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Support of Safety Services through Vehicular Communications: The Intersection Collision Avoidance Use Case

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***Abstract*—Cooperative systems are based on the periodical exchange of standardized information, thanks to which vehicles can advertise their presence, position and the direction they are moving to, and execute sophisticated C-ITS applications that can detect potentially dangerous situations and properly react. The technological pillar, which must enable a Vehicular ad Hoc Network (VANET), is now being debated: the candidates are the traditional WiFi-based approach and the upcoming cellular one. The application effectiveness, however, depends not only on the technology, but also on how fast it is adopted and becomes widespread, i.e., the so-called technology Penetration Rate (PR). In this paper, simulation is used to evaluate the Intersection Collision Avoidance (ICA) application for both candidate technologies, and evaluated as a function of the technology PR.**

***Index Terms*—Vehicular Networks, 802.11p, LTE-V2V Communications, Automotive safety services, ICA Application**

I. Introduction

In recent years the research community has been focusing its attention on cooperative systems, driven by the social and economic advantages expected from Intelligent Transportation Systems (ITS). Among the various fields of application, safety is one of the major area of interest; indeed, the death tool of road crashes around the world is estimated to be 3400 people every day, while tens of millions of people are injured or disabled every year [1]. The target of ending roadway fatalities is pursued both in Europe and in America, the former with the "zero vision" of the European Transport Safety Council (ETSC) [2] [3], the latter with the Road to Zero Coalition (zero road death by 2050) promoted by United Stated National Safety Council (NSC) and National Highway Traffic Safety Administration (NHTSA).

The key principle of cooperative systems is the possibility to have a decentralized network where all the enabled nodes are capable to mutually interact, being part of a community independently from their origin. Vehicles in the community exchange a brick of information (e.g., speed, direction) in order to increase the awareness of the community on what is happening on the road. The higher the number of members in the community, the higher the benefits that can be gained. Thus, the first question the paper will address is: "Given an application , is there a threshold beyond which the application is sufficiently[1] effective?"

As for the network, since its conception, the technological enabler of cooperative systems is the Vehicle to Everything communication (V2X), based on IEEE 802.11p. Recently, the leading standardization body for mobile networks, 3GPP, has begun work on a new standard addressing V2X communication within the framework of the next generation of mobile networks, i.e., the so-called "5G" networks. Such a standard is being touted as an alternative to the traditional IEEE 802.11p approach. 3GPP proposes to adopt two approaches: the one based on the *Uu* interface, where communication from each vehicle needs to pass through an infrastructure node to reach another vehicle (through uplink and downlink connections), and the other based on the *PC5* interface, where direct links, or "sidelinks", among vehicles are possible. The latter is also referred to as C-V2X. In this paper, we will address the performance comparison of IEEE 802.11p V2X networks and the more recent C-V2X standard in safety scenarios.

From the regulatory viewpoint, western governments, like the European and the North American, have adopted an open position with reference to the technology to be chosen for the deployment of cooperative systems. Indeed, the European commission, in the recent Communication document COM(2016) 766 [4] claims that "the C-ITS messages should be unaware of, and thus flexible about, the communication technology used".

Assessing technology effectiveness, with reference to the technology PR, needs the selection of the application which will provide the field of comparison. Guidelines for the selection have been:

1) the potential benefit that the application could provide to the Road Safety;
2) the Governments C-ITS application roadmaps;
3) the maturity of the application from an implementation point of view.

Referring to the Maximum Abbreviated Injury Score' (MAIS) scale to measure the severity of injuries, where

[1]Thresholds are linked to each company business evaluations

MAIS3+ is "serious" and beyond (death probability bigger than 8%), in 2015 ETSC claims [5] that the weight of side impacts in MAIS3+ passengers car accidents accounts for about 35 to 40%; on the same figures also the analysis of US-DOT [6].

Focusing on applications mostly linked to intersections, ICA and Left Turn Assistant (LTA) should be considered, since both are listed as Day-1 applications of European and North America Market. Their crash avoidance effectiveness is similar and it has been evaluated [7], on average, in the order of 50%. On the other hand, looking at the readiness of the application [6], the LTA application appears to be less mature, due to the difficulty of clearly identifying the driver's intention to turn left.

