Intelligent Transportation Systems based on Internet-Connected Vehicles: Fundamental Research Areas and Challenges

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ABSTRACT
Information and Communication Technologies (ICT) rapidly migrate towards the Future Internet (FI) era, which is characterized, among others, by powerful and complex network infrastructures and innovative applications, services and content. An application area that attracts immense research interest is transportation. In particular, traffic congestions, emergencies and accidents reveal inefficiencies in transportation infrastructures, which can be overcome through the exploitation of ICT findings, in designing systems that are targeted at traffic / emergency management, namely Intelligent Transportation Systems (ITS). This paper considers the potential connection of vehicles to form vehicular networks that communicate with each other at an IP-based level, exchange information either directly or indirectly (e.g. through social networking applications and web communities) and contribute to a more efficient and green future world of transportation. In particular, the paper presents the basic research areas that are associated with the concept of Internet of Vehicles (IoV) and outlines the fundamental research challenges that arise there from.

KEY WORDS
Intelligent Transportation Systems, internet-connected objects, vehicles, management, architectures.

1. Introduction and Motivation

According to medium to long term research EU roadmaps, technology will enable the possibility to enhance any real world object, even the simplest, with ICT capabilities. These smart objects will be equipped with sensors, actuators and embedded processors and will need to adopt an open networked architecture, so as to (i) conceal the complexity of underlying technologies, (ii) support interoperability across providers and consumers of information and services, (iii) support scalability, in terms of on-demand addition or removal of objects, and (iv) enable integration of the novel set of supported services with enterprise business processes.

Moreover, communication among internet-connected objects should include their cooperation, enable the acquisition and processing of increasingly big amounts of data from versatile geographical areas, provide the means for the data's intelligent interpretation so as to constitute useful information to machines and/or applications where and when needed, as well as support the extraction of information that can be transformed into collective knowledge from the various objects, leading to augmented social and environmental awareness. Moreover, intelligence in communications should be supported by self-configuration, self-management and self-healing techniques, which would distribute complexity towards the network edges.

An area of applications where telecommunications and information technology find prosper ground in the internet-connected world is transportation. The motivation for this is that automotive vehicles have become an inseparable part of our lives, as they are broadly used in our everyday life. More and more vehicles are sold every year and streets suffer severe traffic jams, especially in large cities, where distances are bigger and consequently, vehicles are even more necessary for transportation purposes [1][2].

Lately, the automotive world is witnessing a trend related to the extensive use of telecommunications systems inside vehicles. This means that transportation is facilitated by means of newly introduced revolutionary telecommunication techniques and gadgets, which aim to improve either the driver's safety, or the passengers' quality of life through entertainment, or both [3][4][5]. In this respect, several innovative and cost-effective mobile services and applications for traffic networks are under investigation, emerging as the cornerstone of the so called Intelligent Transportation Systems (ITS) [3][4][5][6]. By enabling vehicles to communicate with each other via Vehicle to Vehicle (V2V) communication as well as with roadside base stations via Vehicle-to-Infrastructure (V2I) communication, ITS can contribute to safer and more efficient roads [7][8][9].

Communication among vehicles might be performed through the utilization of sensors and also the Internet Protocol (IP) suite. This becomes obvious once perceived that a modern vehicle is nothing less than a mobile multi-sensor platform with hundreds of sensors. The usefulness of those sensors is manifold. First, they can be used to monitor the driver, the vehicle and the environment, with the ultimate goal to support a safe, efficient, economic and ecologic road transport, through real time traffic/safety/emergency management. Moreover, they form the base for a moving intelligence, detecting information and automatically inferring conclusions which eventually allow the vehicle to act on the driver's intention. Interconnecting these vehicular multi-sensor platforms with other vehicles or elements in the infrastructure using communications technology allows for the design and development of numerous novel services and applications.

