Wireless Sensor Networks in traffic management systems

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Abstract: - Citizen wastes an important part of their life moving around a city, considering that most of these displacements are in vehicles, it could be said that good traffic conditions suppose a better quality of life and less environmental contamination. Thus, traffic management systems are one of the most important systems of a city. Nowadays, TICs are being incorporated so as to evolve to the Smart City. One of these technologies are the wireless sensor networks, which grants us awareness of our surrounding context. For traffic management systems, the true state of the context is reviewed, as it is critical for optimal management. Regarding this, it is logical to incorporate wireless sensor network into traffic management systems. This paper has presented the progress made so far in the MOVVI project, which aims to develop a smart traffic management system for an optimum control of the occupation of spaces in cities.

Key-Words: Smart City, Wireless Sensor Network, Traffic management

1 Introduction
The continued increase in greenhouse gas levels in the atmosphere, due to human activity, has raised the temperature level of the planet drastically in recent years. Current forecasts project an upsurge in global temperature between 0.1ºC and 0.2ºC by decade, causing significant global climate changes [1]. This situation, as well as the increasing price of fossil fuels, has greatly stimulated research in green energy sources. Although in the long term the substitution of fossil fuels for other energy sources is the best solution, in short term, those alternatives which contribute to reasonable and sustainable energy management may also impact greatly.

Analyzing the greenhouse gas emissions (Fig. 1), the contribution made by the transportation sector can be appreciated, as it one of the most important.

![Fig. 1 Greenhouse effect gas emissions by sector](image)

The constant increase in vehicle numbers in Europe (e.g. in Spain, according to Eurostat, in 1991 the motorization rate, cars per 1000 inhabitants, was 321, compared to 476 in 2012) [2] and, in general the rest of industrialized countries, has diminished the air quality of our cities, being one of the main causes of pollution in the aforementioned.

The current state of events has led many municipalities to take restrictive measures against contaminating vehicles: London and Stockholm have introduced tolls, Berlin or Lisbon do not allow vehicle circulation in downtown areas, whilst in France similar measures are being considered for their main cities [3].

Since the birth of the semaphore in 1868 in London, the use of regulation technology has augmented progressively. Nowadays devices like information panels, light signals, radars, video cameras, etc. are of common nature both in cities and intercity routes. Nonetheless, most of the current traffic supervision systems follow a time-based pattern for semaphore management, which adjusts according to the hour, day and season of the year. The emergence of Smart Environment technologies in these scenarios, such as Wireless Sensor Networks (WSN), Distributed Artificial Intelligence (DAI), cloud computing, smartphone apps, etc. offer a wide array of opportunities for technology innovation in these fields.
In this context, the MoVVI project [4] proposes an innovative solution. Based on the concept of Internet of Things (IoT), in which every device is interconnected, the creation of a smart and ubiquitous WSN is proposed. The aforementioned will be able to report data to control traffic centers or private space managements (e.g. parking lots, tollgates, etc.), as well as public data bases that will allow data mining from third party applications (e.g. smartphone apps, web services, etc.).

2 Traffic scenario

Different technologies are involved in the design of a traffic system management. In this brief state of the art we focused on sensors, traffic regulation elements and information panels. These devices are found present in the traffic scenario reporting current context information to the system, controlling and regulating traffic lights, and providing information to users, either pedestrian or vehicle drivers. Also, since our approach comes from a Smart Environments point of view, WSN applications, context modelling, interoperability and software architecture are been considered.

