Sharing Context-Aware Information in Vehicular Environments

3^{nd} version

José Santa and Antonio F. Gómez-Skarmeta
Department of Information and Communications Engineering
Computer Science Faculty
University of Murcia, Spain

Submitted on 16 June 2008

Abstract— **Integration of telematics and vehicular communications in next-generation cars will turn the provision of contextual information into the cornerstone of vehicular services. In the world of intelligent transportation systems (ITS) such capability has a key role in the transmission of traffic incidences. Although there are multitude of solutions for the problem of sharing information between vehicles and between the vehicle and the infrastructure, none presents a valid general communication architecture for the notification, storage, management and provision of context-aware information on traffic and current location. Our proposal offers a solution using an integrated vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication paradigm enriched with an information management system. The infrastructure manages all the collected safety hazards heard from vehicles and the interesting information to be provided to the user, and adapts these to the car's context and driver's preferences.**

Index Terms— **Vehicular Communications, Traffic Information Systems, Context-awareness, Ubiquitous Computing, Intelligent Transportation Systems**

CONTEXT

The provision of traffic information has been one of the main challenges in roads all around the world. In Europe and South America, the Radio Data System (RDS) and, the less known, Radio Broadcast Data System (RBDS) in North America, have been initial approximations to the idea of providing context aware information to drivers. The Traffic Message Channel (TMC) uses RDS to deliver travel information to end users. Nowadays, both the research community and public administrations are interested in understanding the impact of an on-board information system on user safety.

The communication channel and the information source are both important issues in such information provision systems. However, quite apart from the over-studied centralised systems, where notifications about traffic are simply collected at a central station, the research community focuses these days on mechanisms for propagating local events to sourrounding vehicles. Here is where the term Vehicular Ad-hoc Networks (VANETs) comes into play. With VANETs it is possible to take advantage of a decentralised and spontaneous network to route messages among vehicles.

Moreover, although the provision of information to the driver and the usage of a suitable communication channel are necessary, a third element should be taken into account in the design of a complete vehicular information system: the infrastructure edge. An effective human or automatic monitoring strategy must be used to assure a correct road network operation. A centralised system is also necessary in applications where critical events must be processed to obtain global knowledge about the road network state and so improve safety and the driving task in general.

The provision of contextual information, the research into a novel vehicular communication paradigm, and the design of a suitable core infrastructure system have been our main goals to help reach a vehicular integrated system which is close to the concept of *smart road* [1].

TOWARDS A UNIFIED V2V AND V2I COMMUNICATION PARADIGM

The necessity of a communication channel to integrate the vehicle in the traffic environment has led intelligent transportation systems (ITS) researchers to investigate vehicular networks. Initial approximations to this problem have been monitoring systems for company fleets, where research is nowadays very specialised [2]. Cellular networks (CN) are usually considered as a vehicle to infrastructure (V2I) communication channel where a centralised system is in charge of tracking vehicles. Researchers soon realised the importance of autonomous cooperation among vehicles. Using a vehicle to vehicle (V2V) communication pattern, a car could notify events to surrounding vehicles [3]. For several years, this has been the main research line in vehicular communications, principally through VANET solutions [4].

Nowadays new interests are arising in the V2I communication field[1], but they are now centered on vehicle integration with the roadside equipment [1]. The deployment of Radio Frequency Identification (RFID) technologies, for example, is being considered for goods tracking or traffic sign recognition. Dedicated Short Range Communications (DSRC) are used in electronic fee collection systems and solutions which provide Internet connectivity to vehicles [5]. Cellular networks have

[1]The V2I term usually refers to a communication link between vehicle and infrastructure, covering both data flow directions, vehicle to infrastructure and infrastructure to vehicle

