The Energy@home Technical Team

Energy@home: a "User-Centric" Energy Management System

Abstract—**This paper describes *Energy@home* project, an Italian initiative of ENEL, Electrolux, Indesit Company and Telecom Italia aimed at enhancing the energy efficiency of the entire house system. The project envisions an integrated platform that enables provisioning of value-added services, based upon information exchange related to energy usage, energy consumption and energy tariffs in the home area network. The *Energy@home* scenario includes several actors: the *Electronic Meter*, which is responsible for providing certified metering data; the *Smart Appliances*, able to adjust its power consumption by modifying their behavior, while preserving the quality of service and user experience; the *Smart Plugs*, able to collect metering data and to implement a simple on/off control on the plugged energy loads other than Smart Appliances; the *Home Gateway*, which acts as the central coordinator of the entire home; and the *Customer Interfaces*, i.e. all the devices used by the customer to monitor and configure his/her energy behavior.**

The *Energy@home* project is a further step towards the development of the so-called *"smart grid"*, that, in the near future, will allow continuous real-time bidirectional information exchange between utilities and appliances in the houses to enable each customer to "self-manage" his/her energy behavior depending on both power supply availability and price. Features for controlling and managing appliances by using ZigBee application profiles is highlighted in this paper.

Index Terms—**Energy management, home automation, ZigBee, application profiles, CECED, smart appliances, connected home, machine to machine, smart energy.**

I. Introduction

THIS paper describes *Energy@home* project [1], an Italian initiative of ENEL, Electrolux, Indesit Company and Telecom Italia aimed at enhancing the energy efficiency of the entire house system. The project envisions a communication infrastructure that enables provisioning of Value-Added Services (VAS) based upon information exchange related to energy usage, energy consumption and energy tariffs in the Home Area Network (HAN) [3]. The proposed home scenario includes several actors: *i)* the *Electronic Meter*, responsible for providing certified metering data. The meter shall be interfaced via a new-generation device, called *Smart Info*, to enable communication with the telecommunication infrastructure and the household appliances; *ii)* the *Smart Appliances*, able to cooperate in order to adjust power consumption by modifying their behavior, while preserving the quality of service and user experience; *iii)* the *Smart Plugs*, which are able to collect metering data and to implement a simple on/off control on the plugged energy loads other than Smart Appliances (e.g. lighting, A/V devices, etc.); *iv)* the *Home Residential Gateway*, which acts as the central coordinator of the entire home, allowing data exchange between the devices operating in the Home Network (HN), in the Home Area Network, and Internet; *v)* the *Customer Interfaces*, i.e. all the devices used by the customer to monitor and configure his/her energy behavior.

From a functional point of view, *Energy@home* project details a system that can provide users with information on household consumption directly on the display of the appliance itself, on the smart phone or on their computer. It is expected that, through easy access to information on consumption and through the possibility of custom application downloading, consumers will be able to use their appliances in a "smart" way by enhancing the energy efficiency of the entire house system. For instance, Smart Appliances can start functioning at non-peak (and therefore less expensive) times of day as well as they can cooperate to avoid overloads by automatically balancing consumption without jeopardizing the proper execution of cycles.

The contribution of the project is two-fold. On one hand, the reference application scenarios and services have been detailed, taking into account incremental levels of interoperability, in order to provide customers with different levels of service, starting from simple awareness, up to the achievement of a fully integrated Energy Management system. On the other hand, an application-level protocol has been proposed, defining the cooperation between the aforementioned devices involved in the residential energy management. The protocol [4] has been designed as an extension of public ZigBee [5]-[6] application profiles, in order to integrate both appliance and energy management specific features.

The *Energy@home* project is a further step towards the development of the so-called "smart grid", that, in the future, will allow continuous real-time two-way information exchange between utilities and appliances in the houses to enable each customer to "self-manage" his/her energy behaviors depending on power supply availability and prices.

