INTEGRATION CHALLENGES OF INTELLIGENT TRANSPORTATION SYSTEMS WITH CONNECTED VEHICLE, CLOUD COMPUTING, AND INTERNET OF THINGS TECHNOLOGIES

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ABSTRACT

Transportation is a necessary infrastructure for our modern society. The performance of transportation systems is of crucial importance for individual mobility, commerce, and for the economic growth of all nations. In recent years modern society has been facing more traffic jams, higher fuel prices, and an increase in CO_2 emissions. It is imperative to improve the safety and efficiency of transportation. Developing a sustainable intelligent transportation system requires the seamless integration and interoperability with emerging technologies such as connected vehicles, cloud computing, and the Internet of Things. In this article we present and discuss some of the integration challenges that must be addressed to enable an intelligent transportation system to address issues facing the transportation sector such as high fuel prices, high levels of CO_2 emissions, increasing traffic congestion, and improved road safety.

INTRODUCTION

It is common that on a typical day in modern society, a person has to face a considerable number of problems with current transportation systems, such as traffic congestion and parking difficulties, longer commuting times, higher levels of CO_2 emissions, and an increased number of accidents, among others. These problems continue to worsen because of population growth and the increasing migration to urban areas in many countries around the world.

A recent report by the United Nations Population Fund showed that for the first time, more than half of the world's population (around 3.5 billion people) lives in urban areas. It is expected that within 35 years, two out of three people will live in a city [1]. According to the United States Department of Transportation, during the 2002-2011 period the number of registered vehicles increased from 234 million to 253 million, the distance traveled by vehicles increased from 2.8 billion miles to 2.9 billion miles, and personal expenditures on transportation increased from 810 billion dollars to more than 1 trillion dollars [2].

Consequently, modern society could face serious problems with traffic congestions. It has been estimated that traffic congestion costs the U.S. economy more than 101 billion dollars per year [3], and the European Union economy approximately 2 percent of its gross domestic product (GDP) [4]. However, building or extending roads alone cannot solve traffic congestion problems because of the high costs as well as environmental and geographic limitations.

In the European Union approximately 12 percent of the total CO_2 emissions is produced by vehicles, which under current vehicle regulations should be reduced by almost 40 percent in new vehicles, from 158.7g/km in 2007 to 95g/km of CO_2 in 2020 [5]. Finally, even though the economic costs of transportation are significant, the human cost resulting from vehicular accidents is high. According to the Commission for Global Road Safety, road crashes kill at least 1.3 million people each year and injure 50 million, with 90 percent of these road casualties occurring in low and middle-income countries. Road crashes cost low and middle-income countries 65 billion dollars annually, exceeding the total amount received in developmental assistance. It is expected that road traffic injuries will become the fifth leading cause of death by 2030 if no actions are taken [6].

Developing a sustainable, intelligent transportation system requires better usage of existing infrastructures and the seamless integration of information and communication technologies (ICT). Advanced technologies in communications, electronic, and computing capabilities are being deployed and applied to assist in the dissemination of information, management of traffic flow and transport networks. Many of these systems have been closed systems that have been operating on their own or within a closed system

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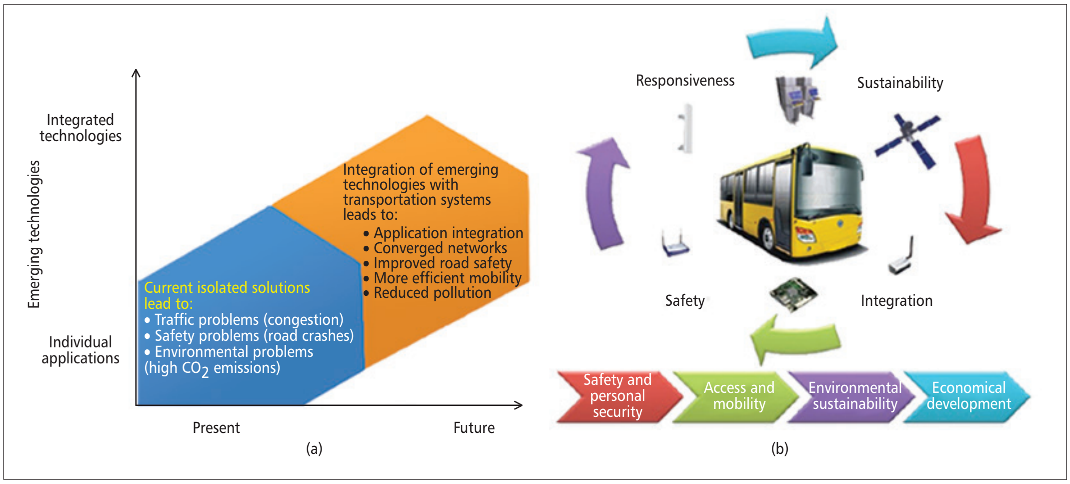

Figure 1. a) Future trends of intelligent transportation systems; b) impact of emerging technologies on ITS.