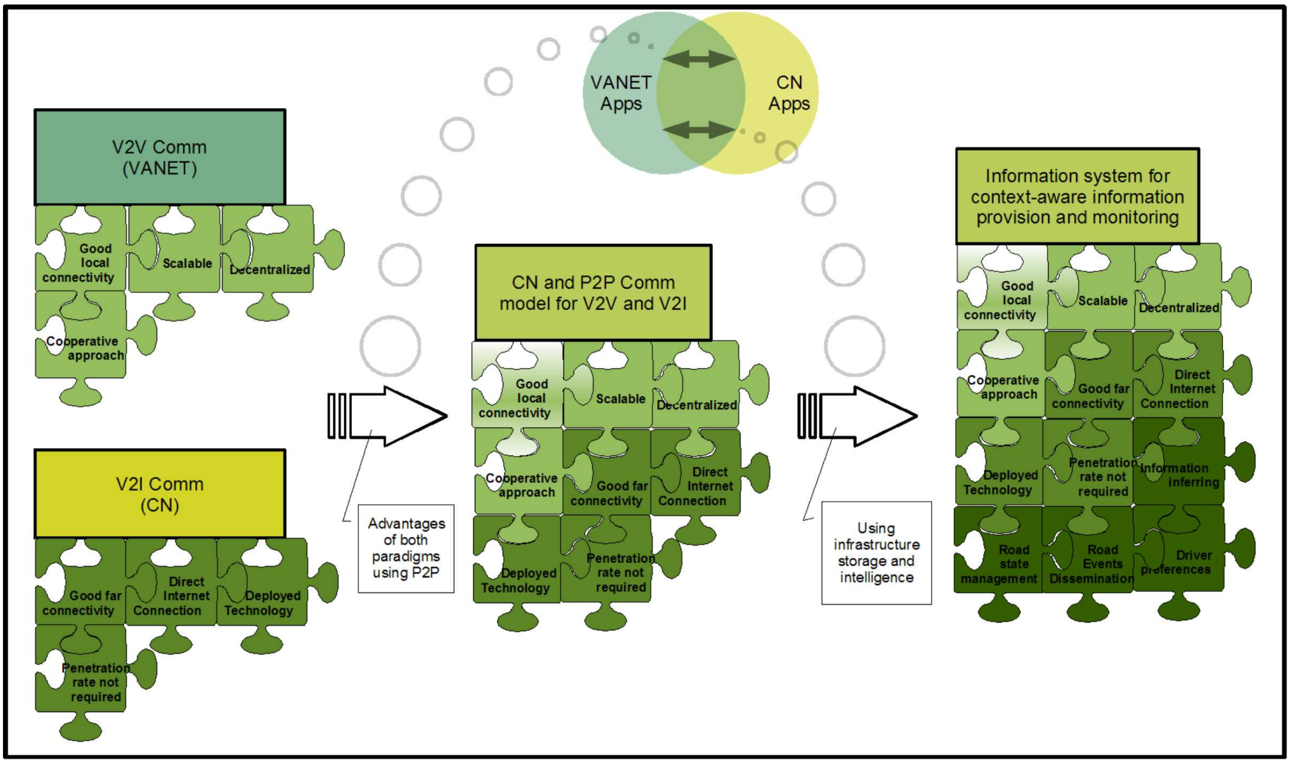


Fig. 1. The advantages of a CN and P2P-based communication system with infrastructure capabilities

also undergone relevant improvements, offering good Internet connectivity in mobile environments, but also supporting common monitoring solutions. CN are now a mature technology suitable for vehicular communications, and in some aspects they offer better performance than VANET solutions [6].

Both VANET and CN have good features for vehicular communications. VANET solutions offer good connectivity among close vehicles, because the decentralised architecture uses cars to create a scalable and cooperative mesh where every vehicle acts as a router. CN, on the other hand, offer long range communications thanks to a direct connectivity to Internet through the operator's network. This communication paradigm has two extra advantages: a high ratio of equipped vehicles is not necessary to assure connectivity, and the use of a proven deployed technology.

Our approach combines the advantages of both VANET and CN and mixes them to establish a starting point from which to embrace all the services they offer individually. Figure 1 illustrates our idea of merging the main advantages of a decentralised solution with the CN technology. Using a peer to peer (P2P) paradigm over the cellular network, we obtain an architecture which takes advantage of the benefits we have in both approaches. P2P networks create a virtual decentralised architecture where individual nodes can communicate without knowing physical details about the underlying network. Latency limitations for close V2V communications are initially inherited from CN. Nowadays, a CN connection cannot match the latency times of VANET systems between nearby cars. However, new improvements point to CN technology as a valid carrier of vehicular transmissions for more and more services, and it can now be considered as a suitable complement to VANET approaches [7]. The cost of the communication channel is also an important issue in CN. Thanks to special agreements between operators and service providers, the cost of CN data connections is gradually decreasing.

The proposal in [8] includes our first steps in the design of such a communication architecture and our initial performance evaluations. This system has been further extended with functional capabilities at the edge of the vehicle, and enriched with its integration in a whole vehicular information system.

THE IMPORTANCE OF "THE INFRASTRUCTURE SIDE" IN CONTEXT-AWARE INFORMATION MANAGEMENT

A V2V network allows vehicles to communicate and propagate information over a limited area. Such a strategy is useful to notify nearby vehicles about traffic hazards, road conditions, traffic jams, and other local events. However, a V2I link offers extra benefits. In this line, our work tries to go a step further, using an infrastructure system to provide context-aware information to drivers depending on their preferences and, in general, take advantage of a global system capable of processing all the events received from the roadside.