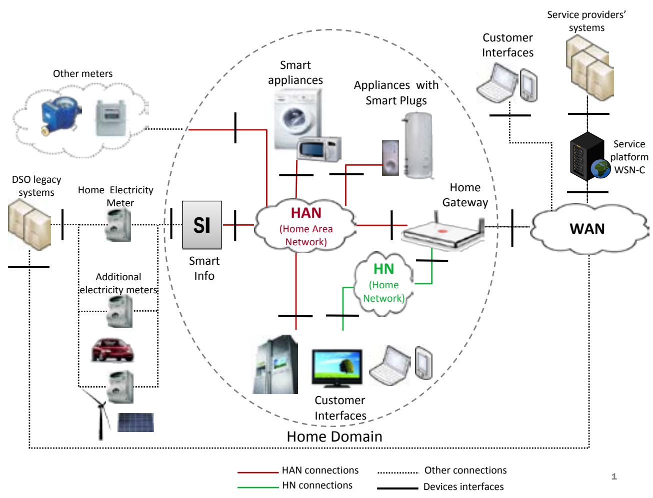

Fig. 1. Energy@home global architecture.

II. General Architecture of Energy@home

The *Energy@home* general architecture is reported in Fig. 1. The dotted area (that includes both the HAN and the HN) represents the user's home domain, where all actors, Smart Appliances, Home Gateway, Smart Info and Customer Interfaces, can cooperate through some communication mechanism (e.g. ZigBee and WiFi). All the depicted interfaces are logical ones and could be implemented through one or more communication technologies.

III. Energy@home Devices

The main actors belonging to the *Energy@home* home area network domain are reported in the following.

A. Smart Appliances

Smart Appliances represent an evolution of the current standard white goods: the new smart devices feature connectivity towards both the home environment and the smart grid, and embed an enhanced local intelligence in order to manage innovative services. Hereunder, some of their possible new functionalities are reported:

- display to the customer information on their energy consumptions (e.g. used energy, instant power, etc.);
- dispatch in the HAN information on their energy consumptions (e.g. used energy , instant power, etc.);
- autonomously adapt their behavior according to information on energy consumptions coming from the house. (e.g. reduce their load when global house consumptions goes beyond a threshold, etc.);
- cooperatively operate with other entities in order to optimize the energy usage through load shifting and load shedding.

In any case, the load control operations, either performed autonomously or under an external supervision, shall be performed under the complete control of the appliance, which assures the correct execution of its working procedure, its results and performance. For example, a smart washing machine, when requested to modify its consumption behavior, shall assure the result of the washing cycle.

B. Smart Plugs

The Smart Plugs can actively participate to in home monitoring and control activities. To this purpose, smart plugs are able to collect metering data and implement on/off control on simple plugged energy loads, other than Smart Appliances (e.g. lighting, A/V devices, etc.).

C. Customer Interfaces

The customer interfaces could:

- display information on energy usage like instant power, historical data, contractual information and similar, from the whole house (coming from the Smart Info) and from every single smart appliance. The level of details and graphical layout of their user interface is freely defined by every device;
- transmit control message to Smart Appliances to request a modification of their behavior;
- configure Smart Appliances to modify their power consumption profile (e.g. a personal computer used to configure a thermostat to activate the controlled load only in certain time slots).

The Customer Interface, from this perspective, is connected in both the HN and HAN. It is foreseen the possibility to have Customer Interfaces accessing the house from the WAN through a specific interface, but the definition of this interface is out of the scope of the *Energy@home* project as previously stated.

Typical Customer Interfaces are personal computers, smart phones, PDAs, *ad-hoc* displays, entertainment systems, in-house monitor and similar. The software application, which implements the user interface, could be local in the device or remotely hosted in another device (e.g. the Home Gateway) and accessed through web-services.

