Testing viability of relay policies for reactive CCA applications in VANETs

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***Abstract*—Relaying mechanisms for *Chain Collision Avoidance* (CCA) applications in *Vehicular Ad-hoc Networks* (VANETs) are crucial when one hop transmissions are not enough to reach all of the vehicles in a platoon at risk of accident. Taking into account that CCA-related information must be distributed to as many vehicles as possible in the shortest affordable time, a reasonable way to determine the viability of using such relay policies is by evaluating the delay to spread information to all recipients and the associated occupation of the communications channel. Furthermore, the inherent transition to reach full technology penetration in the market requires to study how the system of vehicles will behave at different stages of deployment and how different relaying mechanisms may affect the general functionality of the system and what is the influence of background data traffic which can obviously worsen the successful delivery rate (SDR) of warning notification messages.**

I. Introduction and motivation

A. Introduction

Emergent technologies for vehicular traffic are currently the object of research to provide cars with new capabilities which can, among other things, reduce the number of fatalities on the road, provide new end-user services on vehicles and finally improve remarkably the driving experience. Research on vehicular communications is crucial to provide vehicles with an advanced mechanism to react to the different circumstances they have to face on the road, mostly concerning those applications related to safety [1]. It is necessary to previously evaluate the behavior of different sorts of safety-related user services to determine if using them guarantees that driving will be safer for passengers on vehicles under every possible state of the road traffic.

CCA applications are a particular implementation of safety related services which can help drivers make decisions on time in order to avoid possible chain collisions in a convoy of vehicles or at least reduce the importance of the human injuries of an hypothetical accident. Such safety applications have been tested to a certain extent during the past years, and some approaches have already been proposed to accomplish the task of informing drivers timely about an incidence on the road [1]. V2V (*vehicle to vehicle*) communications have been conceived as the basic scheme to transmit information between vehicles in those risky situations in which vehicles must try to stop within the shortest time possible. Such communications capabilities are defined by the protocol stack

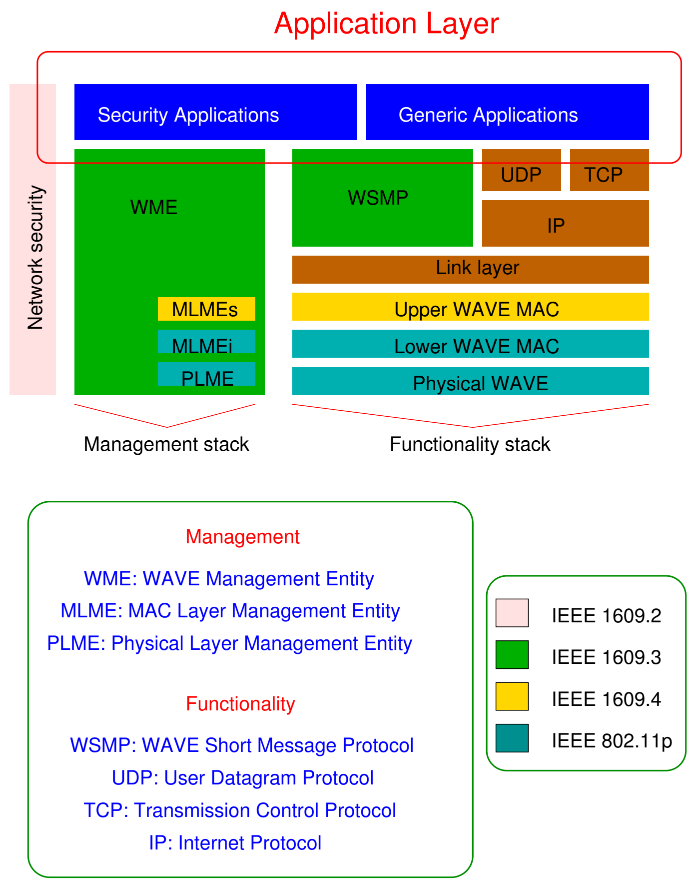

Fig. 1. Protocol stack for the WAVE IEEE 1609/802.11p architecture

WAVE 1609/IEEE 802.11p (see Figure 1), whose final version is expected to appear in November 2010 [2], [3]. IEEE 802.11p is a draft modification of the IEEE 802.11 standard to add wireless communication capabilities in environments with vehicular connectivity. It defines some improvements to the original 802.11 protocol stack necessary to support Intelligent Transportation Systems (ITS) applications on vehicles. This includes data exchange between vehicles at high speeds and between vehicles and roadside equipment, *Roadside Unit (RSU)*, centered in the band of 5.9 GHz (5.85-5.925 GHz).

