Experimental Platform for Infrastructured Vehicular Networks

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Abstract. Vehicular communication technologies allowed the establishment of vehicular networks to support intelligent transportation systems. ITS systems fostered the development of applications and services to be deployed and used in vehicular environments. This document proposes a experimental platform for infrastructure-based vehicular networks, taking into account the creation of a vehicular applications development system. The proposed architecture will consider the context in which the applications are being used and adapt applications execution flow. A scientific methodology and test case scenarios are proposed in order to validate the developed solution and will be performed in real scenarios, in order to cope with the existent limitations of such scenario.

Keywords: Vehicular Networks, Intelligent Transportation Systems, Vehicular Applications

1 Introduction

Vehicular networks are a new class of networks that have emerged thanks to advances in wireless technologies and high investment from both automotive industry and research entities. Particularly, Vehicular ad-hoc networks are a subset of the general class of mobile ad-hoc networks, with several characteristics, presenting different challenges when developing both services and architectures for that type of network. Vehicular Ad-hoc network (VANET)s are a area of interest of road operations, manufacturers, telecommunication operators and academia, that are investing a lot of resources researching on those networks.

Several wireless technologies, standards and architectures were created to cope with the specific requirements of vehicular networks, enabling the development and deployment of a wide variety of vehicular-specific applications and services. The communication among vehicles and between those same vehicles and a roadside infrastructure permits the creation of an Intelligent Transportation System that, by gathering the several developed systems, enables the creation of a enhanced driving experience, by delivering both applications to make driving more pleasant and also safety applications. All groups of interest researching and investing in vehicular networks, have as priority the development and deployment of safety applications, due to the contribution that those can have in saving peoples lives and making driving more safe.

There is a large number of vehicular applications and services possible to be developed, and this work aims to contribute with a solution that allows a quick development of those applications, absenting the developers from some underlying implementation choices. The proposed architecture will have in mind the requirements of specific scenarios of vehicular networks as well as the characteristics of the vast vehicular wireless communication technologies available, abstracting those from the development process of applications, by creating a application interface to be used by developers.

The following document organizes as follows. In section 2 a brief characterization of vehicular networks will be done. Section 3 will refer to the architectures, technologies and applications developed for intelligent transportation systems and finally, section 4 and 5 will describe the proposed architecture and the scientific methodology that will be followed in order to validate the solution.

2 Vehicular Networks Characterization

Vehicular networks are a dynamic ad-hoc network that enables the establishment of connections between moving cars and also possibly with a roadside infrastructure for deployment of novel applications and services to enhance both driving safety and users driving experience. In the section, a brief introduction to vehicular networks will be done, starting by a comparison between vehicular networks and traditional ad-hoc networks and ending with the possible deployment scenarios for vehicular networks.

2.1 VANET a subset of a MANET

A Mobile Ad-hoc network (MANET) is a wireless network of mobile devices, which is structureless and self configured, and where each device may act as end-system or router. MANETs have several characteristics [6], such as, dynamic topologies, limited bandwidth and energy and limited physical security that pose important research challenges, which are being addressed by the research community in different areas, as surveyed in [8].

VANETs are a special case of the aforesaid networks due to the specific properties that distinguish them from other MANETs, such as:

– **Deployment Scenario -** There is a physical environment that restricts the freedom of movement of the nodes, like streets, roads, avenues, highways, junctions, corners, roundabouts, and so on. This scenario particularities have a heavy impact on nodes mobility and led to the definition of new mobility models [33] [18]. Oppositely, buildings and other sort of obstacles present near roads and highways have strong impact on the communication [37], affecting signal propagation conditions. Also, traveling vehicles, that block the Line of Sight (LOS) between the receiver and the transmitter, attenuate the signal when compared to scenarios where there is a clean line of sight between the communicating nodes [27].

– **Mobility pattern -** Nodes (vehicles) have mobility pattern with wide variation, due to the high velocity of traveling vehicles and possibility of being stopped in traffic lights or other traffic events. However, although VANETs do have dynamic topologies, they are not completely random because vehicles movement is restricted to the roads on which they travel.
– **Node Properties -** Vehicles have specific equipments attached or embedded with communication capabilities in order to act as end-system. The equipment can interact with built-in sensors and vehicle Global Positioning System (GPS) device. In VANETs the node does not have any foreseen power constraints [8], as it can make use of the vehicle electrical system. In addition, operating vehicles can afford significant computing, communication and sensing capabilities [32].

As stated in [20], VANETs have to deal with some challenging characteristics, not addressed on other MANETs:

– **Network scale -** Unlike the vast majority of MANETs that usually assume a limited network size, vehicular networks can theoretically extend over the entire road network and include a vast amount of participants, taking additionally potential roadside units into account.
– **Network topology variations -** Network topology may change frequently due to the dynamics of the vehicles movement. Also, the dynamic nature of traffic lead frequently to partitioned networks, with large inter-vehicle gaps with sparse populated scenarios and isolated clusters of nodes.
– **Connectivity -** The connectivity degree is highly dependent on the radio coverage area and the number of neighbor vehicles equipped with wireless interfaces [22]. The connectivity is also different on the distinct deployment scenarios [1], due the vehicles velocity and dissemination and road topology. Also connectivity, in some VANET deployment scenarios, can vary according to the period of the day. For instance, in rush hour, vehicles are stopped near each others offering a high degree of connectivity, being that vehicle density as large as 90 times larger when compared to the night time period [44]. However, if those vehicles are simultaneously communicating, more communication collisions may happen.

In fact, MANETs and VANETs are very much similar on various technical grounds, but some important properties can contrast in both environments as depicted on table 1.

Some other characteristics like the cost of equipment production, available bandwidth, communication range, node lifetime, addressing scheme and many more, differ between MANETs and VANETs [38][4][24]. Some of those properties will be analyzed later on the present document.

It is possible to affirm that VANETs have very different properties when comparing to MANETs, and despite being a subset of a mobile network ad-hoc network, vehicular networks cope with different challenges and must use different approaches to cope with those challenges. And it is also significant to highlight

Table 1: Comparison between MANET and VANET

Property	**MANET**	**VANET**
Mobility Pattern	Random	Road topology constrained
Node properties	No specific devices Power constrains	Sensors and GPS No power constrains
Deployment scenario	No obstacles	Obstacles
Network scale	Small to medium	Potentially large
Network topology variations	Less frequent	Frequent and very fast
Connectivity	Sparse	Variable

that, in VANETs, different deployment scenarios have different properties that will define which approaches are to be choosed in order to grapple with the proposed challenges. Those scenarios are thoroughly described in subsection 2.2.

