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COOPERATIVE VEHICULAR ITS SAFETY TESTS IN PROVING GROUNDS

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ABSTRACT - Cooperative vehicular communication systems have been identified as a key Intelligent Transportations Systems (ITS) technology for improving traffic safety, traffic management and provide Internet connectivity on the move through the dynamic exchange of messages between vehicles (Vehicle to Vehicle Communications, V2V) or between vehicles and road side infrastructure units (Vehicle to Infrastructure Communications, V2I).

Before deploying cooperative ITS systems, it is crucial that their adequate operation is extensively tested, in particular for traffic safety applications. In this context, FOTs (Field Operational Tests) have been launched in the US and Japan and are under preparation in the EU. FOTs will allow testing under real conditions the intended benefits of this promising technology and its interaction with the driver. However, FOTs are not sufficient to test and optimise cooperative ITS systems given their high cost and time limitation that prevents a comprehensive analysis of subsequently added new functionalities. In addition, the participation of drivers in the public road network limit the FOT capability to test the active safety functionality of cooperative vehicular ITS systems under critical conditions.

To overcome this limitation, IDIADA Automotive Technologies (IDIADA), with the support from the Miguel Hernandez University, is creating a cooperative ITS proving ground facility that will allow repetitive testing of the active safety functionality of cooperative ITS systems under critical and controlled situations, and under different operating conditions, including low adherence and visibility. To the author's knowledge, the facility, that will be part of IDIADA's 370 hectares automotive testing complex, is one of the first worldwide initiatives of this type. The testing facility under development includes equipped vehicles and roadside units with WAVE/IEEE802.11p cooperative devices, and a series of cooperative ITS testing protocols. In particular, testing protocols for the following cooperative applications have been defined:

- Intersection Collision Avoidance (ICA)
- Lane Change Warning (LCW)
- Emergency Electronic Brake Lights (EEBL)
- Head on collision warning (HCW)

The protocols define the traffic scenario, conditions and cooperative communications requirements, tests, metrics and data logging following the initial developments under the EU FESTA and Safespot projects.

1. INTRODUCTION

Cooperative ITS have the potential to improve traffic safety, increase traffic management efficiency and reduce the environmental impact of road transport by means of wireless V2V and V2I communication. Nowadays, Cooperative ITS technological solutions are undergoing research, development and prototyping that will lead to new products, standards and services in this area. For Cooperative ITS systems and services to enter the market, they will need to overcome an evaluation and validation process. This process will include large FOTs all around the world in order to ensure the adequate operation of Cooperative ITS in real scenarios on the public roads. In the case of safety related applications, FOTs do not support testing under critical conditions prior to the accident and so safety related Cooperative ITS applications need to be evaluated in proving grounds that provide safe and controlled real-world ITS environment. With this aim, IDIADA with the support from Miguel Hernandez University has created the ITS-EVAL testing platform displayed in IDIADA's proving ground that covers a basic set of safety applications, and includes testing scenarios and protocols, infrastructure, evaluation equipment and Cooperative ITS prototypes.

The remainder of the paper is organized as follows. In Section 2, we introduce the ITS-EVAL testing platform, including a brief description of each application selected for the first basic set implemented, and an overview of the Cooperative ITS prototypes developed. Section 3 presents the results obtained from the first on-site tests which comprise communications performace assessment tests and ICA functionality assessment. Finally, we compile the conclusions and future work in Section 5.

2. ITS-EVAL, COOPERATIVE ITS TESTING PLATFORM

In view of the necessity to evaluate the means of cooperative vehicular communications, and subsequently validate the correct performance of the safety related applications derived, ITS-EVAL platform has been designed in order to cover the requirements of a sample of applications representing the most relevant world-wide cases of use of Cooperative ITS with the aim of increasing traffic safety and reducing the number of accidents. This first basic set of applications will be expanded progressively in order to cover the necessities of vehicle and systems manufacturers, as well as promote research, development & innovation leading to new products, standards and services in the area of Cooperative ITS technologies.

