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Abbreviations

AID	Agent identifier
AMS	Agent management service
API	Application programming interface
BEMI	Bi-directional Energy Management Interface
CCAPI	Control Center API
CHP	Combined Heat and Power plant
CIM	Common Information Model (IEC 61970/IEC 618968)
CRM	Customer Relationship Management
DER	Distributed energy resources
DF	Directory facilitator
DG	Distributed generator
DPWS	Devices Profile for Web Services
DSO	Distribution System Operator
EMS	Energy management system
ESCo	Energy supply companies
FIPA	Foundation of Physical Intelligent Agents
IEC	International Electrotechnical Commission
IP	Internet Protocol
IT	Information Technologies
JADE	Java Agent Development Framework
LSVPGO	Large-scale power grid operators
LV	Low-voltage
MAS	Multi-agent system
MTS	Message transport service
MV	Medium-voltage
NTUA	National Technical University of Athens
RAM	Random-Access Memory
SOA	Service-Oriented Architecture
SOAP	Simple Object Access Protocol
SOC	State of Charge
TSO	Transmission system operator
WS	Web Service
VPP	Virtual power plant

1. Overview

SmartHouses are connected to the distribution network and will interact with all the actors of the system. The scope of this document is to provide a description of architectures and algorithms that will support this interaction.

The first architecture presented here is the PowerMatcher. In this concept, a large number of agents are competitively negotiating and trading on an electronic market with the purpose to optimally achieve their local control action goals. In the market-based optimization, the optimal solution is found by running an electronic equilibrium market and communicating the resulting market price back to the local control agents.

The Bidirectional Energy Management Interface (BEMI) uses an energy management approach that is organized in a decentralized way and avoids a central control of the individual loads and distributed energy resources (DER). In this approach, every decentralized market participant operates a bi-directional energy management interface which optimizes the local power consumption and generation automatically, depending on local as well as central information like e.g. variable tariffs.

The Magic system provides a different approach that enables the coordination of the actors. The system provides an architecture that supports complex interactions between the agents based on an advanced agent communication language. The system is implemented upon the JADE[3] which is a FIPA[4] compliant platform. Finally, the description also provides part of the system organization, since the concept of coordination between the agents imports significant complexity to the system.

In this document, the first part (Chapter 2) presents the architecture of the systems developed by the partners of the project, focusing on the structure of the system as well as on their basic functionalities. The second part (Chapter 3) analyses some basic mathematical algorithms that enable the system to reach to the correct solution. Finally, the Annex provides a list of web service descriptions that are related to this part of the system and that are to be implemented, deployed and tested within the SmartHouse/SmartGrid project.

[3] JADE stands for Java Agent Development Framework, http://jade.tilab.com/

[4] FIPA stands for Foundation of Physical Intelligent Agents, http://ww.fipa.org/

2. Description of the Control Systems

2.1. PowerMatcher

A number of business cases in Deliverable D1.1 of the SmartHouse/SmartGrid project [SH/SG team 2008] are based on the PowerMatcher concept in order to coordinate supply and demand within smart households to fall in line with real-time operational goals of a commercial or technical business party. The thus formed distributed market concept comprises a number of software components that operate in a PowerMatcher network as depicted in Figure 1.

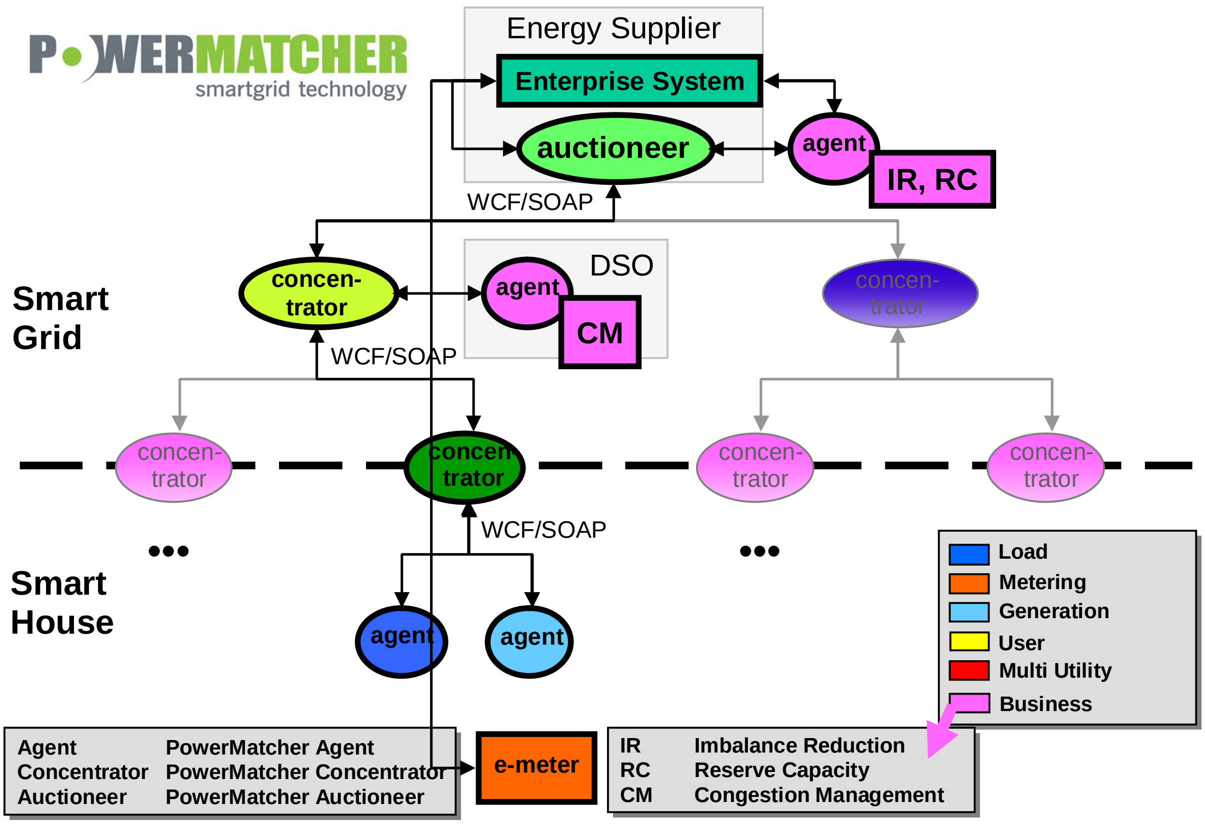

Figure 1: PowerMatcher software architecture

2.1.1. The PowerMatcher Concept

The PowerMatcher concept uses agent technology that allows software agents, representing real-world entities, to interact with each other to perform a task or reach a certain goal. The agents are organized into a logical tree. The root of this tree is formed by the *auctioneer agent* that handles the price forming process. This price is based on the demand and supply functions that are issued by the leafs of the tree – the local device agents – and, occasionally, by an *objective agent*. *Concentrator agents* can be added to the structure as tree nodes. A more detailed description of the agent roles is as follows:

- Local device agent A component that represents an electricity generating or consuming device and negotiates or trades electricity with other device agents through supply or demand bids. Typical hardware on which an agent will be deployed is placed near the device it represents, or at a local gateway, with ability to communicate with the device.
- Concentrator agent A representative of a sub-cluster of local device agents. It concentrates or aggregates the agent's supply and demand bids, and serves as a distributor of the resulting market price to the agents. Concentrator agents can be located at several locations: a home gateway clusters all house activities; a substation may cluster a residential area.

