Architecture and evaluation of a unified V2V and V2I communication system based on cellular networks

José Santa [*], Antonio F. Gómez-Skarmeta

University of Murcia, Department of Information and Communications Engineering, Campus de Espinardo, 30001 Murcia, Spain

Abstract

Vehicle communications are becoming the cornerstone in the future vehicle equipment. More specifically, vehicle to vehicle communications (V2V) are the main object of researching nowadays, because vehicle to infrastructure (V2I) approximations are already being developed as commercial solutions. Cellular networks (CN) are usually applied in V2I solutions, whereas ad-hoc networks are practically the only technology considered in V2V communications. Due to fact that CN are currently a reality and the operators are continuously improving the network, this communication technology could be considered as a candidate to deal with V2V necessities as well. The present paper defends the applicability of CN in the V2V field, and presents a novel communication paradigm for vehicles which unifies both V2V and V2I paradigms into one system. A peer to peer network technology has been used over the CN basis to create a group-based communication infrastructure which enables the message propagation among vehicles and between the car and the road side infrastructure. The architecture has been implemented in both hardware and software terms, and multitude of field tests have been carried out, whose main performance results are shown in the paper.

Key words: vehicle communications, V2V, V2I, cellular networks, ITS

[*] Corresponding author.
Email addresses: `josesanta@dif.um.es` (José Santa), `skarmeta@dif.um.es` (Antonio F. Gómez-Skarmeta).

8 November 2007

1 Introduction

The inclusion of telematics in the vehicle domain has generated some collateral technological developments. Communications among vehicles and between vehicle and road side infrastructure are becoming a key issue in the provision of on-board services. Safety applications and tracking systems have been during years the main proposals in intelligent transportation systems (ITS). However, the amount of services oriented to the vehicle field is currently growing, and not only in terms of on-board solutions, but also applications which imply a communication channel with the infrastructure have to be taken into account. There are a lot of communication technologies which can deal independently with each service requirement. However, installing several network adapters inside the vehicle to consider all the possible service deployments is not a cost-effective solution. The rest of the paper shows a communication architecture which elects the cellular networks (CN) as a suited technology to cover the connectivity requirements of most of vehicular services.

Talking about vehicle communications, service requirements can be covered using two types of network topologies: communications between vehicle and infrastructure, and communications among vehicles. In the first case, on-board services require a 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 such technology can be found in electronic fee collection systems, where drivers are charged automatically, according to some road and vehicle parameters. The approach presented in [1] uses DSRC (Dedicated Short Range Communications) gantries to keep the path followed by a vehicle in order to calculate the associated cost. In V2I systems, the main technologies involved are DSRC, infrared, and wireless LAN. On the other hand, the second group of services with connectivity requirements are the vehicle to vehicle (V2V) solutions. In the current literature, several works for collision avoidance support, and warning mechanisms in general, can be found [2]. For this type of services, the most extended technologies are based on ad-hoc networks applied to the vehicle field (VANET or *Vehicular Ad-hoc NETworks*) [3]. The solution presented along the current paper proposes a communication architecture which deals with both V2I and V2V connectivity requirements. Cellular and peer to peer (P2P) networks are jointly used to design a communication system based on coverage areas.

Road safety, which is one of the most important applications of telematics in the vehicle field, has been widely studied by researchers. 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 methodology often results in designs which treat problems locally; hence, security issues that require a fast treatment over a limited space can be solved. Several interesting papers can be found in the literature dealing with collision avoidance systems [4]. On the other hand, V2I solutions usually allow authorities, and all drivers in general, to know traffic difficulties through a centralized system. Considering all these ideas, our purpose is focused on creating a network design useful for vehicle applications, but obviously taking into account the requirements of a safety system. As it is explained bellow, a reference implementation of a safety system has been developed over the communication infrastructure to test the operation of the communication system. This proves how the message propagation from a vehicle in the proposed network design reaches not only the surrounding vehicles, but also the infrastructure entities.

Several network technologies have been considered in the field of vehicle communications. One way of classifying all of them would be attending the operation range. Bluetooth, ZigBee and Ultra Wide Band (UWB) are suitable technologies for creating personal area networks (PAN) inside the vehicle compartment, whereas Wi-Fi networks have proved its usefulness in V2V solutions. [5] includes a discussion about all these technologies. However, in order to deal with all connectivity requirements for all possible deployable services, it is mandatory to consider the cellular networks. CN have been widely tested for V2I solutions; however, as it is explained along the paper, thanks to the improvements in the transmission of data flows carried out by operators, CN can be valid for V2V solutions as well.

The rest of the paper is organized as follows. In Section 2, the presented network infrastructure is placed into the current research literature regarding V2V and V2I communications. Section 3 includes a description of the main performance parameters in these types of vehicular networks. Section 4 gives reasons why cellular networks are suitable for V2V communications. The network design is shown in Section 5, where it can be found details about the implemented protocols as well. Section 6 includes a description of the developed prototype and the performance results obtained from the system in the message propagation tests carried out over a real environment. Finally, Section 7 contains the conclusions of the work.

