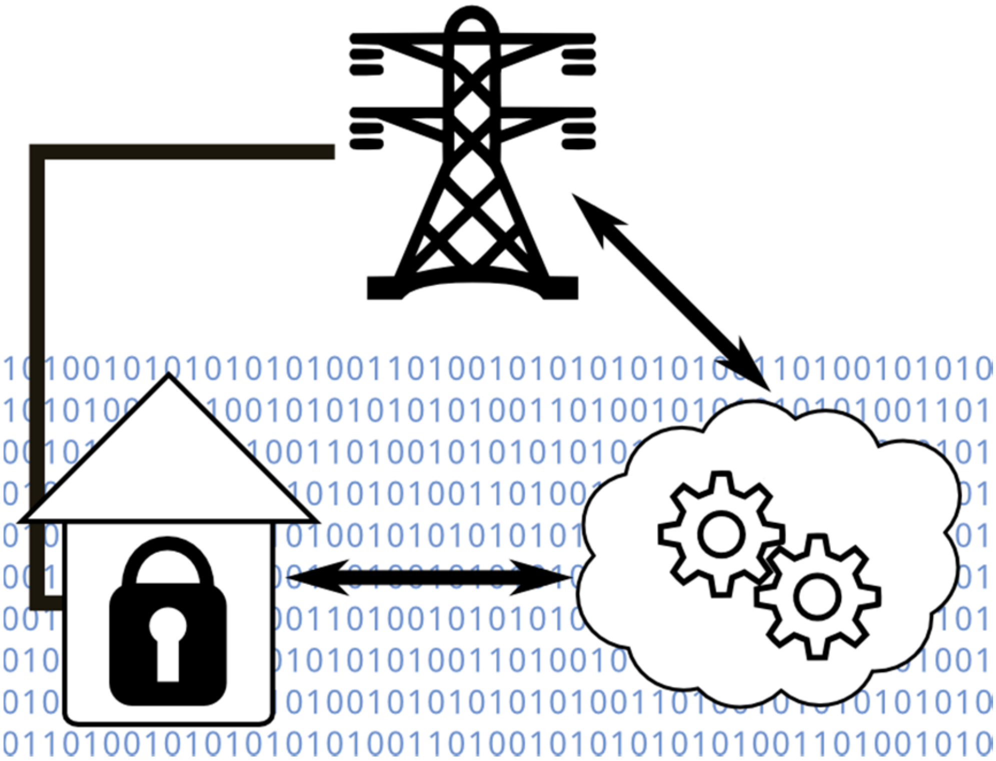
PRIVACY ENFORCEMENT IN A COST-EFFECTIVE **SMART GRID**

Electrical and Computer Engineering
Technical Report ECE-TR-20



AARHUS UNIVERSITY
DEPARTMENT OF ENGINEERING

DATA SHEET

Title: Privacy Enforcement in a Cost-Effective Smart Grid

Subtitle: Electrical and Computer Engineering

Series title and no.: Technical report ECE-TR-20

Author: Søren Aagaard Mikkelsen
Department of Engineering – Electrical and Computer Engineering, Aarhus University

Internet version: The report is available in electronic format (pdf) at the Department of Engineering website http://www.eng.au.dk.

Publisher: Aarhus University©

URL: http://www.eng.au.dk

Year of publication: 2014 Pages: 28

Editing completed: April 2014

Abstract: In this technical report we present the current state of the research conducted during the first part of the PhD period. The PhD thesis "Privacy Enforcement in a Cost-Effective Smart Grid" focuses on ensuring privacy when generating market for energy service providers that develop web services for the residential domain in the envisaged smart grid. The PhD project is funded and associated to the EU project "Energy Demand Aware Open Services for Smart Grid Intelligent Automation" (SmartHG) and therefore introduces the project on a system-level. Based on this, we present some of the integration, security and privacy challenges that emerge when designing a system architecture and infrastructure. The resulting architecture is a consumer-centric and agent-based design and uses open Internet-based communication protocols for enabling interoperability while being cost-effective. Finally, the PhD report present the envisaged future work and publications that will lead to completion of the PhD study.

Keywords: smart grid, privacy, architecture, infrastructure, energy Internet

Supervisor: Rune Hylsberg Jacobsen

Financial support: The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 317761

Please cite as: Søren Aagaard Mikkelsen, 2014. Privacy Enforcement in a Cost-Effective Smart Grid. Department of Engineering, Aarhus University. Denmark. 28 pp. - Technical report ECE-TR-20

Cover image: Søren Aagaard Mikkelsen

ISSN: 2245-2087

PRIVACY ENFORCEMENT IN A COST-EFFECTIVE SMART GRID

Søren Aagaard Mikkelsen

Aarhus University, Department of Engineering

Abstract

In this technical report we present the current state of the research conducted during the first part of the PhD period. The PhD thesis "Privacy Enforcement in a Cost-Effective Smart Grid" focuses on ensuring privacy when generating market for energy service providers that develop web services for the residential domain in the envisaged smart grid. The PhD project is funded and associated to the EU project "Energy Demand Aware Open Services for Smart Grid Intelligent Automation" (SmartHG) and therefore introduces the project on a system-level. Based on this, we present some of the integration, security and privacy challenges that emerge when designing a system architecture and infrastructure. The resulting architecture is a consumer-centric and agent-based design and uses open Internet-based communication protocols for enabling interoperability while being cost-effective. Finally, the PhD report present the envisaged future work and publications that will lead to completion of the PhD study.

Table of Contents

1

Introduction

The purpose of this progress report is to present the first 1½ years of research and the future plans for completion. The document is informally referred to as a “midterm report” for the PhD progression, and it is part of the evaluation in the PhD qualification exam together with an oral examination.

The PhD research is funded by the EU’s 7th Framework Programme (FP) under the project name “Energy Demand Aware Open Services for Smart Grid Intelligent Automation” (SmartHG) and uses this project as a stepping stone for doing research within the same domain. The support of the EU project entails that all research results must underpin the SmartHG project, but includes a liberty to focus on convergent research areas. Consequently, this also reflects in the focus of the progress report.

To provide insight to the purpose, the current progression, and future work, the report first focuses on the research general domain and narrows the focus on the purpose and hypothesis of the PhD project. This is used as a launch pad for emphasizing the key contributions to the research field. The remainder of the report underpins the contributions with first presenting a background section that presents the details about the SmartHG project. Afterward, a presentation of the research conducted on the basis of SmartHG project. Research problems are identified and addressed in cohesion with the SmartHG project, and the outcome is stressed by a conclusion. Furthermore, future work is decuded and elaborated on the basis of the current research stage.

1.1 Field and Aim of Research

Integration of renewable energy sources, diversion of energy sources, and mission critical power demand, are some of those challenges that the electrical grid operators face today and even more in the future (Ramakumar et al., 1993; Liserre, Sauter, and Hung, 2010; Ming et al., 2010; IEEE, 2013). These challenges are mainly generated by new operational scenarios for the power grid that was not envisioned when it were developed decades ago. Moreover, it has become clear that the rising energy consumption must be produced more environmentally friendly. This is due to general acceptance of the fact that the CO_2-emissions produced by the burning of fossil fuels (IEA, 2013), accumulate more greenhouse gases to the atmosphere which leads to global warming.

To overcome these challenges, it is widely accepted that intelligent control of the electrical grid, also known as the *Smart Grid*, will be part of the solution (Moslehi and Kumar, 2010). The current realization of the smart grid integrates Information and Communication Technology (ICT) into the power grid and facilitates intelligent automation of power systems, such that Renewable Energy Systems(RESs) is able to form an essential part of electrical energy production in the future power grid. However, since current electrical energy storage technologies are not economial viable enough to store the required amount of energy, the electricity must be used more intelligently.

To make the electric energy consumption follow the production, it is possible in many countries to buy electricity from the Distribution Network Operators(DNOs) with a rate structure that depends on the supply and demand (Quinn, 2009). Instead of billing with a constant rate during the year, the electricity will be rated based on the fluctuations in demand and production during the day. These rate structures are often called *dynamic pricing schemes* that have the purpose to provide economic incentive for the consumer to follow a certain pattern. One of the simplest scheme is called Time-Of-Use (TOU) pricing, where consumers are offered two rates, one price in the non-critical hours and one price in the critical hours. Other pricing schemes include critical peak pricing Critical Peak Pricing (CPP-F) that extends the TOU with having critical hours where the electrical price is considerable higher than the normal hours. Consumers that accept the risk for following the most volatile dynamic pricing scheme, achieves the highest potential for reducing their energy bill, since they contribute with the greatest dynamic usage.

The industrical sector have created good business cases for energy service providers such as (GridManager, 2014; Panoramic Power, 2014) that assist companies in electrical energy savings and savings on the electrical energy bill. The main reason for this, is that the electricity consumption can much higher for some companies, which results in energy savings that easily outweighs the setup costs (costs to equipment, installation, maintenance, etc.). Typically, the energy service providers offer measurement equipment, energy surveillance services, and consultancy support for their customers for a system with a low payback time. However, the same conditions do not generally apply for the residential sector, thus a market and a cost-effective solution are still missing to incorporate the residential sector.

