MONERGY: ICT solutions for energy saving in Smart Homes

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Technical Report

Definition of Requirements and System Architecture

Anforderungskatalog und Definition der Systemarchitektur
Definizione dei Requisiti e dell'Architettura di Sistema

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Abstract

This deliverable provides the results of the work carried out within the WP2 of the MONERGY project. In particular, the requirements and the system architecture of the domestic energy management system that will be tailored to households located in the regions of Carinthia (Austria) and Friuli Venezia Giulia (Italy) are presented. These are derived from the study of the results of a web survey which has been conceived with the aim of pointing out differences, in terms of energy usage, between the residents of the two regions. Furthermore, energy conservation strategies are discussed.

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 Friuli Venezia Giulia and Carinthia regions.

Within MONERGY, the objectives of WP2 are:

- To characterize the scenarios, and more specifically the appliances, for which the use of the smart plugs provides benefits in terms of reduction of the power consumption. Therefore, to provide an insight on the energy consumptions in Friuli Venezia Giulia and Carinthia houses.
- To set the requirements of both hardware and software for the energy management system.
- To list the gaps of existing solutions used for energy management systems, so to enable fundamental research activity in WP3 and WP4 concerning the study of solutions that go beyond the state-of-the-art of the commercially-available technologies.

Executive summary

This deliverable gives a state-of-the-art of the communication systems and applications developed for domestic energy management systems. Furthermore, it defines the requirements and the system architecture of the energy management system that will be developed within the MONERGY project, in particular under the following points of view:

- **Energy consumption scenarios in Carinthia and Friuli-Venezia Giulia** - Differences in terms of electrical devices used and renewable energy sources exploited are reported.
- **Home energy management systems** - The aspects related to the communication network and the data infrastructure of this kind of systems, encompassing interoperability issues deriving from the integration of heterogeneous devices are discussed.
- **Energy conservation strategies** - Energy conservation strategies suitable for both regions are proposed.

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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

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

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

SOHO small office home office

TV television

WG working group

WLAN wireless local area network

Section 1

Introduction

The progressive installation of 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 progressively participating 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 them in a way that most of the benefits can be made out of it. In particular, as human environments are ecosystems of heterogeneous digital devices, a holistic view on energy awareness is needed. This requires providing interoperability among different devices, as well as standardised interfaces and processes to handle information. In addition, consumption information is required to be processed in order to represent valuable information that can enhance decision making. To this end, in this deliverable, we will discuss the requirements of a whole energy management system (EMS) able to collect and process the consumption information as well as to report them to residents so to affect the use of electrical devices.

Within the MONERGY project, our specific focus and interest is on the regions of Carinthia (CAR) and Friuli Venezia Giulia (FVG). We will therefore tailor our research to the peculiarities of these regions with the aim to provide a valuable mean to improve the sustainability.

The organization of the work is as follows. In Section 2, we report the results of the analysis of a web survey that we carried out in our regions to find differences and similarities in the use of energy. In Section 3, we discuss the requirements for the communication network and the data infrastructure behind our EMS. In particular, we focus on communication aspects, as well as interoperability issues involving devices and data. In Section 4, we report existing strategies in promoting energy conservation and formulate specific solutions that are suitable for both regions. Finally, the conclusions together with the vision and the future work follow in Section 5.

Section 2

Energy usage scenarios in Carinthia and Friuli-V.G.

In this chapter, we present the results of a web survey that we carried out within the MONERGY project.

The starting point of our study is that when planning energy conservation strategies, it is necessary to consider commonalities and differences in scenarios and lifestyles which migh affect the overall energy profile of households. To this end, we carried out an analysis of typical scenarios in CAR and FVG regions, described by the energy greedy appliances, namely those that are most responsible for energy consumption and characteristic patterns of energy use.

The study was presented in [Mon13b] and it is based on the following research questions:

- **Is there difference in the amount and type of electrical devices used in the two regions?** We expect households in Friuli to exploit the presence of a more diffuse gas distribution network rather than electricity. We test this hypothesis by checking differences in terms of energy-greedy devices, such as the ones used for space and water heating, as well as cooking.

- **Is there difference in the diffusion of renewable energy sources between the two regions?** We answer this question by analyzing the number of households exploiting renewable energy for production of electricity, as well as space and water heating.

2.1 Research methodology

In order to outline typical scenarios in the two regions we conducted a small survey study on our project website. In particular, we addressed aspects such as the characteristics of households, type of electrical devices used and occupant behavior. We targeted the study to people older than 18 living in the regions, and offered the survey in Italian and German language. The study was advertised using mailing lists of families, universities and companies across the regions. Therefore, we had people invited to participate rather than selected using random sampling. This implies a certain self-selection bias on the data, but allows us to get sufficient data for analysis and discover possible patterns [Laz10, Bet10].

The validity of collected responses is also determined by demographic data (Table 2.1). Moreover, to cross check critical aspects we duplicated certain questions and placed them in the survey with different phrasings. Also, we ensured anonymity and that each respondent could only participate once. The survey required about 15 minutes to be completed and consisted

Table 2.1: Respondents

Occupant Variable	**Carinthia**	**Friuli-V.G.**
Age 18 - 35	37.1%	59.71%
Age 36 - 45	29.57%	17.27%
Age 46 - 65	31.18%	20.14%
Age > 65	2.15%	2.88%
Primary school	0%	0%
Secondary school	1.61%	3.60%
High school	23.66%	33.81%
Bachelor's degree	4.84%	7.19%
Master's degree	35.48%	38.13%
PhD	29.03%	14.39%
Other	5.38%	2.88%

of 43 questions grouped in 5 different sections:

1. Household information
2. Use of electric devices
3. Sensitivity towards energy consumption and renewable energy generation
4. Sensitivity and expectations towards technology
5. Demographic information

We collected 340 full responses out of 397 participants, with an overall completion rate of 85.64%. In particular, we received 186 responses from Carinthia (96 female and 90 male) and 139 from Friuli-Venezia Giulia (63 female and 76 male). After collecting the data, we screened the dataset to remove anomalies that might compromise the analysis. Although we had defined constraints on the fields to be manually entered by users, it was necessary to cross check them and fix errors when needed, or to treat them as missing values when not possible.

2.2 Scenarios in the regions

In this section, we provide a summary of the main findings of the study. The appendix gives a complete view of the dataset.

2.2.1 Energy-greedy devices

A first important result of the survey is that the use of electrical devices is higher in CAR than in FVG. Whilst this difference is apparent for energy-greedy devices, such as hobs (Table 2.2), heaters (Table 2.3) and boilers (Table 2.4), this is less apparent for consumer electronics and laundry equipment (Table 2.6 and 2.5). Indeed, the more developed gas distribution network in Friuli results in a greater proportion of residents using gas-powered devices, which makes their electric counterpart less popular. On the contrary, in urban areas of Carinthia the presence of distric heating can mitigate the cost of space heating. Table 2.3 shows that the air conditioning is more used in FVG (45.19%) than in CAR (2.16%). Furthermore, the use of air conditioning is more frequent in FVG. Clearly, the higher amount of cooling units in Friuli depends on a warmer climate.

