A Novel Architecture for Retrieving Context Aware Information in a P2P Based Vehicle Communications Paradigm

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Abstract— **New services implemented in new generation cars need communication capabilities to connect with the surrounding environment. Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications are the two main objectives in networks applied to road transport. One of the main services which requires such infrastructure is the provision of location-based information to the driver. Although this problem has been previously studied, an interest arises in adapting this information according to the vehicle's or driver's profile. This requires of a special management of information in order to send only interesting advertisement items to the driver. In the present paper, an architecture which solves both V2V and V2I network requirements and which includes an integral processing of information regarding to the driver's profile is presented. A Peer to Peer (P2P) paradigm, based on cellular networks, is used to create a high level communication architecture. An ontology model has been used to manage and infer the information regarding to the car's context. Both the road and vehicle sides have been implemented in our prototype, which includes a well-equipped sensorized vehicle with a software for testing our design.**

Index Terms— **Vehicular Communications, Ambient Intelligence, V2V Communications, Ubiquitous Computing.**

I. INTRODUCTION

Communications are essential in the current information society. Practically everyone can connect to Internet at work or at home, and even in mobility environments, using different kinds of portable devices. Cars are other places where the user stays during long periods too, so connectivity here is a new valuable field. However, apart from the direct usage of the Internet, some on-board services need specific communication primitives. The provision of context-aware information to the driver is a key item at this point, where the synergy between the vehicular networks, the satellite based location technologies, and the knowledge management systems enable a new researching field.

Considering the connectivity requirements of services implemented on board vehicles, two main types of communication necessities are being considering these days. The first of these is formed by applications which need a local connection with the infrastructure at the road side. This kind of connectivity is usually named as Vehicle to Infrastructure (V2I) communications. Some electronic fee collection systems use, for example, DSRC (*Dedicated Short Range Communications*) readers to keep the path followed by a vehicle in order to calculate the associated cost. Here, the main technologies used are DSRC, infrared, and wireless LAN. The second group of such services are applications with Vehicle to Vehicle (V2V) communication requirements. Solutions for collision avoidance and warning mechanisms, in general, have been developed. For this type of services, the most extended technology is the ad-hoc networks. This aspect is treated in a researching line named *Vehicular Ad-hoc NETworks* (VANET), where infrastructure-less network topologies are applied to the special field of vehicle communications. Wireless LAN transceivers are used here, however they are not configured for connecting with a fixed access point. [1] shows the usefulness of V2V and V2I communications.

As can be read in the rest of the paper, the solution presented here proposes a communication architecture which deals with the connectivity requirements previously described. Hence, services with V2I necessities, and services which have to cooperate with other service edges located in the surrounding vehicles in a V2V frame are considered in our proposal. Another aspect considered in our design is "communications at the service level". Our solution presents a high level mechanism of communication which eases the implementation of services with connectivity requirements. Cellular networks are used, jointly with peer to peer (P2P) networks, to design a communication system based on coverage areas to achieve such architecture.

By using a suitable communication technology, vehicles could be connected to an information system which provides notifications about the current status of a traffic zone. This kind of applications are common in mobile phones, where the current cell in the network enables the provision of location-based advertisements. This model can be applied to the vehicle field. Basically, using a GPS device, the vehicle could be connected to a server which provides it with location based information about interesting places, for example. The next step now would be to consider the user's preferences. If the system was able to adapt the information which is sent to the vehicle according with a profile, the driver would receive only the information he is interested in. In order to design a system with such features, not only is a suitable knowledge representation model necessary, but also an efficient inference technique is mandatory. The inference task must be carried out quickly in the vehicle field, because the context information is updated frequently.

Our work integrates a knowledge management model based on ontologies, using OWL[2] (*Ontology Web Language*) modeling, to represent the information about interesting places in the traffic zones and the driver's profile. The ontology model allows the inference of interesting information about the zone according with the driver's profile, thanks to the formal logic language used in the description of interesting places of each zone and in the driver's profiles. All the reasoning and data storage about interesting places and profiles are integrated in our communication architecture. Thus, as it is exposed along the paper, the data processing and data storage are distributed across the system.

The rest of the paper is organized as follows. In Section II, the presented system is placed in the current researching world about vehicle communications and knowledge management applied to the vehicle field. Section III explains the designed communication architecture, and Section IV describes the integrated system for providing location aware information to drivers. Section V gives details about the developed prototype and, finally, Section VI contains the conclusions of our work.