2 Related work

As it has been stated previously, researching lines in vehicular communications are especially 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 both V2V and V2I communications. In [6], a survey of vehicular communications and its applications is given. Here it is stated the technology which deals with more requirements implementing telematic services in ITS are CN. This defends our idea of using cellular networks in a general telematic framework. In this line the 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.

Technology issues of considering wireless networks in the vehicle domain are exposed in [7]. In this work an overview of the physical and link levels requirements for the VANET field is stated. Taking into account these necessities and limitations, it is possible to contrast our solution, based on cellular networks, with the VANET ones. [8] includes an interesting study of common transmission methods used in VANET, and the delays observed in the message propagation. This presents a starting point to consider the feasibility of a network design based on CN for vehicles. Another example of a VANET application in traffic safety can be found in [9], where a collaborative design is used to estimate the traffic congestion. [10] considers another V2V communication model to solve the problem of avoiding crashes in crossroads. Our work is not centered in a concrete application, like in the two previous works, because the proposed communication architecture is not integrated into an ad-hoc solution. Our goal is creating a generic network platform for vehicular services.

Considering V2I patterns, in [11] a communication technique between the vehicle and the road infrastructure based on the DSRC technology is presented. This illustrates an example of an 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, [12] presents a handover system for wireless LAN networks over 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 to notify events to the road side is shown in [13]. Our system uses the JXTA technology in the vehicle field as well, however, in contrast with the last work, it includes an architecture valid for both V2V and V2I communications. A V2I solution based on CN can be found in [14]. Here, an advanced traffic monitoring system is shown, where vehicles send traffic information to a monitoring centre. Our infrastructure, in contrast to this solution, does not use a central equipment to process all vehicles events. Using a decentralized approach, our system propagates messages over bounded traffic areas.

3 Operation issues in vehicle communications

Due to cellular networks have been used in V2I applications during years, its applicability to this kind of solutions has been proved. The real novelty of the current paper is demonstrating how the CN can be a real alternative to VANET approaches in the V2V field. In order to measure the suitability of our proposal, it is interesting to emphasize the requirements of V2V communications, taking as starting point the most used network topology in this field, which is obviously the VANET one.

Latency The most important factor in message transmissions in vehicular communications is perhaps the latency. This is the time the network spends in transporting a message from the source to the destination vehicle. As it is shown in [8], the latency in VANET proposals is proportional to the distance between the source 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 event notification 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 routing protocols. However, sharing information about the surrounding vehicles is useful for concrete applications as well. Knowing the position of the vehicles ahead of us it is possible 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 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 difficulty of testing new protocols and designs based on VANET over real environments, the most commonly used technique is simulation. Using simulators, it is possible to create scenarios with several mobility patterns and vary the traffic density, for instance. However, simulations do not give a complete idea of the real operation and, sometimes, solutions do not physically developed give the feeling of not to be practical designs.

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

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 Applicability of cellular networks in V2V

The importance of cellular networks in telematic services for vehicles is described in [6], as it has been exposed previously. This work defends our idea of using cellular networks in a service platform for vehicles. However, in order to consider the performance parameters of cellular networks, and its applicability in V2V overall, it is important to take into account some technological aspects. In the field of VANET, the most extended technology are the wireless LAN transceivers, such as 802.11a/b/g and the new 802.11p. On the other hand, the most used technologies 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, the UMTS 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 the vehicle domain, it is important to deal with the most controversial performance parameter: the latency. As it has been studied, cellular networks are able to maintain a regular behaviour in latency times [15][16]. However, the usually 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 is able to give propagation times even better than VANET approaches. Moreover, future plans on UMTS include meaningful improvements in terms of throughput and delay [17]. The High Speed Packet Access (HSPA) will be launched with the objective of improving the operation of data applications. HSPA includes a better throughput and, what is more important, latency times in the order of tens of milliseconds. Initial tests has been carried out in such UMTS changes [18], which use the recently installed HSDPA (the downlink part of the HSPA technology). These initial studies confirm latency times of 60 milliseconds in the reception of data packets from a wired node. If the coming uplink part of HSPA (HSUPA) were considered as well, this would imply that CN would be able to deal with the fast propagation requirements of some critical applications.

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

Regarding the cost of a CN-based system, and comparing it with the hardware used in the VANET ones [19], two issues must be taken into account: the hardware platform cost and the cellular network usage cost. Regarding the hardware cost, an appropriated on-board unit for the deployment of services is necessary. An embedded computer is a good solution for both VANET and the CN-based systems. A screen and some peripherals are common in both approaches. The GPS sensor is necessary for the platform presented here; however, they are usually integrated in VANET systems as well to improve the routing algorithms and, in other cases, the vehicle already includes one of them. The only significant hardware difference between VANET and CN-based systems is the communication transceiver used. As can be read above, in the first case a wireless LAN hardware is usually installed, in contrast to the UMTS modem used in the present work. However, according to the market state, products of both types can be obtained by similar prices.

