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Energy Demand-Aware Open Services for Smart Grid Intelligent Automation

SmartHG

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Second Year Design of Home Intelligent Automation Services

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To make this deliverable suitable for public dissemination, test-bed data have been anonymized.

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List of Acronyms

COP Coefficient of Performance

DAPP-H Demand Aware Price Policies for Homes

DAPP-K Demand Aware Price Policies for Substation-Level Energy Storage Control

DB&A Database and Analytics

DBService Database Service

DSO Distribution System Operator

DTLS Datagram Transport Layer Security

EBR Energy Bill Reduction

EDN Electric Distribution Network

ESS Energy Storage System

EUMF Energy Usage Modelling and Forecasting

EUMF-H Energy Usage Modelling and Forecasting for Homes

EUMF-K Energy Usage Modelling and Forecasting for Control

EUR Energy Usage Reduction

EUR-H Energy Usage Reduction for Homes

EUR-K Energy Usage Reduction for Control

EVT EDN Virtual Tomography

GIAS Grid Intelligent Automation Service

GUI Graphical User Interface

HAN Home Area Network

HDM Home Device Management

HECH Home Energy Controlling Hub

HIAS Home Intelligent Automation Service

HVAC Heating, Ventilating, and Air Conditioning

IAS Intelligent Automation Service

IBR Inclining Block Rate

JSON JavaScript Object Notation

MILP Mixed-Integer Linear Programming

PEV Plug-in Electric Vehicle

PPSV Price Policy Safety Verification

RESTful REpresentational State Transfer

SaaS Software as a Service

ToU Time of Usage

URL Unified Resource Location

Executive Summary

Objectives The main objective of the SmartHG project is to develop effective Intelligent Automation Services (IASs) to minimise residential users energy usage and bill while optimising operation on the grid for Distribution System Operators (DSOs). Work Package 3 focuses on the design of the Home Intelligent Automation Services (HIASs), i.e., services working on the residential user side, and on communication between home devices (e.g., smart meters) and IASs.

Retrospect During the first year, we clearly defined services dependencies, outputs, functional specifications, and we implemented a first prototype of all the HIASs. The Energy Usage Modelling and Forecasting (EUMF) service provided each residential user with a forecast of power profile. The Energy Usage Reduction (EUR) service provided each residential user with information on home energy usage. The Energy Bill Reduction (EBR) aided the user by computing a plan for actuating home appliances so as to minimise user energy bill. As for communication between home devices and IASs, a common database and an open protocol were designed.

Achievements During the second year, all HIASs underwent a complete re-design. The EUMF service has been split in two different services to be used in two different scenarios: EUMF-H is used to offer a medium-term (many days) energy demand forecasting service to residential users, EUMF-K is used to offer a fast, short term (a few hours) energy demand forecasting to other IASs. Also the EUR service has been split in two different services: EUR-H is used to offer an energy usage visualisation service, whilst EUR-K is used to support residential users in evaluating trade-offs between home retrofit options (e.g., increase thermal insulation or increase heat pump Coefficient of Performance (COP)) aiming at improving home energy efficiency. The EBR service has been re-designed to directly control selected home appliances (namely, an Energy Storage System (ESS) and a Plug-in Electric Vehicle (PEV)), so as to be transparent to residential users. Finally, communication protocols used by smart meters inside homes make sensor measurements available to IASs. Such protocols had to be completely re-designed with respect to their first year version, as a new SmartHG partner is providing home devices different from the ones planned in the first year.

Limitations and Future Work The EBR service is based on a simplified model of both the ESS and the PEV. Also EUR-K uses a simplified model of home thermal insulation. We plan to refine the ESS, the PEV, and the home thermal insulation models. EUMF-K currently *lumps* all home heat pumps into one. We plan to improve its results, by considering number and relative positioning of home heat pumps. We plan also to provide a tool to evaluate the economical advantages of installing an ESS. EUR-H and EUMF-H will be integrated with information available from smart appliances on the market. Finally, end-to-end interoperability of IPv6 in the HAN will be added.

Chapter 1

Retrospect

In this chapter we briefly recall the main achievements obtained in the first year version of the SmartHG Home Intelligent Automation Services (HIASs) design.

The activities in the first year of the project resulted in building a first year prototype version of all the HIASs, i.e., of the services working on the residential homes side. Namely, the services dependencies, outputs, and functional specifications were clearly defined. In a nutshell, the following specifications were identified. The Energy Usage Modelling and Forecasting (EUMF) service (Task T3.3) is tailored to provide the residential user with a visualisation tool showing forecast of power profile. The Energy Usage Reduction (EUR) service (Task T3.5) is tailored to provide the residential user with a tool providing information on home energy usage, especially with respect to the heating appliances. The Energy Bill Reduction (EBR) service (Task T3.4) should aid the user by proposing a plan for appliances usage, in order to minimise the energy bill. As for communication between home devices and Intelligent Automation Services (IASs) (Tasks T3.1 and T3.2), a common database and an open protocol were designed. Finally, for each of the services mentioned above, a first version of algorithms meeting the corresponding specifications was designed.

The challenges identified for the second year were the following.

- Design of open protocols for home automation (Task T3.1) must address security and privacy within the Home Device Management (HDM) through a more detailed description and develop an online software component to provide connectivity with the devices protocol on one side, and provide the data services in the common project protocols on the other side.
- Design of open protocols for IAS (Task T3.2) must be compliant with the REpresentational State Transfer (RESTful) web services to provide a seamless communication between IASs.
- Design of EUMF (Task T3.3) should also account for the requirement of providing forecasts to other SmartHG IASs, and not only to residential users.
- Design of EBR service (Task T3.4) should be based on an automatic actuation of proposed actions, since a user may not be willing to follow a plan.
- Design of EUR (Task T3.5) should also suggest actions to residential users, and not only visualise home current energy efficiency.

Chapter 2

Introduction

Work Package 3 (WP3) is devoted to the design of the SmartHG Home Intelligent Automation Services (HIASs). The goal for such services is to reduce energy costs and consumption at the residential level. To this aim, they require as input data coming from Distribution System Operator (DSO) price polices, residential users power consumption, homes geographic location, homes-related information, etc. As an output, their goal is to provide either a technology to directly control home appliances, or information to assist residential consumers to use electricity in an effective way. Furthermore, such goals must be achieved while preserving consumer privacy and confidentiality. From a functional point of view, HIAS control loops are the inner loops of the overall SmartHG functional schema, see highlighted part of Figure 2.1. From an architectural point of view, HIASs are those highlighted in the overall architectural schema of Figure 2.2. This deliverable illustrates the design of HIASs and the communication protocol between them and the home devices. The (Web-based) implementation of HIAS prototypes, based on the design described here, is presented in Deliverable D3.2.2. Such prototypes are then used for the evaluation phase described in D5.2.1. In the following, we briefly introduce each HIAS, also providing an overview of the differences with respect to the first year version.

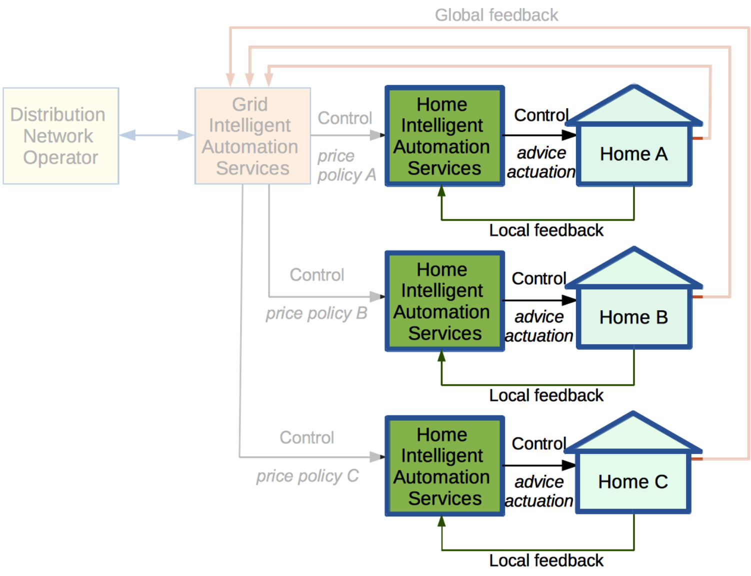

Figure 2.1: Functional schema of SmartHG HIASs.

