On-the-Road Comparison of LTE-V2X Cooperative Awareness Message Distribution between Regular and Vulnerable Road Users

Martin Klapez, Carlo Augusto Grazia, and Maurizio Casoni

***Abstract*—This paper explores the possibility that awareness messages generated by different classes of vehicles might tend to emerge for different reasons, due to different typical driving patterns with different potential impact on channel congestion. Cars and motorbikes have been selected as the vehicles of choice, as they are expected to both disseminate Cooperative Awareness Messages while belonging to two different classes, i.e., regular and Vulnerable Road Users, respectively. Field trials with LTE-V2X have been carried out in an urban environment, as it is the one where differences due to different driving patterns are most likely to emerge. The paper unravels the reasons behind the triggering of awareness messages, presenting the distributions of the triggering conditions together with the PMF (Probability Mass Function) at any specific time of the messages triggered The main trigger has been found to be the distance for both vehicle classes. While having some notable differences, we found the triggers' distributions to be similar. Instead, the average time between consecutive awareness messages has been found to be significantly lower in the case of the motorbike compared with the car, something that may reflect the different vehicle sizes and typical driving styles, and can affect asymptotically the congestion when more motorbikes than cars compose a simulation scenario.**

***Index Terms*—CAM, C-V2X, Field Trials, LTE-V2X, V2X, VRU**

I. Introduction

Nowadays, people travel on roads by a variety of different transportation means, experiencing heterogeneous safety levels. Occupants enclosed in vehicles usually travel in a more protected manner, due to their carriers' collision absorption characteristics and to the safety devices that vehicles like modern cars are equipped with. Contrarily, Vulnerable Road Users (VRUs) such as pedestrians, bicycles, e-scooters, and motorbikes are less protected and more exposed to injuries even in small-scale road accidents.

The role of wireless communications, in the whole picture, is crucial for designing safe road environments, especially in urban scenarios where Non-Line-Of-Sight (NLOS) circumstances are frequent. The interest has been mainly focused around vehicular communications that rely on either IEEE 802.11p or Long-Term Evolution (LTE) Vehicle-To-Everything (LTE-V2X). Their evolutions were recently presented through IEEE 802.11bd and 5G New Radio Cellular V2X (NR C-V2X), respectively [1]. The IEEE 802.11p Wireless Access for Vehicular Environments (WAVE) is a collection of amendments pertaining to vehicular settings made to the IEEE 802.11-2012 standard [2] (now superseded by the IEEE 802.11-2016 standard [3]). The latter is the basis for the so-called Dedicated Short-Range Communications (DSRC). DSRC was envisioned to operate similarly to a network used for emergency communications, but, while the aim of the latter is often to restore communications in areas where infrastructure is damaged by using a backhaul channel [4], [5], [6], [7], DSRC enables from the onset both vehicle-to-vehicle and vehicle-to-infrastructure communications to automatically propagate safety information. In fact, it was originally designed to enable collision-prevention applications [8], but the interest in V2X transmissions quickly spread to encompass consumer-centric services like entertainment, traffic data, navigation, and also autonomous driving. Traditionally more focused on the latter uses, C-V2X has emerged as a competing technology with its own strong points as, for instance, the leverage of cellular infrastructures and the coverage of larger areas by single radio items. The two technologies have been compared in multiple studies, e.g., in [9], [10], and their coexistence has also been hypothesized and investigated [11]. The future of such vehicular connectivity solutions foresees, among others, roles for millimeter-wave communications [12] and multiaccess edge computing [13].

Vehicular awareness messages are standardized at the application layer and as such are independent from the access technology (e.g. C-V2X or IEEE 802.11p) [14], [15]. The idea for vehicles and VRUs is to broadcast these messages in order to reach every node in the area of coverage, distributing relevant attributes like position, speed, curse over ground, etc. According to the ETSI terminology, we deal with two types of awareness messages, Cooperative Awareness Messages (CAMs) and VRU Awareness Messages (VAMs): the former are disseminated by motorbikes and cars, the latter by other VRUs. Note that while motorbikes are categorized as VRUs, they are expected to generate CAMs, not VAMs, as their speed and behavior is more similar to those of cars than those of other VRUs such as pedestrians or bicycles.

This work compares a campaign on real-data collected by a motorbike with a well-known campaign which is car-based and proposed by the Car2Car consortium in [16]. It is important to notice that since our paper looks at the generation pattern at the application level, it is independent by the technology deployed, either C-V2X or IEEE 802.11p. All the results collected are GPS-based and treated in post processing fashion. We then followed the ETSI algorithms formalized in [14] and [15] to

M. Klapez, C.A. Grazia, and M. Casoni are with the Department of Engineering *Enzo Ferrari*, University of Modena and Reggio Emilia, via Pietro Vivarelli, 10, 41125, Modena, Italy (e-mail: {martin.klapez, carloaugusto.grazia, maurizio.casoni}@unimore.it).

identify the awareness messages triggered by the GPS traces with the proper timing.