In order to cover the necessities of each application selected, ITS-EVAL platform is deployed on IDIADA's proving ground including representative scenarios of the selected applications such as intersections, open road, motorway scenarios with 2 or more lanes, etc. The vehicles that participate in the testing are specially equipped with safety features ensuring maximum safety standards are met. ITS-EVAL testing platform is equipped with evaluation devices such as driving robots, differential GPS, and a varied set targets and sensors. With the aim of being able to evaluate the developed testing platform and protocols, as well as to gain experience and knowledge of Cooperative ITS systems, the testing platform implementation included the development of two Cooperative ITS prototypes for V2V and V2I wireless communications.

2.1. ITS-EVAL Basic Set of Applications

The selection of the applications to be included in the basic set was based on the technological solutions with the biggest impact on traffic safety (by a reduction of the highest occurring number of accidents). This study was based on the results of European projects and initiatives such as TRACE (1, 2), eIMPACT (3, 4) and SafetyNet (5, 6), as well as profiles and indicators that the Spanish organism Dirección General de Tráfico (DGT) (7, 8) publishes every year.

The selection was completed with the results obtained from the analysis of a wide set of scenarios, applications and user cases identified in European and American projects such as SAFESPOT (9, 10, 11), VSC (Vehicle Safety Communications) (12, 13, 14, 15, 16) and VII (Vehicle Infrastructure Integration) (17, 18, 19). These projects share a common objective of improving traffic safety through cooperative vehicular communication.

Finally, a set of four applications were selected because of being the most relevant, covering a wide range of user cases and with a higher potential in terms of improving traffic safety. These applications are:

- Intersection Collision Avoidance (ICA)
- Emergency Electronic Brake Lights (EEBL)
- Lane Change Warning (LCW)
- Head on Collision Warning (HCW)

A brief description of each application is detailed in this section.

2.1.1. Intersection Collision Avoidance (ICA)

A significant percentage of vehicle crashes all around the world occur at intersections or are intersection-related. Their causes are often due to drivers' misjudgement of the situation, failure to correctly observe the situation, or inability to correctly perceive the degree of danger. The goal of ICA application is to avoid collisions at intersections by warning the driver in sufficient time to react. The system warns the driver with an in-vehicle hazard warning when there is a risk of a collision crossing an intersection. ICA contemplates the use of roadside infrastructure sensors and/or cooperative vehicular communications, in order to detect presence, location, lane of travel, speed, and acceleration among other factors, of vehicles approaching the intersection point. Cooperative ITS systems are continuously processing information of vehicles present, and sending tailored messages to drivers through an in-vehicle Human Machine Interface (HMI) that is a combination of sound and visual warning. Figure 1 shows an example of ICA scenario.

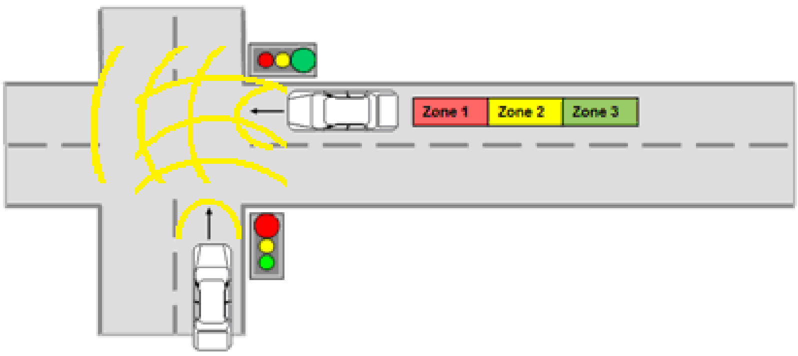


Figure 1. Example of an ICA scenario

The Cooperative vehicular ITS prototypes developed use a warning strategy based on dividing the communication area in three warning zones that are delimited by the time to collision. The in-vehicle system determines whether a collision is likely to happen at prevailing speeds and distances within a certain time interval. In Zone 3, the in-vehicle system is monitoring position and movement of the surrounding vehicles in order to detect a situation of risk. In Zone 2, the system has detected a hazardous situation and informs the driver with an in-vehicle warning. After the warning, if the vehicle still enters Zone 1, the driver will be alerted to the imminent danger of crashing.