2.2 Deployment scenarios for VANETs

Possible environments for deployment for VANETs, have different approaches due to the diverse drivers behaviors and road topology, as well as the traffic properties. There are three types of scenarios on which vehicular ad-hoc networks platforms could be installed:

- **Urban:** The urban scenario corresponds to roads surrounded by buildings and other roadside constructions, where vehicles travel at average speeds of 50 km/h, reaching a maximum speed of 90 km/h. The density of vehicles intensify at rush hours or near traffic lights. Urban environments scenarios have roundabouts and road intersections that affect the vehicles path that can follow several alternatives to reach the same destination.
- **Highway:** It is a open environment with scarce roadside, between the communicating nodes, or constructions nearby. Vehicles travel at a minimum speed of 50 km/h, possibly having a top speed of 200 km/h. The density of vehicles is low, only increasing in case of accident or road construction works, having a low probability of occurring. There are a few entrances and exits to the highway, that may vary from 2 to 5 lanes at each side. Cars may stop, for an indeterminate period of time at gas stations or safety stops.
- **Rural:** A suburban scenario is characterized by having few buildings near the road with the possibility of roadside tree plantations. There may be some crossroads or traffic lights where the density of traffic can increase but it's expected that the concentration of vehicles to be low. Vehicles speeds can go up into 90 km/h but usually it's not expected to exceed the average 50 km/h.

The deployment scenarios also depend upon the different characteristics of roads, movement patterns, node velocity and node density, as stated by *Schoch et al.* [38]:

– **Expected Node Velocity:** Nodes can be vehicles traveling with variable speed or stationary gateways of a physical infrastructure. Vehicles velocity range from zero, when vehicles are stuck on traffic jams, up until 200 km/h on highways. In case of very high relative velocity the communication window between communication parties is very short due to a relatively small transmission range. In case of two vehicles traveling in opposite directions at a moderate velocity of 90 km/h, and assuming the theoretical wireless transmission range of 300m, communication is only possible for 12 seconds. In [21] it is shown that, in controlled environment, a direct communication between a moving car and a stationary gateway lasts 66 second at 90 km/h and 143 seconds at 50 km/h. Hence, node velocity have impact on all layers of the protocol stack, restricting the type of solutions that may be used.
– **Movement Patterns:** Vehicles move according to predefined paths established by roads, but some unpredictable changes in directions can occur at intersection roads, or in rural environments where roads could not be representative of a vehicle path. In a city, the movement vector of the vehicles is not defined, due to the unordered traffic, yet in highways, vehicles form an almost unidimensional well defined path, where virtually there is no margin for alternate routes [4]. Therefore, assuming that road regulations are obeyed, there are upper and lower speed bounds and restriction signs that obligate the driver to move on specific roads and directions, enabling the possibility to include some level of predictability in vehicles movement patterns [5].
– **Node Density:** The density of nodes within transmission range could vary from zero up to hundreds of vehicles. During a traffic jam on a highway with three lanes, where there is approximately one vehicle in every 5 m and a radio range of 300 m, performing a theoretical total of 1000 vehicles within a radius of 1 km around a given car [42]. In case of very low density, performing immediate message forwarding becomes inconceivable, raising the need of a more sophisticated information dissemination methods [38]. The node density is not only directly correlated with the road type, but also with time, where the daytime and rush hour represent, in most of cases, a high density situation.
– **Connectivity Obstacles:** The connectivity between moving vehicles can be affected by several objects of the surrounding environment and by topological characteristics of streets, roads, avenues, junctions, corners that have buildings and other constructions that interfere with the radio propagation. As mentioned previously, other vehicles within LOS between the the communicating entities also act as obstacles. The impact of those obstacles is demonstrated in [40], where it is characterized the difference between the three aforementioned deployment scenarios.

According to these properties, it is possible to summarize the differences of the several vehicular ad-hoc networks scenarios, as shown in table 2.

Table 2: Deployment scenarios for VANETs

Property	**Urban Environment**	**Highway Environment**	**Rural Environment**
Expected Node Velocity	0 km/h - 90 km/h	50 km/h - 200 km/h	0 km/h - 60 km/h
Movement Pattern	Some predictability	Predictable	Possible unpredictability
Node Density	High	Frequently Low	Very Low
Connectivity Obstacles	Potentially many	Few	Few

By analyzing the aforementioned characteristics and properties on the various deployment scenarios for vehicular ad-hoc networks, one can conclude that is not possible to define an architecture that can cope with all the aspects that define each deployment environments. A general framework must contemplate different approaches according to the surrounding environment of the intelligent transportation system installation.

3 Intelligent Transportation Systems

On the present section will be described the various contributions to the definition of a standardized Intelligent Transportation System (ITS) architecture by several past and ongoing projects and the applications that can operate on top of that architecture, keeping in mind the aforesaid VANETs peculiarities and the different approaches on the possible deployment scenarios.

3.1 Related Projects, Consolidation and Standardisation

A vast number of research projects all over the world have been focusing on inter-vehicle communication systems and related problematics. Those projects, financed and supported by industry, governments and academia are currently developing solutions and services in order to establish new standards to VANET environments. Most of them are result of a joint-venture between auto-makers and mobile or roadway operators in order to enhance their equipments and infrastructures with means to deploy and support ITS. Despite the fact that valuable advances are being done in United States of America, by Partners for Advanced Transit and Highways (PATH)[1] project and U.S. Department of Transportation - Intelligent Transportation Systems (USDot ITS) program harmonized by American Vehicle Infrastructure Integration (VII)[2], and in Asia, mainly Japan, several projects coordinated by the Ministry of Land, Infrastructure, Transport and Tourism[3], one will focus on projects and consortia developed in Europe due to applicability and coherence with European Union standards and norms, and also because the main research projects, actually contributing to widely accepted standards, are originally from European grounds [7].

[1] www.path.berkeley.edu
[2] www.vehicle-infrastructure.org/
[3] www.mlit.go.jp/road/ITS/

Some other projects have done important contributions to the collaborative elaboration of a standardised European ITS framework, like **Network On Wheels (NoW)**[14][4], that aimed to solve technical key questions on the communication protocols and data security for car-to-car communications to support active safety applications as well as infotainment application. **WiSafeCar**[5] and **Safe Intelligent Mobility (simTD)**[6] projects are currently developing enhancements to previous projects solutions in order to consolidate V2X (either V2I or V2V) functions to supply several types of applications and services.

Other initiatives, with different and more specific approaches, are also contributing to the definition of a standardized ITS architecture. **Secure Vehicular Communication (SeVeCom)**[7] is focused on the full definition and implementation of security requirements for vehicular networks and **PReVENTive and Active Safety Applications (PReVENT)**[8], a joint venture between European Community research projects and private automotive industry, is developing safety applications and technologies to mitigate accidents, through direct control on vehicles action for, e.g., breaking without driver command.

All the aforementioned projects contribute individually to the definition of new standards of intelligent transportation systems, but a consolidation initiative was a demand in order to collect the individual contributions. The **Communications for eSafety (COMeSafety)**[9] project provides a platform for both the exchange of information and the presentation of results from the contributing projects and initiatives representing the interests of all public and private stakeholders. This project works closely with the eSafetyForum[10], a European Commission initiative that monitors and promotes the implementations and recommendations identified by the eSafety Working Group and also supports the development, deployment and use of ITS to enhance drivers safety.

