A novel vehicle communication paradigm based on cellular networks for improving the safety in roads

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Abstract: Main aim of Intelligent Transport Systems (ITS) applied to roads is to increase their safety. To achieve this aim, many researchers are focused on developing robust and efficient communication links between vehicle to infrastructure (V2I) and vehicle to vehicle (V2V). Most of the works in the current literature are based on ad-hoc networks. This paper presents a network infrastructure based on cellular networks (CN) and peer to peer (P2P) technologies, to develop a communication paradigm for improving road safety. CN are proved to be suitable for V2I communications, while its continuous improvements in data connections encourage to feel optimistic about future possibilities. Apart from the fact that deployment costs are not higher than those in ad-hoc LAN based solutions, our proposal presents the benefit of integrating all V2I and V2V in one design. For localization purposes, a global navigation satellite systems (GNSS) is used. Since we are dealing with safety applications, a very special emphasis on the integrity of the positioning is put, and an integrity parameter is provided to application users. Details of the prototype developed and the tests performed in a real environment are given.

Keywords: vehicle communications; safety applications; location based services; cellular networks; V2I; V2V.

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1 Introduction

The term 'road safety' refers to the set of issues derived from traffic, involving human lives, and all the systems designed to give support to these problems. Due to the amount of lives lost on the road and all the injuries resulted from car accidents, safety solutions have a key relevance inside the intelligent transportation systems (ITS). Using a suitable communication channel, a vehicle that detects a problem can notify it to surrounding vehicles or a central infrastructure. Therefore, vehicular communications result fundamental in order to avoid and diminish accidents in roads.

Most used solution to localize vehicles in safety applications that require a good knowledge of it are the global navigation satellite systems (GNSS) [a]. Typically, the well-known GPS (Global Positioning System) is used to locate problems on the road and obtaining the position of the local and surrounding vehicles. Following these two main milestones of a vehicular communication solution and a suitable positioning subsystem, the rest of the paper will show a safety system to notify traffic problems using cellular networks (CN), which includes a positioning subsystem that provides a reliable confidence value of the accuracy of the location.

As it has been stated, vehicle communications are essential in all the on board services (mainly) oriented to road safety. When talking about vehicle communications, all service requirements can be summarized into two types of network topologies: communications between the vehicle and the infrastructure, and communications among vehicles. In the first case, on-board services require a local connection with the infrastructure located at the road side. This kind of connectivity is usually named as Vehicle to Infrastructure (V2I) communication. An example of this can be found in electronic fee collection systems, where drivers are charged automatically, according to some road and vehicle parameters. The approach presented in Úbeda (2004) uses DSRC (Dedicated Short Range Communications) gantries to keep the path followed by a vehicle in order to calculate the

[a] The term GNSS includes the North American GPS, the Russian GLONASS and the future European GALILEO

associated cost. Here, main technologies involved are DSRC, infrared, and wireless LAN. The second group of such services are the vehicle to vehicle applications (V2V). In the current literature, several works for collision avoidance support, and warning mechanisms in general can be found Franz (2001). For this type of services, most extended technology are ad-hoc networks applied to the vehicle field (VANET or *Vehicular Ad-hoc NETworks*) Blum (2004). The solution presented in this paper proposes a communication architecture which deals with both V2I and V2V connectivity requirements. Cellular and peer to peer (P2P) networks are used jointly to design a communication system based on coverage areas.

Despite the fact that road safety is a very wide term, and many factors are involved in car accidents, there is a real conviction among researchers and vehicle manufactures that telematics can improve the traffic safety. Using an appropriate V2V paradigm, vehicles could communicate among them and propagate security issues. Most of the current research works regarding road safety in these terms are based on VANET approaches. This approach, often results in designs which treats problems locally. Hence, security issues that require a fast treatment in a limited space can be solved. Several interesting papers can be found in the literature dealing with collision avoidance systems Ueki (2005). On the other hand, V2I solutions allow authorities, and all drivers in general, to know traffic difficulties through a centralized system. Considering all these ideas, our main purpose is focused on creating a network design with an integrated safety system dealing with the most of the security issues, and paying attention not only to the vehicles surrounding the problem, but also to the remote entities.

The introduction of road safety systems in vehicles is increasing the adoption of a technology commonly used in route guidance solutions: GPS sensors. GPS is the GNSS solution given by the United States to allow the calculation of an absolute position on the Earth. Currently, the use of these systems together with other onboard services present a growing interest on commercial intelligent transportation systems. Collision avoidance systems, for example, use in a V2V paradigm, the GNSS sensor to locate the surrounding vehicles Chen (2006). Other techniques have been used to locate obstacles in front of the car, such as radars. Despite the fact that GPS is still the most appropriate technology to obtain absolute positioning in vehicles. Nevertheless, in applications which require high accuracy, it is necessary to consider the errors committed in the calculation of the position Kaplan (1996). The main sources of error in GNSS sensors are due to atmospheric conditions and multipath from the satellite signals. There are several techniques to mitigate these problems, such as sensor fusion using Kalman filters and inertial navigation systems (INS) Toledo (2006), and differential correction models. Independently of these methods, for critical applications it is necessary to measure the quality of the location obtained from the positioning subsystem. In road safety services, the accuracy in the vehicle location is fundamental in order to have a correct knowledge of the road state. For instance, considering a position error of three meters, a car crash could be located out of the road. This is the reason why our purpose is to consider an integrity parameter of the GNSS sensor solution, that is, a value which measures the quality of the computed position. In Kaplan (1996), the integrity of a GNSS system is defined as “the ability to provide timely warnings to users when the system should not be used”. This integrity factor is used in the present work to improve the whole safety system performance, since vehicles and traffic problems can be located with a confidence factor.

