Intelligent Transportation Systems: a ubiquitous perspective

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Abstract. The concept of intelligent transportation has been devised about a couple of decades ago and still presents many challenging issues to be addressed so as it can be implemented to its full potential. In this paper we emphasise characteristics such as being user-centred and service oriented to support an important facet of future urban transportation: being ubiquitous. Instead of seeing ubiquitous transportation as a completely different paradigm, we discuss on the characteristics that actually turn ITS inherently ubiquitous.

Keywords: ubiquitous computing, ambient intelligence, intelligent transportation systems.

1 Introduction

With the growth of population in major urban areas and the accelerated increase in number of cars, traffic is becoming generically chaotic. The problem of congestions, differently from what many might think, not only affects the day-to-day life of citizens but also has a great impact on business and economic activities. These issues therefore generate less income, affecting the sustainable growth of cities throughout the world.

Considering current problems of traffic management, control and planning, especially fearing the consequences of their medium and long term effects, both practitioners and the scientific communities have strived to tackle congestion in large urban networks. Research has been carried out basically towards the design and specification of future transport solutions featuring autonomy, putting the user in the centre of all concerns and largely oriented to services. Such efforts were eventually to culminate in the emergence of the concept of Intelligent Transportation Systems (ITS), basically relying on a distributed and advanced communication infrastructure favouring interaction in virtually all level, from users to services, vehicles to vehicles, vehicles to infrastructure, and so forth. Interoperability and integration are crucial in this scenario. More futuristic though is the perspective in which users will play rather a passive role and be taken off the whole process, which will ultimately be managed by the system only, to which autonomous driving is expected to be an important ingredient. Although this view may seem quite hypothetical, it is capable to stimulate and foster much advancement in a wide spectrum of multidisciplinary fields, from engineering and computer science to sociology and urban planning and design.

In this work we basically recall many of the different aspects involved in the original definition of ITS and identify potential applications of the ubiquitous computing concept (sometimes hereafter referred to as ubicomp). Instead of defining a novel perspective for what has been recently coined Ubiquitous Transportation Systems (UTS), we prefer to see ITS from a ubiquitous perspective, emphasising those characteristics that actually turn ITS into ubiquitous systems. Therefore, ITS is inherently ubiquitous! Besides ubiquity, pervasiveness, ambient awareness and intelligence are equally addressed as complementary and conceptually related technologies. Many issues and interesting question marks rise in this context, stimulating different streams for further research, some of which are also discussed.

Following this brief motivation of the topic, the remaining of this paper is organised as follows. In the next section, we discuss on requirements for future urban transport so as it is possible for us to better understand why the whole bunch of technologies presented later on are important. Those are then presented and briefly discussed in the following section. Ubiquitous transportation is then presented in the fourth section, finally followed by some remarks, conclusions drawn and suggestions for future work.

2 Future Urban Transport

Persons and goods are transported for centuries, which have turned transport into an essential part of any economy based on trade. Basically, transport systems are intended to take both people and other goods from certain points to one or more destinations, accounting for users' needs, efficiency, and low cost as well. These systems have become rather complex and extremely large, being geographically and functionally distributed, both in that respecting structure and management.

Contemporary transportation systems have experienced three major revolutions throughout their existence. The first one came with the introduction of electromagnetic communication, allowing for a network of information that enabled greater integration of the system to exchange information more quickly and efficiently. The second great revolution started with the advent of digital systems delivering lower cost services. Then computers started playing an imperative role in transportation, improving efficiency of traffic control and coordination, as well as transport planning. Centralised traffic coordination started as well playing a major role in network design and management. Albeit centralised decision systems can be very efficient in theory, their performance is quite dependent on scale. In other words, they work proportionally to the number of unities processed by the system, becoming many times very slow and therefore lacking efficiency. Such a limitation poses serious problems and present undesirable consequences. As transportation systems are becoming very large, both in terms of structure and dimension, the whole process of acquiring information from all sources, processing the essential data and providing adequate responses timely is rather a very arduous task. This is especially more complex due to real-time constraints and the presence of heterogeneous participating entities.

