# Intelligent technologies for mobility in Smart Cities

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**Smart Cities are associated with a higher quality of life that is determined through several factors including for example basic services, safety and security. Technology makes it possible to compile massive amounts of real-time data to optimize the urban infrastructure, thus improving efficiency and effectiveness of citizens' ability to navigate. The analysis of these location-based data enables us to determine which services could be useful for citizens at a certain time, for example, thereby improving the efficiency of public and transport services. Various aspects of technologies that enable smart mobility in cities are presented in this paper.**

## 1. Introduction

In an effort to organize the characterization of Smart Cities, different categories such as economy, people, governance, mobility, environment, and living Smart Cities have been compiled within the EU project "European Smart Cities" [1]. Other decisive factors that characterize Smart Cities include: information and communication systems; energy efficiency and sustainability initiatives; citizen engagement and empowerment; open data and government transparency; transportation; public safety and security; parking and traffic management, and several other factors [2].

To determine if societal needs or technological trends affect this selection of parameters, it is crucial to investigate the role of the citizens. Similarly to the development process of a software product according to user-centered design principles, it is important to consider the knowledge of future users to find out their needs and guarantee a citizen-friendly living environment. Taking this into account helps prevent, unnecessary growth and development of undesirable or useless information and infrastructure, which would only overwhelm and upset citizens and negatively affect their quality of life.

Knowledge resulting from the analysis of massive amounts of data compiled using technology, can assist in the creation of extensive social benefits [3]. Particularly, digital technologies derived from real-time data optimize the urban infrastructure, thus improving efficiency and effectiveness of citizen navigation. The growing trend towards ubiquitous information communication that results from pervasive computing is particularly embodied in today's smart devices, which already integrate a variety of cost-efficient embedded sensors and facilitate the acquisition of data to study mobility patterns [4].

Research related to these location-based data enables us to take a decision about which services could be useful for citizens in order to improve the efficiency of public and transport services and citizens' quality of life.

This paper addresses different technological approaches for Smart Mobility within cities. It is organized as follows. The upcoming section reviews the state-of-the-art and related work in the area of Smart Cities. Section 3 demonstrates the importance of urban traffic data in Smart Mobility. Section 4 describes the introduction of Autonomous Vehicles in Smart Cities. Concluding thoughts are provided in the final section of the paper.

## 2. State of the art and related work

### A. Smart Cities

Smart Cities are associated with a high quality of life. Quality of life is determined through several diverse factors that include basic services, safety and security, as well as the availability of green open spaces and sustainable transport systems. Other less obvious indicators are actively promoted and elevated citizen interaction and social inclusion, which can be embodied by shared public spaces for cultural and sport activities, for example [5].

The European Initiative on Smart Cities aims to support cities and regions in taking ambitious measures to make certain progress by 2020 towards a 40% reduction of greenhouse gas emissions through sustainable use and production of energy [6]. Similarly, the European Innovation Partnership on Smart Cities and Communities (EIP-SCC) intends to develop collaborative and participatory approaches for cities, industry and citizens to improve urban life through sustainable solutions that include a more efficient use of the energy, transport and Information and Communication Technologies (ICT) [7]. There are already over 14 European projects that have their focus in the sectors "Energy", "Transport & Mobility" or “ICT” that resulted from this European Partnership [8]. Energy-related aspects are addressed by 9 of the 14, while 3 cover all the areas Energy, Transport & Mobility and ICT.

According to [9] European cities have better public transit, and a stronger focus on sustainability and low-carbon solutions. The cities in Europe that in 2014 had developed the most innovative actions related to infrastructures and technologies are Copenhagen, Amsterdam, Vienna, Barcelona, Paris, Stockholm, London, Hamburg, Berlin and Helsinki. However, there is still room for improvement at a European level aiming at a decrease of pollution and carbon dioxide emissions. For example, several European cities have already started plans to restrict traffic and parking in downtown areas, with interruption of the production of industrial plants, or via speed limitations [10] to alleviate the current high levels of carbon dioxide output.

### B. Connectivity

There has been a drastic increment in the number of systems which rely upon sensor data collection. This in turn generates a large body of information and sources to analyze.

Furthermore, there is an overall increase in the application of digital technologies through the deployment of physical sensors in homes, buildings and cities to improve the quality of life of the citizens. The overall goal is to make cities more attractive and sustainable by means of reducing costs and resource consumption. This pervasive computing context opens the possibility of designing Smart City applications which base their functioning on intelligent technologies that simultaneously reside in other applications that communicate with each other. This integration of ICT in conventional city infrastructures is part of the strategic initiatives of the international joint projects of the Connected Smart Cities Network described in [11].