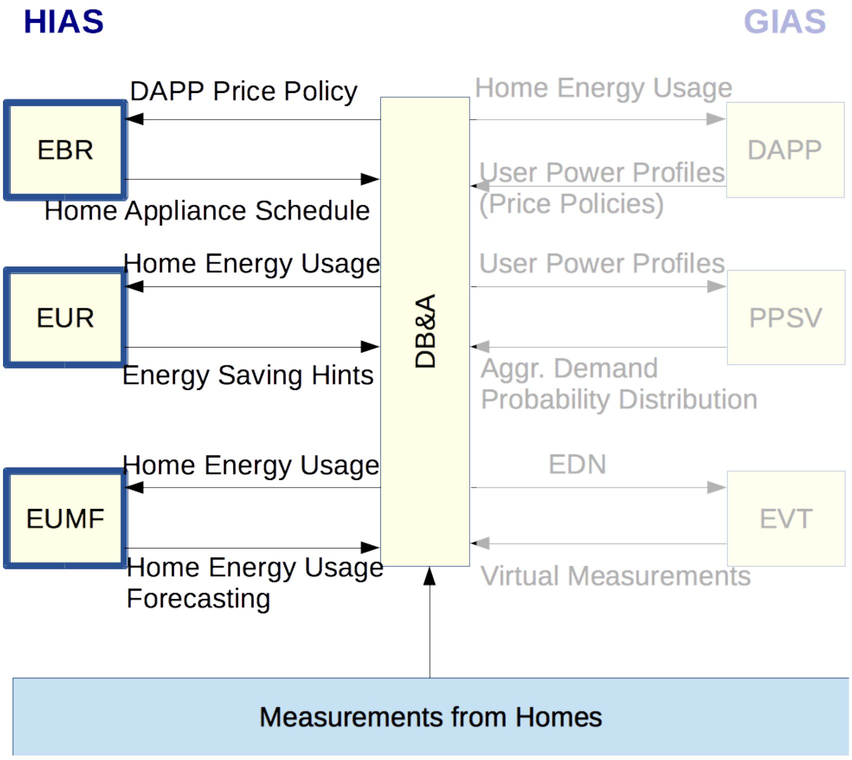

Figure 2.2: SmartHG HIASs architecture.

The Energy Usage Modelling and Forecasting (EUMF) service aims at computing a forecast for the power demand of a single household in the next hours or days. To this aim, EUMF planned to use data from sensors and smart appliances, historical data on the household energy consumption and on the productivity of local generation (e.g., photovoltaic panels), energy certification of the building (now a mandatory requirement throughout the EU), the geographical location of the house, local weather conditions, and, when available, topological and structural data of the building (e.g., thermal- and insulation-related characteristics of the materials used to build walls and windows). In this second year iteration, different and conflicting requirements arose for the EUMF service. Namely, on one side EUMF has to provide in a matter of seconds *short-term* (say, a few hours) forecasting to other SmartHG Intelligent Automation Services (IASs) (mostly to Energy Bill Reduction (EBR) and Demand Aware Price Policies for Substation-Level Energy Storage Control (DAPP-K), see Deliverable D4.2.1 for the latter), and long-term (say, many days) forecasting to residential users. In order to fulfil all such requirements, we split the EUMF service in two services: Energy Usage Modelling and Forecasting for Homes (EUMF-H) (long-term forecasting provided as a Software as a Service (SaaS)) and Energy Usage Modelling and Forecasting for Control (EUMF-K) (short-term forecasting provided to real-time services such as EBR). These services are described in Section 4.

The EBR service aims at supporting residential users in *saving on their energy bill.* To this aim, in this second year we assume that future households will have either an Energy Storage System (ESS) installed or a Plug-in Electric Vehicle (PEV) to be charged. Moreover, we focus on scenarios where Time of Usage (ToU) or Inclining Block Rate (IBR) tariffs are used. Given this, EBR directly sends charge/discharge commands to the ESS and charge commands to the PEV, when present. The idea is to charge batteries when energy costs less, and to use energy stored in the ESS when energy costs more. Note that, in order to reliably drive the home appliances as described before, EBR needs not only to read power demand measurements from home appliances, but also to forecast appliances power demand in the next few hours. Power demand measurements are made available by ad-hoc communication protocols from home devices and HIASs, which are also described in this deliverable. Power demand forecasts are provided by EUMF-K.

The Energy Usage Reduction (EUR) service aims at reducing the energy *usage* of a single residential home. This will be done by detecting inefficiencies in the home electrical appliances as well as in the building itself. As for EUMF, in this second year iteration, different and conflicting requirements arose for the EUR service. Namely, EUR should be used as: i) an auxiliary service for EBR, in order to enable the third year version of EBR to also control Heating, Ventilating, and Air Conditioning (HVAC) systems, so as to further lower down energy bills; ii) suggest actions to residential users in order to improve the energy efficiency of their homes; and iii) provide an energy efficiency visualisation service to residential users. In order to fulfil all such requirements, we split the EUR service in two services, Energy Usage Reduction for Control (EUR-K) (for goals i) and ii)) and Energy Usage Reduction for Homes (EUR-H) (for goals ii) and iii)). These services are described in Chapter 5.

Finally, we also illustrate the communication protocols between HIASs and home devices.

2.1 Motivation

The main motivations for developing our second year version of Home Intelligent Automation Services (HIASs) are the following.

- The ever increasing complexity of both energy tariffs and home appliances fine tuning often prevents residential users to be able to save in the electrical energy bill, by actually using energy when it costs less. This sets the urge for automated methodologies and technologies able to lower down users energy bill.
- Home appliances complexity also prevents residential users to actually use energy in a responsible and optimised way. This sets the urge for automated methodologies and technologies able to assist residential users in this task.
- Such services require in input a forecast for the home power demand in the next few hours, in order to perform their tasks in an optimised way.
- Communication protocols between all services described above and home smart meters and actuators are needed in order to actually deploy the services.
- All the services described above also need to address security issues as for data, users authentication, etc.

2.2 Objectives

With respect to the motivations in Section 2.1, the main goals for our second year version of HIAS are the following.

- To develop effective and efficient services to aid residential users in reducing their electricity bill.

- To develop effective and efficient services to aid residential users in saving electric energy.
- To develop effective and efficient services providing a forecast for the home power demand in the next few hours, in order to aid the other services in performing their tasks in an optimised way.
- To develop effective and efficient communication protocols between all services described above and home smart meters and actuators.
- To design such services so as to address all security issues.

2.3 Achievements

The main achievements of the SmartHG second year are the following.

Re-design of EBR The EBR service has been re-designed so as to directly drive selected home appliances, namely an ESS and a PEV, acting as a controller for them. The goal for such a controller is to minimise the energy bill, while satisfying the power demand coming from all home appliances. This allows us to provide the residential user with an automatic transparent service (i.e., not requiring the user intervention) for energy bill reduction.

Re-design of EUR The EUR service has been re-designed so as to include two different services: EUR-K and EUR-H. The first supports users in evaluating home retrofit options (e.g., increase thermal insulation or increase heat pump Coefficient of Performance (COP)) in order to decrease consumption of electrical energy for home heating. The second provides information on home energy efficiency.