Finally, the third great revolution in transport became evident with the advent of what has been coined Intelligent Transportation Systems (ITS). Now the user is a central aspect of transportation systems, forcing architectures to become adaptable and accessible by different means so as to meet different requirements and a wide range of purposes. Integration is then crucial! This novel scenario has been motivating and challenging practitioners and the scientific community and suggested a completely new decentralised perspective of processes. On the other hand, discussions are still fostered by current ambitions to the Future Urban Transport systems (FUT), even more conscious in terms of environment, accessibility, equality, security, and sustainability of resources. Some of the main features of today's intelligent transportation, to mention a few, are as follows.

Automated computation is an important requirement of ITS. Future transport systems must make decisions automatically, analysing input information and acting accordingly, triggering coordinated actions to improve system performance. Demand for *flexibility* and *freedom of choice* is another important aspect on the user's side. The current lack of flexibility in transportation systems limits their potential to users, especially in that concerning personalised services, which is a major target for criticism by many users. ITS then should be open to flexibility, different options and diver choices, as well as personalised services. Also, *accuracy* is another important aspect, i.e. precise and up-to-date information must be delivered on a timely basis. Indeed, in transport systems that are generally classified as dynamic, errors and other failure situations are proportional to the accuracy of system reactions and responses to requested services. Therefore, latency should be reduced through distributed architectures for reducing response time. As transportation systems are greatly dependent on the network topology and other characteristics, *intelligent infrastructures* become fundamental. New communication technologies, including mobile, wireless and *ad-hoc* networks are improving infrastructures a great deal, enabling it to become an active and interactive part of the system. This is especially important for the implementation of the ambient transportation intelligence concept. A *distributed architecture*, accounting for asynchronous, control algorithms, coordination and management autonomous elements is undoubtedly one of the major currently researched areas of ITS. There are several requirements that must be satisfied, from user-centred to service-based functionalities, turning intelligent transportation into a complex, heterogeneous and intricate artificial society. Current research already considers that ITS architecture must explore distributed algorithms using exogenous information from various sources, making greater use of parallelism and asynchronous capacities of pro-active entities. These characteristics are essential to ITS, and suggest an enormous application potential of Distributed Artificial Intelligence (DAI) based solutions, especially Multi-Agent Systems (MAS) [1].

Accounting for the characteristics aforementioned, multi-agent systems have been greatly studied and applied in developing the concept of future transportation. Especially in the past couple of decades, a great deal of research work has been carried out in this area. Despite ITS geographical and functional distributed dependency, other concepts are also being devised and improved in such as huge research live laboratory, namely pervasive and ubiquitous computing, ambient intelligence and service-oriented architectures, among many others. These concepts ultimately foster advance in many other areas so as to address issues that are flourishing around as ITS and FUT become a reality. Some of such issues include the identification and definition of heterogeneous autonomous entities, definition of the asynchronous nature of entities, as well as which aspect make them concurrent, definition of the adequate communication infrastructures, validation and proof of algorithms and models correctness, robustness, performance and stability. Of course this is far from being an exhaustive list and many other issues are still to arise in such a fascinating study area.

3 Related Concepts and Technologies

By the end of the last century, we have witnessed the emergence of a new vision for the role of electronic devices in people's lives. Such a vision was firstly pointed out by Mark Weiser [2] and basically relied on the use of computer resources and provision of information and services to people whenever and wherever they were wished and needed. This novel concept was widely accepted, and during the past decade researchers applied it to built devices of various sizes, which started to become part of our daily lives. There was an enormous growth of these types of devices such as hand-held personal digital assistants (PDA), digital tablets, laptops, and wall-sized electronic whiteboards for a wide range of purposes. Indeed, coupling these devices with the ability of communicating with people and the surrounding environment in diverse ways actually contributed to the definition of the Ubiquitous Computing, or ubicomp for short. Nonetheless, this concept is not limited to communication or interface. Ubicomp is intended to go further beyond and was designed to specify the adequate infrastructure to provide people with a "24-by-7" information services, meaning users can access service providers 24 hours a day, 7 days a week. This innovative perspective opens up a wide range of different interfaces yet unexplored, introducing a concept called everyday computing, which suggests that over time and the presence of ubiquitous environments, the system itself will create a routine of activities for people, without those who have program them.

