Vehicle On Board Platform: Communications Test and Prototyping

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***Abstract*— This paper describes the process of prototyping and testing an in-vehicle embedded system which allows the driver to communicate with his vehicle, with the gadgets inside it (PDAs, cellular, sensor networks, and so on) and with the road infrastructure in order to consume intelligent transport services. The result of the presented work is an on board prototype and two services which have been developed to validate some characteristics of this embedded prototype.**

I. Introduction

Intelligent Transportation Systems (ITS) can improve the transportation activities in several factors, such as safety, efficiency, pollution or infotainment. Moreover, the new information technologies and communications provide the vehicle with the ability to communicate with other vehicles (V2V) or road infrastructure (V2I) enabling the deployment of many services [1].

Moreover, the continuous emergence of new digital services for the automotive, forces the user to add different 'gadgets' to the vehicle. In this way, covering some needs over time becomes essential. Navigation systems, hands-free or portable media devices are among the top selling devices at any appliance store. Finally, the European Commission has prioritized the implementation of the Green Car initiative which aims to fund research into sustainable road transport. Consequently, an opportunity to use these new technologies in order to provide sustainable transport services has arisen. We consider that the existence of high advanced embedded system in-vehicle, is a key factor for the evolution in all of the mentioned areas.

In this paper, the work of the Intelligent Transport research group from the University of Deusto in the area of vehicle embedded systems is shown. First, projects focused on this topic are enounced, making special mention on projects recently approved by the European Commission. In section 3, the requirements of an on board platform for connecting vehicles with their environment are analyzed. In section 4, the first prototype of this embedded system is described, and in section 5 two services that have been developed to validate some characteristics of the proposed on board prototype are explained. Finally, the future work and conclusions are presented.

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II. Related Work

Except some initiatives emerging for certain manufacturers, such as The Genivi Alliance [2], there is not an on-board platform with an open architecture. There is not any system able to provide access to information from inside the vehicle, from external infrastructure or even from other vehicles and also support the implementation of services, consumers of such information relating to any of the areas of intelligent transport.

There are various initiatives and European research projects in this area. The most significant are summarized below [3]:

CVIS (Cooperative Vehicle Infrastructure Systems): this project is focused primarily on core cooperative technology.

SAFESPOT (Cooperative systems for Road Safety): it offers a solution designed exclusively to detect critical driving situations aimed at improving safety in road transport.

COOPERS (Cooperative systems for Intelligent Road Safety): This project, coordinated by Austria Tech, proposes to connect the vehicles through continuous wireless communication with the road infrastructure to provide services that improve driving safety.

m:Via-Future of the Intelligent Transportation Systems: this project focuses on the use of wireless networks to increase road safety and add value as infotainment, vehicle support, comfort and traffic optimization [4].

Main difference between the solution proposed in this paper and those mentioned above are mainly based on bottom-up approach adopted in our project. Instead of doing the analysis of requirements from the services to be developed, this project focuses on developing a general platform, capable of obtaining information from inside and outside the vehicle, over an open and scalable architecture on which to deploy all services related to intelligent transportation.

III. Platform's Requirements to Provide Intelligent Transportation Services

As it was described previously in section 2, many initiatives have arisen with the aim of providing connectivity between the cars and their environment, in order to deploy new intelligent transportation services. The challenge is to provide connectivity, intelligence and real time information to mobile elements (vehicles) in a lacking of connectivity environment.

A system like this should include on board elements and those systems placed on the roadside. Related to the on board system [5]:

- It is necessary that the system will be able to collect data from the vehicle data buses.
- Interaction and integration of other on board devices and gadgets is a desired capability too. The proposed system might be able to establish communication with on board devices and integrate its functionality into a single device. This system works as a concentrator of current on board devices and gadgets.
- A particular in-vehicle element is the driver and the passengers, because of the way in which the system will interact with them. Thus, on board system has to provide a human machine interface (HMI) compatible with the driving. It enables the provision of information by users to the system as well as the consumption of the services by them.
- Finally, communications with externals elements (Vehicular Ad-Hoc Network - VANETS) are needed in order to broadcast internal data and to access to external services.

These specifications might be supported by a hardware device which hosts the in-vehicle embedded system. Both elements (hardware and software) will constitute the classic On Board Unit (OBU) which is shown in ITS architectures. As well, Moreover, this hardware device has to fulfill some requirements: low consumption and price, wide range of communication interfaces, independence of the car maker, non-intrusive design and driving compliance human interface. Furthermore, it should be based on an open software platform to allow adding new services. This makes the system scalable and flexible for future developments.

