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Experimental Evaluation of a Novel Vehicular Communication Paradigm Based on Cellular Networks

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Abstract— **In the field of vehicular networks, the amount of telematic services which are usually taken into account is very limited. Safety services, and specifically collision avoidance applications, practically receive an exclusive attention. Due to vehicular ad-hoc networks (VANETs) are the most used communication technology, services conceived for the vehicle domain are frequently designed to take advantage of its benefits, but also to suffer its limitations. The intention of this paper is proposing a novel communication paradigm open to the development of any vehicular service with connectivity requirements. This way, not only vehicle to vehicle (V2V) necessities are considered, but also vehicle to infrastructure (V2I) connections are taken into account with the same importance. The work presented here chooses the cellular networks as a valid alternative to VANET approaches in most of the cases, with the added value of V2I capabilities. A design based on peer to peer (P2P) networks has been implemented and tested over a real environment. The hardware/software prototype is explained and main performance measurements prove our system is a feasible communication paradigm for most of vehicular services.**

I. INTRODUCTION

Vehicular networks are becoming a key issue in the development of on-board services. Fleet management applications opened the way several years ago with the usage of cellular networks (CN) to receive vehicle positions at a monitoring station. Since then, the amount of telematic services oriented to the vehicle field has been growing, and vertical solutions mainly addressed to road safety have covered the literature. As the rest of the paper shows, our contribution in this frame is oriented to create a communication paradigm which covers the necessities of most of vehicular services.

According to current state of vehicle telematics, connectivity requirements of vehicular services can be divided in two communication paradigms: vehicle to vehicle (V2V) communications, the most popular network architectures last years, and vehicle to infrastructure (V2I) communications, which are more and more important. In this last case, on-board applications require a connection with the infrastructure located at the road side. Examples of such technology can be found in electronic fee collection systems or fleet management applications, where the most extended technologies are Dedicated Short Range Communications (DSRC), infrared, and wireless LAN. In V2V solutions, vehicular ad-hoc networks (VANETs) using wireless LAN and DSRC cover the communication necessities of safety services overall. V2V solutions over VANET are currently the most studied systems, paying a special attention to safety applications. However, these systems often results in designs which treat problems locally. Security issues which require a fast treatment over a limited space can be successfully solved, but VANET technology is not suitable for services which require a medium or long transmission range and, obviously, for V2I designs. The work presented here offers a general communication platform which treats greater transmission ranges for V2V applications and considers V2I scenarios too.

In order to create a communication system with such a generic nature, it is necessary to consider suitable technologies. As the rest of the paper shows, the cellular networks have been elected, and peer to peer networks (P2P) are used to create a group-based communication paradigm over the CN basis. The P2P technology creates a virtual network over CN, which enables the transmission of information among vehicles and between vehicles and infrastructure, and bounds the propagation of messages. The vehicle edge includes a middleware, using a suitable software platform, which abstract the programmer of high level services of communication details. In order to test the system, a reference implementation has been developed, and a event notification application has been implemented to prove the usefulness of the platform and test the communication performance. In these tests a special attention is paid on latency times obtained from message transmissions, due to this measurement is a key issue in vehicular networks.

The rest of the paper is organised as follows. In Section II, the presented network infrastructure is placed into the current research literature regarding V2V and V2I communications. Section III includes a discussion about the usage of CN in vehicular communications. The network design is shown in Section IV. Section V gives a description of the developed prototype in terms of hardware and software. Section VI includes the performance results obtained from the system in the message propagation tests carried out over a real environment. Finally, Section VII concludes the work.

II. RELATED WORK

Technology issues of considering wireless networks in the vehicle domain are exposed in [1]. [2] includes an interesting study of common transmission methods used in VANET, and the delays observed in the message propagation. Both

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works are useful to contrast our solution, based on cellular networks, with the VANET ones.

Considering V2I patterns, in [3] a communication technique between the vehicle and the road side infrastructure based on the DSRC technology is given. The main drawback here is the cost of deployment at the road edge, which requires the installation of multiple DSRC devices, unlike our approach, based on cellular networks. In this line, [4] presents a handover system for wireless LAN networks over vehicles. Although the idea could be valid for urban or fixed railway zones, its high-scale application in the vehicular domain could be too expensive. A work which captures a P2P approach through JXTA to notify events to the road side is shown in [5]. 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 [6], where an advanced traffic monitoring system is shown. Our architecture, however, exploits the V2I capabilities propagating information over bounded traffic areas.

A study of the feasibility of a CN-based system and, overall, a P2P network for enabling vehicular communications can be found in [7]. Initial ideas proposed in this work agree with our conception of improving the network capacities given by VANET systems in non-local applications. Our work already includes an architecture design, hardware prototypes, a reference implementation, and performance results which proves all these ideas.