- Auctioneer agent — At the top of the PowerMatcher the auctioneer receives all aggregated bids from the concentrators (and, as depicted in Figure 1 higher level objective agents), and runs the market algorithm. The result from the market algorithm is a settlement price that is communicated to all underlying components. A typical location for the auctioneer is a control centre that operates the PowerMatcher connected devices as a virtual power plant.
- Objective agent — The objective agent gives a cluster its purpose. It typically represents a business case, and as such creates bids to achieve an operational goal in the total market cluster. An objective agent typically will be located at a higher level in the network. Objective agents that strives for a technical goal will be located within the grid infrastructure, e.g. at a substation. Commercial objective agents will be located at a commercial control centre.

In Table 1, the information streams are identified for PowerMatcher enabled distributed markets. The information can be classified in different categories: PowerMatcher internal messages, information exchange between PowerMatcher components and local devices, information exchange between PowerMatcher components and business related entities, and information exchange for metering and billing. The latter category is not dependent on PowerMatcher as such, but should be able to handle the variable tariff / real-time prices that result from PowerMatcher enabled distributed markets.

	Information stream	Partner1	Partner2	Proposed protocol / technology	Further layer
PowerMatcher	Bid	Agent, Concentrator	Concentrator, Auctioneer	WCF/SOAP	TCP/IP
	Real-time price	Auctioneer, Concentrator	Concentrator, Agent	WCF/SOAP	TCP/IP
	Registry and Discovery	Agent, Concentrator, Auctioneer	Network Service	WCF/SOAP	TCP/IP
	Forecasts (climate, market)	External Portal / Web service	Agent	SOAP or XML	TCP/IP
Local control	Sensor data	Load / Generator Controller	Local Device Agent	802.11 / RF / PLC	
	Switching commands	Agent	Load / Generator Controller	802.11 / RF / PLC	
Business control	Substation Load	Substation Monitoring	Objective Agent		
	Virtual Power Plant Setpoint	VPP Operator	Objective Agent		TCP/IP
Metering	Own energy usage	Loads, Generators	Electricity Meter	Out of project scope?	
	Real-time metering data	Electricity Meter	Customer Interface Metering Services / SAP Database	See IWES overview	
	Contracted metering data	Agent or Concentrator	Customer Interface Metering Services / SAP Database	SOAP or XML	TCP/IP
	Variable tariff data	Auctioneer	Customer Interface Metering Services / SAP Database	SOAP or XML	TCP/IP

	Electronic bill of customer	Customer Interface Metering Services / SAP Database	Bill-checking application on customer interface	SOAP or XML?	TCP/IP

Table 1: Information streams in PowerMatcher networks for distributed markets[5]

The following paragraph describes the PowerMatcher concept in terms of a multi-agent system (MAS) integrating concepts from control theory and microeconomics to coordinate supply and demand of electricity. The algorithms are explained in the next chapter.

2.1.2. PowerMatcher Coordination

The PowerMatcher concept is developed as a market based concept for coordination of supply and demand of electricity in networks with a high share of distributed generation. In this concept, a large number of agents are competitively negotiating and trading on an electronic market with the purpose to optimally achieve their local control action goals. In Figure 2 it is sketched how control engineering leads to input requirements that are traded at market prices. Agents are used to automate this task. By placing bids on the market agents can weigh different aspects such as cost and comfort. For example, offering more flexibility in local operation may lead to economic benefit (*price*) at the expense of some comfort (*goal state*).

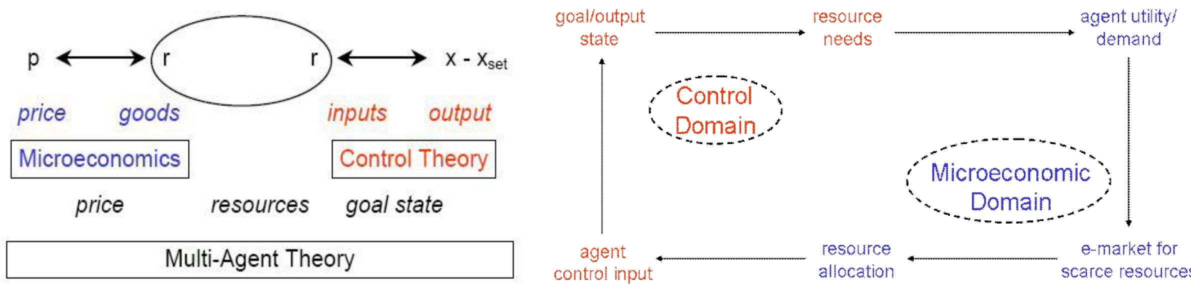

Figure 2: Microeconomics and control engineering unified in a multi-agent system (left: the model of unification; right: the agent process involved)

The PowerMatcher is concerned with optimally using the possibilities of electricity producing and consuming devices to alter their operation in order to increase the over-all match between electricity generation and consumption. In the PowerMatcher concept, each device is represented by an agent which tries to operate the process associated with the device in an economically optimal way. The agents mediate the electricity consumed or produced by the devices by using an electronic exchange market.

[5] Reference business cases: Imbalance Reduction; Reserve Capacity; Congestion Management

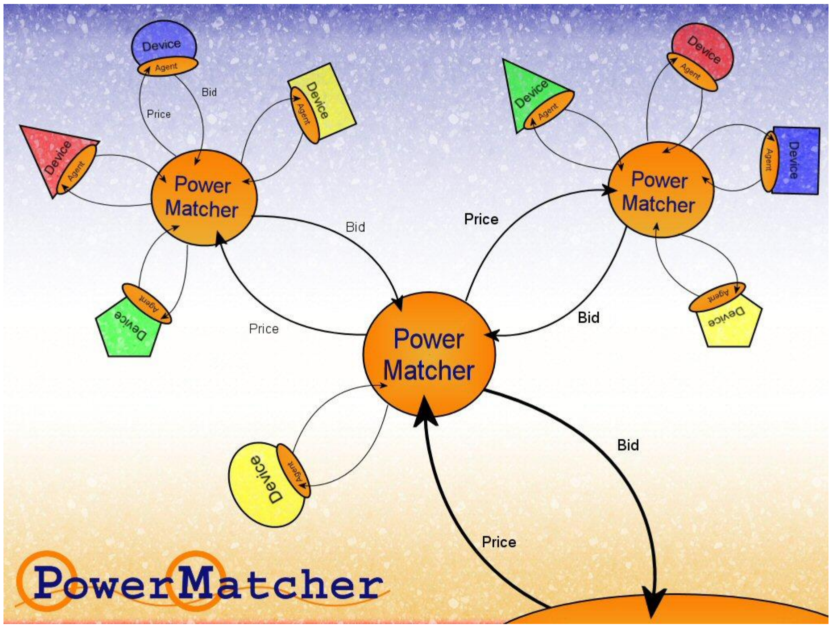

Figure 3: PowerMatcher architecture depicted as a network of networks

The electronic market is implemented in a distributed manner via a hyper-linked structure of so-called PowerMatchers, as depicted in Figure 3. A PowerMatcher concentrator aggregates the demand and supply of the components directly connected to it and passes it on to its higher level controlling component, either another concentrator or an auctioneer. Different types of devices can act as related consumers and producers. The PowerMatcher auctioneer receives the aggregated demand and supply for the whole and determines from it the equilibrium price, which is communicated back to the concentrators and from there on to the agents. From the market price and their own bid function, each agent can determine the power allocated to its device.