The infrastructure proposed needs to act as a gateway between final applications and the mobile networks nodes will aggregate the information provided by the mobile environment (the vehicles) and use it to provide advanced traffic services and applications. Fig. 1 shows the current subsystems and connections between them in a classic ITS architecture for surface transport [6].

Once the proposed architecture is deployed in a real scenario, there is a wide range of services that could be provided. For example: remote monitoring services based on data acquired from the vehicle, traffic management services, assistance services used by the entities which manage the road infrastructures and traffic or passenger information services

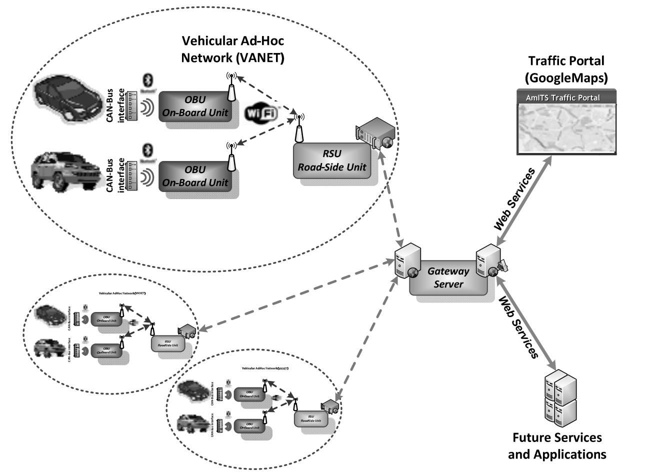

Fig. 1. Components and communications in a classic Intelligent Transportation System's architecture for surface transport.

IV. On Board Unit Prototyping

In order to build a fully functional intelligent transport platform as the one described in the previous section, specific modules have been developed. Two types of modules have been developed: those that are on board the vehicle and those modules that are out of it, that is, the modules that are placed on the road or in a control center.

In this section a prototype of On board Unit (OBU) that has been developed is described. Thanks to this prototype, the user will be able to receive data: a) from the vehicle; b) from the gadgets inside the vehicle (PDAs, cellular, sensor networks, etc.); c) elements placed out of the vehicle; d) from the user, thanks to a Human Machine Interface.

This OBU can be used in any kind of vehicle, regardless of the manufacturer and it must be easily placed inside the vehicle by a user without special skills. Apart of those characteristics, new and future services can be added in a transparent way for the user. Preexisting services and gadgets could be added too.

A. Communications with the Vehicle

One of the goals of this project is that any user can use the platform that is presented here. Furthermore, the control center or the user can obtain data from the vehicle either in real time or those data can be saved in a file.

To satisfy both requirements, we are working with the standard OBD-II [7]. Thanks to this standard, data running in the bus can be sniffed and the user can access to this information.

There are three basic OBD-II protocols in use. While there have been some manufacturer changes between protocols in the past few years, as a rule of thumb, Chrysler products and all European and most Asian imports use ISO 9141 circuitry. GM cars and light trucks use SAE J1850 VPW (Variable Pulse

Width Modulation), and Fords use SAE J1850 PWM (Pulse Width Modulation) communication patterns.

To communicate the OBU with the data bus in the vehicle, a Bluetooth interface is connected to the connector OBDII in the vehicle. This is a commercial device and thanks to it, this communication is transparent to the user. Then, the information is sent to the device that has played the role of the OBU.

Using this interface, the user can collect data related to the vehicle: speed, revolutions, fuel level (load), and engine temperature and so on. Then, these data are analyzed and either they are displayed using a graphical user interface or they are stored. These stored data can be analyzed or sent to the control center which can keep track of these parameters.

B. External Communication

Using the wireless communications systems that OBU implements, the vehicle can interchange information with elements placed on the road. These elements and the vehicles create a Vehicular Ad-hoc Network [8]. Traffic lights, traffic signals, information panels or other devices which collect data from the road could implement a communication system and send data to the vehicles or to a central server through a Road Side Unit (RSU).

In order to examine the essential requirements of communications between a moving vehicle and the RSUs, the NS2 network simulator [9] has been used. In this simulation, a vehicle sends periodically a message to the RSU. The vehicle is moving through different areas under different RSU's coverage. The objective of the simulation is to measure how successful any RSU within the area receives the messages in order to guarantee the message reception.