2.1.2. Emergency Electronic Brake Lights (EEBL)

EEBL application addresses rear-end and backing collisions, which can happen when a vehicle is following too closely for the driver to react to sudden braking by the lead vehicle or because of driver inattention. EEBL extends driver's visual field by forwarding/backwarding warning messages to in-vehicle devices. In a car-following situation, the same strategy as in ICA is used, where time to collision is the time taken for the two vehicles to collide if they maintain their present speed and heading. Moreover, the system assumes that the lead vehicle could brake at full braking power at any time. In essence, it maintains a "critical clearance", the minimum distance necessary to come to a stop in the event the leading car suddenly brakes. Figure 2 shows an example of EBBL car following scenario.

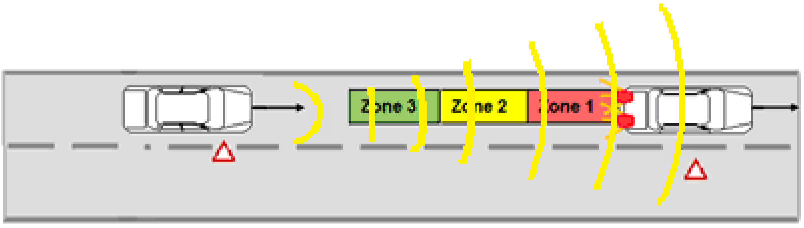


Figure 2. Example of an EBBL scenario

2.1.3. Lane Change Warning (LCW) and Head on Collision Warning (HCW)

LCW and HCW applications address collisions caused when a vehicle leaves its lane in a lateral maneuver crashing into an oncoming vehicle either head-on (HCW) or, in the case of vehicles traveling in the same direction, in a sideswipe or merge crash (LCW). In both cases, when the driver is preparing to start the maneuver, the system determines whether there is risk of collision or not, and in case the maneuver is not safe it generates a warning to the driver indicating to abort it. In order to determine the hazard, on board systems in nearby vehicles are continuously interchanging information about location, lane of travel, speed, and acceleration among other factors. Figure 3 shows a representative scenario of each application.

