Deployment of a vehicular communications platform to test cooperative vehicle applications and Intelligent Transportation System communication protocols

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***Abstract*—In this paper a platform of vehicular communications which allows the development of cooperative vehicle applications to warn drivers against hazardous situations on the road is presented. It has also been designed the communication protocols needed to exchange information among vehicles (V2V) or between vehicle and the infrastructure (V2I). In particular, this paper is focused on two typical active safety applications which are based on the cooperation among vehicles and inteligent elements placed on the road. Once the communication protocol is defined, some tests were carried out in real V2V and I2V scenarios using a compliant IEEE 802.11p prototype developed by NEC.**

I. Introduction

The fact that the number of cars is increasing every day is easy to notice. As a logical result, the number of car-crashes and different types of vehicle related accidents is also increasing. Therefore, new business opportunities and new needs involving road safety have been found. In this context, road manufacturers and authorities have been investing in the study of Vehicular Ad-hoc Networks, or more commonly known as VANETs, which can be defined as wireless networks that do not require any infrastructure and support cooperative driving communication among vehicles, which acts as nodes forming dynamic vehicular networks with other near-by vehicles or roadside units. Thus, the main aim of these VANETs is to help drivers avoid or prevent from dangerous situations, so as to reduce the number of accidents.

The way to solve this problem is to develop a set of applications that could inform drivers about hazardous situations they could find on the highways. These services are based on the cooperation among vehicles and offer great potential in reducing road accidents and therefore in improving drivers' comfort and efficiency of highways from the traffic management point of view.

But first, to provide these cooperative services with a stable and reliable wireless communication system must be deployed on the road infrastructure. For this purpose, different technologies have been analysed in the scenario of infrastructure-to-vehicle (I2V-V2I) and vehicle-to-vehicle (V2V) communications [1] [2] [3].

Once the communication link is stable, then cooperative and warning services could be deployed with the security that all agents involved in a VANET will have the chance of sending and receiving information regarding road events.

According to ETSI TC on ITS a set of applications can be used as a reference for developing cooperative vehicular systems [4]. In the same way, the U.S. Department of Transportation (USDOT) has identified similar applications to be deployed thanks to the potential of Dedicated Short-Range Communications (DSRC) to support wireless data communications between vehicles, and between vehicles and infrastructure.

Hence, the goal of this paper is to describe a communication architecture where these ITS applications based on the description provided by ETSI TC could be deployed.

II. DSRC and IEEE 802.11p Standard Overview

There are different wireless systems that could be used in a vehicle cooperative scenario, such as DSRC, 3G, Bluetooth, WLAN and Digital Radio. Nevertheless, according to the requirements needed for that set of applications, DSRC has been chosen as it is the only one system that [5]:

- Is dedicated to wireless access in vehicular Ad-Hoc networks 1-hop and multihop communications.
- Provides active vehicle services with Line-Of-Sight (LOS) and Non-LOS (NLOS) link scenarios.
- Is ready to operate in a rapidly varying environment and to exchange messages without having to join a

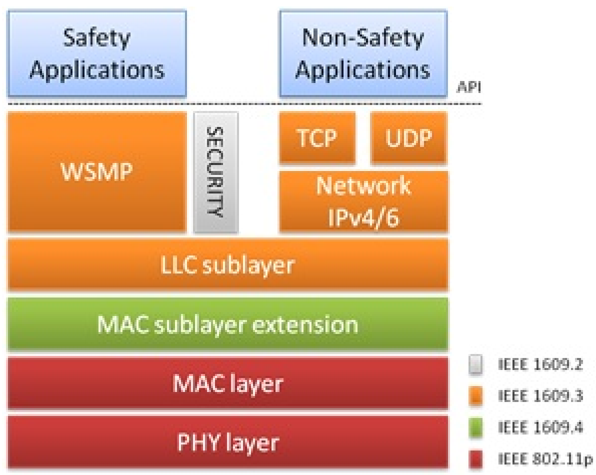

Fig. 1. IEEE WAVE/802.11p protocol stack

TABLE I
REQUIREMENTS OF APPLICATIONS UNDER TEST

	Emergency vehicle warning	**Roadwork warning**
Application	Driving assistance Co-operative awareness	Driving assistance Road Hazard Warning
Latency	Less than 100ms	Less than 100ms
Message Frequency	10Hz	2Hz
Special Needs	Triggered by vehicle	RSU broadcasts periodic messg.
Link	V2V	I2V

Basic Service Set (BSS), that is, without the management overhead.
- Makes possible low latency in communications among vehicles and infrastructure possible allowing sharing real-time information.
- Provides unicast, broadcast, real-time and bidirectional communications.

