POTENTIAL OF CELLULAR NETWORKS IN VEHICULAR COMMUNICATIONS

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ABSTRACT

Wireless communications are extending into the vehicle domain offering value-added services to drivers and passengers. Up to now, cellular networks (CN) have been generally considered in such environment for monitoring solutions, following a vehicle to infrastructure (V2I) data flow. Inter-vehicle communications are, nevertheless, achieved using 802.11 technologies, through vehicular ad-hoc networks (VANETs), which have been applied in safety solutions over all. The current work, however, tries to make the reader aware of the potential of cellular networks not only in V2I, but also for infrastructure to vehicle (I2V) and vehicle to vehicle (V2V) communications. General questions about a CN-based vehicular network are reviewed, paying a special attention to performance issues, and considering VANET technology as a reference. Our results over a real prototype prove the feasibility of CN for lots of vehicular services, dealing with the latency obtained from V2I, I2V and V2V data transmissions.

Key words: Vehicular communications; V2V; V2I; I2V; cellular networks; ITS.

INTRODUCTION

The usefulness of wireless data communications in the vehicle field is noticeable in current monitoring solutions which help companies to manage their transport fleets. These systems are mainly based on a positioning system and a communication channel which is usually developed through the cellular network (CN). These first systems have been, however, the starting point of vehicular communications. New generation services conceived for future cars need a communication system in order to connect the vehicle with the environment (1). Researches of all around the world are currently working on such vehicular networks which, in most of the cases, are too particular solutions.

According to current state of vehicular networks, connectivity requirements can be divided into vehicle to vehicle communications (V2V), which are the most popular architectures in the research world, and communications with the infrastructure, which are currently receiving a great attention. Attending to the data flow direction, the connection in this last case can be established following a vehicle to infrastructure (V2I) or infrastructure to vehicle (I2V) pattern. Examples of V2I and I2V technologies can be found in monitoring systems (V2I); traffic information systems such as RDS or TMC (I2V); or electronic fee collection systems, which use eventual connectivity points in both directions. The most extended technologies in commercial products which follow these communication patterns are CN, FM radio and Dedicated Short Range Communications (DSRC). The research community is not as focused in communications with the infrastructure as in the V2V case. However, providing Internet connectivity to vehicles using road side hardware is however a hot issue (2) (3).

Regarding V2V solutions, vehicular ad-hoc networks (VANETs) using wireless LAN and DSRC are the most considered technologies, and they are mainly used in safety applications. This way, collision avoidance systems (5), and safety applications in general, use V2V communications to propagate messages over the network created by vehicles. VANET solutions fit very well in services which require a fast transmission to surrounding vehicles, but they suffer from routing problems in long transmission ranges where multi-hop techniques must be used (6). In such situations an infrastructure access could improve the performance.

The previous description shows the current state of vehicular communications, where it is appreciable a clear dependence between the deployed service and the network technology. Ideally, a network would be used to connect vehicles among them and with the infrastructure, and it would cover all communication necessities of all possible services located at the vehicle or the road side (7). The current paper makes an initial effort in such way, suggesting the reader to come back to the starting point of this explanation: the cellular networks. The CN have been suffering continuous improvements from initial analog deployments and, according to our point of view, it is a good moment to broadly consider CN not only in V2I solutions, but also in I2V and even in V2V applications. In this line, a discussion about the feasibility of a CN-based vehicular network is carried out through the paper. Our previous work (8) proves the feasibility of such idea, but current work analyzes main performance parameters to be considered, taking into account the VANET technology as a reference point. Recent enhancements have improved data communications in European CN, so a set of new trials have been carried out over real scenarios to test our network architecture.

CELLULAR NETWORKS IN THE VEHICLE DOMAIN

Previous ideas explain that current research lines in vehicular communications are especially focused on the usage of ad-hoc networks, inside the VANET field. The interest of this work, however, lies on proving how cellular networks are also feasible for V2V and V2I communications. In (7), a survey of vehicular communications and its applications is given. Here it is stated the lack of a general network platform for developing telematic services in the vehicle domain. Authors say 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 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 is wireless LAN, using 802.11a/b/g technologies and the new 802.11p one. 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.

