MONERGY: ICT solutions for energy saving in Smart Homes
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Technical Report

Description of interfaces and interactions with smart devices

Beschreibung der Schnittstellen und Interaktionen mit intelligenten Geräten
Descrizione delle Interfacce e Interazione con Dispositivi Smart

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Programme:	Interreg IV Italy - Austria
Project Title:	MONERGY ICT Solutions for Energy Saving in Smart Homes
Project Number:	6462
Lead Partner:	Lakeside Labs (LS) Alpen-Adria-Universität, Klagenfurt, AT
P1:	WiTiKee S.r.l. (WTK) via Duchi D'Aosta 2, Udine, IT
Document Title:	Description of interfaces and interaction with smart devices
Work Package:	WP3
Deadline Date:	March 31st, 2014
Delivery Date:	April 15, 2014
Editors:	
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Availability:	Public

Abstract

The main goals of the MONERGY project are:

- To increase the inter-regional knowledge of technologies and solutions in the field of Smart Grids.
- To promote the research and the innovation in ICT by targeting solutions that have an impact on the reduction of energy-consumption within houses by considering the peculiarities of the Friuli Venezia Giulia and Carinthia regions.

Within MONERGY, the objectives of WP3 (entitled *User interface and software*) are:

- To formulate a simple and effective user interface for monitoring the current state of the overall energy monitoring system and its components. The interface should be extendable, e.g. to display properties and measurements of new device types that may join the house network.
- To develop a network model for the integration of two communication solutions, i.e., power line and wireless.
- To extend the user interface to smart devices by additional features which are relevant for device interoperability.

The overall goal of this research is to lay ground for a ”plug-and-play” architecture that relieves the user from tedious set-up and configuration tasks.

This deliverable introduces the MONERGY domestic energy management system. It is composed of smart plugs, namely power sensors where electrical appliances are connected, and a smart home gateway (SHG) where the logic of the system resides. The SHG is connected with a device that allows the user to manage the whole system. In order to solve issues related to network coverage and robustness of existing EMSs, the MONERGY solution makes use of two communication technologies to connect the smart plugs to the SHG: the wireless Zigbee standard and the power line communication G3-PLC standard. To achieve convergence among different communication

technologies, a network solution is presented. It uses the internet protocol (IP) to achieve connectivity and middlewares for interoperability. Beside the network aspect, this deliverable describes the design of two user interfaces. The first is a simple user interface that allows for monitoring and controlling (switch on/off) electrical appliances. The second is an advanced user interface for a prepaid billing system that implements a billing mechanism where a credit amount (quantity of energy) is purchased in advance by users and it is used to pay when the service is actually used. The user interfaces have been installed in the hardware platforms developed in workpackage 4 of the project.

Executive summary

This deliverable includes the results of the research carried out within WP3. In particular, the following topics are addressed.

- **Interoperability in home energy management systems (HEMS)** - The home energy management system developed within MONERGY includes smart plugs, which are power meters where electrical devices are connected, and a smart home gateway (SHG), namely the network device where the logic resides. In order to provide a robust communication solution, the use of both wireless (Zigbee) and power line (G3-PLC) communication interfaces is considered to connect the smart plugs to the SHG. The interoperability among these different communication solutions is obtained through the deployment of a network architecture where the interconnection among different communication devices is obtained through the use of the internet protocol (IP), whereas, the interoperability can be obtained via middleware solutions.

- **Energy monitor user interface** - The design and the realization of a simple user interface that allows for monitoring and controlling (switching on/off) electrical devices are presented.

- **Advanced user interface** - The design and the realization of an advanced user interface for a prepaid billing system is presented.

Contents

List of Acronyms

6**LowPAN** IPv6 over low-power wireless PAN

ACK acknowledgement

AMR automatic meter reading

API application programming interface

ARIB Association of Radio Industries and Business

BB broadband

BPSK binary phase shift keying

CA collision avoidance

CAR Carinthia

CDF cumulative distribution function

CENELEC European Committee for Electrotechnical Standardization

CSMA carrier sense multiple access

DB data base

DR demand response

DSSS direct sequence spread spectrum

DVD digital video player

EMS energy management system

FCC Federal Communication Commission

FSK frequency shift keying

FVG Friuli Venezia Giulia

GFSK Gaussian FSK

GUI graphical user interface

HA home automation

HG home gateway

IETF Internet Engineering Task Force

IP Internet protocol

ISM industrial, scientific and medical

ITU International Telecommunication Union

JSON javascript simple object notation

MAC medium access control

NB narrow-band

OFDM orthogonal frequency division multiplexing

PAN private area network

PER packet error rate

PHY physical

PL power line

PLC power line communication

PSD power spectral density

QPSK quadrature phase shift keying

RCCB residual current circuit breaker

REST representational state transfer

SEP smart energy profile

SG smart grid

SHG smart home gateway

SOHO small office home office

TV television

WG working group

WLAN wireless local area network

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Section 1

Introduction

The progressive deployment of energy generators from renewable energy sources, such as photovoltaic and wind turbines, as well as the diffusion of electric vehicles, is destabilizing the offer and demand of energy in the grid. In order to control the amount of energy required by their customers, utilities are getting progressively involved in demand-side programs. These programmes include the promotion of efficiency and energy conservation, by raising the awareness of customers towards the footprint of their daily activities. Feedback mechanisms, e.g., consumption information, can be used to this end. The increase in awareness together with the adoption of time changing tariffs is a typical approach followed to realize demand response (DR) programmes, i.e., the users shift the consumption of energy-demanding appliances (e.g., electric vehicles) to off-peak periods.

DR programmes can help the users to live in a sustainable and responsible manner. From a technical point of view, to effectively implement these programmes, it is necessary to collect consumption information and process it in a way that most of the benefits can be made. In particular, as human environments are ecosystems of heterogeneous digital devices, a holistic view on energy awareness is needed. This requires the development of an energy management system (EMS). To this end, throughout the WP2 (entitled *Definition of the Requirements and System Architecture*) of the MONERGY project it has been decided to develop an EMS composed of smart plugs, namely power sensors where electrical appliances are connected, and a smart home gateway where the logic of the system resides. Smart plugs are used to send power consumption information to the smart home gateway through a communication interface. As in WP2 it was shown that existing communication solutions for sensor networks may show coverage problems in home environments, we proposed a solution allowing for integrating wireless devices based on the Zigbee standard, as well as powerline communication devices based on the G3-PLC standard. To the best of our knowledge, there are no devices in the market providing convergence between these two solutions.

Therefore, in this deliverable we first describe the MONERGY network solution to achieve interconnectivity and interoperability among devices that communicate using different technologies. Besides, we present the design of two graphical user interfaces. The displaying of consumption information is in fact crucial to foster awareness and understand user's behaviour.

The organization of the deliverable is as follows. In Section 2, we present the MONERGY network solution for the domestic EMS to provide interconnectivity and interoperability among communcation devices that adopt different technologies. In the first part of Section 3, we present the design and the realization of a simple user interface for the EMS allowing for monitoring and controlling smart plugs, while in the second part, we report the design and implementation of an advanced user interface implementing prepaid billing at the appliance level. Finally, the deliverable is concluded in Section 3.5.2.3.

Section 2

Interoperability and Communication in Home Energy Management Systems

2.1 Introduction

Current research and development efforts are devoted to the deployment of information and communication technology (ICT) within houses and buildings to provide services that will improve the quality of life. Among these services, we can identify three classes: home networking, home automation, and smart energy management. Home networking services, e.g., triple play (high speed internet access, television, telephone), infotainment, and resource sharing in local area networks (LANs), are those that usually require high speed communication systems. On the other hand, home automation services are those that usually require low speed communication systems, e.g., for the automation of windows and doors, for the control of heating, ventilation and air conditioning (HVAC), for lighting and audio/video distribution. While home networking and home automation are well-established applications, smart energy management has only recently attracted significant interest. This is because the efficiency increase is a worldwide priority of the power distribution grid which includes houses and buildings. Efficiency and power savings were identified in 2010 as fundamental objectives to contribute to the Sustainable Growth specified in the "Europe 2020" strategy [eu2]. In the near future, the power grid will become a distributed large scale system that needs to smartly manage flows of electricity produced by big or small plants, i.e., a smart grid (SG) [Lam11, Zab11]. In this context, an important role is played by communication technologies that enable, in the home/building context, the smart management of household appliances, power metering, the control of local renewable energy plants, e.g., photovoltaic generators, the monitoring of electric vehicles charge, etc.. These technologies will allow the implementation of demand side and demand response mechanisms so that prosumers will actively collaborate in the usage and delivery of energy.

From the previous discussion, it is evident that the realization of the smart home (SH) requires the joint delivery of home networking, home automation and energy management services (see Fig. 2.1). Despite the existence in the market of a broad variety of communication technologies, the bottleneck to their pervasive deployment is that they often cannot interconnect, and/or interoperate and in some cases even coexist.

Figure 2.1: The Smart Home services.

2.1.1 Coexistence, Interconnectivity, Interoperability

Usually, the coexistence, i.e. the ability of sharing the same physical medium by two or more devices, is obtained exploiting different frequency bands at the physical (PHY) layer, or through the use of medium access control (MAC) protocols. The connectivity, i.e., the capability of devices to exchange data at PHY, data link (DLL) and network layer, requires the coexistence and can be achieved with a convergent layer above the data link layer or at the network layer. Finally, the interoperability, i.e., the capability of heterogeneous devices to exchange information with a common semantic, concerns the data transport up to the application layer. It requires both coexistence and connectivity, and it is usually obtained through the use of software applications, also known as middleware.

Coexistence and connectivity among different technologies, through PHY or DLL mechanisms, have been the focus of many studies. Representative examples are: the inter-PHY protocol [IEE10] developed within the IEEE

P1901 working group to allow coexistence among two different broad band power line communication (PLC) devices; the ITU-T G.hn standard that has been conceived with the aim of offering interconnectivity among in-home high speed communication devices that work over telephone wires, power lines, and coax (G.hn specifies the PHY and the MAC layers and addresses the coexistence between protocols that operate on different media); the solution developed within the EU-FP7 OMEGA project (www.ict-omega.eu), according to which devices belonging to the OMEGA network share the same inter-MAC layer and consequently they can coexist and they can be interconnected.