Table 2.2: Kitchen devices

Device	**Carinthia**	**Friuli-V.G.**
Hood	69.89%	82.73%
Dishwasher	84.95%	68.35%
Hob	98.92%	82.73%
Oven	95.70%	95.68%
Microwave oven	60.75%	61.15%
Fridge	98.92%	99.28%
Freezer	40.86%	27.34%
Electric hob	98.37%	5.22%
Electric oven	100%	87.97%

To observe differences in terms of energy-greedy devices, we collected information related to the types of appliances used for:

- Water heating (presence of an electric boiler)
- Space heating (use of electric heaters)
- Space cooling (use of air conditioners)

Table 2.3: Space heating and cooling

Device	Carinthia	Friuli-V.G.
Electric heaters / pumps	10.22%	6.47%
Gas	9.14%	63.31%
Oil	21.51%	8.63%
Wood	11.29%	14.39%
Pellet	7.53%	3.60%
Coal	0%	0%
District heating	30.65%	0%
Solar plant	2.69%	2.88%
Geothermal plant	6.99%	0%
Air conditioner	2.16%	45.19%
Number of units	Mdn=1, IQR=1-1.25	M=2, IQR=1-2
Frequency of use	Mdn=2, IQR=1.75-2.25	Mdn=2, IQR=1-3

Table 2.4: Water heating

Device	Carinthia	Friuli-V.G.
Electric boiler	41.40%	12.23%
Gas	6.99%	82.01%
Oil	22.04%	6.47%
Wood	6.45%	2.88%
Pellet	6.45%	0.72%
Coal	0%	0%
District heating	17.74%	0%
Solar plant	15.59%	12.95%
Geothermal plant	7.53%	0%
Number of boilers	Mdn=1, IQR=1-2	Mdn=1, IQR=1-1

- Cooking facilities (presence of an electric hob and an electric oven)

Because it was not possible to quantify the use of devices, we compared the regions according to whether these devices are used. In particular, we ran a one- and two-tailed Wilcoxon U test. We first tested the null hypothesis that the observations collected on the two regions mean the same distribution. We then tested if the number of greedy devices in Friuli is greater than Carinthia. The null hypothesis was rejected in both cases with a $p < 0.05$ (Fig. 2.1). The variety of energy-greedy devices used in Carinthia is therefore higher than in Friuli. Although this can represent higher energy saving potential for Carinthia, the absence of smart meters and time-dependent tariffs does not allow for the exploitation of demand-response strategies.

Table 2.5: Laundry equipment

Variable	Carinthia	Friuli-V.G.
Laundry frequency (monthly)	Mdn=8, IQR=4-12.75	Mdn=8, IQR=5-17
Washing machine	92.47%	87.05%
Dryer	27.96%	5.76%
Washing machine with dryer	4.84%	7.91%
Iron	74.73%	76.98%

Table 2.6: Consumer electronics

Variable	Carinthia	Friuli-V.G.
TV	85.48%	89.21%
DVD/BlueRay player	69.35%	69.78%
Home Theater	7.53%	12.95%
Game console	34.41%	28.06%
HiFi stereo	63.44%	53.96%
Cordless phone	31.72%	66.91%
Computer	96.24%	97.84%
Printer and/or Scanner	73.12%	79.86%

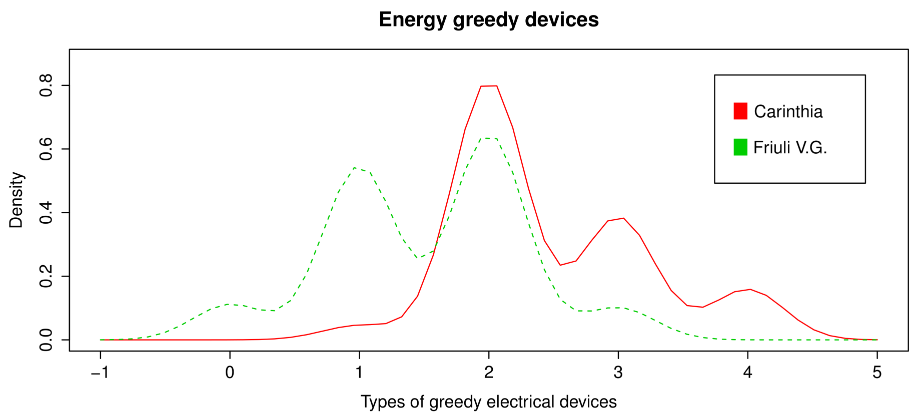

Figure 2.1: Density plot for the types of greedy devices

2.2.2 Presence of a smart metering infrastructure

A further difference between the regions is given by the availability of time-based tariffs in FVG (see Table 2.7). The results reported in the table make perfectly sense, as Italy has already completed the rollout of smart meters. This offers italian households the possibility to exploit time-dependent tariff plans, such as day/night and weekdays/weekend periods. Such features are – at this time – not available in CAR. Nevertheless, we notice that in

CAR the results of the survey show the presence in certain households of a night meter, that is, households can use a different meter to charge the energy consumed by the electric boiler under a cheaper tariff. This provides a means for mitigating water heating costs, although it does not provide any room for demand response strategies since the boiler is the only device that is allowed to run overnight.

Table 2.7: Presence of a smart metering infrastructure

	Carinthia	**Friuli-V.G.**
Time-dependent tariff	16.67%	78.42%
Tariff used for	Electric boiler (10.75%)	Wash. machine (62.59%)
		lights, iron, conditioner,...
Would use tariff for	Wash.machine (48%)	
	Boiler (23%), Drier (20%)	

2.2.3 Sensitivity towards sustainable living

According to the survey (Table 2.7), Carinthians expressed the willingness to exploit dynamic tariffs for operating the washing machine (48%), the electrical boiler (23%), and the dryier (20%). The 67.20% of users from Carinthia declared to have replaced an electrical device during the last 4 years to reduce the consumption at home (Table 2.8). Among those, energy-efficient light bulbs (51%), washing machines (32%), televisions (19.89%), electrical hobs (15%), refrigerators (13.44%) and dryers (9.14%) account for most of replacements. On the contrary, households of Friuli usually can exploit multiple pricing conditions. Users declared to already consider the current cost of electricity when using their washing machine (62.59%), lights (24.46%), iron (22.3%), electric oven (21.58%), dryer (10.79%), conditioner (10.07%) and dishwasher (9.35%). Similarly to Carinthia, lights (38.85%), washing machines (17.99%) and televisions (9.35%) are the most replaced devices.

Table 2.8: Sensitivity towards sustainable living

	Carinthia	**Friuli-V.G.**
Replaced in last 4 years	67.20%	41.73%
Devices replaced	Light bulbs (51%)	Light bulbs (38.85%)
	Washing machine (32%)	Washing machine (17.99%)
	TV (19.89%), Hob (15%)	TV (9.35%)

2.2.4 Exploitation of renewable energy sources

As shown in [Mon13b], to observe the different penetration in exploitation of renewable energy sources, we counted the number of renewable sources exploited per household. In the survey, we asked for the presence of: photovoltaic plants, solar thermal plants, geothermal plants and wind energy plants. We then ran a Wilcoxon U test with a confidence level of 95%. The null hypothesis that the observations are drawn from the same distribution was accepted with $p = 0.96$ (i.e. $p > 0.05$). Fig. 2.2 reports the density plot for the two distributions. We noticed a very low penetration of geothermal

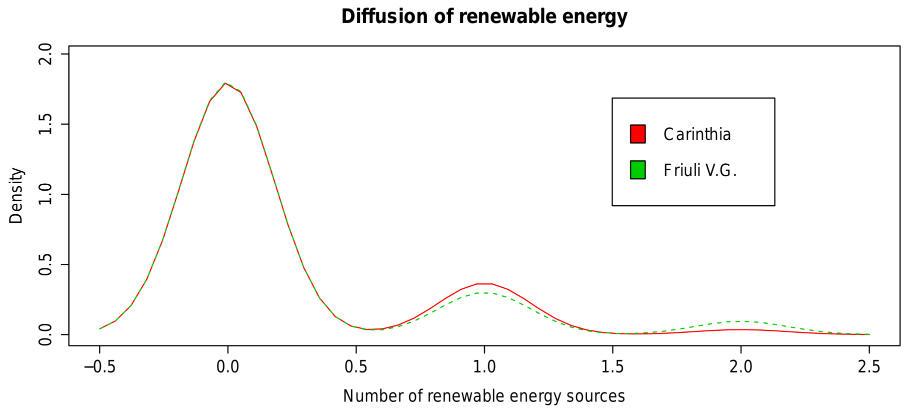

Figure 2.2: Density plot for the number of exploited renewable energy sources.

heating, with just a person per region declaring to use it at home. Moreover, it is interesting to notice that in Friuli the number of photovoltaic plants is higher than Carinthia, with 7.91% and 2.69% respectively. However, the situation is opposite when looking at the solar-thermal heating, accounting for the 16.67% in Carinthia and 13.67% in Friuli.