An auctioneer or concentrator cannot tell whether the devices connected to it are agents or other concentrators, since the communication interfaces of these components are equal. This makes the concept less privacy sensitive, while it is greatly scalable to include large numbers of device nodes.

The PowerMatcher concept can be applied in several business cases. A business case can be implemented at a higher level in the network by an objective agent that order to achieve a predefined goal. This goal is reached without intrusion at the agent level, since each agent is free to express its own supply or demand curve based on local needs

2.2. BEMI

The Bidirectional Energy Management Interface (BEMI) uses an energy management approach that is organized in a decentralized way and avoids a central control of the individual loads and DER. Instead of this, local optimization decisions will be made through the customers themselves (or automatically by appropriate devices acting on the customer's behalf), who can act as consumers and/or producers of electric energy.

2.2.1. The BEMI Concept

Different mechanisms can be applied for achieving that the local decisions result in an optimal situation for the overall system. The approach described herein is the distribution of central information which is relevant for the decentralized market participants. Variable tariffs for generation and consumption have proven to be a good choice for central information, since they not only allow automatic local optimizations, but also prediction of customer behaviour by the tariff provider while keeping transparency and flexibility for the single customer.

In this approach, every decentralized market participant operates a BEMI, which optimizes the local power consumption and generation automatically, depending on local as well as central information like e.g. variable tariffs. The optimization is carried out on the basis of locally available information, which differs from the approach of typical virtual power plant (VPP) implementations. Thus, the customer has access to all relevant data by means of a man-machine interface and, if desired, can also influence the optimization himself. In this way, an active integration of the customer with a high level of transparency is possible. Furthermore, the BEMI implements measurement devices for low-voltage grid supervision, which is a prerequisite for increasing the share of fluctuating distributed generators (DG) we are facing in today's distribution network. Herewith, the BEMI can supply measurement data, e.g. of voltage, grid impedance and frequency.

In order to bundle up functions of a large number of BEMIs and thus to provide distribution grid services, an additional, higher-level component called "Pool-BEMI" is required. This Pool-BEMI should be operated as a technical unit by the energy supplier, where it can also take over the distribution of the central information. In this case, the Pool-BEMI forms the technical interface between energy supplier and BEMIs. Furthermore, it acts as interface between distribution system operator (DSO) and BEMI system, comprising Pool-BEMI, all BEMIs with associated loads and DG as well as the communication technology for these components.

The principle of decentralized decision-making is also employed in case of the Pool-BEMI. This means that the Pool-BEMI also does not directly decide on the operation of DER and loads. The mechanism of variable tariffs can be extended, however, so that the BEMI supply the Pool-BEMI with information about free resources - for example generation potentials - and thus play a more active role. The Pool-BEMI can activate these resources with the aid of price signals, which it makes available to the BEMI as central information. Since the Pool-BEMI is to be connected with the DSO's network control centre, the BEMI System can provide distribution grid services. Thus, support of grid operation by small customers becomes possible, supporting technical integration of fluctuating DG such as photovoltaics or wind power plants. An example for an application enabled by such a system is incentive-based voltage control in the low-voltage grid, which combines local BEMI intelligence and measurement capability as well as tariff generation by the Pool-BEMI. It could be shown that this application can help supporting voltage control in electric networks and increase utilization of energy generated from fluctuating sources.

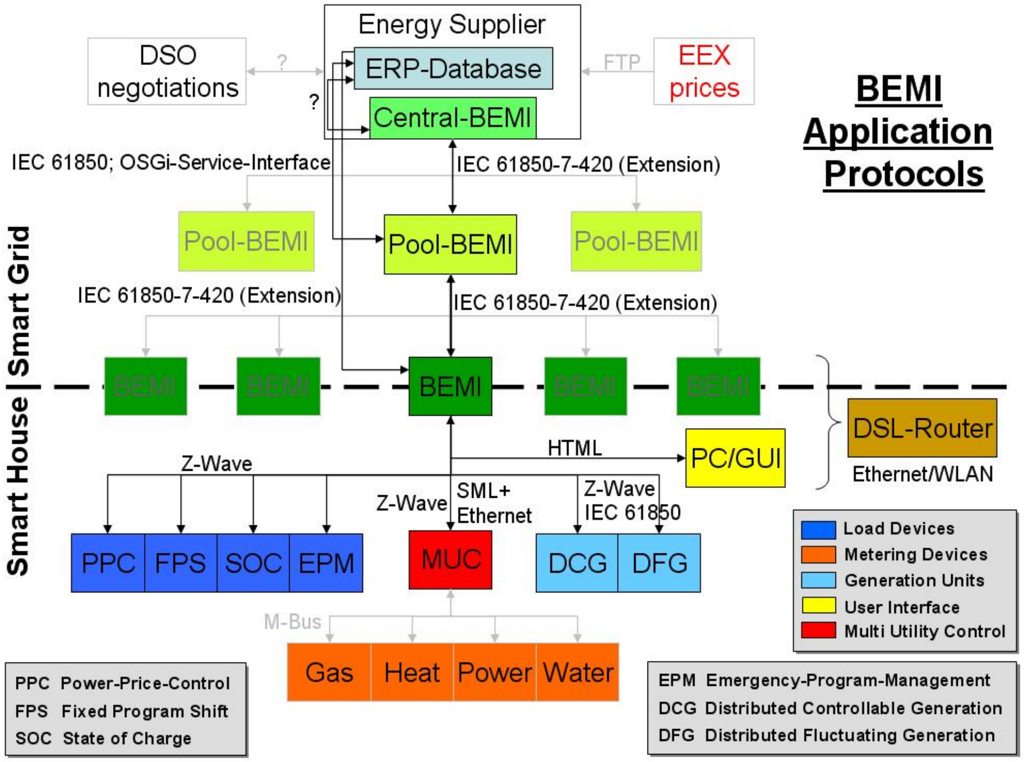

Figure 4: BEMI software architecture

2.2.2. BEMI Coordination Algorithm

Generally, the BEMI coordination algorithms can be divided into two domains: Algorithms that are executed at the customer site by the customer grid interface (BEMI) and algorithms executed at the aggregation level – usually in the domain of an energy provider or the DSO. The algorithms at the customer's site must react on the price profile given by the Pool-BEMI. However, these algorithms also must take into account the processes and the parameters of the devices installed as well as customer preferences. The algorithms on the customer site shall be designed in a way that the energy cost for the customer gets minimized under the constraints defined by the customer. So the local BEMI algorithms are purely customer-oriented.