The rest of the paper is organized as follows. In Section 2, the presented system is placed into the current researching literature regarding vehicle communications for road safety. Section 3 includes the main parameters to be considered in the design of a vehicular network. Section 4 explains the designed communication architecture, giving details about the protocols implemented. Section 5 describes the concept of position integrity and its applicability to road safety. Section 6 shows the prototype developed and the results obtained from the system using real tests. Finally, Section 7 contains the conclusions of this work.

2 Related work

Regarding vehicular communications, as it has been stated previously, researching lines are centered on the usage of ad-hoc networks in the VANET field. The interest of this work, however, lies on proving how cellular networks can be suitable for enabling V2V and V2I communications. In Andreone (2005) some ideas are given about the importance and usefulness of V2V and V2I communications. Technology problems of considering such systems are exposed in Luo (2004). In this work an overview of the physical and link levels requirements for the VANET field is stated. Taking into account this necessities and limitations, it is possible to contrast our solution, based on cellular networks, with the VANET ones. In Kiess (2007), a survey of vehicular communications and applications is given. Here it is stated that the technology which deals with more requirements implementing telematic services in ITS are cellular networks. This defends our idea of using cellular networks in a general telematic framework and, consequently, applying it in the concrete field of safety applications as well. The previous work exposes how exists a lack of a general network platform for the development of telematic services in the vehicle domain. Our solution tries to give a solution to this dilemma. Nadeem (2006) includes an interesting study of the common transmission methods used in VANET, and the delays observed in the message passing. This presents a starting point to consider the feasibility of a network design based on cellular networks. Another example of a VANET application in traffic safety can be found in Chen (2006), where a collaborative design is used to estimate the traffic congestion.

Considering V2I patterns, in Hattori (2004) a communication technique between the vehicle and the road infrastructure based on the DSRC technology is presented. This illustrates an example of a infrastructure-based system. The main drawback here is the cost of deployment at the road edge, which requires the installation of multiple DSRC devices, in contrast to our approach, based on cellular networks. In this line, Okabe (2005) presents a handover system for wireless LAN networks in vehicles. Although the idea could be valid for urban or fixed railway zones, the deployment is limited by the cost. A work which captures a P2P approach through JXTA (JuXTApose) to notify events to the road side is shown in Baresi (2005). Our system use the JXTA technology as well in the vehicle field, however, in contrast with the last work, it includes an architecture valid for both V2V and V2I communications.

There are several works which show the synergy between communications and GNSS technologies in the field of ITS. Ammoun (2006), for example, explain a solution for avoiding crashes in crossroads. In this system, GPS sensor is improved with a Kalman filter which takes into account data coming from INS sensors aboard the vehicle. However, the problem of the positioning error is not clarified. This fact is treated in Tan (2006), and the error expected from the GNSS sensor is included in the collision avoidance system developed. This study considers the error estimations in the sensor fusion and takes into account, basically, the geometry of the satellites used to compute the final position. In the present work, a confidence parameter of the final position is used, based on the integrity of the positioning subsystem. Santa (2006) includes a study of the integrity calculations in the vehicle field. The integrity value obtained comes from the extra information provided by EGNOS (*European Geostationary Navigation Overlay Service*). Another approach to this problem can be found in Toledo (2006), where an integrity value based on the Mahalanobis distance is provided as a positioning quality estimate for an integrate INS/GPS solution.

3 Performance parameters in V2V and V2I systems

Before focusing on the network platform designed for vehicular communications, it is interesting to present the requirements of this kind of networks, considering its application into the road safety field. Taking as starting point the most used network topology in the field of vehicular communications for road safety (VANET solutions), it is necessary to take into account some performance parameters usually considered in the literature:

Latency Maybe the most important factor in the message transmission in vehicular communications is latency. This is the time the network spends in transporting a message from the source to the destination vehicle. As it is noticeable in Nadeem (2006), the latency is proportional to the distance between the origin of the problem and the remote vehicle. This time usually has a value around hundreds of milliseconds for distances below a few meters. However, when the distance grows the delay suffers a meaningful increase, following a linear pattern which can round the 10 seconds for a distance of one kilometer. This behaviour is useful in applications which require a fast notification of events to the surrounding vehicles, such as collision avoidance systems. However, there are safety applications which require acceptable latency values considering a range of transmission greater than a few meters.

Knowledge of surrounding vehicles In VANET networks the knowledge of adjacent vehicles is important, mainly to enable the operation of the routing protocols. Sometimes sharing information about the surrounding vehicles is useful for concrete applications. Knowing the position of the vehicles ahead of us could be used to advise the driver about an imminent decrease of speed, to avoid a collision, for example.

Useful usage of the network One problem in VANET solutions is the amount of useless information received by a vehicle. Sometimes the source car is too far from the destination, or the vehicle is on the opposite direction of a two-way separated road. There are some techniques which try to solve this problem, such as dropping far messages using the GPS location.