The IEEE 802.11p standard is limited by the scope of IEEE 802.11 which is the definition of MAC and PHY layers, as it is shown at Figure 1 [6]. At PHY layer, IEEE 802.11p operates at the band of 5GHz, reusing IEEE 802.11a OFDM (Orthogonal Frequency Division Multiplexing) modulation considering 52 subcarriers that can be modulated using BPSK, QPSK, 64-QAM or 16-QAM modulation schemas. This setup allows, theoretically, a communication range over 1000m (depending on the antennas configuration) and to establish communication among vehicles driving up to 200km/h. At Figure 1 it is shown the protocol stack defined in WAVE standard in which we are based on to develop the applications described and tested in this paper.

III. COOPERATIVE BASED APPLICATIONS

In the field of cooperative ITS services, a huge variety of applications and use cases can be described. The ETSI TC on ITS has defined a Basic Set of Applications to be used as a reference for developers [4]. These entities are able to run four classes of applications: active road safety, cooperative traffic efficiency, cooperative local services and global internet services. In each class, different applications and use cases are defined.

Although this paper is focused on determining the communication protocol needed to develop two specific use cases, they can be the basis for the other applications. In next sections two applications are described and then, they are validated in a real scenario.

A. V2V Application example: Emergency vehicle warning

This application allows an active emergency vehicle to indicate its presence. Like in Spain, in many other countries the presence of an emergency vehicle imposes an obligation for vehicles in the path of the emergency vehicle to give way and to free an emergency corridor. Nowadays people notice that there is an emergency vehicle because of the visual and audible warnings they produce. However, sometimes drivers take too time moving to one side of the road thus the ambulance has to stop or reduce its speed. Therefore, if drivers could know earlier about an ambulance approaching them, they could let it pass and furthermore, this action helps to reduce their intervention time to rescue and/or protect people. The ETSI TC on ITS has defined the main requirements needed for the accurate implementation of this use case. These requisites are summarized in Table I.

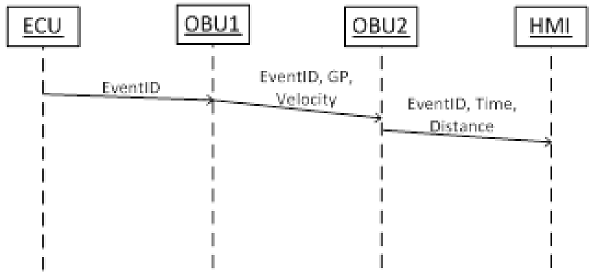

Fig. 2. Emergency vehicle warning communication protocol

Coming back to the definition of the communication protocol, in this situation a communication directly between the ambulance and its neighbour vehicles is needed. When the ambulance driver activates visual or audible warnings the ECU of the ambulance is able to detect them and notify the OBU about this new state. Since then, the ambulance's OBU sends a beacon with its geographical position and speed so that vehicles which have received this message can calculate the distance between them and the ambulance and how much time the driver has to let the ambulance through. The message sequence of the communication protocol is shown in Figure 2. Applying kinematic equations, it is not difficult to obtain the distance and the time between the ambulance and a car. To obtain the distance between both vehicles as the crow flies both vehicle geographical positions are needed. The time that the ambulance takes to get the vehicle is easily calculated once the distance is known.