In this context of connectivity in recent years a huge amount of work has been dedicated to sensors supported by Internet of Things (IoT). Intelligent displays in appliances as platforms to share information with additional mobile devices, to manage a healthier diet or to save energy in the household are some of the applications based on IoT.

But at a citizen level, big expectations have been put into the IoT as technology for an ubiquitous information access via the Internet. The large concentration of resources and facilities that attract people from rural areas to cities [12] is causing a population growth that is making it increasingly challenging for city governance and politics to enact efficient city management. There is great potential in the IoT in developing and connecting technologies which assist in improved city management and better quality of life for the growing citizenry. The number of devices connected to the Internet predicted for 2020 by the European Commission (between 50 to 100 billion) [13] will build the base for cooperation frameworks for access to knowledge resources.

To receive the label “smart” Cities rely on broadband connectivity [3]. A concept representing the elements that constitute a Smart City using digital technologies has been proposed in [14]. A Smart City was differentiated from non-Smart Cities by the authors as an assemblage of different components to understand and coordinate urban problems with innovative technologies in an effective and feasible manner. Their framework covered different dimensions including urban governance and functioning, infrastructure organization, transport, and energy.

The vision of the Internet components, Internet of Things and Internet of Services (IoS), to transform a Smart City into an open innovation platform has been specified in [15,16].

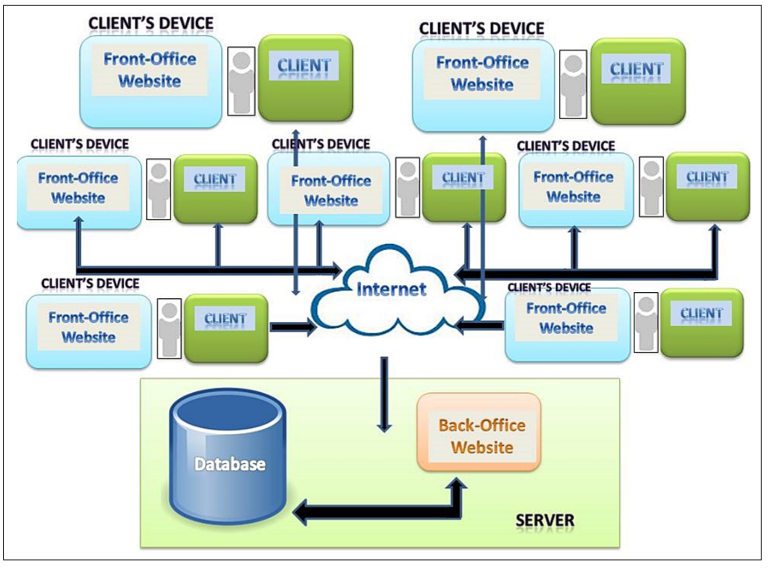
The authors also present a generic concept implementation based on Ubiquitous Sensor Networks.

As the use of IoT to support sustainable development of future Smart Cities entails several difficulties that are related to the different nature of the connected objects, a work was proposed in [17] that described a management framework for IoT. Within this system, objects are represented in a virtualized environment. Through the use of cognitive and proximity approaches the authors make it possible to select the most relevant objects to Smart Cities.

### C. Collaborative Approaches

Collaborative teamwork based on shared mental models is required to create frameworks for understanding joint work [19,20]. This work has to be collectively conceived and shared by several users relying on activity awareness, and this collaboration is also crucial in Smart Cities, where it can occur at local or intercity levels.

*Figure 1.*
*Client-server architecture to share urban information (adapted from [18])*



As local based solutions are expensive to develop and maintain, it is essential to develop frameworks and platforms to share knowledge and best practices. To this end, methodologies that capture data related to citizens preferences and habits help to identify and understand their needs and goals. For example, through measurements to establish relationships between independent variables such as citizen's age and other dependent variables such as ease of use of a certain service provided by the city for which several tasks have been defined.

Citizen feedback on issues and suggestions for improvement of services [21] are a fundamental requisite for a sustainable, efficient city. Modern pervasive communication technologies make it possible to share widely available information between citizens and public authorities so that a subsequent data analysis can be performed by taking advantage of crowd-sourcing data technologies. *Figure 1* shows an example of information client-server architecture to share urban information.

## 3. Urban mobile data

Roads are a shared space for people and vehicles. In the same manner that applied sensor technology is fundamental in IoT and IoS, sensors can be integrated into road infrastructure to recognize and monitor a wide repertoire of activities related to the transportation sector. According to [22] the European Commission's Action plan for the deployment of intelligent transport systems in Europe aims to make road transport and its interfaces with other transport modes more environmentally friendly, efficient and safer. To this end, European standards, for example for the exchange of data, need to be set. Moreover, the EU aims to encourage the use of different transport modes to reduce congestion and greenhouse gas emissions, decrease the number of road traffic accidents and energy consumption.

