Performance evaluation of a CCA application for VANETs using IEEE 802.11p

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***Abstract*—Improving safety on the road is one of the most challenging goals of recent investigations in VANETs (*Vehicular Ad-hoc Networks*). CCA (*Chain Collision Avoidance*) applications are a new emerging means of reducing the number of accidents on the road by providing cars with collaborative communication capabilities, thus allowing them to react against the real risk of accident which may occur in different traffic circumstances. In this paper a CCA application is presented, evaluating the performance of a one-hop notification delivery scheme for vehicles in danger of a chain collision. Security improvements when using such a system are revealed, showing that the transition from a scenario with no CCA support on vehicles to other implementing full CCA capabilities on cars will at first yield some difficulties which must be thoroughly evaluated.**

I. Introduction

New safety related mechanisms to reduce the number of car accidents on the roads are associated primarily to the deployment of new information technologies in cars and roadside equipment. Vehicle to vehicle (*V2V*) and vehicle to infraestructure (*V2I*) communications provide a means with which traffic can be regulated to some extent and in this way reduce the risk of accident, increase driving comfort and implement infotainment communications (Internet access, mail service, etc.) on vehicles [1].

The implementation of these communication mechanisms relies on the protocol stack which is designed for the on-board units (*OBU*) to be installed on vehicles, as well as the roadside units (*RSU*) deployed along the road. Currently the IEEE organization works hard on defining the Standard WAVE 1609/IEEE 802.11p (*Wireless Access in Vehicular Environments*) [2], a specific protocol architecture for communications in scenarios of vehicular traffic. IEEE 802.11p, expected to be released in November 2010, guarantees access differentiation while assigning different policies of prioritized access, which altogether accounts for four different service scheduling schemes [3]. This obviously allows the transmission of different classes of packets while providing effective ways for keeping priority of safety-related applications against other not so critical user services.

Among safety-related applications, those devoted to *Chain Collision Avoidance* (CCA) have received special attention in recent years [4], [5]. These previous works show that CCA services can help reduce the number of accidents and propose some relay schema to improve the notification process. However, it is not clear yet in which situations it is necessary to implement a relay policy and on which basis should be developed such a mechanism. That is, when or why a relay mechanism is necessary, or even whether just a single transmission could be enough; and which of the system parameters, like transmission power, intervehicular distance or reaction time, may have more influence on the CCA operation. In this paper, a CCA application is studied to evaluate the conditions required to retransmit notification alerts in case of emergency deceleration in a platoon of vehicles driving in convoy. We show that relay mechanisms are a complementary aid in certain situations in which for a given transmission power, single one-hop delivery schemes are not sufficient to reach all vehicles inside the platoon. Improvement over systems without any communication capability as well as other factors like the influence of the human's reaction time are also evaluated to show the detailed behavior of such safety related applications for VANETs. Special attention is also devoted to the evaluation of scenarios where not all the vehicles are equipped with CCA support. In fact, our results show that when this situation occurs the number of accidents increases compared to a scenario where no vehicle has CCA support at all. This counterintutive result implies that it is necessary to carefully design the CCA mechanism, specially in the transition period until this technology would become completely adopted.

The rest of the article is organized as follows. In section II a description of relevant related work is introduced, and compared to the features of our CCA application. In section III we describe in detail the most important aspects of the different scenarios we want to simulate and we carry out a performance evaluation accompanied by some illustrative results. Section IV finishes the paper with some concluding remarks, as well as the future work derived from the present evaluation study.

II. Related Work

Ensuring prompt delivery of emergency brake notifications is crucial for CCA applications. Previous research evaluates the performance of different retransmission schemes for CCA applications. It is the case of [5] where a collision avoidance strategy for intelligent transportation systems is implemented. They propose a vehicle clusterization mechanism based on

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different parameters such as speed, intervehicular distance, etc. A risk-aware MAC protocol is also designed (based on IEEE 802.11e), in which an emergency level is assigned to every vehicle in the different clusters, and which is used to modulate backoff stages to keep priority differentation for critical applications. However, this service differentiation is already supported in the draft IEEE 802.11p which is used as the MAC layer implementation of our CCA application. In [4] different broadcast algorithms for emergency notification delivery are assessed to obtain the rate of car crashes under different values of both car and network traffic configuration parameters. A direction-aware protocol and service differentiation between non-safety oriented applications and CCA are evaluated, as well as the effects of channel errors. They consider a naïve approach where all cars retransmit the notification as the baseline mechanism. However, we consider that just single transmission should be evaluated first as baseline. In fact, as we show, this simple mechanism performs equally well except for intervehicle distances in the medium range. The performance of routing mechanisms in this context is evaluated in [6]. The routing schemes are pure flooding, OLSR (*optimized link state routing*) and GAF (*geographic aware routing*). Surprisingly, pure flooding outperforms the other two routing mechanisms in ratio of delivered packets and average end-to-end delay due to the fact that in this method vehicles retransmit everytime a message is received, and consequently the number of relayers is higher and information can reach destination earlier. However flooding generates a significantly large network traffic overhead, and for the sake of efficiency in every CCA application, it is always important to send as less redundant information to the medium as possible.

