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TOWARDS A HOME ENERGY MANAGEMENT MODEL THROUGH A COORDINATOR OF SMART SOCKETS

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The efficient use of energy and its implementation in domestic automation systems is an essential requirement in Smart Cities. However, this requires appropriate measurement devices and an M2M control-communication alternative that offers real-time visualization of the information. This article proposes a prototype of the home electric power consumption management platform, as an advance in generating a model for future Smart Grid. Therefore, the research implements smart socket devices and a coordinator of the communication of a home area network between these measuring devices to have an intelligent control of electric power. As a result, real-time data of the defined electrical parameters have been obtained. This information has been stored in the Internet cloud, also allowing remotely programming and controlling these measurement devices. The present research contributes to generating a profile of total load consumption for residential users and allowing them to know and compare their real consumption with what was reported by the distributors.

Keywords: *HEMS, smart metering, smart socket, smart grid, smart cities*

1. INTRODUCTION

What makes an electrical network to be an intelligent network (Smart Grid) is the ability to communicate with all its users, and these with the general control system of electric power distribution. This provides benefits at different scales, not only to energy suppliers and distributors, but also to the end user in terms of being able to measure their own consumption of household electrical appliances [1], [2]. Therefore, it must be guaranteed that the communications are robust, manageable and safe, so they must be based on standards that guarantee connectivity among the elements of the network and an adequate quality of service, including the information of alarms and connection-disconnection remote [3]. Each of the network layers:

Homes, Neighbourhoods and Urban Areas (Home Area Network HAN, Neighbourhood Network Area NAN and Wide Area Network WAN), must have its own communication standard and also be able to communicate and interoperate with each other [4], [5], [6].

In the present research, a basic electronic structure for a Home Energy Management System (HEMS) is proposed, based on a wireless network of sensors/actuators/agents, controlled by a coordinating device that makes the decisions. The coordinator is responsible for concentrating the data of the terminal devices that measure the electrical parameters of the demand in the home, and then present them through an application for Smartphone. To obtain the information, the coordinator connects wirelessly with the terminal devices (IEEE 802.15.4) that measure and calculate the electrical parameters in the nodes of the network (voltage, current, power, energy, etc.) and communicate the electrical variables of each device that is part of the electrical circuit of the home, in addition to controlling the power supply and recording its status [7], [8].

The proposed system allows effectively regulating the use of energy using measurement and communication terminal devices called Smart Socket and a Communication Coordinator system for automatic meter reading (AMR). The set of these elements forms an Advanced Measurement Infrastructure (AMI) to inform the user of its Response to Demand (DR) through the automation of advanced distribution and dynamic models of pricing [9], [10].

2. EXPERIMENTAL DEVELOPMENT

For the purpose of investigation, a prototype of Automatic Meter Reading (AMR) device has been developed, which measures the electrical parameters in each of the household appliances connected to the home network, with the aim of obtaining a residential consumption profile, for its later coordination to automatic measurement of readings and real-time sending to the Internet cloud. This device, called "Smart Socket Light" (SSL), fulfils the function of a single-phase socket and communicates the parameters measured through the M2M technology to IoT (Internet of Things), as shown in Fig. 1.

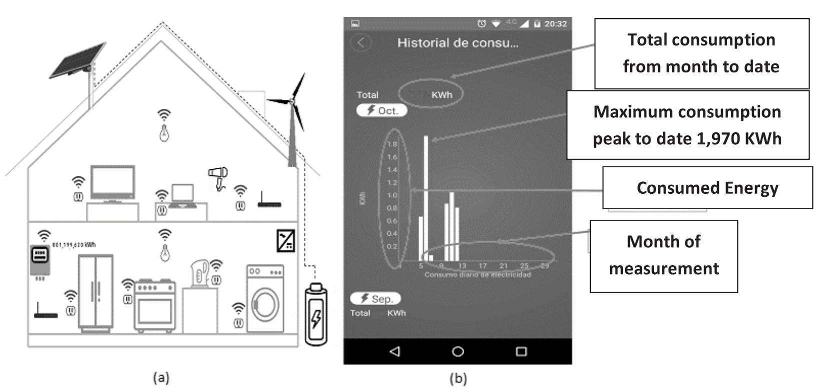

Fig. 1. (a) Communication systems HAN and intelligent measurement based on IoT, (b) History of energy consumption shown on a smartphone.