One problem which has to be solved in a CN-based network design for V2V purposes is the message propagation and routing. Our proposal deals with this problem bounding the message propagation into an area of interest, as it is further explained. A group-based P2P technology has been used to route messages 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 (9), 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 this 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 extra money which has to be paid for the usage of the operator's infrastructure. In the VANET case the communication cost is obviously null, but UMTS data transfers are usually charged per byte transferred. Current trend is paying a fixed quote per month, with an extra cost if the transmission rates fall out of the contract. Nowadays this drawback is gradually being solved. 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 by means of special agreements with operators (10).

PERFORMANCE ISSUES

Regardless of the communication technology used, there are a set of quality parameters which must be taken into account in vehicular network architectures. The network throughput and, overall, the availability and the edge to edge latency must be seriously attended in safety applications. This section covers main performance issues which should to be taken into account in the development of a CN-based vehicular network. For each one, VANET is also analyzed in parallel because it is considered as a reference, attending the vast number of publications considering this technology in V2V solutions. VANET operation is mainly limited to V2V patterns, so the considered performance issues cover only such field. For the CN case, performance questions regard to V2I and I2V as well.

Communication technology

There are many communication technologies which have been considered in the vehicle domain (11), however, in the field of V2V communications, the most extended technology is 802.11 through VANET solutions, as it has been stated. In collision avoidance applications, where it is necessary to receive a continuous information flow from close vehicles, the latency every message imposes to reach the surrounding vehicles is a key issue (12). Nevertheless, a low delay in near vehicle to vehicle patterns does not imply a good performance in services where messages are sent over the network to notify unsafe situations (a car crash, icy surface, etc.), for example. This way, not only one-hop traffic, but also multi-hop patterns must be considered in the performance of VANET approaches (13).

Regarding to CN, recent improvements in operator infrastructures (10) reveal that considering CN not only in V2I, but also in I2V and V2V communications is possible nowadays. New UMTS networks offer new capabilities which clearly distinguish current CN systems from classical GSM networks. Recent studies give latencies of some hundreds of milliseconds in

CN tests (14), which are still too high to send a critical notification to an adjacent vehicle. However, if we consider distances from 100 or 200 meters, current UMTS technology is able to give propagation times even better than multi-hop-based VANET approaches, according to our tests.

Network availability

Network availability is one of the main drawbacks of CN. In VANET designs, a physical infrastructure is not necessary, due to the inherent decentralized design. Regarding CN, operators do not offer the same service over the entire terrestrial surface. Over urban environments, the CN coverage is excellent, and the amount of base stations where the mobile terminal could be connected is really high. In rural locations, however, the CN deployment is poor or even null in some places. This way, a vehicle equipped with a VANET system always is able to emit messages because the vehicle itself is part of the ``infrastructure'', but in CN approaches, the availability limit the operation.

In CN connections, it is also important to differentiate between two important concepts regarding the access to the network: the coverage and the capacity. The coverage can be understood as the possibility of the mobile terminal to use the network, because in this exact location operators have deployed the necessary infrastructure. However the user can be rejected to establish a call or a data connection, even in good coverage circumstances, if the capacity of the network has been exceeded. Depending on several technological issues, such as modulation, frequency allocation, time slot scheduling, etc., this effect has a different impact. This way, the number of users who are concurrently using the network restricts the CN availability as well.

Mobility effects

Apart from the potential access to the network, some problems arise in both VANET and CN technologies due to mobility effects. In (14) experimental evaluations give real results of these effects. In 802.11 transmissions the distance between the sender and receiver is an important factor; the more the distance is, the smaller is the probability of reception of packets, as also show (12) and Ueki2005 (15). In CN, handoffs between base stations are also important, due to the potential decrease of performance in the process. Poor latency and throughput results are obtained if the mobile terminal is moving at locations far away from the UMTS Node B without performing a handoff (16).

Nevertheless, the distance between two physical edges in the communication is not the only noticeable effect. Interference with other radio equipments in the case of VANET should also be taken into account due to the wide usage of the 802.11 frequency spectrum (14). The presence of the equipment at locations of bad orography could also cause communication problems in both VANET and CN systems. Other external factors, like the existence of another vehicles or buildings are considered in realistic mobility patterns for VANET solutions (17).

