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Authors:	Anke Weidlich (SAP), Stamatis Karnouskos (SAP), David Nestle (ISET), Patrick Selzam (ISET), Aris Dimeas (ICCS-NTUA), Sotirios Hadjimichael, Vali Lioliou (PPC), Cor Warmer (ECN), Koen Kok (ECN), Stefan Drenkard (MVV)		
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Dissemination Level

PUBLIC	Public
PP	Restricted to other programme participants (including the Commission Services)
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Executive Summary

This deliverable gives an overview of the state-of-the-art of technologies and aspects that enable information handling and distributed control in future SmartHouse/SmartGrid systems. Section 1 summarises the different stages at which bi-directional information exchange has to be enabled in order to support SmartHouse/SmartGrid technologies: the in-house, house-to-grid and grid-to-enterprise or house-to-enterprise levels. The technologies and engineering approaches relevant to these information exchange levels are further specified in the later sections. Section 2 reviews the current status of the deployment of smart metering and demand response in Europe, focusing on the three countries involved in the project as well as some relevant benchmark countries. In Section 3, possible options for communication in SmartHouse/SmartGrid systems, such as local area networks for in-house communication and wide area networks for communication between the Smart House, the Smart Grid and enterprise systems, are discussed. A review of the standards and protocols relevant for the communication between meters, household devices and the grid or enterprise system is also provided in the same section, as well as a discussion on security and privacy issues in SmartHouse/SmartGrid concepts. Section 4 provides more detailed engineering views of distributed control and information processing in SmartHouse/SmartGrid systems, including the concepts of Multi-Agent Systems and Service-Oriented Architectures. These paradigms have already been applied in previous work of the project partners, so the description should support a common understanding of the subject to the audience as well as to the entire project team. The gap between the state-of-the-art and a future SmartHouse/SmartGrid system as envisioned by the project is made explicit in Section 5. It names the open research questions to be addressed within the project, and gives some hints on possible ways of tackling them.

Deliverable D1.2 is a collection of contributions from the experts involved in the project. In this way, it also shows a snapshot of the state-of-the-art at the beginning of the project. Mutual understanding has increased during the joint work of writing this deliverable, and has set the framework for a common basis necessary for the detailed work in the other work packages. These other work packages will partly precise and extend the technical content of the specific topics, so that the complete knowledge of the technologies will only be available at a later project stage, presented in the next version of D1.2.

Abbreviations

ADSL	Asymmetric Digital Subscriber Line
AMI	Advanced Metering Infrastructure
BEMI	Bi-directional Energy Management Interface
BPL	Broadband over Powerline
CECED	European Committee of Domestic Equipment Manufacturers
Cenelec	Comité Européen de Normalisation Electrotechnique
CSI	Customer site integration
DPWS	Devices Profile for Web Services
DR	Demand response
DSI	Demand side integration
DSL	Digital Subscriber Line
DSO	Distribution system operator
ESMIG	European Smart Metering Industry Group
ETSI	European Telecommunications Standards Institute
FIPA	Foundation for Intelligent Physical Agents
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
HSPA	High Speed Packet Access
HEM	Home energy management
HV	High-voltage
ICT	Information and communication technologies
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
IIOP	Internet Inter-ORB Protocol (ORB = Object Request Broker)
IP	Internet protocol
ISDN	Integrated Services Digital Network
IT	Information technologies
KEMA	Consulting and testing association for the energy industry
LAN	Local Area Network
LON	Local Operating Network
LV	Low-voltage
MAS	Multi-Agent System
MV	Medium-voltage

OPC-UA	OLE for Process Control Unified Architecture (OLE = Object Linking and Embedding)
PLC	Powerline Communication
PPC	Public Power Corporation
PSTN	Public switched telephone network
REST	Representational State Transfer
SCADA	Supervisory Control and Data Acquisition
SGAD	Smart Grid Automation Device
SMS	Short Message Service
SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol
SOHO	Small office / home office
TCP/IP	Transmission Control Protocol/Internet Protocol
TSO	Transmission system operator
UMTS	Universal Mobile Telecommunications System
VPP	Virtual power plant
WELMEC	Western European Legal Metrology Cooperation
WAN	Wide Area Network
WLAN	Wireless Local Area Network

1. Technological Overview in the Context of Smart Houses and Smart Grids

The general infrastructure to be used in order to accommodate the scenarios considered in the SmartHouse/SmartGrid document D1.1 "High-Level System Requirements" is abstractly shown in Figure 1. A key issue is the integration of devices, communication between devices, and integration/communication with the enterprise systems. Information generated at the point of action (device level) is used by other devices, by higher level systems that aggregate and process them, as well as by global services. In that sense, there is an "information bus" where the meaningful information is available for entities to consume. As this information dissemination and exploitation has to be done in an open and interoperable way, Internet-based technologies are considered to be the best candidates to glue the components of the system together. Furthermore, several other technologies can be used beyond basic communication technologies in order to simulate and predict behaviour of such systems, or to provide further system capabilities [Karnouskos/Terzidis 2007].

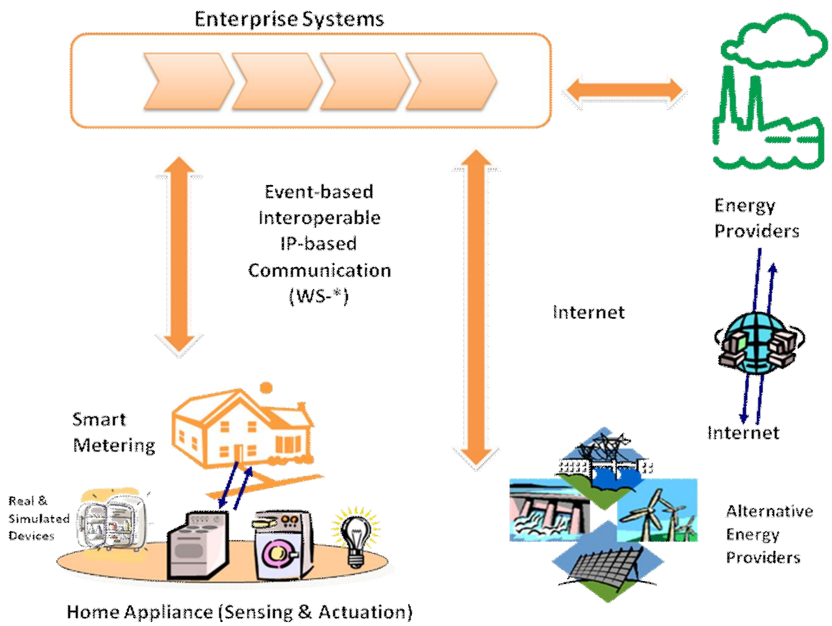

Figure 1: Overview of the SmartHouse/SmartGrid ICT infrastructure

In this document, the information representation and communication standards relevant and necessary to the integration of Smart Houses and Smart Grids are investigated. Within the interaction of Smart Houses with Smart Grids, three main categories of technologies can be distinguished. These are briefly summarized in the following subsections, and the state-of-the-art of the according technologies is described in Section 0:

- In-house technologies (see Section 1.1): These technologies are used mostly for monitoring, control and management of devices within the Smart House itself, as well as for extraction and usage of internal and external information for the Smart House. These include mostly monitoring, but also control capabilities.
- House-to-grid technologies (see Section 1.2): These are mostly used to interconnect houses, and to connect houses to grid operators and utilities, thus enabling an information exchange among them. They also include monitoring, but mostly take over control capabilities.
- House/grid-to-enterprise technologies (see Section 1.3): These are mainly used to couple the information generated within the Smart House or the Smart Grid with enterprise services. As such, the nature of these technologies primarily targets monitoring, while it also supports the management of the infrastructure via decision support functionality that can be used to apply control strategies.

The primary concept in this research project is the decentralization of control. This means that according to the market status, local decisions are taken that affect the nearby consumers. It is therefore necessary to define the key control mechanisms and IT solutions to be adopted in order to exploit the benefits of the SmartHouse/SmartGrid combination. Appropriate monitoring and control mechanisms must be capable of balancing the stakes of the different actors in the system. In the context of this project, the focus is placed on the concepts of Multi-Agent Systems (MAS), device to business integration and Service-Oriented Architectures (SOA). These concepts and their application to SmartHouse/SmartGrid scenarios are analyzed in Section 4.

1.1. In-House

In-house can be defined as all processes that run behind the meter, and includes not only residential households, but also small office environments. The house can be seen as the first level in a layered structure, in which the nano-level refers to the individual households, the micro-level refers to a low-voltage (LV) grid area, the meso-level refers to the medium-voltage (MV) grid region and the macro-level refers to the nationwide high-voltage (HV) grid level. The household level is the first level of optimization of energy flows. Kester [2006] identifies the following desirable technology developments for energy management behind the meter:

User adaptive control: Devices have to be controlled based on the presence or absence of the residents. Typical processes include ventilation, space heating and cooling, as well as lighting. Also, stand-by of devices can be automatically switched off by so-called stand-by killers.

User education: User behaviour is becoming more and more an important factor in energy use. A key question is how to motivate a user in a change in behaviour towards more energy efficiency. Positive incentives may be cost reduction, comfort improvement and a “green” consciousness. The direction of education is feedback, information and help towards the user. However, these educative means should be understandable and relevant with respect to time, place and action.

Demand response of domestic appliances: In order to introduce large scale demand response at the household level, cost and energy efficient standard technology should become available, that enable monitoring and control of devices and facilitate communication between devices and with the electricity network.

Monitoring of installations: Monitoring of electricity use and performance of installations may identify different issues, such as illogical behaviour (e.g. energy use at unexpected periods), inconsistent behaviour (e.g. simultaneous heating and cooling) or performance degradation (e.g. due to lack of maintenance or aging).

A number of common basic building stones can be identified that are required to develop these technologies.

- User interfacing: The user determines the boundaries within which any automated action may be taken. The transfer of user desires to the automated system should be intuitive.
- Sensing: A sensor network is needed to provide information for (a) users, (b) external parties, and (c) intelligent control nodes.
- Actuation: Actuators are needed to enable automated control of devices based on (a) user interaction, (b) external signals, and (c) intelligent control actions.
- Intelligent control: Automated intelligent control nodes may use information from users and external sources to take intelligent decisions on control of devices.
- Smart metering: For energy applications, smart metering is an enabling factor. It provides knowledge of energy use and generation of individual devices over time.
- Communication: Section 3.3 gives an overview of in-house communication standards enabling the information exchange for an intelligent control of devices.

1.2. House-to-Grid

In a scenario in which bi-directional communication between Smart Houses and the electricity grid is possible, the customer can become an active partner who is involved in the market in several ways:

- avoiding peak hour demand by following price signals that reflect the current cost of generating and transporting power to the customer;
- supplying electricity via a photovoltaic panel or a (micro-)Combined Heat and Power (CHP) installed in the Smart House, which then will be electricity-price triggered and not, as now in the case of CHP, heat-demand triggered. This can be made possible by adding heat storage, as heat can easier be stored as compared to electricity;
- being accessible by the DSO to disconnect loads, or activate loads or generation capacities, according to specified procedures agreed upon beforehand.

House-to-grid communication also includes the data exchange between the Smart Houses. Concepts like microgrids consider that the various distributed generation units and load controllers within the system may have the ability to communicate with each other. The ability to communicate allows them to have an increased level of coordination and efficiency. The successful operation of microgrids is based on the development of an intelligent control system architecture comprising distributed information technologies (e.g. intelligent agents), artificial intelligence techniques for online management and control of one or multiple microgrid(s), and sophisticated, though limited, communication capabilities.

Information coming from the Smart Houses can be of use for applications and services at a higher level in the network: at the utility level for commercial use, and at the network operator level for efficient grid operation. Similarly, information from a higher level in the network can be used by the Smart Houses to deliver services to the utility or network operator. This requires two-way communication, either on a peer to peer basis between the Smart Houses and the utility/network operator, or through some kind of aggregation. This latter concept can be worked out into so-called virtual power plants (VPP), a cluster of distributed energy resources (both production and consumption) that can be controlled from a central point in order to optimally operate the distributed devices from the viewpoint of the central controller.

If both commercial parties and network operators are involved in optimizing aggregations of Smart Houses, the Smart Houses will get two incentives for operation of devices, which may and will have conflicting interests. For example, a utility may stimulate consumption of electricity because of low prices, but the immediately resulting increase in consumption may overload the grid.

In a liberalized market, different Smart Houses may have contracts with different commercial aggregators. Commercial aggregators, in turn, have “clients” within different parts of the network. The organization of such aggregations may lead to a market structure as depicted in Figure 2, where Smart Houses are aggregated according to two criteria: their commercial aggregator and their network aggregator. Both parties can give incentives to the Smart Houses. The houses receiving non-conflicting incentives will be more willing to respond. In this way, a global merit order list emerges which balances the stakes of all three involved parties (commercial aggregators, network aggregators, and the Smart House *prosumers*).

Note that the smart meter again is an enabling factor for energy services that are delivered through the above structure. Incentives will only be followed by prosumers’ actions if it leads to profit. This requires a more time varying energy tariff, either by varying prices or through time dependent discounts or increments. Smart energy meters need to store interval based (if not real-time) energy usage and pricing information for user feedback.