There are several fields of study involved in the concept of ubiquitous computing, ranging from the ability to miniaturise processing devices for discrete use in our daily activities, as well as the development of applications that can function as networks of groups for each individual. All these study initiatives have the common goal to develop, explore and extend the concept of ubiquitous computing to its maximum potential. Today we are just starting to understand the implications of continuous immersion in computation. The future will hold much more than constant availability of tools to assist with traditional, computer-based tasks; in the near future, we are going to "wear" computers that are going to track our actions and health and allow us better perform our activities. Not surprisingly, one of the application potential of ubicomp is within intelligent transportation systems of the future. Both practitioners and the scientific community agree that ITS can profit a lot from ubicomp. Next we discuss a bit further on the different concepts and technologies that are likely to take part in such forthcoming ubiquitous transportation world.

As for *human-machine interfaces*, ubiquitous computing has brought into evidence a new concept and way of interaction between humans and machines, sometimes referred to as “off the desktop” interaction environment [9]. This view assumes that interactions between humans and machines will much less be based on traditional interfaces, such as the keyboard, mouse, and display paradigm, and will foster interactions that are more natural to humans, such as speech, gestures and the use of objects of easy manipulation. These natural actions can and should be used as explicit or implicit input to ubiquitous systems. This new concept is being studied for a long time already, and advances have been reported to the point that some of these natural interfaces have been implemented in commercial systems, sometimes replacing the conventional interfaces. One of the advantages of these interfaces is the easy learning and intuitive use, just by imitating the natural ways of human interactions, thus enabling an easy transition and adaptation of users.

The *context-aware computing* is derived from ubicomp in the sense it is one of the keys to ubiquitous environments, so that entities can interact with the environment in a comprehensive manner, obtaining information and adapting their behaviour to the current situation accordingly. According to [3], the importance of context to ubicomp is best explained through the so-called “five W’s”, as it is further discussed below.

Context-awareness to work properly should know *who* is gathered together in the same room. This is important because the exchange of people with the conditions of the environment changes as well. Knowing *what* is being carried out by people is also imperative for the system to perceiving and interpreting human activities which are needed for the interaction with the environment to be completed. The *where* component of contextual awareness has actually been explored more than the other components in many different ways. Of particular interest, however, is coupling notion of “where” with other contextual information, such as “when.” Time is definitely a very important variable in such a perspective, so the *when* component is imperative as well, especially because it may qualify information with regard to time and relationships between situations that occurred in different instants, allowing the system to produce better and timely responses. Even more challenging than perceiving “what” someone does, is understanding *why* a person is doing that and the reasons that actually triggered the action.

Service-oriented architectures (SOA) is a new in information systems and can be basically defined as a group of services that communicate with each other to better serve the end-user. To understand such a concept well, we need to define service, which can be seen as a specific implementation of a function and is able to access both data and resources [4]. So, the goal of SOA is to create an *ad-hoc* topology of application that users are allowed to string together pieces of the functionality, all this constructed on the base application provided by the system.

Basically, the potentials of SOA have been analysed according to two points of view. Firstly, as for technical aspects, SOA-based architectures have many advantages, but some advantages are equally identified. One major advantage is that services are relatively open and accessible by any user or other services, as long as they are able to understand each other. This makes SOA pretty interesting to support services over the Internet, for instance. Among disadvantages, however, security and lack of testing and validated service models are important issues still to be addressed. Secondly, from the economic perspective, the possibilities are great as SOA-based architectures provide the basis for new business opportunities and other similar investments, as well as for the customisation of current services making them adaptable to a new emergent dynamic demand [5].

In the last few decades, with the advent of the digital era and a change of orientation in systems architecture, users are brought to a central spot and services are devised to be autonomous and pro-active. In consequence, new paradigm called *Ambient Intelligence* (AmI) has emerged.

