig. 4a), all the schemes behave in a similar way, although the SBR scheme needs less time to inform 60% of the vehicles (only 0.18 s); the warning message propagation process ends in about 0.9 s for all schemes.

When accounting for obstacles (see Fig. 4b), the SBR scheme, combined with the location-based scheme, outperforms other solutions since the warning notification time is lower (information reaches 50% of the vehicles in only 0.78 s), and the percentage of blind vehicles is lower than others. The presence of buildings in signal propagation paths results in the need for more time to complete the propagation process (1.2 s). The percentage of blind vehicles present will largely depend on the presence of buildings (see Fig. 5a). When obstacles are not taken into account, the percentage of blind vehicles is very similar for all the schemes. When taken into account, the percentage of blind vehicles increases significantly. Our proposed SBR scheme combined with the location-based technique behaves better than others (46% of blind vehicles). As for the total number of packets received per vehicle (see Fig. 5b), we demonstrate that, despite the high number of packets received with the flooding scheme, it behaves worse in terms of warning message notification time and the percentage of blind vehicles due to broadcast storm. When accounting for obstacles, our proposal yields the best performance and it outperforms both the flooding scheme and the location-based scheme. With respect to the flooding scheme, SBR reduces up to 95.84% the number of packets received. As far as the location scheme is concerned, SBR increases the percentage of vehicles receiving the warning messages by around 8%.

6 Conclusion

Achieving efficient dissemination of messages is important in vehicular networks so as to warn drivers of critical road conditions. However, broadcasting of warning messages in VANETs can result in increase channel contention, and packet collisions due to simultaneous message transmissions (usually known as the broadcast storm problem).

In this paper, we introduce the *Street Broadcast Reduction* (SBR) scheme to reduce broadcast storm in urban scenarios and to improve the performance of warning message dissemination. SBR can be combined with the existing location-based scheme for further broadcast storm reduction. Simulation results show that when SBR is combined with the location-based scheme, it outperforms other schemes in high density urban scenarios, yielding a lower percentage of blind vehicles while drastically alleviating the broadcast storm problem.

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