Energy provider and DSO thus need their own algorithms to ensure that they are also able to benefit from the management. The energy provider needs to fulfil the balancing schedule registered for a certain day, which means that the customers shall consume or generate exactly as much energy per balancing interval as acquired from/sold to various sources. When calculating prices for customers also the customer contracts have to be fulfilled as described in Chapter 5 of D1.1. The DSO has to make sure voltage level and line loads are maintained and might have to react to emergency situations. Whereas the energy provider usually defines the price profiles day-ahead like the existing energy exchange markets, the DSO has to react much more quickly. So the algorithms used for grid services make adaptations to prices previously given to the customer before, which allows for separate algorithms for the energy trading and the grid, which do not interfere.

2.3. Magic

The control approach adopted in the agent platform developed by NTUA is called Magic. This control approach may support several aspects of DG and controllable loads operation and is based in the multi-agent system technology. This control approach also focuses on a concept called Microgrid. This is a new type of power system which consists of small modular DG in the low-voltage (LV) grid. This control scheme introduces the idea that all the main decisions should be taken locally, being though in coordination with the other actors. The ability of coordination implies the usage of a high level language from the actors and consists of two main parts. The first part is that although the decision is local, it has taken into account the conversation or the negotiation between the actors. The second part is that a certain degree of high level coordination or monitoring is inevitable.

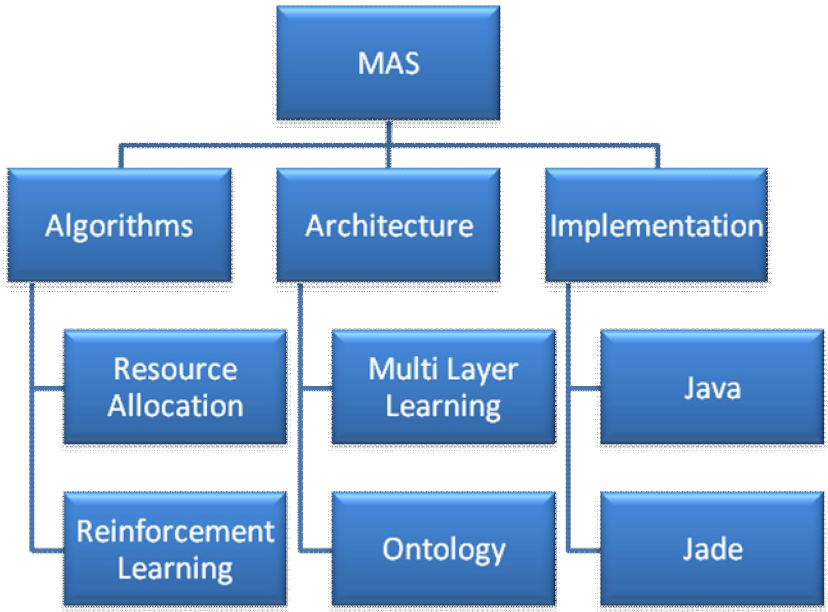

Figure 5: Development of the MAS system

Figure 5 presents the structure of the system development which has three main parts. The first part is the creation of mathematic algorithms that will allow the agents in a distributed environment to solve certain problems. The second part is the system architecture and the framework that will allow the integration of all these services. The final part is the implementation where the source code is developed.

2.3.1. Service Organization

The question of service organization refers to a critical issue regarding the MAS operation. As mentioned before, the operation of the control system incorporates several services that may be local or global. The key issue in the design of the system is to identify the services and classify them.

Within Magic, a very simple but very effective model for this type of classification called Multi-Layer Learning is adopted, for the control of a team of robots who participate in a soccer match. Based on this approach, SmartGrid applications can also be developed. As an example in a Microgid, each agent controls one unit of the system, for example a battery bank, a wind turbine or a controllable load, and has the following characteristics:

- A capability for certain actions, such as production of energy or operation of a switch,
- A variety of behaviours, according to which decides what the next action should be, and
- Some resources such as diesel fuel level or battery state of charge, depending on the type of the unit.

According to the new architecture, the behaviour of the agent is categorised into three levels as shown in Table 2. In this table, behaviours for communication purposes or other strict software engineering tasks are omitted in order to simplify the description. The main idea behind this classification is that the behaviours are grouped depending on the effect on the environment.

Level	Agents	Behaviour	Example
1	1	Single	Battery management
2	Many	Multi-agent	Resource allocation
3	Many / all	Team	Market participation

Table 2: Control levels of the MAS behaviours

The first level includes all the actions and decisions that are necessary to control and manage locally the unit. For example, in the battery management operation, if the agent detects a low state of charge (SOC), it decides to stop the injection of energy to the grid. This is an action that was decided locally without asking for permission from other agents. On the other hand, the decision of starting the charging operation is not local and for this reason the decision should be taken on a higher level.

The second level includes simple tasks that should be completed by more than one agent. For example, after the clearing of the market, the Microgrid receives an order to inject a certain power into the grid and possibly also feed the local loads. The decision for the level of production for each unit can be taken after a small internal auction as described next.

The highest level includes all the services that refer to the ultimate goal of the system, which in our case is the optimisation of the Microgrid benefit. An example for this level is the market participation.

The operation of the various levels can be clearly illustrated in the example of Figure 6, which refers to the market participation. In the first step, the MAS, after negotiating with the energy supply companies (ESCo), should receive a schedule for power production and power consumption that also includes prices. The negotiation and the decisions regarding the participation of the Microgrid in the market belong to the higher level of control which constitutes the team behaviour.

Afterwards, the agents should decide how to realise the schedule. Two schedules are created, one for production and one for consumption. In this way, it is obvious that there are now two sub problems that do not include all the agents. The production schedule includes only the DG units and the consumption schedule only the controllable loads. Focusing on the production schedule, the DG units should decide on how to share fairly the requested production. After the negotiation, each DG has a separate schedule and the control process moves to the lowest level, i.e. is the local level.

In the local level, every DG unit should accomplish its schedule taking into account its special characteristics and status. It is obvious that the special characteristics as well as the status information were taken into account in the previous negotiation. For example, a battery unit would not make any bid if it has no sufficient kWh stored.