The residential sector is responsible for 28% of the global electricity consumption (EEA Report No 6/2008., 2008), and therefore represents a major group with high potential for using electricity more effeciently. Hence, there exist many commercial products that aim at this market. Standalone systems, like intelligent thermostats from (NEST, 2014; Danfoss, n.d.), or intelligent control of lights (LIFX Labs, 2014), but also full-blown home automation systems like (SmartThings, 2014; Ninja Blocks, 2014). Furthermore, there exists multiple projects that attempt to lower the bar for better market penetration for the residential sector (R. Torbensen, 2008; Rovsing et al., 2011). They develop home automation systems that focus on middleware software and software platforms that embrace in-house communication technologies in the Home Area Network (HAN). However, the electricity savings for each residential home are relatively small compared to the investments for equipment there must be installed in each residential house. This has also been identified by (Rune Torbensen, 2011) as a key challenge, and it is suggested that open communication and platform standards, quick time to market applications, and preserving the consumer's privacy as well as their security against eavesdroppers, are key enablers.

Besides creating incentives for the residential consumer, there is still interest for DNOs to get demand-aware service deployed in the residential domain because of the high proportion of global electricity consumption. The DNOs has an interest in affecting the electricity consumption to avoid fluctuations that wear out of cables and substations, but also to avoid power outage and brownouts. Nevertheless, in the current situation there is no system that unifies the DNOs and the residential consumer, since the costs for entering the residential market is too high from the DNO's perspective and this generates a gap.

This PhD project aims at closing that gap by leveraging the SmartHG project (SmartHG-DoW, 2012) through the proposed concept of combining grid services with home automation services in a unified market. Together with creating a service-oriented architecture and a open communication infrastructure, the research will focus on preserving data privacy and security in a cloud-based architecture.

1.2 Hypothesis and Purpose

The hypothesis is constructed in relation to the hypothesis of the SmartHG project but emphasizes the privacy-preserving aspects of the residential consumer.

> It is my hypothesis that the privacy of the residential consumers in the context of smart grid can be enforced in a service-oriented architecture with divergent interests from stakeholders, without losing the ability for being cost-effective, secure, and cooperative in an autonomous manner.

During the PhD study, the research will validate the hypothesis by:

1. Developing and evaluating a privacy-preserving and service-oriented architecture with autonomous and cooperative entities that connects the residential homes and the DNO with intelligent automation services.
2. Developing and evaluating a cost-effective and secure communication infrastructure between the intelligent automation services and the HAN.
3. Developing and evaluating cost-effective and autonomous management entities.

The purpose of the PhD research is to create incentives to the residential consumers while providing a potential balancing service for the DNO without compromising the residential consumers' privacy. This way, more RESs can be integrated into the Electric Distribution Network (EDN) which increases the independence of fossil fuels.

1.3 Contributions to the Research Field

The contributions to the research field are a combination of the work conducted in the "SmartHG framework" and additionally research in extending the autonomously and privacy aspects of the system. The key contributions to the research field are the creation of a smart grid system architecture that are:

- cost-effective for residential consumers and DNOs by having a service-oriented design with Intelligent Automation Services(IASs) deployed in the cloud, and
- allow consumers to own their electrical energy consumption data by physically disjointing the data location into a local and global database controlled by software-based agents that act on the residential consumer's and grid operator's behalf, respectively.

It furthermore includes the design of a smart grid communication infrastructure that

- supports the proposed service-oriented architecture and rests on state-of-the-art open Internet-based protocols using a REpresentational State Transfer (REST) as a architectural style that connects the residential homes and DNOs to the IASs.

1.4 Document Structure

The progress report is divided into four chapters. The introductory chapters introduces research field and generates the foundation of the PhD research. Afterward, excerpts of the research publications conducted[1] are presented together with the future plan for this PhD study. Appendices gives an overview of the past and future work, and furthermore present the content of completed courses in obligation to the rules of the PhD school.

Chapter 1 - Introduction introduces the field of research and the connection to the SmartHG project. It identifies a gap in the current research and states the PhD's hypothesis during the studies together with a number of validation steps.

Chapter 2 - Background gives an overview of the SmartHG project and shows the parts of the SmartHG project that Aarhus University (AU) is responsible of.

Chapter 3 - Privacy-preserving SOA and Infrastructure for the Smart Grid presents the identified challenges and summarizes the results of the conducted research.

Chapter 4 - Conclusion and Future Plans summarizes the work and outlines the future work in the remaining PhD study period.

Appendix A - Publications shows an overview of publications that are related to the PhD project, divided into a scientific and SmartHG part.

Appendix B - Completed Courses lists the courses with appertaining description that was attended during this first 1½ years.

Appendix C - Gantt Chart displays a chart of the future work.

Appendix D - Acronyms gives a list of acronyms used in this progress report.

[1] One accepted and one submitted.

2

Background

This chapter provides the necessary background information for understanding the SmartHG-related concepts which the PhD project leverages. The section will give brief introduction to the SmartHG project and it outlines AU's contributions to the project.

2.1 The SmartHG Project

The SmartHG is a European research and development project that addresses the challenge of lowering carbon economy using ICT. The project has a duration of 36 months and started 1st of October 2012. The corsortium has 11 participants from 6 different countries, where the distribution of expertize is as follows:

- 4 research institutions within the field of computer and electrical engineering,
- 4 energy service providers (Small and Medium Enterprises(SMEs)),
- 2 DNOs, and
- a municipality.

More information about the project's composition and current status can be found on the official website: `http://smarthg.di.uniroma1.it/`.

The motivation for the SmartHG project is based on the large potential that the residential sector has for lowering the global carbon footprint. The residential sector are responsible for 28% (figure from 2005) of the global electricity consumption (EEA Report No 6/2008., 2008), and therefore requires attention in the optimization of the grid. However, the energy savings for each residential home are relatively small compared to the investments for equipment there must be installed in each residential house and therefore has been of minor interest for the DNOs. Nevertheless, the uptake of Electric Vehicles(EVs), Photovoltaic (PV) and Heating, Ventilation, and Air Conditioning (HVAC) on the residential side will continue to stress the EDN more, so a solution for controlling the electrical energy consumption is necessary.

The SmartHG project overcomes the state of affairs by developing a system that appeals both to the residential home users and the DNO. The system consists of IASs that adds value to both parties by providing services that optimizes electrical usage for

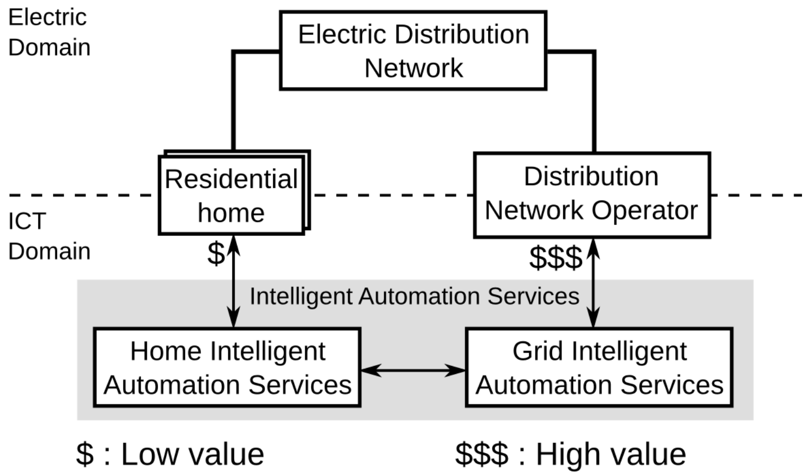


Figure 2.1: Envisaged value added for the residential consumer and the DNO by providing intelligent automation services for both of them. Courtesy of (SmartHG-DoW, 2012).

the residential home users and the DNO as seen in Figure 2.1. The business case is built around an establishment of a service provider market where the IASs are products of this market. The DNOs can become customers to this market, since grid services will provide high value for them. An critical enabler for this market strategy, is the connection to the residential consumer. The residential consumers will be provided home services that are of value for them by lowing the energy bill through a recommend change of energy consumption behavior and by adding them comfort.

The rationale of the SmartHG project is that, the IASs will consist of Home Intelligent Automation Services(HIASs) which will support the residential home users by assisting them in lowering their electrical energy costs and usage, whereas the Grid Intelligent Automation Services(GIASs) will support the DNO in optimizing the EDN. This forms two control loops where the residential users and HIAS constitute the inner loop, and outer loop consists of the residential users and th GIASs as shown in Figure 2.2. Furthermore, the development of GIASs, which are of high value for the DNO, will economical foster the development of HIAS together with an open market strategy, that allows third party developers to develop services for residential home users.

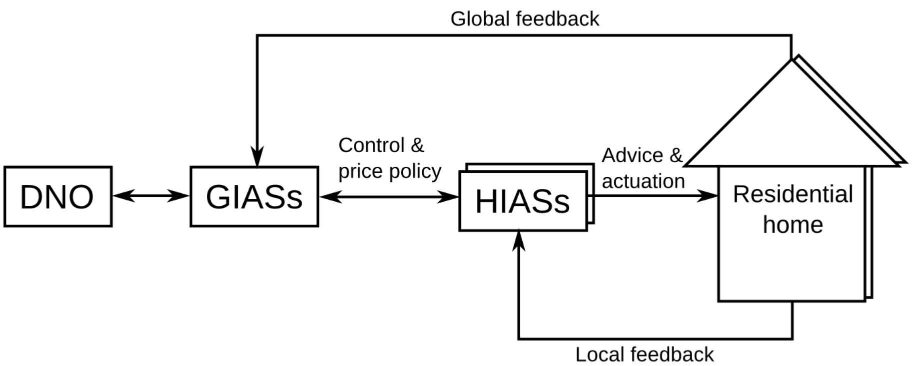


Figure 2.2: The control loops of the local optimization and global optimization by using the HIASs and the GIASs, respectively. Courtesy of (SmartHG-DoW, 2012).