2.2.5 Sensitivity towards Smart Home technology

Table 2.9 shows the penetration of home automation (HA) in the regions. Interestingly, only a small portion of residents is aware of or even owns a building automation system. The 28.49% in Carinthia and the 20.14% in Friuli declared not to even know what the term home automation means. This spots a clear necessity of knowledge dissemination activities in the regions, along with a clearer identification of the benefits arising from the use of these technologies. Nevertheless, most of users declared to be willing to install this kind of systems for displaying consumption information and increasing energy awareness. In particular, most of users expressed the preference for displaying such information on mobile terminals rather than on in-home displays.

Table 2.9: Sensitivity towards smart home technology

	Carinthia	**Friuli-V.G.**
Is aware of HA systems	33.33%	37.41%
Owns a HA system	3.23%	3.85%
Wishes energy awareness	73.12%	79.86%
In-home display	26.47%	46.85%
Web/mobile app	68.38%	52.25%
Other means	5.15%	0.9%

Section 3

Home energy management systems

In the previous section, we have seen that there are differences in the energy usage between people from CAR and FVG. In particular, the analysis of the survey results (see §2) revealed that:

- In FVG, the higher diffusion of gas affects the kind of appliances used for cooking, as well as space and water heating.
- The use of electric boilers, hobs and ovens is noticeable in CAR, while less remarkable in FVG.
- Due to climate differences, air conditioning is extensively adopted in FVG and rarely in CAR.
- The use of consumable electronics is very similar in the two regions.
- More than the 50% of participants from both regions has replaced appliances to reduce the energy consumption.
- Renewable energy sources are more deployed in FVG than in CAR, although their adoption is small, 8% in FVG and 3% in CAR.
- The deployment of smart meters enabled people from FVG to exploit tariff plans which vary during the day and the week.
- In CAR, certain households can exploit a night meter to charge the electric boiler for a cheaper rate.

From the previous observations, it can be noticed that differences affect the way residents of the two regions use energy at home. Therefore, the effective implementation of energy conservation strategies requires the derivation of energy usage profiles, and thus it is necessary to collect events of user's activities in his living environment. To this end, in this section, we discuss the design of a energy management system (EMS) tailored for the two considered regions. In particular, we focus on the communication network aspects such as coverage, topology, number of nodes, metering resolution and communication technologies. Furthermore, we make considerations on the data infrastructure, i.e., the software architecture needed to provide data interoperability in the smart grid (SG) context.

3.1 The communication network

The first step to realize the EMS is to design the communication network. To this end, we need to define:

- The coverage.
- The topology.
- The number of nodes.
- The metering resolution, and thus the data traffic.
- The communication technologies to be employed.

3.1.1 Coverage

In order to derive the network coverage we need to analyze the characteristics of the households. Table 3.1 reports the answers to the questions of the survey related to the type of house and their dimension. Furthermore, Fig. 3.1 shows the cumulative distribution function (CDF) of the number of floors for the different types of considered houses. As we can see, the maximum number of floors is 4 in most cases. The only exception is given by the flats, where we can assume a misunderstanding in the 8% of users, who indicated to live in a flat with more than 4 floors. We therefore limit the maximum number of floors to 4.

Fig. 3.2 shows the dimension of the houses gathered according to the number of floors. As we can see, there are houses whose dimension is greater than 100 m^2 for all the considered number of floors, i.e., 1-4.

From the previous results, we can state that the EMS has to offer a network coverage of at least 100 m^2 per single floor and up to 4 floors.

Table 3.1: Household information

Dwelling Variable	**CAR** [%]	**FVG** [%]
Flat in block of flats	47.31	49.64
Semi-detached house	40.86	12.95
Detached house	8.60	32.25
Other	3.23	2.16
$<$ 30 sm	1.62	2.16
30 - 64 sm	11.29	12.23
65 - 100 sm	34.41	43.17
$>$ 100 sm	52.69	42.45

3.1.2 Network topology

As explained in [CA13], the greatest benefits in terms of energy savings in domestic environments are obtained when real-time information down to the appliance level is displayed. To this end, two opposite approaches can be followed. The first is to connect each appliance to a power meter with a communication interface, e.g., a smart plug. The second is to use disaggregation algorithms [Ega13],[CA13] to identify appliances and derive their energy consumption out of the overall metering data (more details are given in §3.1.4). Although disaggregation can replace multiple sensing units, we decided to focus on the first approach since the use of smart plugs is usually preferred because it gives the possibility to control (switch on/off) individual appliances and it also allows for decomposing the disaggregation problem to smaller groups of devices. Beside the use of smart plugs, we decided to adopt a home gateway (HG) as a central point to locate the logic of the EMS. In particular, the HG will be responsible of collecting data from meters and process them so that users can visualize information according to one or more of the strategies that will be presented in § 4. The choice of using a HG as central point for the EMS has several benefits among which [Tom09]:

- The reduction of the computational capability of the smart plugs and thus of the cost of the whole EMS.
- The possibility to integrate different communication technologies (see §3.1.5).
- Remote access for the users through Internet connectivity, and further, the possibility to exchange data with the energy service provider through Internet or through private networks, e.g., to receive real time energy pricing.

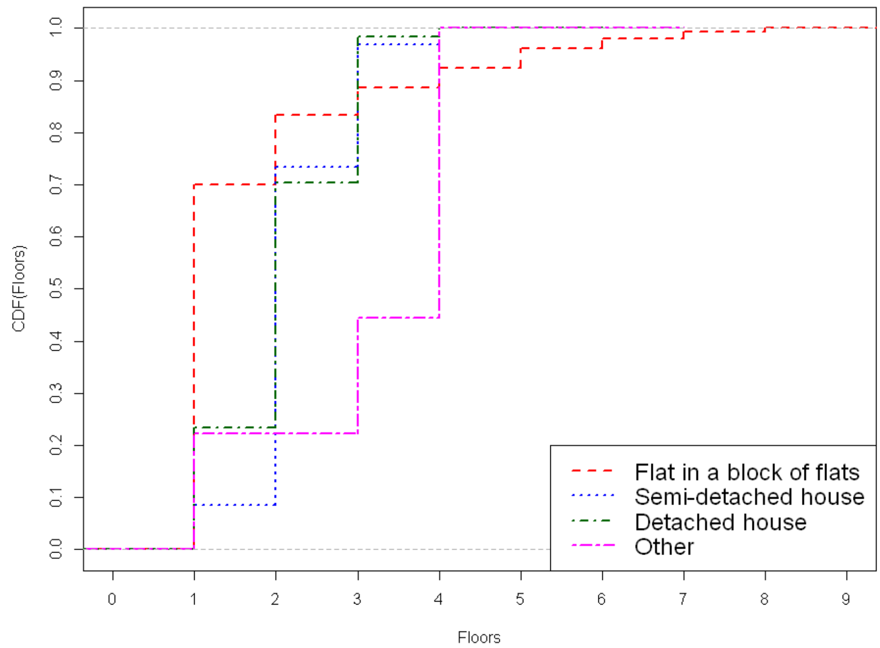

Figure 3.1: CDF of the number of floors for the different type of houses.

3.1.3 Number of nodes

The number of nodes sharing the same communication channel is an important parameter to consider. It affects the network performance, as an increase in number of nodes leads to worse throughput, delay, interference, and robustness. To derive this parameter we need: i) the number of smart plugs per household, namely the number of nodes per logical network; ii) the number of interferers. The latter represents the nodes belonging to other logical networks that use the same communication technology, or nodes using different communication technologies.