Simulation models Due to the difficulties to test new protocols and designs based on VANET in real environments, the most commonly used technique is simulation. Using simulators, it is possible to create scenarios with several mobility patterns and varying the amount of vehicles, for instance. However, simulations do not give a complete idea of the real operation and, sometimes, solutions do not physically developed give the sensation of not being practical designs.

Penetration rate One on the most important issues in vehicular safety systems based on V2V and V2I communication, is the ratio of vehicles equipped with the communication link. In VANET this is a real problem when the portion of equipped vehicles is not enough, because communication via ad-hoc infrastructure is not viable.

Cost Cost of VANET systems is not very discussed in the literature. The hardware which composes the on board equipment in these solutions is basically a computer with networking capabilities and usually some extra navigator sensors.

4 V2V and V2I communication design

The communication architecture presented, based on cellular networks, gives a solution which takes into consideration the parameters described in the previous section. The proposed network presents a generic infrastructure for the vehicular environment, and specially concerned about safety applications.

4.1 CN performance parameters

In order to consider the performance parameters of cellular networks, and its applicability to the V2V and V2I communications for safety, it is important to take into account some technological aspects. In the field of VANET approaches, the most extended technology are the wireless LAN transceivers, such as 802.11a, 802.11b, 802.11g and the new 802.11p. On the other hand, the most used technology in cellular networks in Europe are GPRS (*General Packet Radio Service*) and UMTS (*Universal Mobile Telecommunications System*). While last one is currently in deployment, it offers significant improvements as compared to GPRS; hence, this last option has been selected.

Because the purpose of this paper is using the cellular networks to create an integrated V2V and V2I communication system for road safety, it is important to deal with the most controversial performance parameter: the latency. As it has been tested, cellular networks are able to maintain a regular behaviour in latency times Alexiou (2004). However, the typical obtained values of several hundreds of milliseconds are too high to send a critical notification to an adjacent vehicle. For distances from 50 to 100 meters, nevertheless, current UMTS technology could present propagation times even better than VANET approaches. Moreover, future plans on UMTS include meaningful improvements in terms of throughput and delay UMTS Evolution (2006). Initial tests has been carried out in such UMTS changes Haider (2006), which give values of latency in the order of tens of milliseconds. These results imply that CN will gradually be able to deal with the fast propagation requirements in some environments.

Another problem which has to be solved in a CN network design for sending safety events is the propagation method for the message transmission. As it is noticeable in the next section, our proposal deals as well with the problem of enclosing the notification of safety events in an area of interest. A group-based P2P technology has been used to solve this problem. Following this technique, messages are only propagated to vehicles whose travel can be affected.

Regarding to the cost of a CN-based system, apart from the price of the hardware, it is noticeable the extra money which has to be paid for the use of the operator's infrastructure. UMTS data transfers were usually charged per byte transferred. The current trend these days is paying a fixed quote per month, with an extra cost if the transmission rates fall out the contract. In the future this drawback will be solved gradually. The adoption of this kind of Internet connections among the population, and the massive use of CN for commercial ITS solutions, are expected to decrease the price of the CN bill for vehicular applications through special agreements with operators.

4.2 Network design

It has been stated that cellular networks are an appropriate technology in order to use an unified communication mechanism. That is, cellular networks represent the communications capabilities which allow the implementation of any on-board service with connectivity requirements. Although the current work is centered on road safety applications, the designed vehicular network is valid for some other services. The work presented in Santa (2007) is extended with a middleware which allows the use of a high level communication interface. Using this mechanism, each new service does not require the implementation of its protocol, starting from the TCP/IP basis. This common interface allows message exchange in both V2V and V2I environments.

Using a P2P approach over cellular networks, the vehicle can receive and send contextual information about its current environment. Figure 1 shows a general diagram of the high level communication architecture proposed, with the Group Server and Environment Server agents. Traffic zones are organized in coverage areas, each one using a different P2P communication group. Vehicles are able to move from one P2P group to another through a roaming process between coverage areas. This roaming is based on the location of the vehicle, provided by the GPS sensor. Information about areas is received from the Group Server using a TCP/IP link over UMTS. The Group server stores the geometry of every service area. A local element called Environment Server manages special events inside the area. Event notifications are sent and received by service edges, located either at the vehicle or at the road side (Environment Servers). All messages emitted are encapsulated in P2P packages. Two different techniques of emission have been developed and, consequently, P2P messages can be broadcasted over the area or sent to a specific vehicle.

Apart from the designed architecture, in Figure 1 the three most representative scenarios are exposed from left to right. In the first one, a vehicle is passing from one area to another. The Group Server provides the P2P parameters to maintain the communication in all the active services. Due to the fact that the Group Server sends the area geometry to the vehicle, the latter has to communicate with the central entity only when it is necessary, saving communication resources. In the second scenario, a safety service located in the vehicle notifies a repair event. This event is broadcasted, and all vehicles located in the area receive the warning.

Any event which may require a special treatment, such as a collision can be processed thanks to the fact that the Environment Server also receives all the broadcasted messages. In addition, messages from special services (repair, collision...) are forwarded by the Environment Server to the adjacent areas, in order to improve the warning mechanism. The last scenario in the diagram shows how the Environment Server can be connected to the rest of the road side infrastructure, which may be composed of speed radars, identification sensors, video cameras, etc. Thanks to this, local events can be notified to the vehicles in the area, and useful reports can be sent to the central entity.