In the light of the above, this paper presents the fundamental research areas that comprise the concept of the internet-connected world of transportation. The next section contains an overview of the basic business models that arise from this concept. Section 3 discusses on management algorithms for vehicles, whereas section 4 describes challenges that are relevant to the architecture for internet-connected vehicles. Finally, concluding remarks and an outline of future research are provided.

2. The concept of internet-connected vehicles

Intelligent Transportation Systems

In general, ITS aim to address problems such as transportation safety as well as traffic management by reducing collisions and traffic congestions [9][10]. Research in ITS has been so far focused on the following areas:

a) Traffic assessment and management, where some research efforts deal with traffic information systems based on ad hoc networks, while other present centralized solutions where the traffic assessment and hazard recognition is concentrated in traffic management centers [11];

b) In-vehicle and on-road safety management, which tries to assess the driving style via non-intrusive sensors - monitoring of the driver. The most popular concepts are measuring the deviation from the middle of the driving lanes or detecting conspicuous signal characteristics of the steering wheel angle [12];

c) Driver modeling techniques, which try to provide accurate analyses of cognitive processes of drivers in semi-automated vehicles, to predict the impact of future driver assistant systems on driver workload, behavior and safety [13];

d) Emergency management, which can be divided in (i) management of increased traffic caused by emergency situations, and (ii) management of emergencies that directly affect the safety of the route of individual vehicles [14][15].

e) Affecting environmental effects of transportation by reducing emissions of vehicles though enhanced traffic and transportation management [16].

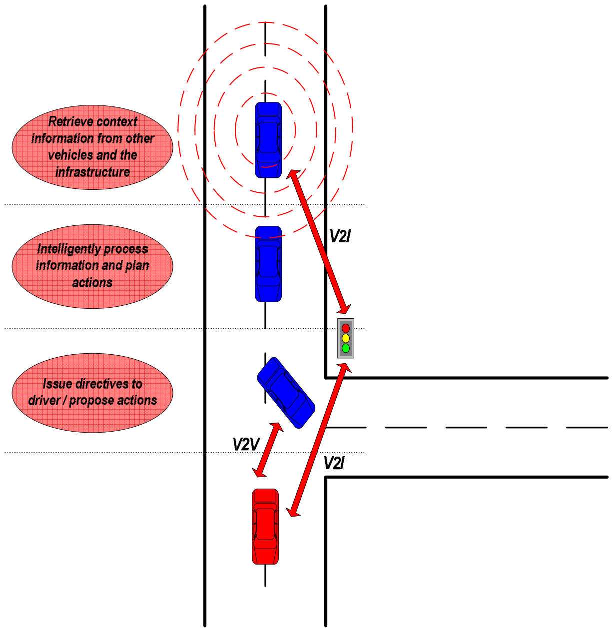

Figure 1: High level view of ITS

A high level view of a simple ITS is provided in Figure 1, where the blue vehicle is aided to avoid an emergency situation caused by the red vehicle that has suddenly gone out of order, through V2V and V2I communications. In particular, after gathering the necessary information, the blue vehicle's intelligent management system that is part of its ITS, informs the driver that he should slow down and potentially make a turn, so as to avoid any unwanted implications. Intelligence lies in the ITS proactive decision upon alternatives, which would otherwise be feasible only after the driver could see/understand the emergency.

However, despite the establishment of ITS, there is still way to go for maximizing transportation efficiency and safety. This is justified as follows:

- The traffic conditions that should be handled by vehicles may frequently change, in a sudden or recurring manner. So, on one hand, traffic needs to be assessed in real-time. On the other hand, traffic patterns resulting from a learning process could add accuracy to the messages communicated to the drivers;
- Legacy traffic assessment and management systems are mainly centralized. Moreover, the communication among the central management entities and the vehicles is being done through internet, satellite or cellular systems. Specifically, vehicles dispose positioning systems and obtain information on the traffic situation. The driver is thus capable of deciding on the most proper direction to follow. This means that, in principle, such systems are complex,

as well as unsuitable for adapting, in short time scales, to context changes.