As an additional feature of the architecture WAVE, a new network layer protocol (along with TCP/IP) is offered, the

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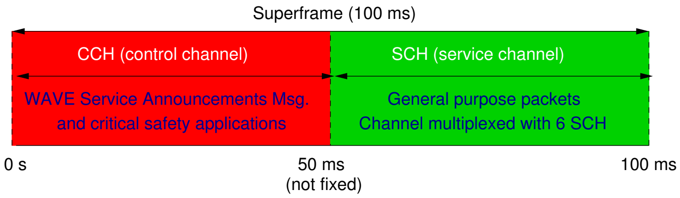

Fig. 2. Frame structure in DSRC for WAVE

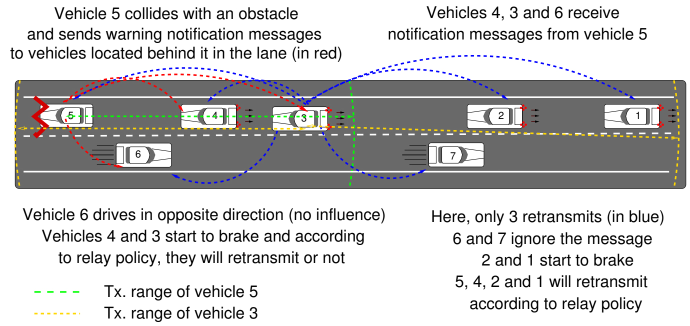

Fig. 3. General scenario for testing relay policies in VANETs with 802.11p communication capabilities

WSMP (*WAVE Short Message Protocol*), which provides a lighter and faster way to transmit information to other vehicles. Although it does not contain either of the advanced capabilities of TCP/IP, like sliding window or message acknowledgment, WSMP special features make it suitable for CCA applications, due to the required low delays which such applications must guarantee when messages are transmited to affected vehicles. For this purposes, a general superframe consisting of both a CCH *Control Channel* and seven time-modulated SCH *Service Channels* are used to exchange messages in nodes supporting IEEE 1609/802.11p (Figure 2). Specially, CCH is the channel devoted to safety applications which uses lightweight packets to deliver information with low delays (WSMP).

B. Motivation

The main goal of this article is to evaluate if relaying can practically improve safety-related applications and when such mechanisms should be used to reach the necessary number of vehicles affected by a risky situation in a platoon, that is, when they cannot be informed with only a one-hop transmission. Therefore, determining which vehicles could be involved in an accident according to their situation in the platoon is necessary to assess if relaying is worth enough. The relay policies we evaluate are the schemes proposed in [4] (NB and I-BIAS), with some improvements. These schemes (Algorithms 2 and 3) will be compared together with a scheme without relaying (Algorithm 1). We perform a thorough evaluation by simulation, testing the behavior of CCA relaying against different parameters that have influence like transmission power, background traffic and percentage of vehicles using CCA. This latter case is specially interesting since the adoption of vehicular technologies will be gradual. We also provide different metrics that help showing the real utility of the mechanism.

The rest of the article is organized as follows. In section II a description of relevant related work is introduced. In section III we describe in detail the most important issues concerning the different simulation cases we want to study and we evaluate the performance of the three relay policies under different configuration parameters. In this action, some illustrative results are also shown and discussed. Section IV finishes the paper with some concluding remarks, as well as the future work lines derived from the present evaluation study.

II. Related Work

Several studies on the reduction and minimization of channel occupation and end-to-end delay in CCA applications have been conducted according to different perspectives [4], [5], [6]. Biswas et al. [4] proposed two protocols for broadcasting CCA-related safety messages, NB (*Naïve Broadcast*) and I-BIA (*Intelligent Broadcast with Implicit Acknowledgement*). In both mechanisms, when a vehicle receives a warning message coming from other vehicle located ahead, a retransmission will follow. In I-BIA, however, messages will be only retransmitted after a random period in which a receiver does not hear the retransmission of a further vehicle which previously received the same message. I-BIA notably reduces the number of data packets sent to the channel (when compared with NB), but random times are not appropriate to give a complete view of the optimum time which vehicles should wait to retransmit (i.e. to maximize the delivery rate and on the other hand to minimize the end-to-end delay).