The adoption and deployment of emerging technologies in transportation systems focus on four fundamental principles: sustainability, integration, safety, and responsiveness, which will play a fundamental role in achieving the main objectives (access and mobility, environmental sustainability and economic development).

environment. But with increasing traffic in recent decades there is an urgent need for these systems to interoperate and communicate with each other, in order to provide a better, safer traveling experience and migrate to intelligent transportation systems (ITS).

Research Contributions of This Work

The main contributions of this work are two-fold. First, the primary goal of this work is to describe and discuss how, through the seamless integration of emerging technologies that include connected vehicles, cloud computing, and the Internet of Things (IoT) with transportation infrastructures, we can achieve a sustainable intelligent transportation system. By doing so we will be able to address issues such as high fuel prices, high levels of CO_2 emissions, high levels of traffic congestions, and improved road safety. Second, we present some of the challenges that need to be addressed in the future to achieve a fully operational cooperative ITS environment that can leverage the three aforementioned emerging technologies. In this context we also highlight some of the recent research projects aimed at addressing some of these issues and challenges.

Intelligent Transportation Systems

Intelligent transportation systems aim to minimize CO_2 emissions, improve traffic efficiency and road safety, as well as reduce vehicle wear, transportation times, and fuel consumption. Figure 1a illustrates the current and future impact of emerging technologies on transportation systems. The adoption and deployment of emerging technologies in transportation systems focus on four fundamental principles, sustainability, integration, safety, and responsiveness, that will play a fundamental role in achieving the main objectives (access and mobility, environmental sustainability, and economic development) shown in Fig. 1b.

Emerging technologies will enable the sustainability of transportation infrastructures. They will foster the efficient use of existing transportation infrastructures in order to regulate, control, and manage vehicular traffic by implementing novel techniques for collecting, processing, and disseminating information based on traffic conditions to improve congestion management and minimize its effects.

Traditionally, ITS have relied on isolated systems. ITS will need to evolve toward systems based on the seamless integration of a wide range of relevant heterogeneous technologies that can collect large amounts of data, process it, and then take appropriate actions based on this real-time information. These actions include influencing a vehicle's or driver's behavior by providing several benefits (reducing stress for drivers and minimizing or preventing road accidents, among others) that can help regulate traffic flow and reduce accidents, redirect traffic away from accidents and alert emergency services as soon as an incident occurs using all the collected information, and help reduce fuel consumption and greenhouse gas emissions.

Connected Vehicle and ITS

Connected vehicle focuses on vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-device systems (V2X) communication modes to support safety, mobility, and environmental applications using different emerging communication technologies such as a vehicle's dedicated short range communications (DSRC) or wireless access for vehicular environments (WAVE). The connected vehicle concept uses the following:
- Connected vehicle technology.
- Connected vehicle applications.
- Connected vehicle technology policy and institutional issues [7].

Connected vehicle technology refers to the development and deployment of a successful platform that allows for growth, expansion, integration of new technologies, the development of applications not yet envisioned, and complex human interactions. It also defines new challenges such as the definition of standards for interoperability; develops new schemes of system security; identifies and addresses technological challenges such as positioning, scalability, and other technical issues such as the clustering of moving vehicles to improve connectivity, the stability of clusters, handoff efficiency, and resilience to errors [8].

Connected vehicle applications focus on the development of applications to address transportation problems. The main research areas are vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications for safety, real-time data capture and management, and road weather management applications. It is crucial that these applications and services also support secure information transfers [9].

Finally, the *connected vehicle policy* focuses on the analysis of critical policy and institutional issues that can affect the successful development of applications and platforms. In this context, the research group, which might be composed of the Department of Transportation, key industry stakeholders, vehicle manufacturers, state and local governments, representative associations and citizens, will manage a research agenda to evaluate the benefits, risks, and results obtained from the successful deployment of connected vehicle technologies and applications.