B. I2V Application example: Roadwork warning

This application allows to provide information about roadwork or other issues and its associated constraints to vehicles which are nearing the place where there could be hazardous situations. The main requirements needed for the accurate implementation of this use case are summarized in Table I. To deploy this use case a communication between the infrastructure and vehicles (I2V) is necessary. The first message in the communication protocol is generated by the Traffic Management Center (TMC), which notifies to the implicated Road Side Unit (RSU) that in its coverage area there is roadwork. As it can be seen in Figure 3, it also sends the geographical position of the points where the roadwork starts and finishes and the speed limit of this stretch. With this information the distance left to the roadwork can be calculated, using equation 2, and let drivers have the time to adapt their speed before they get to that point of the road.

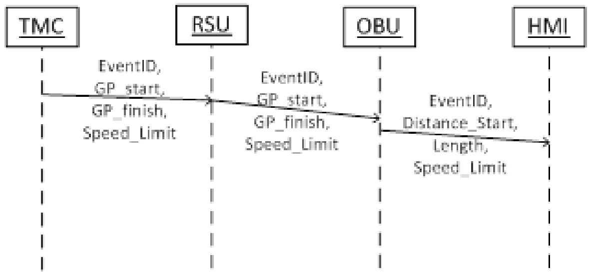

Fig. 3. Roadwork warning communication protocol

IV. SCENARIO DEFINITION

For the purpose of deploying ITS services and applications, a platform of vehicular communications has been designed, where different technologies are implemented to achieve the right exchange and management of data in the system. As it can be seen in Figure 4, in the platform defined there are different agents:

- OBUs (On-Board Units) are the different vehicles travelling the roads. They are composed by a Communication Control Unit (CCU), which is the IEEE 802.11p communication router, and an Application Unit (AU), which is a PC which receives, analyses, saves and shows the different information which arrives by the IEEE 802.11p communication link.
- RSUs are different units distributed along the roadsides and they form the infrastructure with the TMC. Each RSU is composed, as OBUs, by a CCU which exchange information with vehicles, and an AU, which decides what received information is relevant and what to do with it. The RSU ask periodically to the TMC about new events in its coverage area, and it shows them in the RSU interface which can be seen in Figure 6.
- TMC is the Traffic Management Centre and it receives from all the RSUs the information about events happening in their coverage area. Therefore, it manages a database where all the events which have taken place on the road are stored. Thanks to the TMC it is possible to obtain and see in a map the global situation of the roads in a certain time. The database of the TMC is updated with real time traffic issues of the Basque Autonomous Region which are obtained from the Open Data Euskadi initiative.
- HMI (Human Machine Interface) is the device used to show to the driver the information on the screen of a tablet.

