Open Architecture to Raise Awareness of Energy Consumption on the Home Environment

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Abstract. The climate changes as well as the sustainability of our energy supplies present multiple challenges and require a worldwide coordinated response. Europe 2020 is a jigsaw of policies and measures binding targets for 2020 to reduce greenhouse gas emissions by 20%, ensure 20% of renewable energy sources in the EU energy mix, and the reduction of EU global primary energy use by 20%. In the longer term, new generations of technologies have to be developed via breakthroughs in research if we are to meet the greater ambition of reducing our greenhouse gas emissions by 60-80% by 2050. The reduction of the primary energy use can be accomplished with mentality awareness of the home users. By educating ourselves and those around us, our negative behaviors can be changed, creating a culture of sustainability. In order to achieve this goal, we are suggesting an open architecture with a friendly visualization interface that can be used to raise the households inhabitants awareness of their power consumption. With the proposed architecture, energy consumption data can be stored in a remote server and can be further processed in order to extract the power consumption for each electrical appliance, opening the door to the development of service extensions to provide user- and context-aware advice on how to save energy.

Keywords: Architecture, Energy, Wireless, Sensor Network, Power, Measurement.

1 Introduction

Recently, the European Union (EU) introduced the '20-20-20 goals' [1], a set of environment and energy sustainability measures targeting the year of 2020. This commitment set briefly consists in 1) reducing the greenhouse gas emissions by 20%, 2) ensuring that 20% of the consumed energy is provided by renewable sources, and also 3) reducing the EU primary energy use by 20% [1]. An approach toward the latter relies on raising the awareness to the problem within the home, since residential energy consumption can represent 30% to

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40% of the total energy demand in developed nations [2]. Studies conducted in different countries concluded that 26% to 36% of home energy consumption is a result of residents' behavior [3], giving emphasis to the importance of energy consumption awareness in improving residential energy efficiency. The next step is to understand how to encourage household inhabitants to adopt a sustainable behavior. Recent results show that household inhabitants install energy monitoring solutions in their homes mostly 'for saving money, maintaining a comfortable setting' [4] and that they wish real-time information on their in-home resource consumption [4,5]. However, this information alone may not be sufficient to effect behavioral changes, since general users may not know the course of action to follow upon a certain information set. A more effective approach is to provide consumers with sustainable education, supported by the numbers of their own consumption information as a continuous process [3,5], i.e., both before, during and after energy use.

This paper presents EMA (Energy Metering Application), an open architecture for a system with the potential to encourage sustainable energy usage within residential environments. EMA enables the collection and storage of energy consumption data from individual electrical appliances. Besides, this solution provides a user-friendly data visualization in a platform-independent manner, accessible from any device (laptop, smartphone, photo-frame, etc) connected to the Internet. The system is designed for easy setup, using the existing communication infrastructure of the household. Although EMA is in many aspects similar to existing solutions, we are unaware of a structured discussion on the issues relevant for the design of the different components and their integration into an architecture as the one proposed here.

The rest of the paper is organized as follows: Section 2 refers to existing energy metering techniques and architectures. In Section 3, we describe the system requirements and use cases. In Section 4 we detail the design of the EMA system including its key components. Finally, Section 5 concludes the paper and presents future work to be developed within the project's scope.

2 Related Work

Most of the houses in developed countries already have a system to measure overall electricity consumption and charge it accordingly. However, these systems are not designed so that the householders can understand and control their consumption costs, and commonly they are located outside the home. Recently, several energy metering systems oriented to help end-users understand their energy consumption patterns appeared in the market.

