A Holistic Approach to Energy Efficiency Management Systems

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***Abstract*—Improvement in energy efficiency is one of the most effective ways in economic terms to increase supply security and reduce emissions of greenhouse gases. Furthermore, the increased cost of energy resources has encouraged the development of new technologies that allows their efficient use. Through the identification and control of end users consumptions - businesses, residential, public, etc. – these technologies allow us to have more efficient consumption without lowering the threshold of comfort users are used to. The Smart Home Energy project makes a profitable use of these technologies to provide a complete solution that, through user interaction with electrical devices present in the home and integrated into the network, allows on one hand to manage, control, plan and in most cases reduce the electric bill, being aware about the cost of it, and on the other hand, help to improve the environment.**

Keywords-Digital Home; Energy Efficiency; Bill reduction; Cloud.

I. INTRODUCTION

A. Interoperability between systems

A Digital Home [1] offers users an intelligent environment that learns and adapts to the references and needs of its occupants. However, there are many restrictions: the high cost of certain systems, capacity problems, lack of standardization, etc. The most important restriction to solve is the lack of real interoperability between different systems.

Both domotic systems and service robots allow a major modernization in Spanish homes and improve energy efficiency thereof. These two technologies are the ones that provide the greatest technological advances in homes, public buildings or workplaces.

The lack of interoperability makes both systems work and interact independently. This means that if we make them work together, there would be a duplication of performed tasks. So if both systems could coordinate, resources will be optimized and it would improve energy efficiency.

Therefore, it is essential that those devices communicate with each other in a complementary way, i.e. sharing the services to know what is happening around them and take decisions accordingly.

Technically, it is possible to create a common communication protocol at the application level on the protocol stack TCP / IP, and the corresponding adapters for each device. This protocol, as standard, allows the intercommunication between devices that comply with the label that ensures the adequacy of their adapters. It is named DH Compliant [2] and it is a universal and open standard. Because of this, the Smart Home Energy project (hereinafter SHE) is based on technology standards, giving them some advantages that other protocols lack:

- There is neither technological nor brand dependence.
- Savings in solution investment.
- Intellectual and economic richness both in companies and national research institutions.
- Control and simultaneous management of service robots, smart home applications and smart appliances.

B. Device management

In recent years, computers and electrical appliances that are being incorporated at homes are reaching more and more energy efficiency levels. However, its contribution is still not enough in the current energy scenario, where external energy dependence and indefinite rising prices cast doubt on the profitability of these devices compared to the useful life and the necessary investment.

This means that energy saving measures and common recommendations (energy-efficient light bulbs, A + + electrical appliances, awareness campaigns , etc.) are increasingly ineffective in achieving a significant reduction of consumption, prompting the need for more advanced strategies.

From a technical point of view, a home is an extremely complex system with many uncertainty sources depending on environmental conditions and human behavior.

Therefore, the inclusion of monitoring and control systems in real time in our homes is becoming increasingly necessary.

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The incorporation of these management and control devices allows the quantification of the energy performance of a home, recording the consumption values in order to characterize the profiles and habitual patterns. This provides the user - using appropriate predictive models- with the necessary information to anticipate and minimize energy losses.

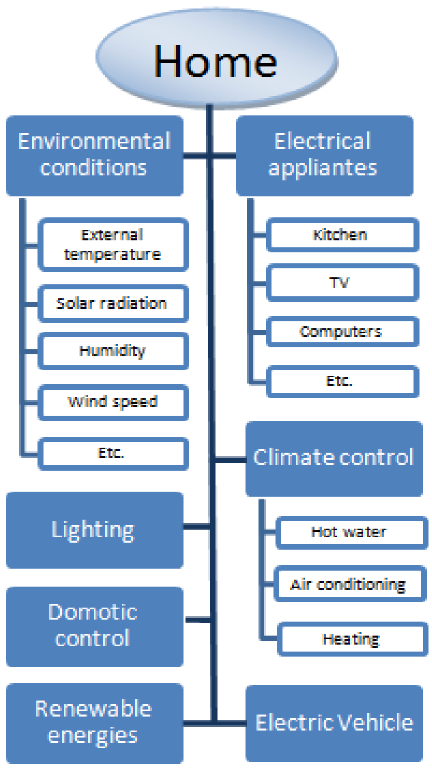

Figure 1. Elements involved in home energy management

C. *Holistic approach*

From a physical standpoint, all elements on a system may interact between each other that may indicate a dependence level that could be characterized by statistical analysis based on observation of variables and parameters.