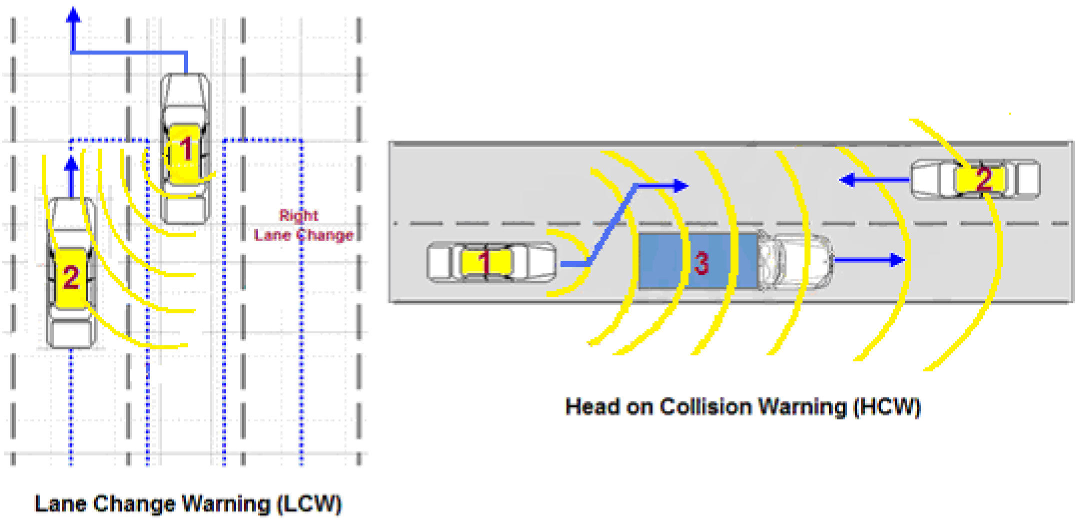


Figure 3. Example of LCW and HCW

For LCW, vehicle 2 is in the blind spot of vehicle 1 and so when the driver of vehicle 1 is preparing to start the left lane change, receives a warning, indicating that the maneuver is not safe. In the case of HCW, the driver of vehicle 1 cannot see vehicle 2 because of the visual obstruction that is caused by vehicle 3. So if the driver of vehicle 1 decides to start overtaking vehicle 3 the system will indicate to the driver to abort the maneuver because it is not safe. This situation would be detected thanks to the communication between vehicles 1 and 2.

2.2. Cooperative ITS prototypes

ITS-EVAL testing platform implementation included the development of two Cooperative ITS prototypes using communication units based on WAVE/IEEE 802.11p technology for V2V and V2I wireless communications. These prototypes can be used as On Board Units (OBUs) or RoadSide Units (RSUs) indistinctly, only changing the type of communication antenna. Figure 4 shows a schematic of a Cooperative ITS prototype.

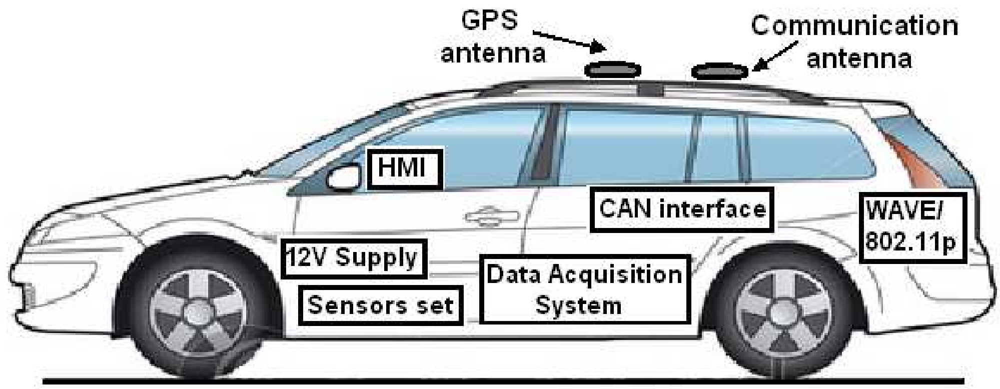


Figure 4. Schematic of a vehicle instrumented with an OBU Cooperative ITS prototype

An OBU Cooperative ITS prototype is an experimental system that includes the hardware and software elements needed for acquiring data from the vehicle (such as GPS position, speed, acceleration, etc.), process it, create communication frames and send/receive them in the WAVE/802.11p communication unit, and finally present the information in an adequate manner to the driver on an in-vehicle HMI. Data acquisition and logging takes place in parallel.

3. VEHICULAR ITS SAFETY TESTS

Once the proposed platform has been described, and the selected cooperative applications and required equipment have been defined, this section presents the results obtained in the varied field tests performed. In particular, section 3.1 shows the results in the conducted communications performace assessment tests. These tests evaluate the system performance under different operational conditions and communication parameters, e.g. vehicle speeds and transmission powers. The communication performance assessment tests are the basis for the implementation and testing of the communication protocols and advanced applications. Section 3.2 shows the developed and implemented ICA application.

3.1. Reliability of Cooperative ITS systems

The main objective of the conducted communications tests is to evaluate the communication performance of WAVE/802.11p systems under real conditions and obtain results and conclusions that can be used as a first step for the implementation of the selected applications. Different communication test scenarios have been identified and will be used to evaluate the communication performance for the selected applications. Next, the scenarios and tests performed for the EEBL and ICA applications are presented.