Re-design of EUMF The EUMF service has been re-designed so as to include two different services: EUMF-K and EUMF-H. The first provides (within seconds) short-term (a few hours) forecasts for home power demand to real-time SmartHG IASs, such as, e.g., EBR. The second provides long-term (e.g., up to a week) forecasts for home power demand.

Re-design of Communication Protocols The communication protocols between home devices and HIASs have been re-designed in order to integrate equipment from DEVELCO in the SmartHG Home Area Network (HAN). This required an adaptation of protocols for meshed ZigBee communication. The way data where collected from home devices had to change in particular with respect to the communication path towards the Database and Analytics (DB&A). Furthermore, a control interface towards home devices was implemented. These devices can be controlled directly by issuing ZigBee control commands or by using a support JavaScript Object Notation (JSON) data format to communicate with the DEVELCO home automation middleware called SmartAMM.

Security Issues The design work has been extended with the design of security for the HAN by using Datagram Transport Layer Security (DTLS) with RESTful web services.

Table 2.1: Mapping between SmartHG tasks inside WP3 and chapters of this deliverable

Task	**Task Name**	**Chapters**
T3.1	Design and Development of Open Standard Internet-based communication between Home Devices and IASs	Chapter 6
T3.2	Design and Development of Open Standard Internet-based communication between IASs	Chapter 7
T3.3	Design and Development of home EUMF service	Chapter 4
T3.4	Design and Development of home EBR service	Chapter 3
T3.5	Design and Development of home EUR service	Chapter 5

2.4 Outline

This deliverable is organised as follows. Chapters 3, 4 and 5 describe the advances in the design of EBR, EUMF, and EUR, respectively. Furthermore, Chapters 6 and 7 describe the communication protocols between home devices and SmartHG HIASs. The overall results of this deliverable are summarised in Chapter 8. Furthermore, Section 8 describes in detail the advancements of this year HIASs design w.r.t. the first year design of the same services, discusses the current limitations and plans future work. Finally, Table 2.1 maps SmartHG tasks inside WP3 to chapters of this deliverable.

Chapter 3

EBR Service Design Description

The second year version of Energy Bill Reduction (EBR) has been designed so as to be synergic with the Demand Aware Price Policies for Homes (DAPP-H) Grid Intelligent Automation Service (GIAS) (described in Deliverable D4.2.1). Namely, EBR works on the assumption that an Energy Storage System (ESS) is installed and a Plug-in Electric Vehicle (PEV) is used on the home on which it has to be deployed (though one of the two may be not present). Given this, EBR controls both the ESS (by sending charge/discharge commands) and the PEV recharging (by sending tuned charging commands) so that the overall electricity bill is minimised.

Nominal usage for EBR is as follows. EBR should be launched once and for all, and runs forever in order to control both the ESS installed at the home and the PEV recharging. Note that, like the GIAS Demand Aware Price Policies for Substation-Level Energy Storage Control (DAPP-K), EBR is a real-time service, thus it cannot by provided as a Software as a Service (SaaS). On the contrary, it must be installed and executed by the final user, i.e., the residential user (see Deliverable D3.2.2). In this respect, it is analogous to the GIAS DAPP-K, which is executed by a Distribution System Operator (DSO) on a given substation.

3.1 EBR: Input and Output

In this section we describe in detail input and output for EBR (for a high-level view, see Figure 3.1). EBR is an executable program, running on the Home Energy Controlling Hub (HECH) of a residential user home. EBR consists in an infinite loop which, every T seconds (one hour in the EBR evaluation in Deliverable D5.2.1), reads data from home appliances and reacts with commands for both an ESS installed in the home and a PEV plugged in for recharging. Namely, in each iteration of such a loop, occurring at time t, the following information is retrieved:

- The remaining capacity of the ESS (in kWh) at time t. This information is directly available from the ESS sensors.
- The remaining capacity of the PEV (in kWh) at time t. Some special value (e.g., -1) is used for when the PEV is not plugged in. This information is directly available from the PEV sensors.
- How many hours the PEV will stay plugged in. This information is provided by the user when the PEV is plugged.

- The power demand (in kW) from all other appliances in the home at time t. This information is available from smart meters through the HECH.
- The cost of energy at time t (in EUR/kWh). This information may be either fixed, if a Time of Usage (ToU) tariff is used, or to be retrieved if it is the Inclining Block Rate (IBR) tariff output by DAPP-H (see Deliverable D4.2.1). In this latter case, an auxiliary process, running in parallel with the actual controller, downloads (once a day) from the Internet the new prices when they are ready, and feeds them to EBR.

Moreover, EBR may be customised with the following parameters:

- a constant representing the maximum power which the user may demand at any time (from the home energy contract).
- the maximum power rate (in kW) for both the ESS and the PEV;
- the round-trip efficiency for both the ESS and the PEV;
- the maximum capacity (in kWh) for both the ESS and the PEV.

Finally, EBR outputs the charge/discharge action at time t for the ESS, and a charge action at time t for the PEV (if present).

3.1.1 EBR: Algorithm

The input-output behaviour described in Section 3.1 is achieved by setting up, for each time t, a Mixed-Integer Linear Programming (MILP) problem. Such MILP problem is based on a forecast of the home appliances demand in the a number N of future time-slots after t. For the PEV, it is the user responsibility to say for how many hours it will stay plugged for recharging. Such forecast is computed using the Energy Usage Modelling and Forecasting for Control (EUMF-K) service, basing on the appliances demand recorded in the last M time-slots. Thus, the MILP problem is defined so as to minimise the energy bill for the residential user under the following constraints, for each of the N future time-slots (including t):

- it is possible to either charge or discharge the ESS, and not both;
- the PEV may be charged only when present;
- the ESS capacity at the next time-slot is obtained by applying a charge/discharge action in the current time-slot to the ESS capacity, by also considering the round-trip efficiency (the starting ESS capacity at time-slot t is the one read from ESS sensors);
- the PEV capacity at the next time-slot is obtained by applying a charge action in the current time-slot to the PEV capacity, by also considering the round-trip efficiency (the starting PEV capacity at time-slot t is the one read from PEV sensors);
- the resulting ESS (respectively, PEV) capacity must always be within 0 and the maximum ESS and (respectively, PEV) capacity;

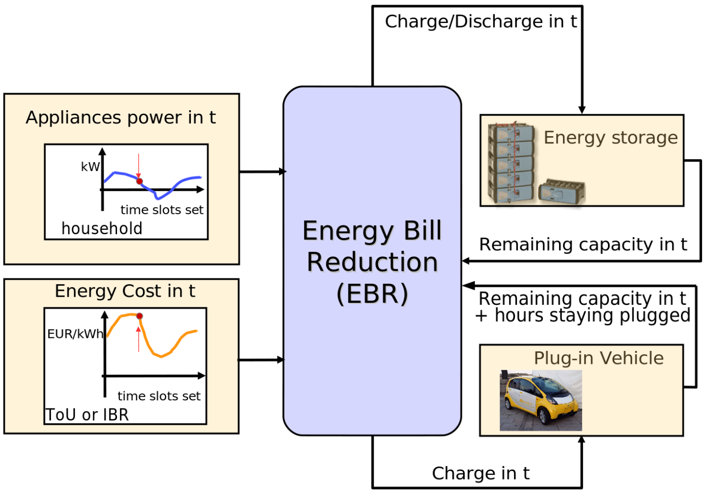

Figure 3.1: EBR input and output. Acronyms used: ToU: Time of Usage, IBR: Inclining Block Rate. See Section 3.1.

- the power actually required by the home results from the appliances demand plus the charge/discharge action for the ESS, the charge action for the PEV, and the power production from renewable sources (to be subtracted);
- the power computed in the previous point must be below the maximum contractual power of the home.

Once the MILP problem has been created, it is solved by means of a MILP solver (either CPLEX of GLPK). Finally, since the required actions at time t for the ESS and the PEV are decision variables in the MILP problem, the value for such actions is extracted from the solution of the MILP problem returned by the MILP solver.