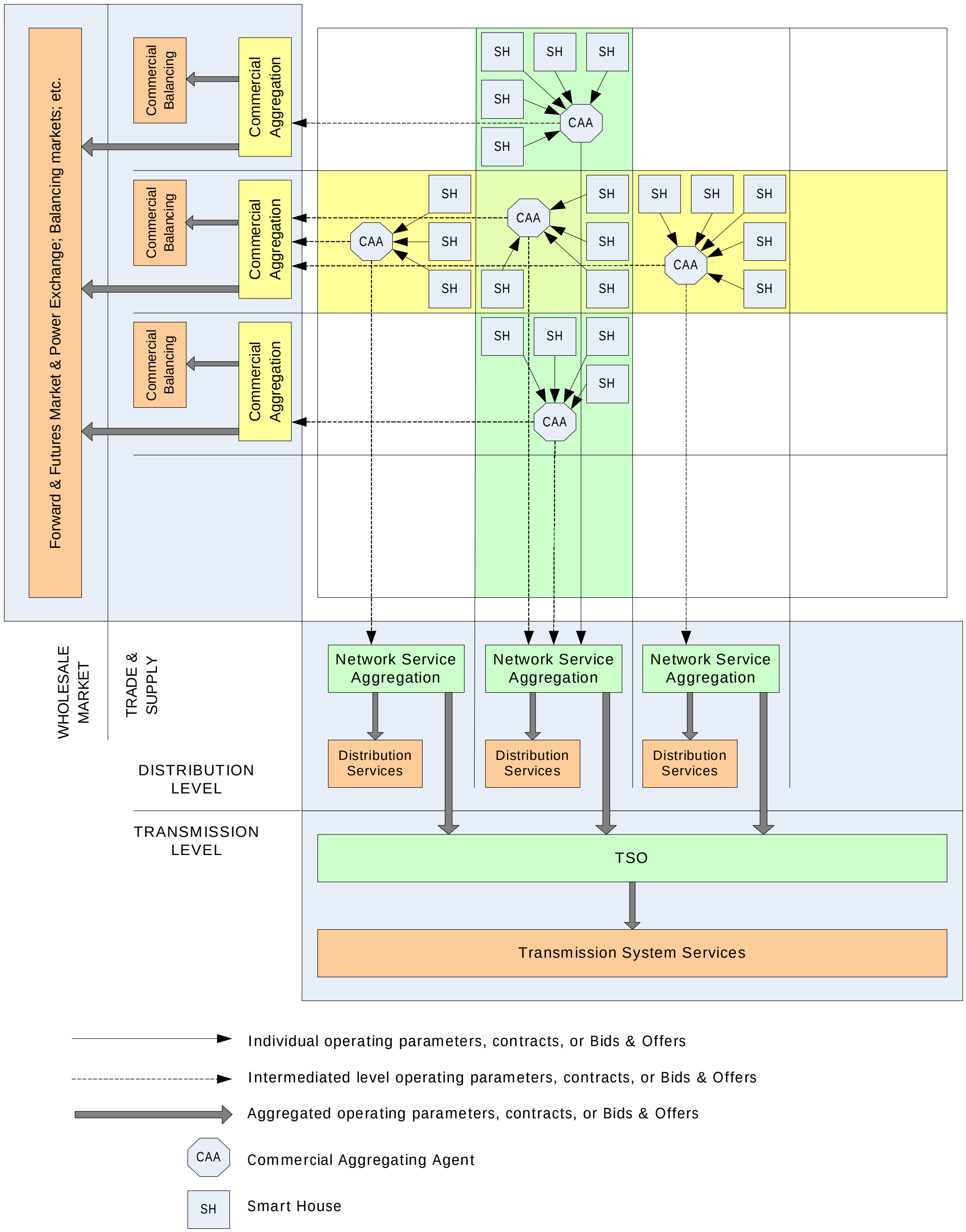

Figure 2: Aggregation of households for dual control goals: technical aggregation for ancillary services delivery to DSOs / TSOs and commercial aggregation for integration into energy markets

1.3. House/Grid-to-Enterprise

One important occasion of communication between Smart Houses/the Smart Grid and enterprises is the exchange of meter data for billing. The enhanced deployment of ICT allows for developing Advanced Metering Infrastructures (AMI). AMI is characterised by a bi-directional flow of information between the meter, the meter data management system, and the business application system. Besides automated meter readings, it offers a large variety of services, such as a remote disconnection and reconnection, as well as control capabilities. Therefore, a large number of messages triggered by various types of events are sent from the meter to the meter data management system, and further on to the business application system.

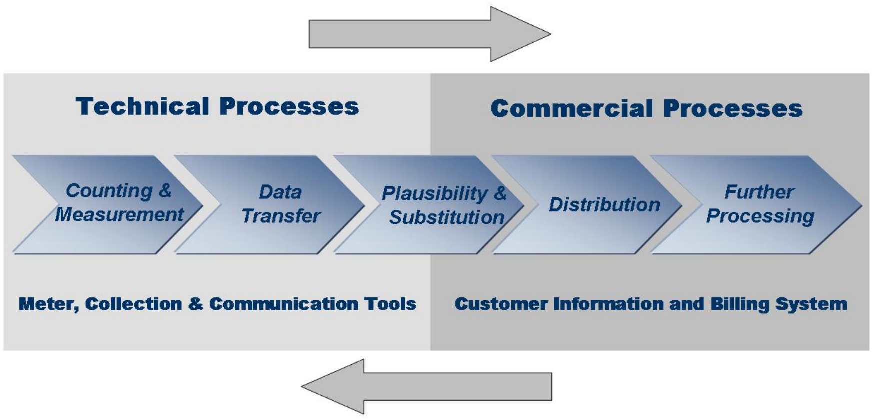

Figure 3: AMI value creation chain (SAP)

The AMI value creation chain (see Figure 3) illustrates one example of communication between the meter infrastructure and the backend system: after the collection (and consolidation) of all relevant consumption and / or meter reading data from the single meters, the information is transferred to a raw database in which the records are stored. Typically, consistency checks and replacement value procedures are applied before storing the data in this raw database. However, these activities can be also performed by the customer information and billing system if necessary, e.g. when receiving implausible values from the automated meter reading systems which would prevent a further processing of the data in settlement and billing. Besides this one-way-communication from the technical to the commercial processes, in an AMI information can also be transferred from the backend system to the single meter.

The system landscape for AMI is shown in Figure 4. Messages from the meters and concentrators first hit the meter data management system, the MDUS (Meter Data Unification System), before they arrive at the SAP system. The MDUS already filters the majority of these messages. For example, a meter might report a meter reading error to MDUS, but only if the meter reports several meter reading errors in a row this information will be forwarded to the business application system. It is, however, still expected that a large number of messages arrive at the business application system. These messages that are based on non-usage events should result in automatic follow-up actions that depend on the triggering event type: a meter error might – for example – result in a service order. Utility companies have to be able to flexibly configure these follow-up actions. Therefore, a configurable, performing AMI business rules engine is needed, that receives the messages and starts the predefined follow-up actions.

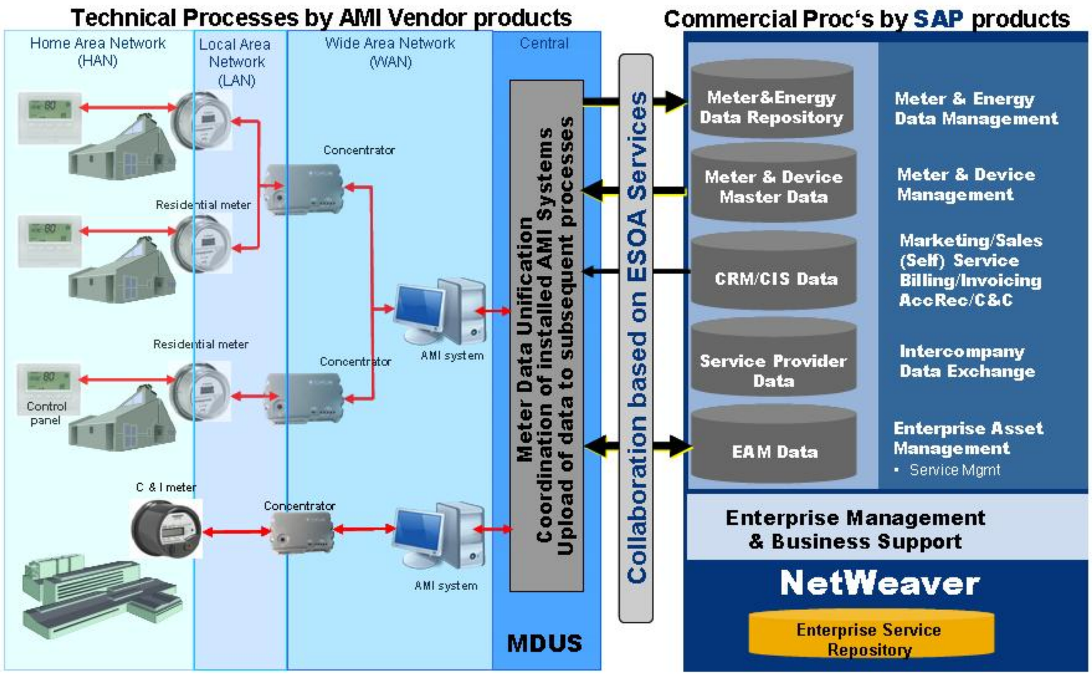

Figure 4: AMI system landscape (SAP)

Most utilities' architectures are currently characterised by a heterogeneous system landscape, i.e. a combination of company-wide applications, best-of-breed-solutions, enterprise resource planning and legacy systems. Service-oriented architectures significantly increase system flexibility and also the interoperability and compatibility in such an environment. That means this architecture offers pre-defined business processes and context-specific web-services. Once these services have been defined, they can be connected with each other to finally result in an entire process according to the individual requirements of a customer. With a service-oriented architecture, the technical boundaries of realising innovative automation processes can be exceeded, and the prerequisites for an efficient implementation of new processes and products is set.

2. Smart Metering and Demand Response Deployment in Europe

2.1. Smart Metering

The availability of detailed data on the energy consumption of households is an important prerequisite for SmartHouse/SmartGrid concepts. However, the advancement of smart metering in Europe is quite unequal among different states. This section gives a brief overview of smart metering deployment in Europe, focusing on some advanced countries (i.e. Italy and Sweden) and on the three countries in which field tests are carried out within the SmartHouse/SmartGrid project. Figure 5 gives an overview of the smart metering deployment status in Europe.

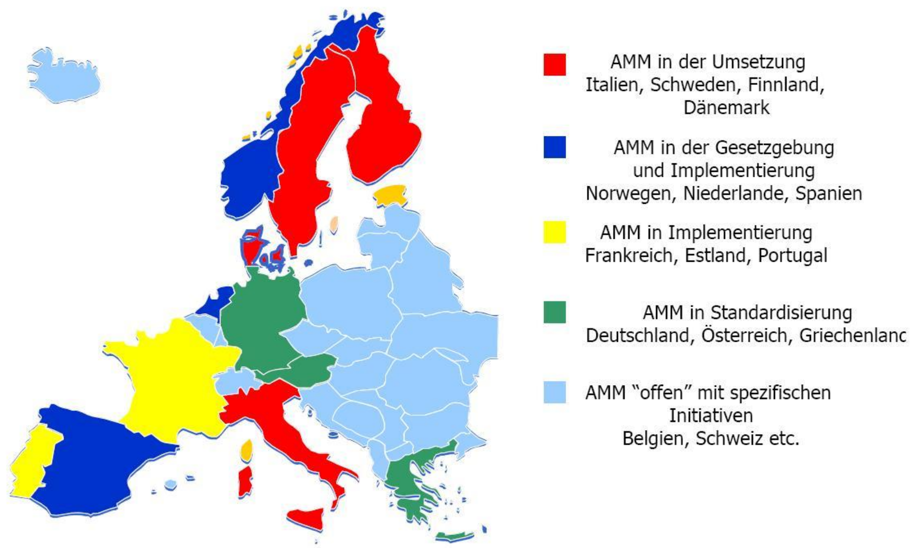

Figure 5: Advanced Metering Deployment in Europe [Landis+Gyr 2008]

- Italy

  The largest project of introducing advanced meter management project has been carried out by the Italian utility Enel, in cooperation with IBM. The aim of the project Telegestore was to create an advanced meter management network for 30 million residential customers that helps to manage peak demand and that allows to better cope with bad payers. Starting in 2001, in most Italian regions more than 90% of all meters have been replaced by the smart electronic meter developed within the project. At the same time, new demand side management tariffs for households have been introduced, and the utility has the capability to curtail power supply to specific customers at any time.

- Sweden

  In 2003, the Swedish parliament passed regulations requiring all electricity meters for the more than five million Swedish utility customers to be read on a monthly basis by mid-2009. A cooperation of more than 30 independent energy companies, which has been formed to purchase new metering hardware in order to comply with the new legislation, opted for Echelon's Networked Energy Services (NES) as a metering system. It is based on the LonWorks network protocol. Also, the two major utilities Vattenfall and E.ON Sverige deploy Echelon's NES as a smart metering system, and have already widely installed the new meters at their customers' sites.

- The Netherlands

  In the Netherlands early 2006 an effort has been started by the Dutch Standardisation Institute NEN to define a pre-standard for smart meters in the Netherlands, the NTA 8130. The NTA 8130 defines a minimal set of functions for smart metering. After finishing this project, a lot of discussion arose on the outcome of the standard, which – according to some parties – lacked functionality to facilitate transition towards Smart Grid solutions. Nevertheless, the Dutch parliament accepted a law stating that starting April 1, 2009, all Dutch households should be provided with a smart meter. The first two years will still be a test period in which only new and retrofit buildings will be required to install a smart meter.

Several utilities and network operators have performed a pilot roll-out of smart meters. Oxxio, a Dutch utility, has been very active in this field and already has integrated automatic meter reading on its billing processes. The network operator Alliander (former Continuon) had a massive pilot including over 80,000 smart meters, focusing on ICT, communication and efficiency in installation processes. Other companies had smaller pilots with smaller numbers of smart meters.

- Germany

  Large-scale deployment of smart meters has still not started in Germany. A couple of field tests have been carried out by utilities, in which usually the use of advanced pricing schemes was tested (see Section 2.2.3). Besides, one notable initiative was the SELMA project[6], in which a legally compliant security concept for smart meters and the data transfer of metering data was developed. The SELMA concept considers the whole metering process chain from calibration and installation, to measurement and billing. Existing international standards for communication and security were used wherever possible. The measurement data signature can be used to easily validate measured consumption data anywhere in the process (up to and including invoicing). It also makes it possible to automate the maintenance process for measuring devices by downloading validated and certified software packets, thereby considerably lowering maintenance costs. The project ended in 2005, and a transition towards mass application was envisaged.

  Due to new legislation, customers will have the right to choose the metering service provider independently from their power supply contract. The owner of the meter, the meter reading company, the grid operator and the retailer are all different actors in the new setting, so every one of these four stages of the value chain can be delivered by different companies. Recently, the first players have started to offer smart metering services in order to differentiate themselves from their competitors (e.g. EnBW Cockpit[7], Yello Sparzähler[online8]). It can be expected that smart metering will, thus, experience a considerable push in the near future.

- Greece

  Smart metering is not yet introduced in the Greek system. However there are at the moment several pilot projects running at the national utility PPC relating to smart metering or remote metering.

