An IoT-based Remote Monitoring System for Electrical Power Consumption via Web-Application

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***Abstract*—Electricity is a fundamental need of the human being that is commonly used for domestic, industrial and agricultural purposes. In this sense, the waste of energy generates millionaire losses for the countries. Technological solutions such as the Internet of Things (IoT) allow connecting the physical with the digital world in order to optimize resources and in this particular case, manage and/or monitor the energy consumption. In addition, the advance of micro and nanoelectronics has allowed the development of communication modules such as the XBee that allows the implementation of a wireless sensor network quickly and efficiently with minimal energy consumption being widely used for monitoring and control tasks.**

The presented prototype takes advantage of the previously mentioned advantages by developing a hardware and software solution. It allows remote monitoring of electricity consumption in a home through a scalable and modular platform using XBee technology and a customized protocol for data communication between the four modules that make up the system. Results are presented that demonstrate the accuracy of the prototype compared to the readings obtained with a conventional electricity meter.

***Keywords*—Monitoring, power consumption, Internet of Things, XBee.**

I. Introduction

Worldwide, energy development is strategic to guarantee the sustainable supply of power from the use of renewable energies, as well as the best use of hydroelectric generation resources. The main goal is progressively to reduce thermoelectric generation, in order to strengthen the transmission and subs-transmission lines present and future to improve supply and demand conditions [1].

The growing development of ubiquitous computing together with emerging technologies such as the Internet of Things (IoT) has driven the development of applications that enable communication between physical objects and the Internet through sensors and the use of embedded systems [2] [3]. The main purpose is to achieve full connectivity along with accessibility to data, automation processes, as well as the reduction of manual works [4].

In this sense, in the field of energy, the way in which the measurement of electricity consumption in households and industries is carried out is inefficient and inaccurate [5]. In the first place, it is necessary to use human resources to visit each location recording the reading of the electricity meters per month. Then, the collected data is processed to calculate the consumption bill per user. This process takes a long time, is laborious and is subject to human errors and meter manipulations.

As an alternative solution, the prototype presented in this paper is based on the Internet of Things (IoT) technology. It is an intelligent meter that allows remote monitoring based on a web application that displays information on voltage and current consumption in a home in a modular way using XBee wireless technology. Additionally, it is a real-time system where data is collected by areas to differentiate how the variation of consumption is in each room with 1-minute time intervals. The results are stored in a database in the cloud. Having an intelligent meter would allow optimizing resources by automating the reading processes and eliminating the need for personnel to perform the readings of the units of kWh, its use would save energy and will contribute to reduce the environmental pollution.

In the following section, details of the proposed system are explained. Section III explains the network architecture implemented to interconnect the entire system, the description of the client applications (front-end), server (back-end) and of the Web portal is included. Experimental results are presented and analyzed in Section IV. Finally, section V provides the conclusions and future work.

A. Related Work

From the article of Bharathi, et. al. [6], a system for monitoring the energy consumption is presented where they propose monitoring the total power consumed using voltage sensors, current sensors, LCD, an ARM LPC 2148 processor and a WiFi module. The data can be accessed through a web page or a mobile application. However, it is not scalable and only has a single wifi module. In addition, it presents problems in the harmonic content of the waveform of the current transducer since it needs a wider dynamic range of measurement.

In turn, in the prototype presented by Montes, et. al. [7], describes a system for monitoring the consumption of electrical energy in homes based on Arduino Mega 2560 with

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an Ethernet module for communication. As in [6], the system is not scalable. In addition, the use of an ethernet module and the wifi model implies an added value in cost unlike the system presented in this manuscript that is modular and uses another type of wireless technology that allows transmitting data more efficiently.

II. Proposed System

The proposed prototype allows to remotely measure and visualize the electricity consumption in a standard home divided into 4 areas: kitchen , social area and 2 bedrooms as shown in the Fig. 1 Each area has a measurement module

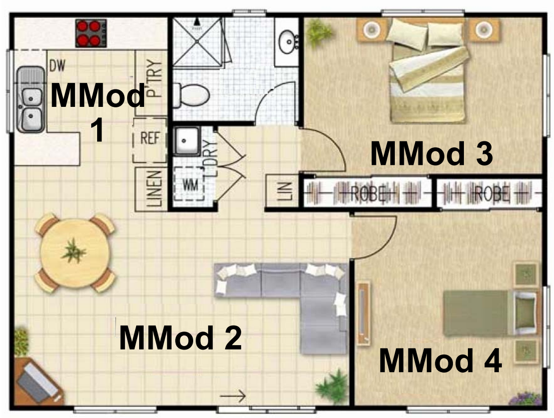

Fig. 1: Location of measuring devices in a standard department

(MMod) responsible for sensing:

- The current consumed by the appliances connected to the electrical network
- The supply voltage.