The paper is organized as follows. Section II briefly overviews related works. Section III introduces VRUs. Section IV describes the equipment utilized, its configuration, and its field setup. Section V presents and analyzes the results, while Section VI concludes the article.

II. Related Works

Example of papers that recently focused on VRUs are [17], [18], and [19]. The study in [18] shows a methodology that allows to integrate connected VRUs in the VEINS simulator and test vehicular scenarios comprehending both regular vehicles and VRUs at intersections. [19], instead, presents a large-scale simulation study of the ETSI Collective Perception Messages, exhibiting a significantly improved awareness of pedestrian VRUs at the cost of a little additional channel resource usage in the case of cooperative perception versus the not-connected scenario in which the amount of perceived pedestrian is limited. [20] also investigates cooperative perception in the context of communication with intelligent road-side units (RSU), increasing the vehicles' awareness of VRUs.

Regarding regular vehicles, [21] employs field tests to validate CAMs and Decentralized Environmental Notification Messages (DENMs) capabilities through several performance indicators, while [22] also investigates the influence of external variables, such as vehicle speed, Line-Of-Sight (LOS), or message dissemination rules, on the performance in the dissemination of CAMs and DENMs. Similarly, [23] employs field tests and large-scale simulations to explore the practical limits of cooperative awareness in both Vehicle-to-Vehicle (V2V) transmissions, in which the infrastructure is not involved, and Vehicle-to-Infrastructure (V2I) transmissions. Due to the time of their writing, these works do not consider the LTE-V2X technology but communications based on IEEE 802.11p instead.

Regarding the latter, [24] reports field tests that, in terms of road shape, path length, and investigated metrics, are similar to our preliminary mobility tests presented in [25], although they are conducted at lower speeds. In [26], we presented a methodology to study packet collision interference due to the hidden terminal problem, while in [27] we studied the technology in high-speed trials. Also with a focus on highway communications, [28] experimentally compares ITS-G5 and LTE-V2X in terms of Packet Delivery Ratio (PDR) and latency.

III. Vulnerable Road Users

Typically, literature focuses on regular vehicles like cars and trucks when designing simulations or experiments involving ICT nodes in intelligent transportation systems and the related networks. At the same time, the interest behind smaller but still potentially smart vehicles like bikes, e-bikes, kick-scooters, e-scooters, motorbikes, etc., is increasing. Indeed, this class of vehicles is classified as "vulnerable" and paired to a different class of messages disseminated: VAM.

VRUs are particularly exposed in the circumstance of a collision with another road user and therefore have to be safeguarded. First and foremost, their safety has to be improved by taking a proactive approach, i.e., raising awareness of their presence. In parallel, and whenever possible, VRUs can also be made aware of the presence of other road users to initiate protective actions. In the extreme case, if there is an immediate risk of collision, this has to be avoided with an emergency maneuver. Warranting VRU protection mandates the synergic combination of different design choices and depends on the examined VRU profile. As a matter of fact, in [29], VRUs are further categorized in three groups, according to the idiosyncrasies of the vehicle itself. More in detail, the groups are based on the size of the 'vehicle´, isolating pedestrians in the first group, light vehicles based on electric motors in the second group, and heavier vehicles like motorbikes in the last group.

With the exception of motorbikes, every VRU belonging to the aforementioned list is expected to issue VAMs. VAMs are different from CAMs issued by vehicles, being more flexible in length and content; furthermore, to reduce network congestion, they allow VRUs to be grouped in new logical entities named *clusters* [30]. As well as all the vehicles that are currently part of the intelligent transportation system of the future, wireless connectivity might play a crucial role in the upcoming years, where VRU improved safety would collect the major benefits. The enabling characteristic is just the presence of a transmitter, and a dedicated hardware, that broadcasts VAMs and receives awareness messages from the other nodes involved in the network.

IV. Field Setup

A. Test Devices and Configuration

The experimental results presented in this section were obtained employing the commercially available AG15 module, manufactured by Quectel. The chipset mounted is the Qualcomm 9150 C-V2X, dedicated to perform V2X operations and therefore, it is compliant to the LTE-V2X Release 14. It works at the n47 band ($5855-5925$ MHz), but in our experiments the antennas were just not connected since we collected GPS samples without broadcast CAM/VAM packets while performing the tests. The key component that we employed is the Global Navigation Satellite System (GNSS) receiver, able to operate in multi-constellation, that allows for the detection of Recommended Minimum Data (RMC messages of standard u-blox satellite devices) messages to have access to relevant information like position (latitude and longitude), speed, and course over ground. Throughout these data, it is possible to estimate CAM or VAM messages in post-processing making our test campaign independent from the V2X access technology. The GNSS hardware used in our tests is depicted in Figure 1.