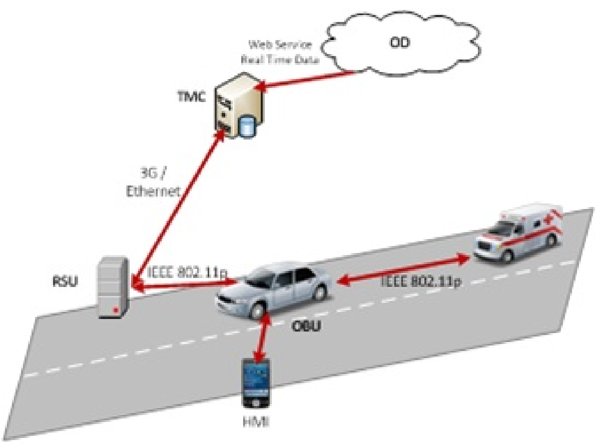

Fig. 4. Proposed platform of vehicular communications

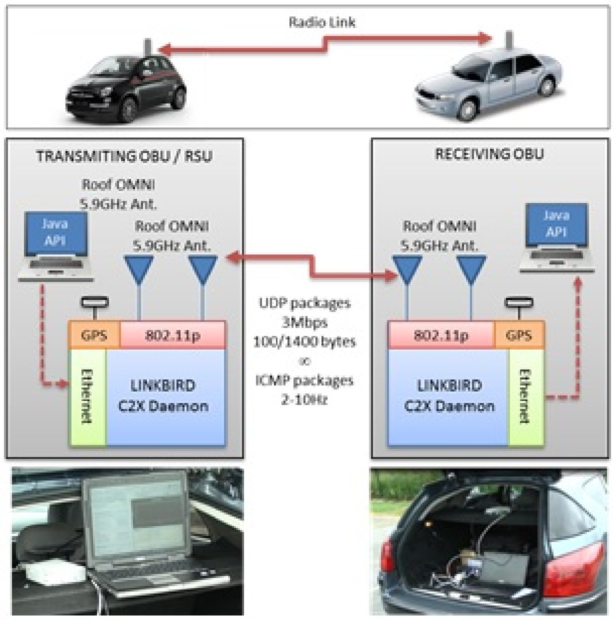

Fig. 5. On board hardware setup

A. Hardware setup

In the evaluation tests of the architecture and applications described, measures of the quality of the communications IEEE 802.11p link were taken in order to determine not only that the architecture works, but also the quality of service that these applications can offer. These measurements have been taken evaluating a single unidirectional radio link, either between two OBUs or between a RSU and an OBU. In both entities, the same hardware has been deployed running as OBU or as RSU. The selected hardware is LinkBird-MX which embedded Linux machines based on a 64 bits MIPS processor working at 266MHz. Besides an IEEE 802.11p interface, these modules are equipped with an Ethernet connector that is used to communicate with the Application Unit, a GPS interface and other interfaces as CAN or RS-232. Figure 5 shows the hardware setup used in the test that have been carried out in the described scenarios. Along with the communication modules, two antennas whose characteristics fit well with vehicular applications are provided. One antenna is tuned to the 178 CCH frequency (5.890GHz) and the other one to the 180 SCH frequency (5.9GHz).

V. EXPERIMENTAL RESULTS

A. Roadwork warning application

To test this safety application, a vehicle-to-infrastructure communication between a mobile OBU and a RSU has been recreated. According to the tests made, the distance coverage by a RSU equipped with an isotropic antenna can be close to 1700m. At Figure 6 it can be seen the RSU implementation.

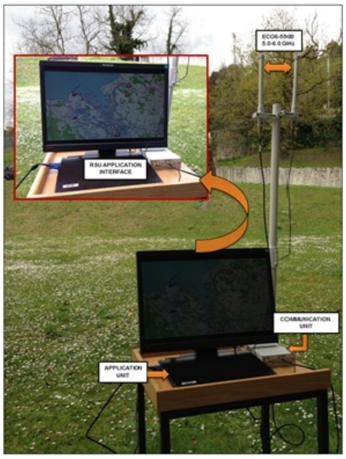

Fig. 6. RSU hardware setup

In this scenario the OBU travels at 40km/h (11,12m/s) along a road that has a straight line of 860m (A to B distance) while RSU sends warning messages. At the maximum RSU-OBU distance, the Packet Delivery Ratio (PDR) was 100% and the average delay was 7ms. At Figure 7 the interface of the OBU can be seen, where the driver is noticed about the roadwork and its position and limitations.

B. Emergency vehicle warninig application

In this test, PDR measurements were collected during a trip from Mungia to Portugalete. The distance between both cities is 34kms and the speed limit of the motorway is 100km/h. The goal in this scenario is to validate the communication link from one vehicle to the other vehicle where both are in movement at high speed and there are other vehicles like cars or trucks in the line of sight of both vehicles. During the trip one OBU plays the role of vehicle in emergency sending continuously warning messages to the surrounding vehicles with a period of 10Hz. The other OBU is the receiver and it analyzes the received message. Different situations were recreated, such as LOS and NLOS situations. Finally, on average the package delivery rate (PDR) was 95%.

VI. CONCLUSIONS

The results obtained in these scenarios disclosed useful ideas which can help vehicular networks and active safety applications developers. Comparing the results obtained in the tests with the main requirement imposed by the ETSI, it can be concluded that the proposed architecture allows the deployment of ITS applications providing Quality of Service.

This architecture allows the deployment of a huge variety of cooperative vehicular applications and to test them in a real scenario. Besides, combining applications which are described in this paper and applications destined to test the quality of service of the communication links, V2V and I2V deployed links can be characterized by the PDR percentage and the delay, and then it can be obtained the probability of delivered sent packets.

Fig. 7. OBU interface

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