Chapter 4

EUMF Service Design Description

In the second year of the SmartHG project, the Energy Usage Modelling and Forecasting (EUMF) service has been split in two new services, namely Energy Usage Modelling and Forecasting for Control (EUMF-K) and Energy Usage Modelling and Forecasting for Homes (EUMF-H). In this section we first motivate such an architectural modification (Section 4.1), and then we separately describe each service.

4.1 From EUMF to EUMF-K and EUMF-H

A demand forecasting service is needed by two SmartHG Intelligent Automation Services (IASs), namely the Energy Bill Reduction (EBR) (see Section 3) and the Demand Aware Price Policies for Substation-Level Energy Storage Control (DAPP-K) service (see Deliverable D4.2.1). In fact, both EBR and DAPP-K need to compute a forecast for the future power demand. Namely, DAPP-K needs to know the forecast of the aggregated power demand at the substation level (see Deliverable D4.2.1), whilst EBR needs to know the aggregated power demand from home appliances (see Section 3). However, because of their real-time constraints, such services cannot rely on a Software as a Service (SaaS) REpresentational State Transfer (RESTful)-based service for retrieving such forecasting. In fact, a network connection may be not always available, and in any case typical network delays may lead to unacceptable behaviours. On the contrary, EBR and DAPP-K need *short-term* forecast, to be computed quickly.

However, a SaaS providing *long-term* power demand forecasting to human users (either residential users or Distribution System Operators (DSOs)) is also needed. Such SaaS, which has not real-time constraints, may also improve the demand forecasting by retrieving information from other publicly available Web services, e.g. of weather forecasting.

In order to fulfil both requirements described above, in this second year we split the EUMF service in two different services. Namely, EUMF-K is a service to be used by real-time services such as EBR and DAPP-K for short-term forecasting, whilst EUMF-H is a SaaS service providing possibly long-term forecasting to human users. In the following, we discuss each of these two services separately.

4.2 EUMF-K Service Design Description

In this section, we describe the EUMF-K service. Nominal usage for EUMF-K is as follows. EUMF-K should be launched once and for all, and runs forever in order to continuously

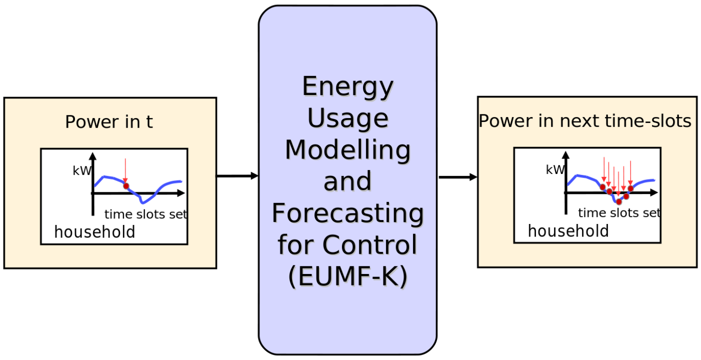

Figure 4.1: EUMF-K input and output. See Section 4.2.1

provide power demand forecast, given the historical input power demand. Note that, being an auxiliary service of a real-time service (either EBR or DAPP-K), EUMF-K is a real-time service too, thus it cannot by provided as a SaaS. On the contrary, it must be installed and executed by the final user (see Deliverable D3.2.2) together with the main service, i.e., either the residential user running EBR or the DSO running DAPP-K. Note however that usage of EUMF-K is not limited to these two IASs, but may be extended to any service which needs a forecast of power demand, given historical power demand.

4.2.1 EUMF-K: Input and Output

In this section we describe in detail input and output for EUMF-K (for a high-level view, see Figure 4.1). EUMF-K is an executable program, running on the Home Energy Controlling Hub (HECH) of a residential user home. EUMF-K consists in an infinite loop which, every T seconds (one hour in the EUMF-K evaluation in Deliverable D5.2.1), reads historical power remand and returns power demand forecast. Namely, in each iteration of such a loop, occurring at time t, EUMF-K reads the historical power demand at time t, and returns the forecasted power demand for the next N time-slots of duration T, being N a customisable parameter of EUMF-K. A further customisable parameter is M as the length of the historical power demand used for the computation (see Section 4.2.2).

4.2.2 EUMF-K: Algorithm

The input-output behaviour described in Section 4.2.1 is achieved as follows. For the sake of clarity, we will suppose that the length of all time-slots (both in input and in output) is one hour, but our algorithm is easily extensible to other time-slot lengths. For each power demand to be forecasted in a given hour in the future, we consider the mean value of the input power demand and the power demand in the previous $\frac{M}{24}$ time-slots (which are internally recorded by EUMF-K itself), referring to the same hour of the day. As an example, in order to forecast power demand between 8 and 9 PM, we will consider the demand in all past time-slots referring to the hour between 8 and 9 PM. Finally, such average is weighted so as to prefer more recent time-slots than older time-slots. As an example, in the EUMF-K evaluation described in Deliverable D5.2.1, the previous day is weighted 0.5, the preceding day 0.25, then 0.125 and so on till the tenth day.

4.3 EUMF-H Service Design Description

In the SmartHG project, the design of EUMF-H service is part of Task 3.3. In this chapter, we describe the specification of the EUMF-H service (mainly which are inputs and outputs of the service), and we briefly describe the algorithms used.

4.3.1 EUMF-H Specification

The aim of EUMF-H service is modelling home energy consumption, as well as local or greenhouse generation. Together with weather information, historical data, and house models, consumption/generation models enable EUMF-H to forecast energy consuption/generation. Weather data and forecast are taken in real time from global Internet services. House models are built starting from geometrical data about houses and TechDom Modeling Tools that allow to deal with incomplete information.

4.3.1.1 EUMF-H Input

The main inputs of the EUMF-H services are:

- historical data about energy consumption/generation;
- GPS data about house location;
- historical weather data and wheater forecast;
- house geometry and house heat parameters;
- pattern usage information;
- house models for energy consumption;

Historical data about energy consumption/generation are stored so far in a internal database in Minsk, not yet integrated in the SmatHG DB&A service. Weather information is taken from global services in the Internet (see Sect. 4.3.2.2). Finally, fuzzy login helps in building flat energy consumption models when some data are missing.

4.3.1.2 EUMF-H Output

The EUMF-H service yields as output:

- historical data about flat energy consumption;
- forecasted data about flat energy consumption;
- historical data about flat energy generation;
- forecasted data about flat energy generation.

4.3.2 EUMF-H Design

In this section, we briefly describe how EUMF compute its outputs and main technologies used by EUMF-H computations.

4.3.2.1 Forecasting ability

In presence of missing data, forecasting benefits from closed methods provided by the Energy Usage Reduction for Homes (EUR-H) service. The EUR-H service uses fuzzy sets mathematics encapsulated in the **libflogic.so** dynamic library, which has been developed for the SmartHG project.

The main forecasting algorithm is shown in Figure 4.2.