In order to compute the number of smart plugs per household, we consider the electric appliances listed by the users in the survey (see Table 3.2). Furthermore, we approximate the number of smart plugs per household by assuming one of them for each of the following appliances: washing machine, dryer, washing machine with dryer, hood, dishwasher, fridge, freezer, electric hob, electric oven, pellet boiler, air conditioner, a group given by TV/home theater/DVD/video games, hi-fi, a group given by computer/scanner/printer, cordless phone, modem, photovoltaic plant. In addition, we assume to collect the consumption of lights using a centralized sensor, such as a current clamp, for each floor. This is a plausible assumption since in both regions a

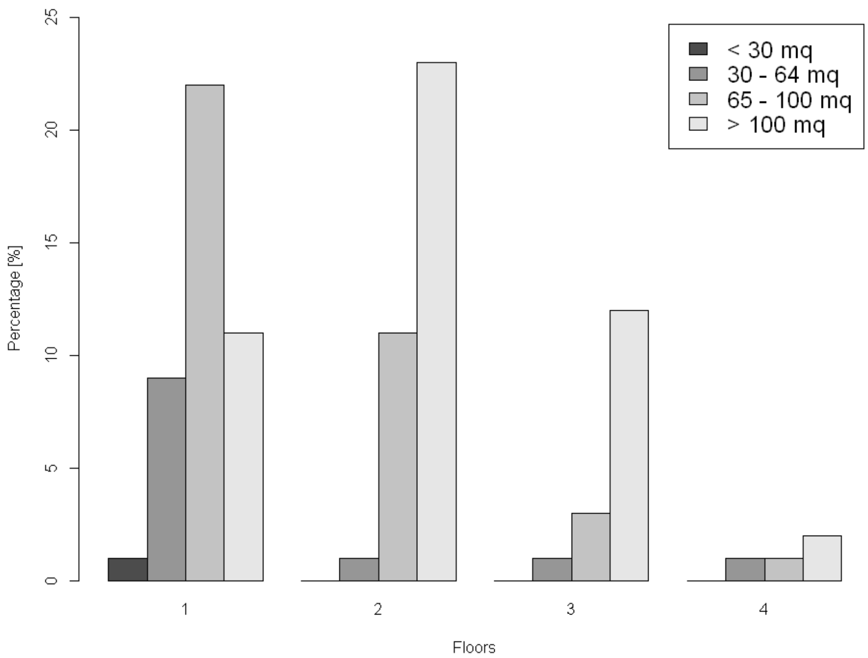

Figure 3.2: Percentage of the dimension of the houses gathered according to the number of floors.

single residual current circuit breaker (RCCB) usually feeds the light circuit of each floor. Fig. 3.3 shows the CDF of the number of estimated smart plugs per house for FVG and CAR. As we can see, surprisingly the behaviors are very similar and the maximum number of plugs is equal to 19. Furthermore, although not shown, we notice that the mean and variance values of the number of smart plugs are {11.8,5.4} and {12.3,5.9}, respectively for FVG and CAR.

To complete the derivation of the number of nodes it is necessary to compute the number of interferers. Although an exact derivation of the latter goes beyond the scope of this work, the following example gives us an idea on how to derive the worst case. Let us consider a building of 8 floors that abuts with other two buildings with the same number of floors. Let us further assume that 4 flats are present on each floor. Assuming a wireless-based system covering 4 floors, the channel can potentially be shared among 7 floors, 4 flats for each floor, and 3 buildings, thus leading to 84 logical networks that interfere with each other (or equally 84 EMSs). Moreover, if we assume to have 19 nodes per logical network (the maximum number of smart plugs), we will have more than 1500 nodes sharing the same medium. This is a huge number of nodes, considering that the goal

Table 3.2: Level of diffusion of household appliances

Appliance	**Carinthia** [%]	**Friuli** [%]
Air Conditioner	2.16	45.19
Computer	96.24	97.84
Cordless Phone	31.72	66.91
Dishwasher	84.95	65.35
Dryer	27.96	5.76
DVD/BlueRay player	69.35	69.68
Electric Boiler	41.4	12.23
Electric Hob	98.37	5.22
Electric Oven	100	87.97
Freezer	40.86	27.34
Fridge	98.92	99.28
Game Console	34.31	28.06
Hi-Fi	63.44	53.96
Home Theater	7.53	12.96
Hood	69.89	82.73
Iron	74.73	76.98
Microwave Oven	60.75	61.15
Pellet Boiler	6.45	0.72
Photovoltaic Plant	2.69	7.91
Scanner/Printer	73.12	79.86
TV	85.48	89.21
Average Number of Air Conditioners	1	2
Average Number of Electric Boilers	1	1

is to build a nearly real-time monitoring system (see §3.1.4). In addition, multiple communication technologies that are present in the house would need to coexist with the EMS, i.e., wireless local area network (WLAN) devices, cordless phones, and other home automation systems. Therefore, a tradeoff between coverage and performance arises for a specific application.

3.1.4 Metering resolution

The metering resolution affects the frequency of information displayed to users, and in a sense the responsiveness of control tasks. Since it depends on the strategy and application one implements, we will consider that multiple appliances might be connected to an outlet and and have to be identified. Indeed, the number of appliances that state-of-the-art disaggregation techniques can detect is limited and dependent on the metering resolution. As

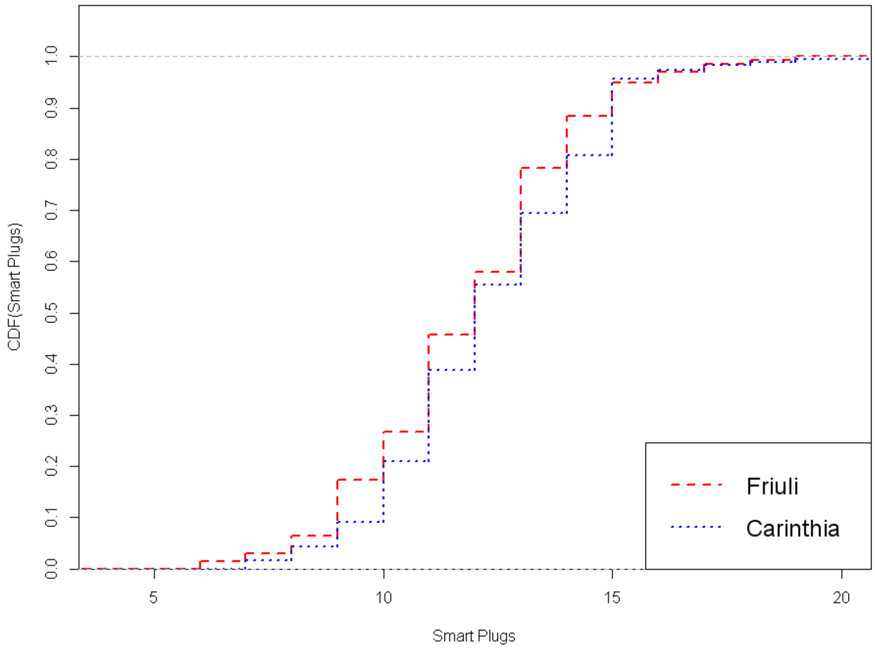

Figure 3.3: CDF of the number of estimated smart plugs needed for Friuli and Carinthia houses.

shown in [CA13], hourly data (i.e. resulting from average power measurements) allows only the correlation of the power profile to environment characteristics, such as time and temperature. Metering frequency between one minute and 1 second allows the identification of about 8 different types of devices. To detect about 10 to 20 types of devices, metering frequency between 1 and 60 Hz is enough, although detecting devices that are in standby mode is not possible. Working in the order of KHz allows identifying 20 to 40 types of devices, whereas about 100 devices can be detected by sampling in the order of MHz. Since in our case the maximum number of node (smart plugs) in the network is 19, we can conclude that sampling between 1 second and 1 minute is enough for most cases.