  - Smart metering project in Larisa: This installation includes a network on the overhead lines based on BPL (Broadband over Powerline) technology. In this pilot project a variety of the systems capabilities are being exhibited, such as:
    - Smart Grid applications that concern remote measurements and control of various elements of the grid as well as cameras that transfer images from remote parts of the grid
    - Electronic meter reading
    - All sorts of broadband data services such as video on demand, Voice over IP, fast Internet etc.
  - Remote meter reading: There are several pilot projects for remote meter reading at PPC, aiming at the introduction and evaluation of certain remote metering software/hardware on the LV Network. Products from many manufacturers are currently evaluated.

[6] SELMA Project (Sicherer ELektronischer Messdaten-Austausch - secure electronic measurement data exchange), http://www.selma-project.de/

[7] http://www.enbw.com/content/de/privatkunden/produkte/strom/enbw_isz/cockpit/index.jsp

[8] http://www.yellostrom.de/privatkunden/sparzaehler/index.html

The general parameters of these projects are: The data transfer between the remote metering equipment and the local agents will be achieved by PLC technology. The data transfer between the local agents and the central metering units will use GSM/GPRS technologies.

2.2. Demand Response

Demand response (DR) can be described as a means to increase the demand side participation in the competitive electricity market. The customer adjusts her electricity consumption in response to an external signal. This signal can be price-based, by setting up special retail pricing tariffs, or program-based, in which customers are given other forms of incentives to adjust their loads [U.S. DOE 2006].

In the last years, a third DR scheme is arising, in which the demand side not just receives a price signal, but is actually involved in the price forming process. Large consumers already can become part of the market, either as separate party or bundled with other parties. For small end-users, this is not yet an opportunity, although several European projects address the issue of aggregation of large numbers of small consumers into virtual power plants. Since in this scheme the end-user demand is really integrated into the electricity market, this type of DR is also called Demand Side Integration (DSI). With the introduction of distributed generation, demand response is no longer bound to end-user electricity consumption but may comprise end-user electricity production as well. Hence more terminology is introduced: Customer Site Integration (CSI).

Sections 2.2.1, 2.2.2 and 2.2.3 give an overview of different approaches. The deployment of demand side management in Europe, with a focus on The Netherlands, Germany and Greece, is summarized in Section 2.2.4.

2.2.1. Price-Based Demand Response Programs

With time-varying retail tariffs, the price of electricity to be paid by the customer fluctuates, to varying degrees, in accordance with variations in the electricity price on the wholesale markets. Customers on time-varying tariffs can reduce their electricity bills if they respond by adjusting the timing of their electricity consumption to take advantage of lower-priced periods and/or avoid consuming when prices are higher.

Typical time-varying tariffs include the following three options:

- Time of Use - energy prices usually vary for different times of the day in order to reflect typical supply and demand situations in fixed time intervals.
- Critical Peak Pricing – usually the same as Time of Use, with the exception that extraordinary prices can be charged in extreme (peak) situations.
- Real-Time Pricing - prices vary according to a given reference, e.g. wholesale prices at the energy exchanges.

2.2.2. Incentive-Based Demand Response Programs

Incentive-based demand response programs represent contractual arrangements designed by grid operators and utilities or retail electricity suppliers to elicit demand reductions from customers at critical times. The corresponding programs give participating customers incentives to reduce load that are separate from, or additional to, those customers' retail electricity rate, which may be fixed or time-varying. The incentives may be in the form of explicit bill credits or payments for pre-contracted or measured load reductions. Customer enrolment and response are voluntary, although some demand response programs levy penalties on customers that enrol but fail to respond or fulfil contractual commitments when events are declared. In order to determine the magnitude of the demand reductions for which consumers will be paid, demand response programs typically specify a method for establishing customers' baseline energy consumption (or firm service) level against which their demand reductions are measured.

- Direct load control - utilities can directly control single loads – not employed in Germany

- Interruptible / curtailable load - usually deployed for large customers – some loads can be curtailed in peak situations
- Demand bidding / buyback programs - consumers can submit bids for curtailing loads in peak situations
- Emergency demand response programs

2.2.3. Distribution Site Integration

Demand response programs described in the previous paragraphs are characterized by the initiation by the utility, and depend on voluntary participation of end-users. Typically, the state of the electricity grid leads to control decisions at a central level, after which customers are approached to resolve the problem.

In the future electricity network, having a large share of decentralized generation, and having more and more all-electric infrastructure (e.g. electrical vehicles), will require distributed control concepts for local grid support. The role of generation and consumption is more in balance, and a logical step is to look for market-based solutions for control, having active customers as market participants. This leads to dynamic responses, with proactive action in case of critical circumstances. End-users no longer react to price changes but are participating in the price formation process. The outcome of the market can be fixed in "real-time" contracts.

This concept, leading to true integration of end-users into the process of delivering electricity, is implemented in the PowerMatcher technology [AAMAS 2005] that will be applied in several of the scenarios of the SmartHouse/SmartGrid project.

2.2.4. Deployment of Demand Response Schemes in Europe

- Greece

  PPC currently evaluates several scenarios related to the development of a new service portfolio, by introducing new products in its supply division, aiming at introducing versatile tools for the demand side management, which is of the utmost importance for defending its supply market share.

  The products examined include:
  - New pricing schemes
    - Fixed / indexed price
    - Discounts schemes
  - Enhanced features
    - Multiple tariff, interruptible tariffs, prepaid schemes
    - Green energy, loyalty
  - Web services
    - Information
    - Sale / after sale services
  - Energy saving / efficiency
    - Consulting
    - Project management
    - Energy audits
  - Automated energy management systems

  The existing regulating environment imposes important hurdles for the implementation of many of the above products, especially the ones related to tariffs.

  PPC is currently offering night time tariffs, with lower prices for residential customers during the night. Under negotiation are also several tailor-made tariff schemes with MV and HV customers, in order to allow smoothing of their demand curve by time-shifting loads from peak hours to valleys. In the summer, where Greece during the last few years is experiencing a shortage of power, there are incentives for MV and HV customers to allow power cuts, with the benefit of price discounts. Under development is also a scheme of cooperation with local authorities for energy savings and better energy control related to street lighting and municipal buildings lighting.

- Germany

Typical time-varying tariffs in Germany are offered for customers who have night storage heaters, where the tariff during night hours is considerably lower than during daytime. Real-time pricing is deployed only in some small-scale field tests (cp. “Energiebutler” by MVV, “Strompreissignal an der Steckdose” by EnBW). Other small-scale examples are e.g. a demand side management program provided by a public services company in Saarbrücken, who shuts off contracted deep-freezers and refrigerators in supermarkets for 1-2 hours when load is high. These cooling devices cool down deeper in times of lower load. Another example is a chemical factory in Wilhelmshaven. Here, the utility can deliver up to 30 MW less power for a certain duration that has been agreed upon beforehand. Up to now, there are only singular demand side management programs in Germany, and few initiatives to deploy this rationale on a large scale.

- The Netherlands

Small consumers can apply for a double tariff meter to be installed. During off-peak time (night, weekend), a much lower tariff is offered to the end-user, giving him the incentive to shift electricity use to these periods. Main appliances that are affected are washing and drying devices.

In a recent study, the total potential for demand response in Dutch households is 700–1,200 MW [SenterNovem 2004]. This is 2.5–5% of the total maximum power demand in the Netherlands. Main obstacles for demand response are lack of proper technology (e.g. smart metering and communications) and incentive structures (e.g. consumers only see a peak and off-peak price). The introduction of smart meters may lead to some DR initiatives based on capacity restriction and prepay services. Small consumers are not enthusiastic about DR, because the security of supply in the Netherlands is very high.

Another report by Deloitte, studies the potential of DR in the Dutch liberalised electricity market. The potential in the wholesale sector is 1,730 MW, of which 1,200 MW is industrial and 425 MW in the horticulture sector [Deloitte 2004]. A total of 1,000 MW is already utilized, 700 MW remains unexploited. Another almost unexploited capacity is in emergency generators, estimated at 1,400 MW.

In order to optimally utilize demand response, commercial users should be flexible with respect to buying and selling electricity. Since acting on the electricity wholesale market introduces operational costs and risks, in many cases the energy management is redirected to utilities or energy service providers.

In the Netherlands, the horticulture sector has a large share of CHP installed. Fed by gas, they produce heat, light, CO_2 (for plant growth) and electricity. By installing large heat buffers and CO_2 tanks, a lot of flexibility is available for electricity production. Although the capacity for each party is rather small, as an aggregated group this flexibility is already utilized in today’s wholesale market.

3. Information Representation and Communication in Energy Systems

For SmartHouse/SmartGrid systems, both in-house and remote communication is necessary in order to transmit relevant data among devices, between the grid and Smart Houses, and between enterprise systems and Smart Houses or the Smart Grid. Therefore, technologies and data formats allowing bi-directional communication over long distances (Section 3.1) and local communication over short distances (Section 3.2) are reviewed in the following. Section 3.3 gives a brief overview about standardisation efforts in the data exchange protocols and 3.4 adds a discussion about how to ensure security and privacy in Smart House communications.

3.1. Wide Area Communication

In order to allow a transmission/distribution system operator (TSO/DSO) or a commercial aggregator to send price signals or other relevant information to the end-user/prosumer, remote communication with the electricity meter must be possible. This section reviews options for Wide Area Network (WAN) communication with the customer interface, including the meter.

3.1.1. Fixed and Mobile Network Communication

Existing public networks such as paging, satellite, Internet and/or telephony (cellular or landline) networks can also be used to provide for communications between meters and utilities. One key advantage of these systems is the ability to deploy an Advanced Metering Infrastructure across a wide area with low densities, and the possible lower upfront cost of deployment since the utility does not need to build a private infrastructure. Some remote meter reading systems rely on paging networks while others rely on cellular or landline telephone networks. Some have used satellite communications. Three key limitations include: being subject to the coverage provided by the public networks, changing protocols (this is especially true in the cellular segment), and operational costs.

With AMI systems based on public networks, if there is coverage at the customer location, installation costs are limited to installing the new endpoint, and setting up the service. Utilities are not required to install any communication infrastructure, which can speed up the deployment process.

As for their rather low capacity demand, metering and consumption data could, in principle, be transmitted via narrowband network communication systems such as PSTN or ISDN; however this requires the sending device to dial a switched connection at every time it wants to transmit data, which leads to additional costs. In contrast, the dissemination of broadband connections with flat-rate tariffs (DSL, TV broadband cable) is growing in many European countries, which allows for sending energy-related data without additional costs [wik-Consult/FhG Verbund Energie 2006]. For the reason of DSL's widespread availability and low cost of transmitting additional data, the first electricity suppliers in Germany who are offering smart metering services and real-time energy consumption to their customers (e.g. EnBW Cockpit, Yello Sparzähler^{online}, see also Section 2.1) rely on this technology and require their smart metering customers to have a DSL connection at their home.

In comparison to fixed network communication systems, mobile network communication systems such as GSM or UMTS are less dependent on an already existing infrastructure. In some regions, in which fixed network based broadband solutions are not economically viable, mobile networks can be an alternative for the transmission of energy-related data between a smart meter and a utility. There are already smart meters on the market which are equipped with an integrated radio module for sending meter data via mobile network communication, such as the GSM or GPRS standard [wik-Consult/FhG Verbund Energie 2006; they name the example of EMETRION IQ-GSM/GPRS[9]].

[9] http://www.goerlitz.com/fileadmin/Dokumente/PDB/EMETRIONIQ-GPRS_PDB_DE.pdf

3.1.2. Powerline Communication

Powerline communication (PLC) uses the existing power lines within a home, building or an outdoor power distribution network to transmit data from one device to another. With a well-designed power line solution, devices should be able to communicate using the existing wiring infrastructure, without any rewiring or modification. This makes powerline communication one of the most cost-effective means for networking devices.

PLC systems send data through power lines by injecting information into either the current, voltage or a new signal. This can be accomplished by slightly perturbing the voltage or current signal as it crosses the zero point, or by adding a new signal onto the power line. The system normally has equipment installed in utility substations to collect the meter readings provided by the endpoint, and then the information is transmitted using utility communications or public networks to the utility host centre for the PLC system.

PLC systems are particularly well suited to rural environments, but have also been successfully used in several urban environments. For utilities with both rural and suburban areas in their service territory, PLC provides an option for using one automated metering technology for the entire service territory for electric meters.

PLC systems initially targeted residential and small commercial metering, but are now able to read for larger customers as well. Any electrical devices connected to the power line can be networked to communicate with each other. Some examples of applications include:

- Intelligent electricity meters: This solution enables utilities to network all of their electricity meters and to read them from a remote central location. A Powerline smart transceiver-based meter can also enable utilities to remotely switch on/off power to a facility as well as to detect any tampering of meters or unauthorized power consumption.
- Networked home appliances: Every device in a home can now communicate with each other as well as with the local electricity meter. These devices could include the refrigerator, washer/dryer, AC/heating, lighting system, security system, pool heating, etc. As a result, utilities and consumers can monitor and manage power consumption more effectively (demand response, see also Section 2.2) thereby increasing cost savings and convenience.
- Power lines were designed to carry power and not data. This means it takes a very sophisticated transceiver to reliably communicate over power lines. Many electrical devices connected to the power lines adversely impact the data that is being transmitted. The quality of the signal that is transmitted over power lines is dependent on the number and type of the electrical devices connected to the power lines and switched on at any given time. The quality of the signal is also dependent upon the wiring distance (not physical distance) between the transmitter and the receiver as well as the topology (wiring architecture) of the power line infrastructure in the home/building. All of the above impediments could vary between buildings, neighbourhoods, and the power grids in various countries, making a universal solution very difficult.

3.1.3. Broadband Over Powerline Communication

Currently, broadband Internet access is offered to residential and small-business customers through DSL, cable-modem, wireless, optical fiber, and satellite technologies. Broadband over Powerline, or BPL, is another mode of broadband access. BPL deployment remains in the developmental stage in most areas where it is available.

BPL utilizes electric power distribution wires for the high-speed transmission of data by transmitting high-frequency data signals through the same power distribution network used for carrying electric power to household users. In a common form of BPL, the broadband connection is provided over the electrical wires that enter a house; a customer can obtain Internet access by plugging a BPL modem into any residential electric outlet served by the BPL system. In another form of BPL, Internet access is provided using a wireless device (such as a Wireless LAN (WLAN) access point) connected to a BPL distribution system outside of the house that communicates with the customer's computer or other equipment inside the house.