In this model, the SSL is communicated wirelessly to a receiving node and Gateway-Access Point coordinator. This agent fulfils the role of creating a bridge for the data and transmitting it through the Internet, allowing it to be viewed by the user on a smartphone or similar devices. This experimental prototype is a basic element to obtain a home energy management system. In this way, the behaviour of the users of a residence is recorded through their electrical consumption needs, such as: cooking, heating, food preservation, communication and recreation, as well as remote switching on and off.

The proposed architecture consists of a microcontroller unit and voltage-current sensors to measure the energy consumption, communication modules and power supply unit. This measurement can be visualized on a screen assembled with a smart connector and show the power consumption in a tablet device. The energy consumption data of the AMR is sent to the cloud, where the data is processed to make an appropriate decision based on the limitations of the available energy, the risks of overconsumption and different alarms. Figure 2 presents the topology of communication network and data storage platform.

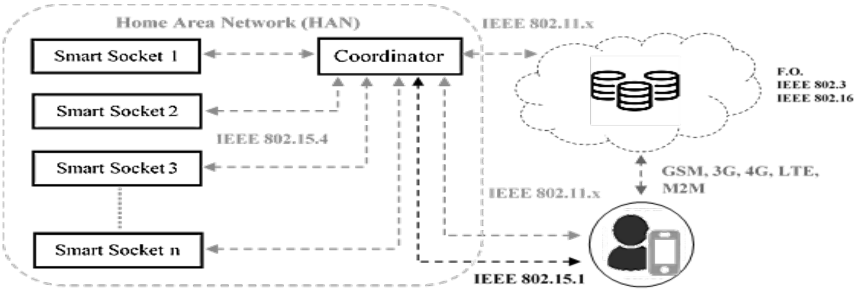

Fig. 2. Topology of communication network and data storage platform.

2.1. Automatic Meter Reading (AMR-SSL)

The SSL corresponds to an intelligent complement for a general electrical outlet; it has the capacity to measure the energy consumption in household appliances (up to 15 Amperes). If a particular device is consuming energy above a threshold value, the device orders for safety reasons its disconnection from the supply, as well as if an over current or short circuit is detected. The proposed model has the flexibility of the device portability to different sockets within the deployed coverage environment and is able to change the identity of the device in the user interface from a smartphone.

The SSL includes a communication interface, a current-voltage sensor, an MCU unit (Microcontroller Unit) and a switching circuit. The functionality of SSL is as follows:

- Measures the voltage and instantaneous current that are present in the device connected to it.
- Calculates the instantaneous power demanded by the device connected to it.

- Calculates the energy consumed by the device connected to it.
- Executes the communication request algorithm to inform the power and make the decision to turn on / off by the Smart Socket Coordinator.

As shown in Fig. 3, the consumption measurement is obtained through a current sensor and a voltage sensor, which measure the voltage and current values respectively, as well as obtain the difference between the zero crossings of these two signals and calculate correctly the powers required by the loads (Active, Reactive and Apparent). The current signal is obtained by a non-invasive sensor and the voltage signal is obtained through a potential transformer with a transformation ratio of 220V to 12V.