Apart from the price of the hardware, the other issue to be considered is the the extra money which has to be paid for the usage of the operator's infrastructure. In a CN-based proposal all the communication resources have to be paid. In the VANET case, keeping in mind that only local services could be deployable, the communication cost is obviously null. UMTS data transfers were usually charged per byte transferred. Current trend these days is paying a fixed quote per month, with an extra cost if the transmission rates fall out of the contract. Nowadays this drawback is being 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 [17].

5 A CN-based vehicular network design

The network infrastructure designed over the cellular network basis is presented in this section. As it is explained, a P2P technology has been used over the CN layer to create a group-based message propagation technique. After a brief overview of the designed network, the protocols designed to maintain the communication channel at the vehicle and route messages over the network are described in detail.

5.1 Network overview

It has been stated that cellular networks are an appropriate technology in order to use a unified communication mechanism. That is, cellular networks present the communications capabilities which allow the implementation of most of on-board services with connectivity requirements. A previous work [22] includes a software platform for developing on-board services, which has been extended with a middleware service which allows the use of a high level communication interface. This is the vehicle edge of the network platform presented here. Using this new functionality, each new service which requires communication capabilities does not require the implementation of a new 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. Fig. 1 shows a general diagram of the proposed high level communication architecture. Traffic zones are organized in coverage areas, each one using a different P2P communication group. These zones are logical areas and they do not have to fit in the cellular network cells. Information about the geometry of each area and its available services are maintained in the Group Server entity. 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. 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). Messages are encapsulated in P2P packages, and two different techniques of emission have been developed. Consequently, P2P messages can be broadcasted in the area or sent to a specific vehicle.

Apart from the designed architecture, Fig. 1 includes the three most representative scenarios 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 over the new area. Because the Group Server sends the area geometry to the vehicle, the latter has to communicate with GS only when it detects the car is out of the current service area. This technique saves communication resources. In order to perform such detection, the on-board software executes an algorithm which checks wether the vehicle is inside the polygon which is created using the vertexes given by the Group Server. In the second scenario, a safety service is used by the vehicle to notify a repairs event. This event is broadcasted, and all vehicles located in the area receive the warning.

Any event which may require a special attention, such as a traffic jam, can be processed because 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 Fig. 1 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 inside the area, and useful reports can be sent to a third party entity.

5.2 Protocol details

It is clear the usage 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 three protocols: communication between vehicle and Group Server, communication between Environment Server and Group Server, and finally the event notification protocol.

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 the communication management. An initial *Area_Update_Query* message is used by the vehicle for registering itself against GS. This one replies with an *Area_Update_Response* which contains the available services in the initial zone and the P2P parameters to allow the subscription to them. The *Disconnect* message serves for ending the communication with GS. The roaming process uses again 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 including its new location with the objective of receiving a new *Area_Update_Response*. When the user wants to use a defined service, the vehicle sends an *Event_Subscription* with the services he is interested in.

It is important to note that, in general, every service has a different P2P group for every area. However, it is possible to define the same P2P parameters for a service over several adjacent areas. If the service does not require a fine grain propagation of messages, it is useful to unify several areas for this service. This case can be seen, for example, in a meteorological service which propagates messages from an information centre, where the forecast is done for a big area. In the roaming process, when the same P2P parameters are used for a service, it is not necessary to perform a connection to a new P2P group, then network resources are saved and the service has a continuous connection.

Regarding the communication between the Environment Server (ES) and GS, Table 2 summarizes all the interchanged messages. The first message used in the communication management with GS is *ES_Registration*, which 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 an *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* message performs this task, by requesting for the P2P parameters of the coverage zone. GS answers with this information by means of *ES_Registration_Update_Response*. The second group of packets are used in the message propagation mechanism. Sometimes it is necessary to ensure that all vehicles near a problem receive critical events. The location of such problems may be close to the border of a 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 services to send events. 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 data contained in this packet are an identifier of the service, the body of the message and the position of the source vehicle. The *Environment_Event* messages are sent by the Environment Servers. This is used by the message propagation method previously described and all the services oriented to the notification of events from the road side in a V2I application. The data included in the *Environment_Event* message contain the same information than the *Vehicle_Event*. Last packet, *Specific_Environment_Event*, allows for sending a message to a specific vehicle, and does not include any information about position. Our current works use this message to send context aware information to the vehicle according to the driver's profile.

6 Implementation and experimental results

The usefulness of the described network design is demonstrated in this section. A real hardware and software platform has been developed to test the operation of the communication architecture. Both the vehicle and the road sides of the system have been developed and, in order to test the architecture, a safety application has been implemented. This tool is used to analyze the performance of the communication system for both V2I and V2V environments.