- Currently, the collection of context information, the solution of optimization problems and the application of reconfiguration decisions is an off-line process, applied in medium (or long) time scales;

Intelligence embedded in vehicles is still at a very low level and there is no assessment in the vehicle of the overall safety status that would rely on a correlation of the global traffic condition and the vehicle and driver behavior.

2.2 The Internet-of-Vehicles (IoV) concept

The concept of IoV envisages vehicles and objects of the transportation infrastructure that are connected through an all IP-based infrastructure, capable of exchanging information directly or indirectly and appropriate for resolving several kinds of issues, so as to result in a more efficient, safe and green world of transportation.

To realize the IoV concept, a certain number of aspects are to be tackled, namely:

- A scenario-driven approach through a thorough analysis of a number of scenarios envisaged to form part of a future world of internet-connected vehicles, such as:
    - Intelligent traffic management
    - Safety and emergency management
    - Eco-driving for energy-efficiency
- Autonomic management algorithms improving the operation of internet-connected vehicles, in terms of safety and traffic management, green-targeted criteria, as well as for enabling services from the vehicular extended internet:
    - versatile data acquisition and aggregation from various internet-connected vehicles, directly and indirectly (even through networks of social type);
    - driver, vehicle and environment modelling for inferring collective and yet individualised knowledge that can be used in context handling
    - producing outputs on a per-scenario basis for optimizing the performance of internet-connected vehicles;
    - service-oriented effective solutions for a massively large networked system, developed by different organizations and spread across the world, used by millions of vehicles and comprising huge numbers of sensing and computing devices with (basic) communication capabilities.
    - A complete functional and system architecture for IoV, based on existing standardsand providing extensions when necessary. The architecture will comprise a set of functional blocks that will be extracted from the requirements (deriving from the selected scenarios) and will include a full specification of interfaces.

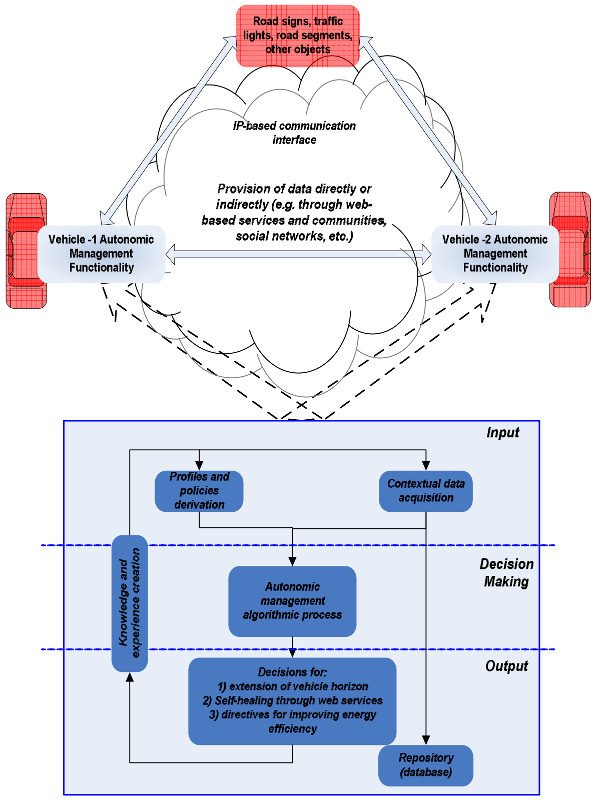

Figure 2: Preliminary illustration of the IoV solution

The concept of IoV is envisaged to create important value-adding mechanisms for the wireless industry (manufacturer, application/service provider) and the user. The vision of internet-connected vehicles that are managed, and coordinated with the transportation infrastructure, by autonomic systems (that are advanced with respect to the state-of-the-art, as explained in the corresponding section) leads to enhanced vehicular service provision, lower costs (components of the total ownership costs), and management decisions with a larger "green" footprint. IoV requires efficient solutions to several technical challenges and also the evolution, bundling and exploitation of different concepts, ranging from autonomic management V2X protocols communication to social networks.