The most important modules in this report are the voltage measurement and the current sensor (Fig 2), since the measurements of these will be analyzed in the controller and their values will be presented in the control interface.

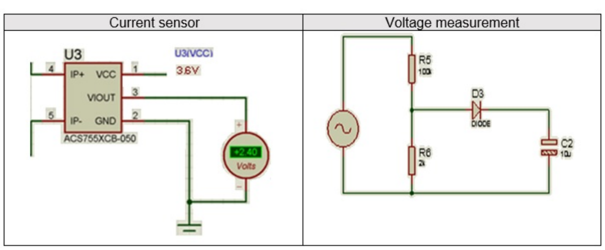

Fig. 2: Measurement circuits

The values obtained are averaged every minute and transmitted wirelessly based on ZigBee technology to a remote server as is depicted in Fig. 3. The historical data is stored in a MySQL database placed in the cloud and can be consulted through a Web page.

For the calculation of the power it is necessary to determine that the values of the magnitudes are in the same wave, and then transform them to RMS values.

For the design of this prototype it is assumed that only active power is consumed, that is, all the loads that are connected to the electrical network are analyzed as resistive. For this reason, it is enough to measure the current consumed and the voltage supplied by the electric line, to know the power consumed considering that the captured values are instantaneous. The block diagram of the module (MMod) implemented to monitoring these variables is illustrated in Fig 4 and explained as follows:

A. Current Sensor

The hall effect sensor ACS712 is used. This is characterized by being linear and minimizing noise. In addition, its cost is low and its analog output signal corresponds to the instant current.

The maximum consumption of household appliances used in a lounge is estimated to be no greater than 2 kW. Taking into account that the power lines delivers 110 V_{AC}, the current sensor has to support a minimum of 17 A which is within the dynamic range supported by the sensor used in this prototype. The sensor output voltage increases proportionally to the current consumption of the connected load with a sensitivity of 0.1 V/A

B. Voltage measurement

The electric line delivers the nominal value of 110 V_{AC}, this value is not constant for reasons of electrical distribution. Therefore, it is necessary to measure the instantaneous voltage to determine the exact value of the electrical consumption in each measurement. For this a rectified voltage divider powered by $V_S = 110V_{AC}$ was implemented, where:

$$V_{out} = \frac{V_S}{100} \tag{1}$$

C. Zero-crossing detector

It is required to detect the zero crossing of the signal to determine which values of voltage and current multiply in the same cycle.

The zero crossing detector developed is simple. It consists in resistor of $5M\Omega$ placed in series to the voltage line and connected to the external interruption pin of a microcontroller (uC). This technique is reliable and useful for measurements at frequencies of 50, 60 and 400Hz with voltages of up to several hundred volts. In this configuration, the I/O protection circuits of the uC are used, which are designed to cut the peaks that can cause an overload of the voltage line.

D. Module XBee

The XBee serie 1 modules have been chosen to establish wireless communication. The implemented network is point-multipoint with a coverage range of 30 m sufficient for the prototype requirements. The XBee works in the band of 2.4GHz and use the 802.15.4 communication protocol. It works as end point in the PAN, it means that they are not able to route packets. A coordinator is required to access to the medium.