It is important to note that BPL technology, in its current form, is not suitable for carrying broadband signals over long distances. The broadband communication channel must be brought into a neighbourhood by other means, and then BPL can be used as the distribution mechanism to reach individual homes or businesses.

Carrier-current systems have been used for many years to conduct low-speed data over power lines. Because of the inherent impedance and attenuation variations of power lines, as well as noise from dimmer switches, motorized electrical appliances, computers switching on and off, and other devices, reliable high-speed communication over power lines has been difficult to achieve. However, the recent availability of faster digital processing technologies and the development of sophisticated modulation schemes have produced new designs that overcome these technical obstacles. These new designs have led to the development of new BPL systems that use spread-spectrum or multiple-carrier techniques and that incorporate adaptive algorithms to overcome the problems associated with noise in the power lines.

BPL works by modulating high-frequency radio waves with the digital signals from the Internet. These high frequency radio waves are fed into the utility grid at specific points, often at substations. They travel along MV circuits and pass through or around the utility transformers to subscribers' homes and businesses. Sometimes the last leg of the journey, from the transformer to the home, is handled by other communication technologies, such as WLAN.

Figure 6 illustrates a basic BPL system, which can be deployed in cell-like fashion over a large area served by existing MV power lines by installing multiple injectors, repeaters, and extractors.

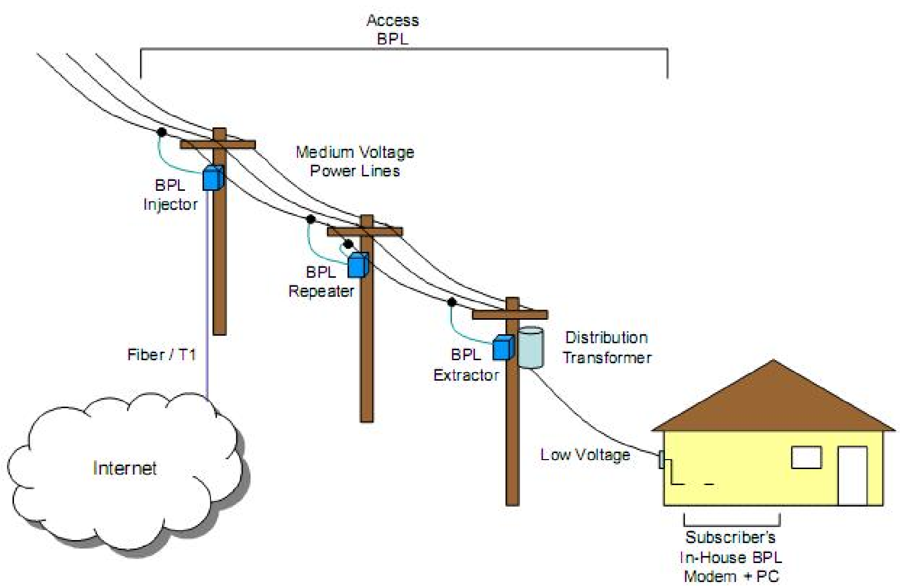

Figure 6: Schematic representation of a broadband over powerline system

The main advantages of BPL technology in building the communications backbone that will enable Smart Grids are the ability to touch, reach and digitize the physical grid. Creating the most robust communication network requires that it touches the key nodes, like transformers on the physical grid, and tackle the true complexities of the grid at the outset.

Drawbacks with using BPL to backhaul data are cost of fiber, installation labour cost and the fact that, should a fault occur on the conductor that the BPL services are provided, all data would be cut off and the communication will be rendered useless.

3.1.4. IEC 61850

The standard IEC 61850 was first introduced for substation communication, but is now preferred by IEC as the "seamless telecontrol communication architecture" for the future communication within the electrical energy supply [Schwarz 2002]. One of the most important features of this standard is the separation of the definition of data models (specifying what content is transmitted and what it means) and the underlying protocols defining how the data shall be transmitted. This concept allows for the extension of the standard to new applications by defining the appropriate data models quite easily. Data models as part of the IEC 61850 family have been approved for wind power plants (IEC 61400-25) and hydro power (IEC 61850-7-410). IEC 61850-7-420 for communication to distributed generation units will probably be available as approved standard within the first half year of 2009. This new chapter also defines basic data models for energy management including operational modes, set point curves and price profiles for electricity production and demand as well as ancillary services.

3.2. Communication for Home Automation and In-House Interconnectedness

In a Smart House, real-time information about the electricity system status (consumption, prices, renewable energy production etc.) needs to be delivered to the customer or to home appliances. This information can either be transmitted via WAN communication options (web sites, SMS or others), or via local network communication.

Besides the communication between the customer site on the one hand and the DSO and the electricity trader on the other hand, communication also has to be possible between the customer interface and the devices installed at the customer's premises (see Figure 7). Moreover, communication between the customer interface and the user display takes place within the Smart House. This communication needs to transmit measurement and status information to the customer interface and switching commands as well as other settings to the devices. Also real-time information about the electricity system status (consumption, prices, renewable energy production etc.) needs to be delivered to the customer display.

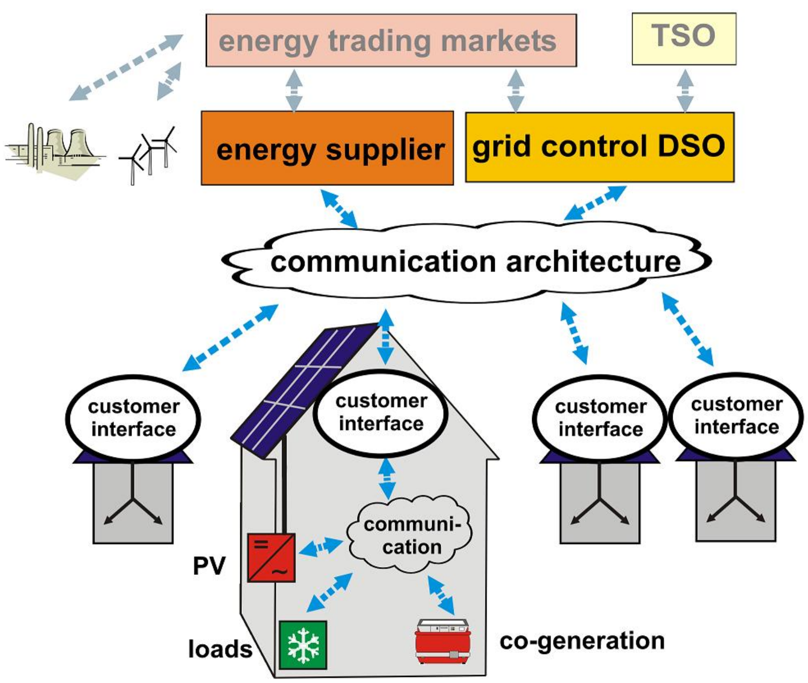

Figure 7: Smart House communication structure

Today building automation is mostly installed in commercial buildings using automation bus systems like KNX or LON. Building automation in private households has not been established in Europe, though. In contrast, TCP/IP-based computer and telecommunication networks are widely used also in private households and small businesses today. The main barriers regarding home automation, which means building automation for small/private customers, are still the cost and the requirement to install the systems in existing buildings. To overcome this situation, it is important to use home automation systems that do not need additional cables, which means signal transmission via radio or the existing electrical cabling. To make home automation feasible for mass market, it will also be necessary to allow for the installation of small systems with limited functionality to start with. These systems should not primarily be designed to provide critical functionality that could affect the usability of the building as a whole when programmed faultily. With this limitation the system can be configured by the customer himself. This approach is also used for most private computer networks in Europe today for those types of customers who prefer to accept occasional disturbances over the cost of professional installation and service. Furthermore, customers who are most interested in using advanced technology in their home are also interested in being able to configure and to control these systems themselves.

3.2.1. WLAN

Wireless LAN uses the 2.4 GHz frequency band for signalling according to standards IEEE 802.11b and 802.11g. In Europe, this frequency band is open to public use, and is divided into 13 channels. WLAN is used widely in computer networks. For use in home automation systems, other standards are more suitable, however. ZigBee uses the same frequency band as WLAN, but in contrast also specifies auto-routing of information packages from one node to any other node allowing reaching devices within the entire building, as long as all nodes can contact any other node of the network. For using WLAN, direct radio signal connectivity between all nodes (clients) and the central access point is required unless special repeaters are used, which would increase cost and power consumption of the system. For this reason, WLAN is not further considered for home automation in this project. WLAN can be very helpful for the connection between the customer interface and the display, however.

3.2.2. Bluetooth

Bluetooth is an industrial specification for wireless personal area networks (IEEE 802.15.1). It enables connections and information exchange between devices such as laptop computers, PCs, mobile phones, printers or digital cameras via a secure short-range radio frequency. As for its intended use for personal area networks, the range of communication via Bluetooth is rather low, approximately ten meters in most implementations. This makes it unsuitable for a communication with a smart meter. For this reason, it is not further considered in this project.

3.2.3. Specialized Home Automation Systems

Several innovative radio and PLC-based home automation systems that fulfil the requirements explained in the introduction to this section are currently coming to the market. Most of them are proprietary systems of one vendor, however. Until now, solutions to home automation challenges have been sought through the development of better sensor networks. Although they are very important parts of Smart House solutions, no single sensor network technology can solve the challenges in this field. Z-Wave, ZigBee, and Digitalstrom are attempts to define a common command language for home networks. So far, none of them has achieved the status of a de facto standard of home networks. Hence, it can be assumed that a future home will use several different technologies. The three named standards are evaluated in more detail below: ZigBee, Z-Wave and Digitalstrom. Table 1 gives an overview on most important characteristics of these standards.

	ZigBee	Z-Wave	Digitalstrom
Promoter / origin	ZigBee Alliance www.zigbee.org	Z-Wave Alliance www.z-wavealliance.org Zensys (DK)	Digitalstrom-Allianz www.digitalstrom.org ETZ Zürich Aizo GmbH, Wetzlar
Areas of application	All kinds of sensor / actor networks	Home automation	Home automation
Medium / frequency	Radio 2.4 GHz	Radio 868 MHz	PLC 50 Hz
Bit rate	250 kBit/sec	40 kBit/sec	Approx. 100 Bit/sec
Batteries	Some years, in case of no WLAN interference	Some years	--
Coverage of entire building	Auto-routing	Auto-routing	Robust PLC signal
Home automation standardization	Smart Energy Profiles (2008)	Part of core specification	In progress
Home automation available products	Approx. 10 (mostly smart meters, display), not installable by users	More than 200, no smart meters, mostly installable by users	--
Standardization process and usage	Spec: members of alliance, usually years per edition	Spec: members of alliance, extensions possible in 8-12 months	Not clear yet, so far only members of alliance
Product development	Free	Members of alliance	Members of alliance
Certification	Possible	Mandatory	Not clear yet
Manufacturer-independent compatibility	Not clear yet	Tested success fully at ISET, high priority	--
Potential interferences discussed	WLAN	--	--

Table 1: Comparison of ZigBee, Z-Wave and Digitalstrom as home automation systems

3.2.4. Systems for Connecting to Household Appliances

Several manufacturers of white goods have created own proprietary systems which allow connecting to their appliances such as washing machines, refrigerators and ovens. Most of these systems can be controlled via a user display or via a gateway from a local PC, and send their communication signals via PLC. Examples for these systems are Miele@home (by Miele) and Serve@home (by Siemens), which is not supported anymore.

A new standard for household appliances interworking is currently prepared with the support of the European association of manufacturers of household appliances CECED as EN 50523. The current draft of the standard does not define any specific parameters of most appliances, however.

3.2.5. REST

Representational State Transfer (REST) is a software architectural style for distributed hypermedia systems like the World Wide Web. The term originated in a 2000 doctoral dissertation [Fielding 2000] and has quickly passed into widespread use in the networking community. REST is an architectural style for building large-scale networked applications. REST describes a networked system in terms of data elements (resource, resource identifier, representation), connectors (client, server, cache, resolver, tunnel), and components (origin server, gateway, proxy, user agent). The RESTful approach could provide an integration approach for the devices in the SmartHouse/SmartGrid context.

3.2.6. OPC-UA

The OPC foundation actively develops the OPC Unified Architecture (OPC-UA)[10], with the goal to advance the OPC communications model (namely COM/DCOM) towards service-oriented architectures and introduce a cross-platform architecture for process control. OPC-UA is a set of specifications applicable to manufacturing software in application areas such as field devices, control systems, manufacturing execution systems and enterprise resource planning systems. These systems are intended to exchange information and to use command and control for industrial processes. OPC Unified Architecture defines a common infrastructure model to facilitate this information exchange.

3.2.7. DPWS

Devices Profile for Web Services (DPWS) is attempting to fully integrate devices with the web service world. DPWS defines a minimal set of implementation constraints to enable secure web service messaging, discovery, description, and eventing on resource-constrained devices. DPWS is an effort to bring web services on the embedded world taking into consideration its constrained resources. Several implementation of it exist in Java and C[11], while Microsoft has also included a DPWS implementation (WSDAPI) by default in Windows Vista and Windows Embedded CE.

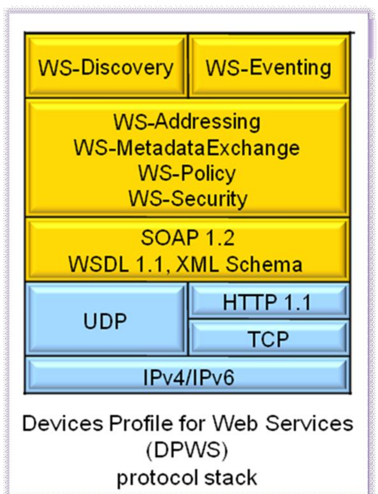

Figure 8: DPWS protocol stack

The DPWS stack supports the following web service standards: WSDL 1.1, XML Schema, SOAP 1.2, WSAddressing, WS-MetaDataExchange, WS-Transfer, WSPolicy, WS-Security, WS-Discovery and WS-Eventing. As a result, dynamic device and service discovery can be realized, while the metadata exchanged can provide detailed information about the devices and its functionality. This is well supported in DPWS with the inclusion of the main data discovery and transfer protocols such as WSDL, SOAP, WS-Transfer etc. Therefore, not only custom made device drivers can be eliminated to a large extend, but also these devices can now be easier and better used by enterprise resource planning applications via widely used technologies such as web services.