3.1.1. Car-following scenario/EEBL application

The car-following tests have been conducted for the communications assessment tests of the EEBL application. In these tests, two vehicles equipped with a Cooperative ITS prototype of an OBU are following each other on a straight road. Both vehicles periodically transmit broadcast packets that contain their positioning and speed information. The communication parameters employed in the different tests are shown in Table 1. The speed and distance between the two vehicles are also included.

Test	Packet frequency (Hz)	Data rate (Mbps)	Transmission power (dBm)	Speed (km/h)	Distance between vehicles (m)
1	2	6	5	50	300
2	2	6	20	50	300
3	2	6	5	90	100-200

Table 1. Parameters for the car-following test

Figure 5 shows the results of the car-following tests, where the lost and received packets are depicted as a function of the distance between the two vehicles and elapsed time. This figure shows that a transmission power of 5dBm (test 1) is not enough to establish communication between the two vehicles at distances of 300m because of the high number of lost packets. However, Figure 5 shows that this transmission power could be adequate for a range of 100-200m (test 3). When using a higher transmission power (20dBm, test 2), a continuous and reliable communication of almost 300m can be achieved, ensuring that a warning message could be delivered to the driver with enough time to react and avoid a dangerous situation.

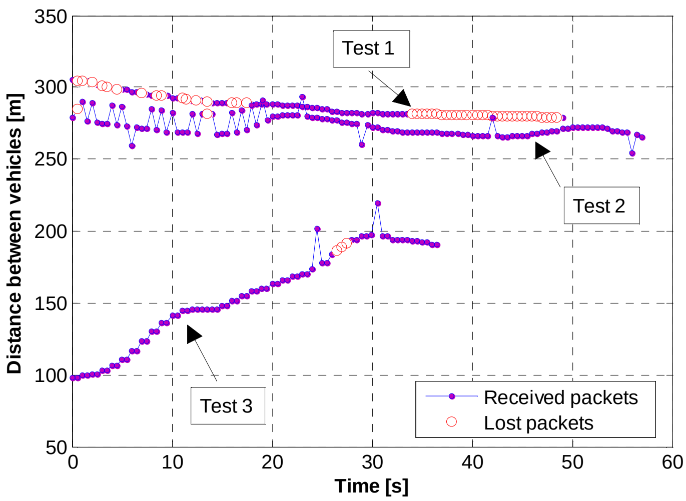


Figure 5. Distance between the two vehicles for the car-following communications assessment tests

3.1.2. Intersection scenario/ICA application

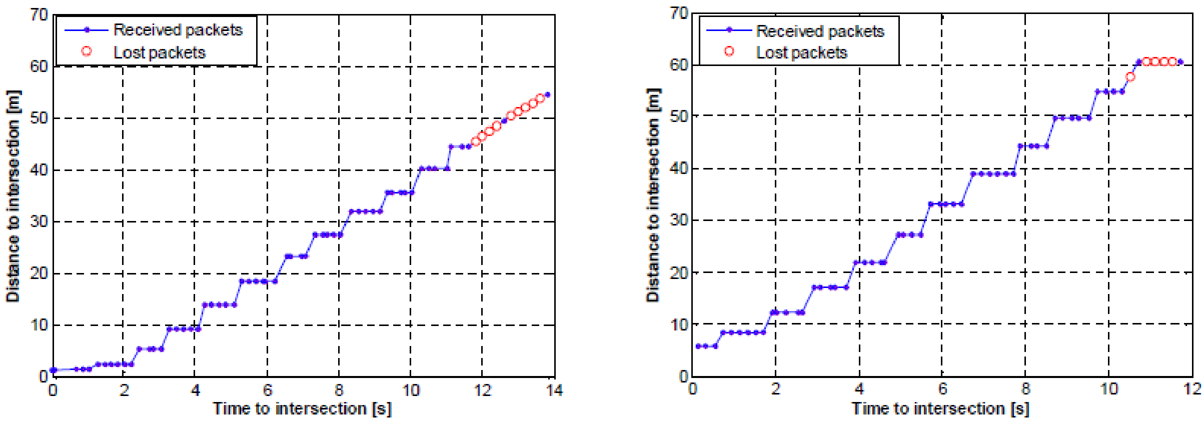
For the communication tests of ICA application, two vehicles are located at an initial distance of 130m from where they start approaching the intersection with a constant speed of 30km/h and a consequent risk of collision. The communication parameters considered in these tests are shown in Table 2. The intersection Scenario selected contains a building that blocks the radio signal propagation. Therefore, the two vehicles are under NLOS (Non-Line Of Sight) propagation conditions until they reach a 30m distance to the intersection point.