To enforce a sustainable solution, the project will built the services around technologies that makes it possible to use them as building blocks on a cloud-based infrastructure. This approach allows future services to reuse the IASs and benefit from existing data. To ensure interoperability in the entire system, a fundamental goal of the project is to use open Internet-based protocols between all entities, such that it allows for a full integration of existing and future smart grid solutions. To summarize, the three pilars in the SmartHG project are:

- Demand-aware home services (HIASs) for supporting the residential consumers.
- Demand-aware grid services (GIASs) for optimizing the management of the EDN.
- Internet-based open protocols between the Smart Home Hardware Devices(SHHDs)[1], the IASs and the DNO.

The development of the SmartHG's parts follows a continuous refinement approach, where the design and prototype progression is periodically evaluated and features are continuously added.

2.1.1 Intelligent Automation Services

The majority of the SmartHG project consists of developing the IAS deployed in cloud. These are not part of AU's main contribution, but have nevertheless influence on the work process and is therefore presented with a small description in this section.

HIAS consists of three services that all deals with the energy usage in each residential home. The services listed below consitute the HIAS.

- **Energy Bill Reduction (EBR)** computes energy usage strategies that will minimize the energy usage.
- **Energy Usage Reduction (EUR)** identifies energy savings opportunities.
- **Energy Usage Modeling Forecast (EUMF)** predicts a forecast model of the usage and local generation of energy.

By using the forecasts of the EUMF and various information e.g. current voltage levels, generation forecasts and EDN constraints, it is possible to support the EDN. The GIASs listed below utilize this information and optimize the EDN operation.

- **Demand-Aware Price Policies (DAPP)** proposes price policies that are fair to steer energy consumption.
- **EDN Virtual Tomography (EVT)** uses information from the EUMF to generate virtually sense the state of internals of the EDN when there are no sensors available.
- **Database and Analytics (DB&A)** stores energy consumption data from the various services.
- **Price Policy Safety Verification (PPSV)** verifies the safety of steering the energy demand in the EDN.

[1]Abstraction of sensors, actuators and generators located in the residential homes

2.1.2 AU's Area of Responsibility

The AU's main area of responsibility covers the specification of the system architecture that embraces the openness and service-oriented principle together with the preservation of the privacy of the residential consumer. Furthermore, it includes design and prototype development of the Home Energy Controlling Hub (HECH) located in the homes and the communication infrastructure in the SmartHG system as illustrated in Figure 2.3.

The HECH is a central controlling entity deployed in each home that connects to the SHHDs. SHHDs are an abstract concept in SmartHG context, which i.a. represents sensors (measurement equipment), smart appliances (dish washers, laundry machines) and generators (solar panels).

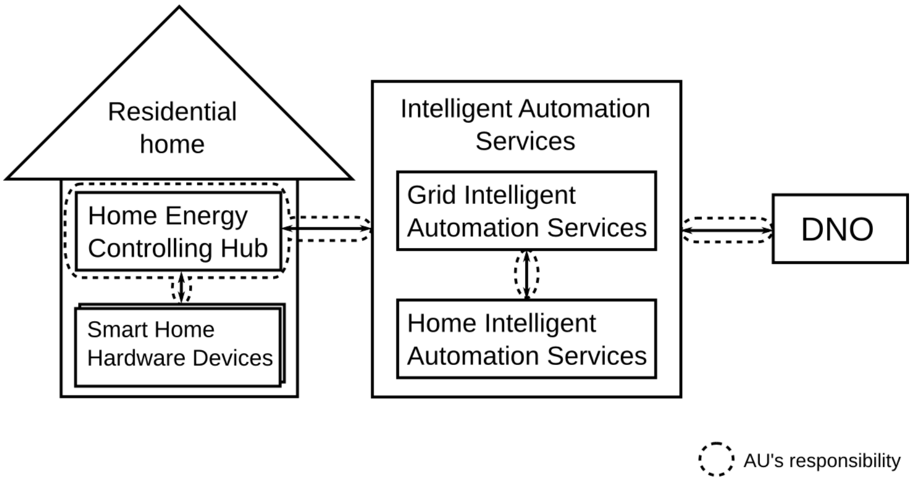


Figure 2.3: Overview of SmartHG system where AU's contribution is indicated with a stiple contour with gray background. In addition to the stipled contour, the design of system architecture is also part of AU's responsibility.

Appendix section A.1.2 gives an overview of the deliverables where AU is main contributor.

3

Privacy-preserving SOA and Infrastructure for the Smart Grid

Alongside the collaborative progression of the SmartHG project, this chapter contains the research conducted concurrently. The research has been encircled by the work frame that the SmartHG project forms. From the project's perspective, the focus has been on specifying a system architecture and an open infrastructure that could provide intelligent automation services to the residential consumer and the DNO. The research added elements to enforce privacy and make to the system cooperative and autonomous while making it cost-effective through Internet Engineering Task Force (IETF) compliant protocols and by using international standards.

This chapter presents the identified challenges associated with specifying the system architecture and communication infrastructure. These challenges are based on a review of related EU projects, standard specifications, and trends in the research area. The challenges are transformed into key factors that are considered as benchmarks for uniting the residential home domain with the grid domain. Using the key factors as cornerstones in the specification phase togehter with an analysis of research domain, system architecture is designed. It contains a skeleton for the communication infrastructure and describes the high-level entities in the architecture that satisfy the obligations according to requested functionality. Last, a conclusion is presented on the basis of the current findings.

3.1 Challenges

The proliferation of the smart devices and the emergence of Internet of Things (IoT) create new opporunities to develop applications that are aimed for the smart grid. Especially, management systems that are able to shape demand according to the production. However, challenges emerge in this complex development process, where design decisions have multiple implications for the smart grid. To grasp the consequences, abstraction levels must be considered.

Figure 3.1 conceptualizes the different abstraction levels of both the architecture and infrastructure. Conceptual reference models present the highest abstraction level that represents models developed by NIST (Bryson and Gallagher, 2012), IEC (IEC, 2009), and CEN/CENELEC/ETSI (CEN-CENELEC-ETSI Smart Grid Coordination Group, 2012).

These models identifies the interfaces between the different domains in the current organization of the electrical grid system. Considering these domains, the design and development of an interoperable smart grid architecture demands for consideration for three types of architectures (IEEE P2030, 2010), namely the communication architecture, power system architecture, and the information technology architecture. Furthermore, key objectives such as Quality of Service (QoS), scalability, security, privacy are identified as parameters for a successful deployment (Yan et al., 2013; Fan et al., 2013; Wang and Z. Lu, 2013).

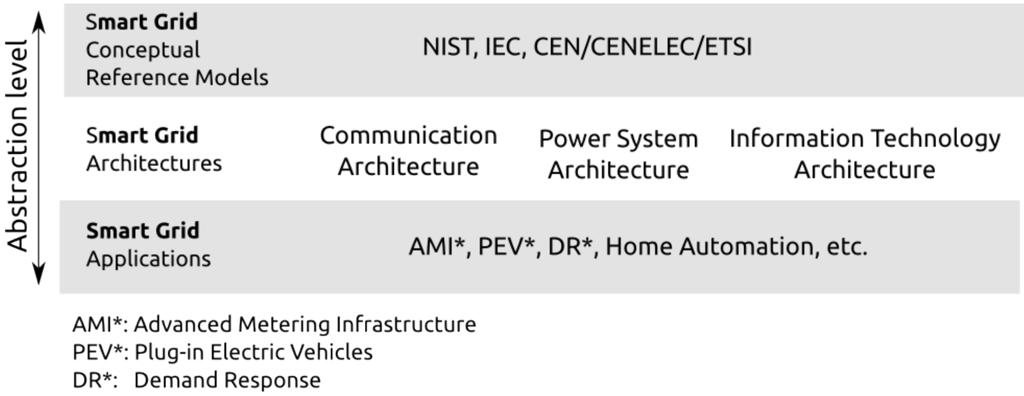


Figure 3.1: Architectural abstraction levels where the top shows the highest abstraction level. Courtesy of (IEEE P2030, 2010).

In this section, we discuss the occuring challenges in the design proces of smart grid architecture and the appertaining communication infrastructure.