[10] OPC-UA: http://www.opcfoundation.org/UA/

[11] www.ws4d.org, www.soa4d.org

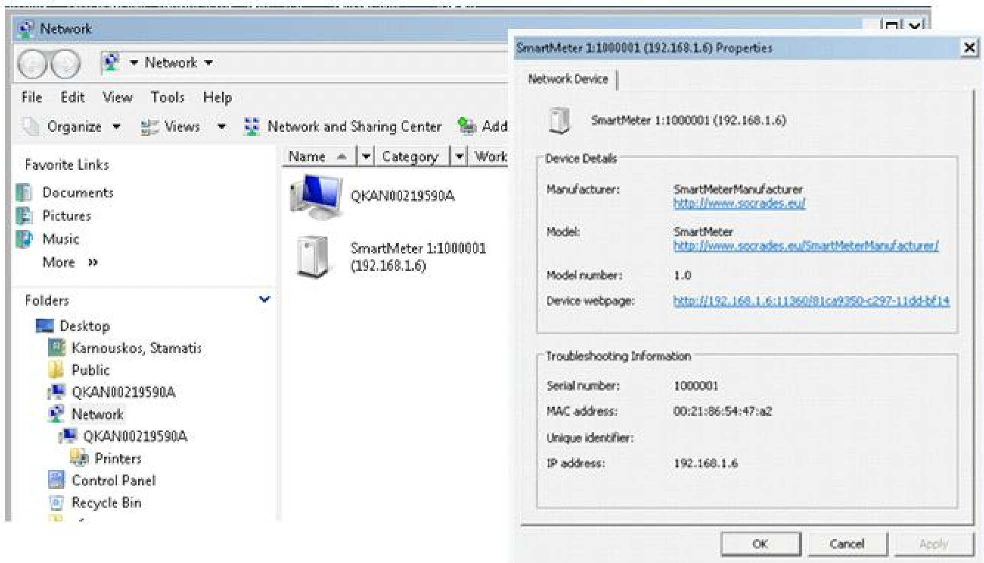

Figure 9: Dynamic discovery of smart meters in MS Windows VISTA

Microsoft has also included a DPWS implementation (WSDAPI) by default in Windows Vista and Windows Embedded CE. Therefore, one can dynamically discover devices that support it (such as the smart meter in Figure 9) and query their data, e.g. their status, serial number etc. In August 2008, the OASIS Web Services Discovery and Web Services Devices Profile (WS-DD) Technical Committee was created to further advance the existing work, e.g. DPWS.

3.2.8. IPv6 (6lowpan)

6LowPAN is an acronym of "IPv6 over Low power Wireless Personal Area Networks", and is the name of the working group in the Internet area of the Internet Engineering Task Force (IETF)[12]. 6LowPAN is the international open standard that enables building the wireless "Internet of Things". It enables using 802.15.4 and the Internet protocol (IP) together and brings IP to the smallest of devices - sensors and controllers.

Today there are several TCP/IP stacks, such as:

- uIP stack from the Contiki operating system (http://www.sics.se/contiki/current-events/uipv6-contiki-is-ipv6-ready.html)
- TinyOS-based IPv6 stack (http://www.tinyos.net)
- NanoStack (http://sourceforge.net/projects/nanostack)
- lwIP stack (http://savannah.nongnu.org/projects/lwip)

Their footprint is around ten kilobytes, except for lwIP that is around 20 kilobytes.

For the SmartHouse/SmartGrid context, this implies that devices of any size could run this stack and be interconnected with other co-existing structures such as gateways, other devices etc., over a standardized and widely accepted communication channel.

3.2.9. IPSO Alliance - IP for all Devices

Sensors for light, pressure, temperature, vibration, actuators, and other similar objects evolve; new applications and solutions are being created and implemented. Indeed, the Smart Grid, "smart cities", home and building automation, industrial applications, asset tracking, utility metering etc. are all taking of IP's

[12] http://www.ietf.org/html.charters/6lowpan-charter.html

rich history and adaptability. The IPSO Alliance[13] was formed in August 2008 with the objective of continuously increasing the base to support and supplement the IP on every device. The IPSO alliance will perform interoperability tests, document the use of new IP-based technologies, conduct marketing activities and serve as an information repository for users seeking to understand the role of IP in networks of physical objects. The IPSO goals are:

- Promote IP as the premier solution for access and communication for smart objects.
- Promote the use of IP in smart objects by developing and publishing white papers and case studies and providing updates on standards progress from associations like IETF among others and through other supporting marketing activities.
- Understand the industries and markets where smart objects can have an effective role in growth when connected using the Internet protocol.
- Organize interoperability tests that will allow members and interested parties to show that products and services using IP for smart objects can work together and meet industry standards for communication.
- Support IETF and other standards development organizations in the development of standards for IP for smart objects.

Bringing IP and i.e. IPv6 to devices today is synonym to the 6LowPAN.

3.3. Standardization Efforts

Key issues for success of in-house communication systems are standardization and interoperability. Interoperability can be defined as the ability of information and communication systems to support data flow and to enable the exchange of information and knowledge, both at a technical (linking of systems) and semantic (meaning of data) level. Standardization is the process that enables this interoperability at both levels.

The PowerMatcher protocol, developed by ECN as a concept for coordination of supply and demand of electricity, serves as an example of a potential standard for semantic interoperability. This protocol describes the demand and supply bids that are made by flexible devices, and includes the structure of the underlying electricity market. The protocol is open to any underlying communication system and has been tested for UMTS, GPRS, ADSL, and Powerline Communication.

IEC 61850-7-420 as a communication standard also aims at physical and semantic interoperability of communication in the area of distributed generation and energy management. The Bidirectional Energy Management Interface (BEMI, see 4.1.4) uses this standard.

In summary, there are already many EU-wide standardized communication protocols – however, these are designed for single sections of the overall communication from the generation side to the loads (see Figure 10). This means that an integrated communication chain is not yet realized by according standards. With an increasing relevance of virtual power plants and decentralized generation, and with the focus on SmartHouse/SmartGrid concepts, an overall integrated communication chain becomes an important prerequisite, and adequate standards supporting this whole chain have to be developed. In the following sections, some further initiatives for the development of standards in the fields relevant to SmartHouse/SmartGrid are briefly reviewed.

[13] http://www.ipso-alliance.org/

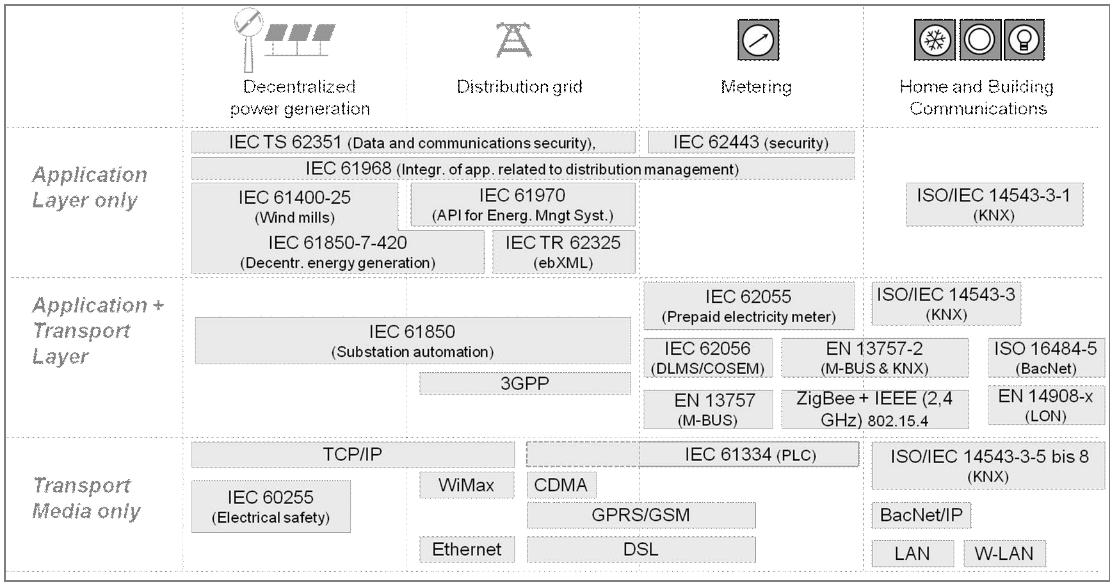

Figure 10: Overview of standards in building automation, smart metering and energy technology

3.3.1. Initiatives Towards Smart Metering Standards

In Germany, the development of a smart metering standard is jointly advanced by the two working groups Figawa and ZVEI, in which the German meter manufacturers are organized. The finalization of the standard is planned for early 2009. However, further efforts are then necessary in order to come to a European standard for smart metering systems. At the European level, the KEMA[14] (by order of the Dutch regulatory authority) and the federation of European meter manufacturers ESMIG (see 3.3.4) are working on the development of a European smart metering standard. The European Commission is going to issue a mandate to a working group comprising Cenelec[15], WELMEC[16] and ETSI[17] – under leadership of Cenelec, this group assigned the task to develop a European standard for smart metering.

3.3.2. OpenADR

Open Automated Demand Response Communication Standard (OpenADR or Open Auto-DR), began in 2002 following the California electricity crisis, and is an open standards-based communications data model designed to facilitate the sending and receiving of DR signals from a utility or from the independent system operator to electric customers.

The intention of the data model is to interact with building and industrial control systems that are pre-programmed to take action based on a DR signal, enabling a demand response event to be fully automated, with no manual intervention. The work on this is ongoing and currently under its second revision – however, there are no practical cases known to the authors where this standard has been used.

14 http://www.kema.com/
15 http://www.cenelec.eu/
16 http://www.welmec.org/
17 http://www.etsi.org/

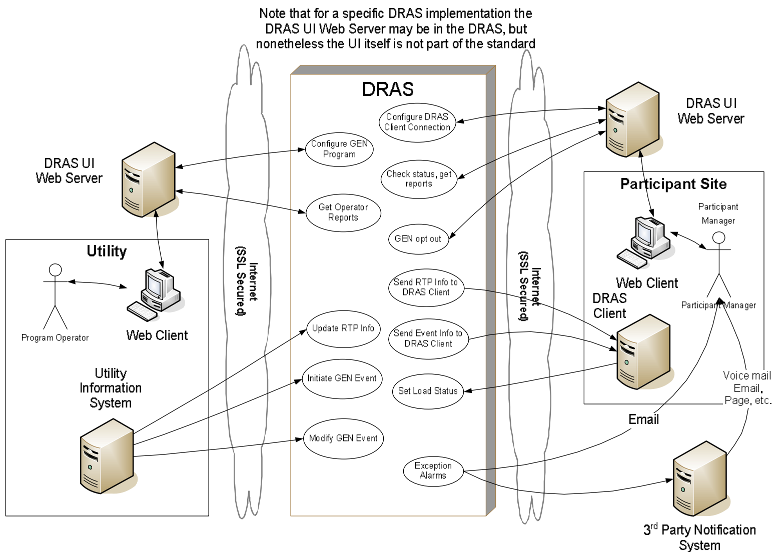

Figure 11: OpenADR: General Automated Events Architecture

3.3.3. Open Meter Communication (MUC)

Open Metering Communication (MUC) is a group of manufacturers who provide products for the field of smart metering in Germany.

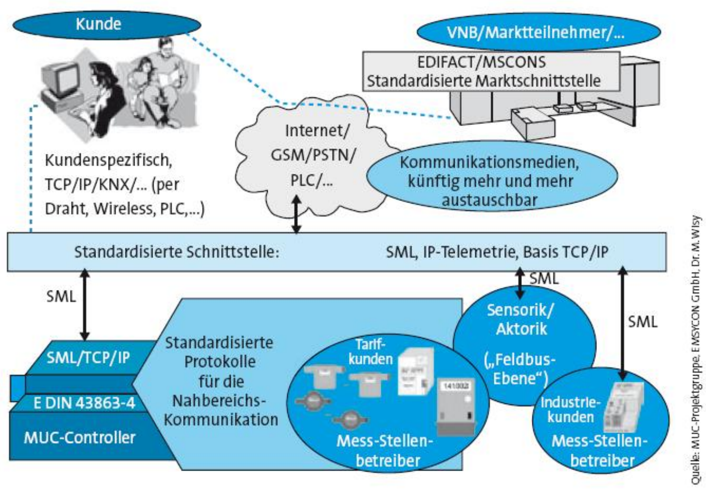

Figure 12: MUC Scope

The aim of the group is to develop an open architecture and to define the functions and interfaces of the single components, based on existing open standards. The demands placed on the system by users are implemented in technical solutions by the manufacturers.

3.3.4. ESMIG

The European Smart Metering Industry Group (ESMIG)[18] is a newly founded initiative which has the objective to deliver the benefits of smart metering by assisting in the development of national and Europe-wide introduction, rollout and management of smart metering systems.

[18] http://www.esmig.eu/

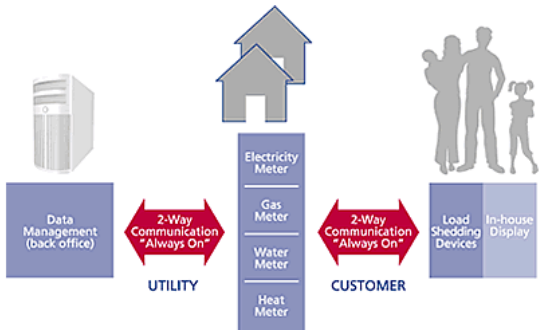

Figure 13: ESMIG scope

The actions of the group will include recommendations with respect to the introduction of smart metering in the EU legislation and the legislation of the EU Member States.

3.3.5. DLMS User Association

Demand side management needs universal definitions and communication standards. DLMS/COSEM is the common language enabling the partners to understand each other.