4.3 Protocol details

It is clear that the use of several protocols among the entities described in the previous section is necessary in order to perform all the processes that have been explained. To understand the operation of the whole system, the exchanged messages are divided into the three existing protocols detailed in the next lines.

Table 1 includes the messages exchanged between the vehicle (V) and the Group Server (GS). The communication is carried out by a message exchange over TCP, using the cellular network interface directly. The first process between these two entities is roaming management. An initial *Area_Update_Query* message is used by the vehicle for registering itself against GS. The *Disconnect* message serves for ending the communication. Roaming process uses the *Area_Update_Query* and *Area_Update_Response* messages. First one is used when a vehicle detects the end of its current coverage area. In that moment, it sends a new *Area_Update_Query* message with its new location. GS replies with an *Area_Update_Response*. This message contains the available services in the zone and the P2P parameters to allow the subscription to them. When the user wants to use a defined service, it sends an *Event_Subscription* with the services in which it is interested. It is important to note that every service has a different P2P group in every area. This allows for distinction among coverage zones.

Regarding the communication between the Environment Server (ES) and GS, Table 2 summarizes all the interchanged messages. The *ES_Registration* message is used by the ES to connect with GS. This packet contains the location of ES, being GS able to search for the P2P parameters of all services available in the zone and reply with the *ES_Registration_OK* message. If any error occurs, GS sends a *ES_Registration_ERROR*. This packet includes the reason of the error. Since Environment Servers are static entities which may be connected during long time periods, they need to update their configuration periodically. *ES_Registration_Update*

Table 1 Vehicle-Group Server communication

Purpose	Messages	Sender
Communication Management	Area_Update_Query Disconnect	V V
Roaming Process	Area_Update_Query Area_Update_Response	V GS
Event Subscription	Event_Subscription	V

Table 2 Environment Server-Group Server communication

Purpose	Messages	Sender
Communication Management	ES_Registration ES_Registration_OK ES_Registration_ERROR ES_Registration_Update ES_Registration_Update_Response	ES GS GS ES GS
Message Propagation	Neighbour_Groups_Query Neighbour_Groups_Response	ES GS

message performs this task, by requesting the P2P parameters of the coverage zone. GS answers with this information by means of *ES_Registration_Update_Response*. The second group of messages are used in the message propagation mechanism. Sometimes it is necessary to ensure that all vehicles near the problem receive critical events. The location of such problem may be close to the border of the coverage area. Consequently, it is necessary to propagate the associated message to the neighbouring areas. In order to perform this task, the Environment Server, which listens to all events, uses the *Neighbour_Groups_Query* message to ask for the neighbouring P2P groups for the service in question. GS replies with this information through the *Neighbour_Groups_Response*. Now, ES can forward the message to the neighbouring areas.

Finally, Table 3 includes the three messages used by the services to send messages. The first message we can see is *Vehicle_Event*. It contains a message sent from a vehicle service edge. All vehicles located in the area, and the Environment Server, receive these messages. The *Environment_Event* messages are sent by the Environment Servers. This is used, up to now, by the message propagation method described previously. The source of the last two messages are vehicles, including the identification of the type of event,the GPS location of the problem (improved with EGNOS), the integrity of the position, and the content of the safety event. Last packet, *Specific_Environment_Event*, allows for sending a message to a specific vehicle, and does not include any information about position.

5 Integrity positioning for safety

GNSS sensors play a key role in the positioning of safety problems along roads. Although there are some other technologies that intend to solve the problem of

Table 3 Vehicle-Vehicle/Environment Server communication

Purpose	Messages	Sender
Message Passing	Vehicle_Event	V
	Environment_Event	ES
	Specific_Environment_Event	ES

positioning, such as cellular network based approaches Schwaighofer (2004), GNSS sensors are currently the most suitable solution for applications which require an absolute location with an error under a ten of meters. When it is necessary to notify a safety event, the accuracy of the position measured is very important in order to avoid traffic problems. In the GNSS field, several strategies have been taken into account to improve the position accuracy. The two main approaches are based on differential corrections Lakakis (2004) and data fusion filters Hide (2005). In addition to this, there is an aspect which is growing in importance these days: the measurement of the GNSS precision. In some on-board services, including road safety ones, it is necessary a value which quantifies the confidence of the position of a safety event. As it is explained in this Section, our work uses a wide area differential technique known as *Satellite Based Augmentation Systems* (SBAS) to improve the GNSS subsystem operation. By using it, it is possible to obtain more accurate GNSS positioning and an integrity factor which measures the goodness of this position.

5.1 SBAS improvements

Although SBAS offers a slight improvement in the calculated position, another aspect considered as crucial for several road applications is the integrity of this position. Monitoring the integrity implies that the goodness of the positions received from the GNSS sensor can be known anytime. In several current road applications such as road pricing systems, intelligent pay-per-use insurances, and a large amount of safety services, the integrity of the position could be a key confidence value on the positioning subsystem.