Energy-aware Plug and Play (EPnP) [6] proposes a network level power management for home network devices. The proposed power management is effective when a service requires the joint interaction of many devices, however the interaction information is kept within the house environment. This can be understood as an hidden cost to householders, since they are responsible for the maintenance of the server and for the security of the stored information. The architecture for a home energy saving system, HESS, is proposed in [7], which provides a real-time home energy monitoring service. Its main objective is to reduce or cut off standby power consumed by home appliances, thus providing an intelligent home energy management service. HESS uses a modular architecture, however the HESS server is a critical system component that must be maintained by the householder. The authors also do not clearly explain if the HESS clients are easily added or removed. The ecoMOD housing project [9] is an on-going design, build, and evaluation of a prototype which contains electrical power, water, temperature, and carbon dioxide sensors. The proposed architecture is complex, not easily deployed by the typical householder and also lacks an interface to give proper feedback to the users. The OWL Wireless Electricity Monitor [14] and Eco-Eye [15] are electricity metering systems which use contactless electric energy metering sensors (clips placed around appliance power cable) connected through wires to a wireless transmitter. A wireless receiver, equipped with a simple display, receives data from the transmitter and shows instantaneous and accumulated energy consumption translated into monetary cost. For both OWL [14] and Eco-Eye [15] the display can show data from only one transmitter that supports a limited number of energy sensors wired to it, and the user interaction is limited to an LCD display controlled through a set of buttons. TREE (Tendril Residential Energy Ecosystem) [16] uses a lower cost metering unit, consisting of a module to be placed between the device plug and the power outlet. TREE is very similar to the system proposed in this paper, but it is designed to be offered as a service by utilities or energy retailers, so it is closed and householders are obliged to buy the service from these companies. Plogg [17] is a complete metering system similar to TREE that provides electric energy metering devices with different wireless communication standards (such as Bluetooth and ZigBee) and sends the data to a backoffice, where it is available for visualization. Plogg offers functionalities which are similar to those provided by EMA, but does not support a device-independent energy consumption display and data is available outside the home only if a static IP address is used. Google Power Meter [18] and Microsoft Hohm [19] do not offer a complete energy metering system, as these focus on storage, processing and visualization of consumption data, offering services like the introduction of active and semi-personalized advices about good energy consumption policies.

A recent study on understanding resource consumption in the home [4] concluded that household inhabitants would like detailed real-time information of their in-home energy consumption as well as tips on how to save resources that are relevant to their situation. Although some were aware of the existence of systems similar to Plogg or TREE, these are perceived complex and requiring extensive rewiring [4]. Moreover, by storing the information in reliable infrastructure and applying data-mining techniques, there is the possibility to extract more meaningful information for the user [8].

3 Requirements and Use Cases

Our ultimate goal is to develop an electricity monitoring system for residential use that is capable of displaying electricity consumption in a way that motivates energy consumption savings on the inhabitants. The system described here is specific to monitoring electricity, but we envision a system that 1) can be easily extended to meter other types of energy, like gas, water or heating. This can be achieved by separating the metering part from the home communication among devices. It should 2) provide understandable information about the consumption of one or more home electrical appliances, calling for a home communication network that can support a large number of devices. Moreover, 3) that information should be accessible in real-time and 4) from any place. This has two consequences for system design: the energy data should be saved in a remote and centralized location located outside the home environment and it should have a device-independent interface so that it is accessible from anywhere. The system should 5) be easily deployable and 6) make use of as much as possible of the existing household infrastructure, driving us to decide for a wireless network to provide communication among the home devices and a router for gateway. Hence, electricity metering units responsible for gathering electricity consumption data from electrical appliances should be easily added to/removed from the system. Further, the network to be able to setup and manage all the electricity meters located in a home requiring only very little interaction. Finally, 7) it should have a an open and modular architecture, so that it can be easily enhanced with other features and integrated with other services.

4 System Architecture

We propose a system architecture following the previously defined requirements and design guidelines. The EMA system, depicted in Figure 1, consists of three main blocks: home, backoffice and user interface. While the first two are sets of physical components, the user interface consists of both the data visualization GUI and the physical devices that enable access to it. This separation is fundamental for a scalable architecture, making use of existent infrastructure (COTS router as gateway, Internet connection, GUI on existing devices) to avoid the necessity of home-located resources capable of constant data processing, saving the end-user unnecessary material, power consumption and maintenance costs. The system follows a service oriented architecture (SOA) where the home environment and user interface use services offered by the backoffice through Simple Object Access Protocol (SOAP) and AJAX. This modularity and use of open interfaces enable the easy integration of EMA or its components with other systems.