### A. Mobility Patterns

The monitoring of mobility patterns can be used to study driving behavior for improving traffic flow through a reduction of traffic congestion and an increase of road safety [23,24]. In addition, pedestrians and other vulnerable road users (VRU) can be supported by mobile applications for use in public spaces or transport in their route choices to minimize potential dangers. Mobility patterns determine habits and selected route, therefore they are crucial in providing personal multimodal mobility services. Crowd-sourcing data available through mobile devices and processed through cloud-based architectures facilitate the monitoring process. *Figure 2* depicts a framework to acquiring, storing, processing and analyzing mobility related data using smartphone sensors.

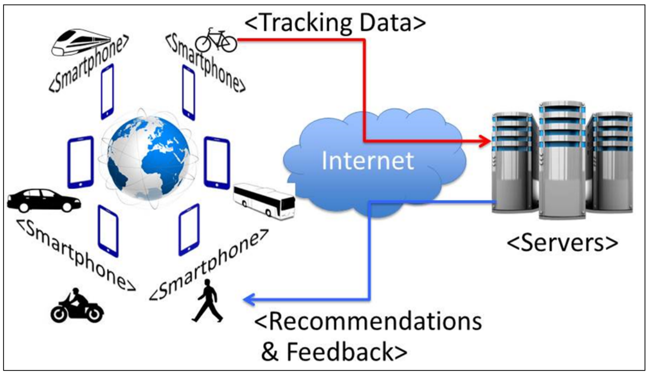



*Figure 2.*
*Framework for the acquisition, storage, processing and analysis of mobility-related data using smartphone sensors [4]*

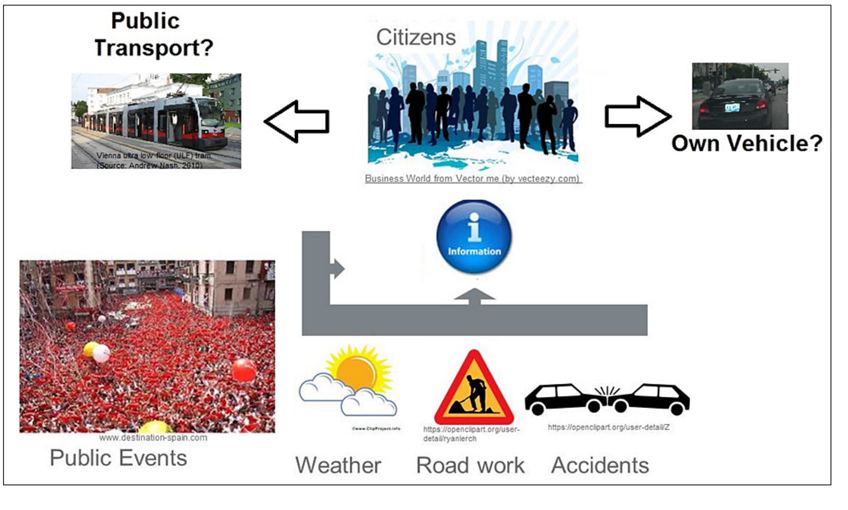
Similarly, pedestrian distraction associated with mobile phone usage can be monitored, as it is becoming a very prominent safety issue, particularly relevant in urban environments with high traffic density [25].

Vehicle-to-pedestrian (V2P) and pedestrian-to-vehicle (P2V) communication technologies for exchanging information work towards improving road use and safety through warnings for users regarding potential dangers. Research, mostly based on GPS data, has been developed in this field. For example, the authors in [26] developed a system based on wireless pedestrian-to-vehicle communication which was able to issue warnings of collision risk.

Since perception and communication are essential for VRU safety, theoretical models and studies have additionally been performed in real-world environments to test the reliability of several systems in [27]. A cooperative system as a combination of both approaches that integrates the outputs of the communication and perception systems was proposed as the optimal solution by the authors.

The use of mobile devices in a road context by drivers and VRU is rapidly increasing. In a vehicular context, proper in-vehicle warnings and function location

*Figure 3.*
*Selected factors that determine the use of public transportation or private vehicles*



that enhances visibility and reduces the distraction potential has been the focus of design by automotive manufacturers for many years [28].

Urban mobile data makes it possible to develop intelligent mobility concepts, in which public transportation replacing private vehicles, and a traffic reduction account for an efficient flow of the remaining vehicles, consequently lowering total carbon emissions. The goal is to achieve a balanced optimization of transit use and personal vehicles, for a faster commute and environmental benefits.