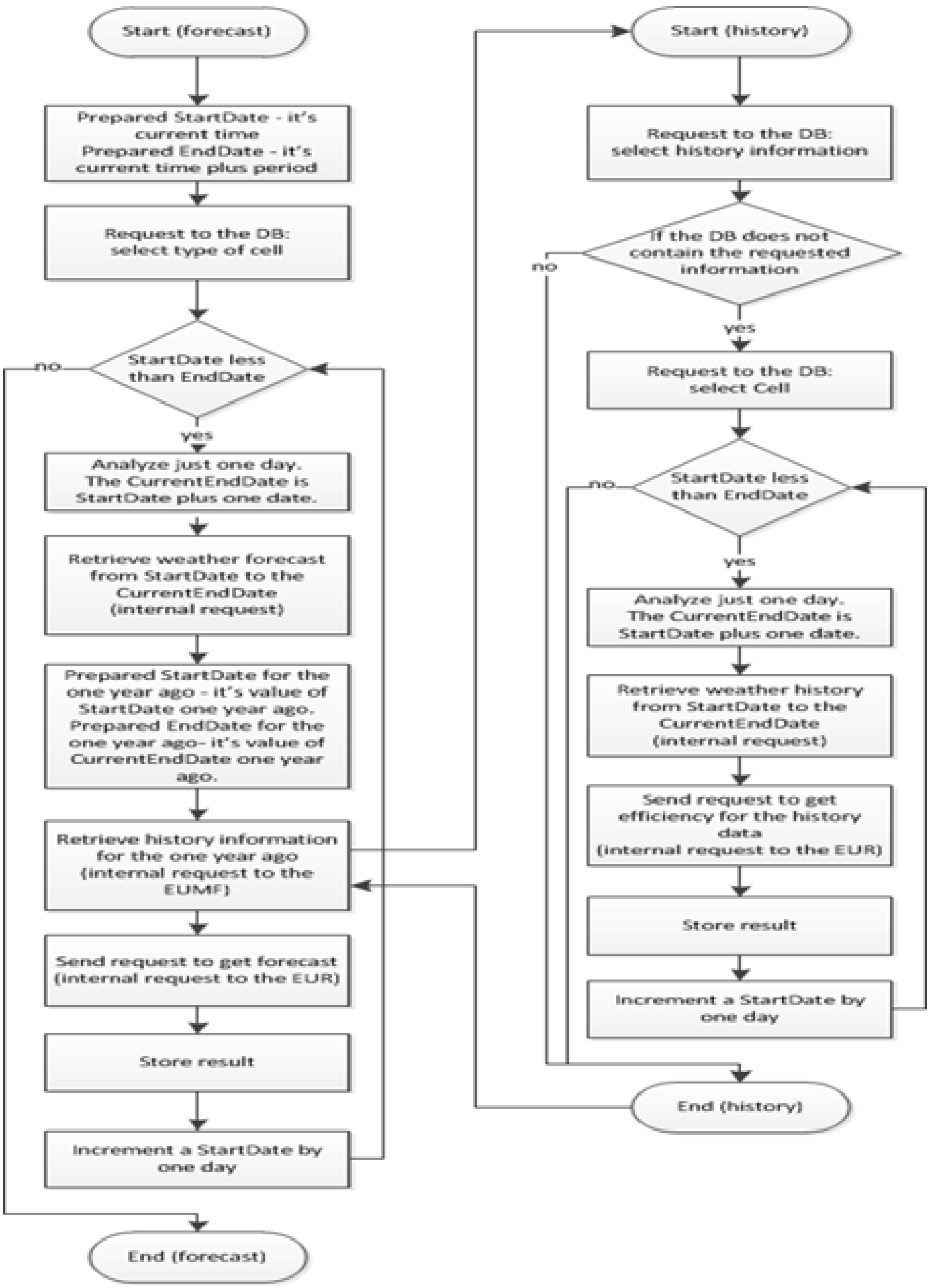

Figure 4.2: EUMF-H service main working algorithm

4.3.2.2 Weather Information Gathering

At this stage of the project work, we have decided to use the HAMweather service (`http://www.hamweather.com/support/documentation/`) as global weather service, in order to get information about weather.

This service has the following features:

- Free developer account;
- Access limitation: 750 queries per day, 15 queries per minute;
- 14 days weather forecast with a per-hour scale;
- Per-hour historical weather data.

Chapter 5

EUR Service Design Description

In the second year of the SmartHG project, the Energy Usage Reduction (EUR) service has been split in two new services, namely Energy Usage Reduction for Control (EUR-K) and Energy Usage Reduction for Homes (EUR-H). In this section we first motivate such an architectural modification (Section 5.1), and then we separately describe each service.

5.1 From EUR to EUR-K and EUR-H

Heating, Ventilating, and Air Conditioning (HVAC) usage in residential homes is becoming more and more widespread. When present, electric heating accounts for more than one third of the total energy consumed in a residential home. Accordingly it is quite natural to focus our EUR service on reducing electrical energy usage for HVAC. We also note that the increasing presence of HVAC and the expected increasing presence of Plug-in Electric Vehicles (PEVs) is one of the main scenarios expected to lead, in the near future, to electricity demand peaks challenging Electric Distribution Network (EDN) management from Distribution System Operators (DSOs).

To attain our goals we design a service, named EUR-K (Section 5.2) in the following, pursuing two main objectives. First, to support users in decreasing consumption of electrical energy for home heating. Second, to support users (through Energy Bill Reduction (EBR)) in reducing their electric bill for home heating.

Of course a residential user may also be interested in evaluating the overall efficiency of the electrical devices in his home. To address such a need we also explored the possibility of developing an EUR service focusing on this point. In the following we name EUR-H such a service (Section 5.3).

5.2 EUR-K Service Design Description

Design of the EUR-K service is part of Task T3.5 of the SmartHG project. In this section, we describe the specification of the EUR-K service in terms of its inputs and outputs.

EUR-K focuses on electricity consumption due to heating and cooling. This is justified by the fact that more than one third of the total electrical energy consumption in buildings (see, e.g. [1]) is used for space heating and cooling.

EUR-K estimates *average* home thermal insulation and thermal capacitance from sensor measurements about: indoor and outdoor temperature, electric consumption from home heat pumps. Here the *average* is taken over user behaviours such as how often

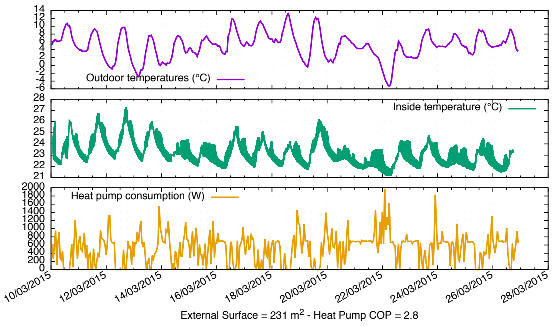

Figure 5.1: EUR-K input example

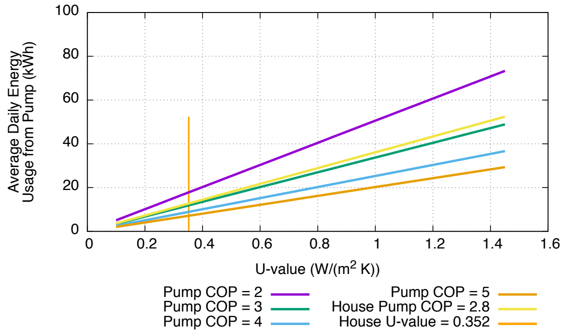

Figure 5.2: EUR-K output example

windows are opened to change air, etc. Estimation of such parameters allows us to relate electrical measurements and heat pump Coefficient of Performance (COP) to home *average* thermal parameters (e.g., U-value).

EUR-K helps user to reduce usage of electrical energy (for home heating) by using its estimated thermal insulation and the value of the heat pump COP, to support users in evaluating home retrofit options (e.g., increase thermal insulation or increase heat pump COP) aiming at improving energy efficiency.

EUR-K helps user to reduce their electricity costs (for home heating) by providing its estimated home thermal parameters (insulation and capacitance) to the (third year) SmartHG EBR service. On such a basis, the latter will use home thermal capacitance as an Energy Storage System (ESS) and compute control strategies for the heat pump so as to shift electrical consumption (due to heating) towards low tariff areas.

5.2.1 EUR-K Specification

The EUR-K service provides energy consumption predictions starting from a house thermal model and historical data.

5.2.1.1 EUR-K Input

Inputs of the EUR-K service are data gathered from Panoramic Power sensors deployed in Svebølle test-bed user homes during the second year of SmartHG.