In [5] a power control procedure is used to avoid redundant use of the channel bandwidth by an estimation of the transmission power according to the safety distance. A remarkable reduction in the number of car accidents is obtained (as well as a smaller delivery delay). Power control can be a good mechanism when the scenario is not highly dynamic, but in the case fading, attenuation and scattering affect continously the reception process power control can be quite complex to implement. Furthermore, in [5] authors use the deterministic *Two Ray* propagation model [7] which does not capture realistically the behavior of electromagnetic propagation in vehicular environments [8]. In [6], *VeSOMAC*, a self-configuring TDMA protocol for the transmission of CWM (*Collision Warning Messages*) is described. Access to the medium is distributed into slots and when compared with contention based protocols like that of the WAVE architecture, it is shown that it is possible to obtain deterministic and lower delay bounds than those of IEEE 802.11p based devices [9]. We will show nevertheless that, despite this fact, IEEE 802.11p can peform well for CCA applications. In this work, we focus on determining which is the situation that makes relaying useful rather than providing a particular algorithm, that is, when relaying really improves the functionality of the system when compared to a single transmission. Since there are a high number of parameters that have influence on the effectivity of CCA, we provide a thorough evaluation by using different

Algorithm 1 No-relay policies

```
while VehiclesCirculating do
  if carcrash = 1 then
    stateMobility ← collided
    stateSend ← retransmitMyPacket periodically
  else if messageRecv = 1 then
    stateMobility ← braking
  end if
end while
```

Algorithm 2 Relaying only from ahead nearest collided vehicle (Naïve Broadcast [4])

```
while VehiclesCirculating do
  if ¬carCrash then
    if msgRecv AND DOA = forward then
      if txNearer then
        if braking = 0 then
          braking ← 1
        end if
        stateSend ← retransmitNewPacket
      else
        stateSend ← retransmitPacketAgain
      end if
    else if msgRecv AND DOA = back then
      stateSend ← ignoreMsg
    end if
  else if carCrash then
    stateMobility ← collided
    stateSend ← retrasmitMyPacket periodically
  end if
end while
```

Algorithm 3 Relaying only from ahead nearest collided vehicle till message is retransmitted by subsequent vehicles (I-BIA) [4]

```
while VehiclesCirculating do
  if ¬carCrash then
    if msgRecv AND DOA = forward then
      if txNearer then
        if braking = 0 then
          braking ← 1
        end if
        while waitingTimeEnded NOT 1 do
          stateSend ← noRetransmit
        end while
        stateSend ← retransmitNewPacket
      else
        stateSend ← retransmitPacketAgain
      end if
    else if msgRecv AND DOA = back then
      if stateSend = noRetransmit AND eventID =
      msgRecv.eventID then
        stateSend ← noRetransmit
      else
        stateSend ← retransmitNewPacket
      end if
    end if
  else if carCrash then
    stateMobility ← collided
    repeat
      stateSend ← retrasmitMyPacket periodically
    until msgRecv AND DOA = back AND eventID =
    msgRecv.eventID
    stateSend ← noRetransmit
  end if
end while
```

metrics that help deciding if collisions are actually avoided because of the reception of a warning message.

Some research has been also devoted to carry out realistic testbeds in which CCA has been evaluated. It is the case of [10], in which different algorithms are presented to guarantee collision avoidance in highway mergings and traffic circles, by using techniques related to partial order and order preserving dynamics. They show the real time applicability of such system by evaluating the behavior of two vehicles in a roundabout scaled drill in which cars are running continously.

III. Evaluation and results

We use the simulation platform *NCTUns 6.0 Network Simulator* [11] to test the viability of using relay mechanisms for CCA applications since it implements the WAVE architecture (introduced in Section I), which allows us to test the performance of CCA for VANETs over IEEE 802.11p [12].

A. General scenario description

Our evaluation study aims at assessing the usefulness of relaying warning messages in CCA applications in scenarios where a collision makes it necessary for a platoon of vehicles to try to stop in the shortest time possible and avoid crashing against preceding vehicles. The basic scenario is thus based on a two way road in which vehicles drive in opposite directions, where only one of them is taken into consideration (Figure 3). Vehicles drive in convoy, reacting to the first collision of another car according to two possible schemes: starting to brake because of a previously received warning message transmited by a collided vehicle (directly from the source or relayed) or starting to decelerate after noticing a reduction in the speed of the vehicle inmediately ahead (the relay Algorithms are explained later in detail).

Vehicles will not be able to change their direction of movement (worst case situation). For all simulation cases speed is set to 33 m/s (around 74.5 mph), a value which is used in average by vehicles driving in highways [13]. For those cases in which we analyze the influence of the intervehicle distance on the metrics under consideration, this parameter ranges between 6 and 72 m. Usefulness of relaying is tested by using two different values for the transmission power, 28 dBm and 10 dBm respectively (the first value provided in the draft standard IEEE 802.11p [3] and the second one is low enough to see in detail how relaying perfoms). When noticing a crash, each vehicle will transmit (according to its respective relaying algorithm) at a maximum rate of 1 packet every 20 ms. Vehicles will brake after an interval of time consisting of the transmission time plus the reaction time of the driver (0.2 s plus a uniformly distributed interval of 0.5-1 s). Relay mechanisms are also assessed subject to different penetration ratios of the CCA technology in the market. Background data traffic is additionaly considered in order to determine the functionality of the relay procedures when influenced by different loads in the communication channel.