A non-profit organization, the **Car-to-Car Communications Consortium (C2C-CC)**[11], consisting of nearly all European vehicle manufacturers, several suppliers, research organizations and other partners was created in order to harmonize all the research and development work in intelligent transportation system, acting as a standardization entity in Europe. The main objective of C2C-CC is to implement ITS to further improve road traffic safety and efficiency using vehicle to vehicle and vehicle to roadside infrastructure communication and applications.

All the main world-class standardization entities, like **International Organization for Standardization (ISO)**, **European Telecomunications Standards Institute (ETSI)**, **Internet Engineering Task Force (IETF)** and

[4] http://www.network-on-wheels.de/
[5] http://www.wisafecar.com/
[6] http://www.simtd.org/
[7] www.sevecom.org
[8] www.prevent-ip.org/
[9] http://www.comesafety.org/
[10] www.esafetysupport.org
[11] www.car-to-car.org

IEEE, are also working towards the definition of norms and standards for technologies used in ITS.

3.2 System Architecture

The following sections describe the reference architecture proposed by C2C-CC. It starts by an overview of the architecture, followed by the details of the design and, at the end, the approaches of the different projects were summarized and discussed.

3.2.1 Components Overview

Four main components are needed to form a cooperative ITS: the vehicle station, the personal station, the roadside station and the central station. The next sections detail each one of them.

Vehicle Station A vehicle, or mobile node, is equipped with wireless communication capabilities for communication with other vehicles or roadside infrastructure. The on-board hardware can be connected to the vehicles built-in network to collect data within the vehicle, using the built-in sensors, and then send that information to the remaining ITS intervenients or process that same collected data to enhance the vehicles environment perception. The C2C-CC initiative defined, on the proposed reference architecture, that the Vehicle Station consists of two sub-components, On-board Unit (OBU) and Application Unit (AU).

The OBU, or Communication and Control Unit (CCU) [2] is in charge of the communications with other vehicles in a vehicle to vehicle communication scenario or with roadside components and infrastructure. Its even possible to integrate the vehicle station with Internet access capabilities using cellular radio networks. A OBU must comprise the following components:

- A Central Processing Unit (CPU) which enables several applications and communication protocols
- Communication equipment with a set of technologies in order to enable V2V and V2I communication scenarios
- A GPS receiver, to support navigation and accurate information on vehicles current position
- A visual interface, not mandatory, to allow human interaction input and information display.
- Communication support with in-vehicle sensors, not mandatory, in order to retrieve reliable information from the vehicles sub-systems

The OBUs in order to enhance communication capabilities, can be integrated with the access technologies such as Global System for Mobile Communications (GSM), General packet radio service (GPRS), Universal Mobile Telecommunications System (UMTS), Worldwide Interoperability for Microwave Access (WiMAX), 4G 3GPP Long Term Evolution (LTE), Wireless LAN IEEE

802.11 technologies and Infrared. Also, many vehicular communications specific access technologies such as DSRC/WAVE and CALM have been developed, and will be further analyzed in section 3.3.

The AU is responsible for processing a single or a set of applications and services, while making use of the OBUs communication capabilities. An AU can be integrated in the vehicles internal systems and be permanently connected to the OBU or through the establishment of a connection with the Personal Station. Both units can be connected with a wired connection, however, a wireless connection is also possible making use of technologies such as Bluetooth[3], Wireless USB (WUSB)[48], Ultra-wideband (UWB)[12] and Infrared.

This distinction between AU and OBU is mere logical, since they can also reside in a unique physical unit [30].

Personal Station The Personal Station is typically a mobile consumer device, such as a smart phone, PDA, tablet or laptop that can provide numerous ITS applications or represent the interface to the driver of the services provided by the AUs[10]. This device is typically assigned to a person and can also store several profiles or preferences of that person, allowing a ITS system to be portable and independent of the vehicle in which the user is traveling. The Personal Station can communicate with the AU in a wired or wireless configuration, being that configuration dependent of the technologies present on such device. It can be integrated or connected, e.g. via Bluetooth, to a vehicle should be considered as part of the vehicle equipment, and therefore generate or receive additional information data. Furthermore, the vehicle may directly use the communication capabilities of a connected personal device and may also take use of its output devices to present information within a vehicle to the driver. Also a personal station could be used as an independent component of an ITS, communicating with roadside infrastructure or with legacy systems, through cellular networks.

Road Side Unit The Roadside Unit (RSU) or Roadside Station, is a fixed installation along the road that also consists in two sub components, a Roadside CCU, responsible for the communication with the Vehicle Station or other RSUs and one or more Roadside AUs, in charge of processing the ITS applications for the roadside equipment. This roadside equipment may be linked via a roadside gateway to road sensors or traffic control units, as traffic lights and Variable Message Signs (VMS) enabling the realization of in-vehicle applications that are aware of the road conditions as well as dynamically adapting and updating the road information based on the information transmitted by the vehicles. Optionally, a border router can connect the ITS Roadside Station to a backbone network, which can be an ITS Roadside infrastructure network or the Internet Domain. The connection to a roadside infrastructure network permits the direct exchange of information between different road stations, that when a Internet connection is available also enables the possibility of communication to a central traffic control server or the usage of Internet deployed services. A RSU can also make use of existing or upcoming wireless infrastructures such as cellular networks, with UMTS, WiMAX and LTE [32].

Central Station The Central Station may supply some value-added applications and services that may be accessed and used by the Road side unit (RSU)'s via a roadside gateway. This way some processing capabilities could be delegated only to the central station that also can store and process information from all the RSUs connected by the gateway. A Central Station may comprise several AU's and is typically connected to the Internet Domain using a border router. The central station can, this way communicate and send information to the vehicles via the roadside gateway, or directly to vehicles through cellular networks via Internet.

Summary Table 3 depicts the main design decisions of the main European ITS projects and initiatives regarding the selection of components.

Table 3: ITS Projects Components Design Decisions

Project	**CVIS**	**COOPERS**	**SAFESPOT**	**NoW**	**simTD**	**WiSafeCar**
Vehicle Station	Yes	Yes	Yes	Yes	Yes	Yes
In-Vehicle Sensors	Yes	Yes	Yes	No	Yes	Yes
Embedded AU	Yes	Yes	Yes	Yes	Yes	Yes
Personal Device	No	No	No	No	No	No
Personal Station	Yes	No	Yes	No	No	No
Personal Station Type	Smartphone	-	Laptop	-	-	-
Roadside Station	Yes	Yes	Yes	Yes	Yes	Yes
Roadside Sensors	Yes	No	Yes	No	No	Yes
AU	Yes	No	Yes	No	Yes	Yes
Backbone	Yes	No	No	Yes	Yes	No
Central Station	Yes	Yes	No	Yes	Yes	No
Internet Integration	Yes	No	-	Yes	Yes	-
AU	Yes	Yes	-	Yes	Yes	-

3.2.2 Network architecture

Different communication scenarios can be envisaged for ITS and different technologies can be used to support the interactions between the components. The following section details these issues.