This fact also takes place in the field of HVAC in homes, since all the elements of the domestic system (people, electrical appliances, lighting, outdoor conditions, etc.) exchange heat with each other by changing comfort conditions (temperature and humidity). For that reason, quantification and analysis of all variables involved in heat exchange must be made from a holistic approach, measuring the contribution of the element of each system and modeling its interaction to propose real energy-efficient alternatives within the conditions of comfort that the user sets.

Applying this integration approach to a energy management system using a suitable learning system, optimal decisions would be made in real time to reduce energy losses (based on "experience" of the system from the beginning of its operation); decisions that could be ineffective or even counterproductive if the mentioned approach is not considered.

This will result in most cases in a reduction on the electric bill, taking into account that the electrical company has an important role in the system.

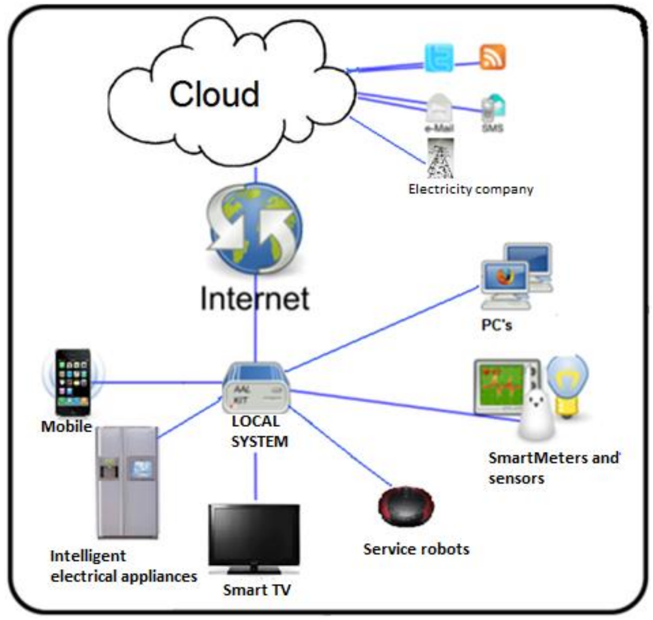

Figure 2. Multidevice architecture scheme

As seen in Figure 2, the great advantage of the architecture stands on the fact of implementing a solution without having to think about which device is addressed.

The rest of the paper is organized as follows. Section II describes the state of the art. Section III explains the proposed solution. In the last section, we draw the conclusions and indicate the future work.

II. STATE OF THE ART AND DISCUSSION ON HOW TO IMPLEMENT THE SOLUTION

Integration of various automation and control technologies in the domestic environment is called “Digital Home”, an idea not only applying to domestic tasks through smart home appliances, but also aiming to cover needs of personal assistance, education and entertainment as well as security and surveillance.

The following sections will discuss the different points to be solved and decisions on the most appropriate technologies to be used in the proposed solution:

A. *Efficient energy management*

The Digital Home proposes an efficient energy management by integrating some features in common with BMS (Building Management System) [3]. such as issues related to the HVAC control, a correct monitoring of

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lighting, allowing a control of consumption and, therefore, its associated costs.

Control of electrical appliances and robots is not covered by these systems, so BMS are a good starting point to define the features and functionality of SHE, even though their ultimate goal does not match the prototype to be developed. In terms of architecture, BMS has a similar structure and characteristics to those presented by the prototype: hardware components (sensors, controllers and actuators), computer processing power and control of all sensors and actuators, user interface (smart-phones, PCs, tablets, etc.) as well as means of transmission.

The meters that will be referenced in Section III generate XML reports, allowing to be processed quickly and giving the necessary information for operation to the SHE system. In contrast to other research, all business logic will be in the cloud and it is going to be described in the next section. As will be seen, the core protocol requires only basic input parameters in order to generate configurable and customizable reports and recommendations, among other functions, independent of the measuring device.

B. Cloud

It is necessary to store the information from the digital home in a centralized way in order to have a database that allows comparative analysis and heuristics. Cloud technology [4] allows us to centralize the information without requiring high-capacity storage in homes as well as to manage and maintain the integrity, security and availability of data, storing replicated data to ensure recovery in case of a loss of information.

