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A New Architecture for Reduction of Energy Consumption of Home Appliances

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Abstract: This paper presents the recent results achieved by AIM consortium [AIM, 2008] in developing and demonstrating a new information and communication technologies (ICT) architecture for modelling, virtualising and managing the energy consumption of home appliances. The architecture aims at fostering a harmonised technological frame for profiling and optimizing the energy consumption patterns of home appliances. The intention is to offer users a number of standalone- and operator-based residential services that will allow them to manage efficiently the energy consumed in households. To make these services possible the frame adopts a generalised method for household appliances management, which is based on an accurate modelling of operational modes of appliances and the ability of the home network to switch on or off some of their internal functions without limiting their control just to the active or stand-by states. As a pilot application, the appliances being considered for the first implementation of the architecture are: white goods, e.g. refrigerators, ovens, washing machines, dryers; audiovisual equipment, e.g. TVs, DVDs, Set-top-Boxes; and home communication devices, e.g. wireless routers, DECT phones, residential gateways, modems. The requirements defined for the architecture concern mainly usability aspects of power management functions, integration with the home network and service deployment. The final result provided by the project is a system with enhanced home network architecture, incorporating services for home appliances energy consumption monitoring and management and using a generic technology. The two major challenges are energy saving and the architecture’s long-term sustainability.

Keywords: Energy efficiency; Residential gateway; Energy management; Energy consumption’s reduction.

1. INTRODUCTION

The main concept of the architecture developed in AIM project [AIM, 2008] is to offer a harmonised technology for managing in real time the energy consumption of appliances at home, interworking this information with communication devices over the home network to make it available to users through home communication networks in the form of standalone or network operator services. By using ICT to achieve technology-driven energy efficiency gains, AIM is supporting the European Union’s Action Plan on Energy Efficiency [EC, 2006]. Figure 1 illustrates the conceptual model that serves the logical basis to AIM architecture. The main innovation in managing the energy of household appliances is the bridge between home communication and power distribution networks with the aim to control the power distribution through communication services.

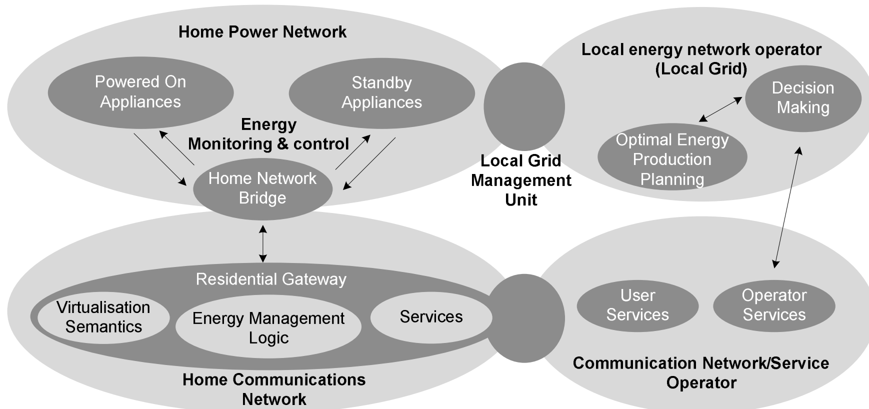

Figure 1. Conceptual model of AIM Architecture

Network operators may use the interfaces of the residential gateway to implement services for mobile and fixed terminals featuring remote energy monitoring and control of the home environment.

Power distribution network operators have particular interest to monitor the energy consumed by large blocks of users on macroscopic level. Accessing households through such a system is an efficient and cost effective way of accomplishing such task.

Residential users may control their environment through the service interface of the gateway that is able to get connected with any type of home terminal, like e.g. wireless PDA, embedded devices, et.. Moreover, the system is able to collect additional information from the environment through a sensor network and create user profiles in order to perform a partially automatic configuration of the energy management policies. Home terminals distribute commands to the appropriate appliance via the EMD, affecting its energy consumption attributes.

The paper is organized as follows. Section 2 describes the AIM general architecture. Section 3 details some usage scenarios and energy saving policies. In section 4, the user interaction with the system are explained and discussed. The conclusions are presented in section 5.

2. AIM ARCHITECTURE

AIM architecture is presented in Figure 2. AIM bridges the outdoor and indoor networks with the view to provide the means for controlling the functions of the household appliances through a number of different applications addressing three user categories: i) Residential users; ii) Network operators; iii) Energy generation utilities.