The board was configured collect GPS data at a frequency of 10Hz, saving the results in a log file then accessible for post-processing elaboration. The data have then been cleaned excluding non relevant informations (e.g., the path to reach the test starting point, the outliers samples due to GPS receiver

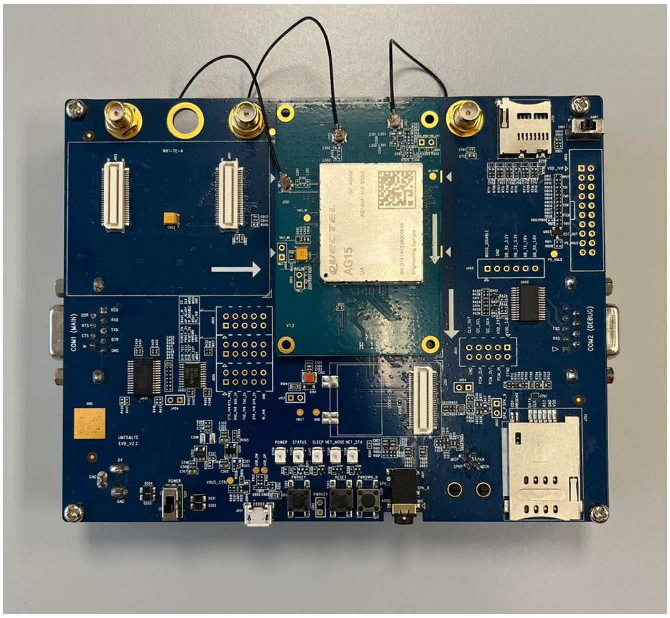

Fig. 1: Quectel evaluation board used for the field measurements.

Fig. 2: Urban scenario.

errors, and non-relevant samples collected just before shutting down the board).

B. Cooperative Awareness Messages

The ETSI standard dictates the CAM generation times under the following conditions, all starting from the last CAM transmitted at time t_1, with position p_1, heading h_1, and speed s_1, and the time t_n which corresponds to the last GPS sample registered with position p_n, heading h_n and speed s_n:

(i) If $(t_n - t_1) > T_{GenCamMax}$.
(ii) If the euclidean distance $|p_n - p_1| > \Delta_d = 4$ m.
(iii) If the heading distance $|h_n - h_1| > \Delta_h = 4°$
(iv) If the speed difference $s_n - s_1 > \Delta_s = 0.5$ m/s.

The thesholds Δ_d, Δ_h, and Δ_s are standardized as fixed. Also the CAM size is standardized, but not to a specific value, in fact it can range between 45 and 400 bytes [31]. This fact points to a second free variable to model congestion when dealing with CAMs and VAMs, indeed, the non-fixed size of the massages can have a severe impact on channel congestion, considering the range of one entire order of magnitude. Moreover, the messages size can also increase following the introduction of security features, like authentication or integrity, as described in [32].

Instead of tackling any arbitrary CAM implementation profile, this work concentrates in particular on their temporal patterns, collecting important feedbacks on the average time between different CAM/VAMs to model the channel congestion in future simulation environments. In our experiments CAMs were not generated in real-time, the collected GPS traces come from a test campaign of 3 hours long performed with a motorbike around the city center of Modena.

C. Urban Scenario

In our motorbike scenario, the measurements were performed in an urban environment, as it is the one where differences with cars due to different driving patterns are most likely to emerge. We compared the results obtained in our environment with the one, with similar characteristics, used in [16], referring specifically to the urban results. Our motorbike traveled among other vehicles, experiencing normal daytime traffic conditions.

The test vehicle repeatedly traveled along the urban path of the city of Modena reported in Figure 2, mainly composed of large streets surrounded by potential obstacles, foliage, and buildings. The vehicle experienced various degrees of traffic, and encountered several red traffic lights and roundabouts.

V. Test Results

This section details the test results about CAMs generated by the motorcycle, for $\Delta_d = 4$ m, $\Delta_h = 4°$, and $\Delta_s = 0.5$ m/s, and compares them with the CAM distribution of test performed using cars in the [16] report.

The possible conditions that may trigger the generation of a CAM are:

- Timeout: corresponding to condition (i) of section IV-B.
- Distance: corresponding to condition (ii) of section IV-B.
- Heading: corresponding to condition (iii) of section IV-B.
- Speed: corresponding to condition (iv) of section IV-B.
- Mixed: more than one of the above are simultaneously satisfied.