2.1 Conventional sensors

Induction-loop traffic sensor is one of the most used methods in traffic monitoring applications. Its operation is based on the change in inductance that occurs when a vehicle (or a metallic object) passes through or stops on the electromagnetic field generated [5]. When a change is detected, the vehicle count is increased. This technology has two main problems: its relatively high installation cost (system needs to be wired and requires a traffic stoppage for some time) and it has a high rate of breakage which increase maintenance costs. Another technology that is increasing day by day its relevance in the traffic management are the vision systems due to the increment of current computational capabilities. Algorithms for vision systems enable license plate recognition, pedestrian detection, vehicle speed estimation, etc., further providing the traffic management body a direct point of view of the road [6]. Usually, these systems are used as speed sensors, and to monitor large traffic areas (e.g. crosses, tunnels, etc.), controlling limited access areas where the traffic is restricted, such as parking access. Cameras, however, present some disadvantages such as: acceptance issues by users, prone to vandalism, fixed infrastructure access requirements (IP or electrical grid), maintenance and, their main drawback, high cost.

Other systems use pressure changes produced by vehicles treading the asphalt to monitor traffic. They range from traditional pressure hose vehicle counter sensor that is attached to the asphalt surface and used to perform specific studies bounded in time, to other permanent systems, such as optical fiber based embedded on asphalt [7]. This latter system base their operation on the reduction of conductivity caused by the crushing of the fiber. Both these systems present similar problems as those of inductive coils.

In the last years, magnetic sensors appeared as an alternative to the traditional induction-loop sensors. These tiny devices, which are usually wireless, are placed inside the asphalt [8]. Its operation is based on the detection of perturbations of the magnetic field that occurs when a metal object passes over them. This technology, beyond vehicle enumeration, is used also to monitor parking places [9]. These devices typically have a higher durability than induction-loops, however, they require more maintenance (battery replacement about every 5 years) and are more expensive. Although these are the most used technologies, it is possible to find other traffic sensors for specific applications, as infrared barriers to monitor a single lane or, more innovative systems, as the implemented in the city of Zaragoza (Spain), which detects Bluetooth devices present in the cars and calculates the time of arrival to the different points of the city [10].

2.2 Traffic control and signalling elements

In this case, the emergence of technologies based on LEDs has represented one of the most important advances in this field. Their low power consumption has made possible the installation of information panels without main power access, using solar panels at those points where the rising cost of it justified its replacement. This same situation has occurred at traffic lights which mostly have been replaced by LED-based devices due to the significant energy savings. In the case of information panels, the mass use of LEDs has meaningfully reduced its cost, being increasingly used in both urban and interurban roads.

Currently, the Dirección General de Tráfico (DGT), main authority in traffic management in Spain, classify their user information system in the next categories: Before the trip (teletext, internet, etc.), during the trip (information panels, RDS-TMC), in any moment (by phone, Radio traffic, auto-guided).
2.3 Context modelling, interoperability and software architecture

Usually, wireless sensor networks communicate with fixed infrastructures through a Gateway. This device behaves as the connection point between physical elements (sensors, actuators, etc.) and their equivalent virtual elements (models of the devices in order to be handled by the control software).

In the Things world, interoperability among devices from different manufacturers is constrained to the use of standard communication protocols which intend to connect them seamless, such as 6lowPAN, RFID, WIFI, or 3G. Other protocols like ZigBee or Bluetooth deepen on the interoperability issue, establishing how the data interchange for some applications should be, by defining application profiles. For example, this allows for a phone supporting the Bluetooth Headset Profile (HSP) the use of any manufacturer’s Bluetooth headset directly. Regarding sensors and actuators, although the IEEE1451 standard [11] proposes a schema to use them independently from their communication technology, nowadays its introduction into the market is minimal.

Focussing on the virtual representation of devices and following the Internet of Things (IoT) paradigm [12], where every object has a counterpart on the Internet, there are standards and ontologies that helps modelling the context, providing virtual representations for the devices that builds Ambient Intelligence (AmI) environments (sensors, actuators, interfaces, etc.). Most of the standards are based on the IP protocol, but this does not ensure the required interoperability for the IoT applications. For example, standards such as the Extended Environments Marks-up Language (EEML), SensorWeb or SenseWeb use XML-based schemas in order to integrate sensors and actuators into the virtual world. However, these schemas focus only on the data modelling, lacking the semantics and ontologies required to turn them into valid tools for making a complex information processing and adapting to a higher abstraction level. Initiatives such as COSE [13] or Dogont [14], among others, propose different ontologies and approaches to model objects (sensor, actuators, interfaces, appliances, etc.) on smart environments, formalizing the devices and binding their contents by semantic relations, and offering access to them through web services.