Routing protocols

Routing protocols used over the physical communication layer obviously have influence on performance. In VANET solutions, there are many protocols available in the literature. The most usually considered strategy in applications which propagate information to surrounding vehicles is the broadcast mechanism (12). However, when multi-hop transmissions are considered, the complexity of routing protocols grows. This way, network links between vehicles have to be proactively maintained or reactively discovered. In (6) an interesting study about the effect of propagation of safety messages through traffic using a multi-hop VANET is considered. As this work shows, some collisions could arise at vehicles located 200 m behind the transmission source and further on, due to transmission delays. Our CN-based system can solve these problems, as it is shown in the tests.

In the CN case, on the other hand, communication protocols are much more established. There are a set of low level routing protocols used at physical and MAC layers between the different elements of the network deployment. Although research in CN is also active, the availability of a real infrastructure is a point in its favour. The usage of CN for an Internet access is an important topic. Several works study the impact of TCP/IP protocols over CN (16), and demonstrate the drawback of using the TCP protocol over a non-wired transport channel in situations where the coverage is not good. To the best of our knowledge, however, there is no any recent work which treats the problem of V2V communications through CN. An I2V and a V2I communication system can be deployed using the inherent Internet access but, as it has been previously said, an overlay network is useful to allow V2V transmissions too. In this work, our approach is based on peer to peer (P2P) networks to create a virtual layer over the CN basis and, furthermore, allow V2V data traffic.

Penetration rate

The problem of penetration rate is well-known in the VANET field. These protocols require the presence of enough equipped vehicles to route messages across the network (18). Although a low penetration rate is obviously a problem in safety of life applications, such as collision avoidance, an excess of equipped vehicles also arises transmission implications. The wireless network has a maximum theoretical capacity (19), and the appearance of packet collisions degrades the communication performance (17). In CN, situations of dense traffic present also a problem. The system performance is not affected when the number of equipped vehicles is low, but in high load circumstances, CN start to give a poor performance when the time slot scheduler need to serve so much users (20).

Vehicle speed

The vehicle speed has a direct effect in the break of links among vehicles when multi-hop VANET designs are considered (18). In the CN case, the speed of mobile terminals is also a noticeable issue (21). At the physical level, effects such as Doppler shift, Rayleigh fading and multipath propagation limit the maximum bit rate allowable in CN at high speed. At link level, handoff issues must be considered. When a mobile terminal passes from one coverage cell to another, a handoff process is carried out. This process is usually performed through measuring the quality of the channel, attending to the signal level from the base station. Different kinds of handoff exist, although they can be summarized in soft and hard handoffs. Soft handoffs do not mean any significant quality of service variance, but in hard handoffs a loss of data packets can even appear. Because the handoff process takes time (dependent of the type), vehicles at high speed could have problems in places where the base station density is too high. And this is the reason why increasing the operation range of base stations at highways is favourable, for example; apart from the obvious reduction in deployment costs.

EMPIRICAL EVALUATION

The previous analysis gives several performance issues which must be taken into account in the design of a CN-based vehicular network. As it has been explained, using CN it is possible to create a vehicular network which deals with V2V, V2I and I2V communications, extending the range of solutions covered by VANETs. This section describes a real design which exemplifies such idea, giving also a real prototype and showing some of our field trials.