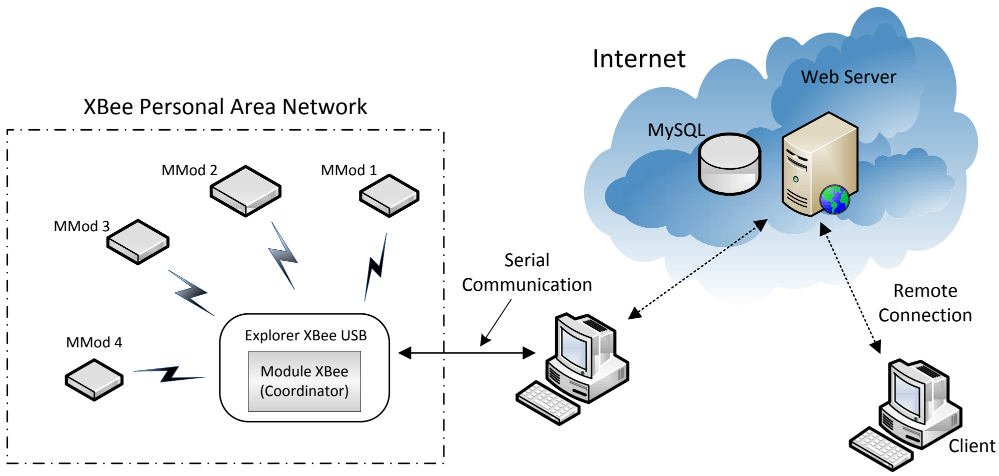

Fig. 3: Remote monitoring system for electrical power consumption

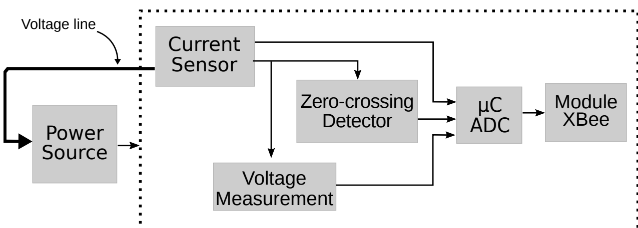

Fig. 4: Block diagram of the Measurement Module (MMod) located in every lounge

The wireless network through the XBee modules provides connectivity between MMod and PC Client that provides remote access through a web page where the history of energy consumption in the home is displayed.

Each XBee is responsible for receiving the average voltage and current data sent by the uC and transmitting it to the Hub module connected to an Xbee Explorer.

E. Microcontroller (uC)

The uC is responsible for sending/receiving data from a PC through the USB port and can send/receive data through a serial connection to the XBee with low latency. The uC is able to manage the information from the wireless devices by serial communication, at the same time that it can receive / send data through USB communication by means of the use of interruptions.

Besides, it receives the signals from the current sensor, the voltage divider and the zero crossing signal. This signals are sampled using the analog to digital converter of 10-bit resolution embedded in the uC. The obtained magnitudes are converted to RMS values and averaged for 1 minute before being transmitted to the client side via serial communication. In total, 360 samples of voltage and current are taken in 1 minute.

F. Power Source

A 3.2 V_{DC} power source was designed to supply energy to the uC, XBee module and the current sensor.

III. Network Architecture

This section describes the elements used and their functions to establish the wireless sensor network and send information to a database hosted on a server.

A. Coordinator

All the nodes of the same WPAN (Wireless Personal Area Network) are coordinated by a single node called Network Coordinator. It organizes and coordinates access to the medium.

The XCT-U software is used to assign the XBee Firmawe as Coordinator. The default communication parameters are also configured: Baud Rate, Parity, Bit Stop according to those defined in the uC. In addition, it is necessary to assign the following parameters:

- PAN ID used to identify the device on the network
- CH Chanel to identify the channel.

Similarly, the configuration of the MMod End Device Firmware is done with the same software XCT-U. So that, the MMods should be in the same network as the Coordinator in order to be communicated. The CH Channel and the PAN ID must be the same as the Coordinator. The destination address must correspond to the one belonging to the Coordinator

B. XBee Explorer USB

La XBee Explorer is used to plug the XBee to a USB port, allowing to connect the board to a computer in order to read and write data from the serial port. Basically, the XBee Explorer acts as a gateway between the PC and the XBee.

In the case of our prototype, the XBee configured as coordinador is the one connected to the XBee Explorer USB. It collects the data from the 4 MMod and transmits it to the client PC client, so it can send it to the cloud.

C. Client

The PC Client initiates the establishment of the communication with the 4 MMods to receive the average values of voltage and current sent by each MMod. To identify the origin of the data, a custom protocol based on alphabet letters was implemented to establish the flow control of the information between both PC client ends and the MMods. Table I details the letters corresponding to the control packages used in each case.

TABLE I: CUSTOMIZED PROTOCOL IMPLEMENTED BETWEEN THE PC CLIENT AND THE MMOD

MMod	Initiate connection		Connection established
	Request	Reply	Ack
1	A	E	I
2	B	F	J
3	C	G	K
4	D	H	L

In the Fig. 5 the handshake sequence between the Client PC and the MMod 1 is shown. First step correspond to establish the connection and then transfer the voltage and current values.

