A Metropolitan Area Living Lab based on a Wireless Sensor Network

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Abstract: This paper presents a Living Lab based on a wireless sensor network with a metropolitan area dimension. It is an experimental infrastructure providing real conditions to facilitate the development and testing of technological solutions in the context of a smart city in subjects such as wireless sensor networks, wireless data transmission, web services, software analytics and visualization systems. The first stage of the Lab is the development of a base target application for sensing the environmental conditions at various locations in an urban area.

1 INTRODUCTION

The concept of Living Lab has many meanings, being the most mentioned the one which states that is a living environment which houses both people and technology, in a semi experimental setting that promotes symbiotic innovation, development and research (Chin and Callaghan, 2013). This signification is sometimes extended or limited according to the vision behind a particular application. (Del Vecchio et al., 2014) presents a review of the literature and contributions about the Living Labs focusing on their implications for the development of entrepreneurial competencies. In the field of education, for example, (Justice and Do, 2012) presents a living lab to promote learning through challenging real-life hands-on experiences that are supervised by faculty, students and staff. In (Vicini et al., 2012) the Living Lab design approach is applied into a paediatric section of a hospital to the understanding, studying and measuring of the interaction between children and services and the potential of Internet of Things in innovation. This paper defines the Living Lab as an experimental infrastructure with an urban area dimension, providing real conditions to facilitate the development and testing of technological solutions in the context of a smart city. The technical contribution of this work is to bring to the entrepreneurial and educational community a platform that allows quick access to the validation of the concept of a new product, to generate experience, and eventually identifying new products to strategic markets in five main lines of technologies: wireless sensor networks, wireless data transmission, web services, software analytics and visualization systems.

The design and implementation of the proposed system has as base target application the sensing of the environmental conditions at various points in an urban area. This will let characterize the air quality in the zone, generating information that can be exploited and analysed by additional software tools. The main features of the system defined for the first stage were the use of wireless technology for interconnection, being hybrid in such a way that it allows the coexistence of different wireless technologies, an open architecture that allows the system to easily expand and improve, the ability to add additional sensors, and its ease of being replicated. The system built for this application stays in a stage ready to be used for other kind of applications, starting to play its role as a Living Lab. It was already being used into an Internet of Things university course.

Section 2 presents the context of the application for the first stage of the Living Lab. Section 3 describes the elements of the system while Section 4 shows the results of the first stage of deployment. Finally, some conclusions and a discussion of the future work are introduced.

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2 MONITORING ENVIRONMENTAL CONDITIONS

There are two application goals for the Living Lab at this first stage. One is to have a computational tool for acquiring information to help the forecasting of environmental contingency situations, for example, to prevent when a pollutant could exceed its allowable limit. The second, is the monitoring of environmental conditions around the most important forest in the city. This serves to identify the way and speed in which the forest is degraded because of urban growth and to help taking corresponding actions to support the survival of the forest. According to international standards (EPA, 2013), it was decided to monitor the so called criteria pollutants: the ozone, the carbon monoxide, the sulphur dioxide, the nitrogen dioxide and particulates less than 10 microns (PM10). Unlike employ a weather station for measuring ambient air pollutants, as is usually done, the use of wireless sensors can provide a more practical, economic and smaller solution at the possible expense of the measurement accuracy.

To identify the technological possibilities used in this kind of applications, some examples reported in the literature can be mentioned. A system measuring carbon monoxide and fine particles is reported in (Wang et al., 2012) and (Liu et al., 2012). It is based on an electronic card using a low power consumption microcontroller from Texas Instruments and a ZigBee radio circuit. The sensors are solid state and low cost. The wireless network is controlled by a Gateway based on an industrial personal computer. A different approach is proposed in (Devarakonda et al., 2013), where a mobile sensor sends the detected values wirelessly by a cell phone linked to a server in internet. This makes the information available on the web. Here two kind of nodes are proposed, one to be placed on a vehicle and one to be carried by a person. The first one is built based on an Arduino card and a cellular communication shield with both a fine particles and a carbon monoxide sensors. The personal node uses a commercial device named NODE having the ability to measure carbon monoxide, moisture, temperature, atmospheric pressure and ambient light. Finally, a different approach is presented in (Boubrima et al., 2015), where a model is described to position environmental pollution sensors in a city in order to lower the cost of implementation, being the number of sensors the main objective.