Figure 2 is a first illustration of the overall IoV solution. It depicts the basic components of the solution, namely:

(a) the autonomic management algorithms
(b) the internet of vehicles as enablers of future green ITS
(c) the IoV architecture fundamental functional blocks

(d) the scenario-driven approach

3. Business models

This area of research needs to use a number of predefined scenarios to develop a detailed business model framework that will fit the overall objectives of the concept. Moreover the Business Model Framework will provide the foundations for the exploitation in order to successfully develop the exploitation plan.

Business models present and describe the market segments with the desired characteristics that will have an inherent interest in the developments of the IoV concept. Moreover, they will accurately define the added value of the products and services envisaged. The business models will, by definition, identify novel revenue streams for parties involved and develop, based on the concept consortium and their business partners, a network of business liaisons able to support with enthusiasm the concept's output and commercial ventures.

Finally an accurate cost analysis needs to take place in order to provide the necessary financial and resources thresholds which will provide the envisaged limits of the concept's Business Plan. Given an indicative 5 year time to market for the concepts most innovative research results, the concept of IoV will have enough time to mature through the business units of companies adopting it and reacting to the first feedback from business experts, user groups and scientific experts even during the lifetime of the concept.

Additionally, the business models area will ultimately need to develop the guidelines for the business strategy. The key elements to analyse will be the market definition, including the type of users and stakeholders; the type of products/services provided; the analysis of existing similar products/services; the competitive strategy and the competitive advantage. This work also implies the development of a Vision, Mission, Core Values, Policies and Image and strategic objectives that will be the input to develop the Business Plan. Moreover, a cost - benefit analysis will be performed in order to assess the monetary valuation of the risks connected to the commercialisation of the products/services developed.

Moreover, another important part of this area needs to be dedicated to the description of the usage scenarios based on which the requirements will be defined. The scenarios will be a depiction of the envisaged impact of the IoV research results and a strict benchmark for the success of the concept.

Last, this area of research is relevant to the realization of a thorough, systematic review and collection of the total requirements and needs from all participating roles of the IoV service chain. Participating companies and research institutions will provide their experience on market needs and various views will be collected through questionnaires that will be designed for this reason.

4. Autonomic Management Algorithms for Vehicles

This research area will provide a modeling and evaluation chain to properly model the state of the vehicles, the drivers and the environment. A particular focus will be to enable a proper abstraction from the physical world including particular the information from human behaviours into the ICT domain. This includes all facets of the physical world as seen though the vehicle's sensors, including meta-information about the uncertainty, ambiguity and quality of the information.

Based on this modeling, this research area will develop an in-vehicle context inference engine which will identify new algorithms to infer higher level contexts from the large number of data given going far beyond a single vehicle horizon. Not only the vast amount of data about the vehicles, drivers and environment which has to be interpreted in a timely and adequate manner, also the distributed nature of the contextual information is a challenge this area will particularly address.

The final aim is to provide a decision base for any entity in a vehicle which directly or in-directly performs an action on behalf of the driver or even his or her intentions. Due to the proactive and complex dynamics of IoV applications, it is important that the context inference process is intelligible (also called scrutable) to allow at any time to understand "what the system knows, how it knows it, and what it is doing".