6.1 Protype vehicle and equipment at the road side

A complete hardware/software prototype has been created and tested. The vehicle used for the system deployment is a car widely sensorized at the University of Murcia [20]. Fig. 2 shows this car and some of its components. The vehicle contains all the basic features of a common car and, through an agreement with the manufacturer, it has been prepared to be enhanced with several sensors, such as odometry, a gyroscope, an accelerometer or a GPS sensor. The GPS receiver is utilized to know the position of the car in the roaming process and locate the launched notifications. The on-board unit is a SBC (*Single Board Computer*) of VIA, with a Linux Fedora Core 4 operating system, and a Java Virtual Machine 1.5. Fig. 2 shows this computer, which is located at the rear part of the passenger seat. As can be seen, the dashboard has been modified as well to install a LCD monitor. 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. For the message propagation tests further explained, however, two laptops were used to make easy the trials. The previous UMTS adapter and a Huawei E612 transceiver have been used to connect the laptops to the cellular network. Both laptops use a Windows XP operating system, with Java 1.5, and a GPS receiver has been used in each test to synchronize the time.

At the road side, the Environment Server has been implemented and its instances execute over a server located in our laboratories. The Group Server runs over the same computer, a Linux-based system with an AMD Opteron multiprocessor architecture.

6.2 On-board software

In order to enable the implementation of software applications over the on-board unit, the OSGi technology has been used. OSGi is a service-oriented framework where applications can be installed, updated or deleted over a general purpose computer which acts as a service gateway [21]. This framework has been included in the on-board computer through a service platform designed for the vehicle domain [22]. By means of this platform, vehicle software can be easily developed, using a modular and portable approach.

A JXTA (JuXTApose) [23] middleware has been developed using the described software platform. Through JXTA, the car can connect to the P2P network created by vehicles and road side entities. JXTA presents a group-based communication environment with the features of a P2P protocol. It forms an underlying network which abstracts the user from internal details.

Using the JXTA middleware, a safety application has been developed to test the feasibility of the communication architecture. Fig. 3 shows this utility, named Message Console. This tool includes an event-based mechanism to notify safety problems. Each 'event' is modeled as a service in the designed network platform. The user can subscribe to any of the eight types of events available on the right box. If one of these transmission services is active, the corresponding events can be received or thrown. In the screenshot provided in the illustration, the driver has activated all the services. However, only three of them are available in the current area. Two events have been received from the network, one of them from a break down service, and the other one from a meteorology information service.

6.3 Performance evaluation

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. Fig. 4 shows the eight coverage areas under consideration. The software and hardware described above has been used to test the correct operation of the system and get performance results.

In order to measure the performance of the message propagation, a wide range of tests have been carried out over the first coverage area defined in Fig. 4. This place is suitable for our purposes, due to the good UMTS deployment and the low traffic density, so it is possible to repeat the same circuit in every test. The latency in the message propagation has been measured edge to edge with a modified version of the on-board software. The source terminal (one of the laptops) sends messages in a fixed one second rate, and the destination one logs the received packets. The message payload contains: the packet type, the location of the vehicle (latitude and longitude), the source vehicle identifier, the message type, and an extra information field. The packet type and the message type are always de same, because a vehicle event is used and only one transmission service is considered, respectively; the information field is filled with the emission time, in order to compute the propagation delay. A total amount of 48 bytes is transfered for every message, over the P2P and CN based network architecture.

Fig. 5 shows a graph of the obtained latency in the message propagation between two mobile terminals. The two laptops were carried in the same vehicle to test the network design over a real mobility scenario. As can be seen, the latency times obtained for every message are around 800 ms, with several peaks due to the mobility effect. The delays over two seconds belong to a low UMTS coverage zone. On the other hand, Fig. 6 plots the latency in a V2I transmission model, where the same circuit was considered and a terminal connected to the wired network was used to receive the messages transmitted by the mobile unit. This fixed terminal is connected to the network platform in the same way ES is. Here the delays are about 600 ms. Because only the uplink channel of UMTS is used in the travel of the messages, there is an improvement in the latency times. The final part of the graph exposes again the coverage problem in this zone of the way. Finally, the latency obtained in the downlink channel using a V2I paradigm is showed in Fig. 7, where the mobile terminal is now in charge of receiving messages from the infrastructure. The latency times fall to 200 ms, which is explained by the asymmetric network service given by UMTS, where the downlink channel offers a better performance. The low coverage zone is one more time evident at the final part of the test, where a latency of five seconds is obtained. As can be inferred from the graphs, the latency peaks have a greater magnitude in the V2V scenario than in the V2I ones. This is due to the fact that in this case mobility effects are considered in both the downlink and uplink channels.

Table 4 summarizes the total amount of message sent in every test, the latency means and the dropping rates obtained in each case. As can be seen, the V2V scenario, which uses both the uplink and downlink channels of UMTS, gives a greater latency time than the other two cases as it can be expected. In fact, it is interesting to note how the sum of the two V2I latency values result practically in the latency mean obtained in the V2V case. The total amount of dropped messages depends as well on the UMTS usage, as can be seen in the last column of the table. All these messages are dropped by the network mainly when the source terminal begins the transmission. JXTA needs a little time after joining to a P2P group to configure the communication channel. When the UMTS network is used, this process carries out some seconds, and the source terminal was configured to study this effect, transmitting just when the group joining phase ends. In any case, considering this issue only appears at the beginning of the communication, as the total amount of messages fransmitted in a P2P group is greater, the dropping rate will be almost insignificant.

