# Sensor network for energy-efficiency programs: characterization and breakdown of the electricity bill using custom wireless smart meters

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***Abstract*—** Understanding and monitoring the electrical energy use is fundamental to encourage consumers and small business owners to implement energy-efficiency measures and, therefore, to cut their energy bills significantly. This works presents the design, development and implementation of an electrical energy monitoring sensor network which can be easily installed to measure and monitor the energy use of every appliance in a house, presenting to the consumer a detailed report of the energy spent by each electrical device (TV, lights, showers, etc.). The measuring units and a coordinator form a wireless network, which is capable of measuring the electrical energy and recording the data of each home appliance in the flash memory of the coordinator. The data stored in the coordinator is sent (via a wireless connection) to a computer where the analysis of the data is performed and a detailed report of the energy breakdown is presented.

***Keywords*—**PLC, Power meter, Sensor network, ZigBee.

## I. Introduction

REDUCING energy consumption and eliminating energy wastage are among the main goals of every country that has made commitments under the Kyoto Protocol.

Understanding the way people make use of electrical power in their residences is a good step to get to know how to improve its usage.

Data collected by the largest electricity distribution company in Brazil, AES Eletropaulo S.A. [1], show that many consumers complain about their high electricity bills, but they usually cannot indicate why and what caused the large energy use.

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This paper presents the development of a sensor network of wireless smart energy meters that presents the detailed characterization and breakdown of the electricity bill, offering a powerful tool to encourage them to implement energy-efficiency measures and, consequently, reduce their electricity bills.

With this detailed information in hands, consumers can understand how much they spend with every single electrical device in a house and, therefore, take measures to reduce their impact on the electricity bill.

In order to be practical, the developed the sensor network formed by wireless smart energy meters has to be simple to install and easy to be deployed in a residence or small business, without requiring any changes in the original electrical wiring.

## II. Applications

The developed system is planned to be offered as a service by the electricity companies, so that both customers who want to know better how they use the energy they are paying for and energy-efficiency programs are potential candidates for using the service.

## III. Elements of the System

The system is composed by five elements: a coordinator, a displaying-processing unit (DPU) and three types of smart energy meters.

The main element of the system is the coordinator. It is responsible for storing the information sent by the smart energy meters and also to sustain the wireless network.

The DPU is basically a PC that connects to the wireless network as an end device, and is responsible for retrieving the information stored in the coordinator, processing it and displaying to the user in an user-friendly report. The DPU does not need to be online during all the acquisition period.

The smart energy meters are responsible for the data acquisition and, as nodes of the wireless network, also perform the function of routing devices.

## IV. Smart Meters

In the first version of the system, for testing the concept, the smart energy meters where developed based on the RZ Raven development kit from AVR [2]. In this case, the microcontroller ATmega1284P was used to acquire the data from the sensors and also send it to the network coordinator, through the wireless system.

The main core of the wireless smart energy meter is shown in Fig. 1.

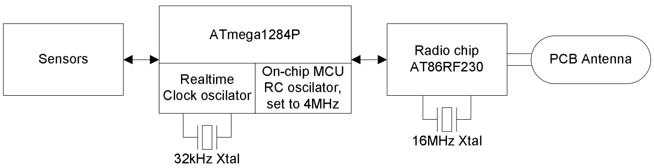


Fig. 1. Smart meters main core.

To measure and monitor the energy consumption of all electric devices in a house without any changes in the original electrical wiring installation, it was necessary to develop three different types of smart energy meters.

### *A. Power outlet adaptor smart meter*

This smart energy meter is to be employed to measure and monitor the energy consumption of every device that can be plugged to a power outlet.

The home appliance power cord is simply plugged to the smart energy meter device, which has a plug to be connected into the AC power outlet, as shown in Fig. 2.

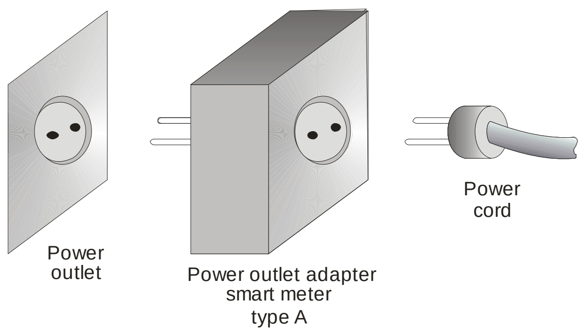


Fig. 2 Power outlet adaptor smart meter installation scheme.