2.1.2 IP Convergent Layer

To realize and exploit the huge potential of the SH, full interoperability (among devices characterized by different standards and technologies) has to be offered seamlessly. To this end, once the coexistence is achieved at PHY/DLL layers, the connectivity among heterogeneous devices can be reached at network layer exploiting the internet protocol (IP). The use of the TCP/IP protocol stack to integrate different communication technologies for SH and SG applications is largely advocated. Previous work that follows this approach is described in [Mio06, Wol09, Els06, Tom09, Zab11] and references therein. Also standardization working groups are considering it, e.g., at the end of 2010, IEEE launched the P1905 working group[1] that is focused on the definition of an abstraction layer for multiple home networking technologies. The abstraction layer will provide a common data and control Service Access Point (SAP) for the home networking technologies described in the IEEE P1901, 802.11, 802.3 and MoCA 1.1 specifications. Finally, a number of standard development groups - among which ZigBee, HomePlug and Wi-Fi alliances - are working on the development of the ZigBee Smart Energy version 2.0 that will offer IP-based control for advanced metering infrastructures and home area networks allowing for interoperability with 802.11 and HomePlug devices.

In the rest of the section, we firstly survey the communication technologies that can be used for SH applications (Section 2.2). As explained, in general, these technologies operate over different media and/or use different standards/protocols. Therefore, they may lack for connectivity. To solve this problem, in Section 2.3, we describe a general home network architecture (Fig. 2.2) that, thanks to the use of the IP protocol, potentially enables for connectivity, scalability, flexibility, distributed control, reliability, and easy integration of heterogeneous communication technologies. Illustrative results that show some of the benefits deriving from the adoption of the proposed SH network architecture are presented in Section 2.4. The peculiar network

[1] http://grouper.ieee.org/groups/1905/1/

characteristics, jointly with interoperability, can be obtained through the use of middleware solutions, which are described in Section 2.5.

Since within MONERGY we are interested in developing an EMS that, based on the results of WP2 [Lab13], will be based on the Zigbee wireless standard and on the G3-PLC power line communication (PLC) standard. We specify the general network architecture to the MONERGY requirements derived in WP2 [Lab13] in Section 2.6.

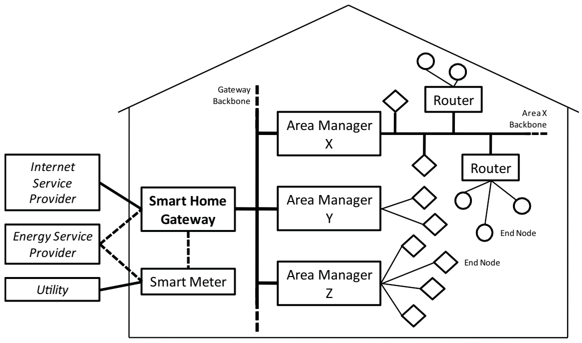


Figure 2.2: The Smart Home network architecture.

2.2 A Survey of In-Home Network Communication Technologies

In this section, we survey the communication technologies that can be exploited for the development of the SH concept. We list them according to the used media and Table I summarizes the main features.

2.2.1 Twisted Pairs and Coax

Twisted pair (TP) is nowadays used for the deployment of IP based local area networks (LAN). Cables are categorized by their cut-off frequency that determines the transmission bit-rate. In reference to this classification, we highlight cat 5, 5e, and 6 cables that support the IEEE 802.3 standard family[2] - also known as Ethernet - that offers bit-rates up to 100 Mbit/s (Fast Ethernet - IEEE 802.3u) and 1 Gbit/s (Gigabit Ethernet - IEEE 802.3z).

Originally, the Ethernet protocol was proposed for use over coax cables. Recently, the use of coax has been considered for delivering entertainment and multimedia services within the home and access networks. In 2007, the Multimedia over Coax Alliance (MoCA)[3] ratified the v1.0 and v2.0 specifications for communication over coax with bit-rates up to 250 Mbit/s and

[2]http://www.ieee802.org/3
[3]http://www.mocalliance.org

1.4 Gbit/s, respectively. In 2010, ITU-T has ratified the Gigabit home network standard (G.hn) (www.itu.int) that specifies the PHY and MAC layers for the interconnectivity of devices using coax, TP, and power lines. Its PHY layer is based on orthogonal frequency division multiplexing (OFDM) and it offers bit-rates up to 1 Gbit/s, while the MAC sub-layer is based on a hybrid time division multiple access (TDMA) / carrier sense multiple access (CSMA) protocol. Eventually, the HomePNA technology[4] provides specifications for home networking over existing coax cables and phone wires offering bit-rates up to 320 Mbps.

2.2.2 Wireless

There are several wireless technologies that can be used for in-home applications. Essentially, they can be grouped according to the offered bit-rate and coverage. Roughly speaking, devices that offer high bit-rate and large coverage are developed for LAN applications, e.g., Wi-Fi compliant devices. In contrast, devices offering high bit-rate and small coverage are developed for personal area network (PAN) applications, e.g., WiMedia[5] compliant devices. Finally, devices offering low bit-rate and a relatively large coverage are developed for command and control applications, e.g., ZigBee networks[6]. All these wireless devices work in the frequency bands known as industrial, scientific and medical (ISM).

In the following, we provide some more details about the wireless technologies.

2.2.2.1 High bit-rate wireless technologies ($> 10\ Mbit/s$)

This category of systems is defined by the standard family IEEE 802.11 and it is known with the term Wi-Fi. Devices compliant with this standard family work in the frequency bands 2.4 GHz (802.11b/g) or 5 GHz (802.11a/n). The offered bit-rate equals 11 Mbps for the 802.11b, 54 Mbps for 802.11a/g, and 600 Mbps for the 802.11n that uses the multiple-input multiple-output (MIMO) technique. The indoor coverage is typically up to 70 m.

802.11 has the PHY layer based on OFDM, while the MAC layer is based on CSMA protocol with collision avoidance (CA) (see Table 2.1). Although Wi-Fi and Ethernet have different PHY/DLL layers, they converge on the same logical link control (LLC) sub-layer (defined in the 802.2 specifications). Therefore, they exhibit the same interface towards the network layer and thus they can be interconnected.

Other high bit-rate wireless technologies are the ones based on ultra wide band (UWB) modulations. Two examples are the WiMedia (www.wimedia.org)

[4] http://www.homepna.org/
[5] http://www.wimedia.org
[6] http://www.zigbee.org

and the WirelessHD (www.wirelesshd.org) standard compliant devices. Both standards are based on multi-band OFDM and are designed for short range communications (<10 m). WiMedia compliant devices work in the frequency band 3-10 GHz and reach bit-rates up to 1.2 Gbit/s, whereas WirelessHD devices work in the frequency band 57-65 GHz and reach bit-rates up to several Gbit/s.

2.2.2.2 Low bit-rate wireless technologies ($< 3\ Mbit/s$)

These technologies have been conceived with the scope of being embedded in small chips and grant low power consumption. There are several low bit-rate wireless technologies that have been developed for home automation applications. Table 2.3 lists the characteristics of the mostly used [Gom10], i.e., ZigBee, Z-Wave, Insteon, and Wavenis. A detailed description of low bit-rate wireless technology can be found in [Lab13]

Table 2.1: High bit-rate Wireless technologies.

	Wireless	
	802.11b/g	802.11a/n
Spectrum [MHz]	2.4 GHz	5 GHz
Modulation	DSSS OFDM	OFDM
Bit-rate [$Mbit/s$]	up to 11/54	up to 54/600
MAC	CSMA/CA	CSMA/CA

Table 2.2: High bit-rate PLC technologies.

	PLC				
	HomePlug AV	HomePlug GreenPHY	ITU-T G.hn	HD-PLC	IEEE P1901
Spectrum [MHz]	2–35 (1) 2–70 (2)	2–30	2–100 (BB) 100–200 (PB)	4–30	2–28 2–60
Modulation	OFDM Bit loading	OFDM/ QPSK	OFDM Bit loading	W-OFDM Bit loading	W-OFDM Bit loading
Bit-rate [$Mbit/s$]	200/500 (1)/(2)	3.8–9.8 3.8–9.8	up to 1 [$Gbit/s$]	190	up to 540
MAC	TDMA CSMA/CA	CSMA/CA	TDMA CSMA/CA	TDMA CSMA/CA	TDMA CSMA/CA

2.2.3 Power Line

Power line communication (PLC) makes use of the existing power line grid to transmit data signals. There is a broad range of applications for which PLC has been or being used, e.g., internet access, remote metering, command and control of home devices, SOHO, and recently, SG applications.

Table 2.3: Low bit-rate wireless technologies.

	Wireless			
Technology	**ZigBee**	**Z-Wave**	**Insteon**	**Wavenis**
Spectrum [GHz]	0.868 0.968 2.4	0.868 0.968	0.904	0.433 0.868 0.968 2.4
Modulation	BPSK DSSS QPSK	FSK GFSK	FSK	GFSK FHSS
Bit-rate [$kbit/s$]	20–250	9.6–200	38.4	4.8–100 (typically 19.2)
Coverage [m]	10–100	30–100	45	200–1000
MAC	CSMA/CA (beaconless) TDMA (beacon enabled)	CSMA/CA	TDMA + Simulcast	CSMA/CA or CSMA/TDM
N. of Hops	30/10/5	4	4	1 (no multihop)
Specs available	yes	no	no	no

Table 2.4: Low bit-rate PLC technologies.

	PLC			
Technology	**G3-PLC**	**PRIME**	**ITU-T G.hnem**	**IEEE P1901.2**
Spectrum	CENELEC A,B,C,D FCC	CENELEC A	CENELEC A,B,C,D/ FCC	CENELEC A,B,C,D/ FCC
Modulation	OFDM	OFDM	OFDM	OFDM
Bit-rate [$kbit/s$]	0.6–240	up to 130	up to 1 $MBit/s$	up to 500
MAC	CSMA/CA	CSMA/CA TDMA	CSMA/CA TDMA	CSMA/CA (G3-PLC)
N. of Hops	up to 8	up to 63	up to 12	-
Specs available	yes	yes	yes	no

Essentially, the PLC devices can be grouped into two categories, i.e., narrow-band (NB) and broadband (BB) devices, according to the bit-rate that they can achieve.

2.2.3.1 Narrow-band PLC Technologies

They have been developed with the scope of offering indoor (home automation) and outdoor (smart grid) command and control services. These technologies are cheap and offer low bit-rates. The frequency bands dedicated from standardization organizations to NB-PLC devices vary among the continents. In the EU, CENELEC issued the standard EN 50065 that specifies four frequency bands for communications over PL networks [Fer10]. The band A (3–95 kHz) is reserved exclusively to power utilities, the bands B (95–125 kHz) for any application, the band C (125–140 kHz) for in-home networking, and the band D (140–148.5 kHz) for alarm and security systems. In the US and Asia, the regulation is different: FCC and ARIB allow PLC devices to work in the band from 3 kHz up to 490 kHz or 450 kHz, respectively.