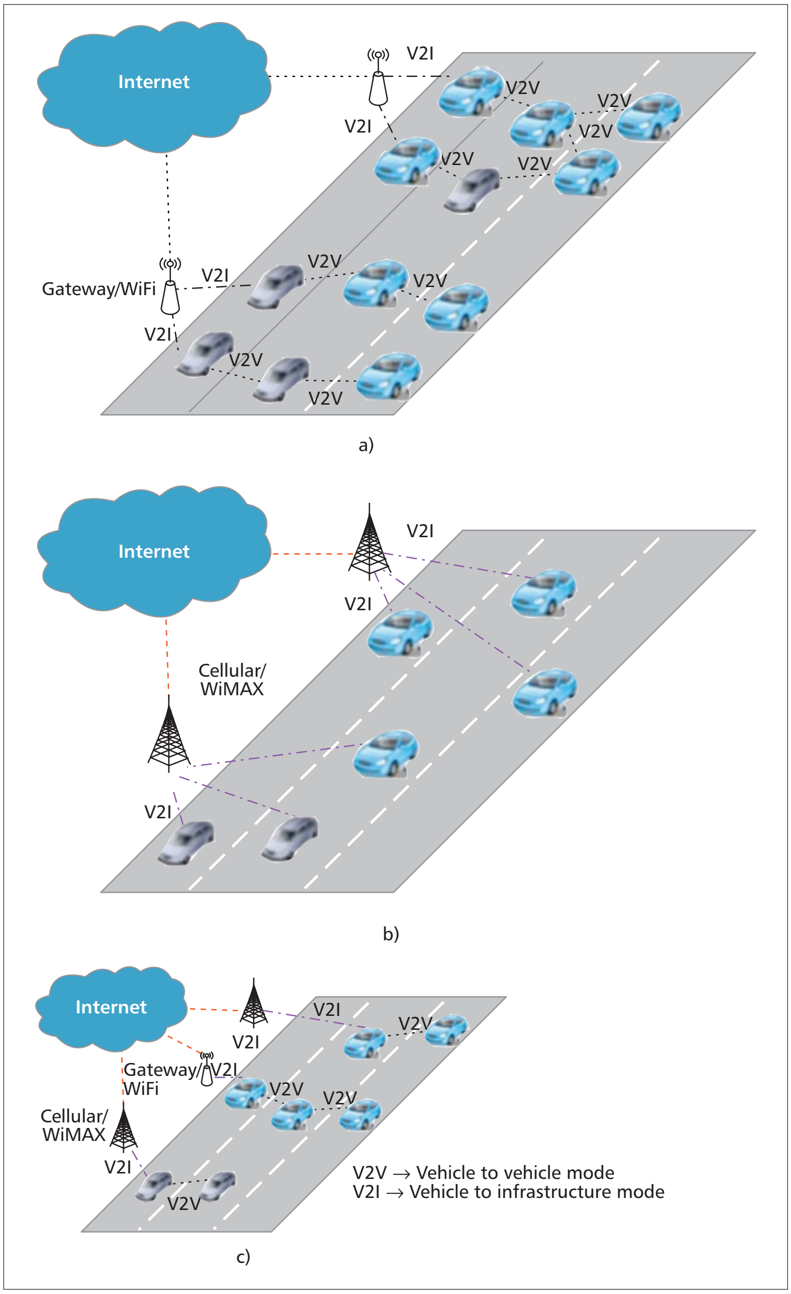

Figure 2. Wireless vehicular networking scenarios.

Sensing Support for Connected Vehicle

The success of connected vehicles will depend on sensing platforms with capabilities to access, collect, and process accurate sensor data. Sensing platforms include intra-vehicular sensor and urban sensing technologies, which are two of the most relevant sensing platforms used to collect information about traffic conditions. Some of the communication technologies used in vehicular environments include DSRC/WAVE, cellular networks, WiMAX, and 802.11p. These technologies can enable operations aimed at improving traffic flow, highway safety, and other ITS applications in a variety of environments. Vehicles equipped only with DSRC can operate in infrastructure-free mode (V2V only), infrastructure mode (V2I), and mixed mode (V2V and V2I) (Fig. 2a). Vehicles equipped with other broadband wireless access technologies (i.e. LTE, WiMAX) can communicate with each other via the Internet (Fig. 2b). For instance, people with smartphones and Internet access can set up a peer-to-peer (P2P) overlay network via the Internet. Finally, when vehicles have both DSRC and other broadband wireless access methods, we can have a mixed access scenario (Fig. 2c).