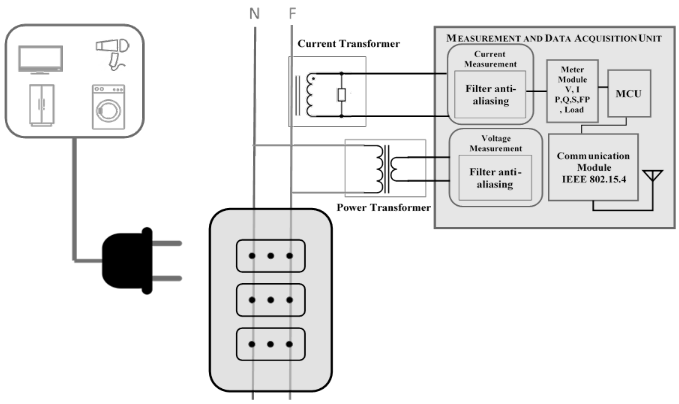

Fig. 3. Architecture of Smart Socket Light.

The SSL device has a unit of measurement of electrical parameters made by the microcontroller ADE7753, which supports the IEC 62053-22 standard, which regulates the electrical energy measurement equipment, more specifically to the "Active energy static counters". This microcontroller has ADCs and DSP patented for high accuracy in the face of large variations in environmental conditions and time.

The features and benefits of the proposed MAR – Smart Socket Light are as follows:

- High accuracy; compatible with IEC 60687/61036/61268 and IEC 62053-21 / 62053-22 / 62053-23.
- Digital on-chip integrator that allows for direct interface to current sensors with di / dt output.
- A PGA in the current channel allows for direct interface to inverters and current transformers.
- Active and reactive energy, sample waveforms, current and voltage rms.
- Less than 0.1 % error in active and reactive energy in a dynamic range of 1000: 1 at 25 ° C.
- Accumulation mode only of positive energy available.
- User-programmable on-chip threshold for line voltage and SAG peaks and PSU supervision.
- Digital calibration of power, phase and input offset.
- Temperature sensor on chip (± 3 °C typical).

- Serial interface compatible with peripheral interface serial interface (SPI).
- Pulse output with programmable frequency.
- Interrupt request (IRQ) pin and status record.

The ATMega328P microprocessor is used for data acquisition, configuration and calibration of the ADE7753, which is also connected by an I2C bus to a real time clock (DS3231).

2.2 Communication Technologies for the Proposed System

The data of current, voltage and power transmitted from the terminal devices represent a small amount of data, which makes a very high bandwidth unnecessary. Therefore, it is established that a speed of 250 kbps is sufficient to carry out transmissions at the HAN level, and this will be the maximum speed required by the data acquisition agents. The IEEE 802.15.4 wireless communication standard is the most convenient from the energy point of view, since it has the least consumption, so ZigBee has been chosen as the standard for communicating the Smart Sockets in the HAN (Table 1).

Table 1

Speed and Consumption of Technologies for Use in Measurement Agents

Technology	Data Rate	Consumption
Bluetooth	1 Mbps	100 mW
ZigBee	250 kbps	30 mW
WiFi	2–600 Mbps	667 mW
PLC	2–45 Mbps	Null

There are several ways to perform measurements of electrical parameters (voltage, current, power, energy, etc.), as well as various ways to communicate the data obtained from the devices. This paper presents the communication of the data, analysing the techniques that will be used to send the information in the standards that are intended to be used for this task IEEE 802.15.4 and IEEE 802.11, for each of the stages of transmission of the proposed platform architecture that is disclosed in the following points. ZigBee is used as an open source wireless protocol that provides benefits such as low cost, low power, low data rate and its compatibility with IEEE 802.15.4 mesh networks.

2.3 Communication to the Cloud

The required topology is based on deploying a network of mesh-type wireless sensors, which will provide multiple routes for sending data. This sensor network is composed of the coordinator, the router and the terminal devices. Through the Gateway incorporated in the Coordinator, it is possible to connect the sensors to the Internet, so that the user can see, through a web page, the status and consumption in real time of their devices, as well as all the electrical parameters of each household appliance as shown in Fig. 4.