The study is conducted according to different performance metrics which are described next:

- **Percentage of accidents**. This metric shows directly the improvement of the system when using CCA under different relaying (or no-relaying) schemes. In this case, for a fixed driving speed, the percentage of collided vehicles is represented against different values of the average intervehicular distance parameter, in Simulation case 1 (Figure 4). In Simulation case 2 the percentage of collided vehicles is shown against the deployment ratio of the technology (Figure 7). Finally, in Simulation case 3 this parameter is faced against the background data traffic present in the channel, in addition to the safety related information (Figure 8).
- **Successful Delivery Rate (SDR)**. This metric is used to quantify the effectiveness of informing vehicles over an incidence of collision. We measure the notification warning delivery success for the different Algorithms we assess. Values are averaged for the whole platoon in Table II.
- **Merit factor in reception**. This metric represents the usefulness of the delivery of warning notification messages. It is calculated by the equation $MF = (1 - P) * SDR$, where MF denotes the Merit factor in reception (1 highest usefulness of messages, 0 lowest usefulness of messages), P is the percentage of accidents in the platoon and SDR is the Successful Delivery Rate. This metric is represented according to the position of the vehicle in the platoon and the average intervehicle distance (Figure 5).
- **Average end-to-end delay**. Here we measure the time taken by a vehicle to receive a warning notification message since the message was first sent, that is, by the source vehicle who registered the incidence. It is calculated to quantify the delay in transmitting safety-related information to vehicles. This metric is represented according to the position of the vehicle in the platoon and the average intervehicle distance (Figure 6).
- **Packet Collisions Rate (PCR)**. This metric is used to calculate the rate of collided packets according to the relay algorithm and the transmission power used. Values are shown in Table II.

The three different relay policies evaluated in this study (we have chosen these schemes because they cover the three basic ways of relaying broadcast messages in the application layer [4]) are presented next:

1) Algorithm 1: There is no relay mechanism. Vehicles transmit warning notifications periodically only when they crash.

2) Algorithm 2: Vehicles will only retransmit messages coming from cars located ahead (forward DOA, *direction of arrival*). However, if a message is received by a car from a preceding vehicle which is closer to it than the first sender of the message being retransmitted till now, the new message will replace the previous one. If the vehicle collides, from then onwards the vehicle will only retransmit messages with his own *eventID* (identification number of incidence).

3) Algorithm 3: Vehicles will retransmit messages from preceding vehicles only after a random waiting time interval during which they do not hear the retransmission of another vehicle located behind. If during this time interval a vehicle receives from a following vehicle the message it was going to retransmit, then the retransmission will be canceled (it is supposed that the packet is already relayed).

B. Results

In this subsection the results obtained for three different simulation cases are presented and discussed. Simulations are performed according to a 99% confidence interval for all the statistics we measure (*t-Student* distribution) and the *Nakagami* fading model is used [8]. Speed is kept fixed for 33 m/s as well as the number of vehicles in the platoon (31). Reaction to stimulus is based on the natural human delay to detect the incidence and start braking (0.2 s plus a uniformly distributed value in the time interval [0.5-1] s). Intervehicle distance ranges between 6 and 72 meters, in 3-meter steps (where car position is shifted according to a normal distribution with respect to the average value of the position on the road (meters) and standard deviation proportional to the intervehicle distance too).

1) Simulation case 1. Influence of transmission power: In this first simulation we want to evaluate the basic differences between using each of the aforementioned Algorithms for relaying with respect to different values of the transmission power. First of all, if we observe the Graphs of Figure 4 we can notice that, despite the differences in the funcionality of Algorithms 2 and 3, when the transmission power is enough to cover all vehicles in the platoon (in this case 28 dBm is enough, IEEE 802.11p standard [3]), relay behaves like that case without relaying capabilities (Graph 4.b). However, the importance of relay arises only when transmission power is not enough to reach an advisable number of vehicles (Graph 4.a).

On the other hand, as an additional important goal, every relaying algorithm for CCA applications must always try to minimize the channel occupation when necessary, because it might be shared with other critical safety applications which could also require a certain bandwidth. Graphs in Figure 5 show the evolution of the Merit factor in reception for the different average intervehicle distances and the position of vehicles in the platoon, according to the transmission power

TABLE I
CONFIGURATION PARAMETERS FOR THE SIMULATION CASES

Simulation case	Tx. power	Relay algorithm	Interv. dist.	% Deployment	Background data traffic
1	10,28 dBm	1,2,3	[6-70] m	100 %	0 Kb/(s*vehicle)
2	10,28 dBm	1,2,3	25,60 m	[0-100] %	0 Kb/(s*vehicle)
3	10,28 dBm	1,2,3	25,60 m	100%	[0-700] Kb/(s*vehicle)