The indoor (home) network is bridged with the outdoor networks through the "AIM system logic" (see Figure 3) whereby users are enabled to manage the functions of household appliances and control the energy consumed in their households.

The AIM system logic is the main building block of the architecture, interconnecting the home network, the outdoor networks and the software substrate for the implementation of energy saving applications. The AIM gateway appears as a building block of the AIM system logic, for what it may optionally host part or the whole of the AIM system logic, or being used as a passive component while the service logic is hosted on the operator service platform. The AIM gateway selects and conduits information to the proper device interface, applies the necessary centralized control logic and enforces rigorous communication encryption. The apparatus that constitutes the local hub of the energy control system is the Energy Management Device (EMD), which is an independent functional entity that conveys control logic for both active and stand-by appliances and energy management functions integrated through a multimode of communication interfaces with the home network and the

AIM gateway. The EMD is controlled by the gateway, using a bus interface that grants access to multiple EMDs from a single access-point, either locally or remotely via an operator network.

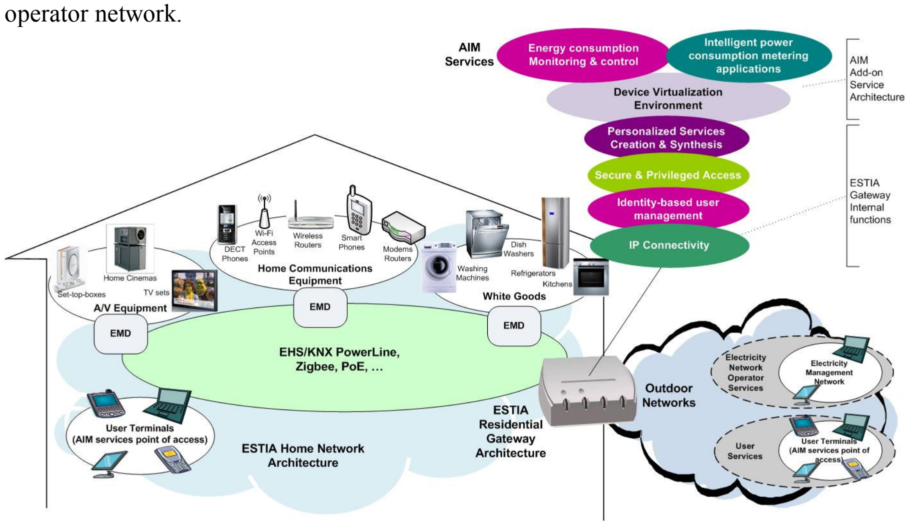

Figure 2. AIM Reference Architecture

2.1 Energy Management Device (EMD)

The EMD must have a unified architecture, which will feature generic interfaces towards the household appliances, the power network and the home network. Due to its generic architecture it can be implemented as a standalone external device, integrated in the AIM gateway, as well as an internal module of the appliance. The EMD shall be accessible either locally, through the AIM gateway or via external operator networks. Privacy and confidentiality of user data circulated in the outdoor networks will be ensured by the application of proper encryption of messages exchanged between the EMDs and the AIM network.

The EMD will offer three generic-purpose interfaces: one towards home communications networks, one towards the mains power network and one for connecting to internal digital control buses of household appliances. With these interfaces the system will be able to integrate with virtually any network environment or household appliance and will provide two types of power management logic:

- Power monitoring, or power metering functions that are applied to power electronics of the household appliances, an encoding logic that turns measurement results into digital values and a monitoring logic that buffers the obtained measurements following user configuration commands.

- Power control, or control logic for selecting which of the several external interfaces will communicate to the household appliance, taking into account the user commands as they have been decoded and submitted by the enforcement logic of a given appliance.

2.2 AIM Gateway

AIM adopted ESTIA [ESTIA, 2006] gateway to use as AIM gateway for scalability, upgradeability and openness reasons, because it is based on the open services execution framework of OSGi. AIM gateway is composed by 3 modules:

- Machine-to-machine interfaces module, which delivers a unified methodology and a common API for the implementation of gateway-based services, incorporating the connected appliances. It defines a novel mechanism that consolidates the different access and communication technologies under a single umbrella.

- Identity management module: responsible for user authentication/identification and for providing personalised applications to the user.