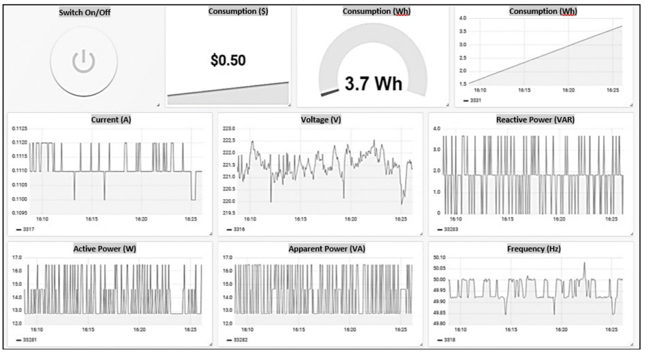

Fig. 4. Real-time AMR application (Radio communication Proposal UTEM-UDA-UdeC).

There must be a coordinator per Smart Socket network, since the network architecture requires having a Master-Slave that allows for the correct coordination of communication with all terminal devices. Its functions are to control the network and the paths that devices must follow to connect with each other, requires memory and calculation capacity. The GW Coordinator connects devices in the topology of the network, in addition to offering an application level for the execution of user code. The final device has the necessary functionality to communicate with its Master node (the Coordinator). In this way, this type of node can be asleep most of the time, increasing the average life of its batteries. A terminal device has minimal memory requirements and is therefore significantly cheaper.

The communication between Smart Socket and Gateway is done through the protocol (IEEE802.15.4), sending a String separated by commas, which has the structure shown in Table 2.

Table 2

Data Structure for IEEE 802.15.4 Protocol

Structure	"ID_Entity	ID_Attribute,	Value	Mark of time"	
Example	UID	UID	222.5	2018-04-09T15:10:09.000Z	
Size	16 B	5 B	10 B	24 B	Total = 55 B

The data frame currently used has a size of 55 bytes. According to the ZigBee protocol, the maximum per data frame is 127 bytes, but in practice using the network functionalities of the protocol it decreases to 100 bytes without encryption and to 82 bytes with encryption. The communication between the Gateway and the Data Centre will be done through the HTTP, MQTT and COAP protocols, sending a JSON object (JavaScript Object Notation). An object sent by the MQTT protocol will be analysed which has the structure that is represented in Fig. 5.

```
Object {    topic: 'entity/ID_Entidad/attr/ID_Atributo',
             payload: {
                   "id_entity":"ID_Entidad",
                   "id_attribute":"ID_Atributo",
                   "value":" 200.5",
                   "timestamp":"2018-04-09T15:10:09.000Z"
            },
            messageId: 'l7f5ZV9',
             qos: 0,
            retain: false }
```

Fig. 5. Communication structure between Gateway and Data Centre.

The data frame currently used has a size of 202 bytes, which determines the basic data load.

3. RESULTS AND DISCUSSION

The graphs of the electrical parameters are obtained in a measurement campaign of several electrical appliances: Refrigerator, Router, Electric Oven, Water Kettle, Smartphone Charger and a Notebook (laptop). From the measurements obtained through Smart Sockets, stored in the cloud, the power graphics are obtained instantaneously and in 24 hours of measurement. It should be noted that these measures only include the most important household appliances within a household and that lighting has been left out. For reasons of space, only the consumption profile of the washing machine is shown. In Fig. 6, washing, rinsing and centrifuging periods of the washing machine are displayed. Cycle 1 (2: 16: 20-2: 28: 51) of the washing machine carries out the filling of the tank by means of the filling pump, which is then followed by the washing by the motor movement connected to the tank. Cycle 2 corresponds to rinsing (2: 35: 09-2: 37: 09) and emptying the tank by means of the discharge pump. Cycle 3 (2: 45: 38-2: 49: 04) performs the same function described in Cycle 1 but with a shorter wash cycle. Cycles 4 and 5 of machine activity are identical to Cycles 2 and 3 (2: 55: 46-2: 58: 13 and 3: 07: 14-3: 09: 01). Cycle 6 (3: 16: 35-3: 21: 57), the most particular in all the operation, corresponds to the rinse with centrifugation, which can be clearly seen as low power due to the deactivation of the motor of the tank and stop with its own inertia.