3.1.5 Communication technologies

In the following, we give a brief overview of the wireless and power line low bit-rate communication technologies that are suitable for energy monitoring applications. These solutions are cheap w.r.t. high bit-rate technologies, they can be embedded in small chips, they grant a low power consumption, they do not need a dedicated wired communication infrastructure and thus have "zero" deployment costs.

3.1.5.1 Low bit-rate wireless technologies

There are several low bit-rate wireless technologies that have been developed for home automation applications. Table 3.3 lists the characteristics of the mostly used [Gom10], i.e., ZigBee, Z-Wave, Insteon, and Wavenis. These wireless devices work in the frequency bands known as industrial, scientific and medical (ISM). They offer bit-rates that vary from some Kbps up to 250 Kbps and a coverage that ranges from some meters up to some hundreds meters, depending on the frequency employed to transmit the signal. Except for Wavenis, all these technologies offer multi-hop connectivity. However, it has to be said that Wavenis also offers the possibility to transmit signal at lower frequency and thus it should offer a better coverage w.r.t. the others technologies. Therefore, all the listed technology can in principle satisfy the coverage and address the requirements listed in the previous section.

It is interesting to note that among the previously listed technologies the only publicly available specification up to the application layer is offered by the Zigbee Alliance (physical (PHY) and medium access control (MAC) layer are specified by the IEEE 802.15.4, whereas network and application layer are downloadable from the Zigbee Alliance web site), although the PHY and MAC layer of Insteon are specified by International Telecommunication Union (ITU)-T G9959 [ITU12].

Beside the previous technologies, Internet Engineering Task Force (IETF) IPv6 over low-power wireless PAN (6LowPAN) working group (WG) has defined the frame format and several mechanisms needed for the transmission of IPv6 packets on top of IEEE 802.15.4 networks. Furthermore, Zigbee Alliance has also developed the IPv6 specification for the upcoming smart energy profile (SEP) 2.0 standard. It is worth noting that the possibility of using Internet protocol (IP) connectivity allows for integrating different communication technologies that make use of different physical media.

3.1.5.2 Narrow band power line communication technologies

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 power line communication (PLC) has been or being used, e.g., Internet access, remote metering, command and control of home devices, small office home office (SOHO), and recently, SG applications.

Table 3.3: Low bit-rate wireless communication 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

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 and the frequency band used to signal. In the following, we focus on NB-PLC devices since they have been developed with the scope of offering indoor and outdoor command and control services although we notice that BB-PLCs can be used as backbone to extend the coverage of NB-PLC devices [Ber13].

NB-PLC 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, European Committee for Electrotechnical Standardization (CENELEC) issued the standard EN 50065 that specifies four frequency bands for communications over power line (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: Federal Communication Commission (FCC) and Association of Radio Industries and Business (ARIB) allow PLC devices to work in the band from 3 kHz up to 490 kHz or 450 kHz, respectively. Therefore, for domestic energy monitoring, we need to consider devices that work in the CENELEC C band. This band is reserved for technologies that adopt carrier sense multiple access (CSMA)/collision avoidance (CA) protocol and thus it is meant to allow

Table 3.4: 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

for coexistence among different NB-PLC technologies that might be present within the household.

Differently from the wireless case, PLC solutions suffer less from interference caused by different logical networks that use the same communication technology. This is because the electrical circuits of different networks are somewhat separated, which in turn allows to more simply create logical and physical networks with smaller amount of interference. However, despite this benefit, there are problems on using PLC solutions in houses where different phases are used to distribute the electricity among the rooms. This is not the case of Italy, but in Austria it is common and therefore a greater attention should be paid in the latter case before adopting a PLC solution for domestic energy monitoring applications. Furthermore, coverage problems may be observed in multi-floor houses [Ber13].

Table 3.4 lists the characteristics of the NB-PLC solutions developed for SG applications, and in particular for automatic meter reading (AMR), i.e., the PRIME [PRI11] and the G3-PLC [ERD09b],[ERD09a] solutions. Both of them have been used for the development of the new NB-PLC standard for SG applications, i.e., the ITU-T G.hnem and the IEEE P1901.2 [Oks11]. We notice that either G.hnem and P1901.2 are designed to work in the different frequency bands, whereas, PRIME and G3-PLC work in the CENELEC A band since they were designed for AMR[1]. The bit-rate offered by these technologies varies from some ten of Kbps up to 500 Kbps in P1901.2 and 1 Mbps in G.hnem, depending on the used band and on the channel conditions. Another important characteristic to notice is that all the listed technologies

[1]G3-PLC also specifies an extension to work in the CENELEC C and FCC bands.

offer multi-hop communication. This is an important point to increase the coverage over highly attenuated channels.

Finally, we notice that both standard offer IPv6 support and thus they can be easily integrated with other communication technologies, e.g., wireless or BB-PLC.

Beside the previously listed solutions, we point out that many NB-PLC technologies that have been developed for home automation applications are present in the market [Fer10][ch. 7], i.e., Insteon, Konnex, X10, CEBus, LonWorks, Universal Power Line Bus, HomePlug Command & Control, Meters & More. However, many of them have not been supported from a standard body[2] and thus we think that this could be a limiting factor for worldwide deployment at least for SG applications.

3.2 Test campaign

Based on the analysis above, we notice that the requirements of the EMS in terms of coverage, topology, and number of nodes, can be satisfied in line of principle using any of the wireless technologies listed in Table 3.3, or the NB-PLC technologies listed in Table 3.4. However, in real scenarios, wireless technologies might show some drawbacks: (i) coverage issues can arise due to obstacles in the propagation of the signal; (ii) coexistence issues caused by the presence of other technologies, e.g., WiFi networks, in the ISM band can limit the performance [Sch08]. On the other hand, NB-PLC technologies might show coverage issues in large buildings [Ber13] or in houses where different phases are used to distribute the electricity among the rooms.

In order to analyze the behavior of wireless and NB-PLC technologies in a real scenario, we performed a coverage test campaign in two apartments located in FVG. The first was a two-floor apartment located in a building consisting of 13 total floors. The first floor of the considered apartment measures about 140 m^2, while the second 30 m^2 (see Fig. 3.4). The second was a single-floor apartment of about 110 m^2 located in a building consisting of 8 total floors (see Fig. 3.5).

We decided to test the Zigbee and G3-PLC technologies since these seem to be the technologies that will be largely deployed in the next years. To this end, we adopted two development kits build by Digi that implement the IEEE 802.15.4 standard in the frequency bands 868 MHz and 2.4 GHz [Dig13], respectively. Regarding, the NB-PLC technology, we adopted the development kit built by Maxim [Max10] that implements a physical and a MAC layer that are very similar to the ones specified by the G3-PLC standard. Furthermore, we considered the transmission over the CENELEC C frequency band.

[2]Konnex is standardized by EN50090 and ISO/IEC 14543.

Since the communication technologies are thought to work as tranceivers for smart plugs, the tests have been performed placing the wireless devices close to the outlets, and the NB-PLC devices plugged into the outlets. A number of 9 outlets have been considered per each house (see Figs. 3.4, 3.5). The tests have been carried out by sending 1000 packets consisting of 32 bytes of data between the outlet O1 and each of the others. Furthermore, since we want the EMS to control the devices, e.g., by switching them on and off, we set each packet transmission to be acknowledged. The wireless devices have been set to transmit with a power of 10 dBm, which represents the transmitted power limit in Europe. Regarding the NB-PLC devices, the development kit does not specify the level of the transmitted power, however, from power spectral density (PSD) measurements, we noticed that the transmitted PSD is around -30 dBm/Hz, leading to about 10 dBm of transmitted power in the CENELEC C band.

Table 3.5 lists the packet error rate (PER) experienced on each of the tested links. It has been computed as the ratio between the number of transmitted packet that do not receive an ACK and the number of transmitted packet.