Figure 1 shows the new capabilities of our network model when communications with the infrastructure are added. The core system can give a global vision of the road network state, processing information from vehicles and roadside hardware,

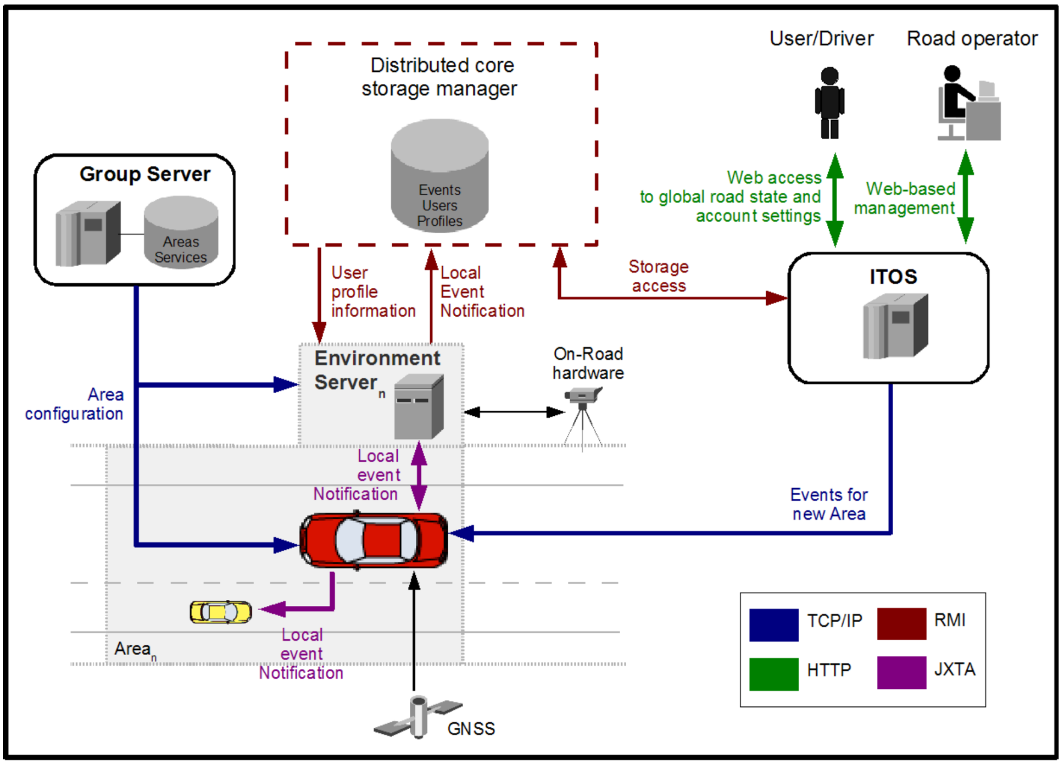


Fig. 2. Complete communication and infrastructure architecture

and performing monitorization tasks. Thus, it would be possible to notify vehicles about traffic problems which affect a long highway, or send a warning message about a forecast of congestion, thanks to traffic jam messages received from vehicles or information feedback from loop detectors at the roadside, or report any pollution problems in an area. These examples are only some of the possibilities such a system offers by means of traffic data analysis and a combination of V2V and V2I communications, so overcoming limitations of current traffic information systems such as TMC. As is further explained, our design proposes a local entity to collect roadside information. This is in charge of a particular traffic area and "sniff" local events from vehicles and roadside hardware.

Information provided to users (or drivers) can also be adapted using such a system. The architecture described in the next sections includes an inferring technique which adapts information provided to vehicles according to the user's preferences. Our initial development of this idea is given in [9]. In this paper, we integrate the management of user profiles in a whole information provision system. Users and road operators can modify system behaviour and relevant points of interest (POI) can be notified to the vehicle according to custom inferring rules. This service exemplifies the potential of infrastructure-based services and the usefulness of the infrastructure to vehicle (I2V) communication link, as a complement to V2V possibilities.

OVERALL COMMUNICATION ARCHITECTURE AND INFORMATION PROCESSING SYSTEM

The main goal of our work is the development of a platform which provides ubiquitous services to vehicles [10], enabling a suitable networking platform for implementing services which span V2V and V2I communications. Figure 2 shows the overall architecture of our proposal. The vehicular network, which involves the entities located at the roadside (grey zone) and the Group Server, is explained in detail in [8]. Every vehicle drives along roads with service provision capabilities; and every coverage area and its associated services are registered in a global entity called Group Server (GS). The services considered in the system have an informative nature and exploit V2V and V2I capabilities, so they include safety services such as breakdown or repairs notification services, or tourism and travel information about the current place. The methodology carried out follows a publish/subscribe scheme where vehicles subscribe to some services and receive asynchronous notifications [11].