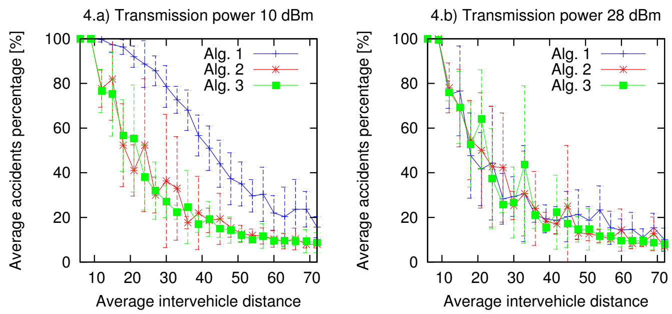

Fig. 4. Percentage of accidents as a function of the average intervehicular distance

TABLE II
SUCCESSFUL DELIVERY AND PACKET COLLISIONS RATE (SDR, PCR)

Power 10 dBm	Alg. 1	Alg. 2	Alg. 3
SDR	87.62%	91.92%	94.23%
PCR	23.19%	55.16%	25.75%
Utility factor	0.4810	0.8188	0.8467

Power 28 dBm	Alg. 1	Alg. 2	Alg. 3
SDR	95.55%	94.64%	95.81%
PCR	11.82%	58.09%	28.78%
Utility factor	0.8297	0.8486	0.8556

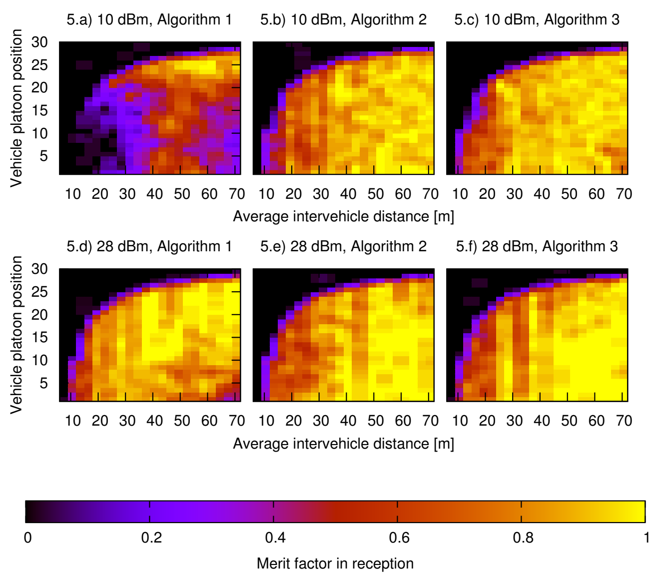

Fig. 5. Merit factor in reception for the system of vehicles

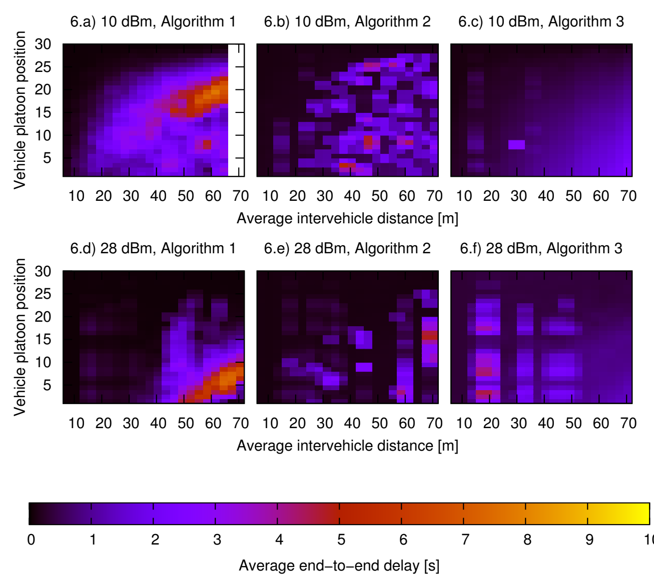

Fig. 6. Average accident notification delay

and the relay Algorithm used. As can be seen, the worst case corresponds to that of Graph 5.a, where only one hop transmissions of 10 dBm (low transmission power) are not heard by an acceptable number of vehicles in the platoon. This causes the Merit factor in reception to reach its lowest values on the left (because vehicles collide massively) and on the right (because vehicles at these average intervehicle distances are too far to receive notification packets). In 5.b it is easy to see that the Merit factor in reception evolves in the same way like in Algorithms 2 and 3. The other four Graphs in Figure 5 show a similar behavior, where SDR is high enough to reduce notably the number of accidents.