The use of SBAS systems allows the calculation of useful integrity factors, such as the HPL (*Horizontal Protection Level*) and VPL (*Vertical Protection Level*) parameters, as described in RTCA DO-229C (2001). In Figure 2 the usefulness of the position integrity is shown. Here, a typical case is illustrated. The vehicle goes through the true path (solid line), but the navigation system estimates that the trajectory is the dotted one. Difference between erroneous and correct paths is the horizontal position error (HPE). Here the HPL parameter is vital in order to bound the confidence area of the GNSS sensor, providing a good estimation (i.e. 10^{-7}/hour probability) of the system reliability on the fact that the true position is within a circle around the computed position. The horizontal alert limit (HAL) can be defined as a proper upper bound for the HPL value. If HPL > HAL the integrity alarm is triggered and the application which uses this information have to consider the position as not reliable. Both HPL and VPL are commonly named as $\mathrm{HPL}_{\mathrm{SBAS}}$ and $\mathrm{VPL}_{\mathrm{SBAS}}$ in order to distinguish between the SBAS-based computations and the receiver autonomous integrity monitoring (RAIM) algorithm factors Kaplan (1996).

As it has been stated previously, every message sent by a vehicle includes the HPL associated with the position. This allows to the receiving vehicles and to the corresponding environment server to evaluate the quality of the position depending on the HPL.

5.2 HPL computation

The calculation of the integrity parameters RTCA DO-229C (2001) is based on the real time processing of the data broadcasted by EGNOS, which contain correction information for all the satellites used in the GPS solution. These data arrive to the user position by many types of messages which are processed. There are several corrections which are considered. Fast term corrections are used to correct for rapidly changing errors, such as satellite clock errors. Long term corrections treat atmospheric and long term satellite and ephemeris errors. Ionospheric corrections try to minimize the effect of the ionosphere in the transmission of the satellite signals. The algorithm also includes an estimation of the local errors committed by the receiver in the position computation, and the multipath of the satellite signals in the reception.

Once these estimations of the errors committed are available, the integrity algorithm must proceed to evaluate the mathematical expressions briefly described in this section. In both the message processing and the HPL calculation, several considerations related to the road transport environment must be taken into account, such as the use of an ENU coordinate system Drake (2002).

The calculation used to compute the HPL value is shown in (1). The K_H constant depends on the level of precision required from the positioning subsystem. The d_{mayor} term depends on the geometry of the satellites used in the position calculations and the error committed using the estimations described above (σ_i^2).

$$HPL_{SBAS} = K_H \cdot d_{mayor} = 6.18 \cdot d_{mayor} \tag{1}$$

The errors considered to obtain the final estimation for the error variance measurements of the satellite used (σ_i^2), can be seen in (2). Here, σ_{flt}^2 is the error variance caused by the imprecisions in slow and fast corrections, σ_{UIRE}^2 is the error variance caused by ionospheric effects in the transmission of the satellite signals, $\sigma_{i,tropo}^2$ is the error variance caused in a similar way by the troposphere, and $\sigma_{i,air}^2$ is the error variance caused at the user edge. RTCA DO-229C (2001) explains the process to obtain all these values in the implementation of a SBAS client. However some explanations are recommended regarding the temporization of the reception of messages, Hattori (2004). The last of these parameters, $\sigma_{i,air}^2$, requires a special treatment that is described in Santa (2006).

$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,UIRE}^2 + \sigma_{i,tropo}^2 + \sigma_{i,air}^2 \tag{2}$$

6 Experimental results

The system described in previous Sections has been implemented in a real platform with the objective of testing the design. Some technological details of the prototype are presented in this Section. This explanation is divided into the vehicle edge and the road side equipment used, and the software implementation in both vehicle and road edges. The results obtained from the tests carried out over a real environment are shown and explained.

6.1 Test prototype

The vehicle used for the system deployment is a vehicle widely sensorized at the University of Murcia. In Skarmeta (2002) it is explained in detail all the hardware installed in the vehicle. The GPS sensor is utilized to know the position of the car, being essential not only for the roaming process among coverage areas, but also for the location of road safety issues. The vehicle in question is shown in Figure 3. The on-board unit is a SBC (*Single Board Computer*) of VIA. The interface between the user and the OBU is carried out by a LCD panel installed on the dashboard. The operating system used in the OBU is a Linux Fedora Core 4, and a Java Virtual Machine 1.5 enables the computer to support all the multiplatform software implemented. In Santa (2007) it can be found more details about the software platform used in the OBU. Regarding the vehicle communications, a cellular network PCMCIA transceiver has been used. The model is a Novatel Wireless Merlin U530, which allows GPRS and UMTS data connections.

At the road side, the Environment Servers have been implemented as software entities, running in a server located in our laboratories. The Group Server runs over another computer. All of them are Linux-based systems, with a common Intel processor.

6.2 On-board software

A new service has been implemented at the vehicle side to test the feasibility of the communication architecture presented. JXTA Sun JXTA (2005) has been the P2P technology used. JXTA presents a group-based communication system with the features of any other P2P protocol. It forms an underlying network which abstracts the user from internal details. Figure 4 shows the Message Console service. Using the P2P middleware, an event-based tool has been created to notify safety events. Each 'event' has been modeled like a safety service in the communications system. The user can subscribe to any of the eight types of events available on the right box. If one of these services is active, the corresponding events can be received or thrown. The events regarding the 'On road information service', 'Tunnel entrance', and 'Speed control' cannot be thrown by a user, being managed by the road side infrastructure. The rest of the available safety services are 'Repairs on the road', 'Collision', 'Car broken down', 'Traffic jam' and 'Meteorology information'. All the received events are shown in the central part of the window.