3.1.1 Information Technology Architecture

Creating a successful open market for smart grid home appliances and creating services that both are profitable for the residential consumers and the grid operators, necessitates that the smart grid architecture complies to many non-functional requirements, e.g. it should be scalable, modular, interoperable, secure, etc. (Hashmi, Hanninen, and Maki, 2011). Most proposed smart grid architectures agree on these conditions, however if the proliferation of the intelligent home appliances should be initiated by the consumer, it is important consider other factors more strongly related to the residential consumer, such as:

- ICT trends for home appliances and data storage
- Incentives for the residential consumer
- The residential consumer's concerns

The ICT trends have a significant impact on how future home appliances would look like, and thereby also how it will interact with the rest of the system. Current trends show that the ubiquity and the interconnection between devices are predominant factors for successful consumer devices. The trends show that it is feasible to produce cheap hardware with powerful computing capabilities and the physical size of the hardware shrinks, hence devices become smaller and lighter than before. This enables relative single-functioning devices to interconnect to other systems without being twice the weight or cost. Furthermore, because of the extra computing capabilities the devices are able to run advanced algorithms in reasonable amount of time, such that they are capable of acting intelligent based on their sensor input. This enables the consumer to delegate objectives to the devices without assisting it towards the objective. In some situations it might actually be unfeasible if a human should assist. For the utility companies to take advantage of a vast amount of data, it is necessary for them to be able to store, share and compute on a collective data sets. The trends show that a cloud platform seems to be the most feasible choice, because of its capabilities of being scalable, sharable, flexible and reliable (Maheshwari et al., 2013).

The most dominating factor for the residential consumers' decision about integrating smart grid devices into their home, is the cost of equipment versus cost saving of their energy bill (IndEco Strategic Consulting, 2013). An essential requirement is that a proposed system must be cost-effective for the consumer without limiting the consumer's behavior to such a degree that they oppose the system. Likewise, the solution must also be cost-effective for the DNO to make them able to offer a system.

The consumer's expectation and concerns are key-factors for a successful deployment of the smart grid. For many consumers there are little understanding of what the smart grid is and its implementation is considered a faraway scenario (IndEco Strategic Consulting, 2013). This insecurity is further intensified by the uncertainty about data security and privacy which remain one of the top concerns for consumers (Polonetsky and Wolf, 2009). Hence, standardization organizations such as National Institute of Standards and Technology (NIST) (McCallister, Grance, and Kent, 2010) and Smart Grid Task Force (SGTF) (SGTF, 2011) have made data handling, security and privacy recommendations to accommodate some of these concerns, but it is still an open issue how this should be implemented. The privacy and security issues are even further exacerbated when it is deployed in the cloud (Simmhan et al., 2011).

3.1.2 Communication Architecture

As illustrated in Figure 3.1 the perspective of the architecture depends on the viewpoint of the domain. This section is divided into network challenges regarding the HAN and the electrical grid, respectively.

Home Area Network

Today, there are a myriad of low-power devices for connecting the HAN that use different communication protocols specified by third-party companies that aim at particular operation domains. Established companies are unlikely to conform to a single standard. Thus, a system infrastructure on the residential side must support the most common communication technologies, without interfering with the chosen protocols the third-party companies use. Insisting for a single communication protocol, such as IP-based solution would be laudable, however it is infeasible to require this adaption of third party companies, since it is still more profitable to create closed incompatible platforms and communication technologies. The home automation system should instead encourage the upcoming companies to use a common communication technology.

As a consequence of considering the HAN as a heterogeneous system, challenges emerge when managing the interoperability between the communication technologies. The technologies fulfill a purpose, and the objective of the smart grid is to embrace a large portion of these technologies. The challenge is to make the communication transparent from the customer's perspective, and make it scalable for a large number of residential houses. Moreover, it is also important that the communication paradigm shows a consideration for energy constrained end-devices such that unnecessary battery draining do not occur by e.g., excessive polling of data.

Furthermore, it is important to lower the complexity of the system. A complex system will discourage the common user to follow produced price policies and will see the system as a burden and not as a good offer. The challenge is to make a self-configuring and flexible system by using protocols that manages setup, administration, service discovery, detection of errors, etc., such that regular users have a minimum of chores but it is configurable enough to meet the "super-users"' demands.

Focus have intensified on security and privacy issues in the local HAN (Vigo, Yuksel, and Ramli, 2012). Standard organizations have create specifications and guidelines for securing the communication from being attacked (SGIP, 2010; SGTF, 2011). The challenge is to design a system where data should be sent securely and privately such that it prevents an attacker from learning confidential information.

ICT in Grid Network

When moving from a traditional one-way energy flow system to a bidirectional flow grid system, where Distributed Energy Resources (DERs) become a balancing factor in the total energy production, new challenges arise for the grid operators. As with the uni-directional grid system, the grid operators must guarantee electricity delivery for each consumer in the bidirectional grid system. The power delivery must be balanced in real-time with respect to the load of the end-points. Usually, there is a balancing market for managing such objectives.

With a bidirectional electric grid system, the steps become more complicated since micro-generating units are able to deliver electric energy back to the system. This is done through systems as PV, the discharging of EV, private wind turbines, etc. Information about generation and usage at the end-points is therefore valuable and a necessity for the DNO to optimize its EDN operations. It will result in more accurate assessments of the balancing needs and life expectancy of the DNO's assets, such as substations and the power cables.

The communication between the home and grid services are an critical element to consider in the future when the residential home users are cooperating with the DNO. The challenge for the communication infrastructure is to ensure that the grid system is provided with timely accurate data, such that the DNO is able to response when there are unwanted fluctuations. In general, the minimal impact the smart grid have on residential market today, is not highly critical in terms of data delivery. However, when the residential market becomes a interacting part of the electrical grid, the system becomes a mission critical system in relation to its operation.

3.2 Results

The resulting architecture is service-oriented and uses this as the overarching structure for fulfilling the key criteria, making the software independent of the vendor and the device type. The Service-Oriented Architecture (SOA) allows the SmartHG project additionally to have a scalable, maintainable and upgradable architecture making it an ideal solution for a smart grid software architecture (Pagani and Aiello, 2012). The designed SOA in the SmartHG project is based on the separations of concerns principle where services and components can be reused dynamically. Each service acts as an individual building block which is loosely coupled to the rest of system.

The communication infrastructure is created based on existing protocols and standards that conform to the preselected choices in the SmartHG project (SmartHG-DoW, 2012). Besides using the IP-protocol as the networking layer to be device-agnostic, the prevailing choice is to use the REST architectural style both in HAN and on the cloud infrastructure. From this starting point, the research has focused on identifying key protocols and standards that embrace these choices.

This section provides an overview of the resulting choices based on the research and by addressing the challenges listed in Section 3.1.

3.2.1 System Architecture

The system architecture are composed of three main identities, where two of them relates to management as seen in Figure 3.2. These management entities each have an intelligent software-agent that can collaborate and negotiate on their stakeholder's behalf. The software-agents operate autonomously by using a goal-oriented behavior settled by their stakeholder. For the Home Device Management (HDM), there is a Home Agent (HA) implemented in the HECH that represents the residential consumer, and for the DNO there are an Grid Operator Agent (GOA) interacts with those. By distributing a HA for each home and having a GOA interacting with these, a collaboration between the residential consumers and the DNO can be established that utilize the IASs deployed in the cloud. The result is a local optimization customized for each residential consumer and a global optimization that supports the DNO's operations.

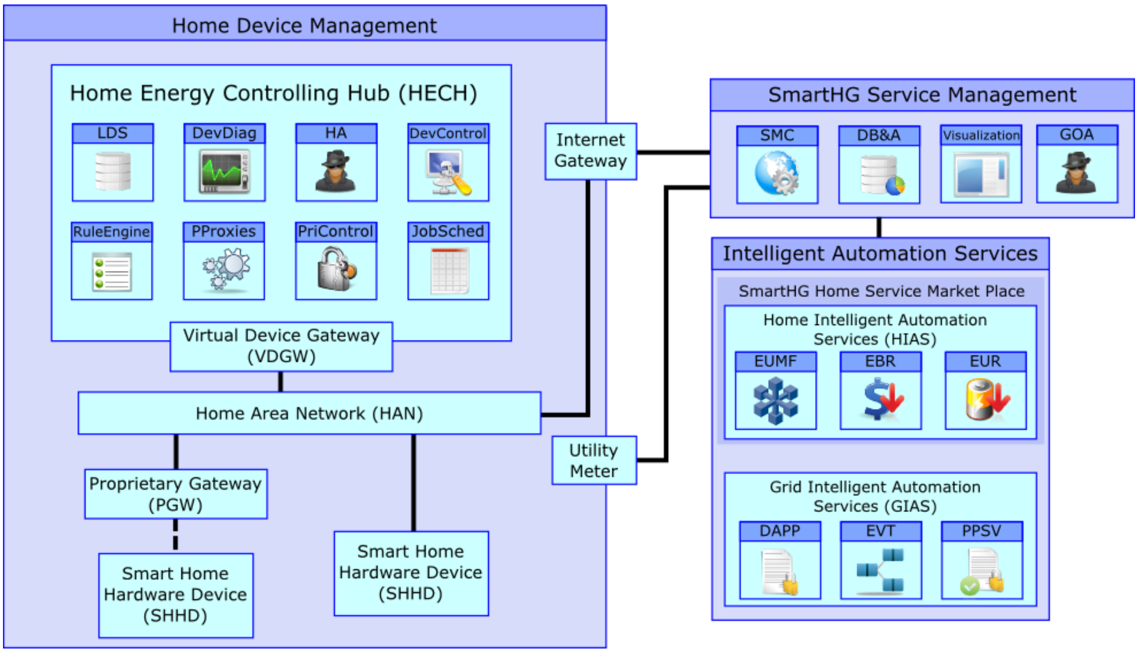


Figure 3.2: System architecture of the SmartHG project.