Figure 6 shows the amount of lost and received packets as a function of the remaining time to the intersection point. Only lost and received packets from the first packet successfully received are considered in the graph.

Test	Packet frequency (Hz)	Data rate (Mbps)	Transmission power (dBm)
1	5	6	10
2	5	6	20

Table 2. Parameters for the intersection tests

By using the selected parameters, a good packet reception is achieved, especially as the vehicles approach the intersection. Figure 6 also shows that, while the first packet was successfully received at 55m from the intersection with a transmission power of 10dBm, when a 20dBm transmission power is used this distance increases up to 61m and the number of lost packets decreases. These results reveal the need for adequate transmission power levels to establish communication between two vehicles at an adequate distance from the intersection to support ICA application.



(a) Test 1: transmission power 10dBm (b) Test 2: transmission power 20dBm

Figure 6. Distance to intersection for the intersection communication assessment tests

3.2. <u>Test results for the ICA functionality</u>

This section is intended to show the implemented functionality for the ICA cooperative application through a descriptive events flow and the results obtained from an application test example.

3.2.1. ICA Events flow

The event flow triggered when two cooperative vehicles approach an intersection is shown in Figure 7.

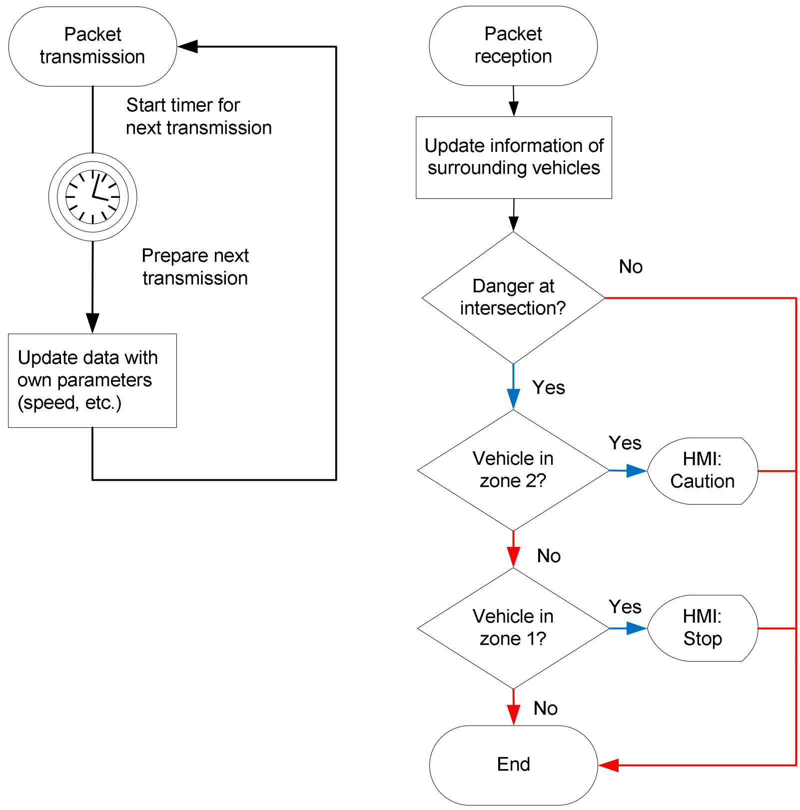


Figure 7. ICA Events flow diagram

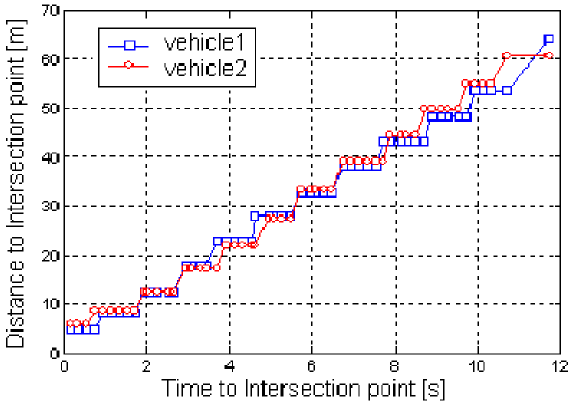
3.2.2. Application test example

According to the event flow diagram presented above, this section illustrates an example of the implemented ICA functionality, in which both drivers ignore the HMI 'Caution' alert and keep their 20 km/h speed until they reach the intersection point. Therefore, both drivers will be alerted with 'Caution' and 'STOP' messages in Zones 2 and 1 respectively. In this case, the three warning zones were set with duration of 3 seconds each. The scenario selected for this test was an intersection with radio signal obstruction caused by a building. The communication parameters for this test are shown in Table 3.