- Services synthesis module: allows the creation of new composite services based on existing service primitives, which are provided according to the user profiles, device profiles and the associated policies.

Most of the energy management functionality will be hosted by the gateway, including: appliance capabilities discovery; appliances and user profiling; virtualisation environment that enables the residential user to access household's energy resources and exploit them in defining energy management processes; management of the user interface; make the energy consumption statistical data towards the outdoor networks anonymous; energy monitoring and management, through providing to the user services with APIs for communicating with the EMD, the device that mainly performs energy monitoring and management; communication between indoor and outdoor components harmonisation.

2.3 Logical Interfaces

Residential and outdoor users as well as third parties shall have access to AIM services through applications compatible with any user terminal type, e.g. wireless/wired terminals such as mobile phones, PDAs and PC based consoles. The user interface coincides with the user application hosted on the user terminal and allowing users to access the services of the home network.

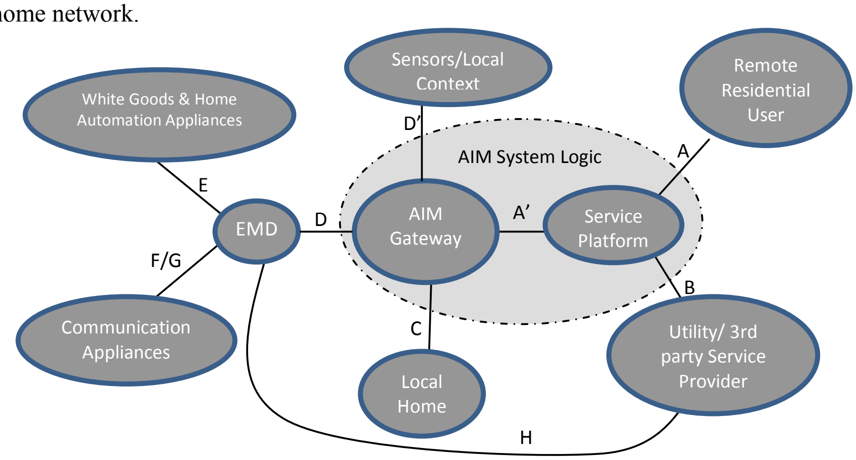

Figure 3. Logical Interfaces of AIM Architecture

Figure 3 presents the logical interfaces of AIM architecture, which are communication links that bind the components altogether. The term 'logical' comes from the logic that conveys their operation, which depends on the type of interconnected components:

- Interface A is a remote access http web browser-based interface that allows the users to access the AIM system for both control and monitoring when they are outside the home network. It should give access to all the regular control and monitoring functionalities, with possibility to restrict access to some of these functionalities only to specific categories of users. Interface A' allows to transparently traverse the main home network gateway whilst maintaining security, because it avoids to open a permanent backdoor that could be taken advantage of by potential intruders.

- Interface B is a logical interface and is independent from the way how the information is transported between both entities that interconnects. Its main function is to provide the required information between the utility and the household.

- Interface C is the interface between the local users and the AIM gateway, representing the logical connectivity of the residential user with the services of the home network and conveying information that allows the user to control energy consumption of the home environment.

- Interface D is the interface between the EMDs and their controlling gateway. Since the AIM domestic network is essentially hierarchical, all flow control will be governed by an AIM gateway that will be the central coordination point and can accept commands from external actors and send them to a specific or a group of EMDs in the system.
- Interface E is the interface between the EMD and a white good. The EMD communicates with AIM gateway over a standard AIM protocol and translate the information from/to the AIM gateway into the proprietary protocol of the white good.
- Interface F/G is the interface between the EMD and communication appliances, e.g. phones, routers, or audio/video equipment, e.g. radio and TV sets. To have power measurements and saving features sometimes additional devices will be needed. have multiple interfaces to communicate among themselves and between other devices and use. The proprietary commands of the communication devices will be translated into AIM commands by the EMD. The data exchange between the EMD and the AIM gateway will use AIM protocol.
- Interface H is an option to connect the EMD directly to the service providers for when there is no possibility to have a gateway with interface for remote control installed at the home network.

3. USAGE SCENARIOS AND ENERGY SAVING POLICIES

The functionality that will be offered by the AIM system is intended to be used by three different types of users, namely utility providers, telecom operators and the local users themselves. In the following we give some narrative examples of the usage scenarios and possible energy saving polices that could be enabled by the system.