In Table 2.4, we report the NB-PLC technologies developed for home automation [Fer10, Chapter 7]. From Table 2.4, we notice that the listed technologies may work in different frequency bands and adopt different modulation schemes and MAC protocols. Therefore, these technologies may coexist but cannot be interconnected. Furthermore, we notice that technologies with overlapping operating bands may coexist exploiting MAC layer specific protocols. To this aim, the CENELEC band C is reserved for technologies that adopt the CSMA/CA protocol.

We highlight that PRIME [PRI11] and G3-PLC [ERD09] were developed for metering applications and are playing a relevant role inasmuch have been used as baseline for the development of the IEEE P1901.2 and the ITU-T G.hnem standards for SG applications [Oks11].

2.2.3.2 Broadband PLC Technologies

They have been developed with the goal of offering high speed home networking. Essentially, BB-PLC devices work in the frequency band 2–30 MHz (and beyond), and make use of advanced modulation techniques such as OFDM and bit-loading to offer bit-rates in the order of hundreds of Mbit/s. The most relevant examples of commercial devices are the ones compliant with the HomePlug AV (HPAV) [Hom05] and the HD-PLC [Fer10, Chapter 7] industry standard. Their MAC sub-layer is based on TDMA for high quality of service traffic, and on CSMA/CA for best effort traffic. Furthermore, their network layer is based on IP. In Table 2.2, we summarize the characteristics of BB-PLC devices. It is interesting to note that both solutions, i.e., HPAV and HD-PLC, have been used as baseline for the PHY layer specification of the IEEE P1901 standard, released in December 2010.

2.3 Smart Home Convergent Network Architecture

To realize convergence of network technologies and enable the delivery of a broad set of in-home services, we envision the general SH network architecture depicted in Figure 2.2. We adopt a tree topology as a combination of bus and star topologies. The major benefit deriving from the use of such a topology is its ability to be scalable, extensible, and reliable. We assume that the nodes may use different transmission technologies. Interconnectivity among them can be reached through IP[7]. Since not all technologies support IP (as it will be discussed in the next section) we need to deploy routers (see Figure 2.2). The functions of the main network nodes are described in the following.

2.3.1 End Node

At the bottom layer of the home network, we find the End Nodes (ENs). They represent the devices of the network that directly interact with the sorrounding environment. According to Figure 2.2, we point out that the ENs can be classified into IP compliant (square) or not (circle) nodes. The latter devices may use a proprietary network protocol (not IP based), thus they need to be virtualized into IP addressable nodes exploiting the Router capabilities.

2.3.2 Router

Nodes compliant to a given standard, not IP based, are grouped in a subnetwork. Each subnetwork is addressable through a Router (see Figure 2.2). The main role of the Router is thus to virtualize each node of its subnetwork into an IP addressable node. This leads to interconnectivity among the network nodes. In detail, a Router has to

- associate a virtual IP address to each EN of the subnetwork,
- get and store the information about each node, i.e., the service provided, the physical link quality and the set of data that the node needs to exchange (e.g., the temperature or power consumption measured by a sensor),
- generate a list that specifies the address and the information of each node of its subnetwork,

[7]We herein assume that the coexistence among the network devices holds.

- translate IP packets into native communication protocols and vice versa.

It is important to highlight that the use of routers is beneficial for increasing the network coverage. In fact, a subnetwork can be split in more subnetworks in the case that some of its nodes are not in visibility. This concept will be stressed when we show the illustrative results in Section 2.4.

2.3.3 Area Manager

We assume to divide the SH network into areas. Each area represents one or more rooms and is managed by an area manager (AM). Different AMs can manage the same class of service, e.g., home networking, home automation, energy management, in different ways. This enables to offer, in a simple way, a specific set of services to a given area of the house.

An AG, under request, retrieves the information regarding the ENs and their corresponding subnetworks, thus it contains a data base with all the information regarding its area. We also envision the AG to be responsible of the routing within its area. In particular, we envision each AG to route packets taking into account the energy efficiency, i.e., the selected paths are the ones that need the lowest energy consumption to satisfy the QoS constraints (e.g., bit-rate, latency, delay). Finally, the AM, under request, can send its own database to the smart home gateway (SHG). By doing this, the SHG has a complete vision of the network and can request the AMs to make actions as a consequence of an event or a user request coming from another area of the house. It is worth noting that the use of more AMs within the house also increases the fault tolerance and the network extensibility. Finally, we notice that an AM can be a physical or a logical entity. For example, in the latter case, it could be a program running on a platform with an Ethernet connection.

2.3.4 Smart Home Gateway

The SHG plays the role of central coordinator and offers Internet connectivity. This is to provide remote management/alert/monitoring of the network and the delivery of web information and entertainment services. Note that the Internet connectivity can be also exploited to connect the house to the energy service provider (ESP) for exchanging data about energy usage and tariffs. Furthermore, since the network can integrate different communication technologies, we can also think to have connectivity between the smart meter, which is typically own by the utility, and the SHG. We notice that, although the integration of SG and conventional home networking applications violates an accepted paradigm, the isolation between the utility network, the energy and Internet service providers can be handled at the middleware layer (see Section 2.5).

On the other hand, the SHG communicates with the AMs connected to the same backbone. The main features of the SHG can be summarized as follows:

- Addressing (if necessary): assign the IP address to the AMs, e.g., DHCP server.
- Service lookup and publication: get the information about nodes from the AMs, and consequently generate its own data base containing the information regarding all network nodes.
- Service maintenance: update its own data base following a network event.
- Routing (if necessary): set up a routing table among the AMs taking into account the reliability or energy efficiency of the links.
- Home function control: ask the AMs to make an action as a consequence of an event or user request.
- Fault detection: detect and report failures of devices.
- Remote access: users can access and/or manage the overall network from a remote position.

As discussed for the AMs, we envision choosing the routing path as a tradeoff between energy consumption and QoS constraints satisfaction. An example of such an approach is given by the IPv6 Routing Protocol for Low power and lossy networks[8], recently approved by the Internet Engineering Task Force (IETL).

2.4 Illustrative Results

In this section, we present illustrative results that show some of the benefits deriving from the adoption of the proposed SH network architecture.

We consider a three-floor house where home networking and energy management services are offered (see Fig. 2.1). Home networking services are offered in some rooms through an Ethernet network. The energy management system consists of smart plugs - capable of measuring the power consumption of the connected household devices and to switch them on/off - and of a energy management coordinator. The energy management communication network is based on G3-PLC technology.

This scenario has been evaluated using the OMNeT++ network simulator. In Figs. 2.3,2.4, we respectively show the saturation throughput (STH)

[8] RPL http://tools.ietf.org/html

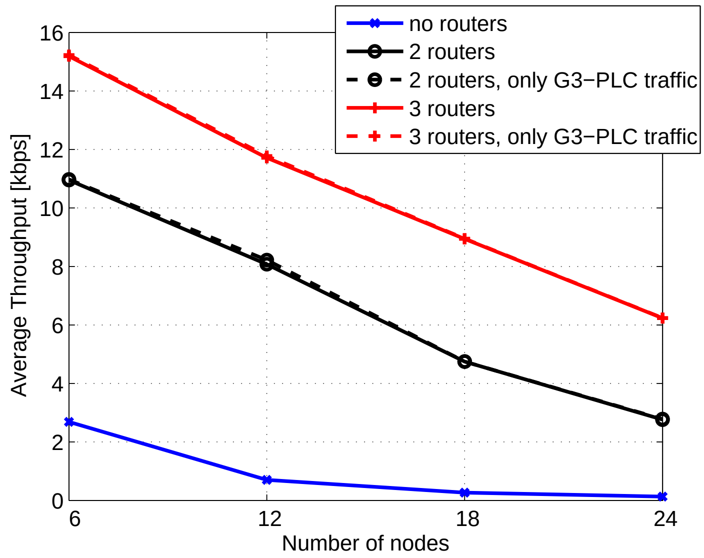


Figure 2.3: Saturation throughput for the energy management network.

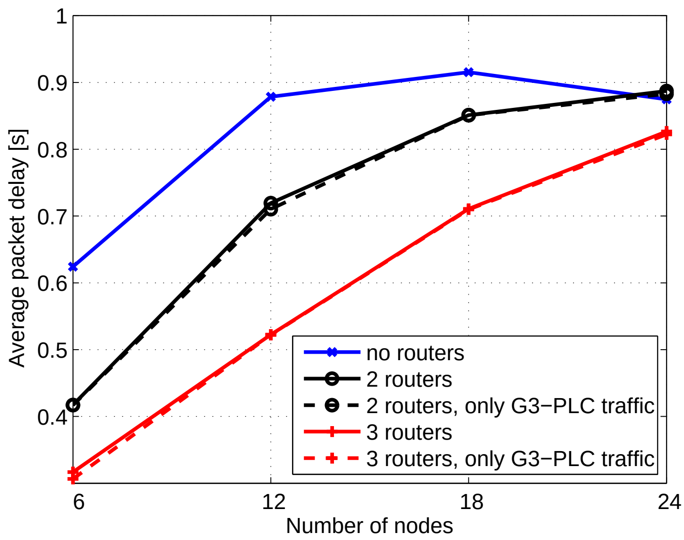


Figure 2.4: End-to-end delay for the energy management network.

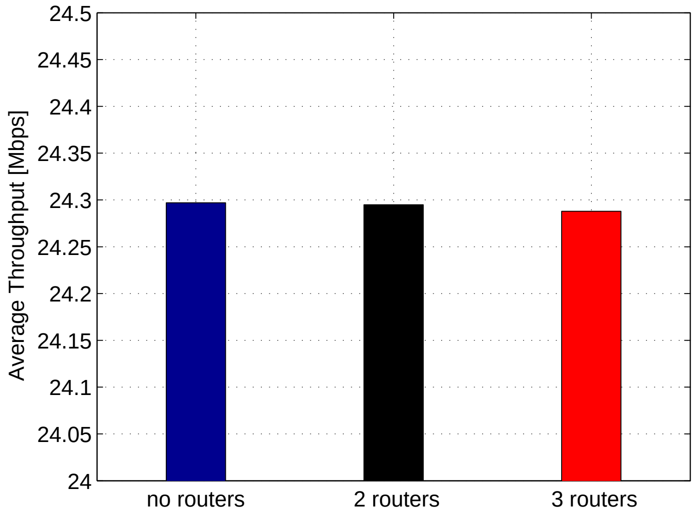


Figure 2.5: Illustrative performance of the smart-home network.

and the end-to-end delay for the G3-PLC network, when no Router is introduced, and when two and three Routers (placed in different floors) are used to integrate the NB-PLC with the Ethernet network. The results are shown considering both, the case when the network traffic is only generated by G3-PLC devices, and the case when also home networking traffic is present. The home networking traffic consists of one HDTV video streaming and one broadband internet connection. We notice that when two routers are used, one is connected to the Ethernet backbone using a BB-PLC connection, in particular with HPAV modems, and the other with cat 5e cable.