AmI is defined as the ability of the environment to sense, adapt and respond to actions of persons and objects that inhabit its vicinity [10, 11]. To accomplish that in full, AmI's philosophy requires some important characteristics. Devices and services must be *embedded*, in other words, they should be an inherent part to the environment itself. Indeed, in recent year, we have witnessed a trend towards the miniaturisation of electronic systems so as they can be easily embedded in other devices and spread out all over the environment. Also, systems must be *context-aware*, meaning they must be able to understand the presence of individuals, their interactions and objects that are around, and with that perception interpret their actions and needs. As users are central to this concept, services must be *personalised*, which feature assumes that the system can build up to converge with the immediate needs of a user. Such latter characteristic also implies that the system must be *adaptive*, in the sense it can adapt itself in response to users' behaviours. Finally, AmI is intrinsically *anticipatory*, using its context-awareness to anticipate users' preferences and intentions and to provide the adequate environment for users to enhance their expected outcomes.

Ubiquitous and pervasive computing are two concepts generally dealt with indistinguishably, and they refer to various computer systems that can be part of a whole system (or be the system itself) that allows connection and interaction between various devices without the direct knowledge of humans who are using them. The two concepts were initially suggested in [2], nonetheless they present small and subtle differences. Indeed, according to the definition of Oxford's Dictionary [6], ubiquitous means something which is present everywhere at anytime, and pervasive is an adjective denoting something that spreads itself on something. Thus, we can intuitively interpret these concepts differently in that a ubiquitous system is passive and expects users' initiative to access services and information in it. On the contrary, pervasive systems are those that autonomously interfere while interacting with users, being pro-active and adaptive most of the time [12, 13].

4 Ubiquitous Transportation

Several significant events that marked the history of humanity have been identified over time and are reflected in all activities of human societies. Of course, these include the evolution of transport means that have played a decisive role in suppressing frontiers between countries and bridging continents in what we call today a globalised world. At the end of the twentieth century, there were many revolutions in a very short period time, mainly due to electronics, information systems, and communication infrastructure. In the 60's, main-frames began to be used, which were known by their large size and difficulty in maintaining the system operational. One great achievement was, undoubtedly, the advent of the transistors age, with the increasing miniaturisation of electronic components and consequently the information systems and interfaces as well. With this new trend in computer infrastructure, new technologies started to appear in a very quick and increasing pace.

One such technology that revolutionized our daily lives was the personal computer, first introduced by IBM in the early 80's. Also, the popularisation of domestic computer desktops has fostered the industry yet considerably more. One of several possibilities that PC has brought was to make it easier to implement digital system relatively powerful to cope with a bunch of different tasks and quite affordable. One typical example of practical use of PC is today's traffic control systems, to coordinate traffic lights in a more efficient way. Nonetheless, mobile communication is also reaching drivers and passengers in their vehicles, increasing even more the potential application of computer systems to transportation. Indeed, with the increase use of computers in a scale never before imagined, communication technologies and infrastructure also benefited of much advance in recent years. Urban scenarios, for instance, are witnessing the advance of ad-hoc vehicular networks (coined VANET) that make interoperation among transport components (both travellers and infrastructure) even more interactive and efficient. The Internet is now present in this mobile world, fostering applications of unforeseeable potential, not only to transportation management and control systems enabling real-time monitoring of traffic activities, but as well to traveller either on an individual or collective basis.

Not surprisingly, the beginning of the new century brought with it the breaking of paradigms and the creation of new concepts, changing the main orientation of management systems, which typically were geared to operations. Today, however, we can identify a new focus on the clients (end-users), as well as their needs and well being. This has driven information system design to take into account user's satisfaction as an imperative requirement that, on the other hand, demanded adaptive computer architectures. The concept of ubiquitous computing also shares such a view.