To support the operation of each agent, a number of software components are identified as shown in Table 3.1. For the HDM, the classes of functionality the HECH includes for the HA, are storage capabilities, device orchestration, privacy administration and service management. For the SmartHG Service Management (SSM), the classes of functionality the system includes are storage capabilities, a visualization service, and a controller that supports a market of services. The sevice market resembles the app-markets there exist today, e.g. from Facebook and Google Play. The home residents will be able to subscribe to services of their needs and the market provides an opportunity for service developers to publish their home automation services. The functionality of the GOA is to intelligently extract information provided by the home services to the DNO.

Entity	Class	Component	Full name
Home Device Management	Management & storage	HA LDS	Home Agent Local Data Storage
	Device administration	DevDiag DevControl Pproxies	Device Diagnostics Device Control Protocol Proxies
	Privacy administration	RuleEngine PriControl	Rule Engine Privacy Control
	Service administration	JobSched	Job Scheduler
SmartHG Service Management	Management & Storage	GOA DB&A SMC	Grid Operator Agent Database and Analytics Service Market Controller
	Service	Visualization	Visualization

Table 3.1: Associations between entities, classes and components in the system architecture shown in Figure 3.2.

The designed system architecture addresses the consumer's privacy by physically disjointing the location of consumption data into two databases. All consumption data is stored at the residential consumer's HECH and depending on the consumer's privacy level, consumption data is sent to the global database DB&A. This way, the system makes the residential consumer, the owner of the produced consumption data and not the DNO. However, by limiting the information sent to the DB&A, the information available to the IASs are also limited which will decrease the QoS-level for residential consumer. The responsibility for this trade-off rests with the consumer.

The system architecture includes incentives for smart home-appliance providers to create auxiliary-services that extends the capabilities of their products by having a service market. This supports the system the cost-effectiveness for the residential consumers.

3.2.2 Communication Infrastructure

To foster sustainability of the envisaged system architecture, the infrastructure utilizes the existing Internet connection in the residential home for transmitting consumption data and control signals. This approach has been recommended (Marsan, 2009) and standardized by leading organizations such as NIST (Bryson and Gallagher, 2012) and IEEE (IEEE, 2013). This has encourage the IETF to select a key set of protocols from the Internet Suite that will enable interoperability (Baker and Meyer, 2011).

Interoperability is identified as the main advantage of adopting the Internet Protocol (IP). It can take advantage of all the technology that has been development the last two decades and adapt for the diversity of environments affected by various conditions e.g. load and weather. Futhermore, it is considered to be future-proof since it is based on an established technology that is believed to evolve to be even more widespread. All reasons that will make the system more cost-effective, thus infused into the entire communication infrastructure.

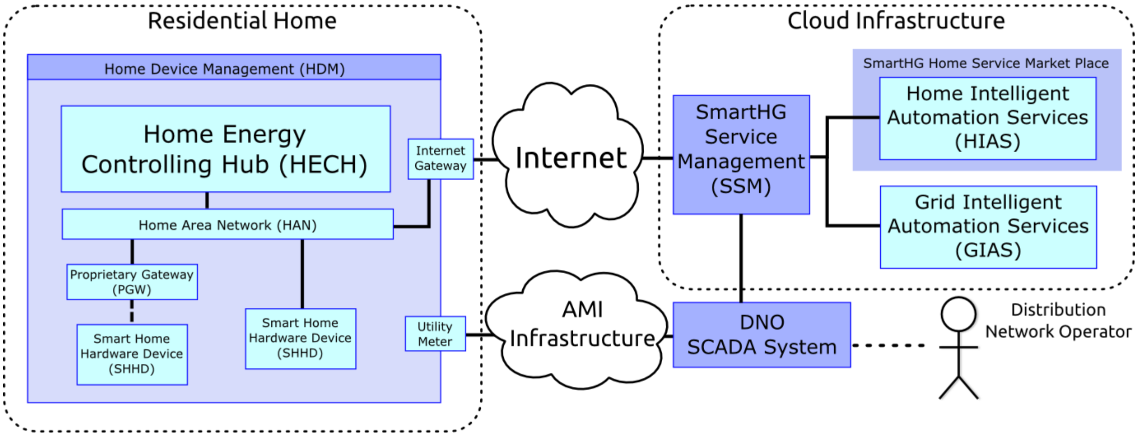


Figure 3.3: The communication infrastructure

Based on the system architecture presented in Section 3.2.1, the communication infrastructure displayed in Figure 3.3 is created. The HDM comprises the demand-aware communication that occur between the SHHDs and the HECH. Information about the total electric consumption and the individual devices are forwarded through the Advanced Metering Infrastructure (AMI) and Internet, respectively. The IASs are hosted in the cloud following a Infrastructure as a Service (IaaS) model. Accordingly, by having an underlying IP-infrastructure, the offered IASs and the SHHDs can be viewed as Software as a Service (SaaS) on this network infrastructure.

For the HDM, a number of networking technologies has been considered, since it clear that one-size-fits-all technology does not seem to exist. While the system and infrastructure encourage for IPv6-based communication, it is necessary to adopt other network technologies as well. To embrace a heterogeneous environment, established and emerging technologies such as Power Line Communication (PLC), ZigBee, and Z-wave are therefore be considered. This demands for a gateway and a proxy that is able to convert between the proprietary stack to the IP stack. This will be explored in the further development, however, there exist frameworks that translates between IPv4/IPv6 (Baker, X. Li, et al., 2011; Mackay et al., 2003) and ways to interconnect ZigBee and IPv6 (C.-W. Lu, S.-C. Li, and Wu, 2011). The next generation of ZigBee called *ZigBee IP* (Don Sturek, 2009) has been identified as the key specification in this process. It utilizes the development of the ongoing research and standardization process of the IP-protocol that accommendate the challenges of emergence of the IoT. In contrast to (Baker and Meyer, 2011), the ZigBee IP specification provides a selection of IETF compliant protocols for the HAN and offers configuration details. The ZigBee IP uses the IEEE 802.15.4 on the physical and MAC layer, like the classic ZigBee, but introduces a IPv6 over Low power Wireless Personal Area Networks (6LoWPAN) adaption layer on top of this. Since the 6LoWPAN stack is suitable for resource-constrained devices, it enables an IP end-to-end connectivity for entire communication infrastructure. IPv6-based communication not only resolves the IPv4 address exhaustion problem, but also introduces stateless autoconfiguration through the neighbor discovery protocol and fragmentation abilities at the source.

The cloud infrastructure containing the SmartHG management platform and the IASs will communication among homes by using the IP-infrastructure and services will exposed as Webservices. To be in conformance with data models in energy management, it utilizes the Common Information Model (CIM) standard (IEC 61970, IEC 61968, and IEC 62325). A conformance to this standard is the Smart Energy Profile (SEP) 2.0 standard (ZigBee Alliance, 2013) that specifies an IP-based energy management system based on the CIM data model. The communication between DNO's system and residential home will be based on this specification. To ensure a secure and private delegation of the data between the services and the DB&A, the SSM will use the OAuth 2.0 framework (D. Hardt, 2012). The consumer will be aware of the granularity of data access, a particular service is able to gain using a glssso authentication service. Thus, privacy is enforced by informing the consumer the access level of the 3rd party services, if they choose to subscribe to these.

3.3 Conclusion

A privacy-preserving and service-oriented ICT architecture has been defined, allowing for interoperable communication based on IP-based protocols. The architecture takes a significantly different approach in typically cloud-based solutions, by dividing the handling and storage of residential consumer's data into two entities, one entity at the residential consumer's side and one entity at the DNO's side, thus allowing the consumer be able to control and be aware of the physical location of the data. To ensure seamless management of the residential side, the HECH implements a home agent that defines three administrative classes: a device administration that manages the interaction with the home appliance, a service administration that manages the services deployed in cloud, and a privacy administration that manages the privacy for the consumer. On the DNO's side, a management of the communication infrastructure for the IASs are realized through the SSM. The communication infrastructure will be based on IETF compliant protocols, but the specifications of the SEP 2.0 and ZigBee IP will create the baseline for further research and development.

4

Conclusion and Future Plans

This chapter presents a summary of the work conducted on the basis of the current PhD research. In conjunction with the hypothesis presented in Section 1.2, a detailed description of the future work is presented in the extension of the existing research. This includes a list of intended publications with appertaining description that in parallel with the SmartHG project work, focus on a set of identified areas that each pose a research gap in connection to the hypothesis.

4.1 Summary of Present Work

The first part of the PhD period contains work conducted in the SmartHG project and research conducted alongside with this. The work covers the identification of architectural challenges and the design of a system architecture based on these challenges together with the specification of the SmartHG project (SmartHG-DoW, 2012). Key elements are introduced in the system architecture which were found based on research in other EU projects, smart grid standards, and research related to a consumer-centric architecture (W.-H. Liu, K. Liu, and Pearson, 2011; Singh, Keshav, and Brecht, 2013). This has lead to a privacy-preserving and service-oriented architecture that allocate management capabilities in the residential home and in the cloud, where data is disjointed in a local and global storage, respectively. Furthermore, it contained the identification of state-of-art protocol standards aimed at demand-aware communication to create a smart grid communication infrastructure for intelligent automation services. Alongside the research and project work, a number of courses has been attended (see Appendix B).