D. Home Gateway

The Home Gateway represents the link between the HAN, the HN and the WAN (e.g. internet). It is able to interface Smart Appliances and other user's devices (e.g. PC) through the communication protocol(s) used in the HAN (e.g. ZigBee) and in the HN (e.g. IP/HTTP) and to provide a broadband

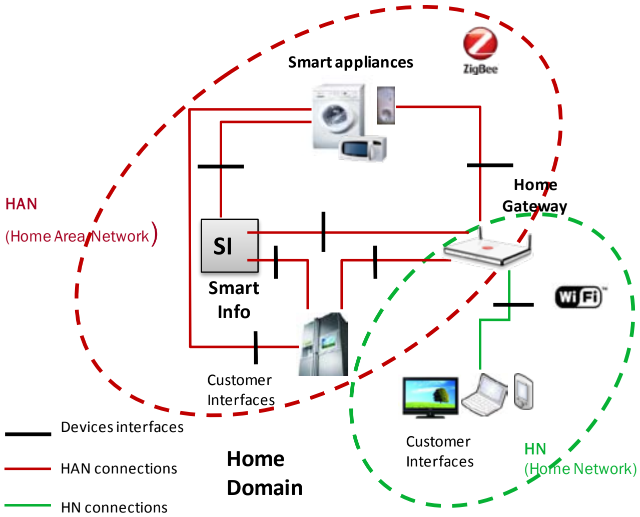

Fig. 2. Energy@home domains and networks.

connection to internet (usually via a standard ADSL connection). Moreover, the gateway is able to collect energy data from the Smart Info and additional information from Smart Appliances, publish them in the HAN and in the HN and use all collected data to control Smart Appliances and optimize their behavior. Finally, the gateway can offer a web user interface and provide an execution environment (e.g. Java OSGi framework) to host third-party application (e.g. a SW component implementing the algorithm to calculate the energy price at a given time, provided by the energy retailer).

E. Smart Info

The Smart Info is the element, provided by the DSO (*Distribution System Operator*), which dispatches energy related information into the HAN. Published data are a sub-set of those already available inside the home electricity meter, hence the Smart Info acts like a proxy of the meter. Additional data could be possibly generated by the Smart Info itself. Noticeably, near real-time instant power (sampled at about 1 Hz frequency or higher) should be acquired by another metering device, likely embedded into the Smart Info. Additional elements (SI') can also be provided by third parties and used to dispatch data generated by other meters into the HAN.

Outstanding components outside the Home Domain are:

- WSN-C: Wireless Sensor Network Center: it manages, together with the Home Gateway, the HAN devices and provides service oriented interfaces for the development of third-party applications;
- Home Electricity Meter: An electric meter, able to measure and record usage data in time differentiated registers, and capable of transmitting such data to central utilities system. Moreover, the meter should provide bi-direction communication to allow remote management of the meter.

IV. Energy@home Scenarios

For an effective use of the energy, the smart sustainable appliances must have an active role in the energy management automatic systems:

- being able to completely control the processes as they are fully responsible for the final result;
- offering, thanks to an active dialog with the customer and the energy sources, a valuable flexibility in terms of time and energy profile (best tariff).

A. Customer Energy Awareness

The user could improve her/his awareness on energy consumption and cost using information coming from the grid and the home itself. Data and information refer to:

- user and contract references;
- current power usage;
- historical consumption data;
- current tariff and tariff time frames;
- overload alarms.

B. Self Management Appliance Regulation

The self management mode is the condition where any Smart Appliance receives price and volume signals from a device (Smart Info or Smart Meter or basic Home Gateway) and proposes the customer the proper starting time to take advantage of the most advantageous tariff. The customer could override the proposal if needed. This is made independently and without any coordination with the other devices.

C. Coordinated Management Appliance Regulation

The coordinated management mode is the condition where any Smart Appliance coordinates its operations with the Home Gateway. The Home Gateway, through a dialogue with the Smart Appliances, plans their operations taking into account price and volume signals, selected household appliances programs and customer needs and constraints.

V. Interactions Among E@H Devices

For an effective use of the energy, the Smart Appliances must have an active role in the energy management automatic systems:

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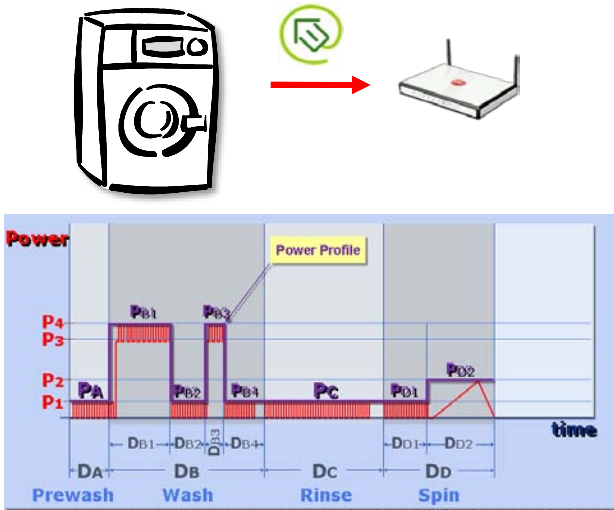

Fig. 3. An example of Power Profile generated by Smart Appliances.

- offering, thanks to an active dialog with the customer and the energy sources, a valuable flexibility in terms of time and energy profile (best tariff).

A key element of the data modeling is the concept of the Power Profile, defined as the estimation of the power that the appliance will need when running a specific cycle or program. The Power Profiles can be divided into different specific Energy Phases. The key parameters characterizing a single Energy Phase of the Power Profile are the following:

- *Expected Duration*: The Expected Duration represents the estimated duration of the specific energy phase;
- *Peak Power*: The Peak Power field represents the estimated power for the specific energy phase;
- *Energy*: The Energy represents the estimated energy consumption for the accounted phase. The Energy value fulfills the following equation:

  $Energy \le PeakPower \cdot ExpectedDuration$;
- *Max Activation Delay*: The Max Activation Delay indicates the maximum interruption time between the end of the previous phase and the beginning of the specific phase. If a special Max Activation Delay value (`0x0000`) is set for the first energy phase of the Power Profile, that means that the whole Power Profile cannot be scheduled.

While the customer energy awareness scenario is always active in *Energy@home*, the energy control of the network can be easily activated or de-activated by the user. The remote energy control feature includes the automatic scheduling of the appliances to minimize cost and avoid power peak (avoiding meter disconnections) and assure the avoidance of the power overload.

In case the remote energy control is de-activated (Fig. 4) the Power profile can still be notified by the Appliance in order

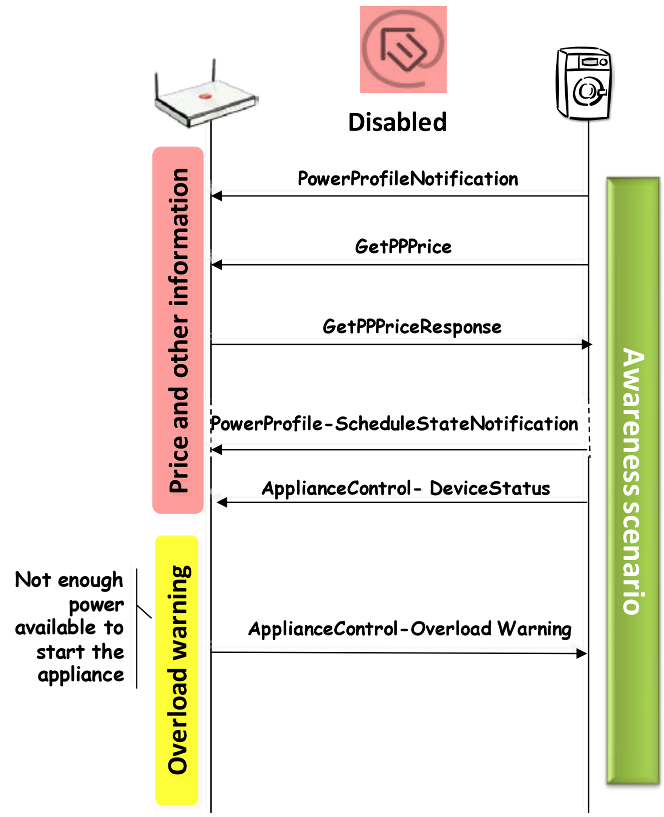

Fig. 4. E@H without remote energy control in action.