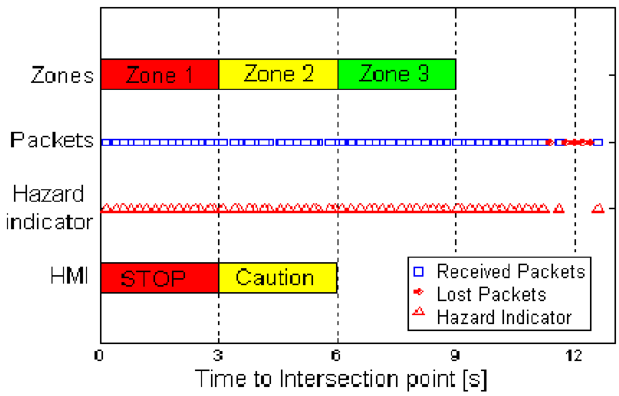
Packet frequency (Hz)	Data rate (Mbps)	Transmission power (dBm)
5	6	20

Table 3. Parameters for the ICA functionality test

Figure 8(a) shows distance from both vehicles to the intersection point versus time to the intersection point. We can observe that both vehicles were keeping constant speed and so their distance and time to the intersection point were very similar, with the consequent risk to collide. Figure 5(b) shows the HMI messages displayed to the drivers in the different warning zones and a hazard indicator, as well as received and lost packets. We can observe that the communication between the systems is initiated at 60 m from the intersection point, at a speed of 20km/h the two vehicles are able to exchange information during more than 10s before reaching the intersection point. This time is enough to warn the drivers of a potential hazard. During Zone 3, both systems are monitoring the motion parameters and predict risk to collision. At entering Zone 2 the on board HMI warns the drivers with a 'Caution' message, and as the drivers do not react, both vehicles enter Zone 3 and receive the 'STOP' message.



(a) Distance to intersection



(b) HMI

Figure 8. Test for the ICA application

4. CONCLUSIONS AND FUTURE WORK

The results shown in this paper reveal the potential of Cooperative ITS vehicular systems to support active traffic safety applications, and also the suitability of the developed testing platform for Cooperative ITS technology assessment. The ITS-EVAL platform is under continuous expansion and improvement in order to cover the necessities of the most up to date developments in the field of Cooperative ITS. Nowadays, some limitations of infrastructure equipment have been identified and will be addressed, as well as an expansion of the set of applications and user cases covered.

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