In addition, when comparing Algorithms 2 and 3 after looking at Table II we find out that Algorithm 3 reduces significantly the number of packets sent to the medium (deduced by the lower amount of packet collisions, PCR). The SDR is thus higher for those cases in which Algorithm 3 is used. As can be also inferred from this Table (comparing Algorithms 2 and 3), using higher values for the transmission power turns out in an increase of the Merit factor in reception, since the number of packet collisions is also smaller.

To finish with this first simulation case, an evaluation of the end-to-end delay evolution is also carried out. SDR is important, but it is also critical to deliver messages as soon as possible (mainly because their usefulness depends on the celerity taken to deliver them). As we can observe in Figure 6, Graphs 6.a and 6.d correspond to the case without relay capabilities. For short intervehicle distances, transmission power

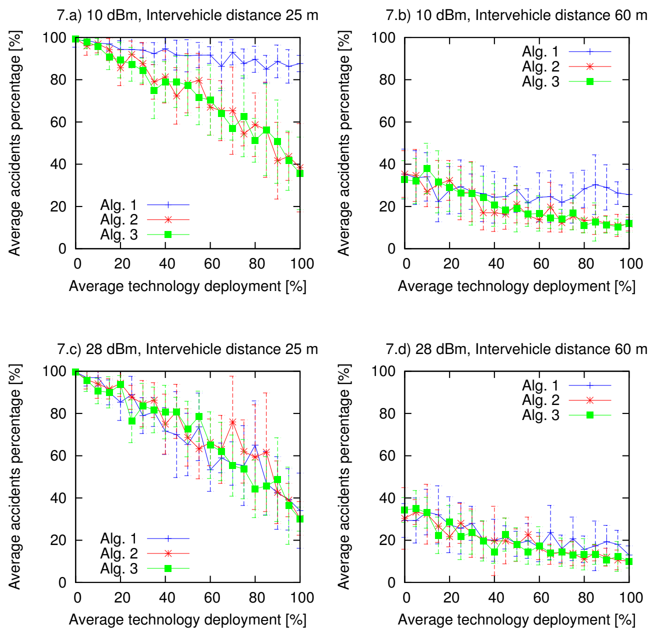

Fig. 7. Percentage of accidents as a function of the average percentage of technology deployment in the market

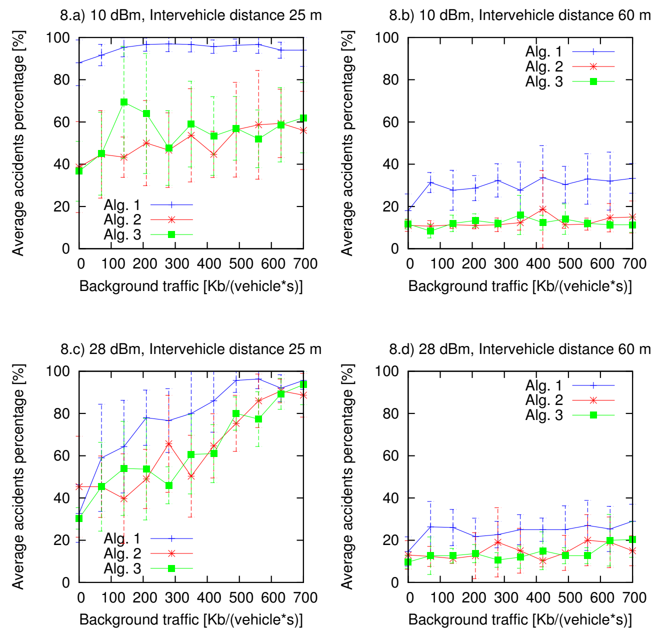

Fig. 8. Percentage of accidents as a function of the background data traffic delivered by vehicles to the channel

is enough to reach all vehicles in the platoon, but for high distances, even vehicles close to the first collided car register a high end-to-end delay (Graph 6.a, further vehicles experience a lower delay because the message they receive belongs to a car behind the first one, which obviously collides later). In Graph 6.d, however, transmission power is enough to reach the whole platoon, and this implies that in general the end-to-end delay is also lower. On the other hand, when relaying is used, a higher number of packets must be sent to the channel. For low values of the transmission power in Algorithm 2, the higher number of packet collisions implies higher delays (that is surprisingly minimized by Algorithm 3 due to its lower occupation of the medium, Graphs 6.b and 6.c). Using 28 dBm of transmission power results in general in a shorter end-to-end delay (Graphs 6.e and 6.f).

From these results we can conclude that relaying is only necessary when the transmission power is not enough to cover a large amount of vehicles in danger of collision. Furthermore, it also needs more bandwidth to retransmit messages to the channel when compared with no-relay (Algorithm 1), whereas no-relay policies do not in general occupy the medium that much and offer at the same time a lower end-to-end delay when high enough transmission power values are used.