This was actually the very first ambition of what was called Intelligent Transportation Systems, in mid 90's. Therefore, ITS is also ubiquitous in nature and, for some reason, this very characteristics of today's transportation systems have remained latent for quite a long time. Quite recently, however, the scientific community is recalling former objectives in ITS and, with today's available technology, Ubiquitous Transportation Systems (UTS) are becoming a reality. It is equally desirable to notice that UTS is not actually a new concept of transportation, but rather is intrinsic to ITS. Most works basically report on the influences of mobile computing and communication on current available transportation systems. Nevertheless, the application potential of UTS is far more promising. Figure 1 is merely a superficial illustration of what the concept of UTS would be. As shown in the figure, the concepts of ITS and ubicomp were created almost at the same time and also the research development in both fields has followed quite the same pace over the last years. So, with the co-existence of both ITS and ubicomp, all elements were present and favourable to the advent of ubiquitous transportation systems.

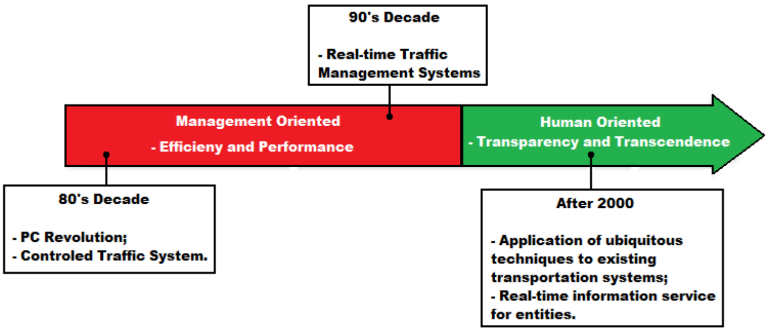

Fig. 1. Historical development of transportation systems

To illustrate this trend, Figure 2 depicts only the intersection areas in the framework of physical structure with the application of technologies for vehicle detection, data processing, communication and GIS/GPS, of ITS, as well as technologies related to wireless and mobile communication. However, if we apply the concept ubiquitous computing to the heart of ITS, there will be other things needing to be changed so that ITS is fully turned into UTS. One effect of such a natural evolution is the adaptation of services in ITS, which are currently process-based. In UTS, however, service-oriented architecture will be fully dynamic adaptable to the users' needs. Thus, it is quite acceptable that there exist lots of aspects that must be studied for the perfect fusion of such two complimentary concepts. If they can be effectively coupled together, then a very powerful transportation system will emerge, with many possibilities of services, not only to transport companies and the market but also to the individual user.

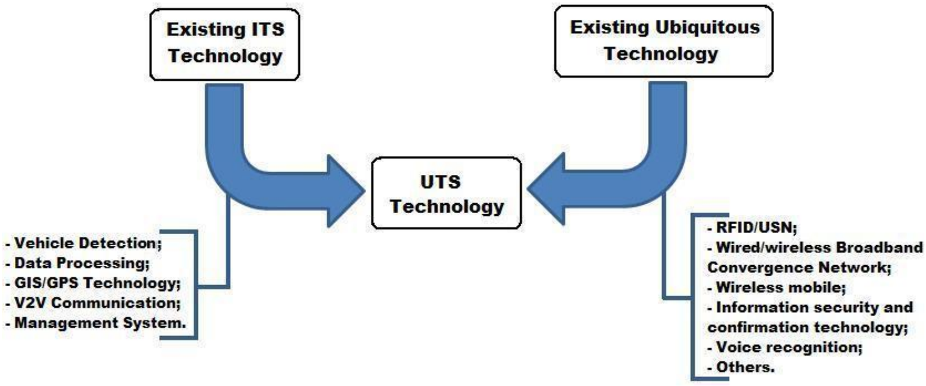

Fig. 2. Explaining how ITS and ubicomp are related to each other

As initially stated in this paper, our goal is to view and analyse intelligent transportation systems from a ubiquitous computing point of view rather than proposing or working on a novel concept of ubiquitous transportation as implied in [7]. Indeed, origins of ITS suggest an infrastructure on the basis of all technological aspects discussed in the previous section, meaning users, services and infrastructure can now interact as peers. Therefore, intelligent transportation systems are ubiquitous in nature. For the sake of simplicity, however, we refer to such perspective as ubiquitous transportation or UTS for short. The terminology is borrowed from [8], but instead of explaining a novel concept we are rather referring to an aspect inherent to ITS.