Communication scenarios In a vehicular network several communication scenarios may be considered [35][28]. Vehicles can make use and communicate with wireless hot-spots along the road, either operated by Internet service providers or by an integrated operator. Legacy and existing cellular communication systems, can also be used. Vehicles can even communicate with other vehicles directly without a communication infrastructure, and therefore cooperatively forward information on behalf of each other. Hence, one may conclude two different communication scenarios in vehicular networks:

– **Vehicle-to-Vehicle (V2V):** Vehicles communicate among them, forming an ad-hoc network

– **Vehicle-to-Infrastructure (V2I):** Vehicles communicate directly with the roadside infrastructure to exchange information.

It is even possible to make an hybrid approach, where are explored both V2V and V2I communication scenarios. Then, vehicles can be considered active nodes that are responsible for collecting and forwarding critical information, as well as processing that information by means of intelligent sensors, forming a coexistence between vehicle networks and sensor networks paradigms.

The information exchange in a V2V topology can be distinguished as:

– **Single-hop Intervehicle Communications (SIVC)**: Vehicles send information directly to the destination mobile node., useful for applications requiring short-range communications.
– **Multi-hop Intervehicle Communications (MIVC)**: The sent information is routed among several communicating nodes in order to reach the expected destination. This information dissemination method is designed to support applications that require long-range communications.

A hybrid vehicular communication system tends to be the most adopted solution since it extends the range of V2I systems. Vehicles can communicate with the Roadside Stations, even when they are not within the wireless range, by using other vehicles as mobile routers in a MIVC topology, extending the transmission range of the vehicles enabling new services and applications to be developed and installed. However, a hybrid solution presents one disadvantage, since the network connectivity may not be guaranteed in scenarios with low vehicle density[22][21].

Components interactions In an ITS, all the components can interact directly with several legacy systems and make use of those systems by using technologies such as WiMAX, LTE, UMTS and WiFi.

Vehicles can communicate with built-in sensors to gather information. Besides the traditional wired connections such as CAN bus and digital I/O ports, that can be used for connecting sensors to other devices, it is possible to use wireless technologies such as ZigBee, Infrared and Bluetooth. RSUs can make use of roadside sensors to collect information about road conditions or traffic. Technologies such as Infrared, Bluetooth, WiFi as well as wired solutions can be used.

In order to vehicles communicate with each others, several traditional or vehicular-specific technologies can be used, such as Wifi, DSRC, MMWAVE, UMTS, LTE and WiMAX. Vehicles can communicate to the roadside infrastructure making use the same technologies, but they can also use ZigBee or Infrared.

Communications within the backbone can be done either by cabled solutions or by wide-range wireless technologies, such as WiMAX, UMTS and LTE. RSUs can exchange information with personal devices via several technologies such as Infrared, Bluetooth, Wifi, UMTS and LTE.

The usage of the aforementioned technologies for the interactions between the several ITS components form the network architecture of vehicular communication systems.

Figure 1 depicts the logical representation of an ITS network architecture.

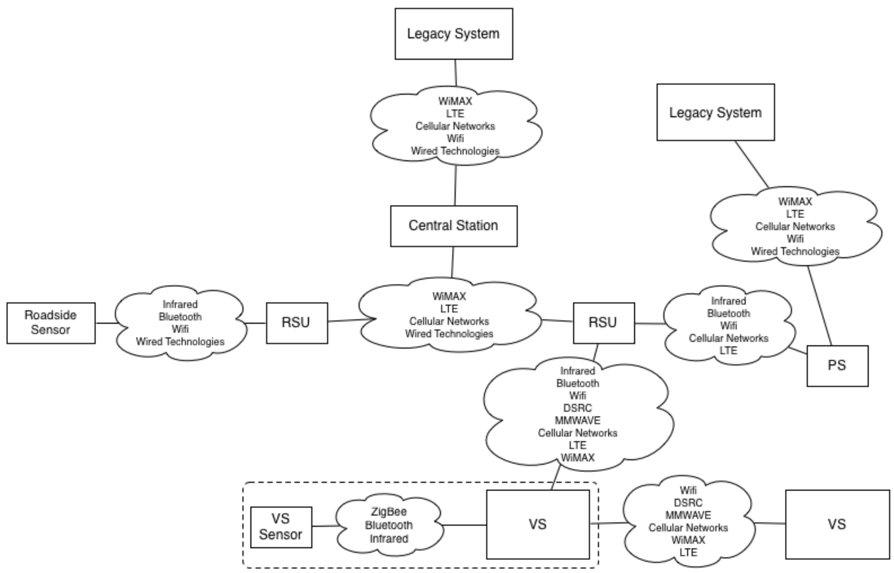

Fig. 1: Logical representation of an ITS network architecture

Summary Table 4 depicts the architecture topology design decisions.

Table 4: ITS Projects Architecture Design Decisions

Project	**CVIS**	**COOPERS**	**SAFESPOT**	**NoW**	**simTD**	**WiSafeCar**
Communication Type	Hybrid	V2I	Hybrid	Hybrid	Hybrid	Hybrid
Routing Type	MIVC	SIVC	MIVC	MIVC	MIVC	MIVC

3.2.3 Summary and Discussion

The above mentioned architecture and equipments, integrated in a ITS network represent an optimistic approach that only considers a technical glide. On a short and medium term period, the investment required to deploy such architectures would be a major impediment, therefore the deployment must be done in several stages. The first stage would be the equipment of vehicles with communicating capabilities in order to start conceiving and deploying V2V oriented applications, with low cost investment in infrastructure. However, the in-vehicles systems to be developed and deployed, should have in mind that the usage of vehicle embedded sensors is limited to recent vehicles. The in-vehicle systems should consider both the presence and absence of those sensors in order for them to be deployable also in old vehicles. At a medium term, the investment in infrastructure should be done in order to supply applications and services that make use of roadside sensors and other centralized services. Yet, one should note that backbone solutions for integrating RSUs are expensive, only likely to be used in highway scenarios where road operators tend to have an already installed backbone infrastructure along their roads.

3.3 ITS Communication Technologies

The communication equipments, present either in vehicles and inside the roadside units, comprises a set of communication technologies that can be explored. Several new technologies, specially developed for VANET, have been proposed and will be described next. To finalize, the most relevant properties of each technology are summarized and evaluated.

3.3.1 Vehicular Wireless Access Technologies

Dedicated Rhort-Range Communications (DSRC) - Standards were developed to allow high-speed communications between vehicles and the roadside, or between vehicles, for ITS. DSRC systems are able to work in a peer-to-peer fashion (vehicle-to-vehicle) without any help from masters (e.g. RSUs). Some DSRC systems, commonly used for toll collection purposes, exist, operating in the 915 MHz unlicensed band with less than 30 meters range. Those systems only provide a 0.5 Mbps data rate, not enough for ITS applications. IEEE developed and approved an amendment to IEEE 802.11 standard for DSRC systems, the IEEE 802.11p. 802.11p is based on the IEEE 802.11a PHY and MAC layer. However some changes were made in order to cope with the characteristics of a vehicular networking environment.