In the example provided in Figure 4, the driver has activated all the available services. However, only three of them are available in the current area. Two events have been received from the network, one of them related to a break down problem, and the second about meteorology information. The implementation of the client does not show the identification of the vehicle and the integrity about the position of the problem, but both can be added easily.

6.3 Evaluation of CN/P2P

The system has been tested over an enclosed zone. Several coverage areas have been defined over the Campus of Espinardo, at the facilities of University of Murcia, and over a near motorway. Figure 5 shows the eight coverage areas under consideration. The vehicle presented was used to cover a path around all the areas. During this travel, the co-driver made use of the on board system and, at a static location, another client was installed on a common computer to receive and send safety events. The implemented software is able to use logs previously saved. At the static edge, the system was configured to simulate the travel over several zones. The tests carried out showed the correct operation of the system, propagating the messages generated over the P2P coverage zones. When a critical event was sent, it was tested that the forwarding message was correctly emitted as well to the surrounding areas. Several logs were stored to check the correct operation of the Group Server and all the Environment Servers. During the tests, the implementation of this centralized part of the architecture was proved to be reliable.

6.4 HPL monitoring

Since our work has been carried out in Europe, the SBAS technology used has been EGNOS. Previous works published by our research group such as Santa (2006), show in detail the system used to monitor the position integrity. The tests made take into consideration the study of the HPL over dynamic environments, and compare the performance of the algorithm using as source of EGNOS messages both the geostationary satellite and an Internet server located at the European Space Agency (ESA). The effect of the lack of coverage from the geostationary satellite and the cellular network has been considered as well.

In Figure 6 the results from the integrity subsystem in a trip around the Campus of Espinardo (University of Murcia) have been plotted. The graphic includes as well the GPS coverage, in number of satellites used to compute the position, and a fixed value for the horizontal alert limit. It is noticeable how the HPL exceed clearly the HAL in two zones. It has been probed the lack of GPS and EGNOS coverage in these locations, where some buildings located near the road cover the line of sight to several GPS satellites and to the EGNOS geostationary one. A bad geometry for the satellites used in the GPS solutions improves the HPL value. In the same manner, the messages lost from the EGNOS satellite degrade the error estimations about the GPS measurements, so the final HPL is greater. During the tests, the operation of the GPS satellites were checked to be good, so the error estimations provided by EGNOS are not considered key factors in the HPL values obtained. A direct relation can be found in the graphic between the number of GPS satellites used for the solution and the value of the HPL. As it is explained in Santa (2006), the reception of the EGNOS messages through the Internet can improve the HPL monitoring in places where the line of sight to the geostationary satellite is poor.

7 Conclusions

The work presented along the paper exposes a vehicular network infrastructure valid for road safety services. The communication paradigm based on cellular networks has been shown as an architecture which deals with the most of requirements of both V2V and V2I communication paradigms. The P2P technology has been used, through JXTA, to implement a protocol to notify safety events. Several entities in the infrastructure are in charge of maintaining an area-based communication, where safety messages are propagated in a controlled way. Due to the fact that the location of security issues on the road is a key factor in the design of safety applications, the GNSS subsystem has been adapted in accordance to this requirement. The emissions from the SBAS EGNOS system has been considered not only for improving the accuracy of the final position, but mainly also to compute an integrity parameter of this location. The HPL factor is the value which measures the reliability of the positioning subsystem. This value has been considered to be sent inside the event notifications, together with the position, in order to give information about the quality of the incident's location.

Several tests have been carried out to prove the viability of the proposed system. The prototype used has been described in terms of hardware and software details, and the places where the field test were done have been described. The results obtained from the integrity subsystem have been analyzed, and it has been detailed the success in the operation test of the communication architecture. Currently, a work in progress studies the performance in terms of delay of the communication infrastructure.

Other future research lines in this field include our current works in the provision of information dependant on the location and the driver profile. Using knowledge management techniques, it is possible to adapt the information about interest places, for example, according to the user preferences. An extension of the overall system is planned as well to implement a third-party entity to centralize the safety events emitted in a monitoring centre. Finally, it is planned to consider the problem of lack of UMTS service and, hence, the absence of the communication network. In this case, the system will consider the emergency call available in the GSM basic networks to treat critical safety events.

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References

B. Úbeda, R. Toledo, J. G. Jordán, S. Montes. (2004) 'A theoretical and practical analysis of GNSS based road pricing systems, considering the EGNOS/SISNeT contributions', *NAVITEC 2004*, Noordwijk.

Franz, W., Hartenstein, H. and Bochow, B. (2001) 'Internet on the Road via Inter-vehicle Communications', *GI Workshop, Communication over Wireless LANs*, Vienna.

Blum, J., A. Eskandarian, and L. Hoffman (2004) 'Challenges of Intervehicle Ad Hoc Networks', *IEEE Transactions on Intelligent Transportation Systems*, Vol. 5, No. 4, pp.347–351.

Jumpei Ueki, Sentarou Tasaka, Yuji Hatta and Hiromi Okada (2005) 'Vehicular-Collision Avoidance Support System (VCASS) by Inter-Vehicle Communications for Advanced ITS', *IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences*, Vol. E88-A, No. 7, pp.1816–1823.