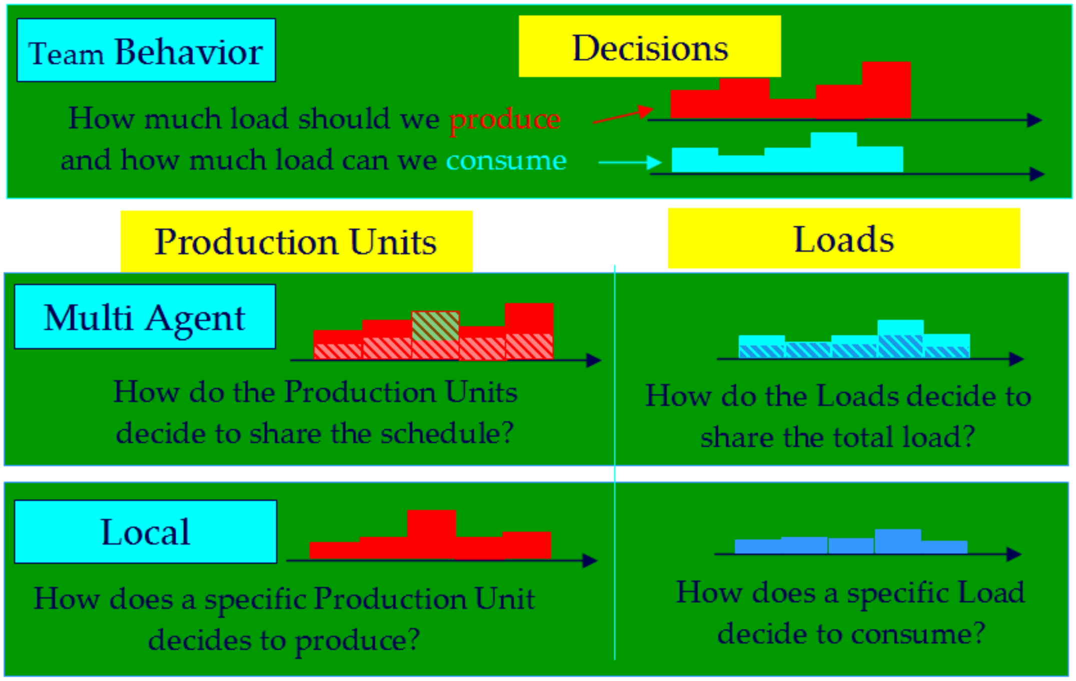

Figure 6: The multi-layer learning

It is obvious that several questions arise about the collaboration of the agents according to the multi-layer learning approach and definitely the first refers to the type of algorithms used for the negotiation. The simple architecture is insufficient for controlling larger number of agents since the complexity increases significantly. Therefore, an extended architecture is introduced in Figure 7. The DG units and the controllable loads form small Microgrids and accordingly small MASs. These MASs form larger MASs and so on. The separation may be realised based on the electrical and topological characteristics like common medium-voltage (MV) transformer.

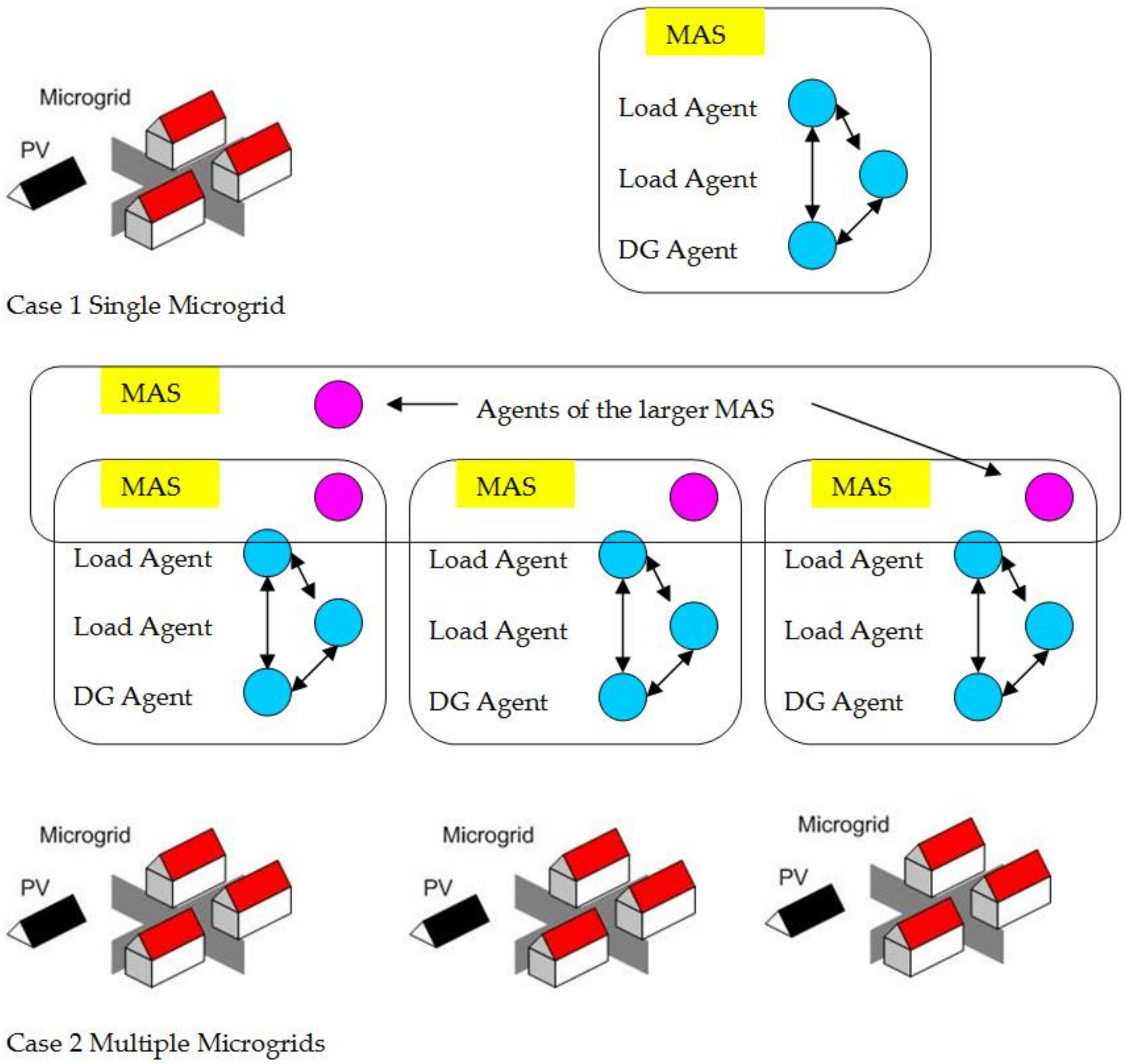

Figure 7: General scheme of MAS architecture

The groups of MAS are organized in three levels. The three levels are presented in Figure 8. All the agents associated directly with the control of the production units or controllable loads belong to the *Field Level*. These agents directly communicate and control a production unit or a load and may be organized in MAS according to physical constraints of the system. Each of these MAS has also an agent that has the responsibility to communicate with other higher level MASs in order to cooperate with them. These MAS belong to the *Management Level*. Finally, these MASs may form larger MASs in order to participate in the *Enterprise Level*.