Using a P2P network with JXTA technology, vehicles communicate between themselves and with the infrastructure. The geometrical information about every coverage area and its P2P communication groups are stored at GS. Thus, every service available in each area uses a P2P group which limits the propagation of messages and changes when the vehicle enters a new area. Vehicles pass from one coverage area to another through a hand-off process aided by a global navigation satellite system (GNSS), in this case the GPS one.

The vehicle uses a TCP/IP-based protocol to send a hand-off request to GS, which replies with the P2P connection details and the geometry of the new area.

Messages transmitted over the JXTA overlay network are routed through logical pipes, and contain information about the source of the message, the type of event and the event payload. When a vehicle which is subscribed to a service sends a message in this communication system, it is received by all the vehicles in the area which are subscribed too. This mechanism offers a V2V communication paradigm. However, it must be noted in Figure 2 how an infrastructure entity, placed in every coverage area, listens to all events notified in the area; this is the Environment Server (ES). ES is thus in charge of processing all the events sent in a V2V scheme, but it also plays a forwarding role between vehicles and the infrastructure in a V2I communication scheme. Because ES is connected to the rest of the roadside hardware, it is able to send certain notifications to vehicles, such as "your speed is over the limit", using a unicast mechanism. Environment Servers are logical entities and, therefore, they can be installed in physical computers located at the roadside, or executed over a server located at the core infrastructure. The last choice offers more flexibility, avoiding scalability and maintenance drawbacks. The connection between the roadside hardware and ES can be physical or remote, which is the case of our RFID prototype.

A complete information system at the infrastructure side has been developed as well. The distributed core storage manager system, represented by a dashed line in Figure 2, is implemented by means of remote objects which are used by the rest of the infrastructure entities through Remote Method Invocation (RMI). ES forwards new events from vehicles and road hardware to the core storage manager. The Internet Traffic Operation Server (ITOS) provides a web access with a complete view of road events. To do this, ITOS analyses the roadside information accessible via the core storage manager. This web application offers a differentiated access to users and operators. Operators, unlike clients of the system, have an administration account with management capabilities. The end user of the web front-end is able to check the state of the roads at home or even using the on-board computer, via the Internet connection.

In order for certain services to offer context-aware information in the current traffic area, the environment has been modeled through ontologies whose instances represent relevant places in the coverage areas. This information is distributed among the Environment Servers, in charge of maintaining the local data base. The user's preferences are modeled as profile ontologies located in the core storage manager. Users can modify their profile through the web application located at ITOS. The devised information provision technique works as follows. Vehicle presence is detected in the hand-off or by a specialised device (such as the RFID reader used in our prototype). When the vehicle is detected, ES request the user's profile to the core storage manager, as can be seen in Figure 2. Using this profile and the available contextual data base, ES performs an inference process and notifies the adapted information to the driver, following a I2V communication pattern. Road operators can manage the contextual data base through the web application at ITOS. Further details about the ontological models and the inference technique can be found in [9].

From the previous explanation it can be seen that information from subscribed services is sent or received by means of events. Such events come directly from other vehicles or from the infrastructure via ES entities. Events from the roadside have a local meaning, because they are context-aware information exchanged in a V2V pattern. Due to hand-offs between coverage areas it is necessary for vehicles to receive important events of the new area they enter, which were previously collected from the roadside. ITOS carries out this task through a TCP/IP-based protocol, as Figure 2 shows.

SYSTEM OPERATION FROM THE VEHICLE POINT OF VIEW

The five most representative scenarios are illustrated in Figure 3. In the first one the driver subscribes to the services he is interested in. To do so, the on-board software sends a subscription to GS in order to receive or be allowed to send notifications from/to the network. Once the vehicle is connected to the system, or when the car enters a new coverage area, a hand-off occurs (second scenario). Because the vehicle receives the geometry of service areas from GS, the on-board unit (OBU) detects the need to perform a hand-off. In this process, it asks for the P2P connection parameters and the geometry of the new area. The on-board software also asks about traffic incidences in the new zone, in order to update its local navigation information.

The third scenario of Figure 3 exemplifies the connection ES maintains with the roadside hardware. Following the design explained in the previous section, we have implemented a prototype where a vehicle is detected using a RFID system and ES provides contextual information to the driver. In addition to this I2V message passing, in the fourth scenario we can see a V2V communication example. Here, the yellow car notifies a repairs event to the rest of the vehicles in the area. This event is also heard by ES, so it is sent to the core storage platform following a V2I paradigm. Finally, in the last case, we illustrate the forwarding mechanism ES carries out when a critical event is received. When a notification from a critical service, such as "Collision", is received, ES asks for the P2P parameters of the same service in adjacent areas and forwards the message. The vehicle which initially generated the event sent the message to all vehicles in the area, but the forwarding strategy assures vehicles in adjacent areas receive the information too.