The results show that a great variety of vehicle services could be developed with these latency times. V2I applications can be obviously carried out with these delay values. For V2V applications, only safety applications which requires a very low propagation time could not support these latency results. In collision avoidance systems it is necessary a very fast propagation of messages, in order to notify a traffic problem to the surrounding vehicles. However, the network design presented here have a real advantage over VANET approaches.

The latency does not increase when the distance from the problem grows. According to the study presented in [24] about the avoided collisions using a VANET system in a convoy of vehicles, it is true that, currently, vehicles just consecutive to the accident would not be warned on time using the CN-based system; however, this study explains that some collisions happen at distances around 100 meters due to the propagation latency. Our design could solve this problem, because for a distance of 50 meters that proposal gives latency times similar to the results already obtained here. As it has been explained, future improvements in the UMTS network will reduce nevertheless these delays.

Another important aspect which has to be taken into consideration is the time the roaming process takes. The group based P2P technology used (in this case JXTA) requires some time to connect to a new communication group. In the analysed network design, the communication group may change if the new coverage area defines new P2P configuration parameters for a service. For this reason it is interesting to study the required time for the roaming phase. Table 5 summarizes the necessary time to carry out the most complex tasks in this process. These are the group searching over the JXTA network, and the creation of the communication pipe. The vehicle prototype was used to travel several times across all the zones drawn in Fig. 4. Because the software architecture has logging capabilities, more tests were carried out without a real driving. The results are divided into the necessary time for the joining tasks at the first time the P2P group is used, and the time which takes successive joints. The group searching phase is practically null in the second and successive joints, as can be observed, because the group had been found previously. The communication pipe creation phase is 1.5 seconds greater in the second case, however. It is necessary to consider that some network establishments are essential for the creation of the pipe, and this work is carried out previously in the group searching phase in the first joint. In the second and successive joints, the P2P group information is taken from a local cache, so some initial JXTA network tasks are necessary. In any case, it is important to note how the roaming process takes around 3 seconds in most of the cases, because people usually drives around the same places.

7 Conclusions and future work

The work presented in this paper includes a vehicular network design which joins the requirements of both V2V and V2I communications. The cellular network has been used in the proposed platform because it is considered as the most general wireless communication technology for the vehicle field. However, the real novelty presented in the application of CN in the vehicle domain can be found in the frame of V2V communications. The P2P group based technology provided by JXTA allows the message propagation among vehicles and between the vehicle and the infrastructure, in both uplink and downlink directions. The network design divides the communication environment in coverage areas where the message propagation is limited. The information about these coverage areas is centralized in a server which provides the roaming information.

The network architecture has been developed in both software and hardware terms, so a vehicle prototype has been defined in order to test the implementation and the infrastructure side has been developed over real servers. Real tests demonstrate the feasibility of the proposed solution. A message propagation study has been carried out, whose tests show delay results in the order of 800 ms for the message propagation between mobile vehicles. These values could be really improved only in a few months when the HSPA technology becomes a reality in the European UMTS network. This results show that a V2V network design based on cellular networks is feasible and its application for services usually implemented using VANET approaches will gradually become a reality.

Future and current works in this line include the provision of context-aware information considering a driver profile. This technique uses the Environment Servers to adapt contextual information according to the driver preferences, and send notifications to the vehicle terminal. An extension of the overall system is planned as well to implement a third-party entity to centralize safety events over a monitoring centre. A web application is being developed to offer a double view of the traffic state for both users and road operators.

Acknowledgements

The authors would like to thank the Spanish Ministerio the Educación y Ciencia for sponsoring the research activities under the grant AP2005-1437, in frames of the FPU program, and to the financial support given by the European Spatial Agency (ESA) under the GIROADS 332599 project. Special thanks as well to the Spanish Ministerio the Fomento for its continuous support in vehicular researching.

References

[1] Benito Úbeda, Rafael Toledo, Juan G. Jordán and Soledad Montes, 'A theoretical and practical analysis of GNSS based road pricing systems, considering the EGNOS/SISNeT contributions', *NAVITEC 2004*, Noordwijk, December 2004.

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

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

[4] Jumpei Ueki, Sentarou Tasaka, Yuji Hatta and Hiromi Okada, '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 (2005), pp.1816–1823.

[5] Tomas Nolte, Hans Hansson and Lucia Lo Bello, 'Wireless Automotive Communications', *Euromicro Conference on Real-Time Systems (ECTRS 05)*, Palma de Mayorca, July 2005.

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

[7] J. Luo and J.-P. Hubaux, 'A Survey of Inter-vehicle Communication', *Technical Report, EPFL*, Lausanne, March 2004.

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

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

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

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

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

[13] Luciano Baresi, Carlo Ghezzi, Antonio Miele, Matteo Miraz, Andrea Naggi and Filippo Pacifici, 'Hibrid service-oriented architectures: a case-study in the

automotive domain', *5th International Workshop on Software Engineering and Middleware (SEM'05)*, Lisbon, September 2005.

[14] Baik Hoh, Marco Gruteser, Hui Xiong and Ansaf Alrabady, 'Enhancing Security and Privacy in Traffic-Monitoring Systems', *IEEE Pervasive Computing*, Vol. 5 (2006), No. 4, pp.38–46.