Further, this research area is also relevant to the provision of the necessary specification means, propose models for programmable interfaces (in a platform independent way) and interact for this purpose with the appropriate standardisation bodies. In this context, we will progress on vehicles architecture specification. In this respect, it will design and implement an in-vehicle process management system. The system will implement cause-action mechanisms based on rules that are defined e.g. to identify faulty or degraded or obsolete services. Such flexibility allows managing many types of exceptions in processes, also considering that web services have both permanent and transient faults. In addition, an in-vehicle communication manager will cater for the processing all the information coming from the vehicle signals (e.g., speed, throttle, brake activity, navigation destination, etc.) and decide what and when transmit to the external world (other vehicles, fixed infrastructure points, service centers). The decision will be taken by probabilistic algorithms complementing an expert-defined rule-based system, with the overall aim to guarantee the communication of data from the vehicle to the external world. The decision process will keep into account real time information e.g. on the network congestion state and the priorities of the messages to be delivered, as well as information about the neighbouring nodes. Furthermore, an in-vehicle human-computer interaction module will be created for the user interaction with other vehicles and the Internet to any vehicle-specific services. This interaction module will be designed in a way to act upon the driver's behalf to a maximum extend where possible.

5. Architecture for Internet-Connected Vehicles

The major objective of this research area is to perform all necessary actions to integrate the vehicles with the internet, so as to ensure the realization of the concept of IoV from an architectural point of view. In detail, this area of interest needs to:

• design and develop the functional and system architecture for IoV with functions that facilitate a higher operational efficiency of internet-connected vehicles; to do so, the system architecture will be adapted to the needs of a system applying autonomous decision-making techniques.

• Specify the necessary supporting functionalities (additional reference points, interfaces and protocols) and propose how those will be mapped onto existing standards and how to be efficiently be prepared for future ITS; this includes several architecture and protocol alignments with respect to Network and Application layer protocol extensions/modifications.

• Explore all networking issues with regards to service platform elements of IoV, so as to guarantee seamless connectiviy in heterogeneous environments;

• Design and develop engineering mechanisms to handle security aspects in a way they render communication inside internet-connected vehicles secure and trustworthy for all communicating parties.

In particular, this research area will provide the general architecture, combining the different components and mechanisms and providing guidelines for the development work. Based on the requirements devised in the business model area, architectural related work will identify and specify the functional blocks as well as the algorithms needed for making the data collected from the vehicles. Most of the work today focuses mainly on pushing sensor data from isolated sensor networks to the Internet. The IoV concept will move beyond this point also studying the appropriate transformation of this data for presentation to and processing by the IoV architecture components. This area will capitalise on existing standards (e.g. IEEE TC ITS) and provide further steps from current SOTA. This includes:

• Building a unique architectural framework that supports both the Telecom Functions (all system operations that ensure proper communication sessions control) and the O&M Functions (all system operations that ensure proper behaviour of the system elements).

• Specification of the system entities (their continuous identification and capabilities) and the self-healing, energy-efficiency and web-based functionalities that will be integrated in the architecture.

• Specification of the interfaces, the interactions and the corresponding signalling protocols for the interactions.

• Functional model and information set specifications for the basic enablers of IoV: Context awareness, context modeling and inference, eco driving, self-healing, autonomic decision making and management, governance of self-managed vehicles.

• Identification of the architecture's specified concepts' impact in standard and emerging network/equipment architectures and the corresponding standardisation opportunities.

• Progress on tool and implementation support by definition of standardised formal languages like DSL (Domain Specific Language) and FDL (Functional Description Language).

• Design and development of virtual gateway to route between different Radio Access Technologies (VANETs, UMTS, WiMAX, DVB, etc.).

In the light of the above, other important research challenges that fall in the realm of this area include:

• Mechanisms to reduce the average IP acquisition latency and the network overhead;

• Naming, addressing and object localization in networks of internet-connected vehicles

• Mechanisms to extend the coverage time of nodes in internet-connected vehicles from a DHCP perspective.

• Investigation of routing protocols including tunneling through non-IP links

• Investigation of OSPF extensions based on novel techniques, which deviate further from the conventional OSPF.