III. CELLULAR NETWORKS: A SUITED TECHNOLOGY FOR VEHICULAR COMMUNICATIONS

As it has been stated previously, researching lines in vehicular communications are especially focused on the usage of ad-hoc networks in the VANET field. This work, however, proves how cellular networks can be suitable for both V2V and V2I communications. In [8], a survey of vehicular communications and their applications is given. Here it is stated the technology which deals with more communication requirements of telematic services inside intelligent transportation systems (ITS) are CN, defending our idea of using cellular networks in a general telematic framework.

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 technologies 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 the 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 CN in 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 [9][10]. However, the values usually obtained 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 [11]. The High Speed Packet Access (HSPA) is being 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 [12], 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 fast propagation requirements of some critical applications.

A V2V vehicular network based on CN must deal with the message propagation method used. As it is noticeable in the next section, our proposal encloses 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. As a result, complex routing protocols (as the VANET ones) and penetration rate restrictions are avoided.

Regarding the cost of a CN-based system, and comparing it with the hardware used in the VANET ones [13], two issues must be taken into account: the hardware platform cost and the cellular network usage cost. 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 current work. However, according to the market state, products of both types can be obtained by similar prices. Regarding the extra cost implies the usage of the operator's infrastructure, the payment method is not completely established, but current trend these days is paying a fixed quote per month, with an extra cost if the transmission rates fall out of the contract. The CN bill is, however, gradually decreasing, thanks to the adoption of this kind of Internet connections among the population, the massive use of CN for commercial ITS solutions, and special agreements with operators [11].

IV. NETWORK DESIGN

The network infrastructure uses a P2P approach over the cellular network basis to enable vehicles to 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 organised in coverage areas, each one using a different P2P communication group. These zones are logical areas which do not have to fit in

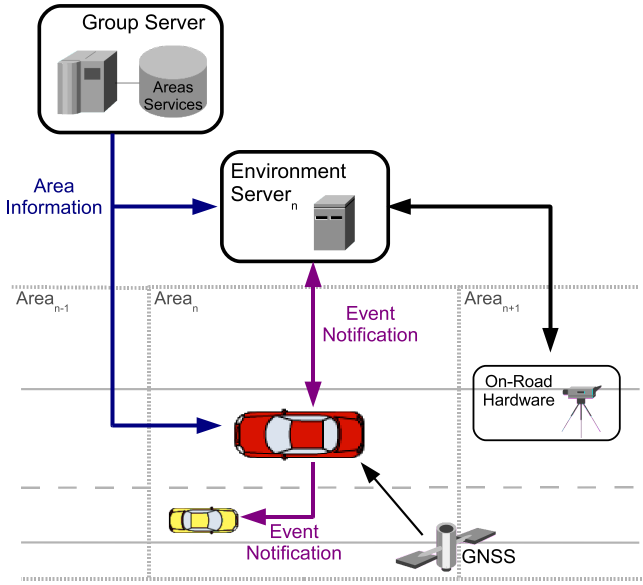

Fig. 1. Main elements and interactions of the CN-based network design

the cellular network cells. Information about the geometry of each area is maintained in the Group Server (GS) 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 vehicle location, 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 (ES) manages special messages 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.

In order to divide the messages transmitted in the network according with its content, every coverage area can include several transmission services. Every transmission service has its own P2P group to share messages, and this group may change between coverage areas, in order to bound the message propagation over the zone of interest. For this reason, the vehicle edge has to communicate with GS in order to maintain the communication for a transmission service along the coverage zones.

The main processes carried out in the operation of the network architecture can be summarised in four scenarios: subscription to services, roaming between service areas, message transmission, and message forwarding. Details about the protocols involved in the system can be found in [14]. Initially, users have to subscribe to transmission services to send or receive information. The logical communication channel must be maintained when the vehicle changes between coverage areas, using a roaming technique. GS provides the P2P parameters to maintain the communication in all the active transmission services over the new area. Because of GS sends the area geometry to the vehicle, the latter communicates with GS only when it detects itself out of the service area. This technique saves communication resources. When a vehicle sends a message, all the vehicles joined to the transmission service and the correspondant ES receive it. Messages which require a special attention are processed by the infrastructure through ES. This way, messages from critical transmission services (repair, collision…) are forwarded by ES to the adjacent areas, in order to improve the propagation mechanism. As Fig. 1 shows, Environment Servers can be connected to the rest of the road side infrastructure, which may be composed of speed radars, identification sensors, video cameras, etc. Therefore some events detected by the road side hardware can be notified to vehicles, and useful reports can be sent to a third party entity.