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

[16] Jesse Landman and Pieter Kritzinger, 'Delay analysis of downlink IP traffic on UMTS mobile networks', *Performance Evaluation*, Vol. 62 (2005), No. 1–4, pp.68–82.

[17] UMTS Forum, '3G/UMTS Evolution: towards a new generation of broadband mobile services', *White Paper, UMTS Forum*, December 2006.

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

[19] Moez Jerbi, Sidi M. Senouci and Mahmoud Al Haj, 'Extensive Experimental Characterization of Communications in Vehicular Ad Hoc Networks within Different Environments', *2007 Vehicular Technology Conference* (VTC2007-Spring), Dublin, April 2007.

[20] Antonio G. Skarmeta, Humberto Martínez, Miguel A. Zamora, Benito Úbeda, Félix C. Gómez and Luis M. Tomás, 'MIMICS: Exploiting Satellite Technology for an Autonomous Convoy', *IEEE Intelligent Systems*, Vol. 17 (2002), No. 4, pp.85–89.

[21] Dave Marples and Peter Kriens, 'The Open Services Gateway Initiative: an introductory overview', *IEEE Communications Magazine*, Vol. 39 (2001), No. 12, pp.110–114.

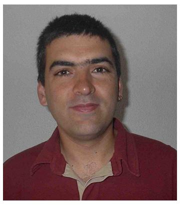
[22] José Santa, Benito Úbeda and Antonio F. G. Skarmeta, 'A Multiplatform OSGi Based Architecture for Developing Road Vehicle Services', *Consumer Communications & Networking Conference 2007* (CCNC 2007), Las Vegas, January 2007.

[23] Sun Microsystems, Inc., 'JXTA Technology: Creating Connected Communities', *White Paper, Sun Microsystems*, February 2005.

[24] Subir Biswas, Raymond Tatchikou and Francois Dion, 'Vehicle-to-Vehicle Wireless Communication Protocols for Enhancing Highway Traffic Safety', *IEEE Communications Magazine*, Vol. 44 (2006), No. 1, pp.74–82.

Vitae

José Santa received the M.S. degree in Computer Science Engineering from the University of Murcia, Spain. Since 2004 he is a Ph.D. candidate with Department of Information and Communication Engineering, at the same university. Research interests are vehicle communications, location based services, positioning systems, electronic vehicle identification, and the intelligent transportation systems (ITS) field in general.



Antonio F. Gómez-Skarmeta received the M.S. degree in Computer Science from the University of Granada, Spain, and the B.S. (Hons.) and the Ph.D. degrees in Computer Science from the University of Murcia. Since 1993, he is Assistant Professor with Department of Information and Communications Engineering at the same university. Research interests include mobile communications, GNSS location based services and ITS. He has published over 50 international papers.