In turn, the Cloud server-side solution provides an elastic system that is able to be sized according to demand using an infrastructure that does not require a high initial investment. It also allows an adaptive storage capacity and information processing to specific needs. This adaptive capacity also improves the overall energy efficiency of the system.

Therefore, this solution provides facilities for software updating, software improvements and developments. This is immediate and transparent for the user because most of the software is centralized and not distributed on each node.

From the user's perspective, Cloud technology provides access to the stored information from any device, anywhere [5].

C. Communication

After the study of various technologies, we chose to use of DPWS (Devices Profile for Web Services) [7] for the communication within the housing as it maintains the philosophy of SOA combined with the convenience of Web Services.

It is necessary also to take into account that the system requires the input in an agile way and an easy integration of different devices. Furthermore, the access to and from the outside will be made over different types of networks – wired and wireless- so communications between digital homes nodes and the Cloud are made using REST API [8].

The implementation of the REST API allows defining a communication interface between software components (API) where an URL represents an object or resource whose content is accessed via HTTP. This solution means that a digital home can notify captured information to the Cloud. These are the advantages of the approach:

- Portability between different languages. This is highly important for integrating different manufacturers and technologies in digital home nodes.
- Performance improvement comparing to other APIs (XML, SOAP, etc.), which is particularly critical due to the large number of potential nodes of the digital homes network.
- Easiness of scalability to consider a probable exponential in the adoption of digital homes.
- REST communication is less "heavyweight" compared to SOAP, so it is faster and consumes less bandwidth.
- Lack of strong typing and changeable data structure at any request.

On the other hand, applications such as consumers' information transferred to and processed in Cloud also will make use of REST API and will serve of these facilities. Furthermore, the REST API functionality can be extended in client applications using widgets or the own applications or if the API is opened by applications developed by the users or communities of these manufacturers, utilities, etc. Next, the qualities of the REST API to exploit Cloud information are highlighted:

- Exploitation and use of information and services in an agile way, as well as easy integration into several applications and devices.
- Resources access is more accessible than SOAP and other heavier protocols that require more processing of the response to its interpretation.
- Customer accessing a REST communication does not require large resources compared to SOAP.

D. DHC Adapters

The SHE (Smart Home Energy) kernel must be based on an open, extensible and modular protocol, so DHCompliant [2] including its open energy service DHC Energy is considered a very suitable option as it allows integration of consumption measuring devices, such as CurrentCost, with the other technologies in the home. The services of DHC communication protocol are set out below:

- DHC- Security & Privacy service provides the security and privacy to prevent fraudulent use of devices and access to data by people or devices outside the system.
- DHC- Groups service coordinates the implementation of collaborative tasks between different devices connected to the system.
- DHC-Localization Service provides the information to locate devices within the home and help them in navigation.

- DHC-Intelligence service provides intelligence to the system by managing rules that control the tasks and predicting sensor data from a previous training.
- DHC-Energy Service [9] improves energy efficiency being probably one of the most effective ways in economic terms increasing supply security and reducing emissions of greenhouse gases and other pollutants.
  DHC-Energy arises from that need by establishing the concept of energy and smart grids [10] in the DHCompliant communication protocol. It defines a set of concepts and energy management savings that allow the user to know in detail the energy consumption data in the Digital Home environment.

The prototype, using an expert system with a rule editor, allows the recommendation of actions on a digital home environment depending on environmental conditions, creating a knowledge database with the consumption.

For this purpose, the expert system, based on its experience, uses the rules to model the system. In addition, this editor enables you to test and simulate the rules. The rule execution is done with an inference engine based on an execution of rules and tree forward.

III. PROPOSED SOLUTION

Therefore, after studying the state of the art, the SHE architecture is proposed. It is specified in SysML, the standard and open language for systems engineering.

A. Requirements

The need to have an intelligent measuring device, Smart Meter: will report in real time about the consumption of gas and electricity, showing the actual rates. The Smart meter [6] shown in Figure 3 (a) and its adapter for connection in Figure 3 (b) are examples of the device that are been used:

Figure 3. Smart meter (Current Cost) and his wireless connection

For tasks that require cooperation among multiple robots, first a leader is chosen among them, depending on the energy consumption of each robot.

