

AVOIDING CAR CRASHES USING CELLULAR V2I COMMUNICATION

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This article describes one of the research activities currently carried out within the Center for Automotive Research and Sustainable (CARS [note 1]) at Politecnico di Torino in the framework of Research Collaboration with TIM. The objective of the CARS Center is to foster multidisciplinary research and training activities, so as to speed up innovation and technology transfer. The activity we describe here tackles road safety, which is one of the key applications envisioned for C-V2I (Cellular Vehicle-to-Infrastructure) networks. Thanks to the exchange of Cooperative Awareness Messages (CAMs), vehicles and other road users can advertise position, heading and speed and sophisticated algorithms can detect dangerous situations leading to a crash. In this context, we focus on an application for collision avoidance at intersections and its deployment in a C-V2I-based infrastructure.

Introduction

In recent years, the development of vehicular network applications has been attracting increasing interest from industries and researchers. A critical field of application of vehicular networks is represented by safety; indeed, according to the World Health Organization in 2015 the number of people who lost their lives in road traffic is more than 1.2 million and an increasing trend in road casualties was observed in 2016 [note 2]. A most significant and, at the same time, challenging safety application is collision detection. One of the basic requirements for vehicles running such an application is that they periodically send CAM (Cooperative Awareness Message) to a detector. These messages are sent anonymously toward the BS (base station) and contain

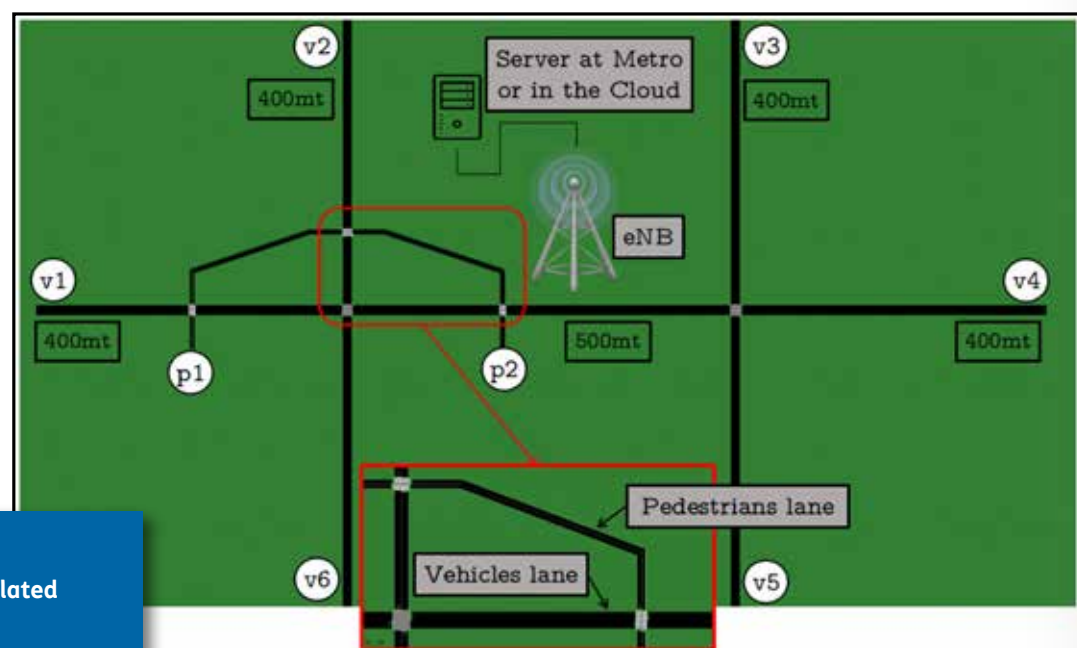
information about position, speed, acceleration and direction of the sender. The collision detector combines all the CAMs received by the vehicles determining if any couple of vehicles is on a collision course. If so, the drivers involved are immediately alerted. The communication between vehicles and detectors happens through BSs that make communication possible even in non-line-of-sight conditions, e.g., due to buildings or other obstacles. The application can be extended also to vulnerable road users such as pedestrians, whose smartphone can send CAMs to the detector. In this way, both drivers and pedestrians are timely made aware of possible life-threatening situations and can take proper action.