III. Simulations and Results

The simulation platform NCTUns 6.0 Network Simulator [7] was chosen to be the main tool to simulate the different aspects of our CCA application. Among other interesting issues NCTUns implements the current draft of WAVE (*Wireless Access in Vehicular Environments*), which was briefly introduced before.

A. General scenario description

The general scenario we want to test consists of a two way road in which vehicles circulate in opposite directions (Fig. 1). We concentrate only on one road direction, where cars drive in convoy. When a collision occurs, cars behind the first colliding vehicle react according to one of two possible patterns: starting to brake due to a notification coming from the first vehicle (Fig. 1), or beginning to decelerate after noticing a reduction in speed of the car inmediately ahead (Fig. 2).

To test the worst case situation, cars do not have the chance of modifying their trajectory of movement. Speed is expressed in m/s, intervehicular distance is varied in steps of two meters, ranging from 6 to 70 meters. Signal transmission power is only accounted for the case with communication capabilities, and takes two values: 22 and 28 dBm. For the drivers' reaction time, two cases are studied: one in which

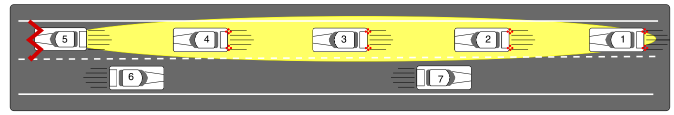

Fig. 1. Simulation scenario with 802.11p communication capabilities

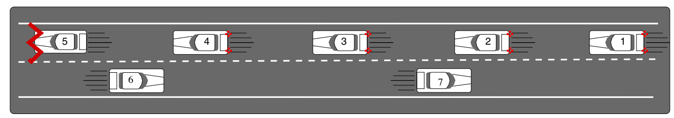

Fig. 2. Simulation scenario without vehicular communication capabilities

vehicles react automatically to the reception of a notification (without any intervention of the driver), and which takes a value of 0.2 s, and the other case, in which after receiving the notification, a driver has to react to this information, thus needing an additional uniformly distributed interval of 0.5-1 s to start braking. And as an additional parameter we evaluate how the system works when support for CCA capabilities among the platoon of vehicles reaches only a certain value of deployment (100%, 75%, 50%, 25% and 0% of the total number of vehicles in the platoon).

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

- **Percentage of accidents in simulation**. In this case, according to a fixed driving speed, the percentage of collided vehicles is represented against different values of the average intervehicular distance parameter.
- **General merit factor of the system**. We measure the quantitative improvement of the system by taking the number of accidents which were avoided using CCA divided by the total number of collided cars in the system without CCA and computing the average for all the intervehicle distances.

B. Results

In this subsection results related to four different scenarios are presented and discussed. Simulations are carried out according to a 99% confidence interval for every case and are performed using a Nakagami fading model, in which we use different values of the Nakagami-m parameter according to the so-called *Combined Approach*, which has already been shown to recreate more faithfully the influence of the environment in the process of electromagnetic propagation in vehicular scenarios [8].

1) Scenario 1: In this first simulation case we compare mainly the functionality of the system with and without the support of communication capabilities, as well as the influence

TABLE I
CONFIGURATION PARAMETERS FOR THE SIMULATION SCENARIOS

Scenario	No. vehicles	Speed	Interv. dist.	Tx. power	Reaction time	CCA Support
1	31,41,51	30 m/s	[6-70] m	22 dBm	0.2 s	100%,0%
2-I	31,51	30 m/s	[6-70] m	22 dBm	0.2 s,[0.5-1] s	100%
2-II	31,51	40 m/s	[6-70] m	22 dBm	0.2 s,[0.5-1] s	100%
3	31,51	30 m/s	[6-70] m	22,28 dBm	[0.5-1] s	100%
4	31	30 m/s	[6-70] m	28 dBm	[0.5-1] s	100%,75%,50%,25%,0%