3.1 Local users

John is a typical worker that goes to work quite early in the morning and comes back home in late evening for dinner and the night his main goal when managing the system is to minimize incurred costs. John wakes up at 7.00 a.m. and, since we are in winter, would like a pleasant temperature in the rooms where is going to live in while he prepares breakfast and dress himself before leaving. The system increases the temperature from night value of 18 °C to 22 °C in the bedroom, bathroom and in the kitchen, while it keeps the temperature low in the living room because John does not use this room in the morning. The system also activates the appliances that John likely need to use in the kitchen and bathroom, keeps in stand-by mode those that may be used, while it leaves off all the others.

Before leaving, John schedule some activities that the system has to execute before he is back, like cooking the diner, run the washing machine, operate the vacuum cleaner robot, etc. When John is not at home the temperature is reduced and the activities that he scheduled are executed trying to minimize energy cost based on real-time price information provided by the utility. The system can take autonomous decisions considering the cost minimization goal and the quality constraints provided by John. For example, diner needs to be cooked and also warmed for 7.15 p.m., cooking time for the dish is 1 hour but it is not necessary to be cooked in a continuous way. The system can decide to power-on the microwave oven for a period of 45 minutes in the morning when energy is cheaper and then complete cooking time at 7.00 p.m. for a period of 15 minutes right before John comes back home.

3.2 Operator energy services

Rose is not happy at all with the electricity invoices she recently received that are quite high. She would like to understand why his home is so energy consuming and how she can reduce energy bills. She has already subscribed to the services of a communication operator and she can access to the operator web portal. The portal allows her to subscribe to an energy consumption monitoring service.

Once the subscription process is completed, she receives a pack with one or more EMD. If this is her first subscription to operator's home services, she also receives a AIM gateway to be connected to the broadband access network.

After self and simple installation procedure, she can access her personalized service pages on the portal and get a detailed description of energy usage (power and money) of each device with a statistics per device type and period of time. She can also get specific suggestions on how to improve energy usage.

Rose soon realizes the energy services can really provide her some benefits and decides to upgrade her subscription to the premium service. Now she can download a widget from the operator to configure the service and send commands or receive status from the devices. She can also use a dedicated application or an Instant Messaging client on her mobile to access the service. Rose decides to configure the service so that the operator can detect when she is not at home and minimize energy consumption and send her notifications or alarms on the mobile phone.

3.3 Utility services

The utility AimEnergy wants to introduce an incentive based service that allows customers to directly participate in savings and benefits the utility can generate through a flexible cost model. To implement such a business model a communication path between the utility and the customers, which provides the required information (tariff/pricing information), has to be established and the customer needs to have a device which is at least capable of displaying the actual tariff-information. This functionality is provided by the AIM gateway.

For introducing the flexible tariffs, the AimEnergy provides a basic service that sends every day to the user a pricing profile for the next day that includes the energy prices per day hour. The utility can also provide an advanced service that allows customers to buy a certain amount of kilowatt-hours for consumption. This service requires more information exchange through the AIM gateway between the utility and the customer, since a purchase order must be carried out as well as the crosscheck of whether the purchased amount of energy is already consumed.

Aim Energy is also offering to a selected set of users an innovative service that is based on the remote control of energy load. Stephan, one of these customers, owns a special refrigerator which is capable of producing cold air and stores it in a separate part of the fridge that can be released when required. The required amount of energy for that operation is known to the utility and when alternative energy generation is able to provide the needed energy (e.g. strong winds for the windmills) the fridge is remotely activated. This service is considered very useful by both Stephan and AimEnergy since they save money and use more efficiently clean energy sources. A similar service is adopted by AimEnergy to control distributed energy generation creating a kind of virtual power plant that manages the available distributed energy generation sources from the customers connected to its distribution network.

4. USER INTERACTION WITH THE SYSTEM

The ability of the AIM system to adapt to user specific requirements and preferences is a fundamental feature that may determine the level of satisfaction of users and the overall success of this kind of energy management systems.