In this article, we evaluate the performance of a system for vehicle-with-vehicle and vehicle-with-pe-

destrian collision detection when C-V2I (cellular vehicle-to-infrastructure) is adopted as a communication technology. In particular, we are mainly interested in the number of collisions that could be avoided and in the number of false positive alerts (i.e., alert messages referring to situations of low or no danger, that the system delivers to the users). Indeed, a low number of false positive alerts is essential in establishing user confidence in the reliability of alerts received through the system.

Reference Scenario

The reference topology we consider (Figure 1) is an urban area composed of three roads, crossing at two intersections, a pedestrian lane and three pedestrian crossings. The



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Screenshot of the simulated scenario in SUMO

intersections and crossings are unregulated, which makes collisions more likely. The entities moving in the topology are vehicles and pedestrians. Each of them is connected to the cellular infrastructure and uses the collision avoidance service, i.e., we assume a penetration rate equal to 1. Vehicles are equipped with on-board units for C-V2I communications, whereas pedestrians carry a smartphone with cellular connectivity. Both periodically send CAMs toward the collision avoidance application server.

In particular, we consider an LTE network with an eNodeB (eNB) located at the center of the topology. The server hosting the collision detector can be located at different points of the network infrastructure, i.e., at the eNodeB itself or at more remote network nodes. In order to study the difference in performance, we consider two server deployments: at the Metro node (very close to the eNB), in an edge computing fashion, and in the Cloud (farther from the eNB). The choice of this urban topology allows us to have a simple but, at the same time, representative scenario, which closely mimics many real-world urban road layouts. In order to assess the performance of the collision detection service in our scenario, we use the SimuLTE-Veins simulator [note 3], which leverages the mobility simulator SUMO [note 4].

We use a realistic mobility model and a realistic generation rate of both vehicles and pedestrians. Ve-

hicles have a maximum speed of 13.89 m/s (i.e., 50 km/h) and they follow a straight path, i.e., there are neither left nor right turns at junctions; pedestrians move with maximum speed of 2m/s on the pedestrian lane, crossing the street at three different spots. Each generated vehicle is randomly assigned to one of the six entry points at the edge of the map (shown in Figure 1 and marked as v1...v6), while each vulnerable user is assigned to one of either ends of the pedestrian lane (p1 or p2).

Design of the Collision Avoidance System

The collision detection system that we developed is shown in Figure 3. The core of the collision avoidance service is the detection algorithm, a generic trajectory-based algorithm that can be applied to any kind of colliding entity (in our case both for vehicle-vehicle and vehicle-pedestrian collisions). Upon receiving a CAM, the algorithm running at the detector determines whether the sender of the CAM (referred to in the following as *focus vehicle*) is on a collision course with another node. To avoid cumbersome notation, we describe below the behavior of the detection algorithm in a qualitative fashion. Also, for simplicity, we refer to interactions between vehicles, although the same principles apply to collisions involving bicycles or pedestrians.