More specifically, EUR-K uses the following data:

- indoor temperature from deployed sensors
- outdoor temperature from deployed sensors
- heat pump electrical energy consumption from deployed sensors
- heat pump Coefficient of Performance (COP)
- total house external surface

An example of input can be seen in Fig. 5.1.

5.2.1.2 EUR-K Output

Outputs of the EUR-K service can be categorised as follows.

Parameter Identification The first step consists in identifying house parameters, namely the average thermal insulation and the average thermal capacitance of the house, starting from the input data.

Computed parameters reflect not only physical characteristics of the house but also inhabitants habits. This stems from the fact that we use real data collected from deployed sensors. In fact, if a family usually leaves windows open during the morning, this will be reflected in a greater heating consumption, which in turn will result in smaller *average* insulation.

Computed parameters are useful in the main control loop of the SmartHG project. We plan to use parameter values in next year iteration of the EBR service, in order to compute control strategies for heat pumps.

Suggestions Computation The second step consists in computing consumption predictions, for different values of the thermal insulation and of the heat pump COP. EUR-K output is shown in terms of a plot (see Fig. 5.2 for an example), showing predictions on the average daily energy consumption as a function of the overall *average* heat transfer coefficient (U-value) estimated by EUR-K. The U-value inversely depends on the thermal insulation and on the total house external surface. Fig. 5.2 shows curves for some meaningful value of heat pump COP.

EUR-K output is a decision support for users, that can easily evaluate economical benefits obtained by a better house thermal insulation (thus moving leftwards on the x-axis of Fig. 5.2) or by using a more efficient heat pump (thus choosing a lower curve in Fig. 5.2).

5.2.2 EUR-K Algorithm

In this section, we outline the algorithms EUR-K is based on.

We approximate the heat dynamics in a home using the *thermal-electrical analogy* outlined in Table 5.1 (e.g., see [2] and citations thereof for further details).

With such an approach the home is modelled as an RC electrical circuit (see Figure 5.3) and each of the input/output elements of EUR-K is represented in such a circuit. Namely: R corresponds to the house thermal resistance (*insulation*), C corresponds to the house thermal capacitance, T_{out} is the outside temperature. T_{in} is the inside temperature and Φ_P is the heat flux generated by the heat pump.

Resting on the above considerations, EUR-K computation is organised in two steps.

1. First, since values for R and C are unknown, we compute (*parameter identification*) such values taking as input historical data (with a 10 second sampling time) about (see Fig. 5.3): outside temperature (T_{out}), inside temperature, (T_{in}), heat pump average power ($P(t)$), heat pump Coefficient of Performance (COP) (η). Then, we look for those values of parameters R and C that minimise the mismatch between house temperatures as measured by sensors and house temperatures as predicted using the electrical model in Fig. 5.3. Note that such a computation does not return us the thermal insulation value provided by the physical characteristics of the house but rather its value when home inhabitants behaviours are taken into account.

	Thermal		Electrical	
	Parameter	Unit	Parameter	Unit
Source	Temperature T	[K]	Voltage V	[V]
	Heat flux Φ	[W],[J/s]	Current I	[A], [C/s]
Element	Conductivity k	[W/K/m]	Conductivity σ	[A/V/m]
	Stored Heat Q	[J]	Stored charge q	[C]
	Thermal resistance R_{ther}	[K/W]	Electrical resistance R_{elec}	[Ω], [V/A]
	Thermal capacitance C_{ther}	[J/K]	Electrical capacitance R_{elec}	[F], [C/V]

Table 5.1: Thermal-electrical analogy

2. Once we have estimated house thermal parameters R and C we can easily compute the home *average* U-value, since we know the home external surface.
3. Using our model in Fig. 5.3 again we can compute indoor temperature and electrical energy consumption time evolution in different scenarios, by changing values of the U-value and the heat pump COP.

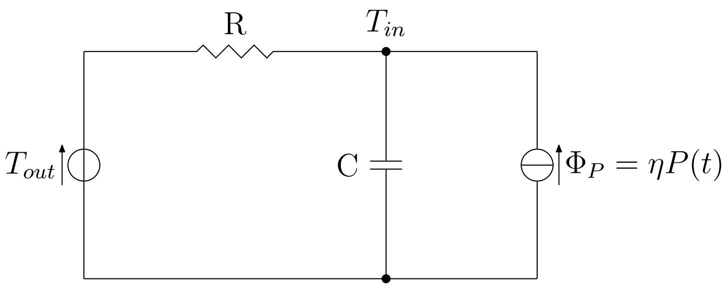

Figure 5.3: Home thermal model used for the EUR-K algorithm.

5.3 EUR-H Service Design Description

In the SmartHG project, the design of the EUR-H service is part of Task T3.5. In this chapter, we describe the specification of the EUR-H service (mainly which are inputs and outputs of the service).

5.3.1 EUR-H Specification

The main goal of the EUR-H service is energy consumption reduction. To this end, *efficiency* computation is one of the EUR-H main features.

Energy usage efficiency cannot be defined without an energy usage modeling. A suitable energy usage model has to be defined, by using past and real time data. For this reason, modelling results obtained by the Energy Usage Modelling and Forecasting (EUMF) service are essential inputs for the EUR-H service. On the other hand, many features of the EUR-H service, based on fuzzy logic, that deal with uncertanty conditions, are in turn useful for the EUMF service to provide useful results.

In this second year iteration of the EUR-H service, we carried out the following steps.

- We designed the general structure of the EUR-H service software;
- We developed and implemented all main features of the EUR-H service;
- We designed the exchange data interfaces, as well as data formats;
- We carried out new mathematics investigation and we include results in the EUR-H service implementation.

5.3.1.1 EUR-H Input

The main inputs of the EUR-H services are:

- historical data about energy consumption/generation;
- weather forecast;
- models of flats energy consumptions.

5.3.1.2 EUR-H Output

The main output of the EUR-H service is the energy usage efficiency of residential homes.

Chapter 6

Design of Open Protocol for Home Devices

In the second period of SmartHG, the Home Area Network (HAN) is constructed from a ZigBee mesh network [3]. This section introduces the ZigBee HAN and describes the open protocol design specified for supporting the SmartHG Intelligent Automation Services (IASs) during the second period of the project [4].

6.1 ZigBee Home Area Network: Overview and Scope

These networks forms stubs in the Internet of Things architecture. Figure 6.1 show an overview a a simple HAN installation.

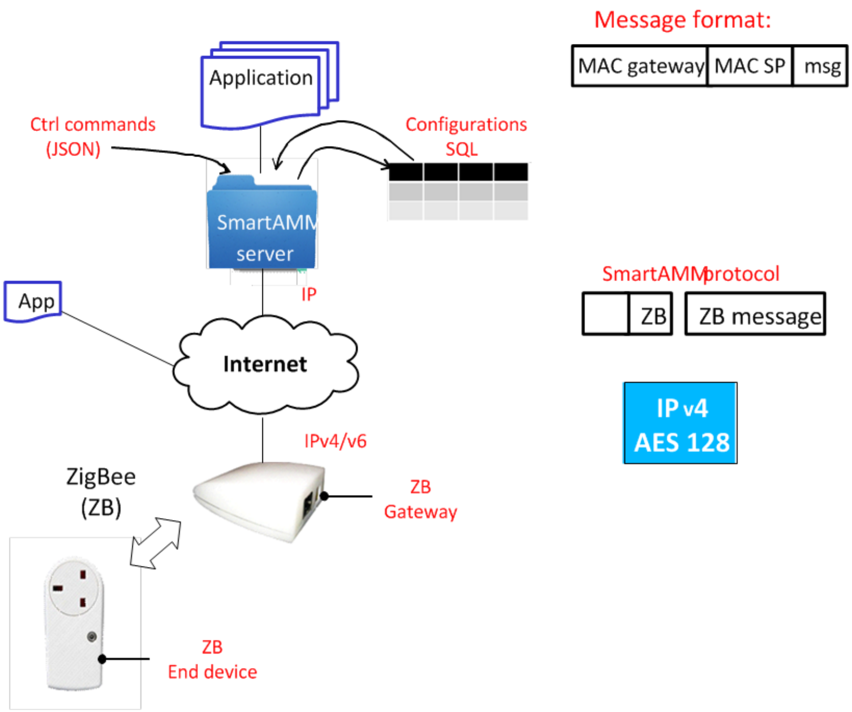

Figure 6.1: Home area network with ZigBee devices from Develco Products.