The scenario simulates a two-way roadway in straight line. The RSUs are placed in both sides of the road. There is a random number of vehicles, from 1 to hundreds, circulating in both directions and the target vehicle goes all over the road from one extreme to the other. During its way, the target vehicle sends periodically the same message.

In Table I, some results for different RSU separations are shown. According to this data, a separation of 400m seems to be the ideal distance between RSUs. If the RSUs are placed closer, overlapping areas appear and alarm messages are detected by two different RSUs. More than 400m of separation do not guarantee a 100% package reception

TABLE I
SIMULATION RESULTS FOR DIFFERENT RSU SEPARATIONS

RSU Separation (m)	Package Reception (%)
500	79,3
400	100.0
350	112,6

C. Internal Communications

As it is described in the previous section, the user can generate information from his vehicle and send it to the VANET. To give out his information, he has instruments to transmit events inside the vehicle [10].

Sensor networks can be deployed inside the vehicle. These can be used to monitor the driver's physical parameters (heart rate, temperature, etc) [11]. The data from these networks could be collected by the OBU for a later analysis. Users' gadgets as PDA or cellular can be used as an interface to generate information or to receive data from the vehicle or the external devices. Thanks to these devices, the user can export data to his laptop at home and register all the information generated in a journey.

As you can see, It may has different sources of information inside the vehicle. Therefore, it is necessary to have a device to handle all communications and serve as a gateway to the user to interchange data with these elements.

D. Human Machine Interface

The main requirement is that the HMI interface is interactive and non-intrusive, that is, it should be used by the driver while driving.

Currently, the developed OBU implements a touch screen that restricts their use when the car is moving, but we work to incorporate a voice system to it.

V. TESTING SERVICES

Apart of OBU, out of the vehicle some systems have been developed to receive data that are sent from the vehicle. Those data are collected in a control unit and are used, i.e., to control the traffic in an area, to fleet management, to know the situation of special vehicles, etc.

According to this approach, we have developed two services which will enable to validate some characteristics of the proposed OBU prototype. Those testing services are described below.

A. Testing of External Communications: Traffic Portal

To test OBU's external communications, an on board service and a web site for traffic alerts broadcasting has been created [12]. In this collaborative service drivers can report real time information about the road state and special events, as well as their position, while they are driving. Some of the alerts or especial events considered are: a prioritized vehicle (policy, ambulance or firefighter) is coming, a vehicle driving in opposite direction is coming, an accident has happened, adverse meteorological conditions and nearing to a jam. To perform this functionality, an event generator has been simulated on board. The Fig. 2 shows the dashboard and the buttons that user can push to send events to the traffic site.

Fig 2. On board event generator dashboard. Using some controls at the dashboard the driver can report some traffic events and alerts.

The information reported by the drivers is available in a traffic portal. This site informs about the state of the traffic in a selected geographical region. Events are reflected with its position, time and date. Moreover, on the traffic portal the information of each vehicle connected to the system is shown. Of each vehicle it is possible to get the position, the route and the type of vehicle, a unique identity and its speed. We distinguish different types of vehicle: common vehicle, ambulance, emergency ambulance, emergency vehicle (fire, police).

The final objective of the OBU external communications concerning to this particular service is that the driver can be reported with real time information about the road state and special events. This information has to be shown inside the vehicle, so a non intrusive HMI to read and display these data have to be implemented. For example, special vehicles as ambulances or police can generate alerts to inform about their situation and route. This information will be received by the RSU and it sends it to the control center. Then it is resent to all the vehicles in the area of the alert. The user, inside the vehicle, receives the alarm in the OBU and it shows a special event on the HMI. Then, the user could take appropriate actions.

Right now, this alerts broadcasting service is based on point to point communications: the user can send events to the central server with his cellular (uplink). When the server receives the event, this is shown in a traffic portal. Presently, we are developing the downlink to inform others vehicles of the events generated by one user.

B. Testing of Internal Communications with the Vehicle: Eco-driving Assistance Service

Using the information from the mechanic and electronic of the vehicle, software applications can be developed. For now, one service focus on eco-driving has been developed

Efficient driving, also called eco-driving is a new way to drive that aims to achieve: a) decreased fuel consumption; b) reduction of environmental pollution; c) increased driving comfort; d) Decreasing risks on the road.