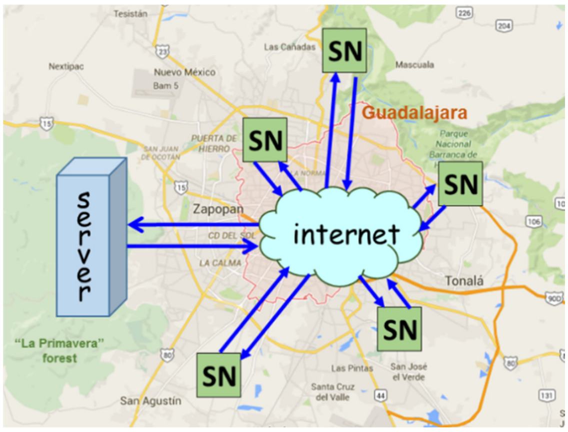

Figure 1: General view of the proposed system.

3 SYSTEM OVERVIEW AND DESCRIPTION

As mentioned before, the proposed system is a wireless network of sensor nodes (SN) dedicated to measure the air quality at different places of an urban area, as shown in Figure 1. The collected information is stored on a server on the internet and made available for consultation. Similarly, a website and a mobile application allow access to the information.

3.1 General Structure and Operating Principle

The structure of the system consists of the following elements, illustrated in Figure 2.

- Several sensor nodes. Each node with the sensors to measure the pollutants. They can be connected to the internet through different kind of wireless links;
- A server on the Internet. It keeps track of each node and stores the collected information in a database. It also provides web services necessary for the operation of the website and the mobile app;
- A web application that allows system management. To add and delete nodes, to add and delete sensor variables to be measured, and to assign a location to each node;
- A Web page and a mobile application. They show the position of the sensor nodes on a map and provides current and historical values of the sensors.

First, the way in which the system operates was defined, establishing the main characteristics of each element of the system. The main operation of the system is based on the communication between the sensor nodes and the server. For this an own protocol for messages exchange was defined. Starting from the normal state of the node, low power consumption, it periodically awakes and perform some tasks such as to take samples of the variables to be measured, send them to the server, and ask the server for a specific action to be done. The server is continuously listening for node messages and eventually can ask the sensor node for some action.

For the sensor nodes we used off-the-shelf devices that we specifically programmed for the system, for which we created some particular libraries. We defined a communication protocol between the nodes and the server as well as a gateway to cope with the ZigBee technology. We developed all the needed software, web services, web pages, and the mobile applications. In the following subsections we describe the characteristics of each element and some of the challenges for its realization.

3.2 The Sensor Node

The sensor node is the starting point of the system. In order to maintain its electrical autonomy its operation was defined to remain in a low power state most of the time and periodically awake and perform the following tasks: to take samples of the variables to be measured, to store locally those values, and connect to the server and perform requested actions such as data transfer to the server, changing settings, etc.

The choice of the technology to be employed for the sensor nodes took into account the following requirements:

- Ability to quickly deploy a solution;
- Being easily configurable or programmable;
- Having a set of robust basic libraries ready to be used in different applications;
- Ability to enhance its hardware platform;
- Interoperability of wireless technologies.

We analysed four possible options that could meet the requirements:

- Fully design the sensor node;
- Use of general purpose electronic control devices such as Arduino and Raspberry Pi;
- General purpose off-the-shell wireless sensor devices, like Digi's XBee and Memsic's sensor nodes;
- Specific Application, open architecture, wireless sensor nodes, like Libelium's Waspmote.

We found that the option that best fulfilled the requirements was the Waspmote from Libelium, a Spanish company mainly dedicated to wireless sensor networks products (Libelium, 2016). Either way, being a device with an open architecture, the development of the system took into account the possibility of using any other technology and not staying constrained to the use of only one provider. These Waspmotes are based on a controller card using an ATmega1281 microcontroller, a real time clock and a solar cell rechargeable battery controller. The sensor interfacing is done through special adapter cards with the possibility of using user made customized cards. It exists two versions of the Waspmote, one aimed to experiment and develop OEM solutions, and the other called Plug&Sense aimed to quickly deploy the device for a specific application, they are shown in Figure 3.

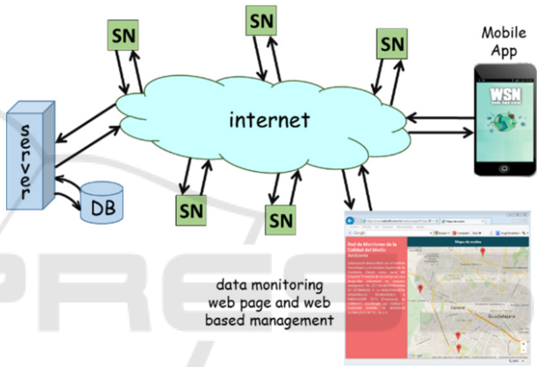

Figure 2: Elements of the wireless sensor network system.