Most of vehicular communications are based on the frequent exchange of short status messages also known as beacons that carry information about the vehicle, such as its position, velocity and acceleration. In 802.11p, beacons are broadcast periodically by each vehicle. Communication range is normally in the order of several hundred meters and, therefore, beaconing provides awareness about the vehicles within the vicinity. Carrier Sense Multiple Access (CSMA) distributed medium access control scheme is adopted in 802.11p. Therefore, beacons are subject to collisions in the wireless channel resulting in performance issues [45].

Wireless Access in the Vehicular Environment (WAVE) - System architecture for the next-generation DSRC technology, which provides high-speed V2V and V2I data transmission [43]. The WAVE system is based and built on IEEE 802.11p and IEEE 1609.x standards.

Communication Access for Land Mobiles (CALM) - Integrated architecture supporting several communication media and application diversity and allowing all kind of communication scenarios, such as, V2I, V2V, multihop, point-to-point and multipoint. CALM comprises a set of wireless access technologies, some of them already mentioned in this section, such as, **CALM 2G/3G** mobile networks to support long distance communication, **CALM MMWAVE** to support short and medium range directed communication, **CALM Infrared** and **CALM M5**, derived from DSRC/WAVE intended to enable direct V2V communication. Other media, such as Bluetooth and WiMAX are also possible to be integrated within CALM set of technologies.

3.3.2 Evaluation of Technologies Used

Table 5 summarizes the wireless communication technologies based upon the following characteristics: commmunication mode (V2V or V2I), directionality (one-way or two-way), latency, data rate, range, transmission mode (unicast, broadcast or geocast), mobility and operating band.

Table 5: Wireless Communication Technologies characteristics and features

Access Technology	Communication Mode	Directionality	Latency	Data Rate	Range	Transmission Mode	Mobility	Operating Band
GPRS / UMTS	V2I and V2V[i]	Both-ways	1.5 - 3.5 sec	80 - 384 kb/s	10 km	Uni / Geo	Yes	0.8 - 1.9 GHz
LTE	V2I and V2V[i]	Both-ways	5 ms	300 Mb/s	∼ 1 km	Uni / Geo	Yes	800 - 2600 MHz
WiMAX	I2V	Both-ways	∼110 ms	1 - 32 Mb/s	15 km	Uni / Geo	Yes	5.x GHz
DVB/DAB	V2I and V2V[d]	One-way	10 - 30 sec	∼1 Mb/s	40 km	Broad	Yes	6 - 8 GHz
WLAN	V2I and V2V[d]	Both-ways	∼46ms	54 - 600 Mb/s	250 m	Uni	Limited	2.4 - 5.2 GHz
MMWAVE	V2I and V2V[d]	Both-ways	∼150μs	∼1 Gb/s	∼ 10 m	Uni	Limited	60 - 64 GHz
Infrared	V2I and V2V[d]	Both-ways	Very-low	∼1 Mb/s	∼ 10 m	Uni	No	2.6 GHz
ZigBee	V2V[d]	Both-ways	∼16 ms	20 - 250 kb/s	∼ 100 m	Uni	Yes	2.4 - 2.5 GHz
Bluetooth	V2I	Both-ways	∼100 ms	1 - 3 Mb/s	∼ 10 m	Uni	Limited	2.4 GHz
DSRC/WAVE	V2I and V2V[d]	Both-ways	200μs	∼6 Mb/s	∼ 1 km	Uni	Yes	5.8 - 5.9 GHz
CALM M5	V2I and V2V[d]	Both-ways	200μs	∼6 Mb/s	∼ 1 km	Uni	Yes	5 - 6 GHz

Summary Despite the fact that some access technologies may be used exclusively in some specific interactions scenario, as shown in 4, most of the ongoing European initiatives do not specify in public documents which ones are being used exclusively for specific interactions. Therefore, it is assumed that the set of technologies that are stated are used in most of the ITS interactions. Table 6 depicts which technologies have been adopted by some European initiatives.

3.3.3 Summary and Discussion

Several experimental tests have been done in several scenarios in order to characterize the performance of a given access technology.

Table 6: ITS Projects Access Technologies Design Decisions

Project	CVIS	COOPERS	SAFESPOT	NoW	simTD	WiSafeCar
Cellular Networks	Yes	Yes	No	No	Yes	Yes
LTE	No	No	No	No	No	No
WiMAX	No	Yes	No	No	No	No
DVB/DAB	No	Yes	No	No	No	No
WLAN	Yes	No	No	Yes	Yes	No
Infrared	Yes	Yes	No	No	No	No
Bluetooth	No	No	No	No	No	No
ZigBee	No	No	No	No	No	No
MMWAVE	Yes	No	No	No	No	No
DSRC	Yes	No	Yes	Yes	No	Yes
WAVE	No	No	No	No	No	No
CALM	Yes	No	No	No	No	No

Most of the wireless access technologies, such as DSRC and WAVE are characterized by their decentralized topology while cellular networks, for instance, UMTS or LTE, imply a centralized topology. Some frameworks, based on the LTE, have been developed [36][17], showing that LTE has better performances than decentralized solutions and also showing that as the number of vehicles increases, more efficient the framework becomes. The authors have also shown that in terms of overhead, bandwidth usage and packet loss LTE remains more efficient. Moreover, the velocity does not impact on the efficiency, whereas decentralized efficiency decreases when the vehicles velocity increases.

In [26], a comparative analysis on UMTS and LTE for vehicular communications have been done, presenting LTE as a viable solution, with many advantages when compared with UMTS. However, in [46], the author surveyed on the benefits of using LTE and 802.11p/WAVE to support some time-constrained applications. One concluded that the abilities of LTE to support beaconing for those applications are poor, being the ad-hoc WAVE architecture more promising, even more when using dual radio devices, which allow having a dedicated transceiver for exchange of time-constrained information, avoiding channel switching during beaconing, and therefore improving the scalability of 802.11p/WAVE.

In [47], a performance evaluation on UMTS, as deployed today, comparing with other Wireless LAN technologies, have been done. The authors have proven that UMTS and 802.11a, does not offer in-time delivery guarantees for applications and services with real-time constraints.

The authors in [13], have done a performance evaluation of the 802.11p/WAVE communication standard, concluding that the technology can not ensure time-critical message dissemination. Some previous work, on how to solve this problem has been proposed by [31], that suggest the use of a relevance-based, altruistic communication scheme that optimizes the application benefit and the bandwidth usage.