The model of the three layers for the distinction of the multiple MASs proposed above, has been based on principles both from the multi-layer learning approach described in the previous section as well as by the way a manufacturing enterprise is organised. Therefore, the field level consists of agents that are directly connected to the DG or the controllable loads and the management level tries to coordinate the multiple MASs. Finally, in the enterprise level, strategic decisions are taken such as market participation. It should be mentioned that the higher the level the more abstract the agents are. Thus, in the enterprise level the ESCo could be considered as an agent.

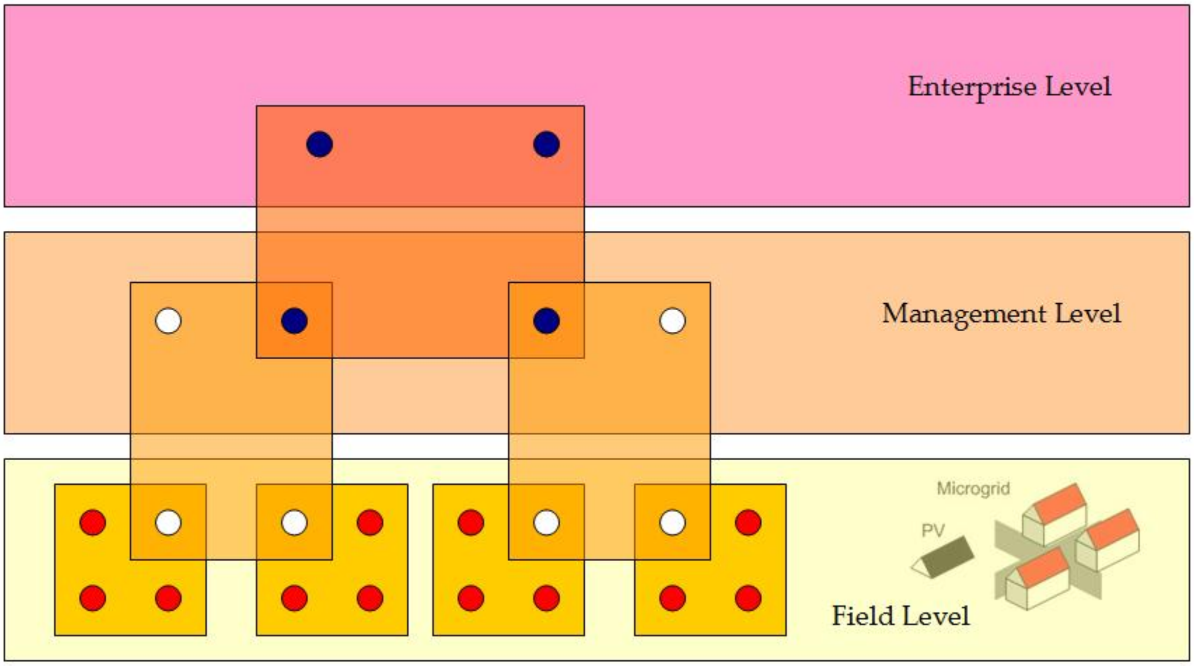

Figure 8: Management of the agents

2.3.2. Implementation of MAS JADE Platform

JADE is a software middleware that allows an easy development and deployment of a multi agent system. This tool provides all the software infrastructure and common functionality that allow developers to focus on the application logic and ontology definitions. Furthermore, it also provides the tools needed for agent system deployment, debugging and monitoring. JADE has the following characteristics:

- Developed completely in JAVA, supports portability for a wide set of operating systems and hardware systems,
- Complies with FIPA (Foundation for Intelligent Physical Agents) standards,
- JADE is an open source tool distributed under the LGPL[6] license.

JADE provides functionalities for the basic features an agent platform should have. These features are implemented by JADE in two ways: JADE services and JADE built-in agents. Additionally, it provides an API (application programming interface) with a set of classes that makes easier the development of a multi-agent system. JADE built-in agents comprise the following:

- Agent management service (AMS): The AMS service is in charge of maintaining a directory of Agent IDentifiers (AIDs) unique for each agent within the agent platform, and which contains transport addresses (amongst other things) for agents registered with the agent platform. Each agent must register with an AMS in order to get a valid AID.
- The AMS offers white pages services to other agents based on its agent's registry. The AMS is also responsible for managing the operation of an agent platform, such as the creation, deletion and migration of agents to and from the platform. It also maintains the life cycle associated with each agent.

[6] LGPL stands for GNU Lesser General Public License, a free software license published by the Free Software Foundation. The LGPL places copyleft restrictions on the program itself, but does not apply these to other software that only links with the programme.

- Directory facilitator (DF): The DF service provides yellow pages services to other agents. Agents may register their services with the DF and query the DF to find out what services are offered by other agents or which agents offer certain services.
- The most important JADE service is the message transport service (MTS): The MTS is in charge of delivering messages between agents within the same Agent Platform and to agents that are running on other Agent Platforms. FIPA specifies the requirements for the MTS regarding the communications between agents in different agent platforms (IIOP, HTTP based communications), this way the inter-operability between agent platforms is maintained. JADE uses RMI for communication between agents in the same platform.

Figure 9 depicts the JADE architecture.

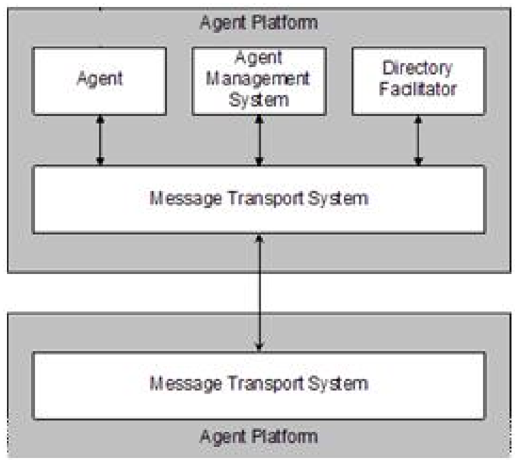

Figure 9: JADE agent platform architecture

2.4. Data Description - CIM

The definition of the web services within the scope of SmartHouse/SmartGrid requires also the definition of a common ontology. This common definition of data models will support the interaction between the applications. The ontology can be based on the IEC 61970/IEC 618968 Common Information Model (CIM), although fully compliance is far beyond the scope of this project.

The IEC 61970 series of standards defines the set of technologies required to enable the integration of control centre applications. IEC 61970 is based on a previous work done by EPRI Control Center API (CCAPI) research project (RP-3654-1). The CCAPI project aimed to enable the easy integration of applications in energy management system (EMS) environments and improve data exchange features, both internal and external. The proposed solution should cover architecture, data model and be completely independent from the underlying technology. The specification resulting from IEC 61970 shares the same objectives:

- Enable the integration of multi-vendor applications, and
- Allow the exchange of information to systems outside the control centre.

It is worth mentioning that the scope is not limited to transmission systems; it also includes distribution and generation systems exchanging real time data.