From Table 3.5, we can make the following observations:

- As we could have expected, the 868 MHz technology shows better coverage than the 2.4 GHz technology.
- Both wireless technologies show the worst performance when transmitting over the link O1-O5 of the first house. This is because, in this case the signal has to across a metal stair and a bearing wall.
- The NB-PLC technology shows the best performance in terms of coverage, although its bit rate is very low (about 1 kbps).

Although not shown, we also carried out coverage tests among different floors of the buildings using the wireless devices. To this respect, we notice that a coverage up to 4 and 6 floors has been observed respectively for the 2.4 GHz and the 868 MHz wireless technology in both buildings.

From the analysis above, we believe that an heterogeneous wireless/PLC network can be the appropriate solution for a reliable domestic EMS, especially in large densely populated networks. Convergence between wireless and PLC solutions can be obtained at the network layer thanks to the use of the IP protocol, e.g., using the Zigbee SEP 2.0.

3.3 The data infrastructure

Domestic environments contain a myriad of different digital devices, using different protocols and data representations. In the previous section, we have

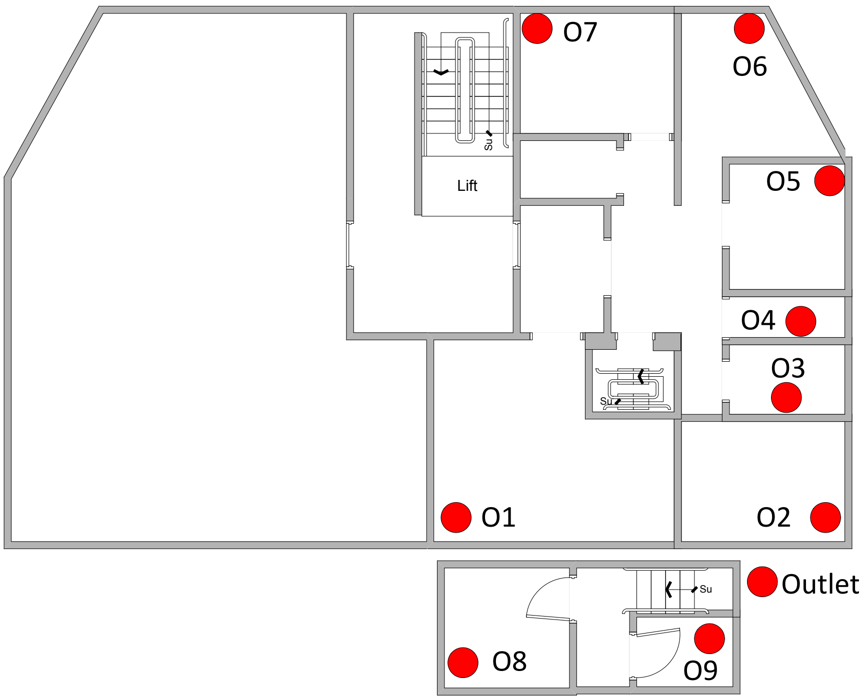

Figure 3.4: Topology of the first house were coverage tests have been carried out.

discussed requirements for the communication network of the EMS, namely for the physical and MAC layers. Application-level protocols can provide an abstraction to mask differences in terms of network infrastructure at physical and data-link level. To this end, in [Mon13a] we discussed requirements to collect and exploit data produced in households within smart grid applications. We proposed a potential architecture addressing the proposed requirements and reported state-of-the-art technologies that can be employed to implement it. Beside focusing on application-level protocols, we reported of the existing effort in addressing interoperability isses, which encompasses integrability of both devices (i.e. for the whole network stack) and data.

3.3.1 Requirements

The smart grid is a cyber-physical system combining the power grid to a data infrastructure, which connects producers and consumers to become more efficient and reliable. To fully exploit data produced in living environments, a reliable and flexible data infrastructure is required to handle the high amount of data produced in such a dynamic environment.

In [Mon13a] we have identified the following requirements:

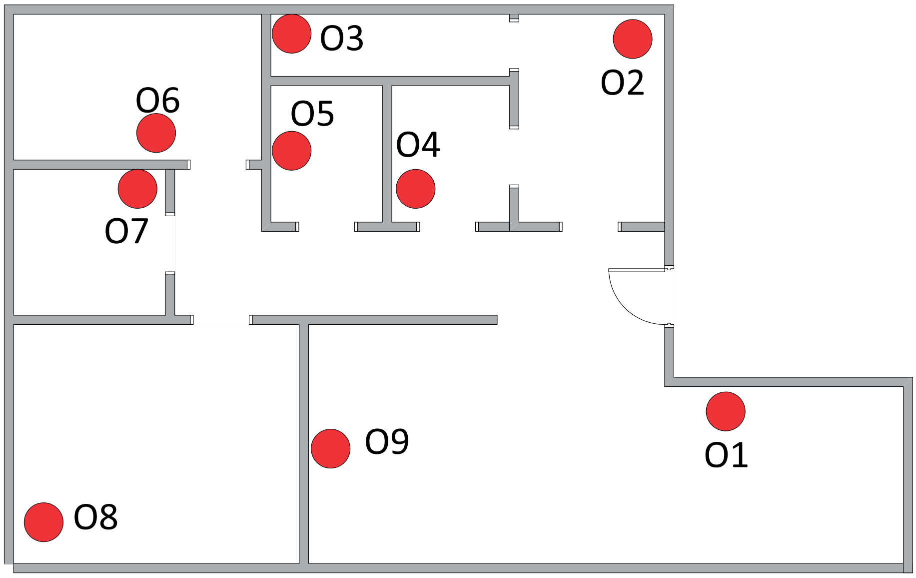

Figure 3.5: Topology of the second house were coverage tests have been carried out.

- **Plug & play mechanism:** Discoverability of services and resources in the network is required to make services usable as soon as they become available [Pit05]. Services are required to provide a description of their characteristics that can be advertised to other peers or retrieved when needed.

- **Accessibility of data:** The architecture should support a data-driven abstraction to increase interoperability and reduce maintainance costs. This data space should be accessible through a uniform interface, such as standard query languages and a well defined application programming interface (API). This requires to semantically annotate sensed data according to well-known design patterns and vocabularies, as well as enhance them with situational information such as time and space.

- **Reliable and neutral data infrastructure:** A repository should store knowledge about properties and context information and ensure availability and continuity of service. Moreover, it should support integrity of data and avoid any discrimination that is not strictly required to guarantee Quality of Service.

- **Confidentiality:** The architecture should provide mechanisms to avoid unauthorized disclosure of information. In particular, it should secure access to the home network and the repository (e.g., using authentica-

Table 3.5: Packet error rate for the tested technologies.

		PER [%]		
Tx	**Rx**	**Wireless** 2.4 GHz	**Wireless** 868 MHz	**NB-PLC** CENELEC C
First house				
O1	O2	0.4	0	0
O1	O3	5.2	0	0
O1	O4	0.4	0	0
O1	O5	**99.8**	**100**	0
O1	O6	**100**	0	0
O1	O7	24.3	0	0
O1	O8	0	0	0
O1	O9	0.1	0	0
Second house				
O1	O2	4.3	0	0
O1	O3	0.3	0	0
O1	O4	1	0	0
O1	O5	0.2	0	0
O1	O6	1.8	0	0
O1	O7	0.4	0	0
O1	O8	**11.8**	0	0
O1	O9	0.2	0	0.8

tion and encrypted communication) and use a sandbox mechanism for applications when accessing user data (e.g., OAuth protocol[3]).

- **Quality of data:** The architecture should ensure appropriateness of data, i.e., consistence with respect to time. For instance, event-oriented systems may not be able to meet strong real-time constraints, as events are queued for an unpredictable time before being dispatched.