to get the price information associated to the specific program selected by the user, so the awareness scenario can still be supported. Moreover the states of the appliance are communicated to the home gateway, which can be accessed by a user interface: following this approach, the user can still visualize if the appliance is running, or if it is already programmed. In case the remote energy control is disabled, however, the Home gateway won't be allowed to schedule the appliance to start at a proper time (delayed schedule) or to control it (activating it remotely, by setting parameters from the gateway or controlling the power consumption to avoid power overload through the use of overload pause commands). When the remote energy control feature is activated the system is able to work autonomously and provide the user the most benefits (active energy management). The Home Gateway in this case will support both the awareness scenario and the coordinated management scenario where the Smart Appliances can be scheduled according two different requirements:

- avoid power overload and meter disconnection;

- select the best time-slots to run the appliances, considering the user's constraints and trying to maximize the cost savings.

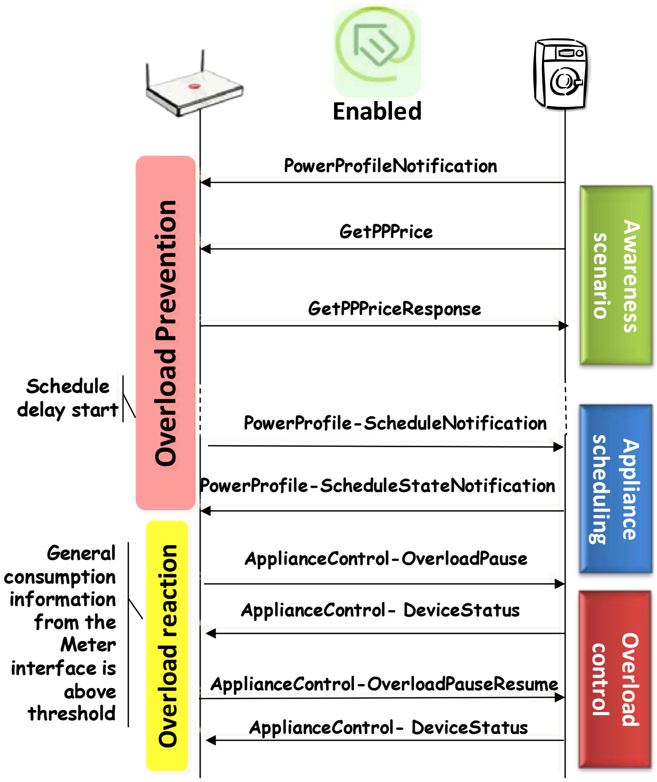

Fig. 5. E@H with remote energy control in action.

The schedule is calculated by the system every time both there is an update on the Power Profile of an appliance and there are user's constraints that need to be taken in account.

The scheduling procedure is a very effective solution in case there is a dynamic energy pricing scheme (multiple tariff schemes, which are difficult to be "manually" exploited by the users) and there are many smart connected appliances in the home environment. Provided that there are appliances on the field that cannot be scheduled (because they are not yet "smart"), there is a "reactive" approach that is covered in the coordinated energy management of *Energy@home*. This mode enable the home gateway to set pauses on active Smart Appliance (*OverloadPause*) in case there is a possible overload affecting the whole home-grid; the appliance can then resume its state with a proper command set by the Home Gateway (*OverloadPauseResume*). This reactive control (different than the so-called preventive-control performed through the scheduling) can be also operated controlling devices such as Smart Plugs with the on/off feature (e.g. using the On/Off cluster defined in ZigBee).

It is worth noting that the reactive feature of *Energy@home* is used to perform the overload control both in case there are not many smart appliances connected that could be scheduled effectively and in case the user's constraints limit the scheduling capability of the *Energy@home* control.

VI. Energy@home and Standards

The *Energy@home* technical specifications describe the specifications of the HAN communication protocol that enables the set of use cases defined by the *Energy@Home* partners. The technical specification [4] defines the wireless protocol to be adopted, the data model, the set of application messages, and the activity sequence diagrams showing the interactions among devices.

The *Energy@home* initiative started with a benchmark on existing standard technologies and solutions in order to leverage on existing tested and proven features. In case it has not been possible to find the proper features needed, new specifications have been provided to fill the gaps in the existing solutions. A key point indeed in the *Energy@home* initiative is that the technical solutions shall be open and scalable to other services and devices in order to build a real ecosystem of devices in the HAN.