It should be noted also that most of this initiatives are based on the Open Services Gateway initiative (OSGi) [15]. The increasing use of OSGi in new applications and consumer goods, as well as the use of Service Oriented Architectures (SOA), is strongly related with the need of durable and easy to update technologies. Development of monolithic software applications in these context is expensive and not sustainable in the mid-term, and it is here where SOA allows for the development of, easy to update, modular applications.

In that sense, OSGi proposes a framework where the code is arranged into bundles that can be managed dynamically. These bundles can be devoted to specific tasks, and communicate each other by means of services published within the framework. This architecture allows to maintain and evolve each of these bundles separately, integrating their full life-cycle (code, build, install, activate, deactivate, update…) without requiring even to stop the entire application [16], [17].

2.4 WSN application

Sensor networks are one of the most common tools used in DAI deployments, as they offer a wide array of possibilities for environmental monitoring in non-invasive self-powered devices. They are comprised of several elements (sensors, actuators, communication modules, etc.) which aim to communicate information to a higher system for data mining and decision making.

The use of communication protocols such as ZigBee, Bluetooth or custom tailored solutions are common amongst WSN, as they allow for enhanced device energy autonomy. WiFi, although less frequent, is also utilized in these type of systems due to its widespread popularity in urban environments and its newly added low energy consumptions features. The previously mentioned protocols also offer different network topologies (tree, star, mesh, etc.), which allow implementations ranging from a few simple nodes to highly complex systems.

Applications for WSN are very heterogeneous, covering a wide spectrum of work areas. Implementations have been made for remote patient health monitoring [18], irrigation and fertilization of crop fields [19], electrical grid power management for household buildings [20], natural disaster prevention [21], amongst others. Traffic control is not oblivious to these systems, as presented by Sharma et al. [22]. The aforesaid can be found applied in smart traffic control systems for traffic jam detection, optimum route search or assisted parking, amongst others. Various studies [23], [24] lay out guidelines for systems which
dynamically adjust the semaphore interaction based on data provided by a given WSN. Others [9], [25], [26] focus on parking space availability, utilizing various sensors to detect vehicle movement to offer real-time space management. Yet few have been able to address both issues in a single smart and intuitive WSN system.

3 The MoVVI approach

3.1 System description

Main objective of the MoVVI Project is to develop a Smart City Application able to manage traffic and parking places more efficiently than current systems. The system is based on a Wireless Sensor and Actuator Network (WSAN) embedded in the environment, which will enable the municipalities, citizens and traffic control centres to access enhanced information, thus optimizing the use of vehicles (decreasing traffic jams, optimizing routes, times and information). Additionally, it may suggest alternatives to the use of particular vehicles according to current traffic conditions.

Initially, a scenario is proposed where sensors, and optionally, control and signalling elements will be deployed on points of interest on streets, parking and roads. Those devices will be grouped into small area networks, called u-Clouds in the context of the project, which will use low power wireless technologies such as ZigBee, and will include dedicated Gateways that will provide Internet connectivity and access to the related municipality management network.

This architecture is highly scalable and considers just covering a small area or the monitorization of an entire city and their metropolitan area. The smart sensors will feed the municipal database as well as Internet open databases with information in several degrees of detail. Thanks to the use of these, it will be possible to account the number of vehicles passing through a specific section, to discriminate the type of vehicle, to detect vehicles driving against the traffic, to estimate the average speed on the road, to monitor the occupancy on parking places, etc.