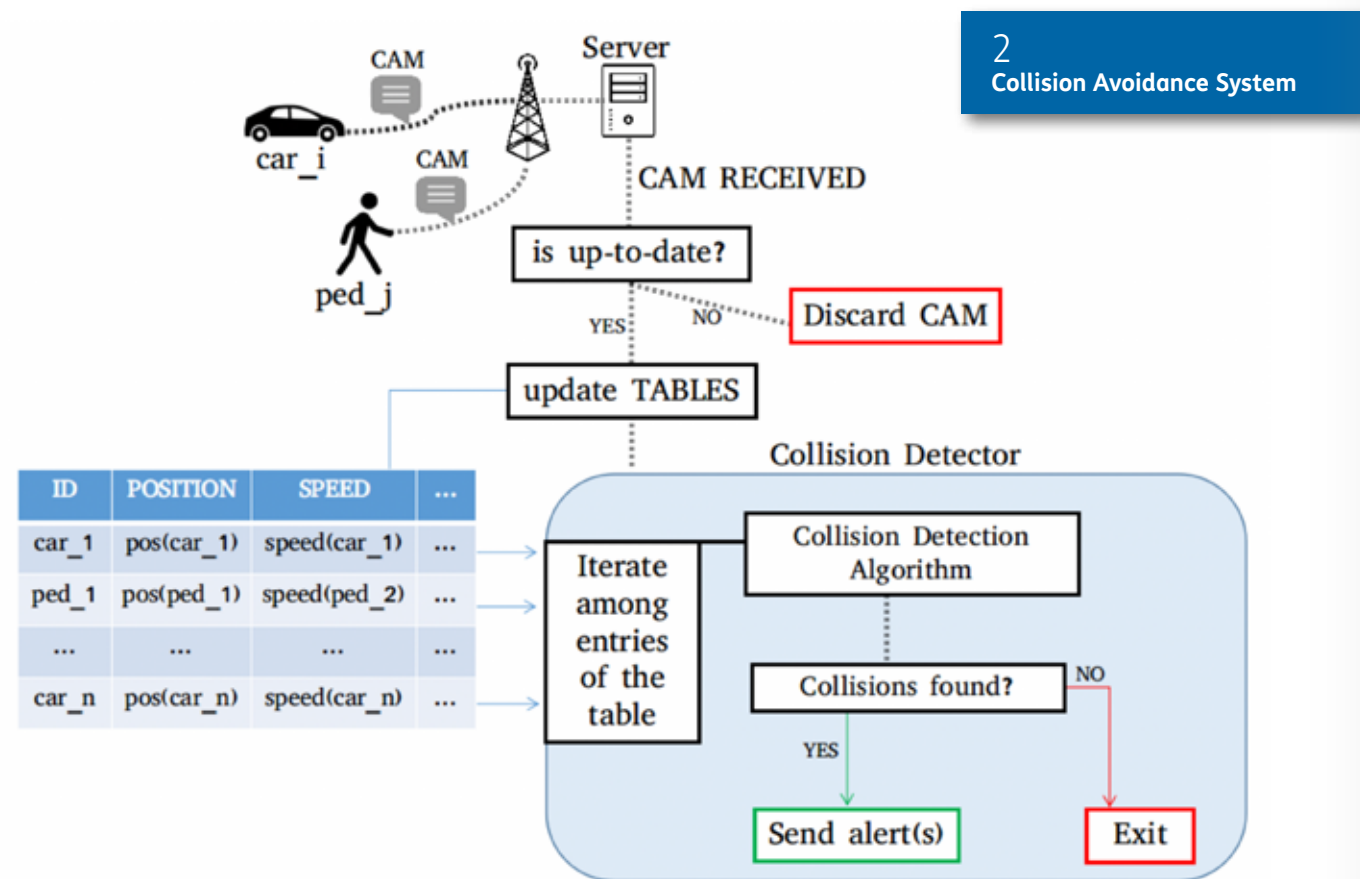
The collision detection algorithm requires as two kind of inputs:

- position and speed of the current vehicle, identified by two vectors (note that the speed vector also includes information on the vehicle heading);
- the latest CAM sent by each vehicle.

For each vehicle that recently sent a CAM, the algorithm computes its position and its distance with the focus vehicle. Then, it computes the time instant t^* at which the distance between the two vehicles is minimum. If $t^* < 0$, the two vehicles are getting farther apart, whereas, if t^* is greater than a threshold t_{2c} (where t_{2c} stands for *time to collision*), the minimum distance will not be reached within t_{2c} from the current time. The algorithm thus determines that no action is required.