Over the past 20 years, the fuel consumption of new cars has been falling steadily due to implementation of new technologies and improvements in the engines manufactured as well as roads. But this is not enough. It is important to consider both the attitude and the driver driving style. These facts are decisive when it comes to reducing fuel consumption and hence harmful emissions.

The main advantages of eco-driving are visible in several areas:

- Improves driving comfort by reducing driver stress.
- Reducing the risk and severity of accidents.
- Average fuel savings of 15%.
- Lower cost of maintenance, brakes, clutch, gearbox, tires and engine.
- Reduce urban pollution which improves breathing.
- Reduction of CO_2 emissions and thereby improve the problems of global warming.
- Energy savings nationally.

The interface developed allows the user to be informed about the optimum gear to which should be driving, and the level of CO_2 emissions at all times. The goal is to use this information to determine the most efficient way to drive.The interface is divided in three key areas: 1) meters of the most important variables of the vehicle in real time; 2) indicator to the right gear at each moment; 3) a set of LEDs to warn to the user about the CO_2 emissions.

- *Real time variables:* thanks to these gauges, the driver can control the data related with the driving: speed, revolutions per minute, percentage of O_2, fuel level, and CO_2 emissions.
- *Recommended gear:* the driver is recommended with the right gear in each time. Thanks to the combination of the speed and r.p.m values obtained through the OBD interface, the optimum gear is calculated and displayed in the interface.
- *CO_2 emissions:* nowadays, the amount of CO_2 emissions is one of the most important parameter for the cars manufacturers, due to its contribution to global pollution, so must be reduced gradually. For its control in the vehicle, in addition to real-time meter of emissions, the system features a color LED display. Through this system of color, ranging from green to red, the user knows how well is its driving behavior on emissions is. When the green LEDs are on, the driver knows that the car emissions are under the threshold provided by the manufacturer. If the orange LEDs are on, the emissions are near to this threshold. Finally, red color displays that the calculated emissions value is over this threshold. In this situation, the driver should reduce the speed to lower emissions. The threshold used to determinate the LEDs' color has been established

using the European Union normative: 140 grams CO_2 per kilometer. In 2012, this threshold decreases to 120 grams CO_2 per kilometer [13].

To calculate CO_2 emissions, information related with the speed and the values collected by the MAF sensor have been used. These data are read by the system using the OBD interface. MAF sensor measures the flow of aspirated air entering the engine. First, the fuel consumption per kilometer must be calculated. Using the value reads by the MAF sensor, the Gallons of fuel Per Hour (GPH) can be calculated using (1). Then Liters of fuel Per Hour (LPH) is calculated at (2). Finally, Kilometers of fuel Per Liter is obtained using (3).

$$GPH = MAF \times 0.0805 \quad (g/h) \qquad (1)$$

$$LPH = GPH \times 3.75 \quad (l/h) \qquad (2)$$

$$KPL = \frac{speed}{LPH} \quad (km/l) \qquad (3)$$

Once the KPL are calculated, the amount of CO_2 per liter depends on the type of fuel used. In a diesel engine, this value is 2.6KgCO_2/liter. In a petrol engine, this value is 2.3KgCO_2/liter. Therefore, the 3KgCO_2/Km can be calculated (4).

$$\begin{aligned} diesel\ emissions &= \frac{2.6\, kgCO_2/l}{KPL(km/l)} \quad kgCO_2/km \\ petrol\ emissions &= \frac{2.3\, kgCO_2/l}{KPL(km/l)} \quad kgCO_2/km \end{aligned} \qquad (4)$$

VI. Towards the Testing of the OBU Prototype in a Real and Controlled Scenario

The OBU external communications are implemented using standards such as Wi-Fi (802.11.p, 802.11.b/g, GPRS…). These communications capabilities were basically tested for the initial prototype in the laboratory, but some critical aspects are impossible to evaluate without an appropriate simulation network which predicts real values [14]. Some of these aspects are for example time response and network congestion. The simulation network and the subsequent implementation of a controlled scenario will help to validate communications capabilities of the OBU. The chosen scenario is the campus of the University of Deusto, shown in Fig. 3.

With this simulations it will be possible to validate the communications with the traffic portal service through the RSU, up to now implemented as a point-to-point connection between it and the vehicle. The challenge is to include the infrastructure as intermediate element between the traffic service and the vehicle. The first step is therefore to implement network simulations to guarantee the success of the services running over the V2I communications.