II. RELATED WORK

Regarding to vehicular communications, as it has been stated previously, the researching lines are centered in the usage of ad-hoc networks in the VANET field. The interest of this work lies in proving how cellular networks can be suitable not only for a direct Internet access, but also for enabling V2V and V2I communications. In [3], a communication technique between the vehicle an the road infrastructure based on the DSRC technology is presented. This illustrates an example of a V2I communication method. 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, [4] presents a handover system for wireless LAN networks in vehicles. Although the idea could be valid for urban or fixed railway zones, the deployment is limited by the cost. A work which captures a P2P approach through JXTA (JuXTApose) to notify events to the road side is shown in [5]. Our system use the JXTA technology as well in the vehicle field, however it also includes an architecture valid for V2V communications.

Several approaches have been presented in other environments about delivering contextual information to the user. Chou et al [6] develop a context-aware museum tour guide, in order to adjust its recommendations about the museum's items to the visitor's individual context. Similarly to us, they build the tour guide based on Semantic Web technologies such as OWL and web rule inference engines, which reduce the maintenance costs. The rules are expressed in ROWL, an extension of OWL, whereas we use the Jena format for expressing our rules. A similar idea, but centered in touristic city tours, can be found in [7]. In this work, the mobile devices gather contextual information (location, preferences…) about the tourist and then it is sent to specific servers that process it and determines interesting places on the tourist's location. The WiFi or GPRS technology is used, and the information is represented in an own language. We advocate for the use of OWL as it is a W3C standard. Another work in this line is [8], changing the scenario to buildings and indoor spaces. In the vehicle field, [9] comprises a multi-purpose management system for contextual information. The system is exposed as valid for the vehicle domain and allows queries about the traffic conditions and route guidance; however, it only presents an application for the urban environment, and does not adapt the retrieved information to the user preferences.

III. HIGH LEVEL VEHICLE COMMUNICATIONS

III-A. DEVELOPING ON-BOARD SERVICES

An important issue in the service development arises when the amount of applications in the vehicle compartment grows. [10] deals with this problem, and proposes a platform for the development of vehicle services based on a general purpose on board unit (OBU). In the vehicle telematics field, a large number of services need communication capabilities. This is the reason why the work presented in [10] is extended with a middleware which allows the use of a high level communication interface. Using this mechanism, each new service does not require the implementation of its protocol starting from the TCP/IP basis. This common interface allows the message exchange in both V2V and V2I environments.

III-B. A SERVICE LEVEL COMMUNICATIONS ARCHITECTURE

Cellular networks are considered as the appropriate technology in order to use a unified communication mechanism. That is, cellular networks represent the communications capabilities which allow the implementation of any on-board service with connectivity requirements. Especially, cellular networks through GPRS/UMTS have a special interest in this work. In the designed system, 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 communication architecture. The traffic zones are organized in coverage areas, each one with a different P2P communication group. Vehicles are able to move from one P2P group to another through a roaming process between coverage areas. This roaming is based on the location of the vehicle, provided by the GPS sensor. Information about areas is received from the *Group Server* using a TCP/IP link over GPRS/UMTS. The Group server stores the geometry of every service area. A local element called *Environment Server* manages special events inside the area. Event notifications are sent and received by service edges, located either at the vehicle or at the road side (Environment Servers). All messages emitted are encapsulated in P2P packages. Two different techniques of emission have been developed, so a P2P message can be broadcasted in the area or sent to a specific vehicle.

Apart from the designed architecture, in Fig. 1 the three most representative scenarios are exposed from left to right. In the first one, a vehicle is passing from one area to another. The Group Server provides the P2P parameters to maintain

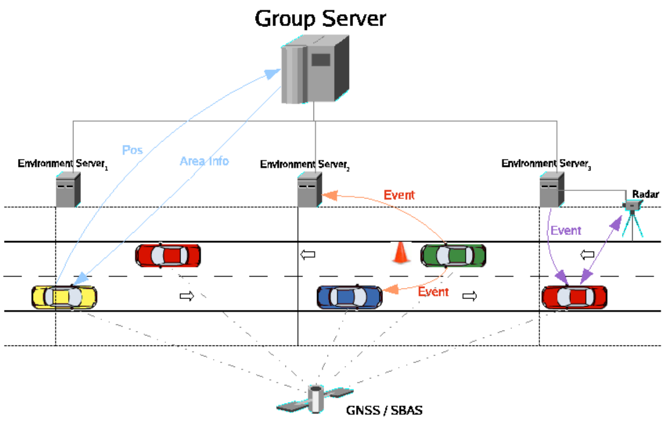

Fig. 1. High level communication architecture

TABLE I

VEHICLE-GROUP SERVER COMMUNICATION

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

the communication in all the active services. In the second scenery, a safety service located in the vehicle notifies a repair event, which is broadcasted in the area. Because the Environment Server also receives all the broadcast messages, it can process any event which requires a special treatment, such as a collision, for example. 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 scenery in the diagram shows how the Environment Server can be connected to the rest of the road side infrastructure, which may be composed of speed radars, identification sensors, video cameras, etc. Thanks to this, local events can be notified to the vehicles in the area, and useful reports can be sent to the central entity.