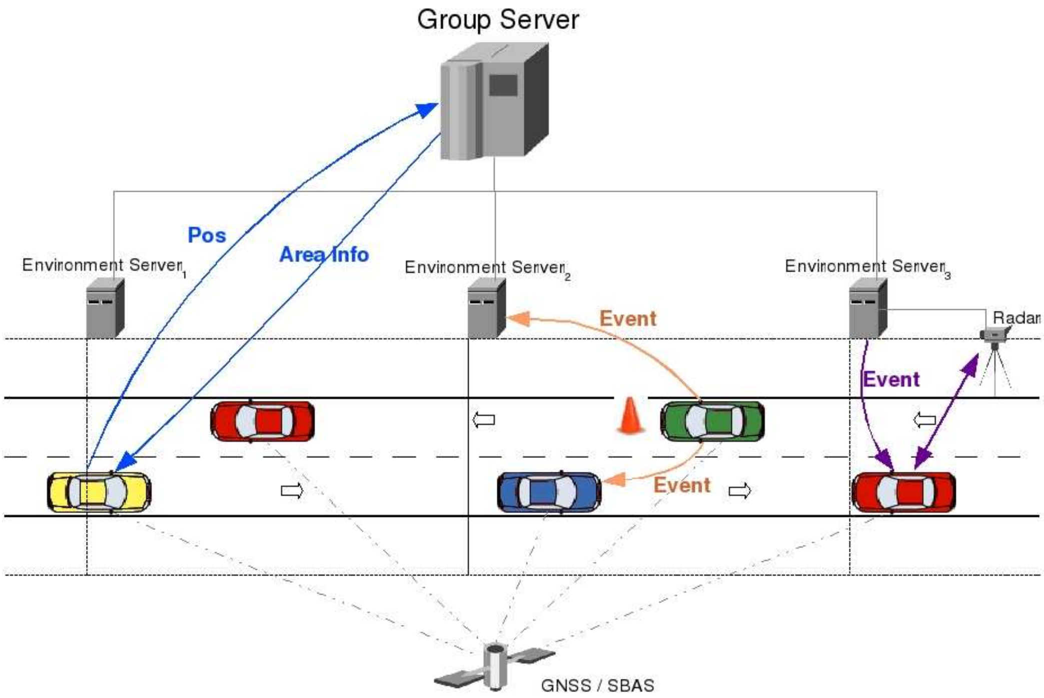


Fig. 1. Network design with the most representative scenarios

Fig. 2. Hardware details about the prototype vehicle

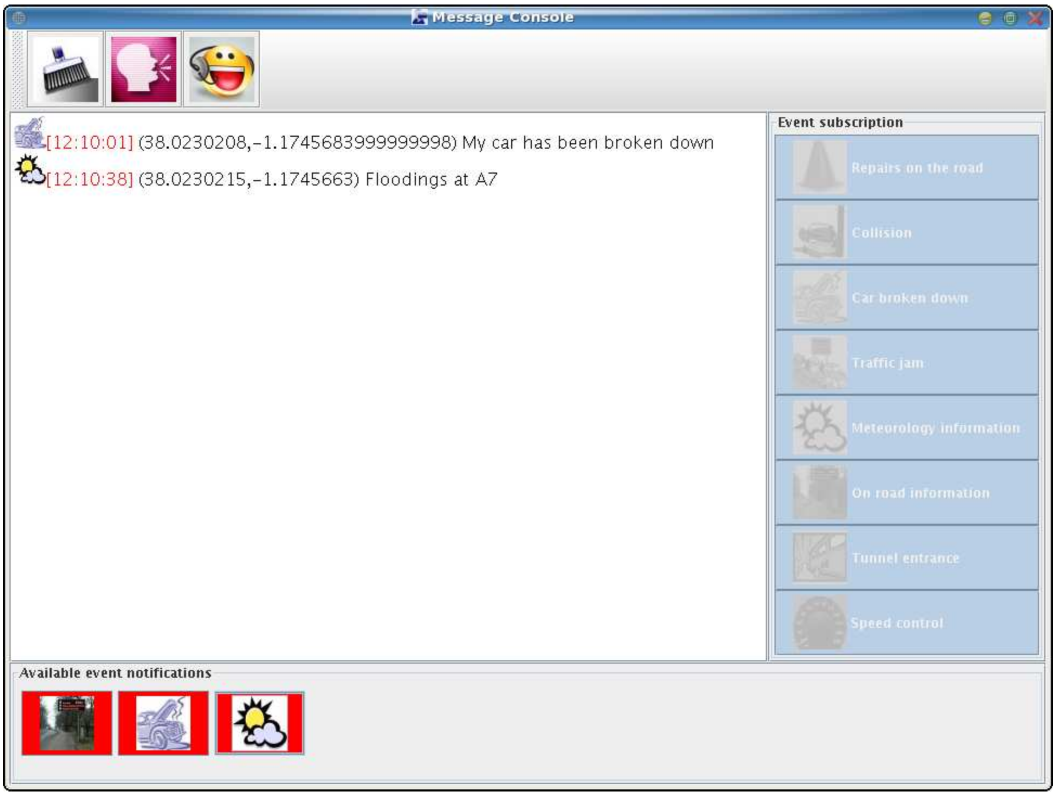


Fig. 3. Safety application developed to test the network infrastructure

Fig. 4. Geographic zone considered in the tests

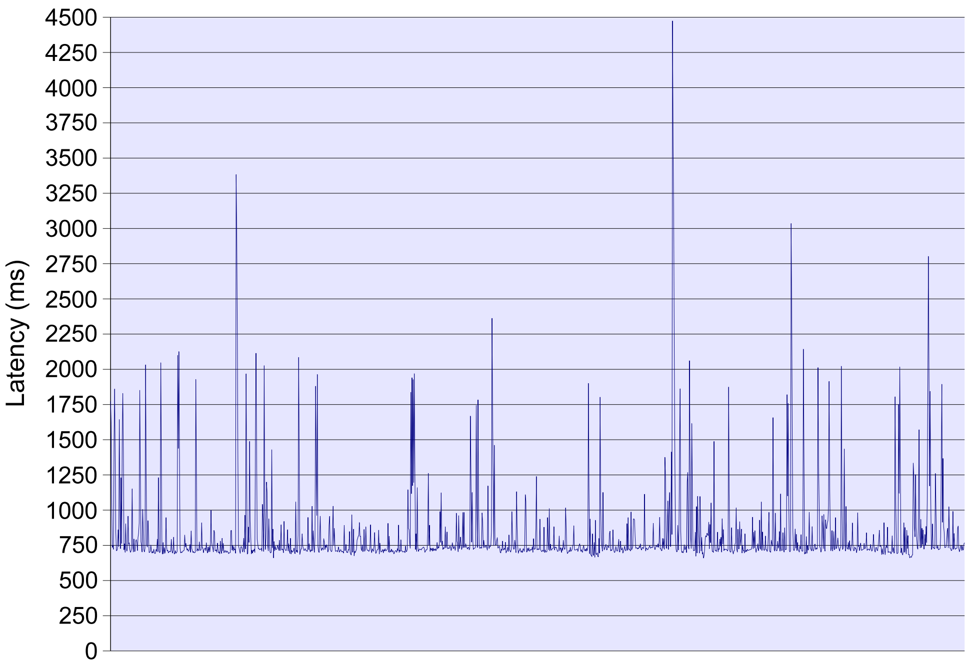


Fig. 5. Latency in a V2V scenario

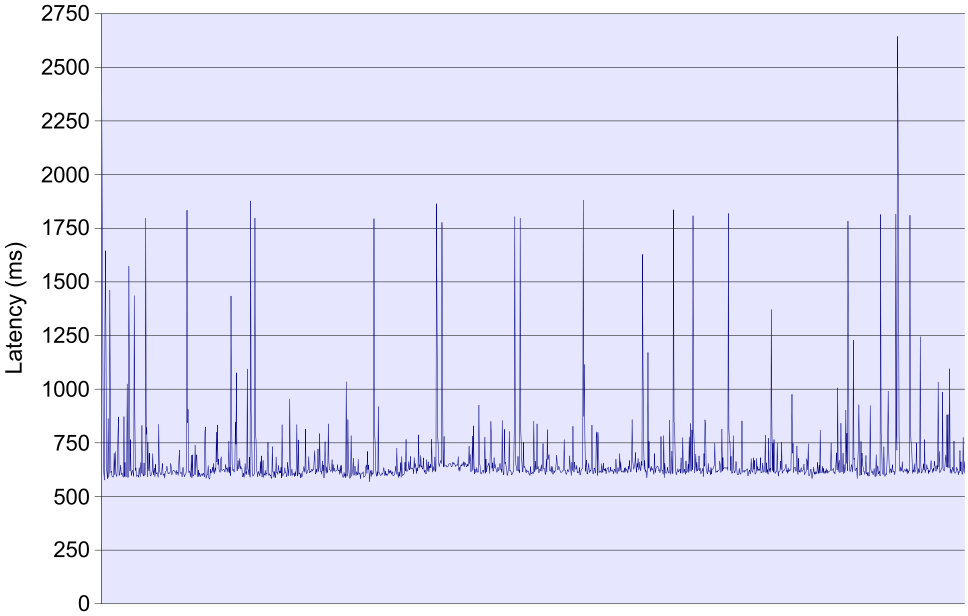


Fig. 6. Latency in a V2I uplink scenario

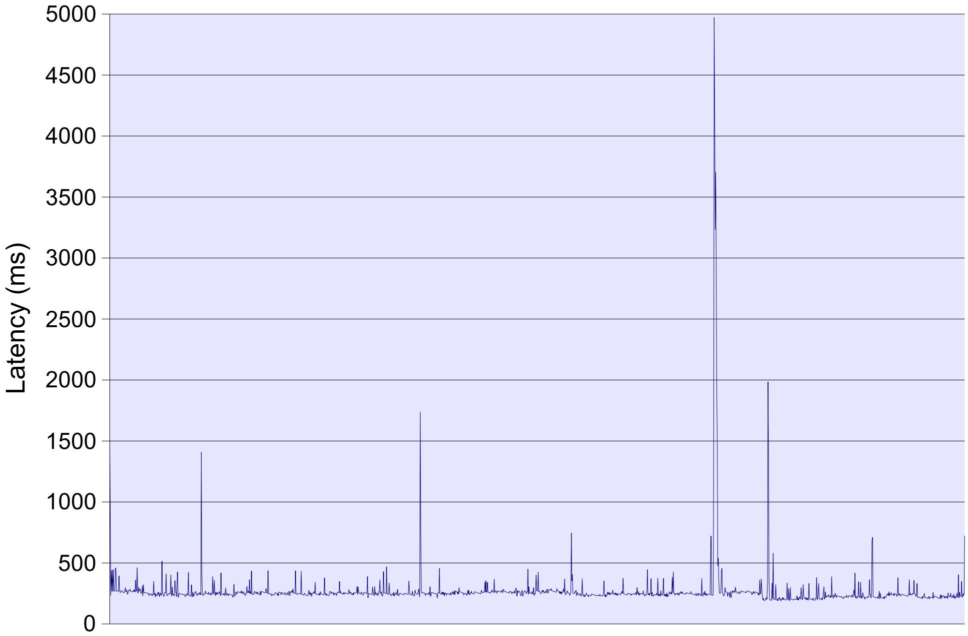


Fig. 7. Latency in a V2I downlink scenario

Table 1
Vehicle-Group Server communication

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

Table 2
Environment Server-Group Server communication

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

Table 3
Vehicle-Vehicle/Environment Server communication

Purpose	Messages	Sender
Message Passing	Vehicle_Event	V
	Environment_Event	ES
	Specific_Environment_Event	ES

Table 4
Performance results

Scenario	Sent messages	Latency mean	Dropping rate
V2V	1463	845.31	1.57%
V2I (uplink)	1589	667.75	0.13%
V2I (downlink)	1653	271.41	0%

Table 5
Time consumption in the roaming process

Action	First joint	Successive joints
Group searching	4581.13	3
Communication pipe creation	2034.32	3513.65
Total	6615.45	3516.65