Yin-Jun Chen, Ching-Chung Chen, Shou-Nian Wang, Han-En Lin and Roy C. Hsu (2006) 'GPSenseCar -A Collision Avoidance Support System Using Real-Time GPS Data in a Mobile Vehicular Network', *International Conference on Systems and Networks Communication (ICSNC'06)*, Tahiti.

Elliot D. Kaplan (1996) 'Understanding GPS Principles and Applications', Ed. Artech House.

R. Toledo, M.A. Zamora and A. Skarmeta (2006) 'IMM-EKF based Road Vehicle Navigation with Low Cost GPS/INS', *IEEE Conference on Multisensor Fusion and Integration*, Heidelberg.

Luisa Andreone and Michele Provera (2005) 'Inter-vehicle communication and co-operative systems: local dynamic safety information distributed among the infrastructure and the vehicle as "virtual sensors" to enhance road safety', *ITS Hannover 2005*, Hannover.

J. Luo and J.-P. Hubaux (2004) 'A Survey of Inter-vehicle Communication', *Technical report, EPFL*, Lausanne.

Wolfgang Kiess, Jedrzej Rybicki and Martin Mauve (2007) 'On the nature of Inter-Vehicle Communication', *4th Workshop on Mobile Ad-Hoc Networks*, Bern.

Tamer Nadeem, Pravin Shankar and Liviu Iftode (2006) 'A Comparative Study of Data Dissemination Models for VANETs', *Third Annual Internatinal Conference on Mobile and Ubiquitous Systems: Computing, Networking and Services*, San Jose.

Andrew Chen, Behrooz Khorashadi, Chen-Nee Chuah, Dipak Ghosal and Michael Zhang (2006) 'Smoothing Vehicular Traffic Flow using Vehicular-based Ad Hoc Networking & Computing Grid (VGrid)', *2006 IEEE Intelligent Transportation Systems Conference*, Toronto.

Gen Hattori, Chihiro Ono, Satoshi Nishiyama and Hiroki Horiuchi (2004) 'Implementation and Evaluation of Message Delegation Middleware for ITS Application', *2004 Symposium on Applications and the Internet-Workshops (SAINT 2004 Workshops)*, Tokyo.

Toshiya Okabe, Takayuki Shizuno and Tsutomu Kitamura (2005) 'Wireless LAN Access Network System for Moving Vehicles', *10th IEEE Symposium on Computers and Communications (ISCC05)*, La Manga del Mar Menor.

Luciano Baresi, Carlo Ghezzi, Antonio Miele, Matteo Miraz, Andrea Naggi and Filippo Pacifici (2005) 'Hibrid service-oriented architectures: a case-study in the automotive domain', *5th International Workshop on Software Engineering and Middleware (SEM'05)*, Lisbon.

Samer Ammoun, Fawzi Nashashibi and Claude Laurgeau (2006) 'Real-time crash avoidance system on crossroads based on 802.11 devices and GPS receivers', *2006 IEEE Intelligent Transportation Systems Conference*, Toronto.

Han-Shue Tan and Jihua Huang (2006) 'DGPS-Based Vehicle-to-Vehicle Cooperative Collision Warning: Engineering Feasibility Viewpoints', *IEEE Transactions on Intelligent Transportation Systems*, Vol. 7, No. 4, pp.415–428.

José Santa, Benito Úbeda and Antonio F. G. Skarmeta (2007) 'Monitoring the Position Integrity in Road Transport Using SBAS/EGNOS and Communication Issues', *Location Magazine*, Vol. 2, No. 1, pp.38–42.

Rafael Toledo-Moreo (2006) 'A High Integrity Navigation System for Vehicles in Unfriendly Environments', *Phd. Dissertation*, Uni. of Murcia Publishing.

Antonis Alexiou, Christos Bouras and Vaggelis Igglesis (2004) 'Performance Evaluation of TCP over UMTS Transport Channels', *International Symposium on Communications Interworking*, Ottawa.

UMTS Forum (2006) '3G/UMTS Evolution: towards a new generation of broadband mobile services'. White Paper.

Aun Haider, Richard Harris and Harsha Sirisena (2006) 'Simulation-Based Performance Analysis of HSDPA for UMTS Networks', *Australian Telecommunication Networks and Application Conference*, Melbourne.

José Santa, Benito Úbeda and Antonio F. G. Skarmeta (2007) 'A Multiplatform OSGi Based Architecture for Developing Road Vehicle Services', *Consumer Communications & Networking Conference 2007 (CCNC 2007)*, Las Vegas.

Schwaighofer, A. Grigoras, M. Tresp, V. and Hoffmann, C. (2004) 'GPPS: A Gaussian Process Positioning System for Cellular Networks', *Advances in Neuronal Information Processing Systems*, Vol. 1, No. 16, pp.579–586.

K. Lakakis, P. Savvaidis, I. M. Ifadis and I. D. Doukas (2004) 'Quality of Map-Matching Procedures Based on DGPS and Stand-Alone GPS Positioning in an Urban Area', *FIG Working Week 2004*, Athens.

Hide, C. D. and T. Moore (2005) 'GPS and Low Cost INS Integration for Positioning in the Urban Environment' *ION GPS/GNSS*, Long Beach.