As we can see, the adoption of the proposed network architecture sensibly improves the performance of the NB-PLC network. In fact, in the considered power line topology each floor is fed by a circuit that departs from a circuit breaker positioned in the main panel. Consequently, as showed in [Ber12], the NB-PLC signal is strongly attenuated when passing through the CBs which considerably reduces the quality of the link between two nodes positioned in different floors. Therefore, the partition of the network in two or three sub-networks is beneficial. Furthermore, since the number of nodes belonging to each sub-network decreases, the sub-network load and the packets collisions are reduced. From Fig. 2.3, we also notice that the increase of STH directly translates in a coverage extension.

Regarding the behaviour of the network when we simultaneously deliver home networking and energy management services, we observe that both network traffics are not significantly affected by each other. This is mainly due to the fact that the G3-PLC network traffic has a low bit-rate compared to the capacity of the Ethernet network.

Figure 2.6: Distributed network system model.

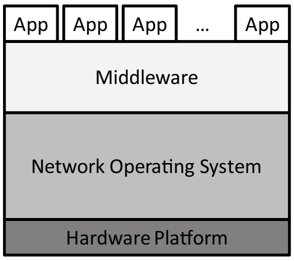


Figure 2.7: UPnP model.

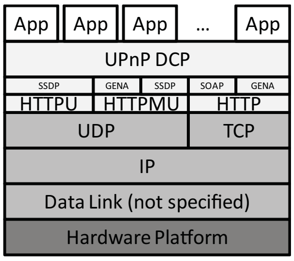
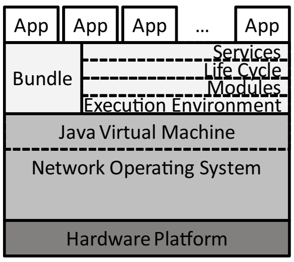


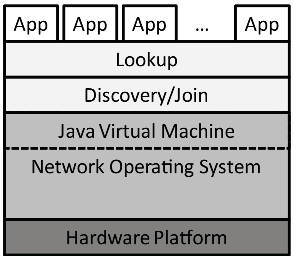
Figure 2.8: OSGi model.



2.5 Middleware Solutions for In-Home Network Interoperability

In order to realize the presented SH network, we need interoperability among the network devices. In this perspective, the SH can be seen as a centralized/distributed system where devices communicate and coordinate their actions exchanging messages by means of a communication network. In such a system, the interoperability among network devices can be achieved through the introduction of a higher level of abstraction: the *middleware* layer. Then,

Figure 2.9: Jini model.



the management of services - which can be centralized or distributed, e.g., home networking, home automation, and energy managament,- will rely on the application software. In the rest of this section, we focus on the middleware layer.

As depicted in Figure 2.6, the Middleware is a software layer placed between the network operating system and the applications. Its aim is to simplify access to heterogeneous and distributed resources. It provides a higher degree of abstraction in distributed system programming by decoupling applications from the lower layers consisting of heterogeneous operating systems, hardware platforms and communication protocols. In this perspective, the most relevant middleware solutions are *Universal Plug and Play*[9], *Open Service Gateway initiative*[10] and *Java intelligent network infrastructure* (Jini)[11].

2.5.1 Universal Plug and Play

UPnP is an emerging standard based on a peer-to-peer software architecture for network connectivity of, possibly, any kind of electronic device. The framework is designed to be independent of any particular operating system, programming language and physical medium. It is also open and based on the TCP/IP protocol stack. Devices belonging to an UPnP network can be classified into controlled devices (or simply devices) and control points. A controlled device acts as a server, responding to client requests from control points. Note that, a device and a control point can operate simultaneously on the same physical node.

As shown in Figure 2.7, the engine of this framework is given by the Device Control Protocol (DCP). It defines the communication between devices and control points exploiting well known protocols and languages, e.g., addressing (DHCP or AutoIP), discovery (SSDP), description (XML), control (SOAP), eventing (GENA) and presentation (HTML). Therefore, the UPnP network does not require any configuration from the user. In fact, once a

[9] UPnP Forum, http://www.upnp.org
[10] OSGi Alliance, http://www.osgi.org
[11] http://www.jini.org

device (or a control point) is connected to the network, it is automatically detected and configured. Furthermore, it exchanges information with the network about services provided and capabilities offered. However, since UPnP is based on the TCP/IP protocol stack, the connectivity among heterogeneous network devices, which are non IP-based, is not always ensured.

Currently, UPnP has been applied for multimedia applications such as audio or video streaming by the digital living network alliance (dlna)[12]. Unfortunately, its application for home automation and energy management services may be limited due to the complexity of running the protocol stack inside devices with low computational capability, e.g., sensors and actuators.

2.5.2 Open System Gateway Initiative

OSGi provides open specifications for service delivery into networked environments. Since it is based on Java, it is operating system independent. OSGi basically consists of a network framework and a set of standard service definitions. The main role is played by the service gateway that coordinates the interaction between the client and the service provider. The latter can be either located within the same network (e.g., for home monitoring and automation) or spread over the Internet (e.g., for a remote alarm system, for web multimedia streaming).

Figure 2.8 shows the system protocol details. As it can be seen, applications or components are packed into bundles and delivered throughout the network. Each bundle carries information about service interfaces, service implementation and required resources. Therefore, the service provider copes with the packaging and advertisement of bundles, while the client downloads and executes the required bundles through the service gateway. Although OSGi was originally designed for service gateways, now it is considered for application in a broad variety of devices, e.g., set-top boxes, Cable/DSL modems, PCs as well as mobile phones.

The main strength of OSGi is the idea of centralizing the network management in the service gateway. However, this can also be a weakness since it limits the system scalability and represents a single point of failure problem.

2.5.3 Java Intelligent Network Infrastructure

Jini defines a set of network architecture specifications for the implementation of a distributed system. It allows for federating clients, services and the resources required by those services. Jini is operating system independent but Java-based since it is an evolution of the Java Remote Method Invocation (RMI). It is also open and based on the TCP/IP protocol stack.

According to Figure 2.9, the core of Jini is represented by the discovery, join and lookup protocols. Furthermore, three main components can be

[12] http://www.dlna.org

defined, i.e., the service, the client and the lookup service. A given service, originated by a service provider, has to be registered in the lookup service before being acquired and used by the client. The service provider stores a set of service attributes into the lookup service using the discovery and join protocols. When the client requests for a service, the lookup protocol moves the service attributes from the lookup service to the client. Eventually, the client is able to exploit these service attributes to obtain the required service directly from the service provider. In this perspective, the lookup service acts both as a repository of service providers and as service trader for clients.

The flexibility of discovery mechanism and the scalability offered by the number of lookup services, which may increase according to the network load, are the main strengths of Jini systems. Nevertheless, the transfer of service attributes (i.e., Java bytecode) requires an amount of memory that is not always available in small devices.

2.6 The MONERGY network solution

The previous description proposes a network solution to offer different classes of services, i.e., home networking, home automation, and smart energy management. Within the Monergy project, we are interested in developing a domestic smart energy management system (EMS). To this end, in [Lab13], we have derived the requirements of the communication network in terms of coverage, topology, number of nodes, metering resolution, and thus data traffic. Furthermore, from the analysis of the requirements, we selected the Zigbee (see Table 2.3) and the G3-PLC (see Table 2.4) communication technologies as the two best candidates to develop the Monergy energy management system (EMS).

From the smart home network architecture that is shown in Fig. 2.2, the Monergy network solution will thus consist of a Zigbee sub-network and a G3-PLC sub-network. The sub-network end nodes will be power sensors (smart outlets) that will exchange data with the sub-network router. Each router will exchange data with the smart-home gateway (HG), which in our case will be the central point to locate the logic of the EMS. It is worth noting that to improve the coverage of each communication technology, more sub-networks, and thus more routers, of each communication technology can be present in a network. Fig. 2.10 depicts the Monergy network solution.

As previously said the HG represents the point of the network where the logic is located. In particular it will be responsible of:

- Gather data from smart plugs and store them in a database.
- Allow the users to manage the energy system by monitoring the electrical devices connected to the smart plugs, and switch them on/off.
- Allow the users to remote connect to the EMS.

All the previous functionalities have to be offered to the users through a graphical user interface. This is the topic of the next section.

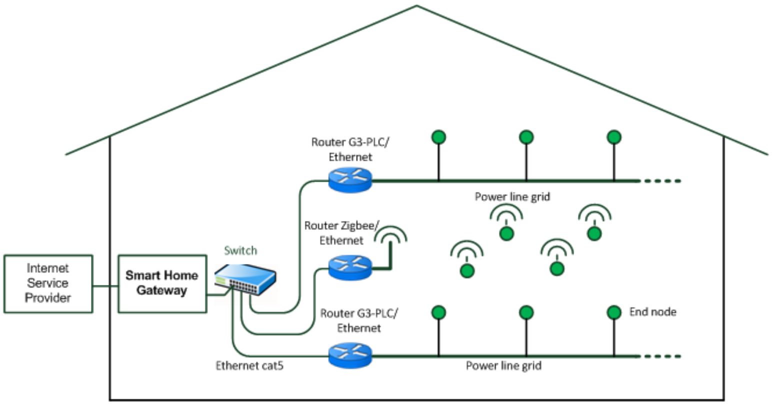


Figure 2.10: The Monergy network architecture.