If t^* is between 0 and t_{2c} , the minimum distance d^* at which the two entities will be at time t^* is computed. The algorithm compares d^* against a minimum threshold s_{2c} (space to collision): if d^* is lower, then an alert message is scheduled to be sent to the vehicles.

We can now describe the rest of the system in Figure 2. The frequency at which CAMs are sent by each entity is 10 Hz, which is the maximum frequency allowed by the ETSI standard [note 5]. This high value allows the whole system to work with updated information. Indeed, considering a lower frequency, e.g., 1 Hz, and a car moving at 13.89 m/s (i.e., 50km/h), the error at the server



(ignoring the transmission delays) would be in the worst case of 13.89 m. Clearly, such a high error is not acceptable when dealing with a safety application.

The detector placed at the server is able to distinguish between CAMs sent by pedestrians and CAM sent by vehicles. This gives us a double advantage. First, when the server receives a CAM from a vehicle, it looks for possible collisions with both cars and pedestrians, while on the contrary, with a message sent from a pedestrian, the algorithm skips the analysis for pedestrian-with-pedestrian collisions. The second advantage involves the pos-

sibility to set different parameters for the collision detection algorithm (i.e., $s2c$ and $t2c$), according to the type of entity which sent the CAM. This allows a better performance of the algorithm, in terms of false positives and false negatives.

Every time the detector receives a message, it checks if the message is up-to-date: if so, the server stores the information of the CAM; otherwise, the CAM is discarded. We set 0.8 s as the threshold beyond which a CAM is considered as stale and discarded. In the case of a fresh CAM, the algorithm checks if its sender is at risk of collision. To improve the system efficiency,

we also introduce a range of action: only the entities within such a range will be checked by the algorithm as potential colliders. The radius varies according to the vehicle speed as follows:

$$Radius = \max\{Speed \cdot t2c, s2c\}$$

When the server detects a pair of entities on a course of collision, they are warned by an alert message. In order to avoid an excessive number of duplicated alerts, the collision detector does not generate the same alert message more than one every second.

Thresholds and values used by the collision detector are summarized in Table 1.

Parameter	Vehicle	Pedestrian
$t2c$	10 s	3 s
$s2c$	5 m	2 m
Max CAM Age	0.8 s	0.8 s
CAM Frequency	10 Hz	10 Hz
Alert max Frequency	1 Hz	1 Hz

T1

Collision Detection Parameters for Vehicles and Pedestrians

Performance Results

We simulate our road scenario letting vehicles and pedestrian follow their trajectories without interference from the alerts received from the communication system. In a post processing phase, we analyzed the logs considering either a human driver or an automated vehicle case. Specifically, we analyze, for each collision, when it occurred and if the corresponding alert message was generated. Furthermore, if the alert was correctly transmitted, we also look at when it was received and

processed by the involved entities. In this way, we can determine if the vehicle had sufficient time to brake before the impact.

Whether a collision is detected in time or too late is determined in post-processing by considering the alert messages that have been received. A collision is considered as “detected too late” if:

$$T_A < T_B$$

where T_A represents the time available to the driver to avert the colli-

sion, i.e., the interval between when the driver initiates evasive actions and the actual collision. T_B , instead, is the time needed by the entity to stop, given its current speed and maximum deceleration. T_A is computed as follows:

$$T_A = T_{FA} - T_D - T_H$$

where the three elements in the above expression are illustrated in Figure 3 in the case of a human driver.

We run two sets of ten 300s-long simulations, one with the server at the Metro node and the other with the server placed in the Cloud. A conservative value of 5 ms for metro-eNB latency and 20 ms for cloud-eNB latency have been assumed. In the post-processing phase, each of the two simulation sets is analyzed considering either the human driver or the automated vehicle case. Intuitive, a better performance can be expected in the automated vehicle scenario, as $T_H = 0$.