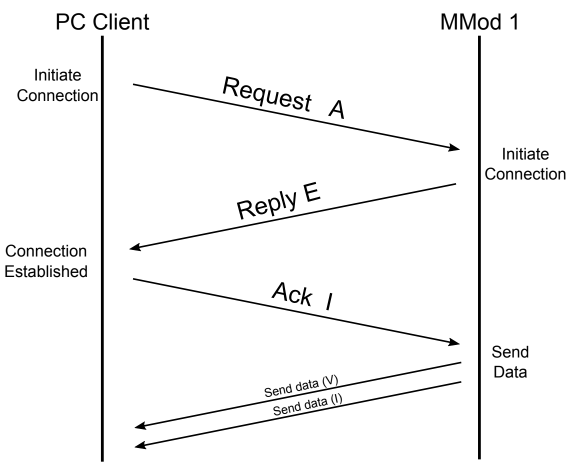

Fig. 5: Handshake sequence between the Client PC and the MMod 1

D. Server

The XBee coordinator is connected to a PC in charge of receiving and processing the data, which in turn store this information every hour on the system Server. The database used is MySQL version 5.1.72-cll-lve.

E. Web Application

The implemented web page allows to remotely view the electricity consumption of the 4 MMods. The linked program developed in Java manages the database in MySQL and calculates every minute the power consumed with the values of voltage and current delivered by the 4 MMod, 60 samples are averaged to obtain the electricity consumption per hour.

The hosting service is used to host the web portal and administer the database. The graphic interface displays information about the data source, date, time, voltage and current. In addition, it is possible to select the display of:

- Historical of the electricity consumption of a specific MMod throughout a specific day.
- Total electrical consumption of several days corresponding to all the equipment that make up the network.

Access to the monitoring portal is protected. Users must validate their entry using a User and a Passwod. Once the access is verified it is possible to delete records and perform daily or weekly consultations.

Remote queries to the web portal are handled by accessing the database server to filter and display the required information.

IV. PROOF OF CONCEPT

To verify that the data obtained by the measurement and monitoring systems of electricity consumption are reliable, several measurement tests were carried out in order to calibrate the devices and also to reduce the measurement errors that may exist.

Table II shows the percentage of error between the magnitudes measured experimentally and the magnitudes obtained with the MMod. The errors obtained in both voltage and current variables are within an acceptable range of operation which gives accuracy to the system

TABLE II: ERROR BETWEEN THE MAGNITUDES MEASURED EXPERIMENTALLY AND THE OBTAINED FROM THE MMOD

MMod	V_{rms} (V)	V_c (V)	Verror %	I_{rms} (mA)	I_c (mA)	Ierror %
1	118.85	119	0.12	38	37.8	0.05
2	119.11	119.9	0.66	43	41	4.65
3	118.02	117.6	0.36	39	39	0
4	118.05	118.1	0.04	37	37	0

A. Contrast test with the electric meter

For these tests, all the data of the power consumed in the department was recorded through the electricity consumption monitoring system, during a period of 5 hours; in order to compare the power measured by the monitoring system with respect to that marked by the electric meter.

The time that the monitoring began was at 10:52 a.m, the electric meter until that moment had a consumption of 32571 kW/h. The monitoring ended at 3:42 p.m, 4 hours and 50 minutes later. The electric meter recorded a consumption of 32576 kW/h, this means an average consumption of 5 kWh.

The proposed systems registered a consumption of 5,755 kWh. It is important to highlight that an error can not be estimated with these measurements, due to the scale in kWh in which the data is displayed in the electric meter. However, the data obtained allow us to assess the accuracy of consumption of the electricity consumption monitoring system with respect to the values measured by the electric company.

V. Conclusion and Future Work

Considering that energy is a valuable non-renewable resource of nature, managing energy allows improving the grid efficiency. In the proposed prototype, a monitoring electrical consumption system is presented. It is composed of four wireless modules for gathering, processing and analyzing information with the advantage of being scalable due to it is modular. It is possible to isolate errors by areas, and correcting them without affecting the others. Additionally, the data always available to the consumer through the Web application can be used to detect where unnecessary electrical consumption occurs, minimize waste of energy, analyze the consumption for hours and relocate the demand. It is important to highlight that the user can know their daily consumption rate in advance and tries to reduce the usage or anticipate the cost of the monthly bill of the electric company.

Although this system was developed for a home, it can be installed in buildings, industries and other large infrastructures using the same design principle with wireless technology for the control and monitoring of electrical consumption avoiding the use of wired networks.

As future work it is proposed to migrate the Web application to a mobile app for smart-phones and tablets, that can supports more information load in the cloud with real-time updates for multiple users, adding services such as generation of alarms in case of failure, consumption patterns, and predictions. The monitoring system presented which uses the concept of the Internet of Things (IoT) can contribute to the development of sustainable smart cities in Ecuador replacing the conventional energy meter with an intelligent meter like the one presented in this manuscript.

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