Section 3

User interface

Households account for a great share of the overall energy consumption. US Energy Information Administration has computed that the energy consumed by residential users in 2008 accounted for the 18%, while Eurostat computed that in 2010 the energy consumed by residential users accounted for the 26.7%. A key role in the future power networks will therefore be played by domestic EMS, which aim at optimising production and demand of energy given the highly fluctuating nature of the grid and the local renewable sources. Beside autonomous controllers driven by dynamic price signals, energy conservation strategies are often employed to promote efficiency. Indeed, displaying consumption information can help making users more responsible of their lifestyle, and foster a change in their behavior. Energy management systems can be used to monitor and manage energy consumption of household appliances, as well as the local production resulting from renewable sources. In [Dar06], interfaces displaying real time consumption were shown leading to savings up to 15%. In [EM10], it is shown that real-time feedback down to the appliance level can generate the greatest saving. Moreover, appliance-level information enhanced by advices can lead to an energy saving of 20% [CA13].

Fig. 3.1 illustrates the Monergy concept for the EMS. Electrical devices are connected to smart plugs, which are power sensors with a communication interface. Smart plugs send power consumption data to the smart home gateway (SHG). The SHG represents the device where the logic resides. A remote device, e.g., a tablet, a smart phone or a computer can be used to manage the whole system through a graphical user interface (GUI).

This section gives a description of a simple GUI of the EMS that is being developed within the Monergy project.

The rest of the section is organized as follows. Section 3.1 presents the design principles and the functionalities of the EMS. Then, Section 3.2 presents the developed GUI for the EMS. Finally, Section 3.3 describes the used software and hardware platforms.

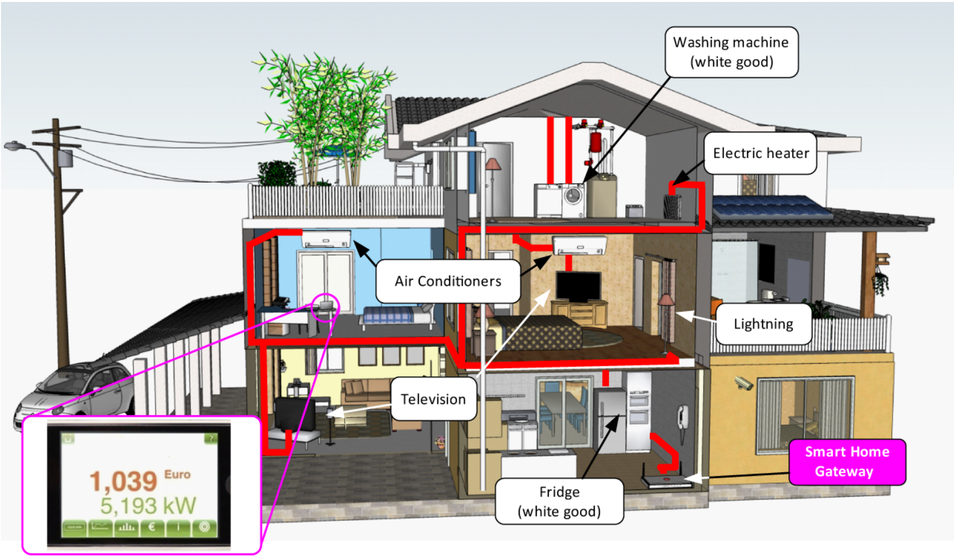


Figure 3.1: The Monergy energy management system.

3.1 Design principles and functionalities

The GUI of the Monergy EMS can be in principle used by people who are not familiar with the use of softwares. Consequently, the GUI shall:

- Guide the user through the installation of the system.
- Contain only essential information that are clear and easy to understand.
- Be robust.

The first principle tells us that the system has to be as much as possible "plug and play": the user shall only specify information that cannot be known a priori by the logic of the EMS. Therefore, the installation phase, namely the discovery of the smart plugs and the gathering of information related to the communication network will be transparent to the user. We identified only a small set of information that is relevant and perceived as useful by the user. This is::

- The room in which each smart plug is placed.
- The electrical device connected to each smart plug.
- The possibility to lock the electrical device connected to each smart plug, namely, the possibility to let the user to switch on/off the device connected to the smart plugs, e.g., it is advisable not to give the possibility to the user to switch on/off the fridge.

- The specification about the energy tariffs.

The second principle tells us that we need to keep low the number of information that the user has to visualize. From our analysis, the following information is needed to make the users aware about their energy consumption:

- For each device the user shall monitor the power spent and the cost so that the relation between power and cost can be understood. This information shall be given with different temporal interval, e.g., instantaneously, hourly, daily, weekly and monthly.

- The aggregate consumption shall be also visualized.

The information visualized through the GUI give to the user an immediate overview of the energy waste in the house, e.g., electrical devices that are running while nobody uses them (TV, computer, printer, heaters/air conditioning in rooms that are not used, boilers, etc.), devices in stand-by mode, switched on lights in vacant rooms, etc.. As a consequence of the increase of the awareness, the user must have the possibility to easily counteract to the waste of energy. Thus the GUI shall give the possibility to switch the devices on/off.

The third principle tells us that the system has to be robust. Robustness can be seen as the capability of the system to recover from unexpected states, to avoid unwanted states, and to signal the problem in case a solution cannot be found. Actions have to be taken in the event that:

- The user does not specify some parameters during the initialisation phase.

- The user submits requests while a request is being elaborated.

- The user submits more requests simultaneously.

- A smart plug is temporary unreachable, e.g., the user unplugged it.

- A smart plug is permanently unreachable.

- The home gateway is temporary not fed, e.g., it is temporary unplugged.

- The home gateway stops working and a reset is required.

3.2 Graphical User Interface

From the analysis of the functionalities described in the previous section, we can derive the state diagram for the GUI. Fig. 3.2 shows it. Each state of the diagram will correspond to a page of the GUI. Transitions between two states are given by a command (red text in the figure) or by an unexpected situation. Although not shown in Fig. 3.2, we highlight that each smart plug status is periodically saved in a data base (DB) when the system is in the Settings or in the Monitoring page. In particular, the table SMART_PLUGS has the following attributes:

- ID(string 16 char, primary key), ID of the smartplug, usually the MAC address.
- TIMESTAMP(datetime), instant of time.
- ROOM(string), room in which the smart plug is placed.
- DEVICE(string), device connected to the smart plug.
- LOAD(integer), power consumption in watts.
- POWER(boolean), on/off status.
- LOCK(boolean), locked/unlocked.

Figs 3.3 and 3.4 respectively show the Initialization and the Monitoring pages, whereas Fig. 3.5 shows an example of daily report that is generated by clicking the daily statistics button on the Monitoring page.

3.3 The software and hardware platforms

The GUI has been developed in html and runs on a web server installed on the Connectport X4 gateway platform provided by Digi International Inc. The gateway is connected to the smart plugs through Zigbee PRO technology. It also presents a LAN and a WLAN interface for remote connection. The employed smart plugs have been provided by Pikkerton Gmbh [Pik12]. Fig. 3.6 shows the used hardware platform and the smart plugs.

Digi provides a Zigbee socket library written in python through which it is possible to set-up the network and make queries to the network nodes [Dig07], namely the smart plugs. It is also possible to integrate html in python scripts thanks to the use of a python module called digiweb [1].

The reports of consumption and cost are generated with the Rickshaw javascript toolkit[2].

[1] http://www.digi.com/wiki/developer/index.php/Module:digiweb
[2] http://code.shutterstock.com/rickshaw/

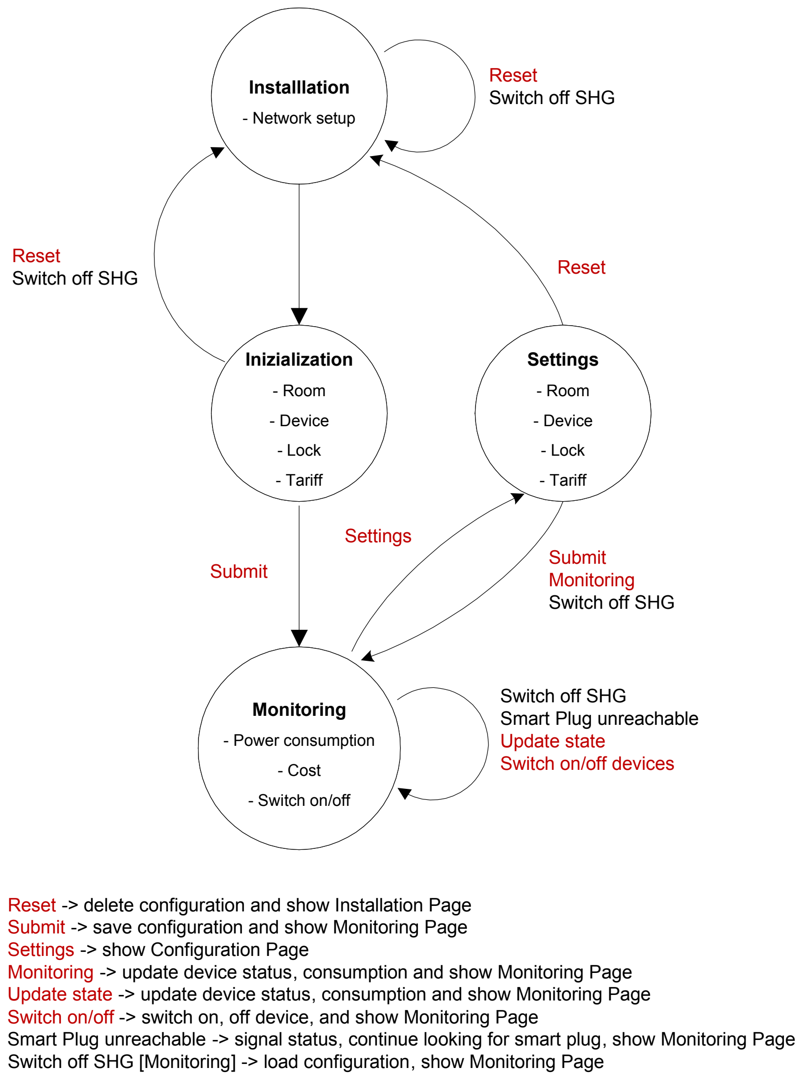


Figure 3.2: State diagram of the EMS. Red text indicates commands, while black unexpected situations.