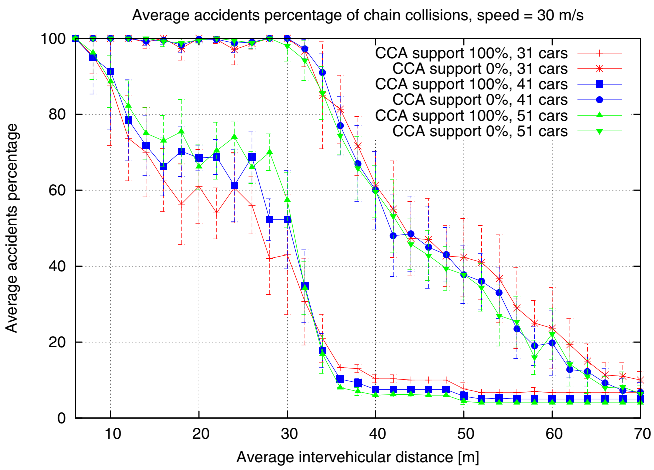

Fig. 3. Percentage of accidents as a function of the average intervehicular distance (Scenario 1, CCA vs. No-CCA)

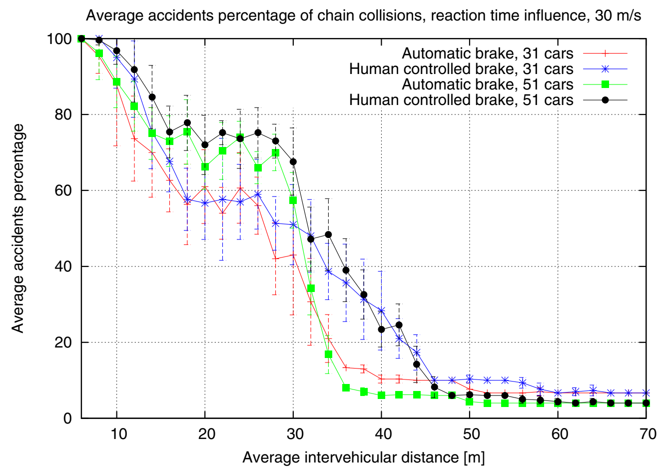

Fig. 4. Percentage of accidents as a function of the average intervehicular distance (Scenario 2-I, automatic brake vs. human controlled brake, 30 m/s)

TABLE II
MERIT FACTOR COMPARISON FOR SCENARIO 1

Vehicles	Merit factor
31	50.29%
41	46.83%
51	45.03%

TABLE III
MERIT FACTOR COMPARISON FOR SCENARIO 2 (30 M/S)

Vehicles	Automatic	Human	Difference
31	50.29%	41.57%	8.72%
51	45.03%	33.31%	11.72%

of the total number of vehicles. Table I shows the rest of the parameters configured for this scenario.

Fig. 3 shows clearly that the use of vehicular communications can highly reduce the percentage of collided vehicles. Depending on the transmission power used, not all vehicles in the platoon are able to receive notification messages on time, hence the behavior of central regions in the range 12-35 m of average intervehicular distance. The behavior of the graph in this region can be explained by those vehicles sufficiently far away from the first colliding vehicle (the sender) which do not receive the accident notification. They cannot start to brake on time and then the percentage of collided vehicles does not decrease so steeply. In the same region, the higher the number of vehicles in the chain, the greater number of collisions, since the number of vehicles which does not hear notifications is also higher. The behavior for the system without CCA support shows that it is needed an average intervehicular distance of 40 meters to have a reduction of at least the 50% of accidents. The improvement (around a 50% for the three cases, Table II) when using the communications system is then obvious. Summarizing, there is a critical region where relaying becomes necessary, which depends on vehicle clustering (intervehicle distance) and transmission range.

2) *Scenario 2:* In this second simulation case we evaluate how the system with CCA capabilities performs when the reaction time to the emergency deceleration (either due to the reception of a notification or because of the brake lights of vehicles ahead) is varied. Simulations compare a scenario of automatic brake reaction (with a latency of 0.2 s) versus human controlled reaction (0.2 s plus 0.5-1 s human reaction time). The rest of the configuration parameter values are shown in Table I.