Challenges for Connected Vehicle

The connected vehicular environment needs to address several challenges in the future before it becomes successful. Despite the high number of projects currently focusing on connected vehicle research, the main challenge that remains is to generate a level of awareness that motivates governments and automobile manufacturers to invest in the implementation of adequate and necessary technologies and infrastructures in vehicles, roads, streets, and avenues. In addition, as we mentioned before, an environment of connected vehicles consists of different heterogeneous emerging technologies collaborating in a complementary way. This in turn requires the development of algorithms that provide intelligence to communication devices installed inside vehicles to make decisions about the best technology to use based on the current environmental conditions and the quality of service (QoS) parameters of the requested application, as well as information security mechanisms used to assure the secure exchange of information. Emergency applications require a network connection with low delays.

In the near future, vehicles could start sensing physiological parameters of passengers using a wireless sensor network installed inside the vehicle. In an emergency situation, the sensed information is then transmitted to nearby emergency vehicles such as ambulances, or to hospitals for them to prepare in advance for the arrival of the passengers in the vehicle. In contrast, assistance and entertainment applications do not have strict QoS requirements. For such applications we need to develop new intelligent algorithms that can continuously sense variables and environmental conditions to select the most appropriate network to fulfill those requirements. To address several of the challenges related to connected vehicle research, various projects have been

Project	Project description
SAFETYPILOT Model Deployment (USA) 1st phase (2012–2013) 2nd phase (2013) [10]	One of the most important connected vehicle projects developed by the University of Michigan's Transportation Research Institute. It has equipped more than 2800 cars, trucks, and buses with V2V and V2I communication devices. The first phase aims to enhance crash avoidance and improve traffic flow. The second phase focuses on connected vehicle operations in real settings, investigates how to increase safety benefits and how often drivers use connected vehicle technologies.
USDOT Connected Vehicle Research Program (USA) Ongoing (2013 – present) [10]	This is the main project of the U.S. Department of Transportation. It analyzes technology to improve public safety, surface transportation mobility, and connected vehicle research policy issues. The main research issue in this project is V2V secure communications.
Cooperative Transportation System Pooled Fund Study (CTS PFS) (USA) Ongoing (2013 – present) [10]	This study was funded by state and local transportation agencies in partnership with the Federal Highway Administration (FHWA). It is researching and testing high-priority connected vehicle mobility applications as well as prototyping and testing practical infrastructure-oriented applications for potential deployment and focus on traffic signal-related applications.
Multi-Modal Intelligent Traffic Signal System (USA) Ongoing (2013 – present) [10]	This project aims to conduct field-testing of a comprehensive traffic signal system using the connected vehicle environment for multiple transportation modes, including general passenger vehicles, transit, emergency vehicles, freight vehicles, and pedestrians. The Multi-Modal Intelligent Traffic Signal System (MMITSS) incorporates the arterial traffic signal applications identified through the dynamic mobility applications (DMA) program design and conducts a field-test on a traffic signal system using connected vehicle for various types of vehicles (emergency, freight, transit).
COMSafety European Union-USA [11] Ongoing (2012 – present)	The goal of the EU-U.S. cooperation on ITS is to speed up the deployment and adoption of connected vehicles, but they have identified interoperability challenges and security issues, and the aim to develop communication standards for connected vehicles.
COMPANYON Project (Sweden) 2013 – 2016 [12]	The idea of this project is to develop a system for implementing truck platooning on roads that can significantly contribute toward reducing the carbon footprint of trucks through V2V communications between trucks.
DRIVE-IN Project (Portugal) 2009 – 2012	This project was developed by three universities: Aveiro, Porto, and Carnegie Mellon. It used a testbed with a fleet of 500 taxis using 3G links for communication. The main aim of the project was to improve the user experience, efficiency of vehicle, and road use with V2V communications (http://www.cmuportugal.org/tiercontent.aspx?id=1552).

Table 1. Recent connected vehicle research projects.

undertaken recently, some of which are presented in Table 1.