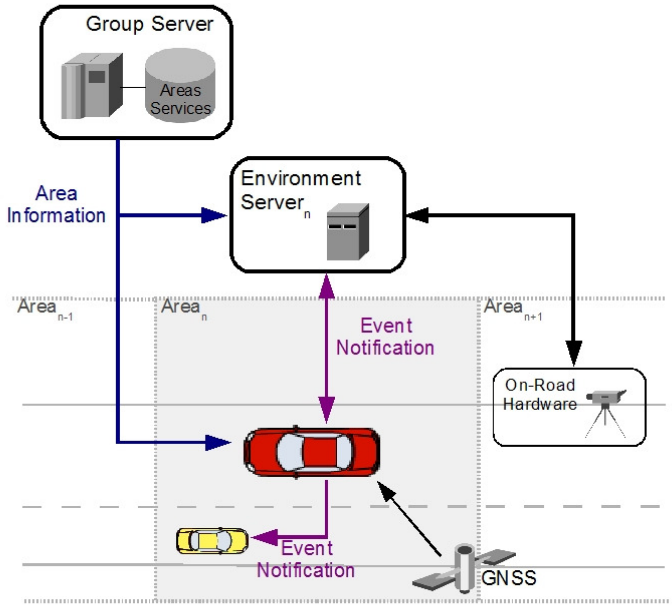

Fig. 1. CN-based vehicular network architecture

Network design

The network architecture uses a P2P approach over the cellular network basis to enable vehicles to receive and send data packets. Fig. 1 shows a general diagram of the proposed communication architecture. Traffic zones are organized in coverage areas, each one using different P2P communication groups. These zones are logical areas which do not have to fit in 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. These data packets 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 which are finally sent as UDP packets. Two different techniques of emission have been developed; consequently, P2P messages can be broadcasted in the area or sent to a specific vehicle. Further details about the network architecture can be found in (8).

Prototype vehicle and on-board unit

A real prototype of the on-board unit has been created and tested. The vehicle used for the system deployment is a car widely sensorized at the University of Murcia (22). Fig. 2 shows this car and the main components of the on-board unit. 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. Serial buses communicate the sensors with the PC via RS-232 and the Controller Area Network (CAN) bus. A San Jose Navigation FV-21 receiver has been installed in the car. The on-board computer is a SBC (Single Board Computer) of VIA, with a Linux Fedora Core 5 operating system, and a Java Virtual Machine 1.5. This computer 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 vehicle communications, a cellular network PCMCIA transceiver has been used. The model is a Huawei E220, which allows UMTS data connections.

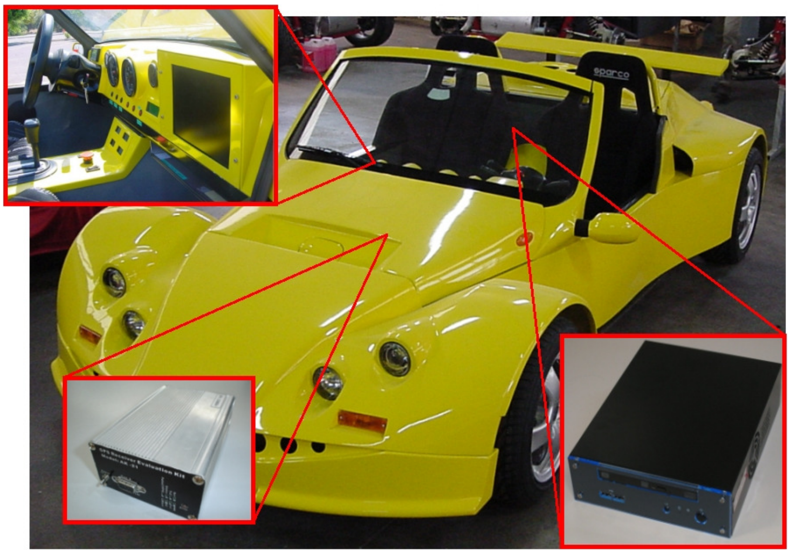

Fig. 2. Prototype vehicle set-up for the tests

The network architecture has been developed for both vehicle and road side edges, using the JXTA technology as a P2P overlay network. This way, both vehicle and infrastructure entities (Environment Servers) contain a JXTA middleware to implement the vehicular network designed. All software developed for the road side elements depicted in the architecture described above executes over a Linux-based system with an AMD Opteron multiprocessor architecture, and the described on-board unit contains the vehicle implementation. For the message propagation tests further explained in the next subsections, apart from the described car, an extra laptop was used inside a second vehicle in order to perform V2V trials. This computer uses a Windows XP operating system with Java 1.5. A Novatel OEM3 receiver and the FV-21 one have been used in both vehicles to synchronize the time. A software which uses this network platform has been installed in both computers to send messages at a fixed rate of one per second; one of these receives these messages and saves a log. The length of the data packets sent through the P2P network is 38 bytes, but JXTA adds an extra overload, hence final UDP packets of 1498 bytes are sent. Both vehicles have been closely driven through the test circuits. A ZTE MF620 transceiver and the Huawei E220 one have been used to connect the on-board computers to the cellular network. Both devices support HSDPA (High Speed Downlink Packet Access), which improves the UMTS performance in terms of throughput and delay, as can be noted if the results obtained are compared with the ones shown in (8). For the V2I and I2V trials, the hardware considered at the common vehicle is installed in one of our laboratories, and the computer is connected to the wired network.