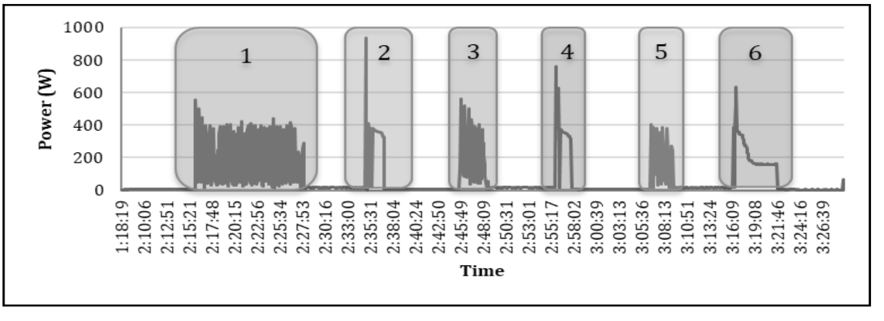

Fig. 6. Demand for washing machine power.

4. CONCLUSIONS

In this experimental research, a wireless AMR type Smart Socket design has been presented, which measures real-time electrical parameters such as Active, Reactive and Apparent Power; Power Factor; Active Energy Consumed by each device with a resolution of 4 seconds. This architecture allows obtaining the totality of the required electrical parameters and to be shown to the user through graphics in an application. The data are obtained in real time and collected in the central node of the Internet cloud, which can be stored and used to program and configure HEMS devices, together with this, to generate a profile of total load consumption for residential users. The data and the graphs of voltage and current may also be used to identify faults in the home electrical system and to record the behaviour of the distribution company and the supply in general, and failures of the electrical distribution system of the sector. The obtained capacity, to connect and disconnect remotely the home charges remotely, will allow consumption, alarms and emergencies to be avoided. In addition, it will generate energy savings and these appliances can be activated at more convenient times in case of having a flexible regulated tariff. This allows projecting a model of Remote Home Energy Management. As a future line of research for the Coordinator (HEMS), it is intended to incorporate the improvement of a power negotiating device capable of estimating the availability of renewable energy, which plays a crucial role in optimising consumption and assigning priority to an individual household appliance.

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MĀJAS ENERĢIJAS PĀRVALDĪBAS MODELIS, IZMANTOJOT VIEDO KONTAKTLIGZDU KOORDINATORU

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K o p s a v i l k u m s

Viedo pilsētu pamatprasība ir efektīva enerģijas izmantošana un tās ieviešana iekšzemes automatizācijas sistēmās. Lai to panāktu, ir nepieciešamas atbilstošas mērierīces un M2M vadības komunikācijas alternatīva, kas piedāvā informācijas reāllaika vizualizāciju. Raksts piedāvā mājas elektroenerģijas patēriņa pārvaldības platformas prototipu, kas ir priekšnoteikums nākotnes viedā tīkla modelim. Pētījuma autori piedāvā viedās kontaktligzdas ierīces un mājas tīkla komunikācijas koordinatoru starp šīm mērierīcēm, lai nodrošinātu viedu elektroenerģijas kontroli. Rezultātā iegūti definēto elektrisko parametru reāllaika dati. Šī informācija tiek saglabāta interneta mākonī, ļaujot arī attālināti programmēt un kontrolēt šīs mērierīces. Pētījums veicina iedzīvotāju kopējā slodzes patēriņa profila radīšanu un ļauj patērētājiem uzzināt un salīdzināt viņu reālo patēriņu ar to, par kuru ziņo izplatītāji.

11.07.2018.