In [34] the authors evaluated the possibility of using WiMAX for vehicular communications applications concluding that in many times the QoS provided by the technology matches the applications requirements. An hybrid system design solution between WiMAX and DSRC was proposed and tested by the authors in [11]. The objective was to minimize the high levels of overhead created by WiMAX in a highly congested system, translating into a significant decrease in efficiency. Their results showed the potential to improve system capacity in congested systems by over 30% allowing more efficient use of infrastructure and a cost reduction to service providers.

A survey on the performance performance of the WAVE and 802.11p standards for vehicular communications have be done in [16]. The authors studied both the overall capacity and delay performance of vehicular networks utilizing those standards. The results showed that the traffic prioritization schemes for the used standards work well, and even in the presence of multi-channel operation implemented by the IEEE 1609.4 the delay of control messages of highest priority remains on the order of tens of milliseconds. Only when the total offered traffic within the radio range approached 1000 packets per second the delay values became excessive. The authors suggested that, despite WAVE and 802.11p appear to perform well for vehicular networks, some work should be done in higher layers to guarantee the overall network load remains under control.

All the aforementioned wireless access technologies present benefits and vanities when used in vehicular environments. The choice of which to use depend mostly on field test results of the given technologies, and available investment funds, when considering infrastructure based access options.

3.4 ITS Applications and Services

Within ITS, several applications and services can be developed. Traditional applications may be used, but generally vehicular oriented applications tend to be the option taken by developers working with ITS applications and services, therefore, one will only consider the classification and characterization of vehicular-oriented applications and services.

Applications can be classified in several ways, and many authors have done different approaches on that subject. While in [28] the authors divide applications in safety applications and comfort applications, [42] divides them in safety and user-related applications. Both of the approaches then subdivide applications in several categories taking into account the objective and priority of each application, as well as the technical requirements like, for instance the need of Internet connectivity, presence of OBUs and others.

As far as vehicular applications are concerned, several addressing schemes are considered in wireless ad-hoc networks, and applications are directly correlated with this addressing schemes [13]. Some approaches have been done using topological and attribute based schemes [8], but most of the developed work uses the following schemes:

- **Fixed Addressing:** IP-Based location where each node have a fixed address assigned to it as soon as it joins the network. This is the most common addressing scheme used in the Internet, being mobile IP an exception.
- **Geographical Addressing:** Location-Based addressing, where each node is characterized by its geographical position, changing its address while as it

moves. Also, the direction of the movement, road identifiers, type of vehicles and other characteristics may be used in this addressing scheme.

On the following sections, will be described services and applications classified as **Safety-Related Applications and Services** and **User Comfort Applications and Services**. Some authors also divide Safety-Related Applications in Transportation Safety and Transportation Efficiency, but on this work the latter classification will be adopted.

3.4.1 Safety-Related Applications and Services

Safety applications are intended to prevent accidents by warning the drivers about traffic or road conditions. The driver can be assisted, while driving, to prevent or avoid accidents, and many studies shown that a large percentage of those could be avoided if the driver is provided with some kind of warning, half a second before the collision. Safety applications and services can be divided into **information**, **assistance** and **warning** categories [23]:

Information: Applications that provide some kind of information to the driver, such as, road conditions and weather information, traffic lights scheduling and speed limits. Also **traffic coordination and monitoring** can be achieved, were the traffic can be analyzed and vehicles can be rerouted in order to prevent roads congestion.

Assistance: Applications that provide navigation assistance information to the driver. Some examples are **navigation and local information**, that present information about local points of interest and travel information, **cooperative collision avoidance**, that allows vehicles to interact with each others and cooperatively avoid accidents, for instance, when changing lane, by detecting nearby vehicles.

Warning: Applications that provide collisions notification or support for emergency management purposes. The notifications can either be used for traffic efficiency, where drivers are warned to avoid the accident, suggesting alternative routes, or for emergency management, where emergency procedures, such as, calling an ambulance or road assistance, can be triggered.

3.4.2 User-Comfort Applications and Services

The main objective of comfort applications is to give user a more pleasant travel. Nowadays, people are used to alway be communicating, either with people or accessing to services available in the Internet. As stated in [23], all kinds applications with may run on top of TCP/IP stack may be applied in this category. User-Comfort applications and services can be divided into **information**, **entertainment** and **business** categories:

Information: Applications that provide information about points of interest such as restaurants, museums and other local information. This type of application demands some type of data archiving and information gathering. Information can also be gathered from vehicles in order to collect data for a number of applications, such as transportation planning, safety analysis or research.

Entertainment: Mainly Internet-based applications such as audio and video streaming, web browsing and E-mail access. Voice and Instant Messaging applications may also be developed, allowing users to communicate either with other vehicles or with other users on the Web, making use of their smartphones or vehicle-embedded interfaces.

Business: Applications that provide support for e-commerce and commercial information like advertises or electronic payments and pricing. Also, companies can make use of vehicular communications in order to track their commercial vehicles and improve the efficiency of freight terminal processes and drayage operation, as well as the exchange of inspection data with regulating agencies and also improve fleet security.

3.4.3 Evaluation of Applications Requirements

In order to deploy the aforementioned applications and services in a VANETs, several requirements have to be fulfilled. Providing safety applications are the major concern when taking into account the network architecture, since they consist mainly of time-critical applications. Also providing delay sensitive services such as multimedia data transfer or instant messaging, must be taken into account. Therefore a list of requirements, arises and the following will be compared with safety and user-comfort applications in table 7

Table 7: Safety and User-Comfort Applications Requirements

Application Type	Interaction Type	Time Critical	Addressing Scheme	QoS	Bootstrapping
Safety	V2V , V2I	Yes	Location-Based	Yes	Dependent
User-Comfort	V2V, V2I , X 2 Legacy	No	IP-Based	Optional	Not Dependent

3.4.4 Summary and Discussion

All ITS Applications and Services are heavily dependent on what communication scheme was adopted, the chosen addressing mode, system penetration and real-time requirements. Most of the projects mentioned in 3.1 are developing their own applications and services while taking into the account the network architecture decisions and the requirements of the given applications. Some research is being done in specific aspects of vehicular applications and services, as in, [19,39], where the authors propose solutions to predict drivers intents and destinations fetching the possibility of creating traffic efficiency enhancer services. In [29] the authors proposed a publish/subscriber communication infrastructure for efficient information dissemination along RSUs. Wireless technologies options have been related with specific applications in the work developed by *Dat et.al.* in [9]. Also, a survey and solution proposal on streaming media distribution along VANETs have been done in [41].

Security concerns within vehicular applications arise, since several new attacks can be done, and the usage of those attacks can have significant impact on peoples lives. One type of attack has been presented in [25], where the author present why traditional security mechanisms do not work in vehicular networks. In [35] it is proposed a framework designed for vehicular environments that cope with some security issues of this specific network type. In general, most of the security designs increase the amount of requirements of each application.