Thus, in this section we establish a relationship between the concepts of ubiquitous computing and intelligent transportation. To understand such a correlation, we need to look back at the primordiums of ITS, when new guidelines were first drawn for the future transportation systems. Initially, it should be noted that forthcoming transportation systems would be drastically based on distributed systems and thus ITS and ubicomp shared common characteristics.

Another important aspect endorsed by ITS is the full integration of users in all processes within the system, via static or mobile devices, prior to a certain journey or en-route, inside vehicles. For such an interaction to be effective and efficient, there should be a fully immersion of devices supported by an appropriate communication infrastructure, which would makes ITS naturally ubiquitous. This confluence, however, has been seen for some time as the emergence of new transport paradigm, namely the ubiquitous transportation systems (UTS). Nevertheless, there is no sharp boundaries between them two and both ITS and UTS can be dealt with indistinguishably.

UTS can be better understood in the light of some ubicomp's prominent features, which according to [8] has four key aspects. First, services must be present everywhere and anytime. Instead of carrying a device wherever someone goes, the device is either physically or virtually available everywhere to anyone. Second, it is not the device and its capabilities that actually matter but the environment. The real value of ubicomp lies in the fact that it is a comprehensive environment rather than a collection of services supplied by individual devices. Third, users are not conscious of devices being used. Thus, using a service does not require conscious awareness of the device, which allows the user to concentrate on the task at hand. Finally, services must be TPO-based (time, place, and occasion). This way, available services should match the prevailing situation and needs of users.

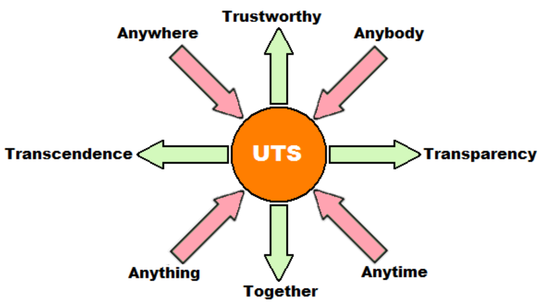

Fig. 3. UTS properties

Therefore, according to the features discussed above [8] it is possible to identify eight important properties of UTS, as depicted in Figure 3. Inward arrows illustrate UTS accessibility properties, such as anything, anybody, anytime, and anywhere. On the other hand, outward arrows illustrate properties UTS should provide to users, such as transparency, togetherness, transcendence, and trustworthiness. These properties are also known as the 4A and the 4T of ubiquitous computing, and will be discussed a bit further in the context of intelligent transportation as follows.

According to ITS original principles, transportation services should be accessible to *anybody* or *anything*, which might be any entity within the system, such as other services that carry out their tasks on autonomous bases. The system must also be accessible *anytime* and *anywhere*, meaning entities can find a service whenever and wherever it is deemed necessary.

In that concerning ITS environment, services quality and integration, transportation systems should be *trustworthy*, i.e. maintain the privacy of users' data at the same time accuracy and timing of services are preserved. Also, systems must be *transparent* to the users, meaning people should not need to be aware of the presence of components while using them. Boundaries between services should also be attenuated to the point users experiment a collective intelligence, with various components working *together* on a collaborative basis. As for *transcendence*, it represents the ability of the system to sense, diagnose and respond not only to the humanly recognisable transportation environment, but also to the humanly unrecognisable one, usually coined as extended reality.

Albeit ubiquitous and pervasive computing are sometimes seen as synonyms, as new technologies and studies are quickly emerging autonomy is even more a reality turning ubiquitous transportation into pervasive systems in the sense previously mentioned. Rather than being simply available, pervasive transportation systems (PTS) play a more active role, influencing transit and seeking better solutions to quickly respond to situations that require an overview of the environment in an autonomous way.