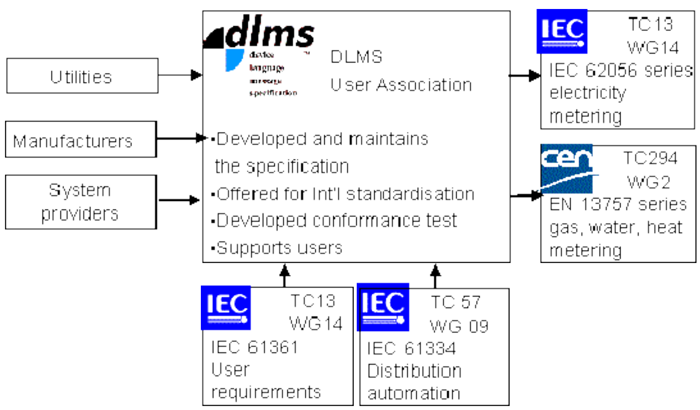

Figure 14 - DLMS/COSEM scope[19]

Device Language Message specification (DLMS) is a generalised concept for abstract modelling of communication entities. COmpanion Specification for Energy Metering (COSEM) sets the rules, based on existing standards, for data exchange with energy meters.

3.4. Security and Privacy in Smart House Communication

Opening up a closed infrastructure as that of energy networks and taking into account the associated business background can not be done without well-tested security and trust models in place. Furthermore, if in the longer term the smart meter evolves to a gateway for household devices, the implications are far reaching, since it is expected that any device will have its own IP address and it will be possible not only to turn it on/off, but also to constantly monitor its behaviour. It is clear that several aspects have to be taken care of in order to provide a secure basis for all the implicated actors. In such a heterogeneous infrastructure as the envisioned future energy one, the author of services to be deployed in the smart meters, the entity that deploys a service, the owner of the smart meter, and the owner of the data may be different entities governed by different interest.

[19] Source: DLMS

A comprehensive threat model needs to be defined. At first, it must be secured that the measurement process cannot be tampered and the data measured cannot be altered (or if this happens there is proof of that). The next step would be to securely transmit the data to the consuming parties. State-of-the-art concepts can be used here e.g. encryption or digital signatures. Projects like SELMA (see also Section 2.1) have already tackled parts of this threat, as it has developed a security architecture that authenticates the measurement data, provides access security and certified software. However, since the smart meter is able to host execution environments, and external entities can deploy services on it, the security model needs to be further elaborated. Issues like repudiation, masquerading, denial of service, unauthorized access need to be successfully tackled.

Finally, since now via the smart meter private information goes beyond simple energy consumption profiling, as their correlation can reveal indication of money flow (amounts of energy produced/bought/sold), personal habits (monitoring of energy consumption per device, possibly at very fine-grained time intervals) and other private context data, it has to be assured that there is no misuse or unwanted exploitation of this information. On the other hand, the end-user will be able to enjoy a variety of sophisticated services and with the right tools be in full control of the personal info s/he shares with other parties, something that is not at high degree possible in practice today (but is implied by the legal framework and the contracts between the parties). Furthermore, the interactions at global level will have to be investigated, and security and trust must be tackled at technology and business model level. The development of an appropriate security, safety and risk concepts and architectures for an advanced metering infra-structure for the future energy networks in total is not expected to be trivial [Karnouskos et al. 2007].

Technologies used to tackle issues raised above are expected to be state-of-the-art and not specifically tailored (at least not at their basic level) for the SmartHouse/SmartGrid context. Besides, many of the concepts under consideration in the project such as DPWS, OPC-UA etc. deal partially with the security issues and provide the basic building blocks.

4. Architectures for Decentralization of Energy Management and Control

The vision of SmartHouse/SmartGrid is to develop concepts and processes for a more intelligent and efficient operation of the electricity system, deploying smart concepts on a large scale. The envisioned order of magnitude of the system size is one million of participating houses, which can each comprise several controllable appliances or distributed power generation units. All system components taken together will produce an enormous amount of data. This data is only of use if it is processed in an intelligent and meaningful way, delivering valuable information to the customer and to operating parties. Models of how data is transmitted and processed thus have to be highly scalable.

Most investigations related to industrial communication focus on a data transport centric protocol specification and communication behaviour. Centralized PLC architectures with over-sampling or proxy technology are the frequently used applications. SmartHouse/SmartGrid will also investigate decentralized control architectures. The impact of the communication channel to the distributed automatic control algorithms become an important topic.

The relatively new research and application field, called Network Controlled Systems, is dealing with

- communication channels models,
- signal quantification during the emission/reception of data packets,
- compression/decompression of the information forwarded by the network,
- queue length management on the router site in order to guarantee the stability or performances of the system considered when the network is congested,
- stabilization of the systems in the presence of delay,
- bandwidth limitation (dependent on the occupancy level of the network) and resources allocation.

There might be need for a multi-field approach integrating

- the control theory of dynamic systems in the presence of delays or data losses,
- the information theory when the data is encoded or compressed and
- the need for taking into account models or estimations of the network behaviour in the control architecture.

In the following, architectural options for SmartHouse/SmartGrid systems are reviewed in the view of the requirement of high scalability. A focus is placed on Multi-Agent Systems (MAS, Section 4.1), Device to Business Integration (Section 4.2) and Service-Oriented Architectures (SOA, Section 4.3), as the SmartHouse/SmartGrid project partners already gained experience with these concepts, and insights from previous work will be considered within this current project.

4.1. Multi-Agent Systems

In the past, multi-agent systems have found application in several settings, without reaching widespread adoption, however. At present, their usage is mostly limited to simulations. Nevertheless, the agent technology introduces functionalities that support efficiently the distributed system needs, such as modularity, decentralisation, dynamic and complex structures characteristics.

The concepts of service-oriented architectures typically provide dynamic discovery and invocation of processes in a loosely coupled manner, facilitating the reorganisation of distributed systems. Therefore, a strong conceptual and complementary synergy between the SOA and the agent-based approaches is seen.

Applying SOA to agent-based control systems, it is expected to contribute to the creation of an open, flexible and agile environment, by extending the scope of the collaborative architecture approach through the application of a unique communications infrastructure. Moreover, one of the reasons why agent-based systems have failed or became more or less technological islands in the past is that they were implemented with communication technologies that obstructed reconfiguration, counteracting the desired autonomy principle.

4.1.1. Agent Definition

There are several definitions in the literature for what an agent is [e.g. Russell/ Norvig 1995, Maes 1995, Foner 1997, Hayes-Roth 1995, Wooldridge/Weiss 1999, Franklin/Graesser 1996, McArthur et al. 2007a,b]. The definitions described in the references have differences, however there are some common concepts: agent, environment, autonomy. According to Wooldridge, an agent is merely "a software (or hardware) entity that is situated in some environment and is able to autonomously react to changes in that environment." The agent can be a physical entity that acts in the environment or a virtual one, i.e. with no physical existence. In our case the physical entity is the agent that acts directly in the power grid and a virtual one is a piece of software that makes bids to the energy market or stores data in a database. Note that a virtual agent can have a physical counterpart that implements control decisions in the power grid

Therefore the environment is simply everything external to the agent. In order to be situated in an environment, at least part of the environment must be observable to, or alterable by, the agent. The environment may be physical (e.g., the power system), and therefore observable through sensors, or it may be the computing environment (e.g., data sources, computing resources, and other agents), observable through system calls, program invocation, and messaging. An agent may alter the environment by taking some action: either physically (such as closing a normally-open point to reconfigure a network), or otherwise (e.g., storing diagnostic information in a database for others to access).

4.1.2. Multi Agent Systems Definition

A multi-agent system is simply a system comprising two or more agents or intelligent agents. It is important to recognize that there is no overall system goal, simply the local goals of each separate agent. However, an agent can represent the system and join a MAS, striving for a system goal, such as a broker agent in a trading system. The system designer's intentions for the system can only be realized by including multiple intelligent agents, with local goals corresponding to subparts of that intention.

Depending on the definition of agency adhered to, agents in a multi-agent system may or may not have the ability to communicate directly with each other. However, under Wooldridge's definitions, intelligent agents must have social ability and therefore must be capable of communication with each other. In SmartHouse/SmartGrid contexts, communication should be supported.

4.1.3. Multi-Agent System Architectures - FIPA

An example of a set of standards for an open architecture is that defined by the Foundation for Intelligent Physical Agents (FIPA)[20]. The FIPA Agent Management Reference Model covers the "framework within which FIPA agents exist," defining standards for creation, registration, location, communication, migration and retirement of agents. Under the FIPA model, an agent resides on a particular agent platform which provides some sort of message transport system to allow the agents to communicate. One requirement of an open agent architecture is that the platform places no restrictions on the creation and messaging of agents, while a second is that some mechanism must be available for locating particular agents or agents offering particular services within the platform. FIPA offers standards for the use of certain message transport protocols such as HTTP and IIOP.

Each agent platform includes two utility agents: the agent management service agent, which is compulsory, and the directory facilitator agent, which is optional. The agent management service acts as white pages, maintaining a directory of agents registered with the MAS platform. The directory facilitator acts as yellow

[20] http://www.fipa.org/

pages, maintaining a directory of agents and the services they can offer to other agents. An agent can use the directory facilitator to search for other agents that can provide services to aid it in fulfilling its own particular goals.

Many early multi-agent systems had closed architectures where the specific interactions were effectively “hard wired” at design time. The FIPA Agent Management Reference model, on the other hand, provides an open architecture, i.e., an architecture to which agents can easily be added and removed. In many power engineering applications, this extensibility is one of the key benefits of the use of agents.

4.1.4. Agents in Power Systems

In the Smart Grid, the electricity infrastructure will be interlinked with an ICT infrastructure in order to control flexible power flows for secure and reliable power delivery. Typically, the Smart Grid will contain secure two-way communication between actors, components and nodes in the electricity grid. Sensors and actuators will provide information and use this information to implement intelligent control decisions at arbitrary places in the grid. This leads to a so-called distributed control as an enhancement to current top-down SCADA control systems.

Figure 15: Definition and characteristics of intelligent agents

In distributed control, data and information flows can be kept as locally confined as possible, establishing autonomy of processes at the local level. This autonomous behaviour typically is one of the strengths of multi-agent systems. Previous EU projects have identified agent-based technology as an essential building block for enablement of the Smart Grid [EU 2005]. Also outside Europe, agents are subject of research in smart power systems. A thorough overview of the potential value of multi-agent systems in power applications, including a comprehensive review of applications is given in McArthur [2007]. Most of the below mentioned initiatives are aimed at actually applying the multi-agent concepts in practice, dragging them out of their theoretical ivory tower.

Crisp/PowerMatcher: Results from the European project CRISP [Kamphuis 2004; Kok 2005; Akkermans 2004] show how agents, using algorithms based on micro-economic theory, and that are implemented using mainstream ICT, can be applied to coordinate large numbers of distributed generators and consumers. This approach has been worked out in the PowerMatcher concept[21], and has been tested since in a number of experimental field tests [Warmer 2006 and 2007; The Fenix Northern Demonstration[22]].

Crisp/Cell concept: Also in the CRISP project multi-agent control has been introduced to manage so-called grid cells containing electrical components including conductors, distributed generation and loads in one or

[21] http://www.powermatcher.net/
[22] http://www.fenix-project.org/

several distribution network feeders. One of the tasks that has been assigned to the Smart Grid Automation Device (or SGAD) agents is fault management and grid reconfiguration, thereby creating a flexible distribution network, in which reconfiguration can be automated based on real-time grid status and power needs [Schaeffer 2006].

BEMI/DINAR: Developed within the German project DINAR the Bidirectional Energy Management Interface (BEMI) is a simple agent situated at the grid connection point of each customer. It represents an intelligent metering cabinet including a load profile meter, a grid surveillance unit, a core computer and a man-machine interface. BEMI optimizes the operation of local devices based on a price signal provided day ahead and on local requirements defined by the user and the local devices [Nestle 2007]. It may also negotiate intraday price adaptations with a central agent, the Pool-BEMI [Ringelstein 2008].

Microgrids: Agents have been identified as operating entities, representing local consuming or producing devices, within microgrids, cooperating and competing for power, keeping in mind other tasks such as producing heat for local environment, controlling local voltage, or providing backup for critical loads.

CSIRO: Australia's national science agency CSIRO has performed a number of field trials in which agents are used to improve energy efficiency. Within constraints for loss of comfort and cost, agents are used to measure and control the local environment by communicating and collaborating with other agents [Platt 2007][23]. They also worked together with a US-based software developer, Infotility, using their *GridAgents* software framework in building an infrastructure in which a gas micro-turbine, photovoltaic arrays, and a wind generator, along with two cool rooms and a zone of a building climate system, are controlled in order to coordinate supply and demand in a microgrid by reacting intelligently to market price signals.

Simulation of SOA device infrastructure: In the future Internet of Things, intelligent embedded devices are expected to not only offer their functionality as a web service, but also to be able to discover and cooperate with other devices and services in a peer-to-peer way. Examples of such devices are the smart meters, as well as household appliances etc. The simulation of such an infrastructure composed of heterogeneous web-service enabled ("SOA ready") devices with the help of a multi-agent system has been proposed [Karnouskos/Tariq 2008].

4.2. Device to Business Integration

One goal of SmartHouse/SmartGrid is to enable the integration of device-level services with enterprise systems. This goal will require the definition of new integration concepts taking into account the emerging requirements of business applications and the explosion of available information from the device level. Of particular interest is the availability of real-time event information, which will be used to specify new enterprise integration approaches for applications such as business activity monitoring, overall equipment effectiveness optimisation, maintenance optimisation, and others.

The next generation of metering and data exchange technologies is known as advanced meter infrastructure technologies. With abilities to support bi-directional flows of information, AMI enables far more responsive sales and service departments and allows customers to make more informed energy-consumption decisions in response to different price signals. All processes and systems involved – both within and beyond company boundaries – can be linked through composite application technologies that consume enterprise services exposed by a process-centric data exchange infrastructure. This, in turn, enables two-way communication between metering systems and enterprise applications so that utilities can build innovative sales and customer service processes.