Integration of Cloud Computing with ITS

Cloud Computing normally includes three layers: application, platform, and infrastructure. The infrastructure layer (infrastructure as a service (IaaS)) creates virtual servers/computers from resources such as computing, storage, software, or communication devices. For example, a vehicle with Internet access can run applications and programs on an advanced virtual computer with strong computation, communication, and sensing capabilities and large amounts of storage. The platform layer (platform as a service (PaaS)) configures components to support services (e.g. file transfer, email). Drivers can develop and deploy applications that can run in the cloud environment. The software as a service (SaaS) layer supports applications in a "pay-as-you-go" mode in the cloud. In this context, some applications such as traffic news, road conditions, or intelligent navigation systems can be provided in vehicular clouds, which can offer a wide variety of computing services as described in [13].

Cloud computing can strengthen ITS by storing and processing the collected information (such as traffic lights, parking meters, cameras, urban sensors, etc.) and creating a historical registry of avenue pattern behavior allowing the road department to make informed decisions on when to remodel or repair avenues, change traffic directions, or install new traffic lights. Recently, the concept of vehicular cloud (Fig. 3) has emerged. The motivation behind vehicular cloud stems from the capabilities of third-party providers to support non-safety-related applications in VANETs that include location-based services, Internet access, vehicular peer-to-peer communications, on-line gaming, and other forms of mobile entertainment. The main advantage of vehicular cloud is that it is not necessary to deploy additional infrastructures because cloud vehicles can use the existing transportation and communication infrastructures.

A vehicular cloud-computing environment exploits the capabilities of vehicles that are used as mobile cloud servers. In this way, cloud computing services are offered by vehicles that have sufficient resources to act as cloud servers, which have sufficient resources and/or Internet access to consumers (vehicles) that rent the resources. Consumers need to discover the mobile cloud servers, be aware of their resources, and communicate and request resources from them. Mershad and Artail identify three main services for

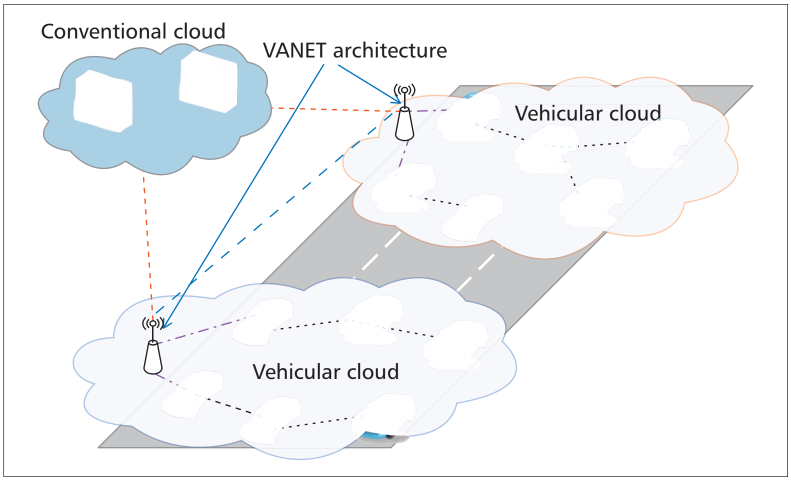

Figure 3. Vehicular Cloud architecture.

vehicular clouds [14]. One is network as a service or NaaS (Internet access), where some smart vehicles have a permanent Internet connection (e.g. via a cellular network), but others do not. The idea of this service is that smart vehicles with Internet access offer their extra bandwidth to others for a certain fee. The second service is storage as a service or SaaS (virtual network hard-disk), where some smart vehicles have high on-board storage capacity and they can share it with other vehicles that may need additional storage. The third service is called data as a service or DaaS (virtual data provider). In this scenario, users in a smart vehicle may request specific data such as a video file, a city map, and the road conditions, among others.

The authors in [15] defined the term autonomous vehicular clouds (AVC) as autonomous vehicles with different resources (computing, sensing, communication, and physical) that are coordinated and can be dynamically allocated to authorized users. In the near future we expect that connected vehicles will be equipped with Internet access and on-board computational, storage, and sensing capabilities. In a typical scenario, the owners of connected vehicles may lease their vehicles' capabilities on demand and receive revenues. Vehicular clouds provide services through connected vehicles and can be broadly classified into two categories. The first category, called infrastructure-based vehicular cloud (IVC), is similar to the traditional cloud-computing environment where a service provider provides ubiquitous services to all vehicles using network communications that involve the roadside infrastructure. The second category, called autonomous vehicular cloud (AVC), is slightly different from IVC because in this type of cloud, vehicles can be organized on the fly to form autonomous vehicular clouds to handle emergencies (i.e. medical emergencies to provide a free pass to medical vehicles, risk condition notifications).

