A Wireless Sensor Network as a Living Lab for the Development of Solutions for IoT and Smart Cities

Jorge Arturo Pardiñas-Mir, Luis Rizo-Dominguez and Luis Eduardo Pérez-Bernal
Department of Electronics, Systems and Informatics, ITESO University, Periférico Sur 8585, 45604, Tlaquepaque, Mexico

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Abstract: As internet connectivity and digital solutions spread all over, it has become necessary to have the possibility of experimenting and developing solutions for the Internet of Things (IoT) into a laboratory with similar conditions as those of the big scale application. Living Labs are a solution for such a need and in this paper we present the implementation of a living lab based on a wireless sensor network (WSN) aimed to help the learning of this technology by giving the opportunity of experimenting and developing solutions. The WSN works primarily on the ZigBee protocol but, being an educational and developing tool, it also permits to add devices working in other protocols like WiFi, 3G and Sigfox, that we have already experienced. The system includes the possibility that the collected data be kept into an internet server and be able to be displayed to users through a mobile application.

1 INTRODUCTION

As internet connectivity and digital solutions spread all over, it has become necessary to have the possibility of teaching, research, and develop solutions for the Internet of Things (IoT) into a laboratory with similar conditions as those of the real big scale application. This need has been identified in the scientific community, so several efforts have been invested in that direction. We think that despites the many meanings given to the term "Living Lab", for example in (Del Vecchio et al., 2014), (Vicini et al., 2013), and (Tang and Hämäläinen, 2012) among others, it is adequate to describe such a kind of facility, as defined by (Eriksson et al., 2006): "a user-centric research methodology for sensing, prototyping, validating and refining complex solutions, in multiple and evolving rea life contexts". In (Chin and Callaghan, 2013) it is argued that Internet-of-Things is a perfect platform for teaching computer science and it proposes a Living Lab approach based on combining concepts taken from iCampus, Smart Box ad Pervasive-interactive-Programming (PIP). They show that their methods have a good potential for introducing students to programming in a way that is simple and motivating.

An experiential learning program, Living Lab, which provides real world experience in all aspects of information technology to students, is presented in (Justice and Do, 2012). It helps students to develop modern technological skills, effective oral and written communications skills, and the ability to perform well in teams. The development of a wireless sensors and controllers network for training students in Automation is described in (Katsaounis et al., 2014). This is a chance for students to keep in touch with a small-scale implementation of a hybrid network. An educational platform for promoting awareness of lake environmental protection is presented in (Wang et al., 2016). It is based on Internet of Things and wireless sensor network technologies, monitoring water quality of lakes and providing data analysis of lake pollution.

In this paper, we describe our approach to the implementation and launching of a Wireless Sensor Network (WSN) as a support for teaching and research on issues related to the Internet of Things. It has the aim of also being a "Living Lab" allowing the development and testing of solutions under real conditions that facilitate its implementation in a larger scale. This project is not focused on a particular course, but it allows experiencing many topics related to the internet of things. Students can use the system, for example, to develop the final project of a sensor course, or to demonstrate the operation of a microcontroller that performs some function within the network. There are students involved in

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application projects related to sensor networks and mobile applications. Some of the topics that this framework allows to study are the four core technologies normally embodied in currently IoT systems: embedded computing, sensors, networking, and cloud computing (Dickerson, 2017). The teaching of these technologies are mainly aimed to students of the following bachelor programs: Electronic Engineering, Computer Systems Engineering, Information Security and Network Engineering, and Engineering in Service Companies.

Our system was developed based on the monitoring of environmental conditions of the university campus, taking into account the main technical subjects required in learning and working with Internet of Things projects. On the one hand, a wireless network has been developed that monitors the temperature and humidity of the soil in different points of the campus gardens. This goal took into account the university needs related to maintaining in good health the gardens and trees of the campus. The collected information is placed in the hands of the university authorities for analysis and undertake of appropriate action. On the other hand, independent wireless nodes have been added that communicate directly with the system, bypassing the wireless network, to provide information on specific aspects or to allow the use of a different technology.