3.3.2 A possible architecture

In [Mon13a] we proposed a potential architecture addressing the requirements (Fig. 3.6). The household is considered as a network of self-describing sensors and actuators, dynamically joining and leaving the network with the help of service discovery mechanisms. For instance, smart appliances are required to provide a profile describing their characteristics in a machine-readable description, so that the functionalities can be automatically used by other devices. The household can therefore be seen as a localised data space, where data are produced and consumed by electrical devices and de-

[3]http://oauth.net/

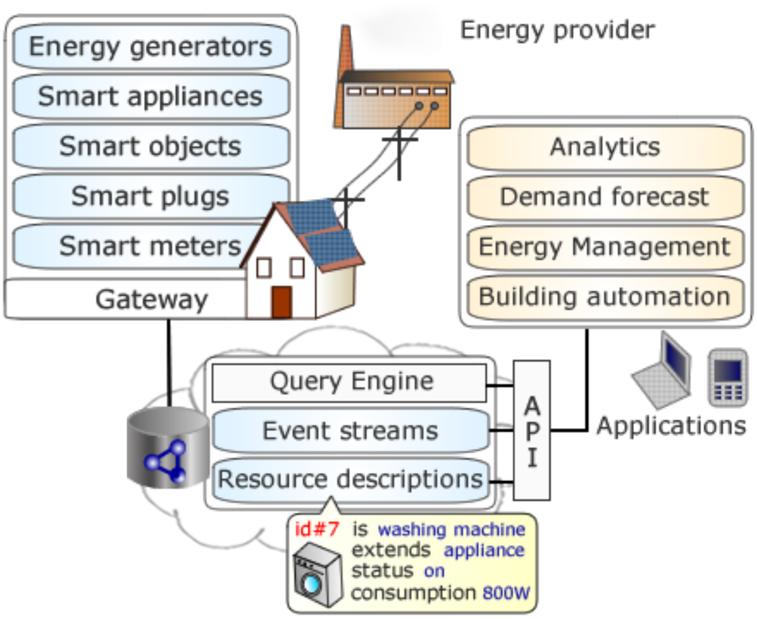

Figure 3.6: Architecture to provide data interoperability in the smart grid: data produced in households is semantically annotated and fed to the cloud. A query engine provides a uniform interface to data that can be exploited by applications.

scribed with respect to shared vocabularies and formats. A gateway manages the connection to Internet, and is required to protect the home network from potential security threats deriving from outside the private space. In addition, it should integrate smart and legacy devices, by detecting running devices and providing a description of them that can ensure their visibility within the architecture. We also discussed the possibility of storing context information in a cloud-based infrastructure, so as to intermediate between households and potential consumers of this information, such as utilities and applications.

Section 4

Energy conservation strategies

Energy awareness is the ability to perceive the effect that has a certain devices on the environment. Effects can be monetary, social and environmental.

The problem of classical billing mechanisms is that users get feedback of their consumption too late after consumption occurred. This makes difficult getting an understanding of how energy is used. Smart metering can mitigate this problem by offering residents a higher detailed consumption information, as data is collected at smaller intervals. Another way of increasing the resolution of feedback is given by prepaid billing, which was shown leading to average savings of 11% regardless of disconnections from the grid [Ozo13].

Persuasive technologies are designed to strive for awakening and informing people about energy. In this section, we report existing strategies and technologies to support users' decision making.

4.1 Pricing as awareness of available energy

Pricing can be used as an incentive to users to make use of energy greedy devices in periods of the day in which energy demand is lower. Pricing should therefore follow modifications in availability of energy, so that users can get an understanding of the availability in the grid in a real-time manner [Alb07].

4.2 Demand awareness

Providing a feedback of energy consumption gives users an awareness of the energy necessary to operate certain devices and can be used to promote energy conservation. In particular, [Dar06] classifies feedback in two categories:

- *Indirect*, when it provides consumption information after it occurred .
- *Direct*, when the feedback concerns the amount of energy in use.

Displaying real-time consumption information has been shown to effectively raise user awareness, leading to a reduction in energy uses of up to 15%. On the other hand, indirect information, such as analytics and trends are necessary to enable learning mechanisms, and consequently, long-term change. In addition, consumption information can be enhanced by positive feedback, such as a reward, which can be monetary or social when the consumption is compared to other people within a community. Goal setting and commitment strategies act as reinforcement mechanisms, and are meant to prevent users taking a certain behavior in future. Accordingly, [Bon12] identifies *antecedent* and *consequent* strategies. While antecedent strategies aim at preventing users from behaving in a certain way, consequent strategies include direct and indirect feedback mechanisms. Nevertheless, studies have also shown that in spite of awareness, the effectiveness of these systems in making people responsible depends on their sensitivity and motivation [Str11]. The effectiveness of feedback mechanisms has been assessed in many previous studies. The analysis in [EM10] relies on 36 studies carried out between 1995 and 2010 to show that consumption information down to the device level leads to the highest energy savings (see Fig. 4.1).

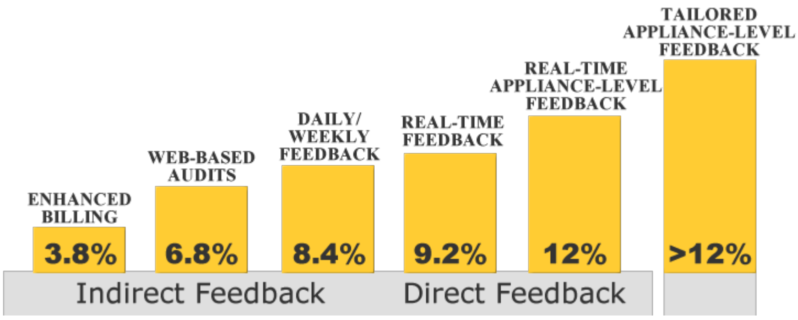

Figure 4.1: Effectiveness of feedback [EM10, CA13]

4.3 Tailored conservation strategies

Interactive systems are required to support users in understanding their use of energy. Device usage data provides enough information to extract a model of the user's behavior at home. The model can be used by applications to offer tailored functionalities. In [Fis13], an empirical study is used to evaluate the effects of personalized energy-related recommendations based on usage profiling. In the AgentSwitch tariff selection agent [Ram13], available tariffs are considered with respect to the user's profile, so as to provide advices for shifting devices to cheaper periods of the day. The evaluation involved 10 users for 3 months, showing that the system can find cheaper tariffs for most of users.

The study presented in [CA13] assesses the effectiveness of various feedback systems to show that the exploitation of user modeling can lead to more effective conservation strategies. The use of recommendation systems is claimed to lead to estimated savings of around 20%.

Conclusions

The analysis of a web survey showed that many differences in domestic energy usages can be found between the residents of FVG and CAR regions. Furthermore, only a small portion of the residents from the two regions is aware of home automation or energy management systems. Consequently, the development of a tailored energy management system together with innovative energy saving strategies are required steps to contribute to the global energy saving needs.

The results of this deliverable lay the ground for the research activity that will be carried out in the other work packages of the MONERGY project. In particular:

- In WP3, we will develop the software solutions for monitoring and controlling the in-home appliances that have new functionalities. Research activity will be carried out to provide a comprehensible and simple user interface for monitoring the current state of the system and the appliances.

- 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 outlets, a data exchange network and a control software that will allow for carrying out a real life monitoring campaign.

- In WP5, in order to get feedback on the applicability of the elaborated concepts, the models will be validated in the lab and real-world test campaign 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 at reducing energy consumption.

Appendix A

The survey study

In this appendix, we report the answers to the survey study. Please refer to 2 for the results of the survey data analysis.