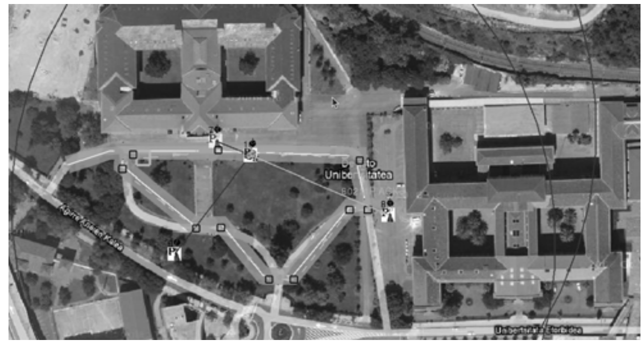

Fig. 3. The testing scenario in the campus of the University of Deusto, consisting of three RSU and one OBU.

The simulation network, besides a valuable tool for research and development of protocols and communication systems, is an instrument equally necessary for the deployment of real networks. A simulation, despite its limitations, is useful to estimate the behavior and performance of a network prior to installation (a good compromise between cost, complexity and fidelity in the results).

A large number of network simulators are available. Some of them are proprietary simulators, like for example OPNET Modeler or COMNET III, which cannot easily simulate the new standard 802.11p (designed for vehicular networks). Apart from the proprietary simulators, there are plenty of simulators that are free software and free of charge (at least for academic purposes) between them can be highlighted: NCTUns, OMNeT++, NS-2, NS-3 or Glomosim.

After working with some of them (e.g., NS-2), it can be asserted that the one most suited to this project is NCTUns [15], since in its new version created in November 2009 it incorporates the above mentioned standard 802.11p.

NCTUns is a very interesting simulator in several aspects. Firstly, it implements the protocols of the most used family of Wi-Fi standard, including 802.11p, also known as WAVE. It also includes WiMax, with its two operating modes (Mesh and PMP) for 802.11d. Moreover, the use of the protocol stack of the Linux kernel and the possibility of using real applications through simulated networks (even in emulation mode) is also an attractive feature.

As shown in Fig. 3, the simulator allows the simulation of vehicular environments, through the insertion of a map. This scenario represented a very simple and resembles reality. This scenario is simplified to represent de campus of the University of Deusto and it consists of three RSU and one OBU, but more complex scenarios can be carried out to test different situations. In these moments we are simulating some scenario parameters, like the throughput statistics, in order to establish the reliability of the complete prototype.

VII. Future Work

Currently we are working to increase the amount of data read from OBD. With these data we will improve the eco-driving service and we will provide other services such as remote diagnostics and monitoring vehicle maintenance. Moreover, we are analyzing how we can use the communication bus in the vehicle to obtain specific information of electrical vehicles. With this data we will provide ICT services geared exclusively to electric cars. Furthermore, we are studying which sensor networks can be used to monitor the driver's physical constants and which services can be offered with this information.

To improve the external communications capacities and related services (for example the traffic alert broadcasting service), we are implementing the downlink between the traffic site and the vehicle. In this way, the user will be reported with traffic information and special events in real time. Although we must admit that the HMI capacities are the less developed; we are working to improve the interactivity in a non-intrusive way using voice recognition systems.

Finally, the On Board Unit prototype, as well as the external infrastructures and services, are planned to be tested in a real but controlled scenario. This scenario will be the campus of the University of Deusto, because it provides a closed and controlled area to experiment with the prototyped OBU and the developed services. These experiments will provide us with additional and useful data to improve our prototype.

VIII. Conclusions

All of the projects presented in the related work of this paper are based on top-down approach. That is: the ITS architecture is designed from the point of view of the services. Once the services are designed, the hardware platform for the On Board Unit (OBU) is developed. The problem of these approaches is that they are no easily scalable, because new services may require new hardware requirements. Most of the times to change the OBU design is very difficult and expensive.

However, the on board platform presented here, as a prototype, is designed following a bottom-up approach. First, the hardware device is designed to support different type of services. So, this on board device meets the characteristics necessary to support new and future type of services.

The challenge of this initiative is to deploy an on board platform with several communications interfaces and to develop services to validate it. Two of those services are shown in this paper (traffic event broadcasting and eco-driving assistance).

To add new capabilities to the platform, to create new services based on new V2V and V2I concepts, and finally, to check the whole system (platform and services) in a real scenario, in order to improve our OBU prototype, are the objectives of the following steps.

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