EMA must provide two basic functionalities: 1) the addition/removal of electricity meters from the system, and 2) gathering energy measurements in a remote server, for storage, processing and adequate visualization. The management of meters in the system (1) can be further split into construction and management of the energy meters network in the home, and the device addition/removal

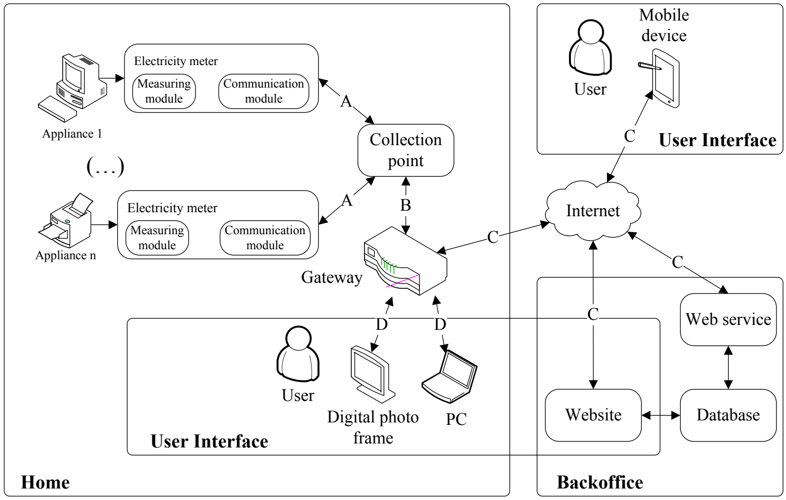

Fig. 1. EMA's system architecture

in the backoffice. The first is readily implemented by wireless technologies available in the market (e.g. ZigBee [10] or Z-Wave [11]), and is accomplished by adopting such a wireless technology for the communication between the electricity meters and the collection point. The second is achieved by running an EMA dedicated application in parallel with the other tasks normally performed by the gateway, in combination with the built-on/in collection point: the latter retrieves the list of associated electricity meters and the EMA dedicated application registers them in the remote server using an appropriate service. This process can be triggered by pushing a button on the collection point. The acquisition of an energy measurement (2) is done periodically upon a broadcast request message sent by the collection point to the electricity meters associated to the wireless sensor network. For each response sent to the collection point built-on/in the gateway, the EMA dedicated application sends the pair (meter id,measurement) to the remote backoffice server.

4.1 Electricity Meter

The electricity meter is the physical component which measures the electricity consumption of a given appliance using the Teridian 71M6511 IC [12]. The electricity meter is to be placed between the AC power outlet and the plug of the electrical appliance to be monitored, so that not only the current and voltage can be sensed, but also the power to operate collected. It contains two separate modules — measurement and communication modules — to provide a straightforward extension of the system to other types of metering, since the communication module can then be applied to any kind of energy measurement module (see requirement 1 in Section 3). The communication module consists of a wireless transceiver IC and RF front-end. We adopted the Z-Wave technology since the auto-configuration of the network and the easy addition/removal of nodes fulfills our requirements.

4.2 Gateway and Collection Point

The gateway is the point that interfaces the home environment and the Internet and the collection point is a device that serves as gateway to the network of electricity meters. It was implemented in a COTS router (specifically the Ubiquiti Routerstation Pro), a device commonly present at home and constantly turned on to provide Internet access to its users, whereas the collection point consisted of a Z-Wave USB device connected through an USB port. openWRT [13] was used as the router firmware, in order to implement the basic system functionalities described in the introductory paragraphs of Section 4. The router hosts an application that consists of two main parts, one responsible for receiving data from the collection point (via interface B) and another that sends the data to the backoffice via Internet (interface C). Again, this separation keeps the system modular: only a specific self-contained part of the application must be changed to accommodate changes in the technology used for interface B or C. Additionally, some effort was made towards the integration of EMA with the Google PowerMeter API. Besides posting the energy measurement values to a remote server these can also be easily sent to the GooglePowerMeter server and visualized in the Google Power Meter interface [18].