III-C. PROTOCOL DETAILS

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

Table I includes the messages exchanged between the vehicle (V) and the Group Server (GS). This connection is carried out by a message exchange over TCP, using the cellular network interface directly. The first process between these two entities is the management of the roaming. An initial *Area_Update_Query* message, used in the roaming process as well, is used by the vehicle for registering itself against GS. The *Disconnect* message serves for ending the communication. The roaming process, which is shown on the left part of Fig. 1, uses the *Area_Update_Query* and *Area_Update_Response* messages. The first one is used when a vehicle detects (through the GPS position) the end of its current coverage area. In that moment, it sends a new *Area_Update_Query* message with its new location. GS replies with an *Area_Update_Response* if the vehicle is inside a new service area. If this is not the case, the vehicle will keep sending notification messages until it reaches a defined area. The *Area_Update_Response* message contains the available services in the zone and the P2P parameters to allow subscribing to them. When the vehicle wants to use a defined service, it sends an *Event_Subscription*. This package contains the identifiers of the services the vehicle is interested in.

TABLE II

ENVIRONMENT SERVER-GROUP SERVER COMMUNICATION

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

TABLE III

VEHICLE-VEHICLE/ENVIRONMENT SERVER COMMUNICATION

Purpose	Messages	Sender
Message Passing	Vehicle_Event Environment_Event Specific_Environment_Event	V ES ES

Regarding to the communication between the Environment Server (ES) and GS, Table II summarizes all the interchanged messages. The *ES_Registration* message is used by the ES to connect with GS. This packet contains the location of ES, so GS is able to search for the P2P parameters of all services available in the zone. This information is given by the *ES_Registration_OK* message. If any error occurs in this registration, GS sends a *ES_Registration_ERROR* with an error identifier. Because the Environment Servers are static entities, which may be connected during long time periods, they need to update its configuration periodically. The *ES_Registration_Update* message performs this task. It only asks for new P2P parameters of the coverage zone. GS answers with a *ES_Registration_Update_Response* if it is necessary. The second group of messages are used in the message propagation mechanism. Because some services are considered as critical (collision, break down...), it is necessary to ensure that all vehicles near the problem receive the event. However, the location of such problems may be close to the border of the coverage area, so it is necessary to propagate the associated message to the neighbouring areas. ES, 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 III includes the three messages used by the services to send messages. When a P2P message is thrown in the P2P group, it is received by all the vehicles subscribed to the service and the ES associated with the zone. The *Vehicle_Event* message contains an event sent from a vehicle service edge. The *Environment_Event* messages are sent by the Environment Servers. This is used, up to now, by the message propagation method described previously. It is possible to send a message to a specific vehicle as well, using the *Specific_Environment_Event* message.

IV. MANAGING CONTEXT-AWARE INFORMATION FOR ROAD SERVICES

IV-A. INFORMATION MANAGEMENT THROUGH ONTOLOGY MODELING

The importance of context is receiving considerable attention in combination with mobile devices as these devices are particularly affected by environmental changes. A general motivation is that context-awareness can serve to compensate for the abstraction that is required in the first place to make systems accessible in changing environments and situations. Several advantages are acquired by modeling these kind of domains with ontological languages such as OWL. First, the information represented by the model can be easily and broadly exchanged among heterogeneous applications that understand this language. Another fundamental capability is the inference process. This allows reasoning about the model, giving as a result the extraction of new knowledge that was implicit in the domain. This inference process is achieved by triggering some predefined set of rules about class hierarchy, types of properties, etc. Taking this idea further, we can define our own rule set that expresses our preferences about the behaviour of a semantically modeled application in each moment. Thus, this application will work according to the user's contextual situation.

Therefore, to deal with this type of scenario that involves context, location and preferences, we are going to make use of ontologies in modeling the user's profile and his context, the location system explained in the previous section, and a set of *context rules*. Context rules model the user's preferences and will determine the behaviour of an application depending on the user's context. In this way, the same application may derive in different activities according to the context rules that are triggered when executing the application. These rules are formed by ontological elements [11].