For the aforementioned reasons, the paper will focus on the ICA application to compare candidate technologies at different level of PR. The paper is organized as follows: Section II analyses the current efforts made by the scientific community to evaluate and compare the different V2X technologies, Section III presents a detailed description of the ICA application and our own implementation, Section IV gives an overview of the simulated scenario, while in Section V simulations results are presented and discussed. The paper ends with our conclusions in Section VII.

II. Related work

A considerable amount of literature has been published on VANET architecture and applications, e.g., [8]–[12]. Many of these works, such as [10]–[12] perform comparisons between IEEE 802.11p and the standard LTE network (non-V2V) for vehicular application. In particular [10] highlights the higher capacity, coverage and penetration of LTE with respect to 802.11p, which is also affected by scarce scalability and unreliable transmission. [12] agrees stating that LTE offers superior network capacity with respect to 802.11p and is suitable for all case studies. On the contrary, [11] considers LTE unsuitable for collision avoidance applications, due to problems caused by Doppler effects and handoffs of LTE networks. The issue of choosing the best communication technology is currently subject of intense debate in the scientific community.

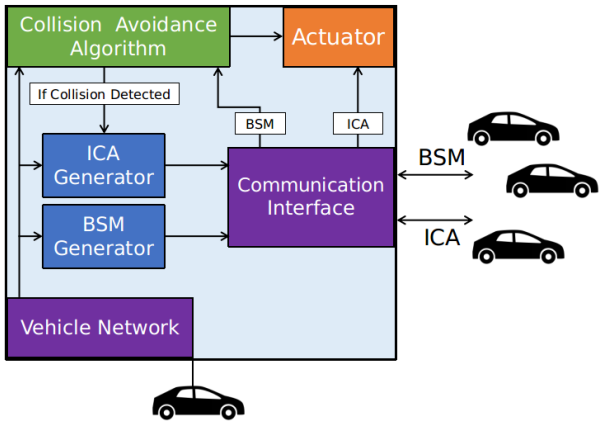


Fig. 1: Vehicle's OBU logic blocks.

Since the introduction, in 2015, of 3GPP Rel-14, the LTE standard for V2X based on the PC5 interface, a much debated question is if it can replace 802.11p as the de-facto standard for vehicular communications. Interesting attempts to compare the two technologies have been made in [13]–[15]. In [13] the authors question the effectiveness of LTE-V2V, stating that the 3GPP standard, being in its early development stages, suffers of many problems including synchronization and resource allocation, especially in out-of-coverage scenarios. In [14] Cecchini *et al.* have demonstrated that LTE-V2V achieves better results in terms of packet reception ratio but, under particular conditions, 802.11p is preferred for what concerns update delay. In [15] the authors claim that 802.11p have to be preferred for limited distances while LTE-V2V offers a bigger connectivity range.

A big part of literature is also focusing on safety applications for VANETs, e.g., [16]–[21]. [16] compares the two V2V technologies claiming that LTE-V2V is able to reach the same beaconing periodicity with less resource dedicated. [17] is instead focused on the intersection collision probability and on the importance of finding the correct beaconing schema. However, the literature does not offer simulation-based studies comparing the differences between 802.11p and LTE-V2V for a promising application such as the ICA. The experimental work presented here, which is partially based on the collision avoidance algorithm introduced in [21], aims to fill this gap and, in addition, it provides one of the first investigations about the influence of technology PR on the performances of road-safety applications.

III. ICA Application

A. Application Description

The ICA application, running on a host vehicle, is activated in the proximity of an intersection and aims at avoiding (or at least mitigating the risk of) collisions with approaching vehicles. ICA is designed to alert drivers about the presence of unseen vehicles or other unexpected obstacles, and possibly to activate the emergency braking system.

The application is based on three main logical blocks:

1) context awareness;
2) risk evaluation;
3) decision blocks.

Context is provided by data fused from multiple information sources: host vehicle data, ADAS sensors (ultrasonic, lidar, radar, camera) or messages exchanged through V2X communication which can be interpreted as a virtual ADAS sensor capable to detect vehicles beyond obstructions and buildings.