[23] http://www.csiro.au/science/SmartAgents.html

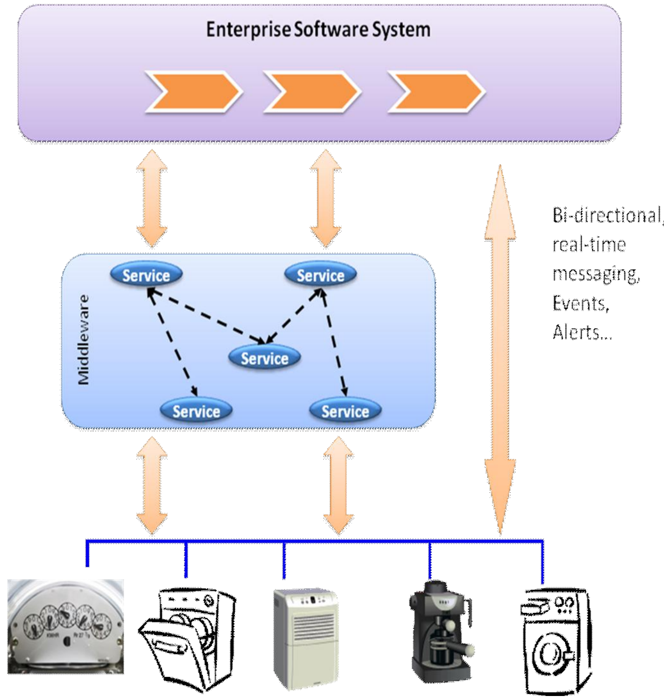

Figure 16: Device to business integration

Figure 17 is portraying a particular communication relationship between the meter infrastructure and the back-end system. The first step in the process involves the collection and consolidation of relevant consumption and meter-reading data from the customers' meters. The meter infrastructure must then transfer this data to a raw database for storage, but not before executing consistency checks and replacement-value procedures for data quality purposes. The information and billing systems can perform these activities – as it might be required when the back-end system of the utility is receiving implausible values from the AMI system, which would prevent a further processing of the data in energy settlement and billing.

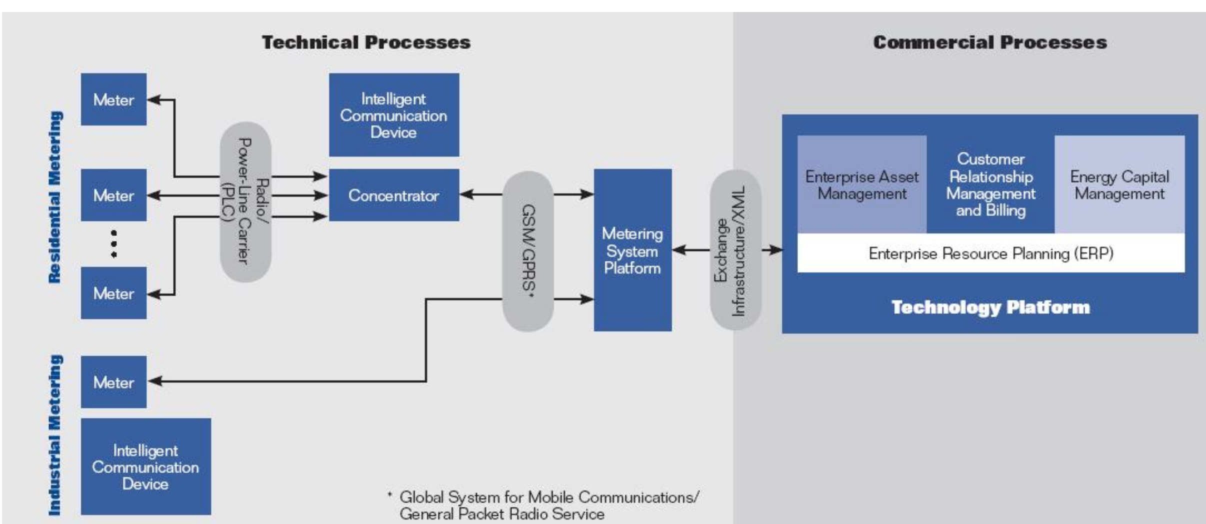

Figure 17: Enterprise to meter integration

4.3. Service-Oriented Architectures

SOA is the basic technology intended to be applied across all layers of the SmartHouse/SmartGrid project. It is comprehensively described covering

- web services,
- relevant standards,
- a framework (based on OASIS), and
- orchestration and choreography

The service-oriented architecture as driven by the main IT companies need specialization for automation-related architectures. Several approaches are known, such as Universal Plug and Play (UPnP), Devices Profile for Web Services (DPWS), OPC/OPC-UA etc. These technologies are today mostly related to specific application fields.

	State-of-the-Art		Grand Challenges
Service Foundations	Enterprise Service Bus	• Open standards-based message backbone • Implementation, deployment, management • Set of infrastructure capabilities implemented by middleware technology • Implementation backbone for SOA (applications as services)	• Dynamically (re)configurable run-time architectures • Dynamic connectivity capabilities • Topic and content-based routing capabilities • End-to-end security solutions • Infrastructure support for application integration • Infrastructure support for data integration • Infrastructure support for process integration • Service discovery
Service Composition	Orchestration	• Service interaction at message level • Perspective and control of single endpoint • Executable business process	• Composability analysis operators for replaceability, compatibility, and typing/syntactic, behavioural and semantic conformance • Autonomic composition of services • QoS-aware service composition • Business-driven automated composition
Service Management	• Web Services Distributed Management (WSDM) • Management Using Web Services (MUWS) • Management of Web Services (MOWS)		• Self-configuring services • Self-healing services • Self-optimizing services • Self-protecting services
Service Design and Development (Service Engineering)	• Port existing components using wrappers • Component-based development, object-oriented analysis and design • Do not address key elements: services, composition, components realizing services • Only address part of the requirements		• Design principles for engineering service applications • Associating a services design methodology with standard software development and business process modelling techniques • Flexible gap analysis techniques • Service governance

Table 2: Overview of state-of-the-art and grant challenges in services research [Papazoglou et al. 2006]

According to the Web Services Architecture Working Group[24], a service-oriented architecture is a form of distributed systems architecture that is typically characterized by the following properties:[25]

- Logical view: The service is an abstracted, logical view of actual programs, databases, business processes, etc., defined in terms of what it does, typically carrying out a business-level operation.
- Message orientation: The service is formally defined in terms of the messages exchanged between provider agents and requester agents, and not the properties of the agents themselves.
- Description orientation: A service is described by machine-processable metadata.
- Granularity: Services tend to use a small number of operations with relatively large and complex messages.
- Network orientation: Services tend to be oriented towards the use over a network, though this is not an absolute requirement.
- Platform neutral: Messages are sent in a platform-neutral, standardized format delivered through the interfaces.

There are several challenges in services research (depicted in Table 2), and SmartHouse/SmartGrid will touch up on some of them. Furthermore, for the SmartHouse/SmartGrid project several web service related standards will most probably be applicable, and therefore will be considered for further evaluation. These are summarized in Table 3.

Reference	Document Title and URL
XML	Extensible Markup Language (XML) 1.0 (Fourth Edition) http://www.w3.org/TR/2006/REC-xml-20060816/
XMLSchema	XML Schema Part 1: Structures (Second Edition) http://www.w3.org/TR/xmlschema-1/ XML Schema Part 2: Datatypes (Second Edition) http://www.w3.org/TR/xmlschema-2/
SOAP	Simple Object Access Protocol (SOAP) 1.1 (W3C Note) http://www.w3.org/TR/2000/NOTE-SOAP-20000508/
WSDL 1.1	Web Services Description Language (WSDL) 1.1 http://www.w3.org/TR/wsdl
WSDL20	Web Services Description Language (WSDL) Version 2.0 Part 1: Core Language (Candidate Recommendation) http://www.w3.org/TR/2006/CR-wsdl20-20060327 Web Services Description Language (WSDL) Version 2.0 Part 2: Adjuncts (Candidate Recommendation) http://www.w3.org/TR/2006/CR-wsdl20-adjuncts-20060327
UDDI	UDDI Version http://uddi.org/pubs/uddi_v3.htm
WS_Addr	Web Services Addressing 1.0 – Core http://www.w3.org/TR/2006/REC-ws-addr-core-20060509/ Web Services Addressing 1.0 - SOAP Binding http://www.w3.org/TR/2006/REC-ws-addr-soap-20060509/
WS_Transfer	Web Services Transfer (W3C Member Submission) http://www.w3.org/Submission/WS-Transfer/

Table 3: Standards related to web services

[24] http://www.w3.org/2002/ws/arch/
[25] W3C Working Group Note 11, February 2004

Reference	Document Title and URL
WS_Eventing	Web Services Eventing (W3C Member Submission) http://www.w3.org/Submission/WS-Eventing/
WS_Reliability	WS-Reliability 1.1 http://docs.oasis-open.org/wsrm/ws-reliability/v1.1/wsrm-ws_reliability-1.1-spec-os.pdf
WS_Man	Web Services for Management (Draft) http://www.dmtf.org/standards/published_documents/DSP0226.pdf
WS_DM	Web Services Distributed Management: Management Using Web Services (MUWS 1.1) Part 1 http://www.oasis-open.org/apps/org/workgroup/wsdm/download.php/20576/wsdm-muws1-1.1-spec-os-01.pdf Web Services Distributed Management: Management Using Web Services (MUWS 1.1) Part 2 http://www.oasis-open.org/apps/org/workgroup/wsdm/download.php/20575/wsdm-muws2-1.1-spec-os-01.pdf Web Services Distributed Management: Management of Web Services (WSDM-MOWS) 1.1 http://www.oasis-open.org/apps/org/workgroup/wsdm/download.php/20574/wsdm-mows-1.1-spec-os-01.pdf
SOA_RM	OASIS Reference Model for Service Oriented Architecture V 1.0 http://www.oasis-open.org/committees/download.php/19679/soa-rm-cs.pdf
SCA	Service Component Architecture (several draft specifications) http://www.osoa.org/display/Main/Service+Component+Architecture+Specifications
WS_BPEL	Web Services Business Process Execution Language V 2.0 (Draft) http://www.oasis-open.org/committees/download.php/18714/wsbpel-specification-draft-May17.htm
WS_CDL	Web Services Choreography Description Language V 1.0 (Draft) http://www.w3.org/TR/ws-cdl-10/
OSGi	Open Service Gateway Initiative http://www.osgi.org/Specifications/HomePage

Table 3 (continued): Standards related to web services

4.3.1. SOA in SmartHouse/SmartGrid Scenarios

The concept of service-oriented architectures is well suited for integrating a large number of flexible and intelligent devices to one scalable overall system. Services could be delivered directly by smart meters, or by other devices that process information; a house energy management system for example could both use and offer web services. The idea behind a service-oriented approach within the SmartHouse/SmartGrid concept is that data is processed at the place where it is needed, and all devices can subscribe to those services that they actually need. For example, a billing process does not need to have to-the-minute information of energy consumption, nor does it need to know exactly which devices consumed how much electricity. It only needs aggregate data, coupled with the applicable tariff at the time of consumption, which could be provided by an according service. A consumer who wants to compare his consumption pattern with that of similar households would be interested in the distribution of consumption among different appliances, but maybe wouldn't care for the availability of electricity from renewable sources at the times of his consumption. So he could subscribe to a service which offers him exactly this information, without transmitting further data that is not necessary for this information.

In such a scenario, services can be seen as tradable goods, and the service providers can generate income from offering the service to other parties. An energy supplier might be interested in offering value-added services to his customers. He could either offer them free of charge in order to be more attractive than his competitors, or he can sell services, charging a fee for those customers who use them. So the energy supplier is most likely to create new services and implement them. At the same time, the supplier uses many web services for his billing processes, and these services may be offered by third parties such as a metering company.

4.3.2. SOA for In-House Services

Within the premises of the customer, a variety of services should be provided by a flexible structure of behind-the-meter hardware and software. In this case, the local agent itself will be enhanced or even be composed of a set of local services. A different architecture will be required to make such services possible. New services come as a piece of software and need to be installed on existing hardware. It is favourable to allow for hardware independent programming of such services and for an administration framework for the software implementing these services. It is also possible that such services are provided by newly installed electrical devices that are connected via a home automation system that usually does not support TCP/IP directly.

OSGi is a framework that allows for administration and interaction of such services based on Java and is designed also to suit requirements of embedded devices if they offer a Java virtual machine. Nokia announced in 2008 to create a new Nokia Home Control Center, which might become a platform that specifically allows for the handling of in-house related services. They propose a solution based on an open Linux based platform enabling a technology-neutral smart home which can be controlled via a mobile phone. The control centre by Nokia supports Z-Wave and will incorporate further proprietary technologies, so that third parties can develop solutions and services on top of the platform; it acts as a dictionary that translates different technological languages so that they can be presented in a unified user interface.

4.3.3. Web Services and Multi-Agent Systems

Web services provide the technology to support the machine to machine interaction that is needed to build distributed systems. The agent community has recognized the potential of web services to extend this technology in order to support autonomous control as offered by multi-agent systems. As a result, FIPA has installed a working group dealing with the interaction between FIPA compliant agents with W3C compliant web services. The main issue is the discovery and invocation of each other's instances. The working group has published a preliminary paper in which a set of requirements are drawn to enable interoperability between FIPA compliant agents and web services [Greenwood 2007]. The requirements include:

- Discovery: finding the location, communication method and services offered by agents and web services. This requires translations between WSDL web service descriptions and FIPA agent service descriptions.
- Messaging and invocation: the addressing scheme and message formats of agents and web services should be mapped onto each other. This requires translations between the FIPA Agent Communication Language and SOAP messages as are common in web services.
- Interaction protocols: An agent interaction protocol describes a communication pattern as an allowed sequence of messages between agents and the constraints on the content of those messages. Similar interaction models between agents and web services should be developed.

The main purpose of the integration of agents and web services is the provision for agents to access any web service they want to use, and to offer the agent services to any interested parties that are not necessarily agents. Thus, the simple request-response model which often underlies the web service applications can be enhanced by applications that require complex interactions between autonomous entities, the latter typically represented by agents.

In the SmartHouse/SmartGrid environment, the ECN PowerMatcher concept for agent-based coordination of supply and demand is one of the techniques that will be applied. It will need cooperation with other concepts, such as the MAS model developed by ICCS and the BEMI model by ISET. The business cases following from these concepts may be able to use common components or services, e.g. for monitoring and control of devices and smart metering, instead of implementing each their own private components.

5. Necessary Progress Beyond the State-of-the-Art

After having reviewed the various technology trends relevant for SmartHouse/SmartGrid concepts, the gap between the state-of-the-art and the requirements formulated within the deliverable D1.1 can be pointed out. In the following, the research questions that have to be answered to fill the gap and to implement the envisioned SmartHouse/SmartGrid system are formulated.