4.3 Backoffice

The backoffice is a server, or cluster of services, in a remote location where the energy consumption data is stored, processed and prepared for visualization. It holds a database which stores information about each user: profile, electricity meters owned, the measurements made by electricity meters over time, as well as any other statistics over those data. The communication between home and the backoffice is based on Web Services. The application running on the gateway sends SOAP requests to the backoffice that hosts a custom Web Service, exposing operations which involve interactions with the database.

4.4 User Interface

The user interacts with the system in two ways: for the installation of the meters and for visualizing the data. The first is discussed in the introductory paragraphs of Section 4. The latter is provided by the third main system block, the user interface, which groups the applications responsible for 1) processing the consumption data and 2) generating the visual information as well as 3) the renderer software. This is primarily a common browser that runs on any device with Internet access, like a mobile device or a regular PC, but it can also be an RSS feed reader on a similar device or on a photo frame, as presented in Figure 2. Alternatively, the Google PowerMeter provides both a structured platform to store energy data as well as advanced visualization functionalities [18].

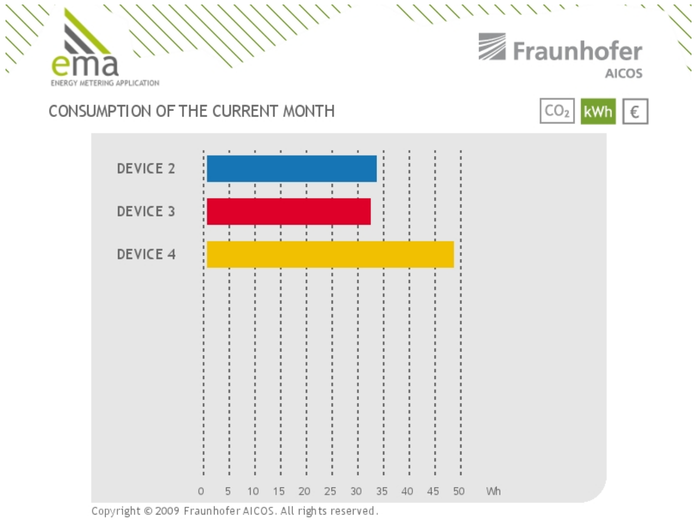

Fig. 2. EMA photo frame screenshot

5 Conclusions and Future Work

This paper presents a modular and flexible approach for detailed measurement of energy consumption in homes, offering user-friendly, platform-independent visualization of that data from any device with Internet access. The EMA architecture allowed the integration of the collection point and gateway into a router with a Z-Wave USB stick connected to it. This way the energy meter network can be easily implemented as a stand-alone system, which is deployed without the need of any type of configuration. The EMA gateway was developed taking into consideration the use cases defined in Section 3. Efforts to integrate EMA with the Google Power Meter API have been spent, despite the early stages of the developments, which allows the addition of a new visualization method and storage of the information in a reliable infrastructure. The modularity of the architecture is the key to flexible deployment of such a system, as it enables easy change/extension of any block of the system without requiring modifications to the other parts, which, in turn, enables the straightforward support of different business models for providing such a service. For future work we should focus attention in the developments of Google Power Meter API since, at the time of the development of this project, the API was still in an early stage. Additionally, the development of service extensions to provide user- and context-aware advice on how to save energy is also an issue to address. Also, other exploratory work will be done related to effective behavioral changes that can be achieved and the best means to achieve it, both in terms of information and visualization techniques and other features desired by the users. Finally, how to offer such a service in economically feasible ways remains to be discussed and studied in a systematic way.

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