Depending on the vehicle equipment, when the risk of a collision is detected, decisions that can be taken range from simple warnings to emergency system actuation, with the proper braking profile. The vehicles taken into account in this paper are not equipped with other ADAS sensors.

B. Design of the ICA Application

Our ICA application relies on the periodic exchange of messages among vehicles. This continuous exchange of information allows vehicles to be aware of the presence of other road users at crossroads. In this way, it becomes possible to foresee potential dangerous situations and warn drivers.

Every vehicle equipped with an OBU embed the logic blocks depicted in Fig. 1. Such vehicles, through their communication interface, periodically broadcast anonymous messages, carrying diverse information such as position, heading, speed and acceleration. These messages are called *Basic Safety Messages* (BSMs) according to IEEE standards (or CAMs by ETSI standards) and are sent with a frequency of 10 Hz (every 0.1 s, i.e., the frequency provided by IEEE and the maximum frequency allowed by ETSI standards [22]). When a generic vehicle v_B receives a BSM sent by v_A, v_B updates its internal storage table with fresher information on v_A, and then the collision avoidance algorithm determines if the two vehicles are set on a collision course. The collision avoidance algorithm used is exhaustively described in [21]. If a hazard is expected, the drivers of the two vehicles must be warned. The driver of v_B is alerted by a notification generated by the *actuator* (Fig. 1), which is displayed by the *Human-to-Machine Interface* (HMI). Simultaneously, an *Intersection Collision Avoidance message*[2] (ICA message) is prepared by the *ICA generator* of v_B (Fig. 1) and sent through its communication interface. As soon as the communication interface of v_A receives the ICA message, the actuator block instructs the HMI to display the danger notification for the driver. Afterwards, the collision avoidance algorithm running on v_B parses any pair of vehicles v_A-v_x to determine if other entities in the scenario may collide with v_A at the next crossroad. If a potential collision is detected, the ICA message is sent to both vehicles. The collision avoidance algorithm is run by every vehicle and triggered on each BSM reception.

IV. Reference Scenario

The reference scenario is the urban area depicted in Fig. 2, composed of three roads and two unregulated road crossings. These crossings are unregulated in order to have a higher collision probability between vehicles. Non-line-of-sight (NLOS) conditions are created by buildings located in the open space between roads.

The entities populating the scenario are vehicles that travel at a maximum speed of 13.89 m/s (i.e., 50 km/h) and follow only straight paths, i.e., they never turn left or right at junctions. This choice is not a technical limitation of the simulation; rather it is dictated by the will to investigate the baseline scenario, without further complications introduced by turn signals, as explained earlier. Vehicles enter the scenario from one of the six entry points at the edge of the map (*v1...v6* in Fig. 2), and their generation rate follows a Poisson distribution with parameter λ. The value assumed by

[2]Message format from SAE J2735 Dedicated Short Range Communications (DSRC) Message Set Dictionary

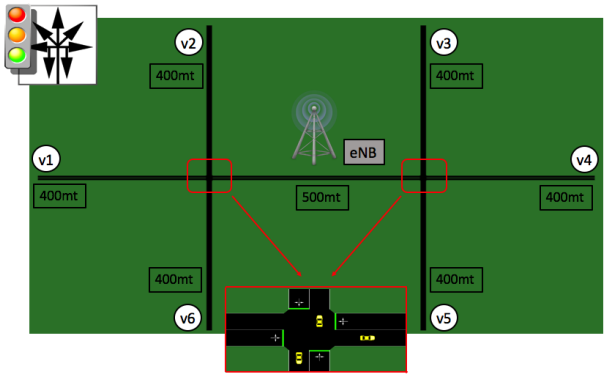


Fig. 2: Screenshot of the simulated scenario in SUMO.