In the case of big cities, this system deepens into the concept of Smart Cities, allowing municipalities for a better management of parking or access restricted areas, and even offering advanced services such as planning or public reservation of these areas. On the other side, the availability of public databases with the traffic information, will allow the development of information applications by the citizens who wish to do so.

The platform will be designed with the objective of allowing for easily adding new sensors compatible with standard communication protocols, as well as increasing the Internet-connected sensor u-Clouds communication infrastructure, and enabling covering other additional needs. Collected data will be processed on the Cloud, and will produce high level information that will be used by municipality managers to enhance space management, as well as it could be offered to third parties for developing their own applications. All this data will be integrated natively into the urban control application for big cities developed within the project, or integrated into any other application by means of an external API.

The general architecture of the system is depicted in Fig. 2. A number of u-Clouds are deployed on the scenario, and collect data from the sensors that are shared among them through their Gateways. Any of the u-Cloud Gateways with Internet connectivity behaves as connection point between the physical world and the remote platform, where Context Management Services and Application Services reside. Context Management Services are in charge of tasks related with information retrieval, analysis and storage, as well as device management, and provides an API for accessing that context data. Application Services are in charge of the specific tasks related to the traffic and parking management, as well as the communication with the legacy traffic management systems already installed. Users may also interact with the services provided by the platform through the Internet.

The overall operation of the system can be better understood with the example proposed in Fig. 3.
Here, the system consisting of a Gateway, several routers and a number of traffic sensors which creates a mesh network is presented. Information displays and semaphores are also considered, although the latter are not accessed directly from within any u-Cloud, but the remote platform. Traffic sensors aligned in the same lane allow to: monitor lane occupancy; estimate maximum, average and minimum speed; detect wrong-way traffic; count the amount of vehicles; or identify vehicle typology (providing the number of shafts). This information allows for tuning dynamically semaphore regulation in order to alleviate traffic.

![Fig. 3. Use case: urban environment.](image)

The same kind of traffic sensor is deployed on the parking places to detect their usage, and the information about available parking places on secondary streets is reported to the users through the information displays present on the main street.

### 3.2 u-Cloud

A u-Cloud is composed, generally, by a router which is the central element of a u-Cloud, several sensors, information displays and actuators. This router is ready to support several RF protocols, amongst others such as Bluetooth and ZigBee which simplifies the communication with a broad spectrum of sensors. In order to enable the interoperability at the application level, as we explain in section 3.2.2 all devices use the Common Thing Protocol, (CTP).

Each u-Cloud could be able to take its own decision depending on the context. This is possible due to the router “intelligence” and data-storage capabilities, being able to implement simple algorithms and pre-processing the sensors information. This situation approaches the system to the paradigm of the Fog Computing.

New Wireless Magnetic sensors are been developed in the MoVVI project. These sensors have two main functionalities: traffic and car parking monitoring. Beyond these traffic sensors, u-Cloud enables the connectivity of any kind of CTP sensor.

u-Cloud is able to support wireless CTP information displays and actuators, though integration is done at platform level, since this infrastructure should be previously installed in the city.

In the next section the main u-Cloud issues related with wireless communications, interoperability and an application example are presented.

#### 3.2.1 Wireless communications

WSN technology represents a significant commercial interest in the current context, being one of the key players in the development of Smart City [27]. This situation is producing a coexistence of wireless protocols that usually ends with the interconnection of the WSN to a fixed infrastructure (Internet) based on IP (Internet Protocol)[28]. In this environment, technologies based on IEEE802.15.4, 6LoWPAN and IPv6 are combining to meet this demand [29], [30].

Depending on the application, it is critical to select the most appropriated technology for wireless connectivity comparing them in terms of coverage, data throughput, network topology or energy consumption. In any case, the more data you need to exchange, the further you need to communicate, the more time you need to be online, the more energy you need, and consequently the quicker you will run out of batteries.