The architecture of the implemented system and the description of the elements related to the management of collected data, its storage and availability on the Internet was presented in (Perez et al., 2015). This paper focuses on the development and experimentation of the wireless sensor network and its communication with the system.

Section 2 describes the architecture of the system as a whole. Section 3 presents the network development and section 4 describes some tests and results. Finally, the conclusions include some ideas about future work.

2 SYSTEM'S ARCHITECTURE

The Living Lab System for the Development of Solutions for IoT and Smart Cities is a system operating in a university campus, aimed to measure mainly environmental variables of the campus. The system is composed of 3 main elements, Figure 1: the wireless sensor network, the acquisition and storage internet service and the information retrieval service.

- The wireless sensor network is in charge of collecting the data through several sensor nodes around the campus. The first series of installed nodes has the capability of measuring soil's temperature and moisture. This information is sent from each node to the network coordinator who, acting as a gateway, send the data to the system server in internet.
- The acquisition and storage of data on the web, is an internet service being in charge of the system server. It keeps track of each node, stores the collected information in a database, and it also manages everything related to the network, like adding and deleting nodes, sensor variables to be measured, and assigning a location to each node.
- The retrieval of information is the server's section providing real time data collected by the nodes. It also allows generating data reports. The data can be consulted and displayed through a web page or through a mobile application via internet.

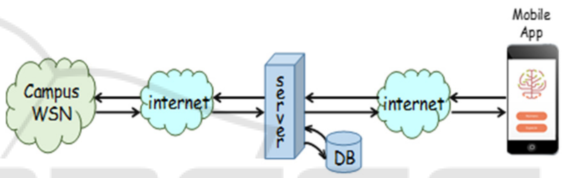

Figure 1: Elements of the system.

The information system design also allows having independent nodes sending its data directly to the server, without belonging to the wireless network, allowing testing special sensor nodes configurations or new sensor technologies.

The university campus, where the system is installed, has a surface of over 41 hectares of which 22 are green areas: gardens and trees. It is a polygon with approximately 530 meters wide and 715 meters long. It exists at the campus over 3,000 trees of about 280 species. In the first stage of development of our system, the wireless network was installed in a delimited area, allowing easily ensuring and monitoring its operation. The system is then a laboratory the size of the campus, with a network of sensors and an information system in operation. The system allows to easily experiencing topics related to the internet of things in an integrated manner: embedded systems, sensors, powering and energy consumption in sensors, use of communication systems for sensors, web services, front-end, back-end, and cloud computing. The services related to the information systems have already been described in (Perez et al., 2015), while in this paper we will focus in describing the wireless sensor network, its operation, experiments and results.

3 WIRELESS SENSOR NETWORK DEVELOPMENT

The wireless network was developed with an initial application target: measuring humidity and temperature of soil, under the requirements of the university office in charge of campus facilities. In this way, we would achieve first the objective of working with a real application. At the same time, its development took into account the possibility of having an easily growing network and of being compatible with different technologies. Taking this as a starting point, it was determined to divide the development of the network into 3 parts: the choose of the technology, the architecture of the network and the sensors to be used.

3.1 Base Technology

It was decided to use a well-known technology as the basis of the network, which would make it possible to operate a network of sensors easily and reliably. This would allow to add new elements little by little and to try new technologies later. The chosen technology was the XBee sensor modules from Digi International, which communicate via the ZigBee protocol working at the ISM 2.4 GHz band, Fig 2. Among the features of these modules are being specifically configurable for activities related to sensing, like defining the inputs and outputs and the sampling time. There is available a Pro version with high transmission power (50mW -17dBm-) and high receiver sensitivity (-102 dBm) focused on network's coordinators and routers and a low power version with less transmission power (2 mW -3 dBm-) and a smaller receiver sensitivity (-96 dBm) focused on end devices. These modules have the possibility of defining 4 analog inputs and 4 digital input/outputs. The communication with the module is made through a serial UART.