2) Simulation case 2. Influence of percentage of CCA deployment: In this second simulation test we want to analyze thoroughly how relay mechanisms can perform under different penetration stages of the technology in the market.

As we can see from the Graphs in Figure 7, the trend of the relay Algorithms 2 and 3 is the same regardless of the transmission power used by vehicles. For these Algorithms the percentage of collided vehicles is always reduced with an increase of the average technology deployment. However, curves are steeper for low intervehicle distances than for higher values of this parameter, that is to say, as the penetration of the technology in the market increases, the improvement on the safety for passengers is more noticeable for low intervehicle distances. Nevertheless, the channel occupation of Algorithms 2 and 3 is much higher than that for Algorithm 1 (no-relay). This can be stringent for other safety applications which may need to use the channel too. As regards Algorithm 1, lower values of transmission power lead to higher rates of collided vehicles (Graphs 7.a and 7.b). When increasing transmission power for Algorithm 1, it behaves very similarly to relaying mechanisms (Algorithms 2 and 3).

From these results we can thus conclude that it is necessary to evaluate under which circumstances relay is critical, because it implies a higher occupation of the channel. Furthermore it is proved that using no-relay mechanisms with standard values of the transmission power (28 dBm, [3]) can be enough to reach a reasonable number of vehicles in the platoon and obtain a behavior very similar to what could be achieved with relaying, and at the same time have a much lower occupation of the medium. Moreover, during the early stages of CCA deployment relaying cannot guarantee that a message will be retransmitted to those vehicles in a platoon. Using higher values for the transmission power and employing derivatives of Algorithm 1 can be enough and even more efficient to deliver safety related information.

3) Simulation case 3. Influence of background traffic: In this case we test how background data traffic can affect the functionality of the CCA notification technology according to the transmission power used and the particular relaying

TABLE III
AVERAGE ACCIDENTS PERCENTAGE FOR GENERAL BACKGROUND DATA TRAFFIC

Tx. power, avg. distance	Alg. 1	Alg. 2	Alg. 3
10 dBm, 25 m	94.72%	50.18%	54.97%
10 dBm, 60 m	29.81%	12.63%	12.21%
28 dBm, 25 m	77.84%	63.69%	62.84%
28 dBm, 60 m	24.33%	14.69%	13.21%

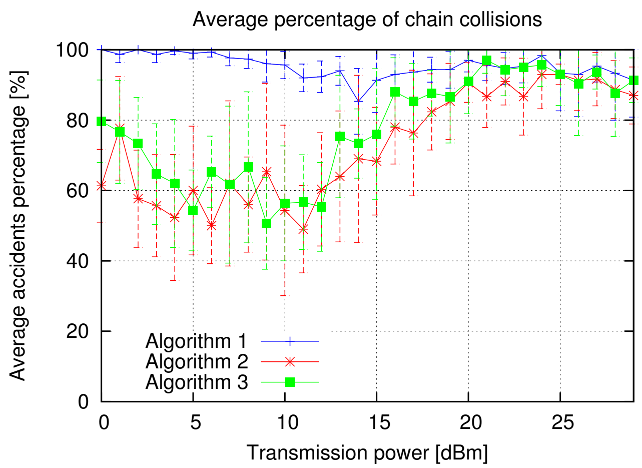

Fig. 9. Percentage of accidents as a function of the transmission power

Algorithm employed.

From Graphs in Figure 8 it is easy to infer that the higher rate of background data traffic produced by vehicles, the higher the number of car accidents in the platoon (regardless of the relay algorithm used). However, Algorithm 1 (no-relay) seems to be more affected by the influence of background data traffic, as can be deduced from the smaller number of warning notification messages that are sent to the radio channel in comparison to the other two Algorithms (2 and 3). Using low values of the transmission power leads to a better behavior of Algorithms 2 and 3 (Graph 8.a) when compared to Graph 8.c because notification packets are delivered with a higher probability to the platoon (due to the lower rate of packet collisions caused by the low transmission power value used to send packets to the medium). However, no-relay behaves much worse since this specific value of the transmission power does not reach the entire chain of vehicles. In Graph 8.c, 28 dBm of transmission power reduces the number of accidents for Algorithm 1 but reduces the performance of relay Algorithms 2 and 3 as background data traffic increases. In Table III we can see in detail the averaged results of the Graphs, showing that Algorithm 3 will normally produce a slightly lower number of accidents due to the less channel overhead it causes.