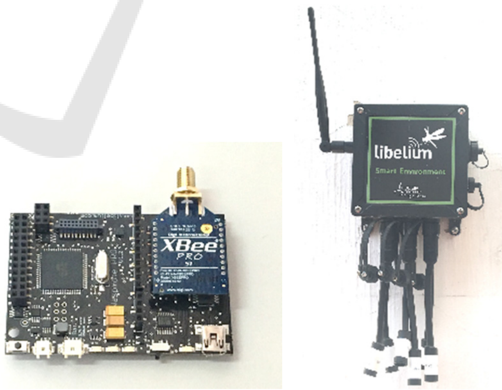

Figure 3: The Waspmote OEM version, left, and the Plug&Sense! Version, right.

The communication between the nodes and the network for the first stage of the project follows two connection strategies related to two different application scenarios. The one without a near connection to the internet, where a link through a ZigBee network from the sensor node to a gateway with internet connection is used. The second scenario envisages having a close internet connection, where a link through a wireless local area network can be established. We also considered and tested a GPRS link, but at the time of writing this document we still haven´t deployed a sensor node with such a communication technology. In both application scenarios it is necessary to have a Gateway that can receive signals from the node and send them over the internet to the server. This situation is shown in Figure 4. For the WiFi case a commercial wireless router was used, while in the ZigBee case a customized Gateway was built.

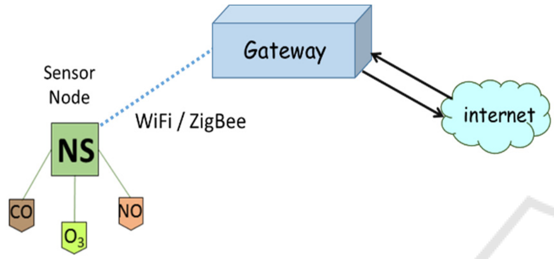

Figure 4: Communication between server and nodes through a Gateway.

3.3 The Server

The server consists of a set of web applications and web services that perform as a whole the following functions:

- To periodically request to the sensor nodes the data collected and stored in its local memory;
- To make available the database on the Internet;
- To provide information related to the nodes connected to the system, such as geographical position and sensor variables that can be measured;
- To provide information to the user related to the data being collected from the system;
- To provide an interface for managing nodes (add, delete and modify) and communicate with them (action messages).

As mentioned before, a proprietary protocol for exchanging messages between the sensor nodes and the server was defined. The main command is the Data Request (DR) and Transmit Data (TD) pair, for which the node prepares the information and sends it to the server. Figure 5 shows the flow of messages between the sensor node and the server for this function in the particular case of using a ZigBee link. In this case, because of limits in length of a ZigBee frame, the information from the sensor node must be divided in smaller packets in order to be managed by the ZigBee gateway which repack them and send them to the server as a one whole frame.

At the beginning, the sensor node awakes and sends a message request (MR) to the server through the ZigBee gateway. The gateway passes the message directly to the server. The server responds with a Data Request (DR), message that is directly passed from the gateway to the node. The sensor node prepares the data and because its length is longer than a standard ZigBee frame, it is divided in 2 packets for the case illustrated in Figure 5. The gateway collects the two packets and builds a single frame to send to the server, who finally responds confirming the good reception