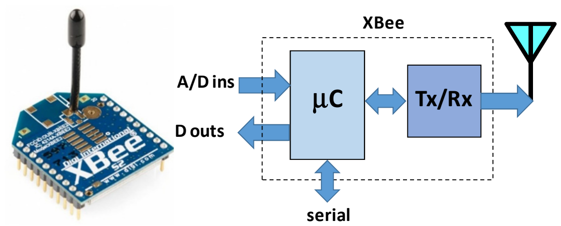

Figure 2: XBee ZigBee module physical aspect and block diagram.

3.2 The Sensor Network

As it is known, a ZigBee network is formed with a single network coordinator (CN) that controls the network, routers nodes (RN) that create the links between all elements in the network and end or sensor nodes (SN), which are tasked with taking samples periodically and transmit them to the network. The implemented WSN uses the two different ZigBee modules in the network according to the functions of the nodes. In the case of sensor nodes, the low power module version is used while for the routers and coordinator nodes the high power version is installed instead. The network is organized in 3 zones, each one with a router in charge of many sensor nodes. Each router in turn communicates directly to the network coordinator or to another router if it is within its range. Fig. 3 shows the block diagram of such an architecture, where HS, ST, and TT are the end devices measuring humidity of the soil, soil temperature and tree temperature respectively. The latter is a sensor not yet implemented. The ZigBee protocol allows the nodes to create automatically the needed links to form the network.

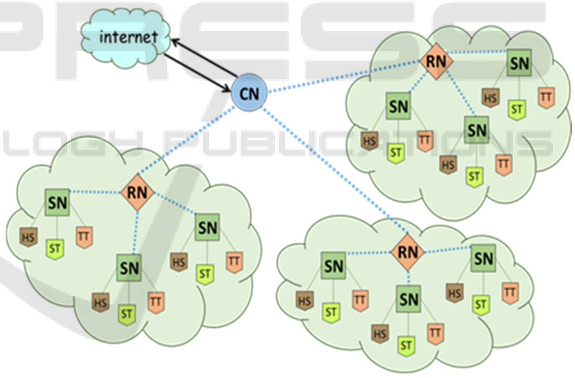

Figure 3: Topology of the implemented WSN.

3.3 The Sensor Nodes

Each sensor node comprises an XBee low power version module, working as an end device, a soil temperature sensor and a humidity soil sensor. We choose sensors aimed to be applied in real environments in order to obtain a reliable and useful behaviour. We selected the Vegetronix THERM 200 and VH400 respectively, shown in Fig. 4. They output an analog voltage proportional to the temperature and moisture. Each node is powered by a 3.7 volt battery, which is recharged through a solar cell. A 3.7V-5V converter powers the sensors. Some nodes are additionally powered by night. The node is configured to take samples around each 30 minutes, send it to the router and return to a low activity state (sleep) until next sampling. The data is transmitted to the sensor network into a ZigBee frame, which in the XBee implementation is a 0x92 API frame. One version of the implemented sensor node is shown in Fig. 5.

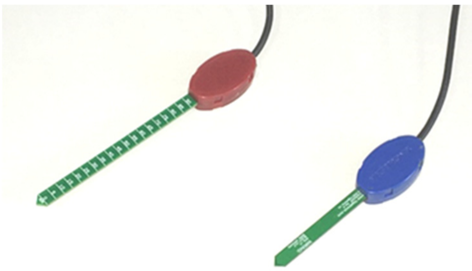

Figure 4: Soil's moisture and temperature sensors.

Figure 5: The Sensor Node.

3.4 The Gateway

The gateway is composed of a microcontroller and a Zig-Bee coordinator. The data arriving from the end devices to the routers is transferred to the network coordinator. The microcontroller analyses the received frame and extracts the voltage values corresponding to the temperature and moisture's sensors. These values are converted to the corresponding temperature and moisture units and they are placed in the format of a new frame, recognizable by the system server. A first version of the Gateway was developed with an Arduino microcontroller board, using a WiFi shield, Fig. 6. It was preferred to use WiFi technology to have greater versatility in the position of the gateway, and increase the possibilities of experimentation.