<u>Field trials</u>

Many tests have been carried out at the surroundings of the University of Murcia. Table. 1 includes information about several tests which start at the same point (Computer Science Faculty), and at a speed in the range of 20-25 Km/h. As can be seen, three types of tests have been made, considering I2V, V2I and V2V communication patterns. The time the trials were made is also important, because the amount of users connected to the CN varies along the day. Some patterns have been found in all the tests carried out. As it is noticeable in the results, tests carried out near 13:00 give the worse results. This belongs to the lunch time at the university. 11:00 is a time which also causes performance problems, due to students and academic staffs that start later their working day coincide with people who have finished their classes in degrees with soft theoretical load.

Test	Type	Time	Delay mean (ms)	STD
T1	I2V	13:11-13:30	227.62	566.78
T2	I2V	12:43:13:07	295.86	1242.86
T3	I2V	11:14-11:39	244.98	561.63
T4	I2V	11:51-12:14	247.72	558.16
T5	V2I	10:23-10:44	248.06	129.96
T6	V2I	10:53-11:16	266.28	231.71
T7	V2I	11:37-11:58	242.91	239.07
T9	V2I	12:04-12:26	236.96	147.46
T9	V2V	11:22-11:43	464.33	903.09
T10	V2V	11:48-12:09	489.62	814.31
T11	V2V	15:43-16:04	378.93	475.92

Table. 1. Tests carried out using the CN-based network

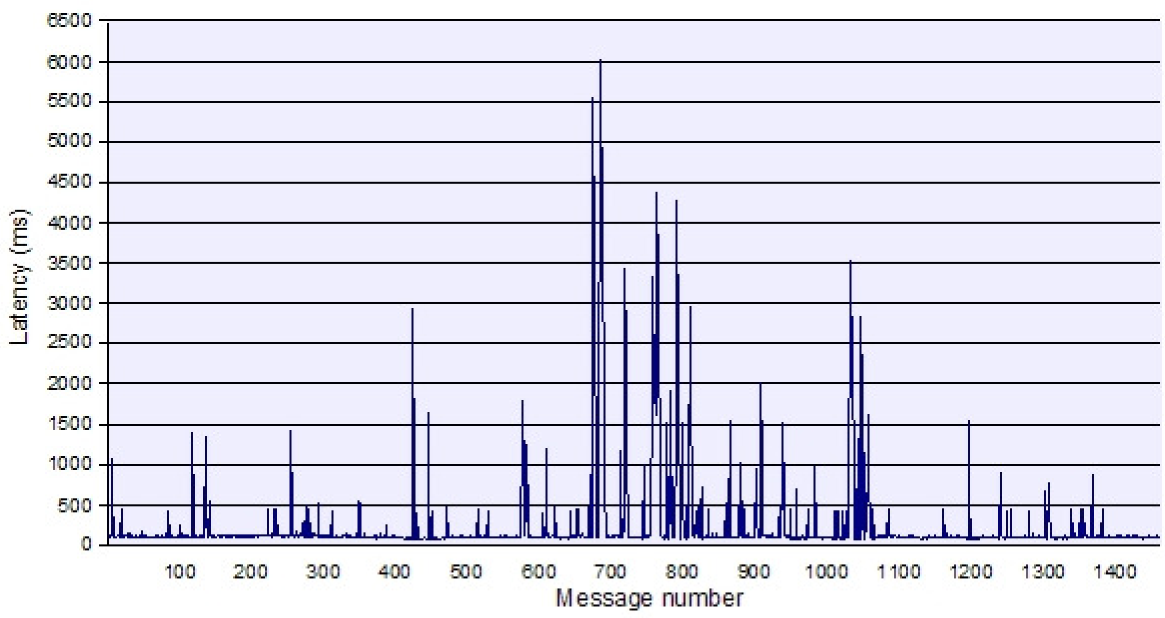

Fig. 3. I2V communication test

Fig. 3 shows the results obtained in test T3, measuring the data traffic in an I2V trial. Latency values are not constant, due to mobility effects and small variations the CN imply in data transmissions. A great zone of transmission problems has been found from message 680 to 820. Here the vehicle is driving out of the campus, crossing an urbanization located at the south of the university. At this zone the vehicle and the CN base station are a long way apart from each other, and the final coverage obtained between houses is low. From message 1030 to 1080 some problems can be seen as well. Here, the bad orography is the main reason of the performance degradation. The vehicle is located at the north-east edge of the campus, and a small hill between the vehicle and the base station decreases the channel quality.

