

A pervasive network architecture featuring intelligent energy management of households

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ABSTRACT

As the problem of energy generation and use becomes apparent, technologies for optimal energy management and rational use gain importance. The present work illustrates an architecture that focuses on energy saving at households, a sector accounting for the 42% of global energy consumption in the European Union. The main part of the architecture is provided by an optimized residential gateway, which bears appropriate home network interfaces and service logic to allow users perform personalized, pervasive programming of the energy consumption of home devices, such as white goods, home communication equipment and audiovisual equipment by enabling real time monitoring of energy consumption in both active and stand-by modes.

Categories and Subject Descriptors

C.2.1 Network Architecture and Design: Network communications, Network topology.

General Terms

Management, Measurement, Design, Experimentation.

Keywords

Residential gateway, energy management, personalization, pervasive computing.

1. INTRODUCTION

Energy consumption at home accounts for one of the most crucial forms of energy spending, along with gas utilisation and electricity spending in commercial buildings. According to the Eurostat statistics on energy generation and consumption for the region of the European Union, in the year 2005, the households sector consumed in electricity and heating 42% percent of the overall generated energy [1]. People use energy to heat and cool buildings to light them and to operate appliances and office machines.

Every time we buy a home appliance, tune up a heating system, or leave our TV switched on, we take decisions that affect the environment. Connected to the illogical use of energy resources is the environmental pollution, urban smog, oil spills, acid rain, and global warming, to mention a few.

Given the energy waste problem and the consequent need for energy optimal use, the present work illustrates an architecture that focuses on energy saving at households. The main part of the architecture is provided by an optimized residential gateway, which bears appropriate home network interfaces and service logic to allow users perform personalized, pervasive programming of the energy consumption of home devices, such as white goods, home communication equipment and audiovisual equipment by enabling real time monitoring of energy consumption in both active and stand-by modes.

The proposed solution makes use of the latest communication technology to bring a number of energy management services for two main user categories; residential users and power distribution network operators. For residential users the objective is to be able to set thresholds of energy consumption at home and thus rationalize energy consumption, while for the power distribution network operators the objective is to be able to monitor energy consumption of large residential areas and optimize energy generation.

In the following sections we outline the main drivers that led to the conception of the network (section 2), we illustrate the building blocks of the overall architecture (section 3) and finally present a number of use cases targeting both user categories.

2. THE CONCEPT

The main concept of energy management logic is illustrated in Figure 1. Both active and stand-by devices energy consumption are monitored through an element that bridges the home power and communication networks, by a residential gateway.

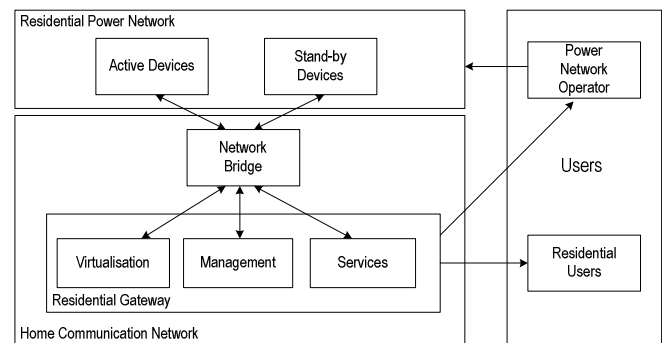


Figure 1: Energy management concept and conceptual topology

Devices status, such as washing programs, refrigerator freezing temperature, etc, are translated by the gateway into energy consumption measurements, which are “managed” by specific logic configured by the user in the context of dedicated “services” and specific actions are taken proactively by the gateway, based on user requirements. The user requirements are set in, thanks to a dedicated “virtualization environment”, which allows, in the context of user applications, virtual representation of devices that can be managed by the architecture, the energy management possibilities each device can get and global strategies that can be applied on selected groups of devices.

3. THE AIM ARCHITECTURE

Figure 2 illustrates the entire architecture of the solution. In this it shown that inter-working of the home appliances with the home network is done via a dedicated functional entity, called Energy Management Device (EMD), which implements, in a generic way and for all the appliance types, energy monitoring and management functions.

various scenarios, such fully automated operation, semi-automatic, user-driven, etc, and for particular intervals of the day.

- Service personalization: Each user has a unique identity with which the network recognizes him and configures the household appliances with the energy management policy his has programmed once and associated with his profile and access privileges.
- Service activation: Once the service is defined and associated with the user profile, it can be activated. Service activation can be done using any terminal, as long as the IP protocol is supported, and may be accommodated in the context of several applications, either provided by network operators or customized ones developed for personal use.