PROTOTYPE DETAILS

The complete system has been developed using a real vehicle, real hardware for the infrastructure, and implementing all the necessary software. The vehicle we have used for testing has been a widely sensorised car used at the university

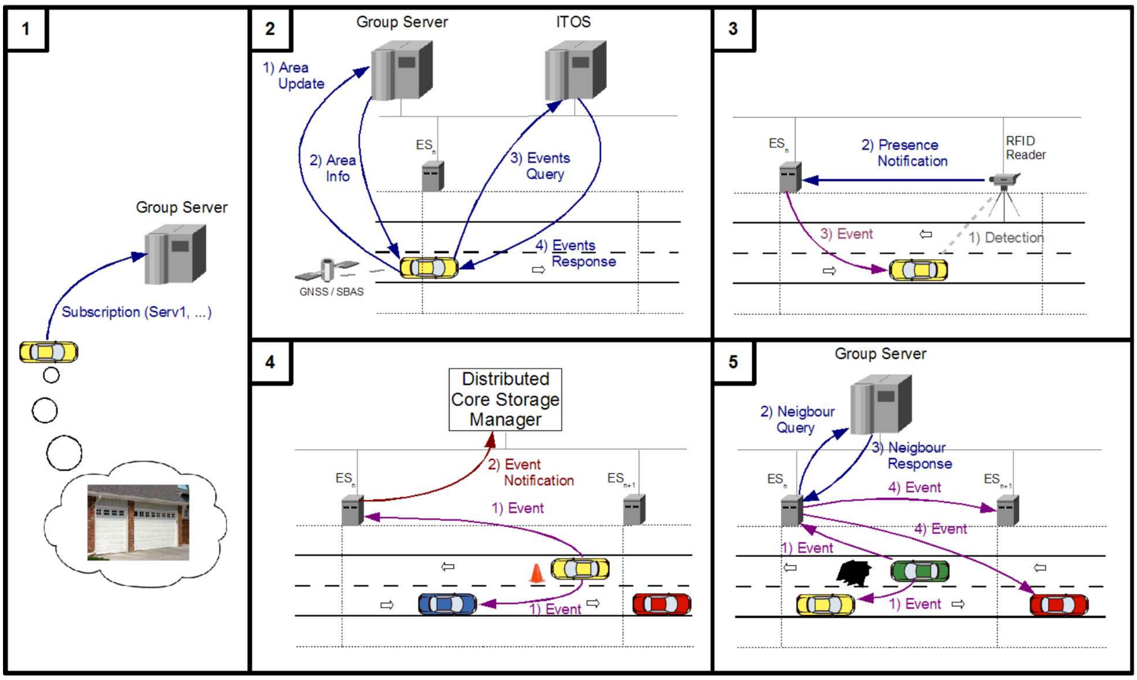


Fig. 3. Operation scenarios and vehicle interaction with the system

of Murcia in several research projects [12]. A Single Board Computer (SBC) and the rest of sensors installed in the vehicle (GPS, odometry, gyro…) compose the on-board unit (OBU). Another vehicle equipped with a GPS and a common laptop has also been used in our V2V and hand-off tests [8]. We have implemented the Environment Server and run several instances over common Linux-based PCs. To test the connection between an ES and the rest of the road hardware, we have set up an RFID reader which detects a vehicle presence through a tag affixed to the windscreen. The photographs on the right part of Figure 4 show this setup. The RFID reader was installed at the test place using an ad-hoc gantry. A laptop was connected via serial port to the reader to send presence notifications to the corresponding ES. The Group Server and the Internet Traffic Operation Server have been developed and then installed over a high performance server in order to cover high rates of queries.

The OBU contains a software platform for developing and deploying services using the Open Service Gateway initiative (OSGi), where applications are implemented as modules [13]. One of these applications is Message Console, which appears on the left part of Figure 4. This application is able to use the information services offered by the previously explained system. The user connects to the services he is interested in by the buttons available on the right part of the window. When the activated services appear in the current coverage zone, their corresponding images appear below and it is possible to receive and send events by clicking over them. The central part of the window shows all the received messages about all active services (road incidences, weather, tourist information…). In this example, the vehicle has received information about hotels and cinemas. The service which provides such information is called “On Road Information”, and uses the RFID system to locate the vehicle in a specific place. When ES receives the presence notification it asks the core infrastructure for the user’s profile, and then infers interesting information for the driver, via its local database about the environment. Finally, ES sends this information to the vehicle, including the matching rate for every point of interest notified. In the example, the hotels which best suit the user’s preferences are “AC Elche”, “NH Amistad” and “NH Rincon de Pepe”, with a matching rate of 43 %. This suitability rate is calculated considering the number of features which match between the user’s profile and the POI element.