• IPv4/IPv6 functions blocks mapping to IoV architecture functional blocks

• Exploitation (through potential modifications) of IPv6 features in the system architecture and the IP transport network; e.g. investigation of WAVE short messaging protocol (WSMP) foreseen to be used on service channel (SCH) and control channel (CCH) and potential provision of gateways to the vehicle, so as not to restrict IoV applications to (one of) the service channels.

• Investigation of emerging needs of IP Mobility that can be treated also with Vertical Handover technologies; this include also the potential utilization of scalable mobile IP.

6. Case study: intelligent parking management

As an indicative area of application of the concept of IoV, this section presents a novel scheme for intelligent parking management based on wireless sensor networks and internet-connected vehicles and objects of the transportation infrastructure.

A first description of the parking management solution is provided in Figure 3. As shown there, the scheme, namely "i-park-wireless" will be based on the following features:

• Ad-hoc formation of networks of sensors among moving vehicles and objects of the transportation infrastructure. The networks' characteristics and parameters will be analyzed in detail, in order to enable information extraction;

- Combination of infrastructure information with data generated from onboard fused sensor data. In addition, knowledge inferred from previous stored and/or learnt experiences will also be used;
- Aggregation and interpretation of in-vehicle sensor measurements. Hierarchical processing of sensor measurements with specialized reasoning techniques will yield information about the vehicle-driver interactions and vehicle state at various abstraction levels;
- Basic learning techniques, such as pattern matching and context recognition that help a system compare current contextual situations with past ones and identify already applied solutions that could be put into effect. However, faster, more effective and more stable leaning strategies should be adopted;
- Issuing of directives to drivers in terms of the most effective traffic management and direction of vehicle towards the identified white parking space. This includes potential real time updates on-route.

The ultimate goal of such a scheme is to utilize internet-connections and sensors/sensor networks, so as to ensure the communication between vehicle and any relevant infrastructure system and efficiently directing the vehicle towards the desired destination (white parking space).

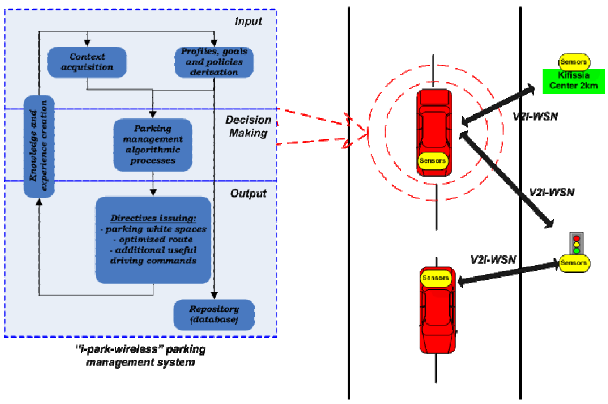

Figure 3: Outline of the i-park-wireless solution

7. Conclusions

With the unstoppable innovations in the world of telecommunications being introduced to human lives every day, novel areas of interest are sought for by research and development projects, as well as discussion fora, worldwide. Those efforts tend to identify novel services, applications and even products, which will aim at focusing at a specific human interest area and resolve issues that will facilitate people in their everyday activities.

An area that attracts increasing interest is transportation. Intelligent Transportation systems constitute the cornerstone of several research attempts at a worldwide level, with several novel concepts being introduced nowadays. A revolutionary idea lies in the attempt to connect vehicles through an all-IP based infrastructure, so as to target transportation, safety and emergency management, all under a green footprint. In this respect, this paper has presented the fundamental research issues that need to be tackled when trying to realize such a concept. In conclusion, it is envisaged that the concept of IoV will attempt to resolve several aspects of the world of transportation that nowadays constitute problems and facilitate transportation in a way that it could be come, safer, more efficient and green for everybody.

Last, the paper has presented a case study that could constitute an application area for internet-connected vehicles, namely parking management. As shown, several exciting areas are created and it is envisaged that research will soon follow the vision of internet-connected vehicles.

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