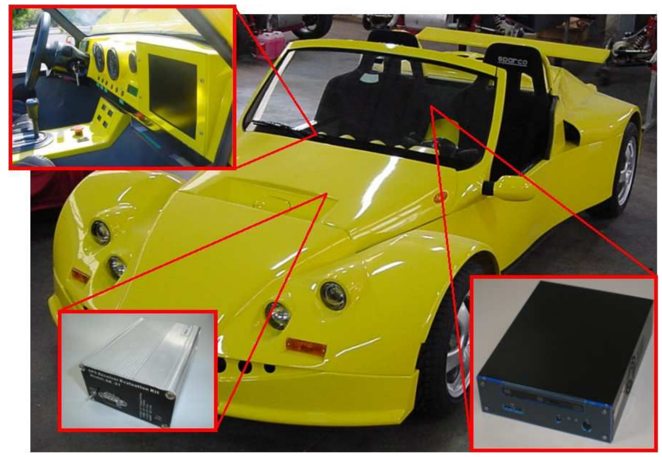

Fig. 2. Prototype vehicle and key components

V. PROTOTYPE

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 [15]. Fig. 2 shows this car and the main components for the network architecture. The vehicle, through an agreement with the manufacturer, has been prepared to be enhanced with several sensors, such as odometry, a gyroscope, an accelerometer or a GPS sensor. A San Jose Navigation FV-21 GPS receiver has been installed in the car. Knowing the vehicle position, the roaming process can be performed, and the car can include its position in the emitted messages. 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 behind the passenger seat. As can be seen, the dashboard has also been modified to install a LCD monitor. Regarding the vehicle communications, a cellular network PCMCIA transceiver has been used. The model is a Huawei E612, which allows GPRS and UMTS data connections.

Due to only one prototype vehicle has been developed, a Windows-based laptop has been mounted in another vehicle for the V2V tests. A Novatel Wireless Merlin U530 modem

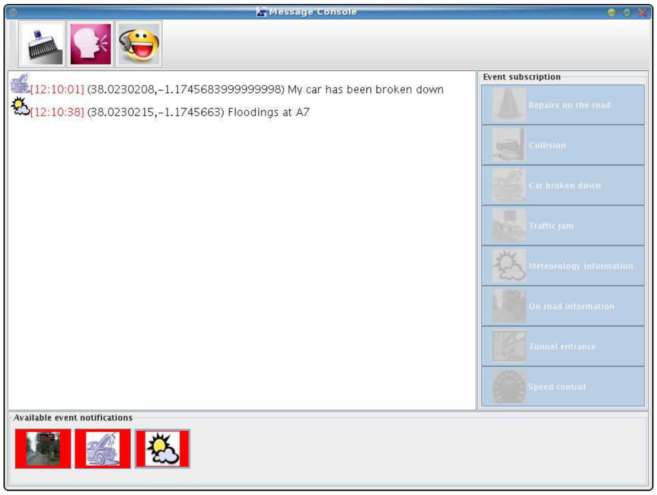

Fig. 3. On-board application which uses the communication system

has been used for UMTS connectivity, and a Novatel OEM3 GPS receiver provides positioning information. The GPS receivers used in both the prototype vehicle and the common one also offer time synchronisation to the computers, in order to obtain meaningful latency results.

An OSGi-based service platform designed for vehicular purposes [16] has been included in the on-board computer and the laptop. By means of this platform, the middleware which allows the usage of the network infrastructure has been implemented as a software module. The P2P technology used in the implementation has been JXTA (JuXTApose) [17]. Through JXTA, the car connects to the P2P network created by vehicles and road side entities using a group-based communication paradigm.

At the road side, the Environment Server has been implemented with another JXTA client and its instances run 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.

Using the described software platform, a message-oriented 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. The communication channels available through the transmission services are exploited here, and the user can subscribe to any of the eight channels 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 image, 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 from a break down service, and another from a meteorology information service.

VI. TEST RESULTS

The system has been tested over an enclosed zone. Several coverage areas have been defined around the University of Murcia, and over a near motorway. In order to measure the

Fig. 4. Test area

performance of the message propagation, a wide range of tests have been carried out over one these areas, belonging to the Campus of Espinardo. Fig. 4 shows the path of six kilometres followed in all the tests. 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 at the sender edge, which generates periodical messages. The source terminal 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. During the tests, the information field is filled with the emission time, in order to compute the propagation delay at the receiver. A total amount of 48 bytes is transferred 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 the two vehicles over a real mobility scenario. The tests were carried out with both vehicles driving close. 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 three seconds belong to low UMTS coverage zones. On the other hand, Fig. 6 plots the latency in a V2I transmission model, where the same circuit was considered and the equipment aboard the common vehicle was connected to the wired network and 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. Due to only the uplink channel of UMTS is used in the transmission