Ambient intelligence (AmI) is top autonomy level of intelligent transportation systems, encompassing both ubiquitous and pervasive properties. Thus, AmI implies a fully autonomous system, managing and controlling vehicles (and travellers, in a general sense) by sensing all parts of the transit environment. The path to this scenario is still a long way ahead, requiring multidisciplinary development, not restrict to devices but also in understanding human behaviour and applying advanced Artificial Intelligence techniques. Undoubtedly, this field emerges with great interest, challenging both scientific and practitioners' communities. To better understand how these concepts have evolved and interacted over time, some basic scenarios are discussed below, as follows.

As for ubiquitous transportation, it is perhaps the very next step towards the implementation of the original concept of ITS. Indeed, today's technology already allows us to experience new properties and services that enhance traditional transportation. For instance, mobile communication allows a user to access and consult traffic conditions while she is still on the way to the car. Also, pedestrians may use multi-modal travel planners to compose better itineraries, encompassing buses, trams, suburban trains, walking and even cabs booked in advance. This is performed on demand, and the system is able to offer the best alternatives according to specific requirements, such as cost, expected travel time, or presence of given points of interest (PoI), e.g., drugstores, restaurants and gas stations.

In pervasive transportation systems, scenarios suggest a much more pro-active set of abilities. Some examples are already in use, whereas much of the benefits expected from such systems are still dreams to come true. For the former, we can mention situations in which emergency vehicles, e.g. ambulances, need to get to a particular place in a congested urban area. In these situations, control systems, aware of the emergency, collaborate by setting all traffic lights across the due itinerary to green, so as to avoid excessive waste of time at junctions. In the latter case, information systems are expected to play a more pro-active role, anticipating users' needs and improving their daily schedule. For instance, as soon as a driver gets in the vehicle, the system might check the driver's agenda and prepare the best itinerary accordingly, while setting the appropriate radio stations accounting for the user's preferences. Many mobile information media would be integrated to deliver the necessary piece of information no matter the user is onboard, in the vehicle, or walking on the street, or at her desk at work.

Transportation's ambient intelligence, on the other hand, would certainly profit from a vast and effective sensors network. Albeit infrastructure and vehicular *ad-hoc* wireless networks (coined VANET) have been evolving steadily over the last few years, a fully intelligent transportation environment still poses many issues to be addressed. Such kind of system, for instance, would be able to handle accidents more effectively. In the event of an accident and if the environment itself were able to perceive and characterise it (e.g. identifying the degree and number of vehicles involved), the adequate means to address the situation would be deployed immediately without the need of one single person calling the emergency services, while re-routing other vehicles to avoid the accident site. Another potential application in urban public transport would include the automatic identification of demand. Let us suppose that for some reason the number of passengers waiting a bus service at a specific stop increased considerably. If the environment, featured with proper sensors and communication abilities, were able to identify the reason for such a transient increase in demand as well as to quantify the exceeding number of passengers, alternative transportation means or contingence services, by despatching additional vehicles into the active fleet, could be delivered accordingly. These scenarios might seem quite futuristic at first glance; nonetheless, they are quite feasible with today's technology and will very likely make part of everyone's daily lives in the near future.

5 Conclusions

Future urban transportation, regardless whether technology is available, motivates much research and development in a wide range of multidisciplinary fields. Safer, greener, sustainable and accessible-to-all transportation has never been closer to reality as today. Indeed, ITS as originally devised about a couple of decades ago put the user in the central spot, surrounded by a wide variety of services, some of which are already currently available. However, to become effectively ubiquitous, some efforts are needed to further develop concepts such as ambient intelligence, pervasiveness and autonomy of services. Whereas first discussions have suggested the creation of a ubiquitous transportation paradigm, a deeper analysis of original ITS ideas actually corroborate our perspective that ITS is in fact inherently ubiquitous. Technology is becoming available day after day and it is just a matter of time for the full potential of ITS-based solutions to be recognised and effectively deployed. The next steps to follow include the specification of fully multi-agent based architecture of a ubiquitous transportation system, using the Gaia methodology [14], as well as a transportation ontology to support services specification.

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