As it is illustrated in Figure 2, the service architecture of the energy management solution is accommodated on an open residential gateway, called ESTIA [2], which, on one hand, provides all means of communications with the appliances of the

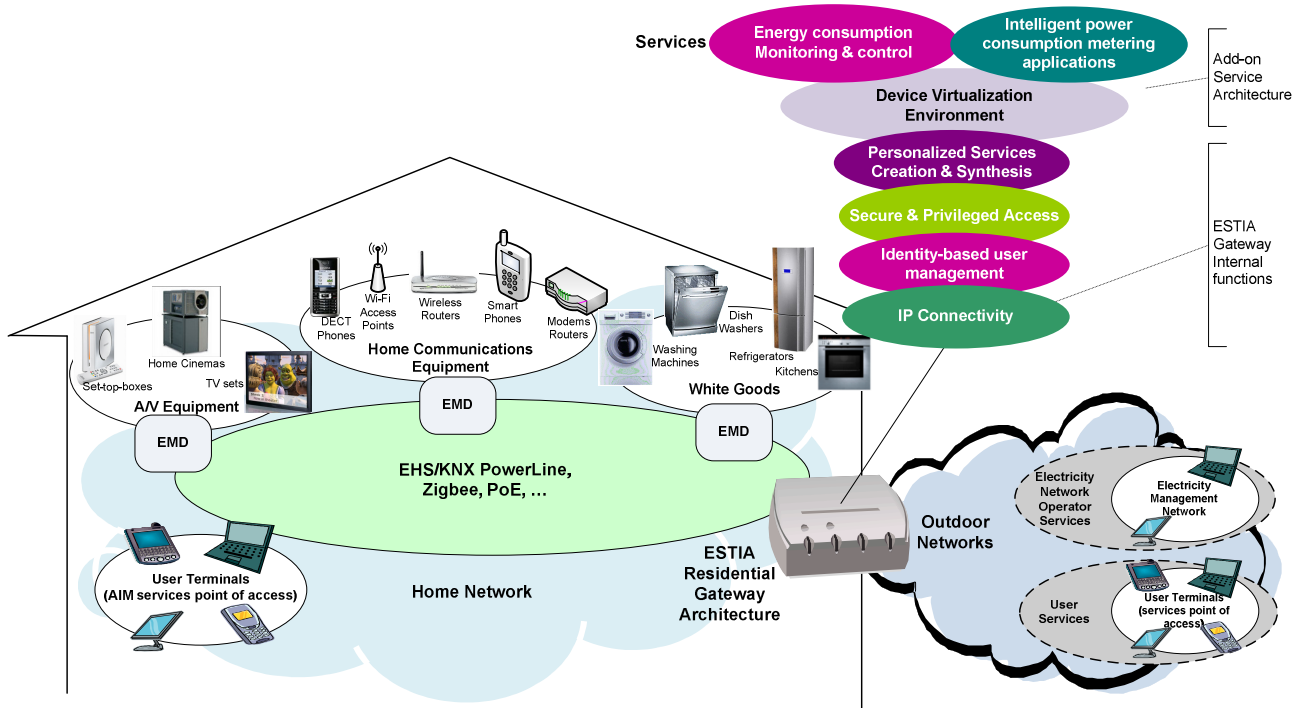


Figure 2: Overall energy management architecture

EMDs utilise an independent, common for all appliances architecture that conveys logic for both active and stand-by appliances and features generic communication interfaces to the home network.

The main goal of the EMDs is to interfaces the functions of household appliances to a residential gateway, which accommodates logic for:

- Service definition: Using the virtualization environment of the gateway, users are able to define an energy management policy for the appliances of their home and apply it under

home environment, via a multitude of physical interfaces (e.g. Powerline, WiFi, etc) and an open services deployment environment (OSGi, etc), while on the other hand allows scalable deployment of additional, higher-layer protocols.

3.1 The ESTIA gateway architecture

An outline of the ESTIA gateway architecture is depicted in Figure 3 (block in centre).

It is divided in five layers interoperable with network components, including the User Terminals and the Household Appliances.

The first layer of the architecture consists of network general purpose interfaces allowing communication with user terminals

like PDAs, WiFi phones, DECT phones and appliances like Fridges, Ovens, Washing Machines, TVs & Set-top-boxes.

The second layer consists of the networking technologies that are used for the physical interconnection of the gateway and the ESTIA network components. These technologies include Ethernet, WiFi, DECT, Powerline, Bluetooth, IrDA etc.

media transcoding functions and device control functions assisting the deployment of personalized audiovisual applications. The fifth layer of the architecture is reserved for personalised applications deployment.