λ must ensure a number of vehicles that is neither too low nor too high, otherwise it is not possible to correctly test the performance of the ICA service. Indeed, with a small number of vehicles we get little or no collisions while, with too many vehicles, intersections are clogged by long queues of snail-paced cars and collisions are virtually non-existent. Accordingly, we studied the growth of the average number of vehicles for different values of λ. The maximum value for which the scenario is not saturated is λ = 1.2. In our simulations we set it to 0.7, a value that allows us to observe a number of collisions that is sufficiently high to ensure statistically meaningful results. The communication among vehicles is ensured by on-board units (OBUs). According to the simulated communication technology, the OBU enables either the assisted C-V2V communication (the so-called "Mode 3") or 802.11p communication. Since a network-assisted C-V2V communication is simulated, an eNB is deployed at the center of the topology. Vehicles and eNB exchange control information, i.e., packets including synchronization and resource allocation scheduling. As far as 802.11p is concerned, no Road Side Unit (RSU) is present, since in this case vehicles do not need to transmit or receive control messages: channel access is regulated by CSMA-CA and thus no synchronization is required.

The simulations run to test the performance of the ICA application are performed through two different simulation frameworks: *SimuLTE-Veins* [23] and *Veins* [24]. The first is used to simulate the C-V2V communications whereas the second simulates 802.11p communication. Both frameworks leverage the SUMO mobility simulator [25].

V. Simulations Methodology

A. Simulations Case Studies

The first step of our work consists in running simulations using only the SUMO traffic simulator. In this way, it is possible to collect the number of accidents that occur in a scenario without communication among vehicles. In particular, we run 10 600 s-long simulations. This set of simulations represents our benchmark, on top of which we can evaluate

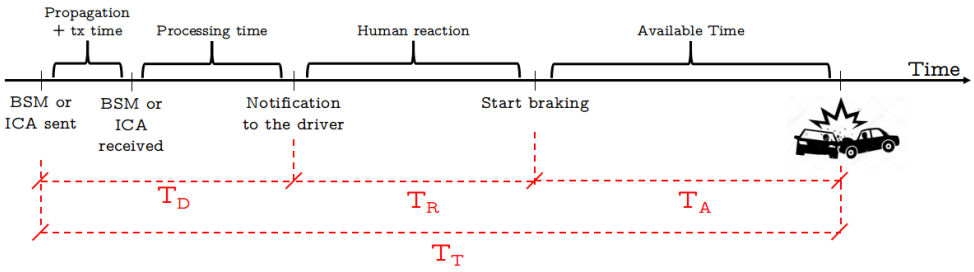


Fig. 3: Time-line describing the communication between vehicles.

the number of collisions that can be avoided introducing our application . As mentioned above, the two different communication technologies considered are IEEE 802.11p and C-V2V while their PRs vary according to four values: 10%, 25%, 50%, 100%. In every simulation, vehicles capable of exchanging messages use the same technology, i.e., all of them use either 802.11p or C-V2V.

The ICA application is tested considering two different approaches. The first is the one described in Section III-B, based on the transmission and reception of both BSMs and ICA messages, in which the vehicles evaluate the collision risk both for themselves and for all the other entities in the scenario. The second approach only relays on the exchange of BSMs since ICA messages are not generated. Therefore, in this scenario, vehicles run the collision avoidance algorithm only for their own safety.

Summarizing, our analysis can be divided in three parts:

- *Benchmark*: the simulations are run with SUMO (i.e., the V2V communication is absent) and the number of detected collisions is collected;
- *Case A*: the simulations include communication among vehicles and vehicles exchange only BSM messages;
- *Case B*: both BSMs and ICA messages are transmitted and received.

Moreover, the performance of the ICA application is assessed simulating two different transmission channels. The first one is a simple model in which the (log-normal) path loss depends only on the distance between the vehicles. The second model mimics more closely a real-world situation with NLOS conditions. Indeed, in this model we consider both the shadowing effect due to the buildings (typical of a urban environment) and the multipath fading. The latter is accounted for using the Nakagami model, which is particularly suited for vehicular scenarios.