B. Establishment of the charging information

We selected the most economic energy configuration. The user can see the types of charging (maximum consumption, cost per kWh, etc.), being able to select the best rate, so that the user can choose what time will a device be enabled or disabled according to tasks being performed, time of day and the tariffs to be applied.

Figure 4 shows a sequence diagram describing the process.

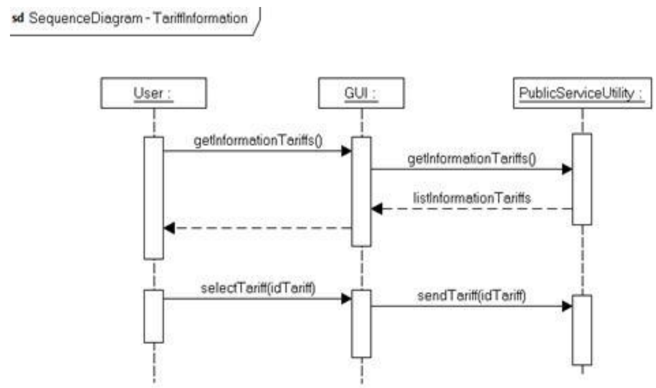

Figure 4. Sequence diagram: Obtain pricing information

C. Device states

It is also important to know the user's preferences to be compared with the data that shows the state of the device and the power source - either renewable or normal electrical supply. The sequence diagram that represents the different states of the device is shown on Figure 5.

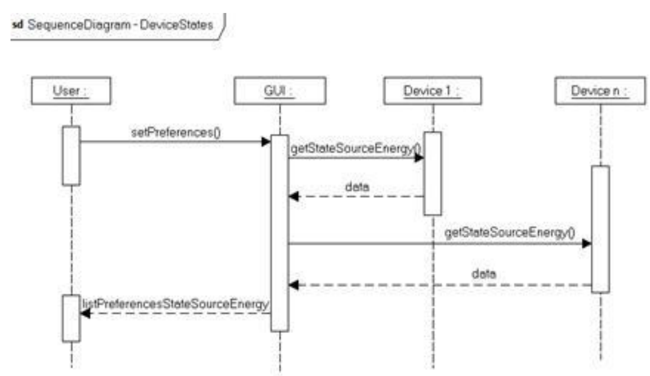

Figure 5. Sequence diagram: Device state

D. Temperature regulation

Using metadata is one of the main ways of managing energy savings. Through that, the internal and external temperatures are known, as well as other certain characteristics of the environment (humidity, number of sunlight hours, rain, wind, etc.). It is described in the following sequence diagram.

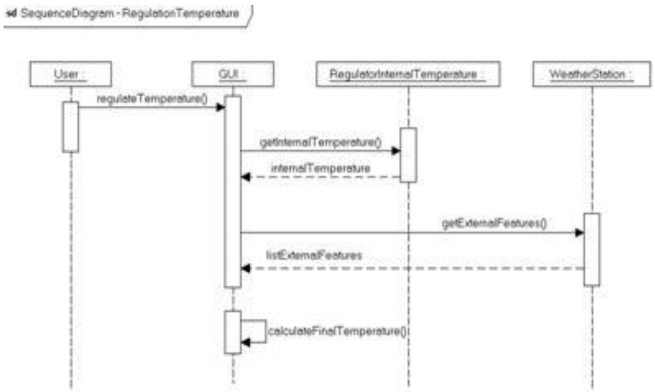

Figure 6. Sequence diagram: Temperature regulation

E. *Energy profiles*

There is a large number of devices that are held to regulate their energy consumption (TV, mobile phones, computers, etc.). Therefore, the DHC-Energy defined a set of patterns of energy consumption:

- Off – This profile is used to point out that the user does not need the device and the power consumption is zero.
- Stand by – The device is awaiting orders. Its power consumption is minimal.
- Low - The device is operating at low capacity. In this profile, the energy saving rate will be the highest.
- High - The device is operating at full capacity. In this profile, the energy saving rate is the lowest.
- Emergency - Full capacity of use. There will be no energy savings.

Assignment of a profile for a device: The user will be able to choose one of the define profiles for each device or each home.