Looking at the graphs we can distinguish a region between 0 and 30 m of average intervehicular distance for the Fig. 4 and a similar region between 0 and 40 m of average intervehicular distance for the Fig. 5 in which automatic braking does not imply a significant improvement over human controlled braking. However, in the middle region which takes from 30 till 50 m of average intervehicular distance in Fig. 4 as well as in the region from 40 till 60 m of average intervehicular distance in Fig. 5, it is easy to notice that the improvement of

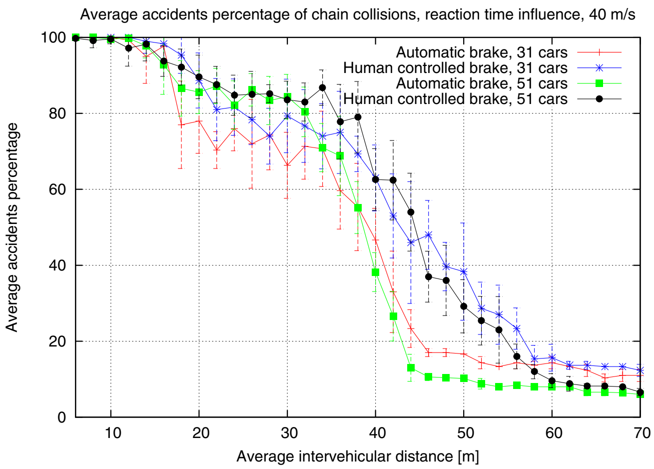

Fig. 5. Percentage of accidents as a function of the average intervehicular distance (Scenario 2-II, automatic brake vs. human controlled brake, 40 m/s)

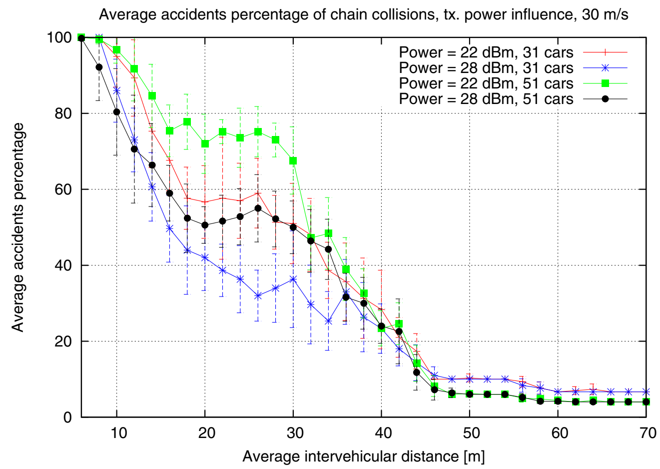

Fig. 6. Percentage of accidents as a function of the average intervehicular distance (Scenario 3, transmission power influence)

TABLE IV
MERIT FACTOR COMPARISON FOR SCENARIO 2 (40 M/S)

Vehicles	Automatic	Human	Difference
31	40.24%	29.05%	11.19%
51	37.85%	26.45%	11.4%

TABLE V
MERIT FACTOR COMPARISON FOR SCENARIO 3

Vehicles	22dBm	28dBm	Difference
31	41.58%	53.08%	11.5%
51	33.31%	46.33%	13.02%

automatic braking over human controlled brake is important, due to the fact that for these distances vehicles already have a real chance of stopping without colliding. Thus we can conclude that at middle intervehicular distances the reaction time factor has a major influence over the number of accidents.

In Tables III and IV we can see the differences in the merit factor of the system for every simulation. We can notice that the higher the speed of vehicles is, the worse the merit factor gets, as can be deduced from the fact that higher speeds require larger distances for vehicles to stop without colliding. Let us remark that these values provide an overall system improvement *averaged through all the intervehicle distances*.

3) Scenario 3: In this scenario we focus on the performance difference when changing transmission power values in our CCA application. We test the functionality provided by our application by assuming two different transmission power values (22 and 28 dBm). The rest of the configuration parameter values are found in Table I. Fig. 6 shows the results obtained.

As can be expected, higher values of the transmission power imply a larger number of vehicles under signal coverage, hence resulting in general in fewer accidents. It is remarkable how there is a certain value for this parameter that provides a considerable reduction in the amount of accidents, and shows what seems more intuitive, that the notification must reach a minimum safety distance to minimize the number of collisions. Merit factor (Table V) shows that when transmission power covers a larger number of vehicles it is possible to reduce more significantly the amount of accidents (Fig. 6). We conclude here that a retransmission policy, as an additional system, should mostly operate according to the location of vehicles in a convoy in order to further reduce the maximum number of collided vehicles when the transmission power is fixed and cannot reach the whole platoon of cars. Therefore, our evaluation study may serve to feed and tune the appropiate parameters to activate the relay system. Intuitively, from our study, we can realize that this complementary system does not have to be complex and must be designed to minimize the number of safety notification packets provided they travel as long and fast as possible.

4) Scenario 4: In this subsection we evaluate how the system works when the support for CCA capabilities does not reach the 100% of deployment among the different cars in the platoon. The rest of the values for the configuration parameters can be found in Table I.