B. Evaluation on the effectiveness of the ICA application

Whether a collision is detected in time or not is determined in the post-processing phase. The time-line describing the communication between two vehicles is shown in Fig. 3. A collision is considered as "detected" only if:

$$T_A > T_{BRAKING}$$

$T_{BRAKING}$ is the time needed to stop the vehicle and it is computed taking into account instantaneous speed and maximum deceleration. T_A is instead the time available to the driver, from the moment in which a proper alert message is issued in the vehicle HMI to the actual collision and it is computed as follows:

$$T_A = T_T - T_D - T_R$$

where:

- T_T: it is the time interval between the generation of the message triggering the collision avoidance algorithm and the actual collision;
- T_D: it is the time interval between the moment at which the message triggering the collision avoidance algorithm is sent and the moment at which an alert is notified to the driver through the HMI.
- T_R: the time needed by the human to take proper action after being prompted by a notification. It is fixed to 1 s, as suggested by [26] and [27], in which different factors such as age, travel length or environment, are considered.

A collision is labeled as "detected too late", instead, if the value of T_A is lower than $T_{BRAKING}$. Finally, a collision is considered as "not detected" if the ICA system did not detect a harmful situation that ended up in a real collision.

VI. Results and Discussion

The goal of the simulations is to analyze the performance of the ICA application. According to different technology PRs (10%, 20%, 50%, 100%), both the standards 802.11p and C-V2V are involved to enable the service. Each simulation is performed twice: in a first step a simple channel is considered, then shadowing and Nakagami fading models are introduced. The results are averaged over 10 simulations 600 s-long.

A. Case A: BSMs only

In Case A, vehicles exchange BSMs only among themselves and have to autonomously detect possible danger situations at the next crossroad.

The results of simulations for both channel models and for both technologies are reported in Fig. 4 and Fig. 5. They are expressed in terms of percentage of collisions detected, detected too late or not detected.

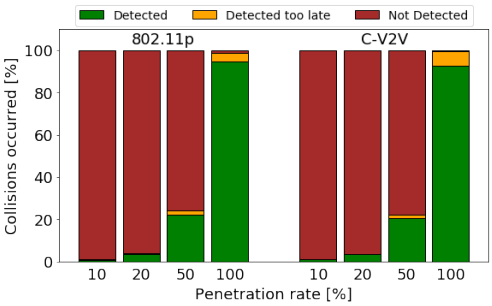


Fig. 4: Results for Case A - Simple Channel

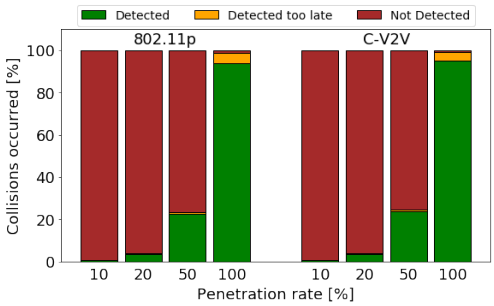


Fig. 6: Results for Case B - Simple channel

1) Simple channel: what stands out from Fig. 4, is that the ICA application is highly sensitive to the PR of the technology, independently of the communication protocol adopted. The trend is clear: the higher the PR, the higher the percentage of collisions correctly detected. It is important to highlight that these results depend on the joint probability that two vehicles set on a collision course are both equipped with an OBU. Consequently, the number of collisions detected is not linearly dependent on the PR. This finding is significant because it suggests that a V2V-based ICA application may not be worth developing in the next few years. According to predictions, based on the number of registered vehicles and vehicle sales in the U.S. in recent years[3], in 2028 the percentage of connected vehicles will be close to 45%. However, as can be seen from the histograms, with a PR of 50%, the performance of the ICA application is unsatisfactory since over 70% of collisions are not detected. Comparing the two communications technologies, the results show little difference. Indeed, it is only with a PR of 100% that both standards display nearly-optimal performance, detecting over 95% of collisions in a timely fashion.

2) Realistic channel: adding shadowing and Nakagami fading, the performance of the ICA application worsens. In particular, the percentage of undetected collisions increases for both the technologies. For 802.11p with 100% of PR, the undetected collisions move from 1.46% to 5.06%. A comparable degradation can be seen also in the C-V2V case. However, contrary to expectations, these results do not show a significant effectiveness degradation. Indeed, with a PR of 100%, the percentage of collisions detected in time is still high, around 85% for both technologies.