It is based on the energy meter integrated circuit AD71056 [3] from Analog Devices, that measures the amount of energy consumed and has an output which is a frequency proportional to the energy being measured. The ATmega1284P microcontroller in the smart energy meter counts those pulses and, every 5 minutes, send the total number of pulses to the coordinator.

### *B. Clamp smart meter*

This smart meter make use of a current clamp to measure the current on electrical devices that are wired directly to the AC mains, as it is the case of showers in Brazil, and the amount of time it is kept on. Of course, by measuring only the current and not the voltage on these devices, the energy has to be calculated, what is done by the network coordinator, when it receives the data sent by the meter module. To calculate the energy accurately, the AC voltage is measured in one A/D converter available in the coordinator.

### *C. Light smart meter*

This energy meter is used to measure and monitor the energy consumption of lightning devices which are not accessible by the clamp meter (for example, fluorescent lights in ceiling mounting fixtures). This smart energy meter uses a photodiode to detect the light status (on or off), and when the photodiode detects that a light was turned on, the microcontroller is woke-up and starts to measure the amount of time that the light is kept on. It is necessary one meter module for each lighting set that is commanded by one switch.

During the system installation/programming, the power of all lights that are monitored by one photodiode is stored in the microcontroller's memory. Thus, the energy consumed by the set of lights is easily calculated by the software in the DPU.

## V. Wireless Sensor Network

The smart energy meters form a wireless network based on the ZigBee [4] protocol, which is very appropriate for the application, since it is low power and implements a wireless protocol that support *ad hoc* topology.

The DPU connects to the ZigBee network as an end device by an USB dongle attached to the PC.

The power outlet smart energy meters also perform the function of routers, by connecting end devices to the coordinator. The clamp and the light smart energy meters, which are battery powered,. In order to obtain a long battery life these energy meters are used as network end devices, because the current drained by a router would reduce the battery life, increasing the operational costs of the system. In Fig. 3 it is shown an illustration of the wireless network.

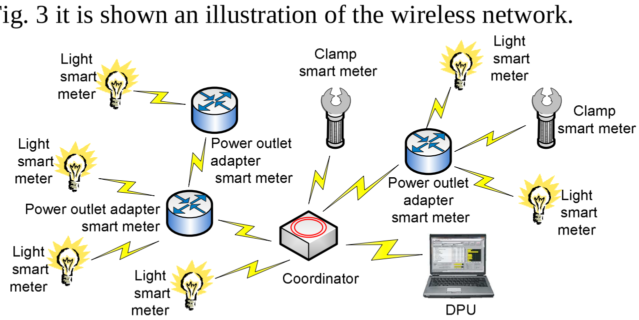


Fig. 3 Network.

## VI. PLC

Sometimes, due to the characteristics of the local being monitored or due to the building structure/construction, it is difficult to establish the communications between some end devices and the coordinator or a router. For example, in an industrial installation with two nearby buildings which are enough far away one from the other that the ZigBee wireless network cannot link one building to the other.

In some cases a power outlet adapter can be placed between the two buildings, in order just to make a bridge to those distant end devices.

However, in cases where this strategy cannot be used, a second ZigBee network can be assembled and a connection link between the networks must be established.

In this project it was developed an architecture where each ZigBee network (two or more) are connected via their respective coordinators, which send/receive data to each other using a serial protocol implemented with a Power Line Communication – PLC link. Just like any other device in the network, the slave coordinator will send the data to the master coordinator every five minutes. Thus, the master coordinator will concatenate all the data in only one point, so that the DPU can retrieve it at once.

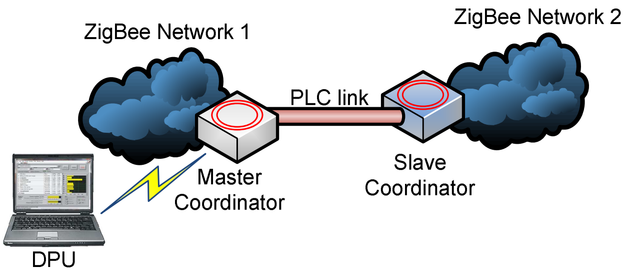


Fig. 4 PCL linking two ZigBee networks

## VII. Data Acquisition

All the information acquired by the smart meters is sent to the coordinator at every five minutes.