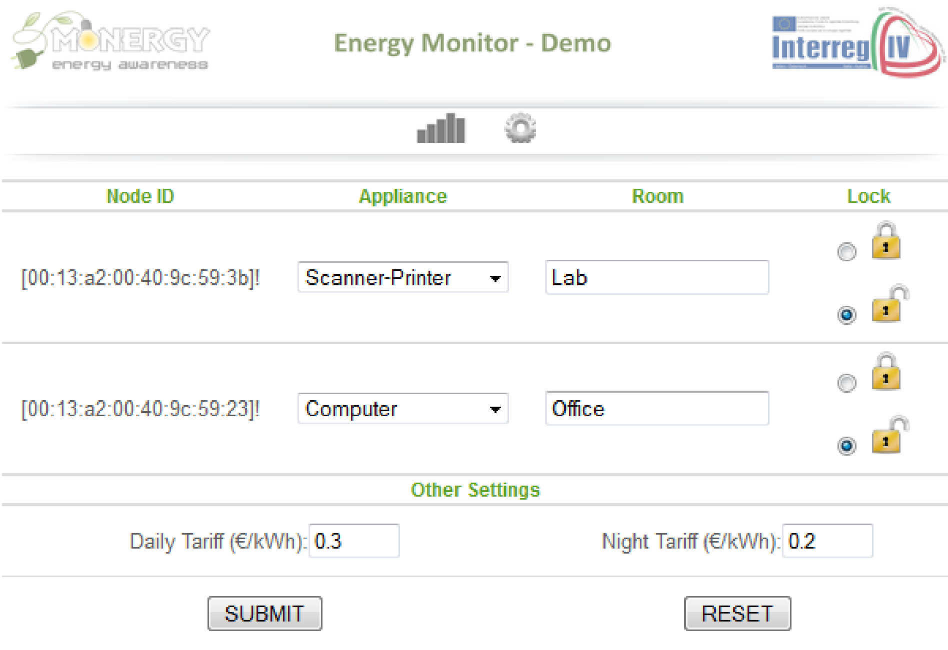


Figure 3.3: Initialization page of the EMS.

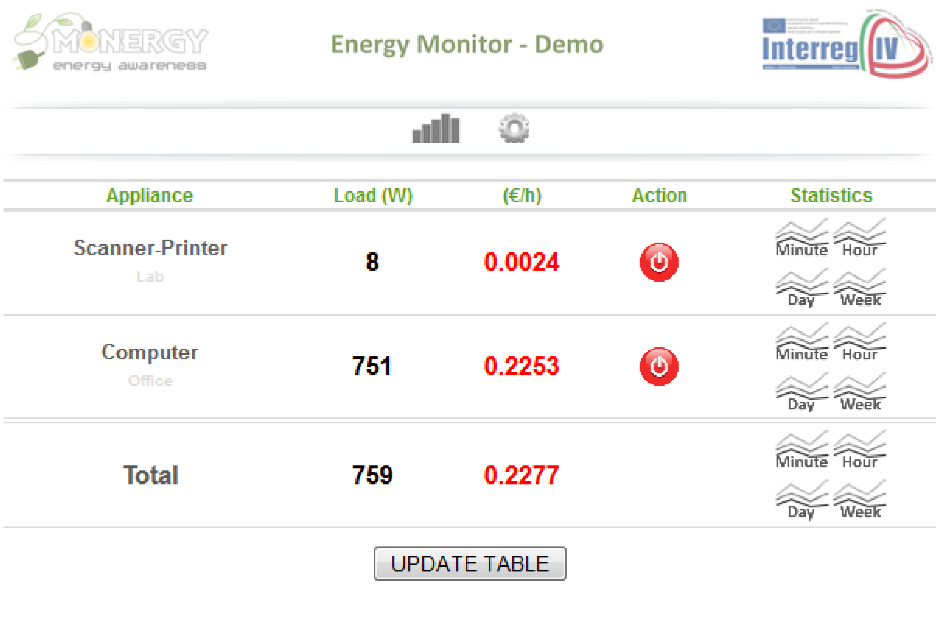


Figure 3.4: Monitoring page of the EMS.

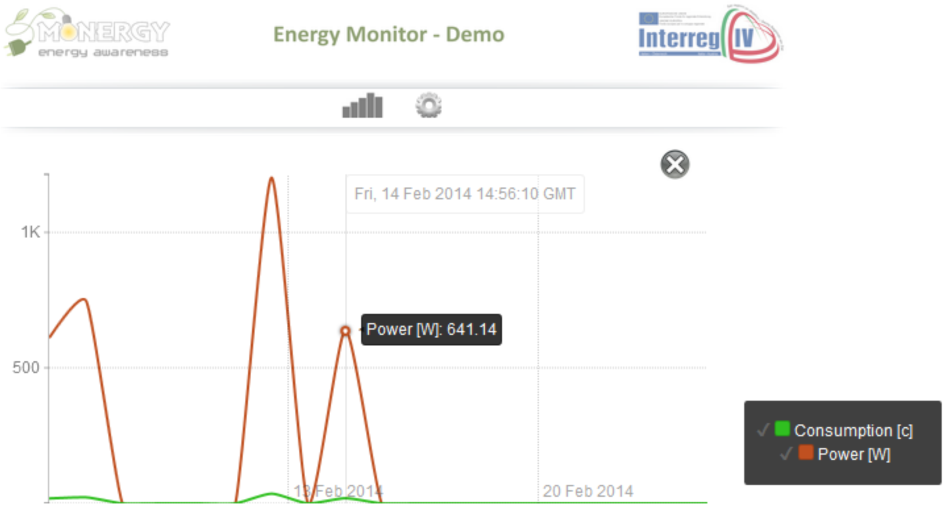


Figure 3.5: Example of daily report of the EMS.

Figure 3.6: Digi Connectport X4 gateway and smart plugs.

3.4 Persuasive interfaces

Energy awareness is the ability to perceive the effect that operating electrical devices has on the environment. Effects can be monetary, social and environmental. Persuasive technologies are interactive systems designed to aid residents in understanding their energy footprint. The objective is to support residents' decision making so as to steer them towards a more sustainable lifestyle.

Intuitively, energy awareness is given by the awareness of the energy available in the grid or locally, as well as the energy required to run certain appliances. Therefore, assigning a cost to human activities can increase energy awareness for the following reasons:

- **Dynamic pricing as awareness of available energy** Pricing schemes incentive users to operate in periods of the day in which the demand and cost of energy is lower, thus it might help providers limit the demand in peak periods. Pricing should dynamically consider the offer of energy, so that users can allocate the energy necessary for their activities by bidding an amount in a real-time manner. This would offer an understanding of the energy available in the grid, as well as the amount of energy necessary to operate certain devices [Alb07]. Although this is not yet available in Austria, Italy has already completed the rollout of automatic meters and customers can already get charged based on time-dependent tariff plans.

- **Demand awareness** Money can be used as non-technical measure unit for energy. Moreover, a wallet tracking the expenses for energy of each resident down to the appliance level can: i) enable self-learning and ii) provide an understanding of most expensive devices, which might promote replacement with more efficient ones. In addition, an event-based representation of consumption information can help users better understand the cost, in terms of energy and money, of their daily activities. An event is a tuple $\langle start, duration, consumption, price \rangle$ specified by the timestamp, the duration, the overall energy and the tariff, respectively. Beside requiring less storage space than timeseries data, interval-based events provide also a straightforward representation for temporal data mining algorithms [Lax06]. Statistical queries could be run on the dataset to extract usage models in order to enhance the feedback returned to the user.

In [Mon13b] and the first MONERGY project deliverable [Lab13], we analyzed peculiarities of the regions that might affect the overall energy profiles of households. We outlined typical scenarios and devices most responsible for residential energy consumption and we reported about existing conservations strategies to promote energy efficiency. We concluded that the best achievements in terms of savings can be reached by displaying real time appliance-level information [Dar06, EM10], with expected savings of 20% when customers are also provided with automatic recommendations [CA13]. Beside, prepaid billing at the household level was shown leading to average savings of 11% regardless of disconnections from the grid [Ozo13].

3.5 Prepaid appliance-level billing

Given the findings of previous studies on energy conservation strategies in domestic environments, we decided to combine prepaid billing to disaggregated consumption information.

A prepaid billing system is a billing mechanism where a credit amount is purchased in advance and used to pay when the service is actually used. Classically, the service becomes no longer available as soon as the credit is used up. While this is a common model in fields such as telephone billing, it is only starting now to get attention as billing mechanism for energy applications [Ozo13, Liu13]. The approach undertaken combines prepaid billing to appliance-level consumption information. Users can specify the amount of money they intend to spend per device, so as to get charged when operating the device according to the current cost of energy. The cost of operating a device is given by the energy demanded for a specific task or event, and the energy cost for the time period, computed as: $Cost_{event} = \int_{t_{start}}^{t_{end}} C(t)P(t)\,dt$ with respectively C and P as the energy cost and the power, and t_{start} and t_{end} as beginning and end of the event.

A similar approach was undertaken in [Liu13], where a prepaid billing system is used for a student dorm. A mobile application displays credit left and current trends, and provides a basic forecast of the next payment due to minimize disconnections. Although the work represents a first effort in assessing prepaid billing in multi-user environments, it does not scale to the appliance level. Therefore, to the best of our knowledge, our system is the first example of such a strategy kind. In [Mon13a] we presented a first version exploiting an open source sensing platform to collect consumption data. We managed the appliance credit using a cloud-based webservice and implemented a notification system to inform users of credit overdue.

In this section we propose a detailed formulation of pay-as-you-go devices. Furthermore we discuss open issues and improvements, and anticipate future directions of the project.

3.5.1 Requirements

For the realization of a prepaid billing system for household appliances we have identified the following requirements:

- **Gathering consumption information:** Collecting consumption information of appliances is needed to track their operational costs and can be derived both from meter data and from distributed sensing units. Non-intrusive load monitoring (NILM) [Zei11, Ega13b, Ega13a] disaggregates the power profile of loads out of the overall household consumption. On the other hand, smart outlets can track power usage of connected loads, based on voltage and current measurements. Similarly, smart appliances are aware of consumed power, based on local measurements or built-in profiles, which are deployed with the device [Elm12]. Consumption information is exposed both to users and machines, through machine-readable descriptions of features and data that can be directly retrieved over a network.

- **Appliance detection and classification:** Energy awareness is not solely about measuring energy consumption. Understading how energy is used in daily life activities is necessary to pospone certain devices within demand response programmes. A first classification of devices was provided by [Ran10]. Devices are classified in 4 groups with different priorities: anytime (green) , peak power (yellow), emergency only (red) and never (black). This can provide to a scheduler a basic understanding of the importance appliances cover in user's activities. The key enabler technology for appliance classification is the already mentioned non-intrusive appliance load monitoring (i.e., NILM [Zei11]), as the system will have to deal with mobile devices, which can be dynamically moved and re-plugged at a different position.