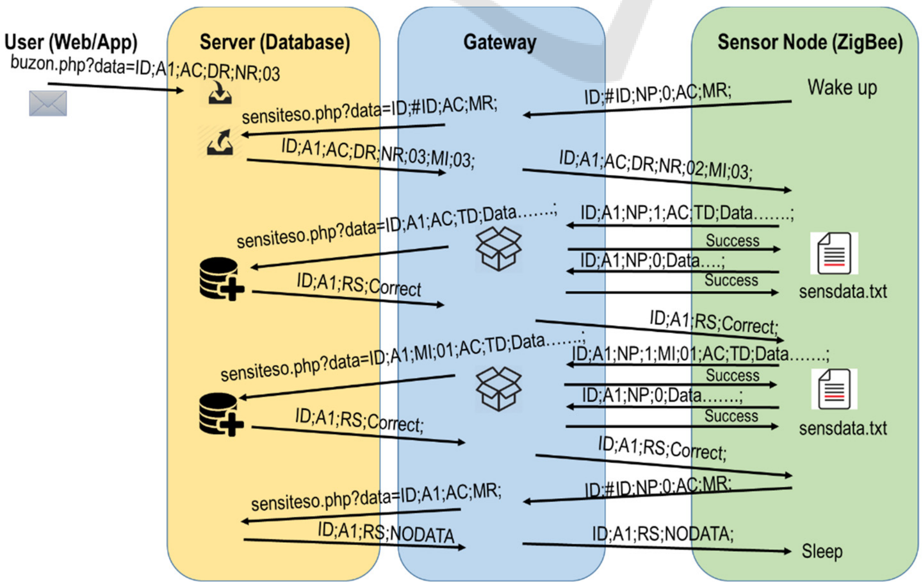

Figure 5: Time chart example of the communication protocol.

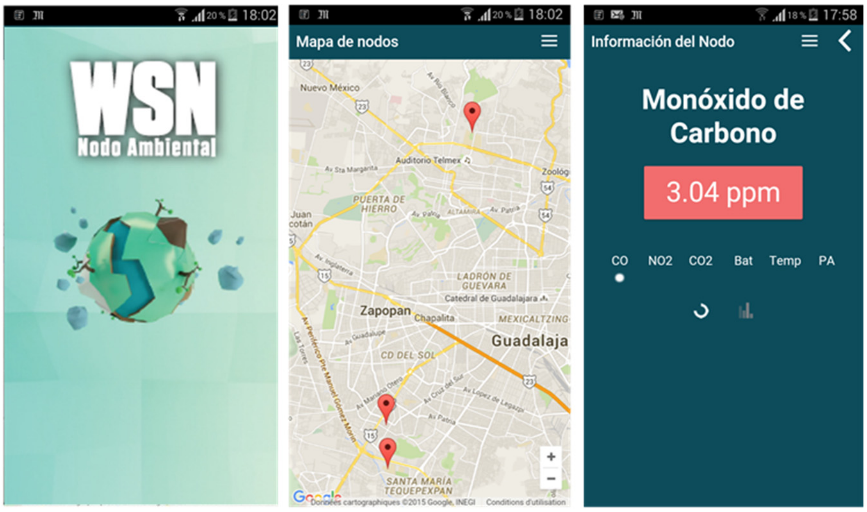

Figure 6: Screenshots of the mobile application.

of the frame with a *Correct* message.

This way of interacting between the gateway and the node allows to build standard frames to be sent to the server, avoiding the use of an exclusive treatment of data for the ZigBee case at the server.

3.4 System Management Web Application

The system management is made through a web application developed in php and running in the server. It allows to register, unregister, and edit the sensor nodes and its characteristics, and to make the same thing with the sensor to be employed. For each node you can fix its protocol identifier, its position, and the different sensors associated.

For each sensor you can fix the label to be used in the protocol, and the name and units to be shown in the information display application. According to this, the system allows you to add any new sensor to be measured and to associate any sensor to a particular node independently of the rest of nodes and sensors.

This gives the system the versatility of not being constrained to only one kind of application.

In addition to the functions above, the management application can generate a set of basic data reports, either by node or by dates.

3.5 Website and Mobile Application

The website and the mobile application were developed to show the information collected by the system in a simple way. The first one is optimized for a computer screen, while the second one is optimized for a mobile device.

The function assigned to these elements is to display the following information:

- The position of the sensors on a map;
- The sensors associated to a node;
- The latest value of a chosen sensor;
- The historical values of a chosen sensor.

Figure 6 illustrates the appearance of the mobile application.

4 RESULTS

As the time of writing this paper, 4 sensor nodes have been deployed along the city. Figure 7 shows one of the nodes installed on a roof. They measure 4 of the criteria pollutants: ozone, carbon monoxide, carbon dioxide, and nitrogen dioxide, plus air temperature and relative humidity.

Figure 7: A sensor node located at the roof of the department building.

Three of the deployed nodes are connected to the internet via WiFi while the fourth one is connected by a ZigBee gateway. The ZigBee connection is made up with XBee ZigBee S2 radio modules from Digi International. Each node has been powered with a 3.7 V - 6600 mAh battery rechargeable through a 7V – 500 mA solar cell.

The debugging of the node and the server program was made possible through the use of two specially developed web services intended to closely follow the different stages of the system. A *log* service shows all messages exchanged between the server and the nodes, and a *read* service lists a number of latest information frames being stored in the server. Table 1 shows an example of the data corresponding to one information frame.