The case of the car is reported by Figures 6-22 and 6-25 of [16] where the pattern of CAM generation is presented for the urban environment including Volkswagen and Renault vehicles. In the case of the Car 2 Car report, which describes the CAM pattern of cars, we do not have access to the triggering conditions that generated the specific message, therefore, we

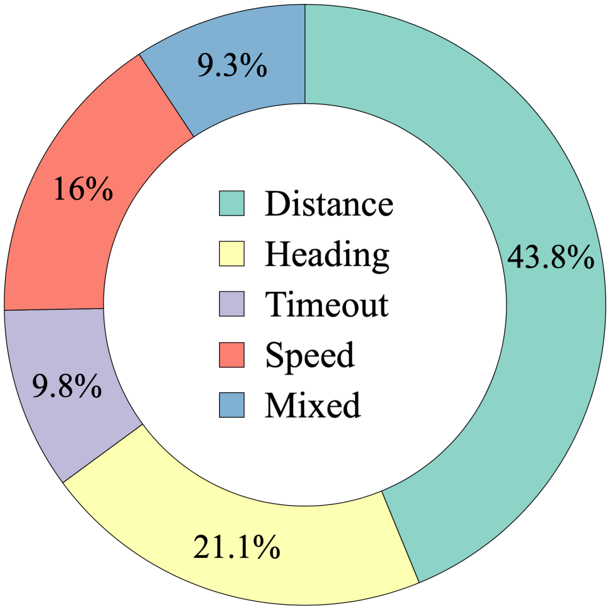

Fig. 3: CAM Triggers distribution: Motorbike

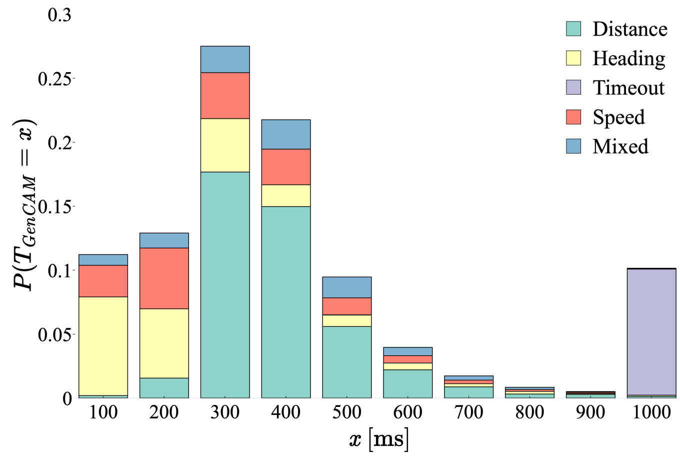

Fig. 4: CAM triggers and T_{CAM} PMF: Motorbike

focus on the average time between two consecutive CAMs. According to the results of [16] the average value of T_{CAM} in a urban scenario is equal to 480 ms.

With reference to a comparable urban scenario, Figure 3 reports the percentage of the triggering conditions while Figure 4 the PMF of T_{CAM} for a two-wheel motorcycle. In this case, the data comes from our campaign in the city center of Modena. We can notice that the distance variations account for less than half of the total (approximately 44%), heading variations are relatively frequent, and the occurrences of the other conditions are lower than 20% each.

The presence of a significant amount of heading triggers is understandable, as a motorcycle typically exhibits a more agile drive-style with respect to a car., involving several tilt changes, accelerations and braking. Moreover, Figure 4 uncovers the main reason for the CAM generation with a T_{CAM} lower than 300 ms, i.e., a large amount of heading variations; from a T_{CAM} higher than 300 ms, the main reason for CAMs generation shifts to distance, which is in turn caused by higher speeds.

With the motorbike, we recorded higher probability than with the car of having a T_{CAM} below 400 ms; inversely, from a T_{CAM} of 400 ms upwards, the probability is lower for the motorbike. Indeed, a significant difference found between the two vehicle classes is that the average T_{CAM} is lower for the motorbike, which settles on a value around 400 ms, translating into consecutive CAMs being on average less separated in time.

VI. Conclusions

This work discussed the result obtained during a real-test campaign involving a motorbike in a urban environment. The goal has been to collect, and process, the GPS traces which are involved in the generation of CAM/VAM messages. Analyzing the data collected during the test campaign, we found that the distance trigger is the leading one and that heading variation accounts for a significant part of the total. This is likely due to the typically more agile driving pattern of a two-wheel vehicle compared with a standard car.

The analysis of the collected data has revealed the impact of the various triggering conditions of CAMs that were gathered through numerous field tests performed in an urban setting, allowing us to assess the average differences between cars and motorbikes.

The paper has also shown that, compared with the car, the VRU category represented by motorbikes exhibits a lower PMF. This result might have a huge impact in modeling simulation scenario involving smart vehicles disseminating CAMs/VAMs due to the fact that motorbikes impact more on channel congestion compared to cars.

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