If we compare in Fig. 7 the cases with full (100% of vehicles equipped with CCA) and null support (0% of vehicles) versus the other results (25%, 50% and 75% of vehicles with CCA support) we can notice two major features. At first, it is clear that in general for short intervehicular distances (under 40 m) the higher the percentage of CCA support among the convoy of vehicles, the fewer the number of car accidents. This implies that CCA support is beneficial for low intervehicular distances because in average the number of car accidents is always reduced when the percentage of CCA support is increased. However, at longer intervehicular distances, having a mixed compound of vehicles with and without CCA capabilities (as it would happen at different deployment stages) turns out in a worse behavior of the system which is reflected in the regions at the right side of the graph in Fig. 7. In these regions, for 25% as well as for 50% and 75% support, the number of accidents

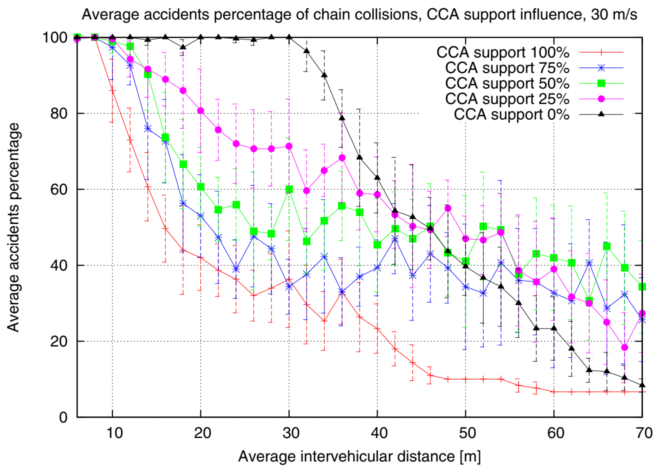

Fig. 7. Percentage of accidents as a function of the average intervehicular distance (Scenario 4, CCA support influence)

TABLE VI
MERIT FACTOR COMPARISON FOR SCENARIO 4

Vehicles	100%	75%	50%	25%
31	53.08%	26.36%	13.91%	6.69%

in average is higher than for the case without CCA capabilities. This behavior can be explained assuming that whenever a vehicle receives a notification or notices a deceleration of its next ahead vehicle, it will always try to stop timely to avoid crashing with its inmediately ahead neighbor. Obviously, this may cause a vehicle to collide with its neighbor behind due to a lack of CCA support of the following car. Table VI shows that a 25% of reduction in the number of CCA-equipped vehicles in the platoon turns out in half the value of the merit factor with respect to full CCA support (26.36% versus 53.08%). For the other two cases, as we can see, the merit factor is also notably lowered.

We can conclude that, in spite of the simplified scenario evaluated, CCA may reasonably entail a dangerous risk at these intervehicular distances when full CCA support is not possible. This basically would not be a problem if CCA were not used. For this reason, it is obvious that for a correct introduction of the technology in the market these cases must be fully evaluated and a study of how can be solved the apparently problematic transition of null CCA support to full CCA support among vehicles with communication capabilities must be necessarily conducted.

IV. CONCLUSIONS

The use of CCA capabilities in vehicular networks guarantees passengers to drive with a much higher level of safety (when full CCA support is implemented in vehicles among the platoon). The dependence of collided vehicles against intervehicular distance actually relies upon the speed of vehicles, the reaction time to the event, the transmission power (only for CCA) and to a remarkable extent the percentage of CCA support among vehicles inside the platoon. Reaction time can increase the number of accidents if the brake system relies on the driver's reaction when compared with the automatic brake system of the vehicle, mostly for middle intervehicular distances. Speed always plays a crucial role in results. Obviously, the higher the speed of vehicles, the greater the number of accidents. Transmission power is also a critical factor when we compare simulations of CCA applications for different values of this parameter. As we could see here, a very simple one-hop delivery policy can perform well when power can reach most of the vehicles in the convoy. However, when it is not possible, the number of accidents increase partially, as illustrated in previous scenarios. On the other hand, the transition between the current state of vehicular traffic (without communication capabilities) and that with full 100% support must be seriously evaluated. We have shown that for CCA applications, when not all vehicles support communication capabilities some undesiderable phenomena can appear, turning the system perform worse and implying a larger amount of accidents for some cases in which not using CCA would be a better idea. Our future research is to study how this issue can be solved and improve the presentation of results so that we can also show the severity of accidents (it is not the same crashing at 5 m/s or 30 m/s). We will also investigate different mechanisms for an efficient retransmission policy which can minimize the number of packets delivered, while keeping it as simple as possible, at a fixed transmission power value determined beforehand.

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