3.2 The Energy Monitoring Device (EMD)

The Energy Management Device represents the main device

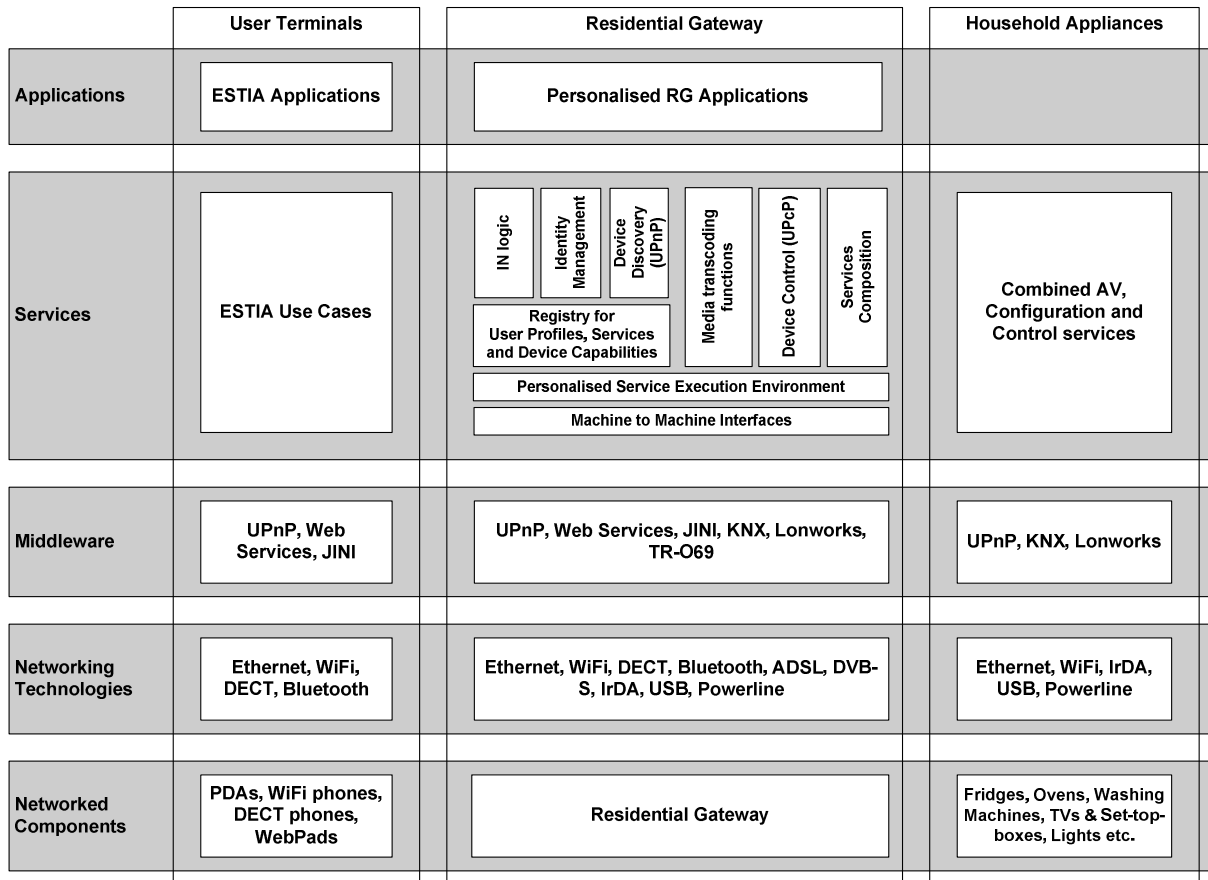


Figure 3: The internal architecture of the ESTIA residential gateway

The third layer consists of the communication technologies (middleware) that are used for the logical interconnection between the gateway and the home network devices and user terminals. These technologies include middleware like JINI and JXTA, Web Services and UPnP [3] for service communication and device configuration, KNX [4] and Lonworks over Powerline for the communication with the Household Appliances etc.

The fourth layer consists of building blocks such as the machine to machine interfaces (M2M) for the autonomous communication between the ESTIA devices. The services are executed on the ESTIA Personalized Service Execution Environment on the Residential Gateway. Services personalization is based on a Registry maintained inside the Residential Gateway, consisting of User Profiles, Services and Device capabilities. This registry is being used by the IN logic, the Identity Managements and the Device Discovery functionality realizing the ESTIA personalized architecture together with the Service Decomposition functionality. Last but not least, the Residential Gateway provides

around which the energy management logic of the network is built.