Figure 4 also shows the navigation capabilities of the on-board software. This feature is currently implemented to support both Google Maps and GIS data (in the image). The software draws both previous road problems, received during the hand-off, and the new ones by means of icons over the road. The polygon which covers the current coverage area is also depicted using a light red line. When the vehicle is close to a road event (initially sent by a vehicle, a roadside sensor or manually fixed by an operator), the application shows a warning about it and the remaining distance to reach the incidence. The application shows the warning graphically, but further details are given through a spoken alert. In the example, a warning about the proximity of a breakdown on the road has been raised. This event is represented as a yellow mark on the map. As can be seen, the user is always informed of a road incidence by means of the warning icon, the spoken alert and the navigation map. The central text panel also notifies traffic incidences from other vehicles (V2V) or roadside sensors

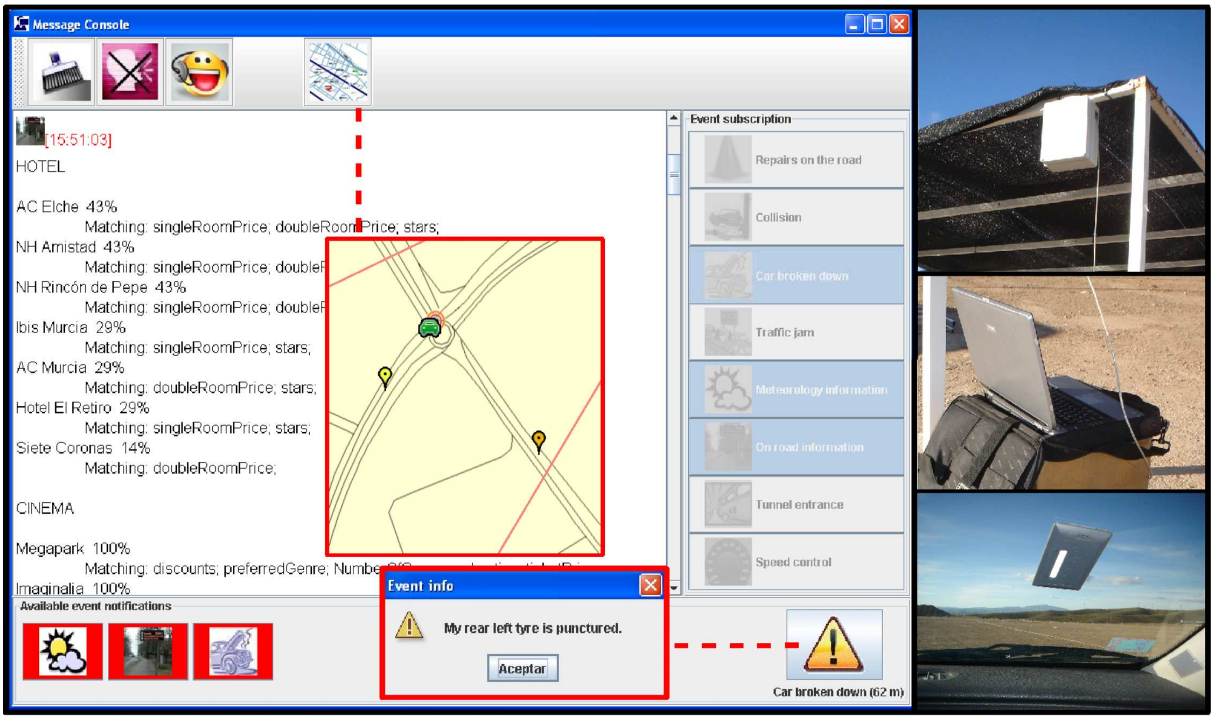


Fig. 4. On-board software and roadside hardware

(I2V).

The distributed core storage manager is composed of a set of RMI entities which perform information management tasks (Profile Manager, User Manager and Road Event Manager) and a remote MySQL data base which physically stores all data. The RMI entities work as independent applications, and each one publishes a remote object which is used by ITOS and ES. In our prototype, the RMI applications and the MySQL server run on the high-end computer cited, but they can be installed in different hosts.

In Figure 5 we have included two screenshots of the web application located at ITOS, implemented using JSP. Road incidences are depicted over map images created from GIS data, but also Google Maps is supported. In the map view provided in the first screenshot, a road operator has logged in and is currently reading information about a traffic jam event reported by a vehicle in the surroundings of Murcia. All road event types can be seen on the left part of the window. Every incidence is drawn with a coloured mark over the map which identifies the event type, and its associated information can be accessed by clicking on the icon. A common user is only allowed to see information about the road network, but the operator can also insert, delete or modify events and manage the users registered in the system. Each user can, nevertheless, change his own profile via this application. As can be seen in the bottom screenshot, the user can change his preferences in order to vary the information received from the infrastructure. To date, several features can be selected about several kinds of POI, such as cinemas, restaurants, petrol stations, service areas and so on.