5.1. Clarify the Economic Value of SmartHouse/SmartGrid Concepts

From the viewpoint of a utility, the avoidance of peak load and the more equally distributed load over time contains an important potential for cost savings. Today, production capacity is mainly dimensioned for the peak demand and therefore associated with a high financial risk and with low capacity utilization for peak power plants. With a bi-directional communication between utilities and the end-user, peak loads can be avoided by offering more flexible tariffs and enabling the customers to run their electrical devices more intelligently during off-peak periods. The economic value of these concepts has to be analyzed and realistically numbered in order to deliver a solid basis for decisions of investments into Smart House or Smart Grid concepts. The research questions to be answered comprise an estimation of the amount of investment and operational costs that can be saved by SmartHouse/SmartGrid concepts; on the other hand, it has to be analyzed how financial incentives for end-users must be designed so that they deploy their devices according to the requirements of the generation and grid side, leaving enough profits for the utilities.

While the benefits that can be gained through smart metering or an advanced metering infrastructure alone, e.g. reducing power theft or increasing the efficiency of business processes such as meter inspections or disconnection and reconnection of devices, have been studied in several analyses [e.g. Darby 2006, U.S. DOE 2006, Houseman 2007], the additional benefit arising from bi-directional communication has not yet been quantified. The impact has to be quantified in terms of monetary benefit, considering its allocation among the various stakeholders.

Besides the technical feasibility of enabling Smart Houses to contribute to delivering ancillary services to the grid, the economic benefit of this possibility is an equally important determinant to the success of SmartHouse/SmartGrid concepts.

5.2. Gather More Realistic Information on Customer Behaviour

It is advisable that any technological solution assisting or commanding end users is not just developed with *design logic* as a starting point, but also with *user logic* in mind [Jelsma 2001]. Design logic is the logic underlying the design of the technological solution. Often, reasoning is mainly driven by the function of the design and is clouded by "professional" views. User logic is the logic that guides the user in its use of a product of design. User logic can vary between different users due to age, gender, lifestyle, etc. and due to different sensitivity to incentives, such as economics, ecology, comfort requirements, reliability. A design process may deliberately or not support or counteract the logic of the technology user. Therefore, in a good design process user influence, either by direct participation or consultation of users, or by representation, is indispensable. In this way, a number of the potential barriers may be thrown down. The European project Changing Behaviour[26] specifically aims at bridging the gap between technological energy changes and practical use.

The SmartHouse/SmartGrid project aims at the residential and small office/home office (SOHO) environment as well as commercial buildings and industrial customers at the LV and MV network. There is a clear distinction between residential / SOHO customers and commercial users. In the following, the focus will be on the first group. In a residential house, the following types of devices give potential for energy efficiency as targeted by SmartHouse/SmartGrid:

[26] http://www.energychange.info/

- Storage type devices, either by battery (UPS, electric vehicles) or by electricity controlled heat buffering (tap water heating, space heating, cooling and freezing). In order not to loose functionality, the state-of-charge must be maintained within a certain range.
- Shiftable operation devices that can be shifted over time but have a fixed total demand or supply, such as washing and drying processes, or ventilation.
- Reduced operation devices that can change their power usage or supply for some time, such as dimmable lighting or emergency generators.
- A special case are the must run devices, that require operation driven by user needs, such as audio and video appliances or computers. The latter will even be stricter in an office environment than in a residential home.

Market-based control for each of these device types may need a different adaptation level from customers, as can be seen in Table 4.

	Shiftable operation device	Storage type device	Reduced operation device	Must run device
Awareness of management potential	High: peak / off-peak tariffs	Low: unaware of flexibility	Medium	High
Economics	Direct visibility of cost/benefit	Low visibility of cost/benefit	Direct cost driven energy reduction	No interference allowed
Control strategies	Smart user interface required; Automation possible	Automated control required	Smart user interface required; Automation possible	User in control
Barriers	Acceptance	Believe Acceptance Reliability	Acceptance Benefit	Reliability

Table 4: Adaptation of market-based control for different device types

Customer awareness is most visible for shiftable devices, as many customers are already familiar with the ratio of on-peak and off-peak prices. As a result, washing machine operation can be manually shifted towards the night. If more time-varying price schemes are used, the operation of the devices becomes less clear, requiring some kind of automated reaction to price changes. Shifting operation leads to peak reduction and therefore indirect energy efficiency due to more efficient central generation or more efficient use of available renewable sources. Note that instead of economic incentives, also ecological incentives can be used as control signal, motivating direct use of renewable production [Herrmann 2008].

Using the flexibility of storage type devices also leads to peak reduction and therefore to indirect energy efficiency. The potential of this flexibility is far less visible for customers. In their vision, the device is directly coupled to a task (space heating or tap water heating, or charging an electric vehicle). Therefore, control should be taken out of the hands of the customer as much as possible, providing him only with a user interface to define the task of the device. The invisibility of such a controlled process may lead to disbelieve and lack of acceptance. In a field test in the Netherlands, a number of micro-CHPs have been controlled based on varying prices. Parts of the barriers were addressed by measures such as: use of the thermostat as an accepted user interface; and making no concessions to user comfort. The reliability issue was addressed by providing a back-up conventional control in case of failing of market-based control [Warmer 2007].

Reduced operation devices can be directly coupled with peak load reduction. Just like shiftable operation devices, they will require an automated reaction to price changes. However, this may lead to a barrier in acceptance, since not everyone will be pleased when lights are suddenly dimmed or switched off. And emergency generators will only allow operation if the benefits outweigh the marginal cost and environmental issues are not at stake, such as noise.

For the special group of must run devices, reliability of power supply is the main issue. In normal circumstances this poses no problems, but in critical circumstances, in which either supply or capacity shortage exists, these devices will need a high priority for operation compared with other devices. The Smart House can assist in delivering the extra reliability, especially if electrical storage is available.

A number of general issues may need attention, because they also might raise barriers for the introduction of market-based control:

- User feedback of energy consumption has shown its potential in direct energy savings up to 5-15 % in several European case studies. However, the feedback should be clear and unequivocal, and more direct feedback leads to better results.
- Since customers are used to fixed cost per kWh, variable price schemes may have low acceptance, and may only be accepted if the real benefit can be made explicit. One way to overcome this is not to work with variable prices, but with discount schemes for participation in certain programs.
- Market-based control may not directly lead to energy savings at the household level. However, the total energy efficiency in the whole system can become higher, because peak reduction due to demand response allows shutting off less efficient peak generation plants. Market-based control can also enhance the integration of renewable energy sources. This must be made visible to the customer, so that s/he can better understand the efficiency increase and the concrete savings that resulted from his or her reaction to the price signals.
- The acceptance of external control may be low. This may be overcome by new initiatives, such as a shift in focus from energy to energy services, e.g. thermal comfort services in stead of gas use / heat delivery.
- Sharing information on kWh use may lead to privacy violation, giving insight on user behaviour: In the Netherlands, privacy is used as an argument against smart metering by consumer organisations, since detailed meter information can give ample knowledge about the life style of the customer.
- New market structures for local trading require new regulation. According to current regulation small users are precluded from participation in the wholesale market. Commercial aggregators may position themselves as intermediates to the market.

These issues will have to be clarified by field trials confronting real customers with real-world Smart Houses in Smart Grids and appropriate data collection and evaluation.

Within the scope of SmartHouse/SmartGrid, all the LV and MV customers should be considered. There are different requirements among these consumers which are defined by their needs. The majority would seek economic benefits from the concepts introduced in the project. However a small number of customers considers the quality of power supply as the most critical part and is willing to pay more accordingly. One important parameter is the costs that the SmartHouse/SmartGrid technologies will induce on customers. Assuming that the financial impact will be considerable, it is probable that the target groups should be restricted to the following:

- Large consumptions (MV industrial customers)
- Financially comfortable (high-income) customers
- Young (age-wise) consumers, who are willing to adapt to new technologies
- New housing settlements, probably in tourist areas, in well-developed islands etc.
- Big shopping areas (malls etc.)

An area where the SmartHouse/SmartGrid technologies can have an immediate and much easier acceptance is in government-controlled buildings, especially in areas with high concentration of government activities. In these cases, "convincing" the customers will be much easier, while there are considerable loads that can be monitored and controlled, e.g.:

- Lighting of offices: there are days of the year, or even hours within a day, where outside lighting is adequate. In these cases, smart remote holistic control can be of assistance.
- Air conditioning of buildings: setting of temperatures in central systems can be adjusted taking into account outside temperatures and grid requirements.

At the beginning, the customer that will interact as active market participant will not be an average customer, but rather an economically and technically/ecologically engaged minority. However, the idea is to also reach and include the average customer. The intensity at which such a customer will participate in the market will finally depend – beside any economic benefit – on the complexity of the system and the ease of use/operation. Therefore the customer-system interface should be given attention allowing an interaction of different depth level, including a fully automated mode, allowing a step-by-step learning process and displaying rather fast and easy any benefit.

5.3. Design a SmartHouse/SmartGrid System that is Practically Applicable on a Large-Scale

It has been outlined how Smart Houses can become decisive elements of Smart Grids in the future. Several challenges have to be solved for this goal, though. A lot of standards are available for different elements already. However, these standards are mostly not interoperable yet, or they lack a commonly accepted semantics definition that can express the specific information required for Smart Houses and Smart Grids. This concerns web services as well as local service frameworks such as OSGi. Also, existing software that has been designed for enabling Smart Grid applications which have been described as business cases in deliverable D1.1 of this project, like the PowerMatcher and the BEMI technology have to be further developed in order to be fully compatible to suitable standards in the areas described before (in-house communication, wide area communication and SOA). This is necessary in order to allow for automated interoperability of the entire system from control stations at grid operators and energy traders as well as electronic market places to the electrical units controlled, such as co-generation systems, cooling and heating systems, electric vehicles, washing machines, but also transformer taps, measurement units and automated relays in the grid.

The development must also aim at reaching tough cost goals of the hardware used in the distribution grid in order to allow for mass application, but also high levels of customer friendliness, robustness towards user behaviour, plug&play installation and efficiency of communication. Transmission of price signals might be required within a few seconds, and existing communication infrastructure should be used for reasons of lower costs.

The current status of discussions within the SmartHouse/SmartGrid project foresees to only consider electricity and the power grid. However, it might be worth to also take into account heat and/or natural gas as two further important energy flows. The motivation for this more holistic approach is that besides the only electricity-supplying utilities, there are also many companies offering multi-commodity services. In Germany for example, there is a traditional structure of municipal utilities that supply not only one "media" such as electricity or water, but also others such as gas and water.

Electricity is a bit different as it cannot be stored and the purchasing of electricity on the market just-in-time is an additional challenge causing costs and bearing economic risks. Therefore, a better balanced or at least better predictable load curve avoiding expensive peak demand is in the aim of the supplier (here decentralised electricity triggered CHP with heat storage are of advantage). Gas and water could better be stored, and the daily load curve and related purchasing prices are of less relevance. However, for the grid, its capacity design and stress respectively maintenance needs, electricity, gas and water show similarities. A grid used in a balanced way can be reduced in sense of peak reserves, and is less stressed causing less repair costs. Finally, for the metering, a multi commodity is looking for similar devices and procedures, both regarding the metering, the customer surface, and in particular the signal processing and signal/information transfer. Therefore, whatever is developed for the electricity market should be enabled to allow other media to be metered and treated with one interface and one or a similar protocol.

From the utility (MVV) point of view, the kind of products for energy delivery and ancillary services that should be considered within the SmartHouse/SmartGrid project are the following:

- Dynamic tariffs (variable by time, load) by energy supplier and grid operator
- Energy management services for private customers as well as business customers
- Further energy related services (e.g. security checks via smart metering)
- Use of energy data (smart meters, sensors) on the demand side for the intelligent online coordination of "smart house devices"
- Control of power consumption reducing load peaks and offering new energy services, on the side of the network carrier for the optimum control of the flow of electricity, and on the side of decentralized generation for new trading services

The interconnected Greek power system (excluding the islands) has an inherent structural difficulty due to the fact that the most of the generation lies in the north, close to the lignite reserves, while the bulk of the load is in the south, in Attica area. The transmission of power is effected via three 400 KV, double circuit lines. This creates problems of stability and voltage control during the day and of excessive reactive power during the night. Furthermore, in the summer, the consumption is increased significantly, thus certain amount of energy must be imported via interconnections. In the islands the picture is different – the decisive factor here is the robustness of the transmission and distribution system. These are required to support a huge increase of loads during a short tourist period. Taking into account the structure and the difficulties of the Greek power system, the ancillary services in order of importance are:

- Spinning reserve
- Cold reserve
- Voltage support
- Black start

It is under consideration, which of the above ancillary services can be considered by the SmartHouse/SmartGrid project. The reason is that the quantities are not always compatible, between the country's electric system and the micro-grid of a SmartHouse/SmartGrid. A more "convenient" environment can be found in the isolated systems of the Greek islands.

5.4. Be Aware of Possible Restrictions and Opposition: Threat Analysis

The most sensitive issue with the operation of SmartHouse/SmartGrid is related to confidentiality and privacy policy. There must be restrictions to third parties in accessing personal data of the customers. However, these restrictions may limit certain business options, thus creating opposition. For example, a load forecast service may require accurate knowledge to the behaviour of the consumers. However nowadays citizens are very sensitive in sharing private data and may set restrictions.

Another issue that may create opposition is related to the objective function and the goals of the operation of SmartHouse/SmartGrid. The selection between market participation, provision of ancillary services or support of local needs is not easy taking into account the needs of each party. For example, the end-users may prefer an environmental friendly behaviour despite possible financial losses.

The evaluation of the economical benefits and results of SmartHouse/SmartGrid concept is the only procedure that will indicate the entities that will or will not have positive benefits. The key question is whether the benefits of SmartHouse/SmartGrid concept are sufficient to depreciate the investment for the equipment. In the case in which Smart Grid technology is introduced based on additional legal requirements, additional investment cost may occur that does not lead to the same amount of cost reduction in grid operation in the short term. It is obvious that – directly or indirectly – the additional cost would be shifted to the customers. Therefore, if the concept of SmartHouse/SmartGrid fails to provide sufficient benefits, the end users would have to pay more.

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