4.2 Future Plans

The plan for the remaining part of the PhD study, is associated to the plan for the research and development of the identified key elements in the SmartHG project. This is a consequnce of that the expected results produced by the PhD research must have a linkage to the SmartHG project. However, the research currently planned may lead to new research areas which are not envisioned yet.

This section lists the remaining work in the SmartHG project and the envisioned publications in connection with the research. Appendix C illustrates the expected work plan through a Gantt chart.

4.2.1 SmartHG project

Since the workflow in the SmartHG project follows an iterative refinement approach, AU will have yearly deliverables of following tasks:

- Design and prototyping of the HECH located in the residential home.
  - Integration of partners' equipment with the HECH creating a heterogeneous network.
  - Development of HA that orchestrates SHHDs, interfaces to the HIAS and preserves the residential consumer's privacy.
- Design and prototyping of the SSM entity located in the cloud.
  - Development of Service Management Controller (SMC) component that coodinates the IASs in the cloud.
  - Development of context-aware visualization service that displays the consumption data of the consumer.
  - Development of a HA and GOA that interacts.

4.2.2 Planned Publications

The section presents the title and description of the intended publications during the remainder of the PhD study.

- **PUB1 – Security Bootstrapping and Management of IPv6-based and Resource-constrained Devices in the HAN**

  The emergence of IoT enables heterogenous network entities to communicate based on IPv6 and web services. The concept of IoT also applies witin the residential home network, where there is an increasing number of devices either directly supplied with electricity or battery-driven. The security considerations for IP-based communication are well-established in the traditional settings, where it requires user interactions, however, it is still not fully clear how the IP protocols should be applied for resource-constrained devices (Garcia-Morchon et al., 2013). This is especially a problem in the bootstrapping phase. The establishment of a trust domain has been proposed (Hjorth and Rune Torbensen, 2012), but requires user interaction that may be circumvented by using pairing-based cryptography protocols. The purpose is to bootstrap IPv6-based and resource-constrained devices into the HAN using pairing-based cryptography.

- **PUB2 – Simulation of a Multi-agent System for Demand Side Management using the SEP 2.0 Protocol**

  The collaborative and intelligent behavoir demanded for Energy Management Systems(EMSs) for controlling the residential homes suggests for an autonomous system. In research these systems are often implemented as Multi-agent systems(MASs) that are able to act on their user's behalf without intervention (Asare-Bediako, Kling, and

Ribeiro, 2013). The MASs should be able to reach a compromise based on the instructions initial given such that given incentives, like dynamic pricing from the DNO, a trade-off is e.g. made between user comfort and electricity price. However, the recently proposed SEP 2.0 protocol standard have not yet been tested for its applicability in a large scale setup. The purpose is to find out to what extend the SEP 2.0 protocol in a multi-agent architecture, is applicable of supporting a large scale network in the smart grid in terms of performance and scalability.

- **PUB3 – Service Controller for Orchestrating Future Smart Grid Services**

  The SMC is the service coordinator and broker in the SOA. It connects the residential consumers with the service providers. Furthermore, it links the DNO to the system and provide a central entity for all actors. The SMC offers services for residential consumers and enables developers to deploy their services into a market place for home services. It allows each individual consumer to browse and subscribe to desired services, thus each consumer can customize the set of services they want to subscribe to. Thereby, it does not only act as a central repository for the services to register to and service consumers to subscribe to, but also as an authorization service that connects all services in the SOA. The purpose is to support the hypothesis of the PhD research by making the consumer in control of the data sharing.

- **PUB4 – Visualization Service with Asynchronous and Context Aware backend for Measurement Data**

  One way of minimizing energy usage and cost, is to visualize the energy usage for the residential consumer. Typically, making the consumer aware of their consumption, make them change their behavior if they easily can adopt to a new pattern. To visualize data, naturally requires one or more data sources. To ensure awareness of the data location, the data storage is divided into two places; one in the residential house and one in the cloud, where the IASs can reach the data (if permitted by the residential consumer). The local data storage stores all data the residential consumer want to view, but he/she does not necessarily want in the cloud. The purpose of the research is to have global visualization service using local data, thus enforcing privacy by never transmitting sensitive data out of the LAN.

4.3 Final Remarks

This progress report has given an overview of the work that has been conducted in this first 1½ years of research. The report shows that there has been a strong association to the SmartHG project in this first part and research has been committed to the project. The future plans shows a greater deattachment, but where the research results still can contribute to the project. The hope with the research contributions, is to create incentives for the DNOs and residential consumers to collaborate on mutual market in the smart grid by respecting the privacy and security of the consumer. The progress of the PhD research is believed to lead to timely completion of September 2015.

Bibliography

Asare-Bediako, B., W.L. Kling, and P.F. Ribeiro (2013). "Multi-agent system architecture for smart home energy management and optimization". In: *Innovative Smart Grid Technologies Europe (ISGT EUROPE), 2013 4th IEEE/PES*, pp. 1–5. DOI: 10.1109/ISGTEurope.2013.6695331.

Baker, Fred, Xing Li, et al. (2011). *Framework for IPv4/IPv6 Translation*. Tech. rep. URL: http://tools.ietf.org/rfc/rfc6144.txt.

Baker, Fred and David Meyer (2011). *Internet Protocols for the Smart Grid*. Internet Engineering Task Force. URL: http://www.ietf.org/rfc/rfc6272.txt.

Bryson, J and PD Gallagher (2012). *NIST framework and roadmap for Smart Grid Interoperability Standards, release 2.0*. Tech. rep.

CEN-CENELEC-ETSI Smart Grid Coordination Group (2012). *Smart Grid Reference Architecture*. Tech. rep. URL: http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/xpert_group1_reference_architecture.pdf.

D. Hardt, Ed (2012). *The OAuth 2.0 Authorization Framework*. Internet Engineering Task Force. URL: http://tools.ietf.org/html/rfc6749.

Danfoss. *living by Danfoss*. URL: http://www.living.danfoss.dk/.

Don Sturek (2009). *ZigBee IP Stack Overview*. URL: https://docs.zigbee.org/zigbee-docs/dcn/09-5375.pdf.

EEA Report No 6/2008. (2008). *Energy and environment report*. en. URL: http://www.eea.europa.eu/publications/eea_report_2008_6.

Fan, Zhong et al. (2013). "Smart Grid Communications: Overview of Research Challenges, Solutions, and Standardization Activities". In: *IEEE Communications Surveys & Tutorials* 15.1, pp. 21–38. ISSN: 1553-877X. DOI: 10.1109/SURV.2011.122211.00021. URL: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6129368.

Garcia-Morchon, O. et al. (2013). *Security Considerations in the IP-based Internet of Things*. Internet draft, Work in Progress. Internet Engineering Task Force.

GridManager (2014). URL: http://www.grid-manager.com/.

Hashmi, M., S. Hanninen, and K. Maki (2011). "Survey of smart grid concepts, architectures, and technological demonstrations worldwide". In: *2011 IEEE PES conference on innovative smart grid technologies latin america (ISGT LA)*. IEEE, pp. 1–7. ISBN: 978-1-4577-1801-4. DOI: 10.1109/ISGT-LA.2011.6083192. URL: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6083192.

Hjorth, Theis Solberg and Rune Torbensen (2012). "Trusted Domain: A security platform for home automation". In: *Computers & Security* 31.8, pp. 940–955. ISSN: 01674048. DOI: 10.1016/j.cose.2012.07.003. URL: http://linkinghub.elsevier.com/retrieve/pii/S0167404812001046.

IEA (2013). *CO2 Emissions From Fuel Combustion Highlights 2013*. Tech. rep. IEA. URL: http://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2013.pdf.

IEC (2009). *Power system control and associated communications – Reference architecture for object models, services and protocols*. Tech. rep. URL: http://www.iec.ch/smartgrid/downloads/sg3_roadmap.pdf.

IEEE (2013). "IEEE Vision for Smart Grid Communications: 2030 and Beyond". In: pp. 1–390. DOI: 10.1109/IEEESTD.2013.6577600.

IEEE P2030 (2010). *IEEE P2030*. Tech. rep. IEEE. URL: http://grouper.ieee.org/groups/scc21/2030/2030_index.html.

IndEco Strategic Consulting (2013). *Smart grid consumer engagement: lessons from North American utilities*. Tech. rep.

LIFX Labs (2014). *LIFX - The lightbulb reinvented*. URL: http://lifx.co/.

Liserre, M., T. Sauter, and J.Y. Hung (2010). "Future Energy Systems: Integrating Renewable Energy Sources into the Smart Power Grid Through Industrial Electronics". In: *Industrial Electronics Magazine, IEEE* 4.1, pp. 18–37. ISSN: 1932-4529. DOI: 10.1109/MIE.2010.935861.

Liu, W.-H.E., K. Liu, and D. Pearson (2011). "Consumer-centric smart grid". In: *Innovative Smart Grid Technologies (ISGT), 2011 IEEE PES*, pp. 1–6. DOI: 10.1109/ISGT.2011.5759170.

Lu, Chia-Wen, Shu-Cheng Li, and Quincy Wu (2011). "Interconnecting ZigBee and 6LoWPAN wireless sensor networks for smart grid applications". In: *Sensing Technology (ICST), 2011 Fifth International Conference on*, pp. 267–272. DOI: 10.1109/ICSensT.2011.6136979.