3.5 Synthesis

Several design decisions are to be made when defining a ITS vehicular network architecture. Although some standardization is available, those do not specify the technologies and equipment to be used, leaving that aspect to be decided by the projects teams. Design decisions have to be done always considering the predefined requirements for the ITS that is being developed, the application requirements and degree of market penetration needed. Most of the aforementioned technologies and applications have been developed having in mind the VANETs characteristics, however the integration and deployment of them all in a real scenario has been shown a challenge to both operators, developers and academia.

Most of the tests and results presented previously are developed for a big scale networks with high degree of ITS penetration. Therefore it is necessary the development of a solution that allows a incremental deployment of ITS applications and technologies. This implies that the both the framework and applications are the most agnostic possible from the underlying implementation.

4 Architecture Design

The following section will explain the architecture design developed to cope with the objectives of this work. The main goal is to facilitate the development of vehicular applications by creating an abstraction layer to be used by the developers which provides a set of services to be used. That abstraction layer will also control the applications used, having the intelligence to adapt applications performance according to the context in which applications are being used.

4.1 Requirements

The objective for this work is to facilitate the fast development of applications to be deployed in vehicular environments, having as requirements:

1. Application Programming Interface (API) to facilitate the development of vehicular applications with common functionalities
2. Low cost platform
3. Context aware configurable platform

The final architecture must contemplate the easy development of applications, allowing programmers to select easily what kind of information they need in a common and easy to use API, abstracting them from the underlying technologies and specifications. The used platform will have as basis the INESC-ID ARM based platform which already has some work developed previously which will be thoroughly explained in 4.2. All the code development will make use of open source technologies and code. The platform will have the possibility to adapt itself and the deployed applications to the context where the device running it is being used.

4.2 System Architecture

In order to facilitate the development of a low-cost platform, the system will have as basis the previous work done by INESC-ID thesis, which have developed a platform that permits the abstraction of some low-level details such as message ordering, access technology used or beacons gathering to retrieve neighbors position. Figure 2 depicts the architecture of INESC-ID platform and two of the available modules will be used. The **Facilities** module, which provides functions as; application registration and unregistration, request neighbors list, request neighbors location, listen to received HELLO[12] messages and chose messaging type (Unicast, Geocast, Broadcast). The**Plugins** module which functions such as subscribe of send information on the *Sender* module, alter HELLO send timers and store values on the neighbors table, change message buffer size and change HELLO message aggregation methods. Several underlying functions are available, but those will be considered as an abstraction to imply a modular implementation of this architecture, using only the functions put available by the Facilities and Plugin modules.

The proposed solution, making use of the aforementioned platform, will develop three main features:

- **Application Development Middleware (ADM)**, which will gather and supply, from the underlying modules, parsed data to applications, divided by applications characteristics and requirements. Developers will have a easy to use and access resource, with parsed information, so that applications can make use of it.
- **Context Manager Adapter (CMA)**, which will coordinate the applications flow, taking into account the context in which those are being executed and also external events, e.g., accidents, speed increase, emergency situation, vehicle state, among others. Applications priority will depend on the context, and the CMA will be responsible for that coordination and also for

[12] Beacon used for the neighbor discovery protocol[15]

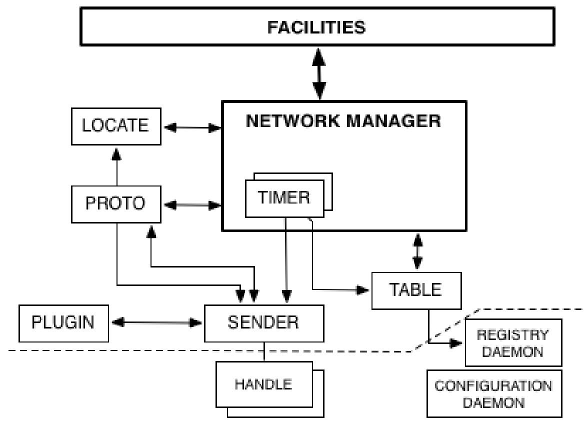

Fig. 2: INESC-ID vehicular platform diagram

acting directly on the functioning of the underlying modules of the INESC-ID platform, through the *Plugin* module.
- **Application Registry Bank (ARB)**, where all de applications should be registered. This module is controlled by the CMA module.

All the developed applications will collect their data from the **ADM** module, which will supply normalized functions to retrieve data from the underlying modules, acting as an API for vehicular applications development. The functions put available will be developed according to the several applications types and respective requirements. The **CMA** module, through **ADM** interactions will be aware of the context in which the platform is being used and will have control over the **ARB**, controlling the applications execution flow. This way **CMA** will be held responsible for choosing and coordinating which applications are being executed and control the priority that each application has. The following events will be taken into account for application triggering and prioritization:

- Accident or eminent accident detected
- Vehicle with warning status (low fuel, flat tire, engine damage, emergency driving, etc.)
- Vehicle stopped due to traffic
- Vehicle traveling at high speed

The proposed solution, besides delivering a easy to use application development environment for vehicular applications, should act as a coordinator entity for scheduling applications flow within vehicular environments, depending on the context in which the platform is being executed. Figure 3 depicts the diagram for embedding the present solution into INESC-ID platform.

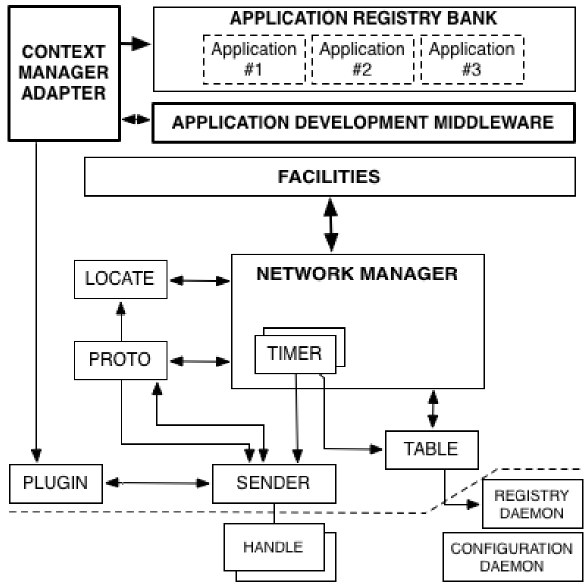

Fig. 3: Proposed architecture design diagram

5 Scientific Methodology

In order to validate the previously mentioned architecture solution will be developed a test prototype in which some illustrative applications will be installed and tested. A survey has already been done in order to analyze which applications will be developed based on their common requirements and categories. The applications chosen for testing purposes were:

- **Traffic Monitor:** Inform the driver about traffic information giving the ability to share and report accidents as well as anomalies on the freeway.
- **Safety Assurance -** Automatic feedback about road/traffic conditions. Display of warnings if traveling at unsafe speed or unsafe driving, by analyzing driving behavior. Detection of road accident and warning display.
- **Freeway Assistance:** Ability to ask for freeway assistance, and have confirmation and feedback about the estimated time of arrival (ETA) for the assistance team.
- **Services Subscribe:** Possible to subscribe and receive services feeds, as news, stock market or Internet RSS feeds.
- **Zone Information:** Display of zone information, whether for points-of-interest or dangerous road topology.
- **Dynamic Toll Payment:** Toll value calculated based on the road and traffic conditions and in type of driving.