IV-B. ONTOLOGY MODELING ADAPTED TO THE GENERATION OF CONTEXT AWARE INFORMATION IN A LARGE SCALE ENVIRONMENT

We have augmented semantically our P2P architecture by means of modeling the context aware information and the driver's profile, using different ontologies that have been developed in order to satisfy the requirements of the system commented. One of these requirements is its distributed composition. Consequently, the ontologies are spread among the different components of the architecture. First of all, it is important to distinguish between the scheme and the instances of an ontology. Whereas there is only a scheme that represents the domain modeled, there could be various instances of that

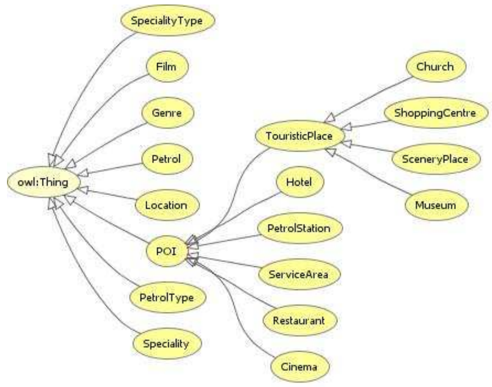

Fig. 2. Service Ontology in a hierarchical diagram

```
# Check menuPrice
[menuPrice:
              (?profile rdf:type prf:Profile)
              (?profile prf:restaurantProfile ?rp)
              (?rp prf:maxMenuPrice ?maxmp)
              (?rp prf:minMenuPrice ?minmp)

              (?res rdf:type srv:Restaurant)
              (?res srv:menuPrice ?mp)

              le(?mp,?maxmp)
              ge(?mp,?minmp)
              ->
              (?profile prf:matches ?res)
              (?res srv:matchesWith 'menuPrice')
]
```

Fig. 3. A context rule for matching the driver's preferred menu price

scheme for the concrete information captured. For example, the Profile ontology contains a scheme with the different preferences of a driver about restaurants, hotels, etc., and there is (at least) one instance of this scheme per each driver.

Going back to the distribution issue, the Profile ontology (scheme and instances) is stored in the GS. By indicating the vehicle identifier, GS returns the driver's profile, if it exists. On the other hand, the Service ontology (Fig. 2) is stored among the Environment Servers. This ontology models the context information of each area, i.e., the elements that could be of interest to the users. Each ES maintains the same schema, but the instances are specific for each zone controlled by them.

By combining the Profile ontology with the specific Server ontology of each ES, we can perform the inference process. Now, in order to incorporate the driver's preferences to the model, we make use of context rules. In Fig. 3 an example of these rules is shown. Concretely, this rule infers the restaurants whose menu price is between a maximum *(le(?mp,?maxmp))* and minimum *(ge(?mp,?minmp))* value stated by the driver. If this condition is hold by any restaurant, it is added to the list of driver's profile matches, specifying which condition is satisfied. One advantage of using context rules is that they can be used with any driver's profile or any specific instance of Service ontology. As a result, the same rules can be applied in any ES. Moreover, since the rules are defined in a external file to the source code, recompiling is avoided in case that we need to add new behaviours or change them.

In Fig. 4 a sequence diagram of the proposed system is shown. As it has been stated, the method by which ES detects the location of the vehicle is independent from the inferring

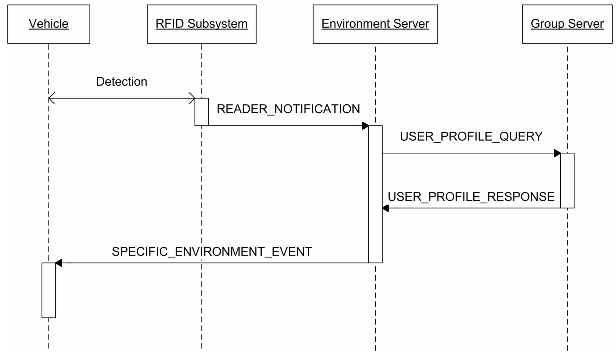

Fig. 4. High level communication architecture

Fig. 5. Prototype vehicle used in the development

and the knowledge model. In this approach, a RFID (*Radio Frequency IDentification*) system is used to detect the presence of a vehicle. All the messages involved in the process of contextual information inferring are shown. First, the vehicle is detected by the RFID subsystem at a specified location, sending a *Reader_Notification* message. This message contains the vehicle identifier, so ES can use this information to search for the driver's profile. The message *User_Profile_Query* is addressed to do this task. GS looks for the driver's profile in its data base and, if the profile does not exist, it replies with a *User_Profile_Not_Found*. In other case, GS replies with a *User_Profile_Response*, which contains the driver's OWL profile. Now, ES processes the local information about the area, together with the driver's profile, to infer the interesting notifications in the zone. When this information is computed, a *Specific_Environment_Event* message is sent to the vehicle in question. The service edge at the vehicle is in charge of showing this information in an appropriate way.