CONCLUSIONS

Our system comprises a complete context-aware information provision system for the road environment. However, in such a general system there are multitude of interesting areas we are currently working on. We are especially interested in the hardware at the roadside. Identification of vehicles is only one of the many capabilities of RFID in vehicular environments. Traffic sign recognition or goods labelling and tracking are some future ideas to be included in our system using RFID. We are also performing more field trials with our integrated V2V/V2I and CN-based communication platform in order to prove that our solution is a feasible alternative to VANET approaches in most applications. The infrastructure capabilities in terms of information provision and traffic monitoring are continuously growing too, with new functionalities oriented towards both the operator and the end user. We are evaluating new capabilities to be included at the infrastructure edge by means of geographic information systems (GIS). With a GIS it is possible to analyse data from the roadside according to the road network features. All this work is being carried out with the aim of creating a novel, versatile and useful information system for the vehicular environment.

ACKNOWLEDGEMENTS

The authors would like to thank the Spanish Ministerio de Ciencia e Innovación for sponsoring this work under grant AP2005-1437 of FPU program, the Spanish Programa de Ayuda a los Grupos de Excelencia de la Fundación Séneca 04552/GERM/06, and the Spanish Ministerio de Fomento for its continuous support in vehicular research.

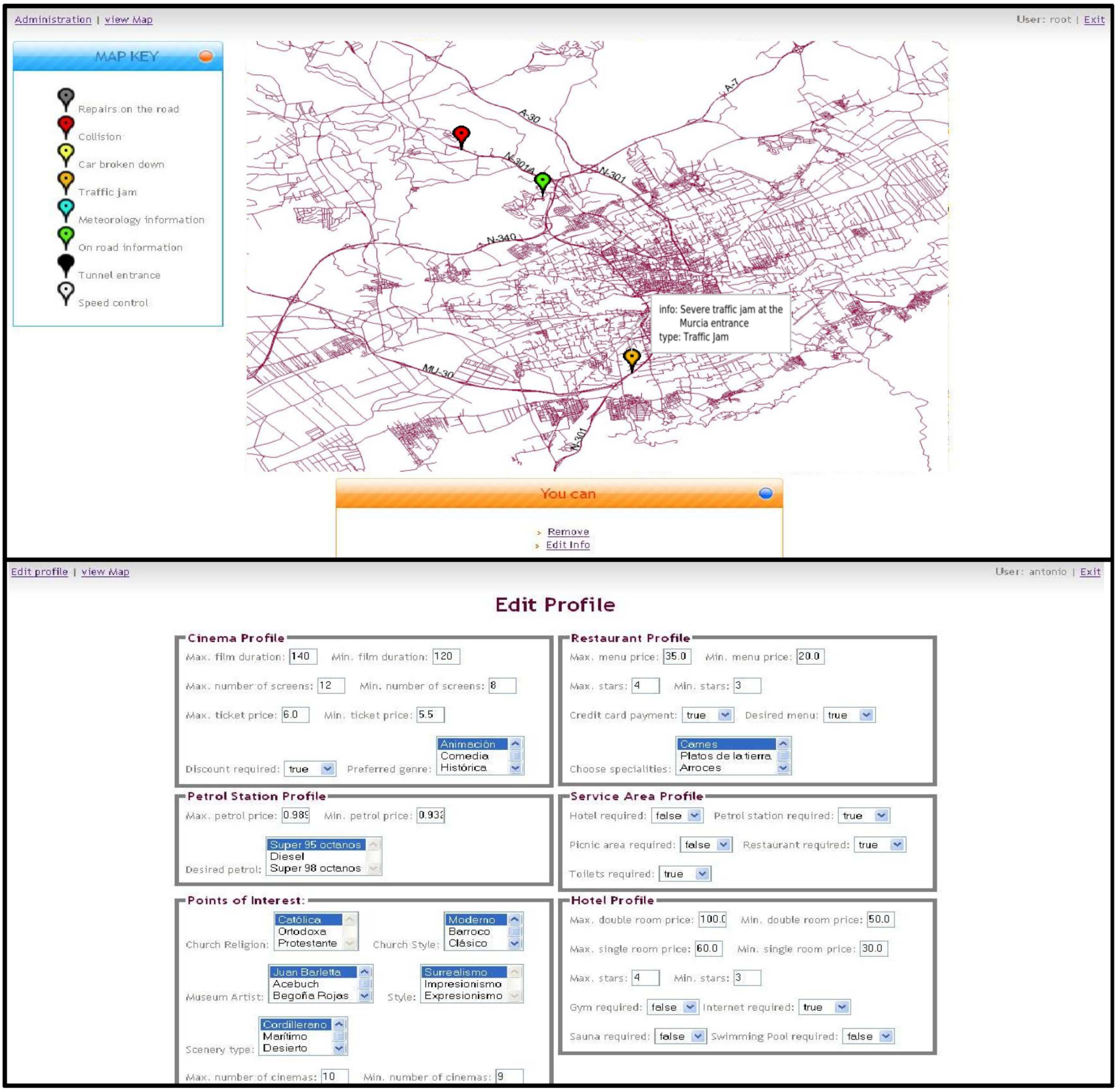


Fig. 5. Monitoring and user management application

References

[1] S. Fuchs et al., "Context-Awareness and Collaborative Driving for Intelligent Vehicles and Smart Roads," *1st Int'l Workshop ITS Ubiquitous ROADS* (UBIROADS 2007), *IEEE Global Information Infrastructure Symp.* (GIIS 2007), 2007.

[2] B. Hoh et al., "Enhancing Security and Privacy in Traffic-Monitoring Systems," *IEEE Pervasive Computing*, vol. 5, no. 4, 2006, pp. 38–46.

[3] S. Biswas, R. Tatchikou, and F. Dion, "Vehicle-to-Vehicle Wireless Communication Protocols for Enhancing Highway Traffic Safety," *IEEE Communications Magazine*, vol. 44, no. 1, 2006, pp. 74–82.

[4] W. Kiess, J. Rybicki, and M. Mauve, "On the Nature of Inter-Vehicle Communication," *Proc. 4th Workshop on Mobile Ad-Hoc Networks* (WMAN 2007), 2007, pp. 493–502.

[5] G. Hattori et al., "Implementation and Evaluation of Message Delegation Middleware for ITS Application," *Proc. 2004 Int'l Symp. Applications and the Internet-Workshops* (SAINT 2004 Workshops), 2004, pp. 326–333.