Results obtained in a V2I case are given in Fig. 4. As it is noticeable, the main problematic zone is also appreciable here between messages 540 and 720. The second small hidden zone is less appreciable. Comparing results given here with the I2V case, two relevant comments arise. First of all, in the I2V case there is a greater noise in the results. There are more peaks along the path. Second, a better performance results could be expected from the I2V tests, because the downlink channel of UMTS is used. However, as can be seen in Table. 1, similar latency values are obtained in both I2V and V2I trials. This is due to the low level protocols used. According to our traces, collected by a network analyzer, all JXTA messages sent by the source of messages travel to the destination one through a JXTA entity called *Rendezvous Point*. Although the UDP protocol had been activated to carry JXTA messages, to prevent retransmissions, this is only taken into account from the source to the rendezvous. The rendezvous point forwards the messages to the receiver by means of TCP. This technique causes the TCP to be used in the I2V case over the UMTS network, what degrades the performance, as it was mentioned in previous sections.

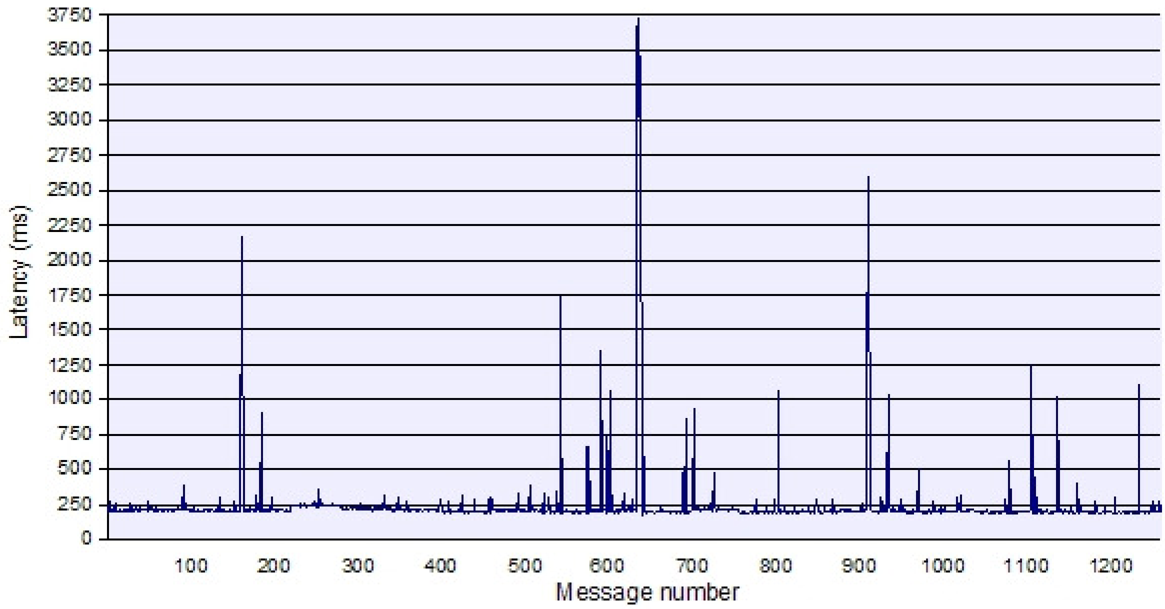

Fig. 4. V2I communication test

Finally, a test which covers a V2V transmission is depicted in Fig. 5. This is the test T11. As can be seen, the two zones where the CN performance degrades are more appreciable. This is due to both the uplink and downlink channels are used. An initial noise is also noticeable at the beginning of the test, because the normalization of the network behaviour took some time. The HSDPA technology uses a feedback mechanism where mobile terminals report the signal quality to the base station, in order to modify the scheduling method used. Because the vehicles started the circuit at a low/medium coverage zone, some time is necessary to stabilize the network operation; the time the vehicles spent in approaching to the base station.