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Timeline of the communication between the detection server and the human driver

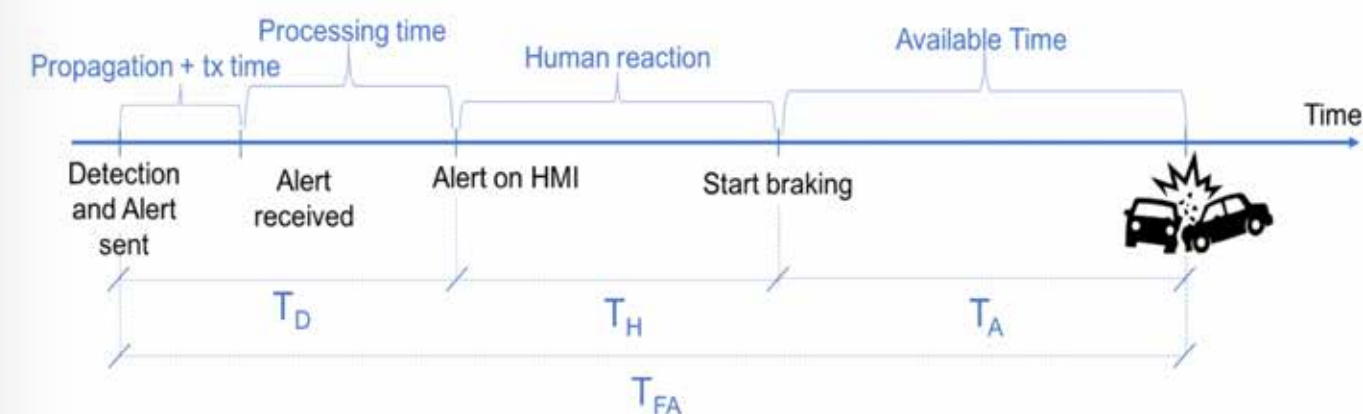


Figure 4 shows the effectiveness of our collision avoidance system in terms of number of accidents that can be prevented. The four bars show the number of vehicle-with-vehicle detected, late-detected and undetected collisions among those reported by the SUMO simulator. A collision is reported in SUMO each time the polygon describing an entity overlaps with the polygon describing another entity. The two left-most bars refer to the case in which the server is placed at the Metro node, both in the human driver case and in the automated case, while the other two refer to the scenario where the server is in the Cloud.

The first important result that we highlight is the effectiveness of our al-

gorithm: under the aforementioned settings, it reaches 100% in case of automated vehicle and over 80% in case of human driver, regardless of the location of the server. A second relevant result, is the absence of "Not detected" collisions in the four case studies.

Another issue to investigate is the study of the quality of alerts that are actually received by the vehicles, in order to find the fraction of false positives, i.e., the alert messages referring to situations of low or no danger. False positives are not as critical as undetected collisions but they may be a cause of distraction for human drivers. We will thus look at:

- total alerts sent: total number of alerts sent by the server to vehi-

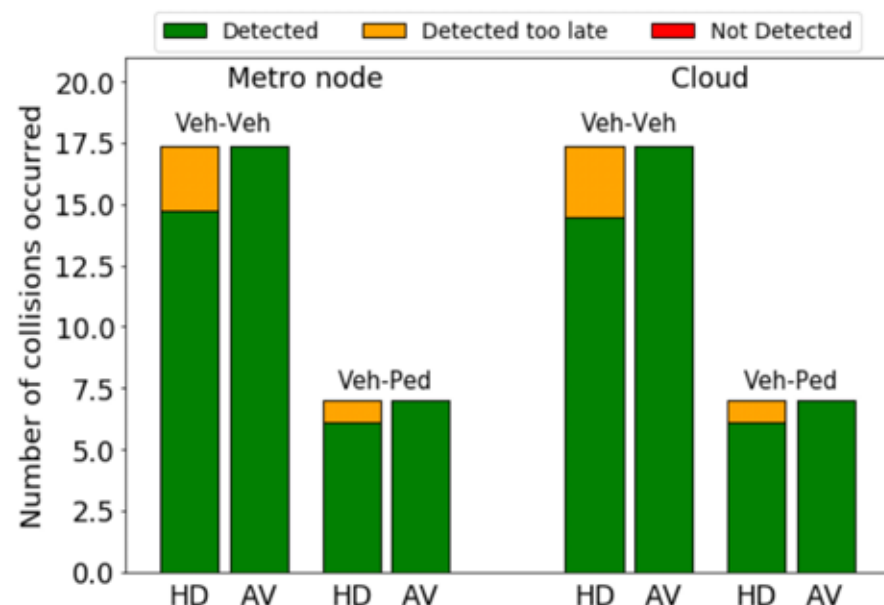
cles to warn them about detected collisions;