Table A.1: Dwelling characteristics

Dwelling Variable	**Carinthia**	**Friuli-V.G.**
Household ownership	69.35%	88.49%
Residents	M=2.64, SD=1.18	M=2.95, SD=1.05
Flat in block of flats	47.31%	49.64%
Semi-detached house	40.86%	12.95%
Detached house	8.60%	32.25%
Other	3.23%	2.16%
$< 30\ m^2$	1.62%	2.16%
30 - 64 m^2	11.29%	12.23%
65 - 100 m^2	34.41%	43.17%
$> 100\ m^2$	52.69%	42.45%
Floors	Mdn=2, IQR=1-2	Mdn=2, IQR=1-3

Table A.2: Number of hours spent at home on weekdays and beside sleeping

Carinthia	**Friuli-V.G.**
Mdn=6 hours, IQR=5-8	Mdn=5 hours, IQR=4-7

Table A.3: Laundry

Variable	Carinthia	Friuli-V.G.
Laundry frequency (monthly)	Mdn=8, IQR=4-12.75	Mdn=8, IQR=5-17
Washing machine	92.47%	87.05%
Dryer	27.96%	5.76%
Washing machine with dryer	4.84%	7.91%
Iron	74.73%	76.98%

Table A.4: Kitchen appliances

Device	Carinthia	Friuli-V.G.
Hood	69.89%	82.73%
Dishwasher	84.95%	68.35%
Hob	98.92%	82.73%
Oven	95.70%	95.68%
Microwave oven	60.75%	61.15%
Fridge	98.92%	99.28%
Freezer	40.86%	27.34%
Electric hob	98.37%	5.22%
Electric oven	100%	87.97%

Table A.5: Water heating

Device	Carinthia	Friuli-V.G.
Electric boiler	41.40%	12.23%
Gas	6.99%	82.01%
Oil	22.04%	6.47%
Wood	6.45%	2.88%
Pellet	6.45%	0.72%
Coal	0%	0%
District heating	17.74%	0%
Solar plant	15.59%	12.95%
Geothermal plant	7.53%	0%
Number of boilers	Mdn=1, IQR=1-2	Mdn=1, IQR=1-1

Table A.6: Space heating and cooling. The frequency of use of air conditioners is "Not every day", "Less than 2 hours per day" and "More than 2 hours per day", and it is represented as order 1-3

Device	Carinthia	Friuli-V.G.
Electric heaters / heat pumps	10.22%	6.47%
Gas	9.14%	63.31%
Oil	21.51%	8.63%
Wood	11.29%	14.39%
Pellet	7.53%	3.60%
Coal	0%	0%
District heating	30.65%	0%
Solar plant	2.69%	2.88%
Geothermal plant	6.99%	0%
Air conditioner	2.16%	45.19%
Number of units	Mdn=1, IQR=1-1.25	Mdn=2, IQR=1-2
Frequency of use	Mdn=2, IQR=1.75-2.25	Mdn=2, IQR=1-3

Table A.7: Consumer electronics

Variable	Carinthia	Friuli-V.G.
TV	85.48%	89.21%
DVD/BlueRay player	69.35%	69.78%
Home Theater	7.53%	12.95%
Game console	34.41%	28.06%
HiFi stereo	63.44%	53.96%
Cordless phone	31.72%	66.91%
Computer	96.24%	97.84%
Printer and/or Scanner	73.12%	79.86%

Table A.8: Energy wasting behavior. The scale "No, never", "Yes, sometimes", "Yes, often", "Yes, always" was represented with the order 1-4

	Carinthia	Friuli-V.G.
TV in standby mode	M=2.19, SD=1.18	M=2.37, SD=1.10
	Mdn=2, IQR=1-3	Mdn=2, IQR=1-3
Lights forget on in unused rooms	M=1.79, SD=0.60	M=1.633, SD=0.63
	Mdn=2, IQR=1-2	Mdn=2, IQR=1-2

Table A.9: Renewable energy generation. The scale used for the peak power was 1-3, respectively for plants smaller than 2.7KW, between 2.8 and 4 KW, greater than 4 KW

	Carinthia	**Friuli-V.G.**
Photovoltaics	2.69%	7.91%
Peak power (KW)	Mdn=3, IQR=2.75-3	Mdn=2, IQR=2-3
	"greater than 4KW"	"between 2.8 and 4 KW"
Thermal solar plant	16.67%	13.67%
Geothermal plant	0.54%	0.72%
Wind turbine	0.0%	0.0%

Table A.10: Metering infrastructure

	Carinthia	**Friuli-V.G.**
Presence of time-dependent tariff	16.67%	78.42%

Table A.11: Devices for which the user would exploit a time-dependent tariff

Variable	**Carinthia**	**Friuli-V.G.**
Lights	9.14%	2.16%
Washing machine	47.85%	19.42%
Dryer	19.89%	2.16%
Iron	13.44%	7.19%
Air conditioner	3.23%	5.04%
Electric heater	8.60%	3.60%
Electric boiler	22.58%	2.88%
TV	8.06%	0.72%
Computer	5.91%	3.60%
Game console	2.15%	0.72%
Vacuum cleaner	13.44%	4.32%
Hood	3.76%	1.44%
Electric hob	7.53%	0.72%
Electric oven	8.06%	7.19%
Microwave oven	2.69%	0%
Other	8.60%	1.44%

Table A.12: Devices for which the user exploits a time-dependent tariff

Variable	Carinthia	Friuli-V.G.
Lights	1.08%	24.46%
Washing machine	1.08%	62.59%
Dryer	0.0%	10.79%
Iron	0.54%	22.30%
Air conditioner	0.0%	10.07%
Electric heater	4.30%	6.47%
Electric boiler	10.75%	2.16%
TV	0.54%	7.91%
Computer	0.54%	9.35%
Game console	0.0%	1.44%
Vacuum cleaner	1.08%	9.35%
Hood	1.08%	1.44%
Electric hob	0.54%	0.0%
Electric oven	0.54%	21.58%
Microwave oven	0.0%	0.72%
Other	1.61%	11.51%

Table A.13: Replaced an electrical device in the last 4 years to reduce the overall consumption

Carinthia	Friuli-V.G.
67.20%	41.73%

Table A.14: Replaced devices in the last 4 years

Variable	Carinthia	Friuli-V.G.
Lights	51.08%	38.85%
Washing machine	32.26%	17.99%
Dryer	9.14%	1.44%
Iron	8.60%	5.76%
Air conditioner	0.0%	2.16%
Electric heater	2.69%	2.16%
Electric boiler	8.60%	4.32%
TV	19.89%	9.35%
Computer	17.74%	4.32%
Vacuum cleaner	11.83%	2.16%
Hood	5.38%	0.72%
Electric hob	15.05%	0.0%
Electric oven	8.60%	3.60%
Microwave oven	5.91%	1.44%
Other	25.81%	5.76%

Table A.15: Home automation systems

Variable	**Carinthia**	**Friuli-V.G.**
Knowledge of any HA system	33.33%	37.41%
Does not even know what HA means	28.49%	20.14%
Ownership of a HA system	3.23%	3.85%
Intention to purchase one within 2 years	16.67%	18.0%
Usefulness of consumption feedback	73.12%	79.86%

Table A.16: Preferred feedback type

Variable	**Carinthia**	**Friuli-V.G.**
In-home display	26.47%	46.85%
Web app (for pc, smartphone, tablet, etc.)	68.38%	52.25%
Other means	5.15%	0.9%

Table A.17: Demographics

Occupant Variable	**Carinthia**	**Friuli-V.G.**
Male	48.39%	54.68%
Female	51.61%	45.32%
Age 18 - 35	37.1%	59.71%
Age 36 - 45	29.57%	17.27%
Age 46 - 65	31.18%	20.14%
Age $>$ 65	2.15%	2.88%
Primary school	0%	0%
Secondary school	1.61%	3.60%
High school	23.66%	33.81%
Bachelor's degree	4.84%	7.19%
Master's degree	35.48%	38.13%
PhD	29.03%	14.39%
Other	5.38%	2.88%
Worker	0.0%	3.60%
Clerical worker	86.02%	44.60%
Entrepreneur	4.84%	5.04%
Retired	2.15%	3.60%
Student	4.84%	28.78%
Other	2.15%	14.39%

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