- **User identification:** User identification is necessary to unambiguously distinguish the user from other sources and consumers of events in a smart environment. Indeed, the collection of events from the interaxction with the user is required to model human behaviour and use inferred information to offer tailored services. Whilst identification can be achieved by carrying a badge [Wan92], an RFID [Phi04, Sti08, Pat05] or using cameras [Zuo05], it should be unobtrusive for the user, and provide full control of the information exposed. The high penetration of smartphones could provide a flexible means for interacting with smart devices. The possibility of accessing an interface-less ecosystem of digital appliances is, in essence, centralizing what today is a distributed interface. This would provide users with a uniform interface to access devices, as currently they are exposed to features in different ways and need a learning period before being ready to user services.

- **Hard vs. Soft policy:** A distinction on the interaction modality is necessary. In presence of a hard policy, the user is required to access the outlet to which the appliance is connected in order to enable and use it. The user is allowed to power his appliance only if there is enough credit left for the device. Therefore, he will be prevented to use the appliance as long as his credit is not sufficient. On the other hand, a soft policy considers that blocking the user's will can be too obtrusive. Rather than blocking the operation of the device, in presence of a soft policy the user can still use the appliance, and get informed when the credit runs over. This policy allows for boosting user's energy awareness by keeping track of his consumption and expenses, while keeping intrusiveness low.

- **Awareness levels:** People might present different cognitive abilities and skills. Permission categories are indeed necessary, because the user might otherwise decide to add new credit on the device to get rid of limitations placed under the mentioned policies. Administrators should therefore be able to select the kind of policy adopted for certain users along with the possibility to get their credit increased. In the energy context, a typical example might be children spending their portion of demand for playing video games. Since they might not be as aware as their parents, the presence of a wallet tracking the way they use their energy can support their parents in limiting the time spent playing video games. In addition, the presence of a monetary value required to operate appliances would prevent them from playing video games for the whole day, as they would run out of credit for this specific category of devices.

3.5.2 The Monergy advisor

In [Mon13a] we proposed a basic implementation of the system. The system consists of three main components (Fig.3.7):

- **A measurement infrastructure** collecting consumption data at appliance level;
- **A cloud-based web service** managing the billing mechanism and producing analytics;
- **A mobile application** providing a centralized interface for appliances and notifing users for credit.

3.5.2.1 Measurement infrastructure

As already mentioned in 3.5.1, a prepaid billing system down to the appliance level requires continuous monitoring of appliance level energy consumption. For the absence of standardised smart appliances to use outside laboratory settings we decided to use an off-the-shelf smart plug solution.

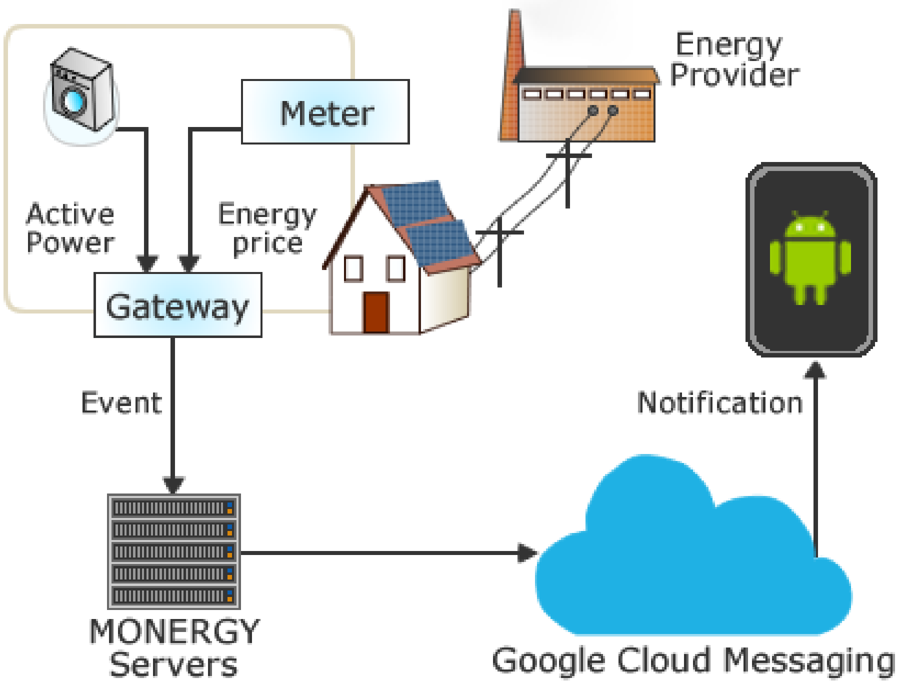


Figure 3.7: The architecture

In our first version proposed in [Mon13a] we used the OpenEnergyMonitor[3] platform to collect active power measurements. The platform is an open source and open hardware energy monitoring solution. We employed a raspberry Pi as a gateway, to gather the samples and detect operational events, associate them to situational information (i.e. time, event consumption and tariff) and send them to a cloud-based webservice running on the Google App Engine infrastructure. However, the presence of inaccuracy on the measurement inputs and the need of relays to implement the hard policy (see 3.5.1) convinced us to select a different alternative. The Plugwise[4] platform consists in a Zigbee network of outlets, collecting active power measurements from the connected load. The wireless network can be contacted via a provided usb stick. The system comes along with *Source*, a private software to sense and control devices. However, due to the scarce openess and support we opted for the *python-plugwise*[5] library, an open-source im-

[3]http://openenergymonitor.org
[4]http://www.plugwise.com/
[5]https://bitbucket.org/hadara/python-plugwise/wiki/Home

(a) Gateway

(b) Measurement units

Figure 3.8: The measurement platform shown in this Figure consisting of a Raspberry Pi with a ZigBee dongle and the Plugwise metering plugs

plementation of the plugwise protocol. In this way, we are able to interact with the network from any operating system.

In our deployment, we implemented the gateway functionalities on a Raspberry Pi and we used the Plugwise Basic kit[6], which consists of 9 sensing nodes. In particular, our daemon[7] collects active power samples from the nodes and uses a pool of appliance models (described by power levels) to detect on/off events. This requires models of the devices to be deployed as a configuration file, along with other settings such as the sampling frequency and the duration of the epoch. We call the collection of samples from all node an epoch. Tests with the platform showed that in the best case all samples can be retrieved from the nine distributed nodes in less than a second. However, the lack of dependability in the power value retrieved from the node and the occasional presence of timeouts required the implementation of a retrial mechanism. The daemon runs an epoch by collecting power measurements for each node and concludes it by sleeping for the remaining time, specified as input. In presence of mispelled packets, the node is skipped and all left behind are retried only in case the time is enough to ensure a homogenous granularity between the epochs. In addition, timeouts are managed through a blacklist. As timeouts can result from a temporary erroneous status or disconnection of the node from the network (i.e., when unplugged), a back-off time is necessary to avoid delays in the epochs. Therefore, nodes are blacklisted to prevent the daemon from delaying the epoch, until they become newly available. The mechanism is implemented using timers, so that nodes can be automatically removed from the blacklist when expiation is conclused.

Once the status of the devices is detected and the event concluded, the event is described as its starting time, duration, energy used and current tariff under which the device was operated. The energy consumption for the event is given by the lenght of time interval multiplied to the average power of the samples, which is computed progressively between consecutive samples. As shown in Fig. 3.7, the time and the price signal are received from outside the home network. In particular, we used the network time protocol (NTP) to retrieve time from a reliable source. On the other hand, the price signal can be read on the Smart meter, when present, or updated from a remote server in case the utility exposes this information. Whilst adaptive pricing is not yet available for Austria, the rollout of smart meters in Italy made the exploitation of time-dependent tariffs possible. For our purposes, it is implemented as a separated configuration file, reporting tariffs in terms of time interval and cost.

The events are collected in a time window and finally sent to a web service running at our premises. The webservice exposes all functionalities

[6]https://shop.plugwise.com/consumers/packages/home-basic

[7]The daemon is freely available at http://sourceforge.net/projects/monergy/

through a REST API, and it uses a token to authenticate requests. Upon reception of samples, the server decreases the credit according to the given energy used and the cost under which the appliance was operated.

3.5.2.2 The web interface

The cloud-based application[8] runs on the Google App Engine[9] infrastructure, which manages the prepaid billing mechanism and offers basic analytics. In particular, it displays the user's wallet and all his domestic activities and their cost on a timeline (Fig.3.9). For the purpose, we used the template engine Jinja2, as well as the Google chart[10] and Chap links[11] chart libraries. All of the functionalities are exposed through a representational state transfer (REST) application programming interface (API), using a javascript simple object notation (JSON) protocol and a token to authenticate requests.

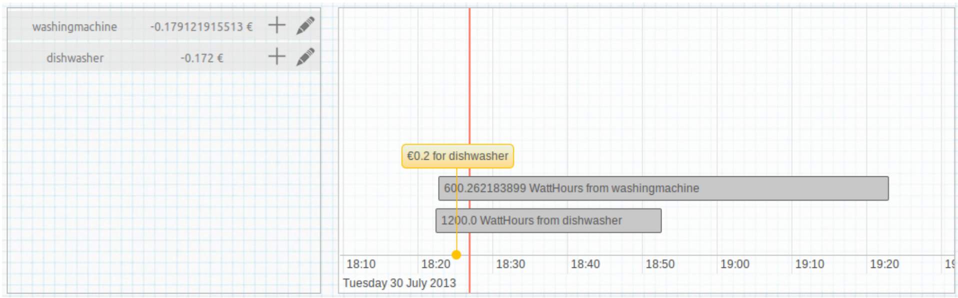
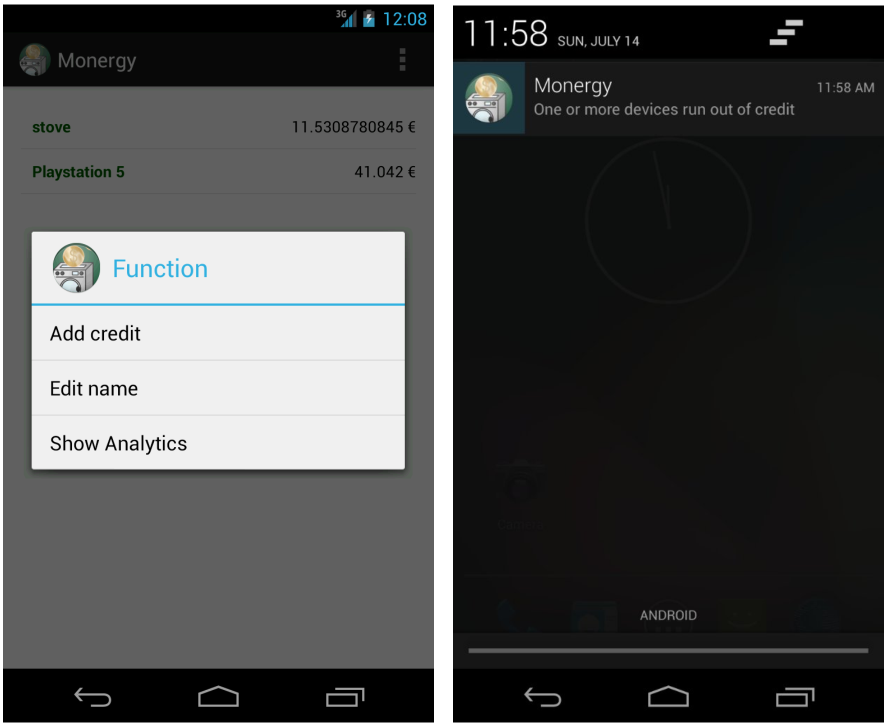