In the figure the DEVELCO ZigBee gateway is shown as a stand-alone box. The ZigBee gateway has the role of providing IP network connectivity to the HAN. This is accomplished through a stateful mapping of IP addresses to ZigBee endpoints by using their unique MAC addresses as identifiers thus creating a set of MAC service points (MAC SP). Hence, an IEEE 802.15.4 frame in the ZigBee HAN will use the MAC address of the gateway as source/destination address and the MAC SP as the destination/source address for delivering a message (msg) over ZigBee.

In addition, to the stand-alone gateway (shown in Figure 6.1) the project is also working with a DEVELCO ZigBee gateway dongle that can be integrated easily with the Home Energy Controlling Hub (HECH) using serial communication over USB.

Currently, one IPv4 is supported by the ZigBee gateway.

6.2 ZigBee Mesh Networking

The DEVELCO home automation equipment comes with a tool for diagnostics and troubleshooting of the ZigBee mesh network. Figure 6.2 and 6.3 show examples of the tool in action. Figure 6.2 shows the telegrams which are sent and received in the ZigBee mesh

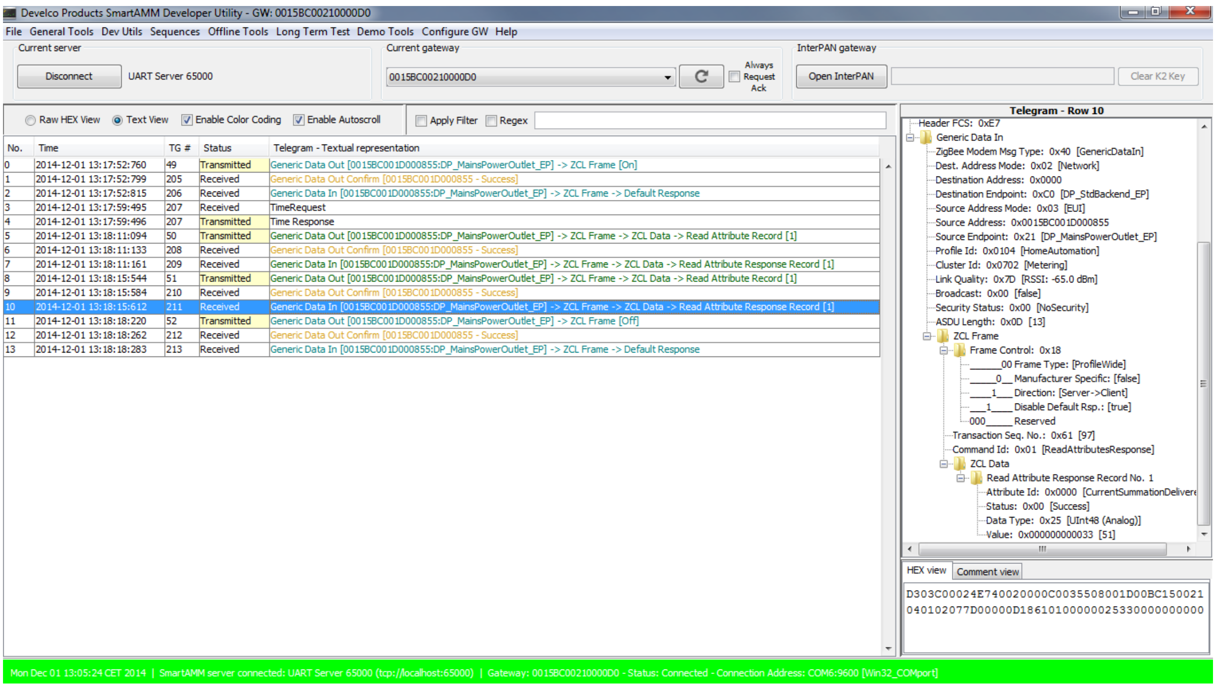

Figure 6.2: SmartAMM developer utility.

and they are captured in the DEVELCO Java application name "SmartAMM Developer Utility". The test is run with a ZigBee wall-plug i.e., a smart plug connected with a boiler and that connects with a ZigBee gateway.

Figure 6.3, shows the configuration of the USB ZigBee gateway which is working as COM port forwarding. The DEVELCO Java application named "UART Gateway Manger" is forwarding the serial port data of `COM6` to a SmartAMM server which is located in `localhost:61001` as shown in Figure 6.3.

6.2.1 SmartAMM Middleware

Typically, home automation applications based on DEVELCO technology will make use of the SmartAMM middleware supplied together with the hardware products. The mid-

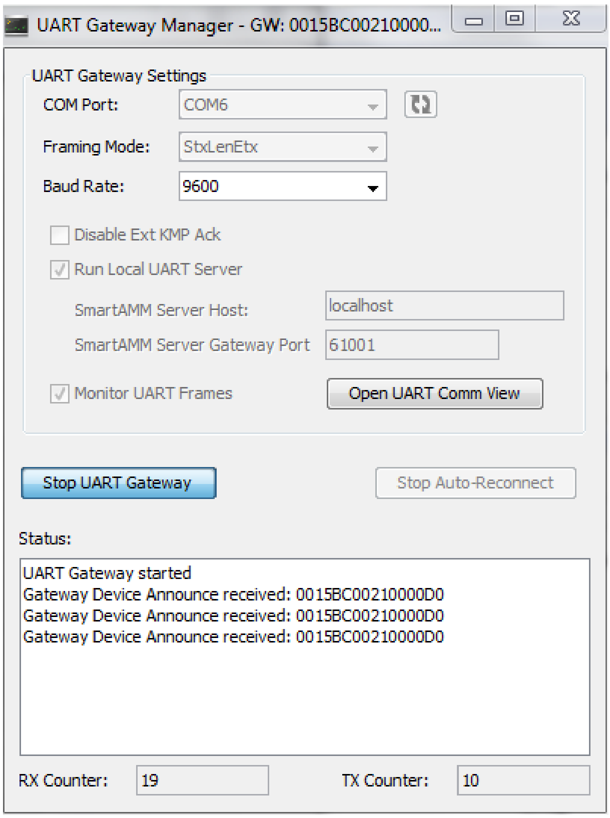

Figure 6.3: UART gateway manager.

dleware is written in Java and code and documentation is provided free of charge but without warranty. Ths allows the customers of DEVELCO to customize their back-end solutions. In similar manner, the SmartAMM middleware is used by the SmartHG project to customize the solution to fit the need of the Database Service (DBService).

The SmartAMM service from DEVELCO offers a rich set of interfaces. The list below summarizes the interfaces chosen for our prototype implementation.

- SQL data interface: The SmartAMM middleware supports SQL data interface for data receiver from the ZigBee devices.
- JavaScript Object Notation (JSON) for control signaling: The SmartAMM supports and interface to interpret control signaling as JSON formatted messages.
- ZigBee native interface: It is possible to natively "tunnel" ZigBee messages through the SmartAMM service (Not shown in the figure).
- IPv4 to IPv6 protocol mapping (future work). Currently, only IPv4 is supported. The next generation of the DEVELCO gateway that was released in October 2014 also support IPv6.

The SmartAMM middleware runs a proprietary protocol that essentially encapsulates the ZigBee message.