V. PROTOTYPE DETAILS

The system described in the previous sections has been implemented in a real platform. All technological details about the prototype are explained in this section. The explanation is divided into the vehicle edge, the road side equipment used, and the software implementation at the road side and, mainly, at the vehicle edge.

V-A. *VEHICLE ON-BOARD UNIT AND TEST CAR*

The vehicle used for the system deployment is a vehicle widely sensorized at the University of Murcia. In [12] it is explained in detail all the hardware installed in the vehicle. Here, the car was used for a project whose aim was the implementation of an autonomous vehicle. Inertial navigation devices, satellite positioning receiver and odometer captors are the most important sensors for the proposed system. Thanks to this hardware, it is possible to create services that are dependent of the vehicle context. The GPS sensor is utilized to know the position of the car and, therefore, it is essential for the roaming process among the coverage areas. The car in question is shown in Fig. 5. The on-board unit is a SBC (*Single Board Computer*) of VIA. The interface between the user and the OBU is carried out by a LCD panel installed on the dashboard. The operating system used in the OBU is a Linux Fedora Core 4, and a Java Virtual Machine 1.5 enables the computer to support all the multi-platform software implemented. In [10] it can be found more details about the software platform used in the OBU. Regarding to the communications, a cellular network PCMCIA transceiver has been used. The model is a Novatel Wireless Merlin U530, which allows GPRS and UMTS data connections.

V-B. *ROAD SIDE EQUIPMENT*

At the road side, the tests have been carried out using a set of areas defined over the campus of the University of Murcia, as well as several kilometers of a close motorway. Eight areas has been used to probe the communications architecture. The Environment Servers have been implemented as software entities, running in a server located in one of our laboratories. The Group Server runs over another computer. All of them are Linux based systems, with a common Intel processor. Every ES is equipped with a Jena[14] inference engine configured for the reasoning process.

With the purpose of testing the provision of contextual information, all the described road side equipment has been improved with a RFID system. Using a tag located on the windscreen of the car, the reader can detect the presence of a vehicle. The tests in this case have been carried out in an open environment located at the campus of the University of Murcia. When the vehicle pass near the reader, a notification is sent to the Environment Server.

V-C. *SOFTWARE IMPLEMENTATION AT THE VEHICLE SIDE*

A new service has been implemented at the vehicle side to probe the feasibility of the communication architecture presented. JXTA (JuXTApose) [13] has been the P2P technology used. JXTA presents a group based communication system with the features of any other P2P protocol. It forms an underlying network which abstract the user from the internal details. Fig. 6 shows the Message Console service. Using the P2P middleware, an event based mechanism has been created to notify traffic incidences. Each "event" has been modeled like a service in the communications system. Eight types of events are available in the right box, so the user can subscribe to any of them. The most important service is named *On road*

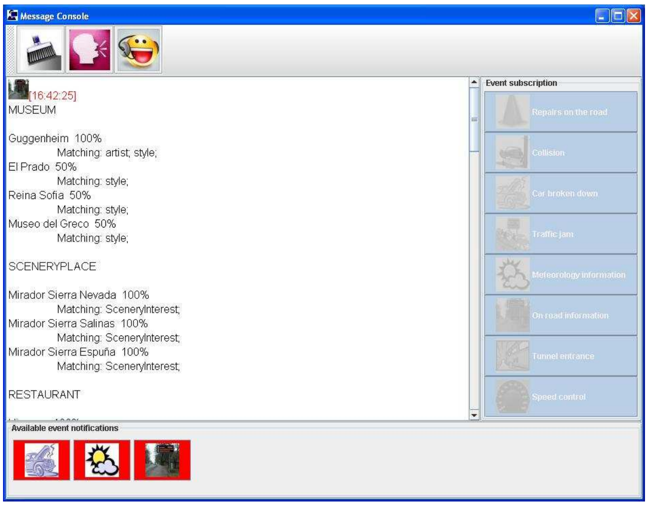

Fig. 6. An screenshot of the vehicle application

information. If any of the services is active, the corresponding events can be received or thrown. The events regarding to the on road information service cannot be thrown by a user, because it is managed by the road side infrastructure. All the received events are shown in the central part of the window.