Previous results give relevant improvements with regard to the latency values obtained in (8). The HSDPA technology has been encountered to enhance our CN-based vehicular network, so better results are even expected when the HPUPA is also available. In any case, current results about 250 ms of latency for V2I and I2V transmissions, and 450 ms for V2V communications, enable the implementation of a wide variety of services for both the vehicle and the road side edges. General information services following the line given in (23) have a direct application, but even safety services which do not require propagation times in the order of tens of milliseconds could be deployed using such network infrastructure.

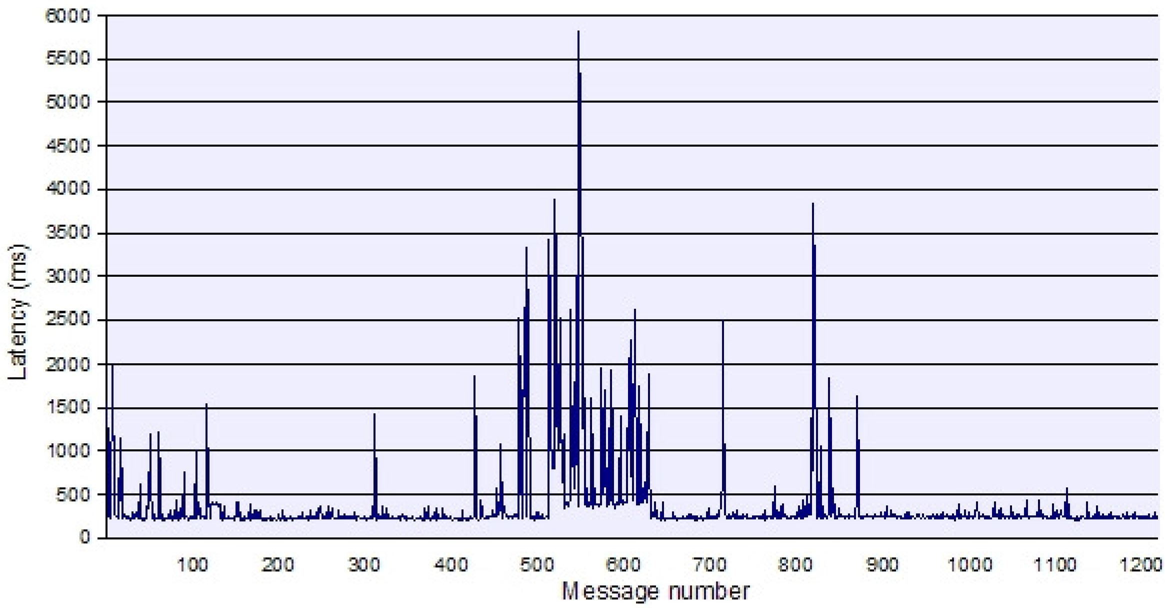

Fig. 5. V2V communication test

CONCLUSIONS

The paper has been focused on proving the feasibility of cellular networks in vehicular communications. Apart from the common usage of such networks in V2I solutions, our work defends the applicability of CN in I2V and V2V communication patterns too. This has been made dealing with general considerations of deployment, but paying a special attention to performance issues. In this analysis VANET technology has been used as a reference point, and a wide study in the literature supports our explanation.

Our proposal of a CN-based vehicular network has been also shown. This system uses a P2P overlay network to group messages emitted by vehicles inside an influence zone. This architecture allows V2I, I2V and V2V communications, and its feasibility and performance have been analysed with a real prototype. The most important tests carried out over a real environment have been showed. According to the results, the CN-based network has been found as suitable for implementing a great amount of vehicular services, such as road information provision, location-based POI notifications or warning systems.

Current lines include the research on a core system at the infrastructure side which uses the vehicular network and provides infrastructure based services. We are also performing more tests with the system prototype, in order to cover a more significant amount of environments. It is expected, nevertheless, evolutions in CN improve the performance of the system and extend the amount of services feasible to implement with such technology.

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