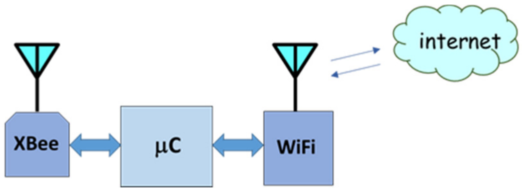

Figure 6: The Gateway architecture.

4 RESULTS

4.1 Installation Tests

The installation and operation of the Wireless Sensor Network was carried out experimenting with different positions of nodes and distances between them. The sensor nodes were installed at ground, between the trees. It was found that a good distance to avoid losing any frame was in general a maximum of 30 meters. It is good to remember that the sensor nodes transmit with a maximum power of 2 mW (3 dBm) and have a

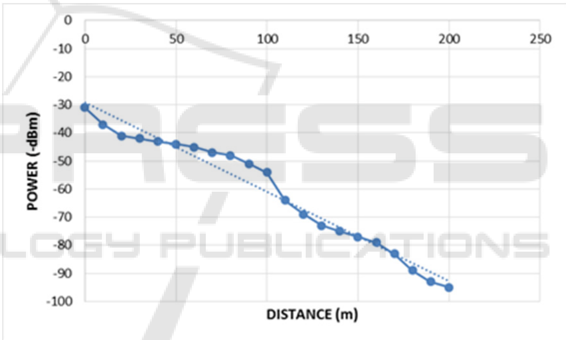

Figure 7: Received power vs distance between the network coordinator and one router.

Figure 8: The Wireless Sensor Network Architecture.

receiver sensitivity of -96 dBm. On the other hand, range tests were made between routers and the coordinator, both of them transmitting with a maximum power of 50mW (17dBm) and with a receiver sensitivity of -102 dBm. Here the distance to locate routers apart from the coordinator was found to be around 150 meters. Fig. 7 shows the results of one of the tests. The final location of nodes into the network at the test stage is shown in Fig. 8.

4.2 Monitoring of Environmental Variables

As said before, being the first job of our system to behave as a Living Lab, the network was designed to serve the campus authorities to collect environmental data concerning the health state of gardens and trees of the campus. With this information, the office in charge of the campus facilities will have the possibility of taking actions to improve, for example, the irrigation system. Additionally to the temperature and moisture of soil, we have added to the system, as required by the same office, two different kind of sensors. One device, a Waspmote Libelium Plug & Play!, measuring some air pollution gases and connecting to the ZigBee network. The second device measures some variables related to the water quality of the campus water treatment plant. It connects independently to the internet server through WiFi. Figure 9 illustrates, as an example, the web information page showing the graphic of the Oxydation Reduction Potential values of water, collected during September 2017.

4.3 Learning Laboratory

As a Learning Laboratory, our system has helped in the development of training experiences for students in their last year of engineering, in different technical areas. This work has been done under real application conditions. Some of the tasks carried out by the students have been:

- Design and implementation of a voltage converter card for analog sensors.
- Programming a ZigBee-WiFi Gateway using the Waspmote device from Libelium.
- Programming a SigFox enabled sensor node based on the Freescale (NXP) KL43Z.
- Addition of functions to the server's data reception service, such as the automatic time stamping of the received frames and improvement of graphics display.
- Improvement of network management tools.

Some of these activities allowed some students to participate in a project to install a wireless sensor network in a forest. The objective is to monitor, within a limited area, the variables that can show the improvement of soil characteristics. In this project, we have collaborated with professors from other areas, such as chemical engineering and environmental engineering.

Figure 9: Example of webpage showing Oxydation Reduction Potential values of water.

5 CONCLUSIONS

This paper presents a wireless sensor network that is part of a system acting as a Living Lab. It helps at the same time the development and learning of technology solutions for IoT and Smart Cities under an easy manageable scale but with similar conditions as the application implemented at full scale. The WSN platform was implemented successfully, allowing the collection of useful data for the care of the campus gardens. It is ready for experimenting new technologic approaches or new products. It has helped students to experience and learn about these technologies. The system makes it easy to add a new technology sensor, or to test a new topology, for example. In the short term, the next steps in the development of the system are to increase the number of sensor nodes, to expand the network coverage, and to give the Gateway more intelligence for doing more local processing.

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