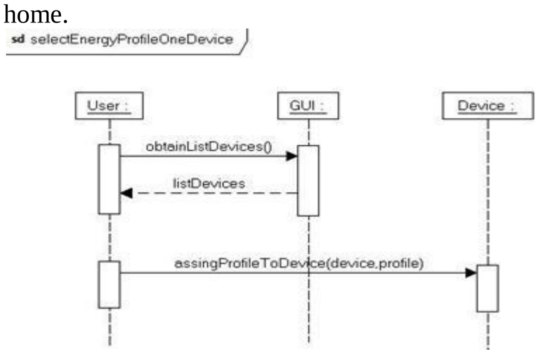

Figure 7. Sequence diagram: Election of the energy profile

F. *Change Profile*

If a device remains in an inactive state, the device must change its energy profile for a lower profile.

G. *Service and devices description*

The DHCompliant device description should contain a list of DHC-Energy services. This XML description must contain the name of the DHC-Energy service and SCPDURL description with the URL to the extended service description.

This architecture is summarized in a main block, which is implemented using Cloud Servers, Smart Home Energy Management System, and blocks for adapters that will have the common interface ConnectedDevice (device connected). On the other hand, the recommendation system will have a distributed architecture between the cloud and the devices in the home. The information sharing took place by exchanging an XML file. After being obtained from the SHE adapter (DHC-Energy), this information is sent to the cloud.

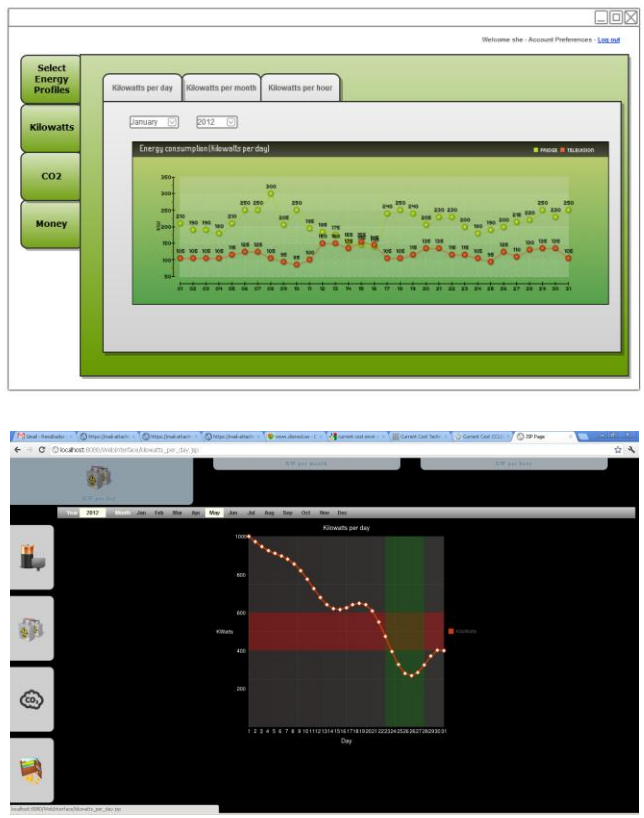

Figure 8. Prototype interfaces

As it is shown in Figure 8, the information will be displayed on screens, which take into account different aspects of usability, accessibility and of course, the functional aspects of providing the user of the information that allows to manage the environment devices and Smart Grid that are in the user digital home. As there are different manufacturers working within the SHE, implementations depend on each particular company or manufacturer. Prototypes that are independent of a particular solution have been proposed and they are being used by various technologically neutral members of the consortium.

IV. Conclusion and Future Work

This architecture work allows to determine that an open stage of interaction between devices and the Smart Grid can be set by providing more capabilities than pure traditional energy efficiency (such as accounting and reductions in consumption). It also allows the establishment of a consumption profile of the different heterogeneous devices a user has at home, as well as a referral system in the cloud associated with business intelligence that allows reducing even more the energy expenditure. All this is done in a distributed way but through a single point where the user interacts.

It can be also concluded that this technology has advantages over other approaches because it is open, distributed, scalable and requires little or no configuration by the end user. In addition to the technical advantages, other advantages include the open environments and standards that will produce more open market scenarios. The results of these market changes are beyond the scope of this communication.

This first interaction has been outlined in architecture, prototyping the various adapters and software to deploy in the cloud. It remains to be completed, and tested for selected use cases in the project Smart Home Environment.

One open issue is the analysis of the scalability of the technology. Different scenarios could be simulated (for example using queuing theory) to understand how a large-scale deployment would consume more or less computational resources on the Cloud side and of the recommenders.

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