Sensors are usually powered by batteries, and their installation is complicated, so it is of great interest that their autonomy be as high as possible. Therefore, the main guideline when selecting its wireless technology is low consumption. The ZigBee protocol (into 2.4GHz band) has been selected as an alternative due to its ability to work with different types of network topology, enough bandwidth (250kbits/s), bearable latency times, adequate coverage range (+500m with LRS option) and, also, it is a standard widely established on the market.

Focusing on the MoVVI project it is possible to identify three levels of communication:

- Inside the u-Cloud. The u-Cloud is an Ultra-Low Power Wireless Sensor Network (ULPWSN) which includes all the...
communication between the traffic sensors and the closest router. In this area, there has been an intensive development of custom devices that use RF protocols of short range, in the past few years. This enables a market with great availability of a wide range of devices for covering different needs.

- Between u-Clouds. This level of communication could be consider as a Wireless Neighbourhood Area Network (WNAN) and includes the communication between routers and Gateway in a mesh network based on ZigBee
- Between the Gateway and the IP world (Wide Area Network, WAN)

Fig. 4 presents our technological proposal and shows its communication levels.

![Diagram of u-Cloud communications levels](image)

The system architecture is built around the router of each u-Clouds. These routers, are part of the ZigBee network that interconnects the u-Clouds to each other and with the Gateway. Additionally, the routers of the u-Cloud that may require it, will support other protocols. Explicitly, the protocols that have been considered as additional are Bluetooth and the low frequency RF protocols of existing devices. The adopted solution allows the inclusion of new communication protocols, both internally into u-Cloud, and between u-Clouds. In regard to the latter case, the joint use (even the replacement) of ZigBee with other technologies such as WiMax or LoRa, is being contemplated.

### 3.2.2 Interoperability

Communication standards ensure stack layer’s interoperability (network management and maintenance, security, data exchange, etc.) between devices connected using the same protocol. In a u-Cloud, devices that share a common protocol could be connected directly amongst them. Moreover, the router connects devices using a wireless communication protocol with devices that have another protocol, behaving as a translator between protocols. However, once that connectivity between devices has been achieved, to ensure interoperability, it is necessary both the exchange of data, as well as the understanding of the information embedded in the data. Aforementioned, there are several protocols that try to incorporate this "understanding of knowledge" and “abstraction of the device” to ensure the device operation and its interoperability between them.

On the one hand, not all protocols support abstractions of the device operation, and those that do, may not be efficient when operating on devices with limited resources. On the other hand, it is necessary that these abstractions are the same, so that different devices can interact with each other. We have proposed the Common Things Protocol (CTP) [31] as a solution to the problem of interoperability between heterogeneous devices in the MOVVI project.

CTP aims to provide a specification that allows interoperability among communication standards while keeping simplicity, functionality and efficiency. CTP takes into account both the existing specifications in the standards and the needs from the final applications. It integrates the strategies, concepts and terms of some of the alternatives mainly the TED (Transducer Electronic Data Sheet) concept from IEEE1451 to provide device’s information and the ZigBee concepts of clusters and bindings. The definition process is approached from an ontological perspective considering that devices must perform some function while being in contact with users and context. CTP usually fulfilling the following paradigms:

- **Context Interaction**: embed sensors, actuators (to modify the environment) and/or simple human interfaces.
- **Distributed Computing**: to implement from the simplest logic to complicated services or data processing algorithms.
- **Communication**.