Although the IEC 61970 series of standards is far from being complete, the CIM is receiving a significant growing support from leading manufacturers. On the one hand, EMS/DMS/SCADA manufacturers come into effective use of the standards paving the way to followers while on the other hand standard gaps, pending issues and errors are identified and solved. A second source of support is envisioned at the Large Scale Power Grid Operators (LSVPGO) association formed by Transmission System Operators (TSO).

All classes in CIM are grouped together into packages depending on their role within the power system. CIM contains eight main packages, and a global domain package used for defining data types. The Core, Wires and Topology packages contain all the basic classes for defining the physical characteristics of a power network. The Wires package include classes that are used to represent the electrical components of a network, such as Transformers, Lines and Switches, while the Core and Topology packages define the interconnection of components.

- Core — The Core package contains the parent PowerSystemResource class, from which all other classes concerned with the physical properties of the network inherit.
- Wires — The Wires package defines all parts of equipment electrically connected to the network, as well as supporting classes for defining additional properties. This includes classes for the components that are physically connected to the network at the points of common coupling.
- Generation — The Generation package is includes two sub-packages, Production and GenerationDynamics.
- Production — The Production package is used for defining various kinds of generators, and includes a class hierarchy for defining the components of Conventional Thermal or Hydro generators. The package also includes definitions of cost information such as Cost Curves and Net to Gross curves.
- GenerationDynamics — The GenerationDynamics package contains the description of Prime Movers, including turbine types or boilers for Nuclear Stations.
- LoadModel — The LoadModel package deals with modeling of consumers through curves and associated data. The EnergyConsumer class defines the physical connection between the network and customer.
- Topology — The Topology package provides definitions of how equipment about the electrical topology and how the various equipment/devices are connected.
- Measurement — The Measurement package is used to define the Measurements received from a particular Power System Resource. The Meas package contains entities that describe dynamic measurement data exchanged between applications.
- Outage — This package is an extension to the Core and Wires packages that models information on the current and planned network configuration. These entities are optional within typical network applications.
- Protection — This package is an extension to the Core and Wires packages that models information for protection equipment such as relays. These entities are used within training simulators and distribution network fault location applications.

3. Algorithms for Market Participation and System Control

3.1. Market-Based Coordination

In market-based control, agents in a multi-agent system are competing for resources on an equilibrium market whilst performing a local control task (e.g. classical feedback control of a physical process) that needs the resource as an input. For this type of MAS, it has been shown by formal proof that the market-based solution is identical to that of a centralized omniscient optimizer [Akkermans et al. 2004]. From the viewpoint of scalability and openness of the information architecture, this is an important feature. In the centralized optimization all relevant information (i.e. local state histories, local control characteristics and objectives) need to be known at the central level in order to optimize over all local and global control goals. While in the market-based optimization the same optimal solution is found by communicating uniform market information (i.e. market bids stating volume-price relations), running an electronic equilibrium market and communicating the resulting market price back to the local control agents. In this way, price is used as the control signal. It is important to note that, whether – in a specific application – the price has a monetary value or is virtual and solely used as a control signal depends on the particular implementation and on the business case behind the application.

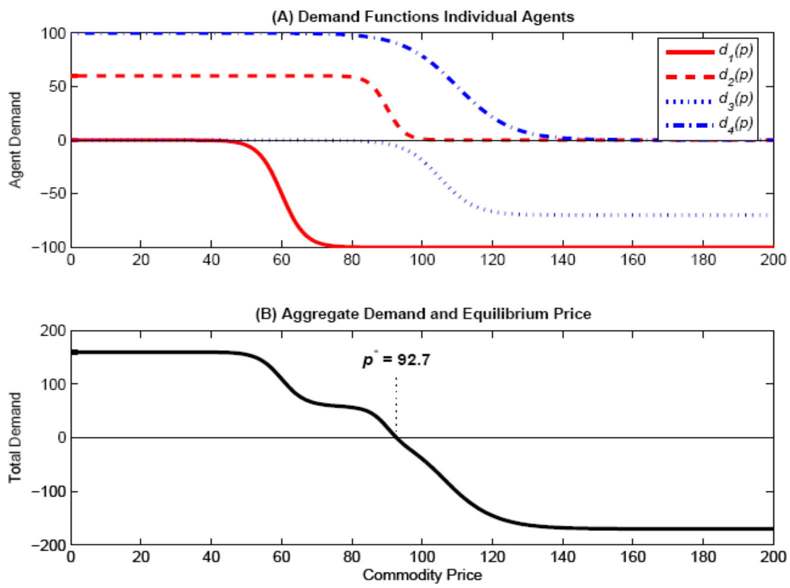

Figure 10: Example general equilibrium market outcome (A: demand functions of the four agents participating in the market, B: aggregate demand function and general equilibrium price p*)

In a typical application of market-based coordination, there are several entities producing and/or consuming a certain commodity or good. Each of these entities is represented by a local control agent that communicates with a market agent (auctioneer). Each market round the control agents create their market bids, dependent on their state history, and send these to the market agent. These bids are ordinary, or Walrasian, demand functions *d(p)*, stating the amount of the commodity the agent wishes to consume (or produce) at a price of *p*. The demand function is negative in case of production. After collecting all bids, the market agent searches for the equilibrium price p^*, i.e. the price that clears the market:

$$\sum_{a=1}^{N} d_a(p^*) = 0$$

where *N* is the number of participating agents and $d_a(p)$ the demand function of agent *a*. The price is broadcast to all agents, who can determine their allocated production or consumption from this price and their own bid.

Figure 10 shows a typical small-scale example of price forming in a (single commodity) general equilibrium market with four agents. The demand functions of the individual agents are depicted in graph (A). There are two consuming agents, whose demand decreases gradually to zero above a certain market price. Further, there are two producers whose supply, above a certain price, increases gradually to an individual maximum. Note that supply is treated as negative demand. The solid line in (B) shows the aggregate demand function. The equilibrium price p* is determined by searching for the root of this function, i.e. the point where total demand equals total supply.

The PowerMatcher concept has made one innovative change in the above described traditional market setup. In order to react immediately to events within the electricity infrastructure, the *event based market* concept has been developed. Events can happen due to user actions (a user requiring space heating who sets the thermostat higher), or due to grid events (network congestion), or due to commercial reasons (existing imbalance in a portfolio of a program responsible party). Events can trigger a (change in) bid immediately, without waiting for the next market round. The bid is transferred to the auctioneer and if it leads to a significant price change, the price is communicated directly to all other affected agents.

3.2. Distributed Resource Allocation

The core of the algorithm applied is based on an auction algorithm for the solution of the symmetric assignment problem. This method provides maximization of the internal benefit of the system. The symmetric assignment problem is formulated as follows:

Consider n persons and n objects that should be matched. There is a benefit a_{ij} for matching person *i* with object *j*. In the presented application, the benefit for each person is his revenues for obtaining object *j*, i.e. an agreement for producing a certain amount of energy. The main target is to assign the persons to objects and to maximize the total benefit:

$$\sum_{i=1}^{n} a_{ij} \quad (1)$$

The price p is an algorithmic variable that is formed by the bids of all persons and so expresses the global desire. The prices of all objects form the price vector. These prices should not be confused with the market prices. Furthermore, the difference between the benefit and the price is the actual value of an object for a specific person. The actual value for a specific object is different for two persons, since it is related to the benefit. At the beginning of the iterations, the price vector is zero and so the actual value is equal to the benefit, although variations of the proposed methods use initial non- zero values for faster convergence.