- true positives: alerts that have been sent and refer to collisions that occurred. They include:
 - true and timely positives: alerts for which the driver had enough time to brake before the collision happened;
 - true but late positives: alerts for which the driver did not have enough time to brake before the collision happened;
- false positives: alerts that have been sent and refer to collisions that would not take place.

shows the results of this analysis. The false positive percentage is high, greater than 60%, although their relevance is not so great, and it is caused by the limitations of our simulator. When we analyzed the logs, we found that 60% of the false positive alerts are sent to vehicles that got less than 2.3 m apart and that there are no vehicles warned by a false positive alert whose minimum distance is more than 5 m. This highlights that the false positive alerts are transmitted in situations that are indeed dangerous – a factor that is particularly important when possible inaccuracies of the positioning system are taken into account.

As a final remark, although the percentage of false positives is quite high, a C-V2I-based system can ensure high reliability in collision detection, and even false positives re-

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Vehicle-with-vehicle (Veh-Veh) and vehicle-with-pedestrian (Veh-Ped) collisions detected, detected too late and not detected, for the Human Driver (HD) case and the Autonomous Vehicle (AV) case, and for different server placements.



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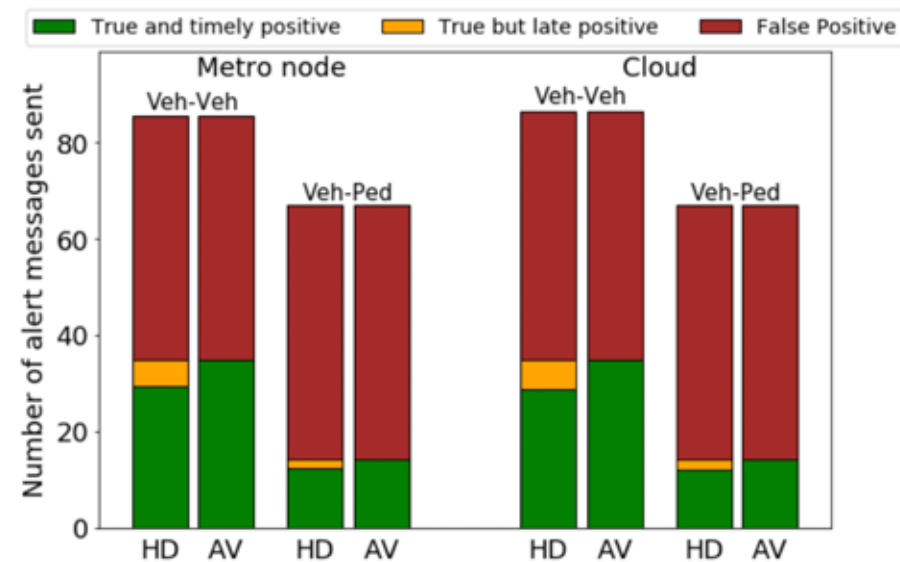
The complexity and rapid evolution of the technologies involved in automotive engineering and intelligent transport systems require a large number of skills acquired in different disciplines. In this context, the goal of the CARS Center is to build, inside the Poli-tecnico di Torino, an environment in which multidisciplinary research and training activities can be fostered to speed up innovation and technology transfer, in a territory with a strong industrial vocation that has been the cradle of the national automotive industry. To pursue the abovementioned aims, the Centre addresses the following research areas, which are strictly interconnected to each other:

- **Green Vehicles**, including (i) new powertrain and chassis technologies for future hybrid/electric vehicle to achieve higher vehicle and energy efficiency as well as safety improvements; (ii) powertrain & vehicle system integration, and control strategies; (iii) affordable zero/low emission vehicles, i.e., alternative and low-carbon fuels, advanced combustion for reduced CO2 footprint, and technologies for energy storage.
- **Safe & Integrated Mobility**, including (i) active, passive and preventive safety for passengers and vulnerable road users; (ii) enabling SAE high level automated vehicles, i.e., optimization and integration of sensors and actuators, decision & control algorithms for V2X interaction through 5G and other radio technologies, testing of driver support systems; (iii) design and operation of sustainable ground-based transport systems, and prototyping and analysis of energy consumption of non-self-propelled automated people movers.
- **Affordability & Competitiveness**, including (i) affordable lightweight products and processes (new



materials for interiors, vehicle body, and chassis structural parts), along with new composite materials integrating sensors/data transmission; (ii) competitive automotive innovative cycles for quick adoption and standardization of new processes and automation of manufacturing processes.

- **Urban Mobility and Logistics**, including (i) development of IT services and platforms for mobility and logistics systems, exploiting user-generated mobility data; (ii) city logistics and last-mile distribution models with focus on distribution network design of multi-tier storage and consolidation systems; (iii) technologies for last-mile distribution systems and security applications; (iv) design and validation of business models and public-private financing schemes for mobility and logistics systems; (v) models for the assessment of environmental, energy and socio-economic impacts, and decision support systems.
- **Sharing Mobility**, including (i) monitoring and analysis of current and potential trends; (ii) integration in traffic monitoring systems; (iii) evaluation of innovative strategies for EVs recharge ■



5 False positive statistics for vehicle-with-vehicle (Veh-Veh) and vehicle-with-pedestrian (Veh-Ped) collisions for the Human Driver (HD) case and the Autonomous Vehicle (AV) case, and for different server placements.

fer to actually dangerous situations. Furthermore, large margins of improvement are possible if additional information coming from on-board sensors (cameras, radars, lidars...) is merged with that available through the C-V2I interface, and advanced data fusion algorithms are used so as to provide the driver with a comprehensive, yet accurate, warning system.

Conclusion

In this article, we have described one of the research activities performed within the CARS center at Politecnico di Torino. In particular, we

focused on an efficient C-V2I-based system for automotive collision avoidance, and tested it under different scenarios. By exploiting the transmission of CAMs toward the collision detection server, the latter determines whether any pair of vehicles, or vehicle and pedestrian, are set on a collision course, and, if so, it issues an alert message. We deployed the server in two different points of the network, namely, in the Metro node and in the Cloud, and we considered both human drivers and automated vehicles. Two main directions for future research can be envisioned: (i) investigating the gain that cellular vehicle-to-vehicle (C-V2V) communications can bring; (ii) assessing the benefits that may

come from data fusion performed on CAMs and sensory data such as those collected via cameras, radars and lidars ■

Note

- [1] <http://www.cars.polito.it>
- [2] World Health Organization, Global Status Report on Road Safety 2015 and 2016.
- [3] SimuLTE and Veins. http://simulte.com/add_veins.html
- [4] SUMO Simulation of Urban Mobility. <http://sumo.dlr.de/>
- [5] ETSI EN 302 637-2 V1.3.1 (2014-09), Intelligent Transport System (ITS), Vehicular Communications, Basic Set of Applications.



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