According to previous Graphs in Figure 8 we have noticed that as the transmission power of vehicles increases, interference between notification packets and background data traffic sent to the environment will also get higher, thus causing a

TABLE IV
AVERAGE ACCIDENTS PERCENTAGE FOR ALL TRANSMISSION POWER VALUES

Algorithm	1	2	3
Avg. percentage	95.32%	72.82%	77.48%

significant growth in the number of car accidents. On the other hand, if transmission power is too low it will take longer for vehicles to receive safety information as the number of hops to reach destination will also be greater, and of course car accidents will consequently increase. As a result, a mechanism to adapt the transmission power according to the background data traffic present in the channel could be a good approach to keep the number of car accidents always low, regardless of the load of the communications channel. In the case in which every vehicle produces a parallel background data traffic of 700 kb/s, we can see in Figure 9 that there seems to be an optimum transmission power value for those cases in which relay Algorithms 2 and 3 are used, which will take a value between 5 and 10 dBm. This value depends on the current topology of the platoon of vehicles, the background data traffic and to a minor extent, the relay Algorithm used. In Table IV we can see that in average for the results obtained, only Algorithms 2 and 3 can guarantee a certain reduction in the number of collided vehicles. Even more, Algorithm 2 offers a better result than Algorithm 3 since SDR for this case is greater (because more notification messages are retransmitted), although the channel occupation is also higher.

We can conclude from this particular simulation test that background data traffic can be too damaging for safety related packet transmissions in which information must be delivered within the least time affordable. Above all, no-relay can be seriously affected by parallel background data traffic, as could be shown in Figure 8. With relaying, there will be a higher channel occupation, but it will be also guaranteed that packets will reach destination with a higher probability. However, performance of relay Algorithms will be worse as the transmission power is increased, whereas no-relaying mechanisms can perform better in this case when faced against low values of the transmission power.

C. Summary of results

In this subsection, the most relevant results obtained in the present evaluation study are summarized.

- When the channel occupation (in CCH) is minimum, one-hop transmissions with enough transmission power values guarantee high SDR in comparison with relay Algorithms, at the same time reducing the channel overhead and showing a similar behavior to relay Algorithms as regards the number of car accidents.
- No-relay can guarantee in general lower end-to-end transmission delays (mainly because messages are not retransmitted). This is only effective in those cases where there is no background data traffic sent to the radio channel.

- During the transition phase between 0% and 100% technology penetration, no-relay behaves very similar to the relay options if transmission power reaches a high enough value (normally the standard value, 28 dBm).
- Background data traffic affects dramatically the reception of warning notification messages, as can be indirectly deduced from the higher percentage of accidents which take place. There might be a theoretical optimum value for the transmission power which gives us the best trade-off between the lowest channel occupation (for a lower interference) and the SDR (in order to inform vehicles among the shortest interval of time over the incidence), so as to reduce the number of car accidents in the presence of additional background data traffic.

IV. Conclusions and Future Work

Relaying warning notification messages in CCA applications is a necessary requirement when the channel's bandwidth is shared with other different applications. Simulation cases in this evaluation study have revealed that under circumstances of low channel load, it is enough to use no-relay mechanisms to transmit CCA related information to vehicles in the platoon affected by an incidence of collision. Nevertheless, when the level of background data traffic is increased, relay can guarantee a better Successful Delivery Rate (as shown indirectly by Graphs of Figure 8, due to a lower rate of car accidents). In this respect, transmission power also plays an important role, since higher values of this magnitude allows for a higher number of vehicles to be under the zone of signal coverage. As a result, there is also a higher amount of data packets which are heard by vehicles and thus the packet collision probability also gets increased (more noticeable when comparing relay Algorithms in Graphs 8.a and 8.c in Figure 8). This makes us believe that there is an optimal value of the transmission power that allows for a correct functionality of the system (minimizing the number of accidents) and at the same time minimizing the problems associated to data packet collisions, which can reduce the Successful Delivery Rate. A mechanism that can estimate the channel load and provide an optimal value for the transmission power (reducing the channel load as much as possible, but allowing for an acceptable SDR) is a good chance to continue developing improvements for the present reactive CCA application. On the other hand, we have assumed for Algorithm 3, that the waiting time interval is always proportional to the sensitivity distance (the distance which in average the transmission power can cover according to the fading model used). It could be a good idea to perform an analysis of the behavior of the SDR and the end-to-end delay according to different configurations of the waiting time interval in Algorithm 3. Furthermore, another interesting aspect to be taken into account is to study under which circumstances of mobility vehicles are more prone to suffering an accident. It is the purpose of the authors to study relevant mobility models like the Human Driver Model [14] to generate an statistical model which can be used to define a risk factor for every vehicle as regards the possibility of getting involved in an accident. This could be used to provide significant improvements to the CCA mechanism, since packets would not be only sent after either suffering a collision or because of the relay of previously received information, but also due to the prediction of a possible situation of danger, thus informing vehicles even before about what is going to happen.

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