It is commonly recognized that there are basically two important issues for user acceptance, namely the perception that the system is under direct control all the time and that it is easy to use and able to adapt automatically to needs without complex configuration processes. In the AIM system the user direct control of the system is guaranteed on one side by the possibility to interact manually with all appliances and devices at any moment and on the other side by the definition of a set of user preferences that allow enforcing some specific behaviour. This is obviously not enough for providing an easy to use system, reason for what the AIM system includes also user profiling in order to self-adapt to user habits and to the normal way it uses home appliances. User profiling can take advantage of the supplementary functions provided by a sensor network that can provide some inputs to the system on user identification, user presence at home (and in a specific room), and the level of some physical parameters like the temperature and the light.

4.1 User profiling

User profiling process includes basically two functionalities: a mechanism for recording some events that can characterize the way in which users interact with the home environment and the available appliances, and a simple learning algorithm that allows extracting from all these data some reasonable settings of the energy management system that is expected to be the most appropriate meet user requirements. The final goal of the user profiling function is replacing some of the required system settings based on a manual interaction with a user interface with an automatic configuration procedure that can be performed on request. To this extent, this function must be able to provide inputs to the energy management system exactly in the same way a user could do through the user interface and it can be considered a plug-in of the system that can be enabled of disabled by the user.

The event recording system allows storing the presence of users at home and in specific rooms and the period of times in which it used specific devices according to: i) the day of the week (typically week-days, week-ends, holydays), ii) the time of the day (the granularity may be quite coarse like e.g. half-hour or hour).

From these data the learning system can extract some characteristics of the user habits in the form of probability distributions. For example, it can derive the probability distribution of the user presence at home during week-days and weekends, the probability distribution of the presence in the living room, the probability distribution of using the HiFi audio system, etc. If relevant, the learning system can also extract joint probability distributions like for example the probability of using two devices at the same time.

Based on this user profile characterization, the system can take same decisions on the energy management settings for basically two main purposes:

- Set in a low power mode devices when the probability of being used is very low and set them in some active mode when the user will likely use them (like e.g. activate screen, remote control, etc.);
- Schedule activities requested by the user in periods of times that fits requirements (like e.g. run the washing machine program before the user is back home, heat the milk 5 minutes before the user comes in the kitchen, etc.) .

In some scenarios, user profiling function can take advantage of some feedbacks provided by the user on some undesirable settings performed by the system automatically. For example, if the user is forced to activate manually a device that was set in power save by the system, this can generate a penalty to the learning algorithm that can be translated into a modification of the parameters that determine algorithm decisions.

4.2 Sensor network

The sensor network provides the basic tools for gathering the information on user behaviour and its interaction with appliances from the home environment. Moreover, the sensor network provides measurements of some physical parameters like temperature and light that can be used by the system to perform some automatic adjustment of the energy management system (like e.g. regulating lighting system according to the level of natural light from windows, control the heating/conditioning system to set temperature in the rooms according to the user profile, etc.). The sensor network can also provide a mechanism for user identification (so that different profiles can be created for the different users living in the same apartment/house).

The sensor network can be implemented using several available technologies. However, wireless sensor networks are today considered the most promising and flexible technologies for creating low cost and easy to deploy sensor networks in scenarios like those considered by AIM project.

The sensor nodes can be equipped with several sensing devices. For the AIM scenarios the most relevant sensing devices include presence detection (that can be simple radar based devices or sophisticated localization systems), user identification (like e.g. RFID readers), temperature and light sensing.

Data collected by the sensor network are delivered to a sink node that is in charge of aggregating it and providing inputs to the user profiling module.

5. CONCLUSIONS

In this paper we have presented the main characteristics of the energy management system that is currently being defined by the AIM project.

The final result provided by the project is a system with enhanced home network architecture, incorporating services for home appliances energy consumption monitoring and management and using a generic technology frame so as to be in order to be applicable on other appliance types, e.g. heaters and solar panels. The gateway architecture is, as it had to be, able of performing energy management of home appliances via the home network. The system is a high technology product to be massively adopted by: residential users, for making optimal use of energy at home; service operators, for the development of a new breed of energy aware services for residential use; and power distribution network operators, for optimising their energy generation planning and administer efficiently cases of energy over-demand.

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REFERENCES

The AIM Consortium. A novel architecture for modelling, virtualising and managing the energy consumption of household appliances-AIM, *http:// www.ict-aim.eu*, 2008.

The ESTIA Consortium, Enhanced Networked Architecture for Personalised Provision of AV Content within the Home Environment, *http://www.ist-estia.org/*, 2006.

The European Commission, Action Plan for Energy Efficiency: Realising the potential. Communication from the Commission, Brussels, 2006.