[6] J. Rybicki et al., "Challenge: Peers on Wheels - A Road to New Traffic Information Systems," *Proc. 13th Ann. ACM Int'l Conf. Mobile Computing and Networking* (MobiCom 2007), 2007, pp. 215–221.

[7] C. Wewetzer et al., "Experimental Evaluation of UMTS and Wireless LAN for Inter-Vehicle Communication," *Proc. 7th Int'l Conf. ITS Telecommunications* (ITST 2007), 2007, pp. 287–292.

[8] J. Santa and A.F. Gomez-Skarmeta, "Architecture and evaluation of a unified V2V and V2I communication system based on cellular networks," *Computer Communications*, 2007, vol. 31, no. 12, 2008, pp. 2850-2861.

[9] J. Santa, A. Muñoz, and A.F.G. Skarmeta, "A Context-Aware Solution

for Personalized En-route Information Through a P2P Agent-Based Architecture," *Proc. 2007 Int'l Conf. Computational Science and Its Applications* (ICCSA 2007), LNCS 4707, Springer, 2007, pp. 710–723.

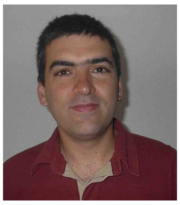
[10] I.Y.L. Chen, S.J.H. Yang, and J. Zhang, "Ubiquitous Provision of Context Aware Web Services," *Proc. 2006 Int'l Conf. Services Computing* (SCC 2006), 2006, pp. 60–68.

[11] G. Cugola, and H. Jacobsen, "Using Publish/Subscribe Middleware for Mobile Systems," *ACM SIGMOBILE Mobile Computing and Communications Review*, vol. 6, no. 4, 2002, pp. 25–33.

[12] A.F.G. Skarmeta et al., "Mimics: Exploiting Satellite Technology for an Intelligent Convoy," *IEEE Intelligent Systems*, vol. 17, no. 4, 2002, pp. 85–88.

[13] J. Santa, B. Úbeda, A.F.G Skarmeta, "A Multiplatform OSGi Based Architecture for Developing Road Vehicle Services," *Proc. 4th Ann. IEEE Consumer Comm. and Networking Conf.* (CCNC 2007), 2007, pp. 706–710.

José Santa is a PhD candidate at the Department of Information and Communication Engineering at University of Murcia. His research interests include vehicle communications, context awareness, location based services, positioning systems, electronic vehicle identification, and the intelligent transportation systems field in general. He received his MS in Computer Science Engineering from the University of Murcia. Contact him at Universidad de Murcia, Campus de Espinardo, Facultad de Informática, 30100 Murcia, Spain; josesanta@um.es.



Antonio F. Gómez-Skarmeta is an Assistant Professor at the Department of Information and Communications Engineering at University of Murcia. His research includes mobile communications, pervasive systems, network security and intelligent transportation systems. He received his PhD in Computer Science from the University of Murcia. Contact him at Universidad de Murcia, Campus de Espinardo, Facultad de Informática, 30100 Murcia, Spain; skarmeta@um.es.