Vehicular Cloud Challenges

Vehicular cloud faces numerous challenges for its success. The performance of the vehicular cloud can be affected by the high mobility of vehicles, which reduces the ability of a specific vehicle to serve as a cloud server. In other words, the duration of vehicles acting as a cloud server in the coverage area of other vehicles is fairly short and the economic benefits for cloud servers would be minimal. Security and privacy challenges in vehicular clouds also include the authentication of highly mobile vehicles and the complexity of trust relationships among multiple players caused by intermittent short-range communications. Finally, another challenge is the definition of selective network coding methods to enhance the reliability and efficiency of information dissemination. However, we should also consider network design and scalability given the high number of data sources and customers that will be involved [16]. Table 2 presents some recent vehicular cloud projects that have been undertaken.

Integration of the Internet of Things (IoT) with ITS

For a long time the main type of communication has been human to human. However, it is expected that in the very near future every object will be connected. "Things" can exchange information by themselves, and the number of "things" connected to the Internet will be much larger than the number of "people" who may become the minority of producers and of information traffic. It is expected that machines communicating with other machines on behalf of people will dominate the future of Internet communications. This new vision is called the Internet of Things (IoT) era in which new types of communication between humans and things, and among things themselves, will be achieved. One recent work [18] proposes a taxonomy that will help define the components required for the Internet of Things covering all the layers of the OSI reference model. The authors define three IoT components (hardware, middleware, presentation), which enable seamless ubiquitous computing for users or devices.

Recently, the integration of the Internet of Things with intelligent transportation systems has been explored (as described in [19]). The Internet of Things will complement the evolution of intelligent transportation systems based on the concept of object-to-object communication. ITS can provide the hardware element of the IoT with devices such as radio frequency identification (RFID) tags and readers, sensor technologies, positioning systems, and emerging technologies to collect information about traffic conditions in the environment where they are placed. Such information could include, but is not limited to, road conditions, traffic accidents, road repairs, or redesigning of avenues. For example, a distributed set of wireless sensor nodes could be used to detect vehicular behavior (speed, direction, flow cuts, and travel times) and sends this information to processing devices (these devices could be integrated within the same environment as the sensors or within a cloud environment) to make intelligent decisions such as dynamic traffic light times and changing the number of lanes available in each direction, among others. In addition, data can be stored and processed in virtual servers through cloud computing (middleware element). This information can be used in the future to model traffic and drivers' behaviors, using wheel drive sensors or diadems to read neural signals to detect mood changes, stress levels, or general body con-

Project	Project Description
Instant Mobility Project Ongoing (2011 – present) [17]	This project, developed by the UK Consortium, examines the transport infrastructure as a service. The objective of the project is the definition of scenarios on dynamic traffic management and integrated urban space on how to use future Internet technologies such as cloud data storage, cloud computing virtualization, or services in the cloud. Its goal is the application of advanced Internet technologies to develop and explore a concept to transform the mobility of people and goods in the future.
Volvo and Ericsson partnership Ongoing (2012 – present)	The collaboration of Volvo and Ericsson is focused on cloud integration into vehicles to allow Volvo cars to access infotainment, applications, and communications. The goal is the integration of vehicular cloud services in all car models to provide consumers with the same level of digital services they have in their homes or at work (http://www.gizmag.com/volvo-ericsson-infotainment/25488/).
WINSmartEV Project Ongoing (2008 – present)	A UCLA project aimed at developing a cloud-based scalable architecture for energy storage, consumption, and management for electric vehicles complemented with the integration of control technologies such as wireless and RF-monitoring. The objective of this project is to reduce energy cost and usage and to increase the stability of local power systems (http://www.winmec.ucla.edu/ev.asp).
Green eMotion Project Ongoing (2012 – present)	IBM and Green eMotion partners are developing a network of electric vehicle charging services in Europe based on a cloud-based platform that allows charging stations located around Europe to share payment information. The goal of the project is to allow energy providers, car manufacturers, and charging point owners to share and integrate services on a cloud-based IT platform (http://www.greenemotion-project.eu/home/index.php).