The internal architecture of the EMD, depicted in, comprises three generic-purpose interfaces, one towards home communications networks, one towards the power network and a third one for connecting with the internal digital control buses of the household appliances.

With these three general-purpose interfaces the system can be integrated within virtually any home network topology and household appliance and provide two types of energy management logic:

- Energy consumption monitoring: Consisting of a) energy consumption measurement functions applied on each household appliance, b) encoding logic that translates measurements into digital values and c) monitoring logic that allows relating obtained measurements towards the network using appropriate signalling messages.

- Energy consumption control: Consisting of logic that implements control of energy consumption per appliance, taking into account user configuration. Energy control is implemented by exploiting the knowledge of EMD concerning the type and number of functions each appliance support and their contribution to energy consumption.

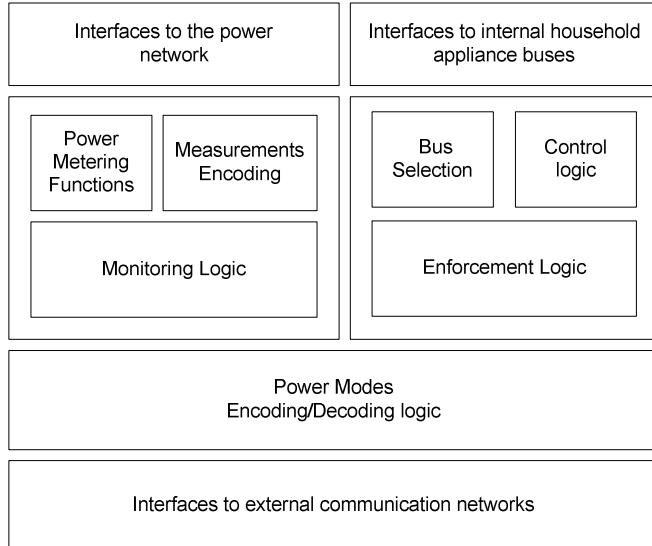


Figure 4: EMD internal architecture

The power modes encoding/decoding logic involves functions that perform encoding of energy measurements and status information towards the user and decoding of user commands into primitives that can be parsed by the EMD energy management logic.

- Energy management commands, such as masking of appliance functions, switch off/on, etc.
- Information of the appliance type the message is directed to.
- Information concerning management of the internal EMD operation, such as requests for retrieving energy consumption status, overall energy consumption estimation, etc.

In the opposite direction, concerning the messages being sent towards the user, the power modes encoding/decoding logic performs measurement encoding by:

- Message type.
- Appliance type.
- Power mode level.

Via the EMD, residential users are able to monitor and control the energy consumption of their home environment. Generality in performing these functions is achieved by adopting on the EMD a slim IP protocol version, which allows the functionality of the device to be seamlessly integrated within popular intelligent protocols and stacks that implement automated device discovery, identification and basic functions configuration.

The physical interfaces of the EMD towards both the household appliances and the residential gateway are of IEEE 802.11 and KNX type, ensuring compatibility with popular wired and wireless communication networks, such as Zigbee, Bluetooth and powerline, etc.

Under the given protocol configuration the EMD device can be used for the realisation of:

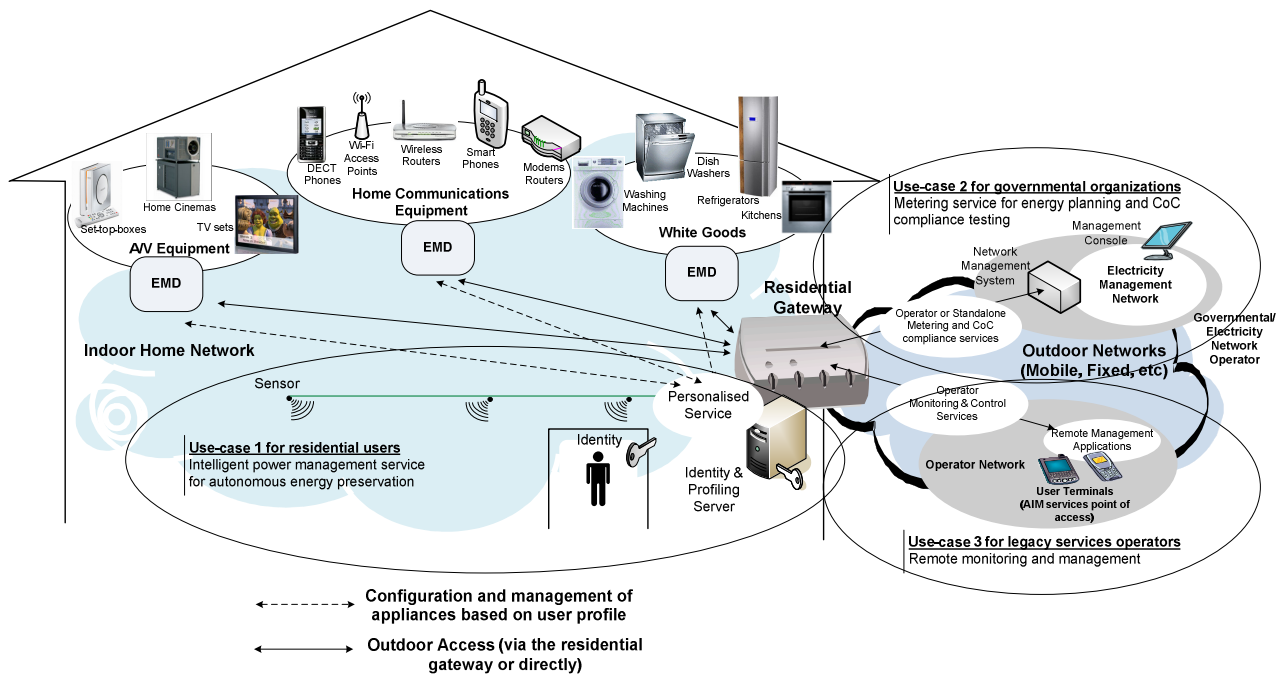


Figure 5: Energy management use-cases

In particular the EMD unit receives messages containing:

- Intelligent administration of energy consumption of household appliances. For instance DSL modems can be

switched off at night or working hours while people are at work, washing machines cannot run power consuming washing programs during summer time, etc.

- Real time monitoring of appliance consumption: Users are able to monitor the energy consumption of their home in real time and program upper energy consumption thresholds.
- Management of stand-by devices: Stand-by devices can be administered against their power consumption transparently to the home users. The EMD device features intelligence in tracing and switching off stand-by devices [5], autonomously, by invoking general use, network controllable power switching devices. This technology is mainly based on the interception of events, being sent over the home network to a centralized control point at the moment an appliance enters the stand-by mode, and in more intuitive scenarios, on the implicit identification of the function the appliance is in, charging from energy consumption.

4. USABILITY SCENARIOS

A number of use-cases (Figure 5) targeting specific user groups have been designed as relevant for being supported by the discussed network architecture:

- Use-case for residential users (intelligent service for autonomous energy preservation): This use-case makes use of a sensor network that can be installed at home and be used for recognizing incoming/outgoing users. Using the knowledge of which user comes in or goes out, the home network performs administration of stand-by devices autonomously and configures the energy consumption of rest active appliances to levels corresponding to user requirements. The supplementary sensor network is of wireless type and integrates with the residential gateway by means of employing user identities and profiles [6], all stored in the gateway database.
- Use-case for governmental organizations (metering service for energy planning and Code of Conduct compliance testing): This use-case targets the user group of energy production plans and governmental organizations in charge of planning energy policy at national/international level. The use-case performs real time acquisition of power consumption measurements to be aggregated for yielding energy utilization statistics and thus be helpful for organizations charged with environmental/energy policies and power plants to better plan energy production and avoid unnecessary resources dissipation. Seen from a different aspect this use-case may also be used for testing compliance of the household appliances to the designated Code of Conducts (CoC) [7] set the EC per product family, in order to be characterized as green products considering low CO₂ emissions and minimal energy consumption.
- Use-case for networks operators (remote monitoring and management): The use-case targets again the user group of residential users by offering a number of operator services that allow them to access and control the energy dissipation of their households remotely, over operator networks. To achieve better usability prospects, the services are optimized for use on mobile phones, through which the user is able to monitor in real time the power consumption at home and do

intelligent configurations, such as assignment of alerts in the event of excess of user configured values, and so on.

5. CONCLUSIONS

In this work we have presented a network architecture optimized for use in the implementation of energy management services. The main part of the presented architecture is offered by an intelligent residential gateway that bears functions for policies management and implicit appliances identification and proactive configuration. The same gateway bears a virtualization environment, through which even inexperienced users can pick up scenarios and configure their own energy management policies. Another innovation of the presented architecture is offered by the EMD device, which brings the necessary interfaces for controlling the internal functions of household appliances and a protocol stack compatible with popular home communications protocols.

6. ACKNOWLEDGMENTS

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