The power outlet adapter smart energy meters send the amount of energy consumed already calculated and processed while Clamp smart meters send the mean value of the electrical current along with the time the device was kept on. The light smart energy meters send only the amount time the lightning device was turned on.

Every time the coordinator receives data from a power outlet adapter smart energy meter or a light smart meter, it saves that data directly to its memory. When the data comes from a clamp smart energy meter, the coordinator also measures the mean value of the AC voltage and uses it to process the amount of energy consumed before saving this data.

At the end of the monitoring period the DPU can retrieve the information stored in the coordinator.

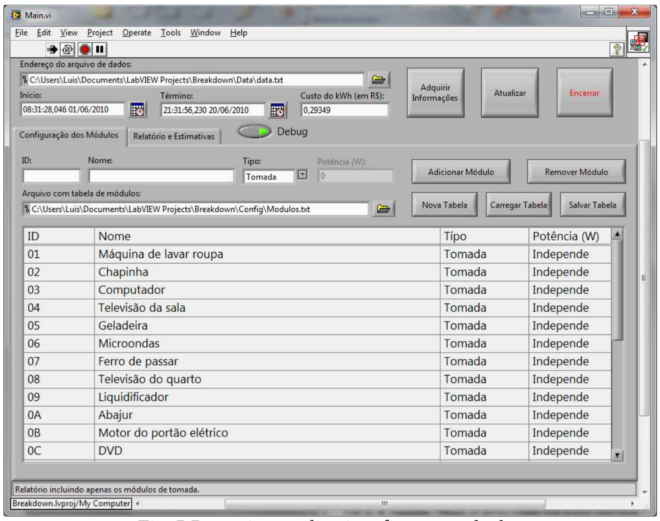


Fig. 5 Reporting application, first control tab.

The second tab, as shown in Fig. 6, is the report itself. It presents to the customer all the electrical appliances with their respective consumption, and their impact on the electricity bill. It also calculates an estimative of the monthly electricity costs.

The list can be filtered by smart energy meter types, and a graphic at the right shows the percentage of consumption that each electrical device is responsible for. This graphic can be switched between energy (in Kwh) and cost.

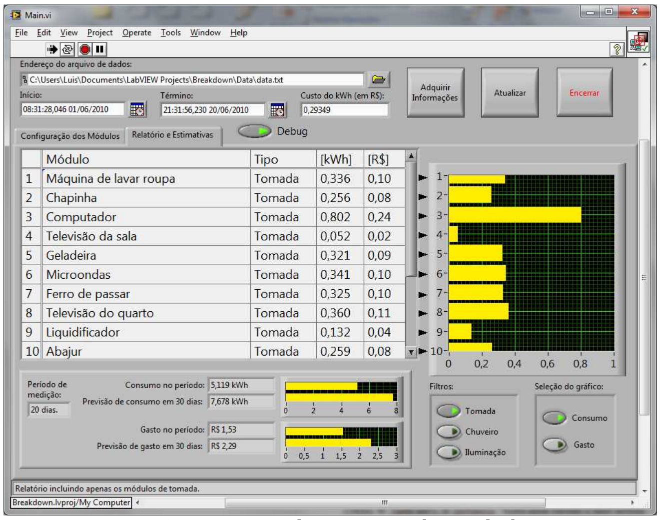


Fig. 6 Reporting application, second control tab.

## VIII. Conclusion

This paper presents the development of a hybrid network sensor system able to measure and characterize the breakdown of the electricity bill using custom wireless smart energy meters.

Although the accuracy of the energy measurements performed with the proposed system is reduced due to the use of the clamp and light smart energy meter, the gains in installation and deployment simplicity were key elements to the success of the project.

The fact that the clamp and the light smart energy meters present errors in the calculated energy which are up to 4.5%, depending on the AC voltage fluctuations of the residence under test, is not a critical issue. This accuracy is adequate to present an excellent estimation of the energy breakdown of the electricity bill, showing the customers how and what can be done to reduce their electricity costs.

The hybrid architecture developed (wireless+PLC) proved to be an important feature of the system, since it can be used in virtually any installation, since there is no theoretical limit for the number of ZigBee networks that can be connected via the PLC link.

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