[3]NTSHA https://www.nhtsa.gov and USDT https://www.transportation.gov

B. Case B: BSMs + ICA messages

In Case B, every vehicle equipped with an OBU can send alert messages to other drivers to warn them about an impending collision. The major impact of the ICA messages is expected in the case in which the channel model includes both shadowing and fading. Indeed, when two potentially colliding vehicles are not in LOS, and a third vehicle is in LOS with both of them, the latter can react more quickly to the danger, sending the ICA message to the two drivers in time to avert the collision.

The results for this case are reported in Fig. 6 and Fig. 7.

1) Simple channel: the results in Fig. 6 show a behavior similar to the one observed without ICA messages, since the number of collisions detected in time with a PR equal to 100% is around 95%. As explained above, this is because the introduction of ICA messages brings few advantages considering all vehicles in LOS. The main benefit is a general improvement of the system responsiveness. Indeed, we observed a marked decrease of late-detected collisions in the C-V2V case, which move from 6.83% in Case A to 3.90% here.

2) Realistic channel: the results in Fig. 7 support the conclusions previously made. Indeed, the effectiveness of the

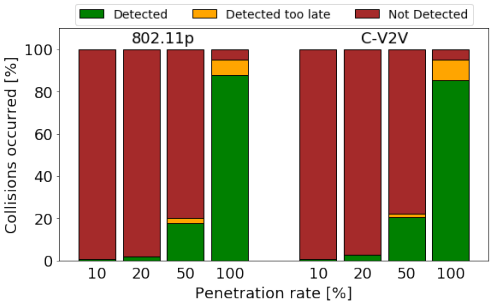


Fig. 5: Results for Case A - Realistic Channel

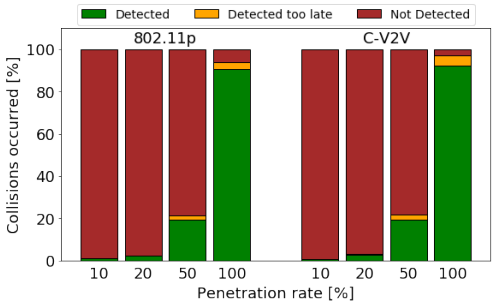


Fig. 7: Results for Case B - Realistic channel

ICA application can be enhanced with the ICA messages when vehicles are in NLOS (i.e., when both building shadowing and fading attenuate the signal). The comparison of these findings with those reported in Fig. 5 (Case A - Realistic channel) shows an increase in the number of collisions detected in time: on average, 5% for both standards.

VII. Conclusions

In this paper, we analyzed the performance of an ICA application in which the communication between vehicles was enabled by two technologies: IEEE 802.11p and C-V2V. We considered different technology PRs (10%, 20%, 50%, 100%) and two transmission channel models. The implementation of the ICA application followed two approaches: one in which vehicles, according to the information received by the exchange of BMSs, determine the collision likelihood between themselves and other vehicles. The other, based on the generation of a second kind of messages, the ICA message, through which vehicles warn other cars about possible collisions. Every case study is evaluated in terms of effectiveness of the application, i.e., the percentage of collisions that can be avoided introducing the V2V-based application.

Simulation results highlighted that only a very high PR ensures good application performance (over 85% of collisions avoided). Consequently, ICA applications based on V2V only, may not be one of the most effective services to implement in the next few years, unless considering a solution that relies on both the information obtained via V2V communications and collected through on-board sensors (e.g., radar, lidar, and cameras).

With 100% PR, 802.11p and C-V2V have similar performance and both are very reliable. Furthermore, for the scenarios in which shadowing and fading are accounted for, we can make two observations:

1) C-V2V performs slightly better since the collisions detected in time are 92%, versus 90% obtained using 802.11p;
2) the transmission of ICA messages can help, introducing on average, for both the technologies, an improvement of 5% in the number of correctly detected collisions.

In summary, beside exploring how to merge effectively sensory data with the information received through V2V communications, future research directions should also assess the performance of such an enhanced application in the case of low values of technology PR.

Acknowledgment

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