Table 8 depicts the applications requirements and table 9 the type of information needed. All the mentioned applications are loss and delay tolerant, but demand reliability on the data received.

Based on the analysis results, the applications chosen to be developed for the proof of concept were **Traffic Monitor**, **Safety Assurance** and **Zone Information**, due to the variety of requirements and packet information needed, being representative of the expected applications types of a ITS.

Table 8: Applications Requirements

Application	**Application Type**	**Addressing Mode**	**QoS**	**Position Accuracy**	**Security**
Traffic Monitor	Safety	Location-Based	Best-Effort	Yes	Privacy and Authentication
Safety Assurance	Safety	Location-Based	High Prio.	Yes	Authentication
Freeway Assistance	Safety	Location-Based	High Prio.	Yes	Privacy and Authentication
Services Subscribe	Comfort	IP-Based	Best-Effort	No	Privacy and Authentication
Zone Information	Comfort	IP-Based	Best-Effort	Yes	Privacy and Authentication
Dynamic Toll Payment	Comfort	IP-Based	Best-Effort	No	Privacy and Authentication

Table 9: Applications Packet Content

Application	**Direction of Movement**	**Road ID**	**Vehicle Type**	**Driving Info.**	**Current Location and Speed**	**Weather/Road Condition**	**Neighbor Info.**
Traffic Monitor	Yes	Yes	Yes	No	Yes	Yes	Yes
Safety Assurance	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Freeway Assistance	Yes	Yes	Yes	No	Yes	Yes	Yes
Services Subscribe	No	No	No	No	No	No	No
Zone Information	Yes	Yes	No	Yes	No	No	No
Dynamic Toll Payment Yes	Yes	Yes	Yes	Yes	Yes	No	No

As mentioned, it will also be used the INESC-ID platform, already described. A survey on the DSRC solutions available in the market was also done, and was considered the use of the equipment **NEC Linkbird-MX**. This equipment is a test platform that has an IEEE 802.11p embedded interface, as well as other traditional technologies for wireless communication. It also features an embedded ARM micro processor and supports Linux kernel 2.6.19, which allows the install of the kernel developed for the INESC-ID platform. Other technologies are also embedded, for instance, GPS receiver, CAN bus, USB and ethernet. This was the available equipment that best suits the purposes of this work, outmatching the other solutions that did not offer such batch of technologies.

The applications will be tested in a controlled environment using vehicles equipped with the developed solution and testing the interaction and communication with both RSUs and other vehicles.

5.1 Testing Procedures

Hyphothesis Assuming the existence of a roadside infrastructure and vehicles equipped with VANET communication capabilities, vehicles will have a number of applications installed on their OBUs and will make use of those in several situations, created by real events.

Tests Using a test scenario with two vehicles and two roadside units, some connectivity tests will be done in order to analyze the wireless communication technologies and developed system performance in both V2V and V2I communication. The tests to be performed are the following:

1. **Conn. Test #1:** Two moving vehicles, traveling at 50 km/h in opposite directions, communicating with each other.
2. **Conn. Test #2:** Two moving vehicles, traveling at 50 km/h in the same direction, communicating with each other.
3. **Conn. Test #3:** One moving vehicle, traveling at 50 km/h, communicating with a RSU, exchanging information.
4. **Conn. Test #4:** One moving vehicle, traveling at 90 km/h, communicating with a RSU, exchanging information.

For each of the aforementioned connectivity tests, should be obtained information, such as, communication range between two communicating nodes, the amount of packet loss in the communication according to distance and traveling speed of the nodes and the amount of data that is possible to exchange between the two nodes. This tests will be done using the available wireless communication technology, either 802.11p or the traditional wireless LAN technologies. Comparison between both technologies will also be presented. The results of this tests will be used to conclude the feasibility and applicability of the proposed solution in real scenarios.

After performing the aforementioned connectivity tests, the following test case scenarios will be done:

1. **Test Case #1:** Traveling vehicle reporting an accident to the neighbor vehicle and roadside unit. The neighbor vehicle will display a warning of accident detected and present an alternative route.
2. **Test Case #2:** Vehicle receiving information from RSU about road and weather conditions.
3. **Test Case #3:** Vehicle system displaying information and warning the driver about unsafe driving from another vehicle nearby.
4. **Test Case #4:** Vehicle receiving zone-specific information from two different RSUs while passing through them.

Expected Results From this tests it is expected to measure the performance of both safety and comfort applications in both normal and emergency scenarios. The results should allow one to conclude the applicability of such systems, in the real scenarios assumed by the hypothesis. Some notes on the existing limitations of both wireless access technologies and developed solution will be concluded, having a list of the limitations to consider when developing similar systems.

6 Conclusion

Intelligent transportation systems through the usage of vehicular networks allow the development of several applications and services that aim to improve both driving experience and safety. A number of initiatives and research projects already depicted some of the know issues and developed solutions to cope with those, enhancing the possibility to create standards and systems for ITS. VANETs, although being a subset of general MANETs have to cope with different challenges, due to the specific characteristics of having vehicles as communicating nodes. Also, those networks can be deployed in several scenario, having each one of those, specific characteristics that will create implementation limitations. Therefore, it would be hard to develop a general platform or framework that could be used in all those scenarios.

Within a ITS several network architectures may be used, depending heavily on the requirements and available budget for the deployment of those networks. Either only considering inter-vehicular communication or also the existence of a roadside infrastructure, a number of projects developed vehicular technologies to cope with the respective requirements. Also, vehicular-specific wireless access technologies have been developed, due to the lack of performance of the traditional technologies. However, all the developed solutions always consider a high degree of implementation and deployment of such technologies. One concluded that a more realistic approach is to consider a staged deployment of vehicular communication systems.

Traditional applications used in the Internet, were not conceived to be used in vehicular communication environments, demanding the creation of vehicular-specific applications and services. Those applications, can be generally classified as safety related and comfort related. The first classification considers applications that are intended to prevent accidents by warning drivers, while the latter aims to deliver a more pleasant driving experience. The developed applications have specific requirements and are dependent on the wireless technologies used and the architecture adopted on each network where they are being used. Some important security issues are also raised, due to the possibility of some attacks having an impact on peoples lives.

Having all of the above in mind, a solution was presented to cope with some open issues, like the applications dependence of the underlying structure of the network and also of the context in which those applications are being used. The proposed system aims to be the most agnostic possible of the underlying technologies and will adapt applications flow according to the event happening on the context in which applications are being executed like, emergency situations, high traffic density, among others. The proposed solution will offer a API to develop vehicular applications, abstracting the developers of some low-level details and allowing applications to be created independently of the underlying implementation and technologies.

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