Mackay, M. et al. (2003). "A scenario-based review of IPv6 transition tools". In: *Internet Computing, IEEE* 7.3, pp. 27–35. ISSN: 1089-7801. DOI: 10.1109/MIC.2003.1200298.

Maheshwari, Ketan et al. (2013). "Evaluating Cloud Computing Techniques for Smart Power Grid Design Using Parallel Scripting". In: *2013 13th IEEE/ACM International Symposium on Cluster, Cloud, and Grid Computing*. IEEE, pp. 319–326. ISBN: 978-0-7695-4996-5. DOI: 10.1109/CCGrid.2013.26. URL: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6546108.

Marsan, Carolyn Duffy (2009). *Q&A: Why IP is the right choice for Smart Grid*. URL: http://www.networkworld.com/news/2009/102909-smart-grid-ipv6-qa.html (visited on 10/22/2013).

McCallister, E, T Grance, and K Kent (2010). "Guide to protecting the confidentiality of personally identifiable information (PII)". In: *Recommendations of the National Institute of Standards and Technology*, pp. 1–59.

Ming, Zeng et al. (2010). "Research of the Problems of Renewable Energy Orderly Combined to the Grid in Smart Grid". In: *Power and Energy Engineering Conference (APPEEC), 2010 Asia-Pacific*, pp. 1–4. DOI: 10.1109/APPEEC.2010.5448334.

Moslehi, Khosrow and Ranjit Kumar (2010). "A Reliability Perspective of the Smart Grid". In: *IEEE Transactions on Smart Grid* 1.1, pp. 57–64. ISSN: 1949-3053. DOI: 10.1109/TSG.2010.2046346. URL: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5467283.

NEST (2014). *Life with Nest Thermostat | Nest*. URL: https://nest.com/thermostat/life-with-nest-thermostat/ (visited on 02/26/2014).

Ninja Blocks (2014). *Ninja Sphere*. URL: http://ninjablocks.com/.

Pagani, Giuliano Andrea and Marco Aiello (2012). "Service Orientation and the Smart Grid state and trends". In: *Service Oriented Computing and Applications* 6.3, pp. 267–282. ISSN: 1863-2386. DOI: 10.1007/s11761-012-0117-z. URL: http://link.springer.com/10.1007/s11761-012-0117-z.

Panoramic Power (2014). URL: http://www.panpwr.com/.

Polonetsky, Jules and Christopher Wolf (2009). *How Privacy (Or Lack of It) Could Sabotage the Grid*. URL: http://www.smartgridnews.com/artman/publish/Technologies_Metering_News/How-Privacy-Or-Lack-of-It-Could-Sabotage-the-Grid-1352.html (visited on 2009).

Quinn, Elias Leake (2009). "Privacy and the New Energy Infrastructure". In: *SSRN Electronic Journal* 09. ISSN: 1556-5068. DOI: 10.2139/ssrn.1370731. URL: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1370731.

Ramakumar, R. et al. (1993). "Economic aspects of advanced energy technologies". In: *Proceedings of the IEEE* 81.3, pp. 318–332. ISSN: 0018-9219. DOI: 10.1109/5.241495.

Rovsing, Poul Ejnar et al. (2011). "A reality check on home automation technologies". In: *Journal of Green Engineering* 303, p. 327.

SGIP (2010). *NISTIR 7628 - Guidelines for Smart Grid Cyber Security: Vol. 2, Privacy and the Smart Grid*.

SGTF (2011). *Expert Group 2: Regulatory recommendations for data safety, data handling and data protection*. Tech. rep. URL: http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/expert_group2.pdf.

Simmhan, Yogesh et al. (2011). "An Analysis of Security and Privacy Issues in Smart Grid Software Architectures on Clouds". In: IEEE, pp. 582–589. ISBN: 978-1-4577-0836-7. DOI: 10.1109/CLOUD.2011.107. URL: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6008758.

Singh, Rayman Preet, S. Keshav, and Tim Brecht (2013). "A cloud-based consumer-centric architecture for energy data analytics". In: *Proceedings of the the fourth international conference on Future energy systems - e-Energy '13*. New York, New York, USA: ACM Press, p. 63. ISBN: 9781450320528. DOI: 10.1145/2487166.2487174. URL: http://dl.acm.org/citation.cfm?doid=2487166.2487174.

SmartHG-DoW (2012). *SmartHG project: Annex I - Description of Work. Grant agreement no: 317761, Version date: 2012-07-02.*

SmartThings (2014). *SmartThings*. URL: http://www.smartthings.com/.

Torbensen, R. (2008). "OHAS: Open home automation system". In: *Consumer Electronics, 2008. ISCE 2008. IEEE International Symposium on*, pp. 1–4. DOI: 10.1109/ISCE.2008.4559480.

Torbensen, Rune (2011). "On emergence of pervasive home automation". Ph.D. dissertation. Aalborg University.

Vigo, R., E. Yuksel, and C.D.P.K. Ramli (2012). "Smart grid security a Smart Meter-centric perspective". In: *Telecommunications Forum (TELFOR), 2012 20th*, pp. 127–130. DOI: 10.1109/TELFOR.2012.6419164.

Wang, Wenye and Zhuo Lu (2013). "Cyber security in the Smart Grid: Survey and challenges". In: *Computer Networks*. ISSN: 13891286. DOI: 10.1016/j.comnet.2012.12.017. URL: http://www.sciencedirect.com/science/article/pii/S1389128613000042.

Yan, Ye et al. (2013). "A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges". In: *IEEE Communications Surveys & Tutorials* 15.1, pp. 5–20. ISSN: 1553-877X. DOI: 10.1109/SURV.2012.021312.00034. URL: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6157575.

ZigBee Alliance (2013). *Smart Energy Profile 2 Application Protocol Standard*. Tech. rep. April, pp. 13–200.

A

Publications

In the PhD study, there has been produced a number publications related to the SmartHG project and furthermore, conducted scientific publications as an offspring of this. This appendix presents both the scientific publications and the deliverables affiliated to the SmartHG project.

A.1 Related to PhD project

A.1.1 Scientific Publications

Accepted

- Rune Hylsberg Jacobsen and Søren Aagaard Mikkelsen, "Infrastructure for Intelligent Automation Services in the Smart Grid". In: *Wireless Personal Communication (Springer), 2014*.

Submitted

- Søren Aagaard Mikkelsen and Rune Hylsberg Jacobsen, "Privacy-preserving Service-Oriented Architecture for the Future Smart Grid" submitted to *Service Oriented Computing and Applications Journal, 2014*.

Planned publications

- Security Bootstrapping and Management of IPv6-based and Resource-constrained Devices in the HAN.
- Simulation of a Multi-agent System for Demand Side Management using the SEP 2.0 Protocol
- Service Controller for Orchestrating Future Smart Grid Services
- Visualization Service with Asynchronous and Context Aware backend for Measurement Data

A.1.2 SmartHG Deliverables

Besides software design and prototype development, the SmartHG project includes a yearly reporting, consisting of deliverables for public dissemination. The deliverables contain contributions from the partners involved in their field of expertise. AU has mainly contributed to the development related to the residential home and the orchestration of intelligent services in the cloud with special focus on the communication protocols.

The initial method for handin the deliverables was through a number of Internal Reports(IRs), i.e. one deliverable could consists of 6-8 internal reports, where each internal report had a main contributor. The organization of this has been changed during the course such that each deliverable has one main contributor now. The first list below shows the first hand-in of the deliverables consisting of a number of IRs where AU was main contributor. The next list below consists of the revised deliverables where AU was main contributor. The number in the (xx) represents the written percentage of the deliverable and the number of pages.

Internal Reports

- D2.1.1 - System Specifications (~28%)
    - ◇ IR2.2.1.1 - System Architecture (22p)
    - ◇ IR2.3.1.1 - Specification of Open Protocol for Home Devices (14p)
    - ◇ IR2.4.1.1 - Specification of Open Protocol for DNO (13p)
- D3.1.1 - First Year Design of Home Intelligent Automation Services (~13%)
    - ◇ IR3.1.1.1 - Design of Open Protocol for Home Devices (7p)
    - ◇ IR3.2.1.1 - Design of Open Protocol for IAS (4p)
- D4.1.1 - First Year Design of Grid Intelligent Automation Services (~10%)
    - ◇ IR4.5.1.1 - Design of DNO - IAS Protocol (9p)
- D3.1.2 - First Year Prototype of Home Intelligent Automation Services (~5%)
    - ◇ IR3.1.1.2 - Prototype of Open Protocol for Home Devices (4p)
    - ◇ IR3.2.1.2 - Prototype of Open Protocol for IAS (4p)
- D4.1.2 - First Year Prototype of Grid Intelligent Automation Services (~13%)
    - ◇ IR4.5.1.2 - Prototype of DNO - IAS Protocol (11p)

Rehandin of deliverables

- D2.1.1 - System Specifications (35p, ~65%)
- D3.1.1 - First Year Design of Home Intelligent Automation Services (7p, ~70%)

A.2 Not related to the PhD project

Published

- Philip Schleiss, Nikolaj Tørring, Søren Aagaard Mikkelsen, and Rune Hylsberg Jacobsen. “Interconnecting IPv6 wireless sensors with an Android smartphone in the Future Internet” in *2012 2nd Baltic Congress on Future Internet Communications (BCFIC), 2012, April.*

B

Completed Courses

During the PhD studies, a course programme has been designed to include courses with relevance with respect to the research activities and to enhance dissemination skills. All the below listed courses are completed during the progress of the first 1½ year of PhD study.