In the example provided in Fig. 6, the driver has activated all the available services, but only three of them are available in the current area. An event regarding to the "On road" information service has been received. As can be noted, the driver's profile has been used in order to adapt some tourist information available in the current coverage area. This information has been printed in the window, showing the matches with the user's preferences. It is noticeable how *Guggenheim* matches with one hundred percent of the user likes, but the three other museums only match at a fifty percent.

VI. CONCLUSIONS

The paper exposes the work carried out in the synergy between the vehicular communications and knowledge management fields. A communication technique, based on cellular networks and the P2P protocol provided by JXTA, has been designed to offer the programmer a high level mechanism to use V2V and V2I communications in her on-board services. In addition, an integrated context-aware system to provide location-based information according to the driver's profile has been proposed. Semantic Web technologies as OWL have been selected to represent the information of the model, and an inferring process is followed to adapt information about the traffic zone according to the driver's profile. The prototype exposes the feasibility of the whole system. It includes the use of a real vehicle, adapted to the intelligent transportation field, and the design of a specific road side environment, in order to perform the tests.

In the future, real tests are planned to be made with the aim of testing the performance of the communication architecture against the network approachs based in the ad-hoc topologies. Another future line of work will be the evaluation of moving the driver's profile from the GS to the vehicle's OBU, in order to study the effects produced in the system's performance and reliability.

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REFERENCES

[1] Luisa Andreone, Michele Provera. "Inter-vehicle communication and cooperative systems: local dynamic safety information distributed among the infrastructure and the vehicle as "virtual sensors"to enhance road safety". *ITS Hannover 2005, Hannover. January 2005.*

[2] Mike Dean, Dan Connolly, Frank van Harmelen, James Hendler, Ian Horrocks, Deborah L. McGuinness, Peter F. Patel-Schneider, Lynn Andrea Stein. "OWL web ontology language reference." W3C Working Draft, 31 March 2003. Available at http://www.w3.org/TR/2003/WD-owl-ref-20030331

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

[4] Toshiya Okabe, Takayuki Shizuno, 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.

[5] Luciano Baresi, Carlo Ghezzi, Antonio Miele, Matteo Miraz, Andrea Naggi, 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.

[6] Chou, S., Hsieh, W., Gandon, F. L., and Sadeh, N. M. 2005. Semantic Web Technologies for Context-Aware Museum Tour Guide Applications. In Proceedings of the 19th international Conference on Advanced information Networking and Applications - Volume 2 (March 25 - 30, 2005). AINA. IEEE Computer Society, Washington, DC, 709-714.

[7] Juan Ignacio Vázquez, Ana Belen Lago, Iker Larizgoitia, Ignacio Uria and Rafael Bañales.WALLIP: Una plataforma de servicios con percepción contextual basada en localización. Ubiquitous Computing and Ambient Intelligence. CEDI 2005. Granada, Spain. September 2005.

[8] José M. Falcó, Roberto Casas, Álvaro Marco, Jorge Falcó. Using GUIA to "Wayfindig"in unkown builidings. Ubiquitous Computing and Ambient Intelligence. CEDI 2005. Granada, Spain. September 2005.

[9] René Meier, Anthony Harrington, Vinny Cahill. "Towards Delivering Context-Aware Transportation User Services". 2006 IEEE Intelligent Transportation Systems Conference (IEEE ITSC 2006), Toronto. September 2006.

[10] José Santa, Benito Úbeda, 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.

[11] Andrés Muñoz, Antonia Vera, Juan A. Botia, Antonio F. Gomez Skarmeta. Defining basic behaviours in ambient intelligence environments by means of rule-based programming with visual tools. 1st Workshop of Artificial Intelligence Techniques for Ambient Intelligence. ECAI 2006.

[12] Skarmeta A.G., Martínez H., Zamora M.A., Úbeda B., Gómez F.C, Tomás L.M. "MIMICS: Exploiting Satellite Technology for an Autonomous Convoy". IEEE Intelligent Systems. N IV. V. vol. 17, pp. 85-89. July 2002.

[13] "JXTA Technology: Creating Connected Communities". Sun Microsystems, Inc. Palo Alto. February 2005.

[14] Jena web site. http://jena.sourceforge.net