Figure 3.9: The timeline view

3.5.2.3 The smart notification system

An android application[12] was implemented to allow users to manage their appliances. In particular, users can display the credit left on each device, increase it, display the last additions and the history of operations, as well as rename the device (Fig. 3.10). Beside offering a quick gateway to the system functionalities, the application provides a smart notification mechanism, by which the terminals are notified upon the credit gets over. The Google Cloud messaging infrastructure was used to notify push messages triggered by our web service. In this way, mobile terminals running our application can receive notifications while keeping low battery use and network communication.

[8]http://intelligentenergyadvisor.appspot.com
[9]https://appengine.google.com/
[10]https://developers.google.com/chart/
[11]http://almende.github.io/chap-links-library/timeline.html
[12]https://play.google.com/store/apps/details?id=at.aau.monergyapp



(a) The appliance list (b) Notification system

Figure 3.10: The Android application

Conclusions

This deliverable elaborated the aspects related to communication systems, interoperability, energy measurement, and user interfaces in the context of the MONERGY project. There are several possible solutions for networking devices in an EMS. With the Monergy network architecture, we propose a solution that integrates different networking solutions in different subnetworks into a home gateway, where the functional logic for the EMS is located. We examined different smart plug types as possible measurement nodes in such a system. A cost-efficient solution is presented by using commercial-off-the-shelf smart plugs together with a Raspberry Pi platform acting as gateway. The main part of this document elaborated on the user interface advising the resident about the household's energy consumption and possible advisory strategies. The results of this deliverable lay the ground for further research activity to be carried out in the upcoming work packages of the MONERGY project. In particular:

- In WP4, we will focus on the hardware architecture. Robust communication network protocols exploiting both wireline and wireless technologies will be studied. The goal is the realization of a validation test bed comprising smart plugs, a data exchange network and a control software that will enable a real life monitoring campaign.

- In WP5, in order to get feedback on the applicability of the elaborated concepts, laboratory validation and real world testing will be carried out. The data from the monitoring campaign will be elaborated so that energy usage models and energy management strategies can be devised aiming a rational and efficient use of energy.

Bibliography

[Alb07] M. H. Albadi and E. El-Saadany. Demand Response in Electricity Markets: An Overview. In *Power Engineering Society General Meeting, 2007. IEEE*, pages 1–5, 2007.

[Ber12] L. D. Bert, S. D'Alessandro, and A. M. Tonello. An Interconnection Approach and Performance Tests for In-home PLC Networks. In *Proc. of IEEE Int. Symp. on Power Line Commun. and its App.*, Bejing, China, March 2012.

[CA13] K. Carrie Armel, A. Gupta, G. Shrimali, and A. Albert. Is disaggregation the holy grail of energy efficiency? The case of electricity. *Energy Policy*, 52(C):213–234, 2013.

[Dar06] S. Darby. The effectiveness of feedback on energy consumption: a review for DEFRA of the literature on metering, billing and direct displays. Technical report, Environmental Change Institute, University of Oxford, 2006.

[Dig07] Digi International. *Digi Python Programming Guide*, 2007.

[Ega13a] D. Egarter, V. P. Bhuvana, and W. Elmenreich. Appliance State Estimation Based on Particle Filtering. In *Proceedings of the 5th ACM Workshop on Embedded Systems For Energy-Efficient Buildings*, BuildSys'13, New York, NY, USA, 2013. ACM.

[Ega13b] D. Egarter, A. Sobe, and W. Elmenreich. Evolving Non-Intrusive Load Monitoring. In *Proceedings of 16th European Conference on the Applications of Evolutionary Computation*, Vienna, Austria, 2013. Springer.

[Elm12] W. Elmenreich and D. Egarter. Design guidelines for smart appliances. In *Proceedings of the Tenth Workshop on Intelligent Solutions in Embedded Systems (WISES)*, pages 76 –82, 2012.

[Els06] D. Elshani and P. Francq. The Anatomy of a Universal Domotics Integrator for Globally Interconnected Devices. In *Proc. of Int. Conf. on Pervasive Systems & Computing*, pages 17–23, June 2006.

[EM10] K. Erhardt-Martinez, K. Donnelly, and J. A. S. Laitner. Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities. Technical report, American Council for an Energy-Efficient Economy, Washington, D.C., 2010.

[ERD09] ERDF. *PLC G3 Physical Layer Specification*, 2009.

[eu2]

[Fer10] H. C. Ferreira, L. Lampe, J. Newbury, and T. G. Swart. *Power Line Communications: Theory and Applications for Narrowband and Broadband Communications over Power Lines*. Wiley & Sons, NY, 2010.

[Gom10] C. Gomez and J. Paradells. Wireless Home Automation Networks: A Survey of Architectures and Technologies. 48(6):92–101, June 2010.

[Hom05] HomePlug Powerline Alliance. *HomePlug AV White Paper*, 2005.

[IEE10] IEEE. *IEEE Std 1901-2010, IEEE Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications*, 2010.

[Lab13] L. Labs and WiTiKee. Monergy Technical Report: Definition of Requirements and System Architecture, September 2013.

[Lam11] L. Lampe, A. Tonello, and D. Shaver. Power Line Communications for Automation Networks and Smart Grid. 49(12):26–27, Dec. 2011.

[Lax06] S. Laxman and P. Sastry. A survey of temporal data mining. *Sadhana*, 31(2):173–198, 2006.

[Liu13] T. Liu, X. Ding, S. Lindtner, T. Lu, and N. Gu. The collective infrastructural work of electricity: exploring feedback in a prepaid university dorm in China. In *Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing*, UbiComp '13, pages 295–304, New York, NY, USA, 2013. ACM.

[Mio06] V. Miori, L. Tarrini, M. Manca, and G. Tolomei. An Open Standard Solution for Domotic Interoperability. 52(1):97–103, Feb. 2006.

[Mon13a] A. Monacchi and W. Elmenreich. Insert-coin: turning the household into a prepaid billing system. In *Proceedings of the 5th ACM Workshop on Embedded Systems For Energy-Efficient Buildings*, BuildSys'13, pages 26:1–26:2, New York, NY, USA, 2013. ACM.

[Mon13b] A. Monacchi, W. Elmenreich, S. D'Alessandro, and A. M. Tonello. Strategies for energy conservation in Carinthia and Friuli-Venezia Giulia. In *Proc. of the 39th Annual Conference of the IEEE Industrial Electronics Society*, Vienna, Austria, 2013.

[Oks11] V. Oksman and J. Zhang. G.HNEM: the New ITU-T Standard on Narrowband PLC Technology. 49(12):36–44, Dec. 2011.

[Ozo13] M. Ozog. The Effect of Prepayment on Energy Use. Technical report, DEFG LLC, Washington DC, March 2013.

[Pat05] D. Patterson, D. Fox, H. Kautz, and M. Philipose. Fine-grained activity recognition by aggregating abstract object usage. In *Wearable Computers, 2005. Proceedings. Ninth IEEE International Symposium on*, pages 44–51, 2005.

[Phi04] M. Philipose, K. P. Fishkin, M. Perkowitz, D. J. Patterson, D. Fox, H. Kautz, and D. Hahnel. Inferring Activities from Interactions with Objects. *IEEE Pervasive Computing*, 3(4):50–57, Oct. 2004.

[Pik12] Pikkerton Gmbh. *Manual ZBS Devices*, 2012.

[PRI11] PRIME Alliance Technical Working Group. *Draft Specification for PoweRline Intelligent Metering Evolution V1.3.6*, 2011.

[Ran10] V. V. Ranade and J. Beal. Distributed Control for Small Customer Energy Demand Management. In *Fourth IEEE International Conference on Self-Adaptive and Self-Organizing Systems, SASO 2010, Budapest, Hungary*, pages 11–20. IEEE Computer Society, 2010.

[Sti08] M. Stikic, T. Huynh, K. Van Laerhoven, and B. Schiele. ADL recognition based on the combination of RFID and accelerometer sensing. In *Pervasive Computing Technologies for Healthcare, 2008. PervasiveHealth 2008. Second International Conference on*, pages 258–263, 2008.

[Tom09] S. Tompros, N. Mouratidis, M. Fraaijer, A. Foglar, and H. Hrasnica. Enabling Applicability of Energy Saving Applications on the Appliances of the Home Environment. *IEEE Network*, 23(6):8–16, Nov. 2009.

[Wan92] R. Want, A. Hopper, V. Falcão, and J. Gibbons. The active badge location system. *ACM Trans. Inf. Syst.*, 10(1):91–102, Jan. 1992.

[Wol09] S. Wolff, P. G. Larsen, K. Lausdahl, A. Ribeiro, and T. S. Toftegaard. Facilitating Home Automation Through Wireless Protocol Interoperability. In *Proc. of Int. Sym. on Wireless Personal Multimedia Commun.*, Sep. 2009.

[Zab11] A. Zaballos, A. Vallejo, and J. Selga. Heterogeneous Communication Architecture for the Smart Grid. 25(5):30–37, Sep. 2011.

[Zei11] M. Zeifman and K. Roth. Nonintrusive appliance load monitoring: Review and outlook. *IEEE Transactions on Consumer Electronics*, 57(1):76 –84, 2011.

[Zuo05] F. Zuo and P. H. de With. Real-time embedded face recognition for smart home. *IEEE Trans. on Consum. Electron.*, 51(1):183–190, Feb. 2005.