Regardless of its functionality, each thing will always “live” in a certain location and time and will have its “capabilities” (processor, communication transceiver, memory, etc.) and “restrictions” (power source, operation ranges, etc.) that are represented into the endpoint BASE of CTP. This endpoint constitutes the basic set of attributes and functionalities of any device. Depending on the specific functionalities that integrate the device, it will also implement multiple application endpoints that should be of any of the three categories of devices (derived from their capacity to interact with the context): SENSOR, ACTUATOR or HMI. Thus,
an endpoint can be defined as each of the sub-devices that have a complete functionality and, altogether with the others, build the device. Additionally, a cluster is defined as a set of commands, events and responses which together define a communication interface between two endpoints. Commands are usually action requests to an endpoint (of the same or different kind) that should send back a response informing about the action result; e.g. ask for a sensor value and get it back. The ontology defines attributes which are implemented in the protocol as GET/SET requests and responses. Events are asynchronously generated messages sent to previously subscribed endpoints. CTP describes a reduced and simple communication interface defining the meaning type and range of the parameters when needed, so CTP is self-contained and auto-defined.

CTP is encapsulated in the upper layers of existing protocols (into payloads), trying to maximize the capabilities of the native protocol. For example, if CTP is used over ZigBee, the definition of a CTP binding is done according to native capabilities of the ZigBee standard protocol. In this way, CTP can adapt to different requirements with high efficiency. Currently, CTP has been incorporated into various types of devices for development systems with different purposes, such as energy monitoring for buildings, ambient intelligences (AMIs) applied to home automation, environmental monitoring, smart signal, human interface devices, etc.

### 3.2.2 Example of application

Currently, we are working on the setup of a test and exhibition system in the public parking space of the campus Rio Ebro, at the University of Zaragoza (Spain). Firstly, this setup will be used to test and validate the technological developments of the project during 2 years. Finally, at the end of the project, the setup will be used to optimize the parking usage. On the one hand, it will grant detailed information of the traffic access (frequencies, traffic jams, etc.). On the other hand, it will inform users about the availability of parking places through Smartphones, internet or through the information displays, enabling new services for the University, such as controlling the load/unload parking areas, offering on line parking reservations, etc.

Focusing in the system design, as it is shown in the Fig 5, it is formed by five u-Clouds:

- u-Cloud 4 is formed by 8 MZTS placed in parking places, another 8 monitoring the access and an information display. This display shows the number of free parking places available in the controlled area. Also a weather station with temperature and humidity ZigBee sensor has been added to this u-Cloud.
- u-Cloud 5 is formed by three MZTS which monitoring the access area to the parking.

Inside the u-Cloud, each router manages the connected device, checking periodically the health of each sensor. This information is send to a platform through the Gateway (note that in this case the router placed in the u-Cloud 4 is playing the role of Gateway thanks to its access to the IP connectivity).

When a parking space changes its status, an event is sent to the remote platform which actualizes its status. This event is also used by the u-Cloud 4, which manages the information display, in order to update the number of available spaces.

Access sensors will be monitoring the number of vehicles in each line, reporting in configured intervals. Note that the sensors could work in real time, but with a high cost for their batteries.

Finally, the meteorological station, which is monitoring temperature and humidity, may use the wireless infrastructure, thanks to its CTP sensor devices, reporting periodically data to the platform.

### 4 Conclusion

In this paper the effect of traffic in cities, particularly its environmental impact, has been highlighted. The scenarios in which the traffic management systems operate, have been exposed. Moreover, of current the introduction of sensors, context
modelling and WSN as mechanisms to improve the solutions present, have been reviewed.

With foregoing considerations, an approach has been carried out for the MoVVI project, presenting a novel architecture for a smart traffic management system. The architecture is designed around two basic elements, u-Clouds and Gateway, and has been focused on using wireless communications, as well as devices embedded in the environment, to interact with it.

The concept of u-Clouds has been further developed as a means to handle the heterogeneity of devices, while also allowing the deployment of the infrastructure along wide spaces in the city. Two of the most critical aspects of the u-Cloud have been reviewed in great depth: wireless communications and interoperability between devices. This last aspect presents its self as a challenge, thus the use of a self-developed protocol (CTP), which has been tested successfully on previous projects, has been proposed as a solution, and

Finally is showed the example that currently is getting ready to fine-tune the technology and analyze results.

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