Table 2. Vehicular Cloud projects.

dition, enabling notifications to be sent to nearby vehicles about dangerous or aggressive driving patterns, allowing them to avoid accidents.

The interaction of IoT elements (such as traffic lights, RFID tags and readers, cameras) can lead to intelligent management and optimized operations in the transportation system, thus addressing problems such as traffic jams, accidents, and inefficient transportation, among others. The integration of IoT within ITS, along with the collected information generated within the environment, will enable a quick response to emergencies. As a result, this will improve the efficiency of the existing transportation infrastructure and transportation information (such as traffic lights, parking meters, cameras, urban sensors, etc.) using algorithms, protocols, and mechanisms for information processing to distribute the information quickly and efficiently to help address traffic problems such as accidents, casualties, and congestion points.

The integration of IoT with ITS faces several research challenges. Tracking and managing the high number of devices that will be involved in the integration of IoT in ITS remains a significant challenge. Standardization bodies need to define novel approaches for device identification and the generation of unique Identifiers (IDs). Some of the open questions we need to address may include: How to use these IDs as addresses to forward and route information? How to design an ID-based IoT for ITS? Traffic data collected from IoT sensors can carry sensitive private information about drivers. In addition, information transmitted wirelessly is prone to eavesdropping and various types of attacks. We need secure mechanisms in place to protect personal or confidential information.

Another challenge is the development of federated systems that allow different devices from multiple environments to seamlessly move from one network to another using the same authentication credentials (e.g. by using the same authentication information across different communication technologies in a vehicle). One possible approach to address this authentication issue would be the establishment of a global trusted network for transportation. To address some of the research challenges associated with integrating ITS with IoT, some recent projects undertaken to date are shown in Table 3.

Conclusion

The main objective of intelligent transportation systems is to improve the security, efficiency, and control of transportation through the dissemination of relevant information within the environment where they are applied. However, for ITS to be successful, the use, integration, and deployment of emerging technologies for transportation systems becomes imperative.

In this work we have presented some of the most relevant emerging technologies that can complement ITS. Connected vehicles allow vehicle-to-vehicle and vehicle-to-infrastructure communications using wireless technologies to exchange relevant information. We also showed how cloud computing offers information and entertainment to drivers, complementing the current development in transportation systems but focusing on traffic control and road safety. Finally, we discuss how IoT will also complement ITS by allowing communication with any other electronic device that can access the Internet. We argue that by leveraging the seamless integration of the three emerging technologies with ITS, we can develop more sustainable transportation solutions and improve road safety in the future.

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Project	Project Description
IoT6 Project October 2011 – September 2014 [20]	A FP7 European research project that explored the potential of IPv6 and related standards (6LoWPAN, CORE, COAP, etc.) to overcome current shortcomings and fragmentation within the Internet of Things. Its goal was to research, design, and develop a highly scalable IPv6-based service-oriented architecture to achieve interoperability, mobility, cloud computing integration, and intelligence distribution among heterogeneous smart things components, applications, and services.
i-MOVE project Ongoing (2013 – April 2014)	The project focused on investigating the potential use of mobile technologies and the "Internet of Things" to revolutionize the transport sector. The idea is to share developers' collected data from a wide range of objects affecting transport systems around Liverpool (United Kingdom) to help benefit everyday life by supporting management, environmental sciences, healthcare, and product maintenance (http://www.aimesgridservices.com/aimes-wins-national-internet-of-things-research-project/).
BMW and Siemens trial system [21] 2010	BMW and Siemens developed a communication prototype based on a set of sensors installed in traffic lights and cars that constantly gather information about traffic conditions and driving behavior aimed at optimizing the automatic start-stop function of braking when approaching a traffic light and to send warning messages to vehicles behind about icy roads, traffic jams, or similar situations.
Smart Parking in London (January 2014 – present)	This project has been initiated by Westminster's council in the United Kingdom, and the Smart Parking firm installed 3000 infra-red sensors in paid-for parking spots to reduce congestion and carbon emissions. The sensors detect whether or not the parking spot is occupied. Its mobile application directs drivers to an empty space using a real-time map (http://www.cbronline. com/news/5-uk-internet-of-things-transport-projects-4416598).

Table 3. IoT-related vehicular projects.

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