Fig. 6. *Energy@home*, CENELEC standards and ZigBee Home Automation profiles.

Following this approach *Energy@home* is providing an extension of standard ZigBee Public Profiles (specifically the Home Automation Profile) by integrating connected appliances, power meter interface (Smart info) and user-centric energy management system. ZigBee [2] is a very low-cost, very low-power-consumption, two-way, wireless communications standard. Solutions adopting the ZigBee standard are embedded in consumer electronics, home and building automation, industrial controls, PC peripherals, medical sensor applications, toys and games. The ZigBee Alliance [2] is a consortium of more than 400 companies

Fig. 7. Example of user interface on TV: general dashboard.

Fig. 8. Access to historical data in the cloud.

which is developing together solutions for energy, home, telecom, commercial and residential application domains.

In order to define the interaction model with the Smart Appliances, *Energy@home* adopted the standard CENELEC EN50523 [8]-[9] as specified by CECED (*European Committee of Domestic Equipment Manufacturers*) and mapped it into specific ZigBee clusters. *Energy@home* is also working with ZigBee Alliance, CECED and Home Gateway Initiative (HGI) to promote the requirements for home energy management and control and cover them by adopting a standard approach. Specifically, it is desirable for *Energy@home* companies to have the support of the features of power profiling of Smart Appliances, appliance control and scheduling, included in the next release of ZigBee Home Automation specification, since this is considered a user-centric energy management application profile which could enable the services described in [3].

Fig. 9. ENEL Smart Info device.

VII. Experimental Results

Fig. 7 depicts an example of the general dashboard, implemented on a TV, which is used to gather the information from the meter via the Smart Info device (Fig. 9) and get information (consumption and status) from the Smart Appliances. The overall power, measured by the meter and transferred to the HAN through the Smart Info device which acts as a meter interface, is reported in the center of the dashboard. The overall power, according to the specific level, could trigger from the Home Gateway alarms and warning messages that are sent to the devices connected to the home area network. It is also possible from the user interface to compare the energy performance with historical data in order to have a feeling on the changes of the behavior during time (Fig. 8).

Other information that are communicated to the users are the number of overload that the system prevented using the overload avoidance feature and the money saving obtained by adopting the scheduling of the Smart Appliances.

VIII. Conclusions

In this paper a general overview of *Energy@home* architecture has been presented. The purpose of the initiative, the use cases addressed by the technical solution and the description of the devices and their interfaces defined in *Energy@home* have been discussed. Features for controlling and managing appliances by using ZigBee application profiles have been highlighted in this paper.

The need of leveraging on existing standard solution and extending them to cover the requirements from Appliance, Telecommunication and Utilities industries has been described

Fig. 10. Indesit Co. Smart Appliance showing price information.

Fig. 11. Electrolux Smart Appliance showing price information.

as one of the key aspects of the *Energy@home* initiative. One of the most relevant aspects experienced in the *Energy@home* collaboration is also the understanding that only enabling a standard communication interaction within the HAN among the different devices it will be possible to expand the opportunities for all the companies, compared to single proprietary solutions.

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REFERENCES

[1] Energy@home website: http://www.energy-home.it.
[2] ZigBee Alliance website: http://www.zigbee.org.
[3] Energy@home Technical Team, "Energy@home Use Case", version 1.2. Available online.
[4] Energy@home Technical Team, "Energy@home Technical Specification" v0.9.
[5] ZigBee Alliance, ZigBee Cluster Library Specification, 2007.
[6] ZigBee Alliance, ZigBee Specification, 2007.
[7] IEEE, IEEE Standard for Information technology--Telecommunications and information exchange between systems--Local and metropolitan area networks-- Specific requirements Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low Rate Wireless Personal Area Networks (LR-WPANs), http://standards.ieee.org/getieee802, 2006.
[8] BSI British Standards, document BS EN 50523-1:2009, "Household appliances interworking - Part 1: Functional specification", July 2009.
[9] BSI British Standards, document BS EN 50523-2:2009, "Household appliances interworking - Part 2: Data structures", July 2009.

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