Communication in Microgrids (2 ECTS) – A PhD course held at Aalborg University that introduces and gives state-of-the-art examples of communication systems in microgrid systems. It contained lectures about distributed algorithms for synchronization between the main electric grid and the microgrid. Residential and microgrid targeted communication protocols like PLC, ZigBee and 6LoWPAN were part of the curriculum.

2012/11/28 – 2013/11/29

Middleware and Communication Protocols for Dependable Systems (5 ECTS) A course on master level with focus on communication protocols for dependable systems, often embedded systems, and middleware technologies. The course gave an overview of fundamental principles for distributed real-time communication over fixed networks to be used in development of distributed dependable systems with real-time requirements; communication protocols such as (TT-)CAN, Flexray and switched Ethernet solutions were introduced. The middleware part included publish/subscribe architectures, such as DDS, COBRA and ICE.

2012/11/06 – 2013/01/08

Academic English for non-native speakers (3 ECTS) – A transferable skills course for PhD students held at Graduate School of Science and Technology (GSST) to improve their academic writing skills, especially focusing on writing scientific papers.

08/04/2013 – 18/04/2013

Complex Reneweable Energy Systems (5 ECTS) – A master course that provided an overview of the most important renewable energy sources such as wind energy, solar radiation, hydro-energy and biomass. It focused on the physical commposition of the generators, e.g. wind mills, solar panels, etc., such that weather data could be transformed into potential energy sources, while also taking seasonal time and physical conditions of the location into account. The course gave an insight of how the future renewable energy system should designed to balance the production and load.

11/04/2013 – 17/06/2013

DATASIM Summer School 2013 (2 ECTS) – A summerschool held in Belgium (Hasselt) for PhD students and researchers with focus on e.g. mobility modeling, big data handling, agent-based modeling for mobility and travel behaviour, and applications thereof. The applications included generation of business models for electric vehicles (EVs) and the interconnection to the smart grid. The summerschool included a graduate symposium where the PhD students where allowed to present their research and get feedback from senior-researchers with the same field of expertise.

15/07/2013 – 18/07/2013

Introduction to Science Teaching (3 ECTS) – A transferable skills course for PhD students held at AU's GSST. The course provided guidance for orchestrating teaching activities and managing the classroom.

13/08/2013 – 27/08/2013

Cryptography (10 ECTS) – A master course held at Department of Computer Science at Aarhus University. The course contained basic concepts and definitions in cryptography. Furthermore, it provides detailed knowledge of cryptographic algorithms and techniques for analyzing these. This includes fundamentals such as secret-key and public-key cryptosystems, hash functions, message authentication codes and digital signatures. The security of these cryptography primitives was analyzed formally by using well-established security definitions.

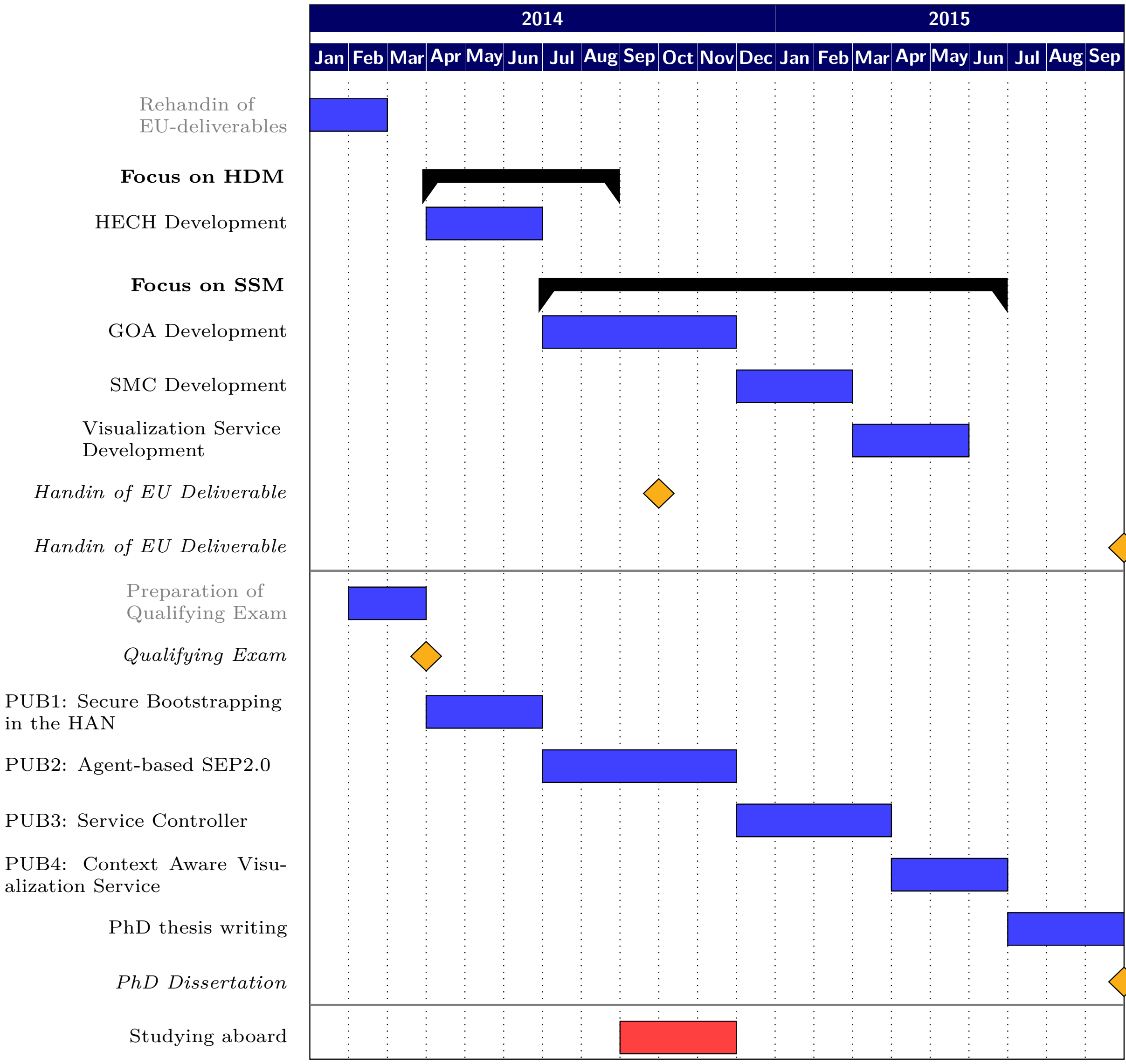
28/08/2013 – 21/01/2014

Together the courses account for 30 ECTS points, as required of the GSST at Aarhus University.

C

Gantt Chart

This appendix presents a Gantt chart for the further progress of the PhD study. The Gantt chart is divided into two sections, where the first section represents the work directly related to the SmartHG project, and the second section to the corresponding research.



D

Acronyms

6LoWPAN IPv6 over Low power Wireless Personal Area Networks.
AMI Advanced Metering Infrastructure.
AU Aarhus University.
CIM Common Information Model.
CPP-F Critical Peak Pricing.
DAPP Demand-Aware Price Policies.
DB&A Database and Analytics.
DNO Distribution Network Operator.
EBR Energy Bill Reduction.
EDN Electric Distribution Network.
EMS Energy Management System.
EUMF Energy Usage Modeling Forecast.
EUR Energy Usage Reduction.
EV Electric Vehicle.
EVT EDN Virtual Tomography.
FP Framework Programme.
GIAS Grid Intelligent Automation Service.
GOA Grid Operator Agent.
GSST Graduate School of Science and Technology.
HA Home Agent.
HAN Home Area Network.
HDM Home Device Management.
HECH Home Energy Controlling Hub.
HIAS Home Intelligent Automation Service.
HVAC Heating, Ventilation, and Air Conditioning.
IaaS Infrastructure as a Service.
IAS Intelligent Automation Service.
ICT Information and Communication Technology.
IETF Internet Engineering Task Force.
IoT Internet of Things.
IP Internet Protocol.
IR Internal Report.
MAS Multi-agent system.
NIST National Institute of Standards and Technology.
PLC Power Line Communication.
PPSV Price Policy Safety Verification.
PV Photovoltaic.
QoS Quality of Service.
RES Renewable Energy System.
REST REpresentational State Transfer.
SaaS Software as a Service.
SEP Smart Energy Profile.
SGTF Smart Grid Task Force.
SHHD Smart Home Hardware Device.
SMC Service Management Controller.
SME Small and Medium Enterprise.
SOA Service-Oriented Architecture.
SSM SmartHG Service Management.
TOU Time-Of-Use.

Søren Aagaard Mikkelsen, Privacy Enforcement in a Cost-Effective Smart Grid, 2014

Department of Engineering
Aarhus University
Edison, Finlandsgade 22

8200 Aarhus N
Denmark

Tel.: +45 4189 3000