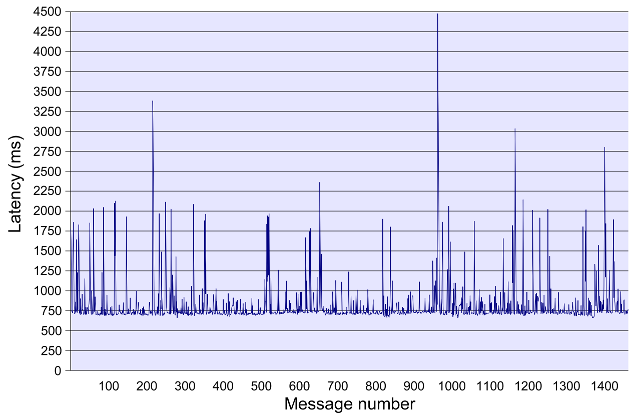

Fig. 5. V2V results

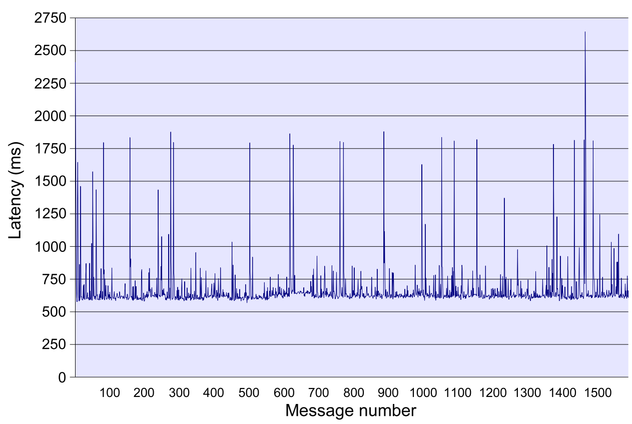

Fig. 6. V2I results (uplink channel)

of the messages, the latency results are better. The final part of the graph exposes again a coverage problem in this stretch 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 wired node). 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 between messages 1180 and 1280, where a latency value 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 the first case the mobility effects are evident in both the downlink and uplink channels.

Table I summarises the total amount of messages 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 noticeable how the sum of the two V2I latency values results practically in the latency mean obtained in the V2V case. The total amount of dropped message

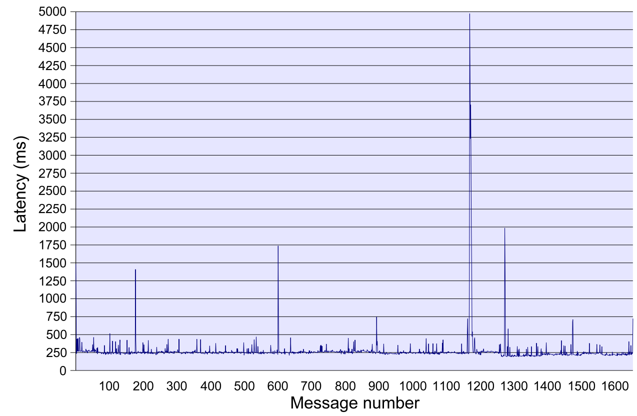

Fig. 7. V2I results (downlink channel)

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 some packets can lost. In any case, considering this issue only appears when the communication starts, as the total amount of messages transmitted in a P2P group is greater, the dropping rate will be almost insignificant.

TABLE I
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 %

The results show latency times which enable the development of a great variety of vehicle services. 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 has a real advantage over VANET approaches. The latency does not increase when the distance from the problem grows. According to the study presented in [18], 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 this 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 and the roaming time, which could be a problem if the coverage areas are too small.

VII. CONCLUSIONS AND FUTURE WORK

The paper proposes a network design which covers both V2V and V2I communication paradigms, and takes into account the requirements of most of vehicular services. Cellular networks have been used in the platform emphasising its utility in the vehicular field, and P2P networks have been considered jointly with CN to create a group-based message propagation design. 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 and run over servers located in our laboratories. The tests carried out over real environments demonstrate the feasibility of the proposed solution. A message propagation analysis 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 in a few months, when the complete HSPA technology is deployed over the European UMTS network. These results show that a vehicular network design based on cellular networks is feasible and its application for services usually implemented using VANET approaches will gradually become a reality.

Current works are being carried out over the proposed communication infrastructure, in the line of providing the driver with context-aware information and safety notifications. A complete information system is being developed at the road edge to reach these aims. Several improvements are being considered as well for the messages emitted by vehicles and infrastructure, optimising the necessary data to be included in packets. New tests are planned with these modifications, using moreover the HSPA technology and considering problematic scenarios.

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