In the first stage of the project it was chosen to use standard sensors with a medium accuracy. The values collected will be analysed and compared to reference sensors of a higher accuracy in order to adequately calibrate the standard ones. Figure 8 shows a screen corresponding to the historical values of one of the sensors measuring the temperature of the environment.

Table 1: Sample of registered data.

id	id Node
17606	A1
data	
{"id":"A1","ac":"td","ts":"2016-03-28T18:06:14-0400","bat":"97","temp":"31.61","hum":"6.79","c02":"2.72","no2":"0.14","03":"0.00","co":"0.87"}	
date_hour	
2016-03-28 18:06:14	

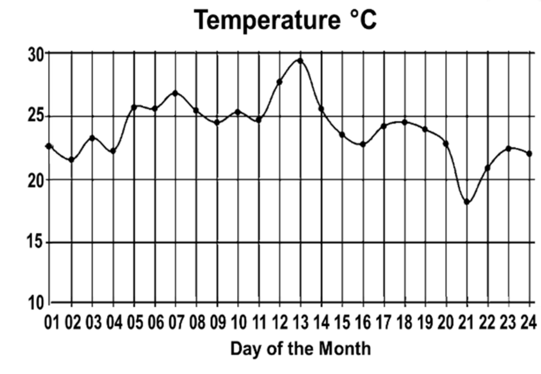

Figure 8: One month historical values graph for the temperature of the environment.

The performance of the electrical autonomy of the nodes was monitored through the charge capacity of the batteries. It was found that the nodes rest autonomously powered by the rechargeable battery and the solar cell. This is the case for two of the nodes which have lasted for more than 5 months without additional powering. The other two nodes were powered recently. Figure 9 shows the average charge percentage of the battery of one of the nodes for the last 5 months. The performance of the charge capacity of the battery without recharging was also tested. Figure 10 shows that after almost two weeks of operating without solar cell the charge of the battery dropped from 97 % to near 80 %, meaning that during a similar period the node can survive before a new recharge in case of a failure of the solar cell.

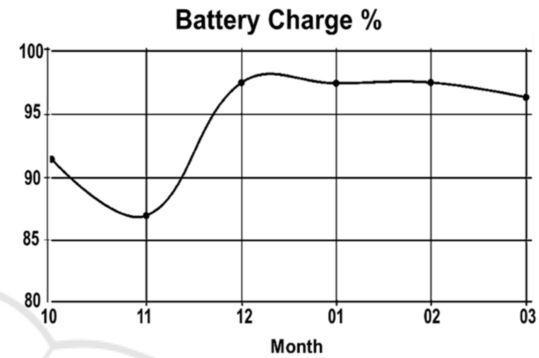

Figure 9: Average charge percentage graph of a node's battery with solar cell during 5 months.

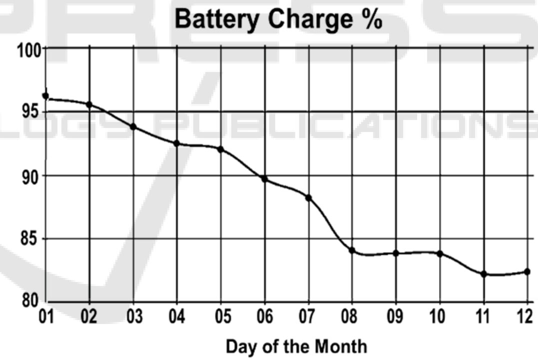

Figure 10: Average charge percentage graph of a node's battery without solar cell during twelve days.

5 CONCLUSIONS AND FUTURE WORK

This paper presents the development and some experiences regarding the implementations of a whole system for monitoring the air quality at different locations in a city through a wireless sensor network and an internet based information and management system. All of this working under real conditions. It represents the materialization of an infrastructure to experience and validate tangible concepts and proposals to develop solutions to the problems present in cities, a Living Lab for smart cities.

In the first stage of development of the system 4 sensor nodes have been deployed and its good operation has been verified.

In the next stage of development the calibration of the standard sensors employed in the system will be adjusted compared to factory calibrated accurate sensors. New sensor nodes will be added to the system using new communication links as 3G and LoRa.

The use of the system as a Living Lab has already started into an undergraduate course about wireless sensor networks and Internet of Things. It has also began the collaboration with a research group dedicated to strength a buffer and transition zone around the most important forest near the city aimed to the conservation of the forest. The location of next nodes will be set according to the objectives of the group.

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