Chapter 7

Design of Open Protocol for IAS

The Intelligent Automation Services (IASs) developed in the second year of the SmartHG project are dependent on each other. The interdependencies between such IASs are shown in Figure 7.1 (we refer the reader to Deliverable D4.2.1 for the description of the Grid Intelligent Automation Services (GIASs)), together with the communication between Database and Analytics (DB&A) and the Home Energy Controlling Hub (HECH),

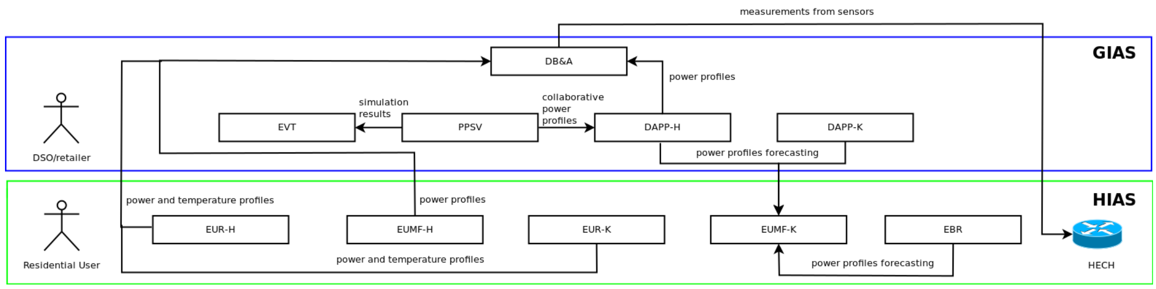

Figure 7.1: Interdependencies among SmartHG IASs. Arrows indicate when a service depends on another service.

In order to allow such communication between IASs, in this second year we split the services in two categories as follows.

- IASs without real-time requirements: DB&A, EDN Virtual Tomography (EVT), Price Policy Safety Verification (PPSV), Demand Aware Price Policies for Homes (DAPP-H), Energy Usage Reduction for Homes (EUR-H), Energy Usage Reduction for Control (EUR-K) and Energy Usage Modelling and Forecasting for Homes (EUMF-H);
- IASs with real-time requirements: Energy Usage Modelling and Forecasting for Control (EUMF-K), Energy Bill Reduction (EBR) and Demand Aware Price Policies for Substation-Level Energy Storage Control (DAPP-K).

Given this, the nominal usage for IASs without real-time requirements is through a Web service where authenticated users may invoke the IAS by providing the required inputs. Both inputs and computed outputs of each IAS invocation are stored in a REpresentational State Transfer (RESTful) service dedicated to the given IAS. Thus, communication between IASs without real-time requirements is simply performed by accessing the RESTful service of the target IAS. Since creation of and interaction with RESTful service is well understood [5], this allows us to implement IASs communication in a simple and reliable way.

As for the IASs with real-time requirements, the nominal usage is to download the object code from a Web service (upon authentication), and to install it on the user premises. In this case, communication directly takes place as EUMF-K is embedded in the code of both EBR and DAPP-K.

For a more detailed discussion on how the Web services and the RESTful service mentioned above are organised, we refer the reader to Deliverables D3.2.2 and D4.2.2.

Chapter 8

Conclusions

In this deliverable we described the second year version of the design of all SmartHG Home Intelligent Automation Services (HIASs), i.e., of the SmartHG services which work on the residential homes side. Prototypes of such services are described in Deliverable D3.2.2. In the following, we present advancements with respect to the first year iteration, main limitations and outline directions for future work.

8.1 Advancements

In this section, we discuss the main advancements we obtained with this year SmartHG HIASs design w.r.t. their first year versions. To this aim, we discuss the enhancements for each HIAS.

EBR: The first year version of Energy Bill Reduction (EBR) consisted in a plan describing how to turn on/off the home appliances. It was the residential user responsibility to apply this plan, so as to minimise the energy bill. In this second year, the EBR directly drives selected home appliances (i.e., the Energy Storage System (ESS) and the Plug-in Electric Vehicle (PEV)), in a way which is transparent to the residential users. This results in a more usable and reliable service.

EUMF-K: The Energy Usage Modelling and Forecasting for Control (EUMF-K) service provides a forecasting service to real-time Intelligent Automation Services (IASs). It has has been developed this year, thus it cannot be compared with any first year version.

EUMF-H: The second year design of EUMF-H completed and improved the algorithms on which its first year ancestor Energy Usage Modelling and Forecasting (EUMF) relied upon. This includes a new thermostatic model, able to improve consumption forecasting and to provide new information to the Energy Usage Reduction for Homes (EUR-H) service.

EUR-K: The Energy Usage Reduction for Control (EUR-K) service supports users in evaluating home retrofit options (e.g., increase thermal insulation or increase heat pump Coefficient of Performance (COP)) in order to decrease consumption of electrical energy for home heating. It has been developed this year, thus it cannot be compared with any first year version.

EUR-H: The second year design of EUR-H completed and improved the algorithms on which its first year ancestor Energy Usage Reduction (EUR) relied upon. This includes releasing a new version of the fuzzy logic library EUR-H is built upon, as well as integration of the new information provided by the Energy Usage Modelling and Forecasting for Homes (EUMF-H) service outlined see above.

Home communication protocols: The communication protocols between home devices and HIASs had to be re-designed in order to accommodate DEVELCO home automation middleware SmartAMM.

IASs communication protocols: The communication protocols between IASs have been completely re-designed. Namely, in the first year such communications were centralised in the Database and Analytics (DB&A) whereas in this second year iteration, we built separate REpresentational State Transfer (RESTful) services for each of the IASs. This makes communication between IASs direct.

8.2 Limitations and Future Work

Limitations of the second year HIAS design, together with the planned actions to overcome them, are discussed in Table 8.1.

Table 8.1: Limitations for the second year design of HIASs & how we plan to overcome such limitations in the third year HIASs design.

Topic/HIAS	Limitations of second year	Future work for third year
EBR	EBR is currently based on a simplified model of both the ESS and the PEV	In order to improve results with currently available technology, we plan to develop more precise models for both the ESS and PEV. Furthermore, we also plan to use other available energy storage appliances already present in residential homes such as heat pumps. To this aim, an integration with the EUR-K service (that estimates home thermal capacitance) will be realised.
EBR	It is not possible to estimate if it is indeed convenient to buy an ESS (with given characteristics), install it at home and let EBR drive it, before buying the ESS itself.	A Web-based service able to perform such an estimation is currently being tested. It will be released in the third year.
EUR-K	The current design of EUR-K models the whole home as a single-mesh electric circuit.	We plan to investigate how to model the home as a multiple-mesh electric circuit modelling each room and each heat pump separately. Furthermore, we plan to design a Graphical User Interface (GUI) to assist the user in providing information to model the home.

Table 8.1: Limitations for the second year design of HIASs & how we plan to overcome such limitations in the third year HIASs design.

Topic/HIAS	**Limitations of second year**	**Future work for third year**
EUMF-K	EUMF-K currently works by performing a weighted average on the input power demand.	In order to improve power demand forecasting results, we plan to design an algorithm based on more complex, still fast, computations.
EUR-H, EUMF-H	Many smart appliances currently available on the market are able to provide some of the data needed by both EUR-H and EUMF-H.	EUR-H and EUMF-H will be enhanced so as to be able to exploit information from smart appliances currently available on the market.
Home communication protocols	The current iteration of the design of open protocols for home devices is limited by lack of end-to-end interoperability of IPv6 in the Home Area Network (HAN)	In the third year, end-to-end interoperability of IPv6 in the HAN will be added
IASs communication protocols	The current iteration of the design of open protocols for IASs communication requires each service to know the exact Unified Resource Location (URL) of the target service	In the third year, we will investigate how to introduce a directory system for service discovery.
Other	Smart-meters in the residential home are not fully integrated with the HAN and the Home Energy Controlling Hub (HECH)	The possible ways the smart-meters in the residential home can be integrated with the HAN and the HECH will be investigated.

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