To this end, improvements in urban mobility have been initiated through planning of routes in real time. As several factors such as weather, maintenance work, accidents, public events, etc. determine the use of public transportation but also of private vehicles [3], it is important to provide clear and accurate real time information that allows commuters to make decisions regarding the use of public transportation or personal vehicles, and also to select the mode of transportation that better fits everyone's needs *(Figure 3)*.

### B. Urban Traffic Data

Urban traffic data can be acquired through sensors available on road infrastructure or on the cars themselves. The authors in [29] deployed Bluetooth scanners along the freeway/arterial network in the road proximity to study and characterize urban traffic conditions. The collected travel time information enabled an effective traffic management, control and flow optimization as well as the basis for improving existing routing algorithms, positively affecting costs related to logistics and reducing the environmental impact. Exchange of information through cooperative systems is imperative to enhance road safety. To this end, urban environments provide the test bed conditions required to perform realistic field test experiments with massive amounts of valuable data. This allows for the testing of a variety of protocols, as well as interaction with in-vehicle systems and services.

For example, within the design and development of the See-Through System [30,31] experiments under real conditions were performed in order to test potential connectivity issues and data transmission delays using the 802.11p standard wireless communication protocol.

## 4. Introducing autonomous vehicles in Smart Cities

Realistic Vehicular Ad Hoc Networks (VANETs) and the related technology, for example those implemented in autonomous car applications, will change cities as we know them. As stated by the executive director of the car manufacturer Ford, Mark Fields, "2016 will be a revolutionary year for automotive and transport, in which we will see radical advances that will change the way to move".

According to the International Organization for Road Accident Prevention [32], human error is the cause of 90 percent of the road accidents. To alleviate the number of accidents, the introduction of Autonomous Vehicles (AV) on our roads represents an opportunity for increased road safety as the automation will make driver intervention in the control of the vehicle unnecessary *(Figure 4)*.

*Figure 4.*
*Autonomous vehicle passenger that does not require overseeing the driving task*

Other advantages of the use of driverless vehicles will be an uninterrupted traffic flow and energy consumption reduction through a decrease of the aerodynamic impact on the vehicles. This will be ensured by sensors that will control the spaces between vehicles and the observance of the safety distance. Moreover, Autonomous Vehicles will foster the sharing of vehicles without the need of owning them.

It is expected that AV represent more opportunities to develop innovative in-vehicle technology for entertainment or information purposes that will require a cockpit design adaptation and modification of the car controls for more flexibility of movement within the vehicle.

The potential boredom and road monotony associated with the higher automatism of the vehicles might lead to a driver situation awareness reduction. This condition will have to be compensated by new ways of prominent and understandable continuous feedback that might, on the other hand, decrease the joy of use. Research in the field is imperative to guarantee an optimum level of automation that demands a balance of cognitive workload.

Autonomous Vehicles are already reshaping our current societal business organization as they enable new business opportunities based on car sharing. It is not clear yet who will be the future customers or who will maintain ownership of the vehicles, for example whether they will be owned by the suburbian commuter population themselves. Maybe the comfort that AV provides will cause an increase in population relocation to suburbs, and consequent environmental problems will follow. If self-driving cars are getting popular among citizens, and downsides such as potential hacking exposure or safety concerns are surpassed, their traveling comfort and privacy will seriously compete with the use of public transportation.

On the other hand, AV will require a lower number of cars per household, create more opportunities for car sharing, demand fewer parking lots and will entail better use of road space (as they allow for narrower city lanes and therefore more room for pedestrians and green spaces). This in turn will count towards an improvement of the quality of life in cities.

Whether road redesign will be required (i.e. by adding dedicated lanes for AV) or adaptation of infrastructure such as marking for road signals, or even VRU marking for better recognition, is necessary, is not yet clear; but in this case it will represent an opportunity for improvement.

## 5. Conclusion

This paper gives an overview of different aspects and factors that determine the qualification of modern “Smart Cities”.

Even if a big number of projects and initiatives have been started to provide citizens with efficient and effective services, there is still room for improvement, particularly concerning environmental benefits. Applied sensor technology is fundamental in sharing knowledge and fostering communication within and between cities, as well as in gathering feedback from citizens, in particular those adopting IoT and IoS technologies in their cities. Environmentally friendly, efficient and safer road transport that fosters multimodal transport through the exchange of data, is a crucial objective to reduce congestion and greenhouse gas emissions. To this end, sensors can be applied into road infrastructure to recognize and monitor a wide repertoire of activities related to the transportation sector.

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