The Radio Technical Commission for Aeronautics (2001) 'Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment'.

S. P. Drake (2002) 'Converting GPS Coordinates ($\phi\lambda h$) to Navigation Coordinates (ENU)', Ed. DSTO Electronics and Surveillance Research Laboratory, Cap. 2.

Skarmeta A.G., Martínez H., Zamora M.A., Úbeda B., Gómez F.C and Tomás L.M. (2002) 'MIMICS: Exploiting Satellite Technology for an Autonomous Convoy', *IEEE Intelligent Systems*, Vol. 17, No. 4, pp.85–89.

Sun Microsystems, Inc. (2005) 'JXTA Technology: Creating Connected Communities'.

Figure 1 High level communication architecture

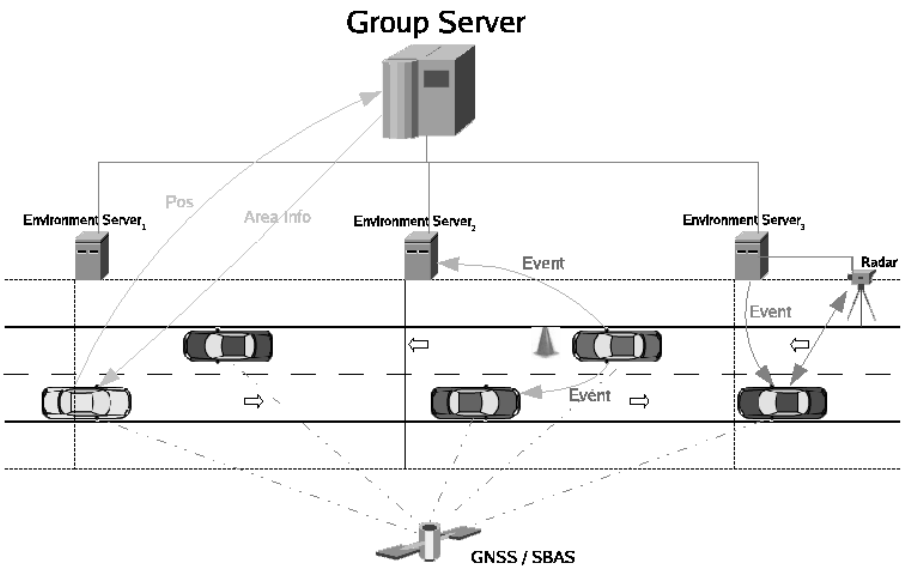

Figure 2 Usefulness of the horizontal protection level

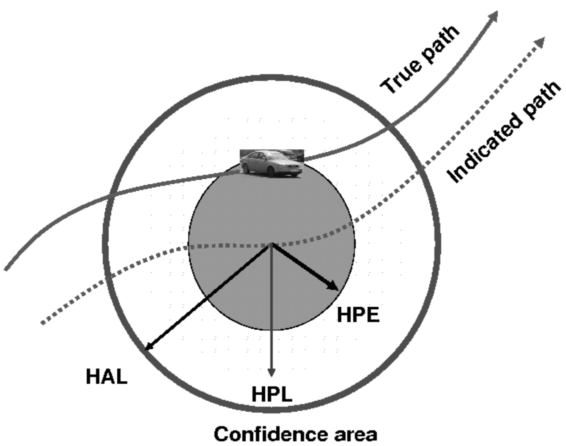

Figure 3 Prototype vehicle used in the development

Figure 4 An screenshot of the vehicle application

Figure 5 Coverage areas considered in the test zone

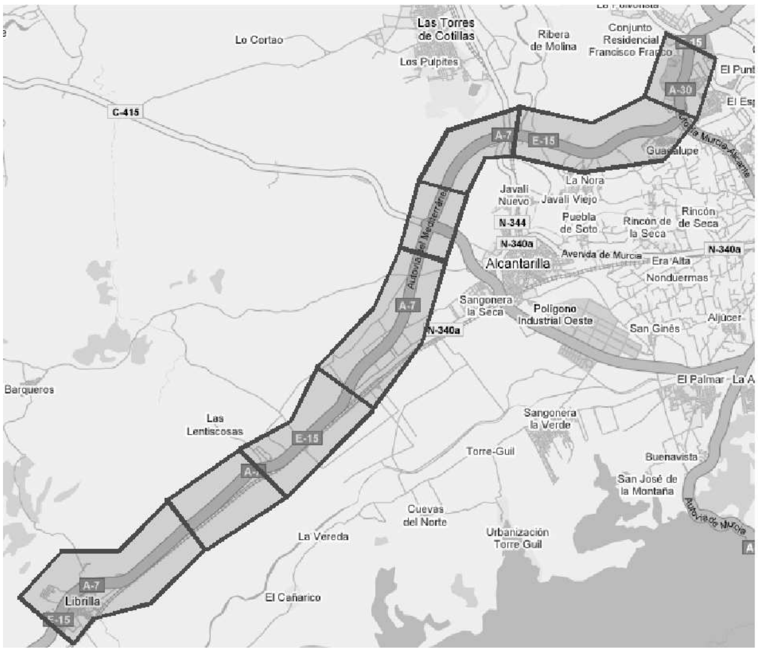

Figure 6 HPL and GPS coverage results from a dynamic test