In order to clarify the above terms, we consider an example with two objects and two persons that belong to a larger set of persons and objects. The first person has a benefit vector {a11,a12}={10, 9}, the second one has benefits {a21,a22}={7, 10}. Taking into account only the benefits, the first person has higher benefit for the first object and the second person for the second object. If we assume a price vector p={1, 8}for the two objects, the actual values for the two persons are {9, 1} and {6,2}.Both players desire the first object more, since both have greater actual value for it than for the second, however the second person has greater benefit for the second object, than for the first. It can be said that the benefit represents local information for each person and the price vector global information for the whole system. The price for an object increases until at most one person wants it. Increasing the price of an object is an indication that there is another person that desires this object, too.

The auction algorithm used calculates the price vector p, in order to satisfy the ε-complementary slackness condition suggested in [Nestle 2008; Bendel/Nestle 2005]. The steps are described next.

At the beginning of each iteration, the ε-complementary slackness condition is checked for all pairs (i,ji) of the assignment. The *ji* is the object *j* that person *i* wants to be assigned to. So the formulation of this condition is:

$$a_{ij_i} - p_{j_i} \geq \max_{j \in A(i)} \left\{ a_{ij} - p_j \right\} - \varepsilon \quad (2)$$

A(i) is the set of objects that can be matched with person *i*. This inequality has two parts: αij-pj is the actual value of object *j* for person *i*, as described before. The right part refers to the object that gives maximum value to person *i* minus ε. ε is a positive scalar, added in the bid of each object, in order to avoid possible infinite iterations in case two or more objects provide maximum benefit to the same person, as will be explained later.

If all persons are assigned to objects, the algorithm terminates. Otherwise, a nonempty subset *I* of persons *i* that are unassigned is formed. Similarly, the nonempty subset P(j) is formed by the available objects. The following two steps are performed only for persons that belong to *I*.

The first step is the bidding phase, where each person finds an object *j* which provides maximal value and this is:

$$j_i \in \max_{j \in A(i)} \{a_{ij} - p_j\} \qquad (3)$$

Following this, the person computes a bidding increment

$$\gamma_i = u_i - w_i + \varepsilon \qquad (4)$$

u_i is the best object value

$$u_i = \max_{j \in A(i)} \{a_{ij} - p_j\} \qquad (5)$$

and w_i the second best object value

$$w_i = \max_{j \in A(i), j \neq j_i} \{a_{ij} - p_j\} \qquad (6)$$

According to the previous equations, the bidding increment is based on the two best objects for every person. The price of an object rises, if there are two or more bids for it and the price increment is the larger bidding increment between the bids. It is obvious that, if the scalar ε=0 and the benefits for the first and the second best object are the same, then γi=0 and this leads the algorithm to infinite iterations. The ε scalar ensures that the minimum increment for the bids is γi=ε.

The next phase is the assignment phase, where each object j selected as best object by the nonempty subset P (j) of persons in I, determines the highest bidder

$$i_j = \max_{i \in P(j)} \{\gamma_i\} \qquad (7)$$

Object j raises its prices by the highest bidding increment $\max_{i \in P(j)} \{\gamma_i\}$, and gets assigned to the highest bidder ij. The person that was assigned to j at the beginning of the iteration, if any, becomes unassigned.
The algorithm iterates until all persons have an object assigned. It is proven that the algorithm converges to the optimal solution, as long as there is one. The maximum number of iterations is

$$\frac{\max_{(i,j)} |a_{ij}|}{\varepsilon} \qquad (8)$$

and the algorithm terminates in finite number of iterations if

$$\varepsilon < \frac{1}{n} \qquad (9)$$

The above algorithm is further explained by considering three persons and three objects. All bidders have zero benefit for the third object and the benefit for the rest of the objects is a constant C>0. So the benefits for the objects are aij=0 for i=1,2,3 and j=3 and the other benefits aij=C>0. The initial prices are considered zero. For this example, the first four iterations of the algorithm are presented in Table 3.

Number of iteration	Prices	Pairs	Bidder/ Object	Increment
1	0, 0, 0	(1,1)(2,1)(3,1)	3/1	ε
2	ε, 0, 0	(1,2)(2,2)(3,2)	2/2	2ε
3	ε, 2ε, 0	(1,1)(2,1)(3,1)	1/1	2ε
4	3ε, 2ε, 0	(1,2)(2,2)(3,2)	3/2	2ε

Table 3: Results of the auction algorithm for the first four iterations

The second column of the table called “Prices” shows the price of the three objects at the beginning of each iteration. The column called “Pairs” shows the pairs (persons, object) that are assigned at the end of the iteration. The fourth column called “Bidder/ Object” shows which person was the bidder at the end of the negotiation and for which object a bid is made. Since we have only three objects and three persons, there can be only one bidder in each iteration. The last column shows the bidding increment at the end of the iteration. In the first iteration, all persons desire object 1, so there are bids for this object. It should be mentioned that, in case the bids are equal, some selections are random or based on rules. The initial selection could be the second object or two persons could bid for the first object and the other for the second. The selected strategy does not affect the convergence of the algorithm. According to the benefits, all the persons in this iteration have the same increment bid, the value of the bid is ε and the winning bidder is the last person. In the second iteration the bid increment for all persons is 2ε because:

$$\gamma_i=(u_i-w_i) + \varepsilon=\varepsilon+\varepsilon=2\varepsilon \quad (10)$$

In this example the need of ε is clearly illustrated, because otherwise no price would increase. All persons desire object 1 or 2, since the benefit is C>0 for both of them. In the last iteration the prices of 1 or 2 object will be greater than C, object 3 receives a bid and this is the end of the algorithm.

3.3. BEMI Algorithms

3.3.1. BEMI Algorithms at the Customer’s Site

As described above these algorithms are customer oriented, which means a cost minimization (or profit maximization in case of a generation unit) under certain side constraints. In most business cases the operation of each device included into the automated management can be optimized separately based on the price signal provided. Only in case restrictions or additional objectives regarding the total power profile of the customer are made, optimization algorithms for the devices need to be dependent on each other, which shall not be used for the BEMI approach in the context of the SmartHouse/SmartGrid project.

The computing core of the BEMI implements the energy management system (EMS). It receives information from the Pool-BEMI, usually the tariff profile for the following day. Based on this information the computer calculates optimal schedules for each device in the management system using a specific algorithm for each device type. Such devices are freezers and fridges, electrical heating and warm water generation, air conditioning and ventilation, washing machines, dryers and dish washers as well as cogeneration devices. In the future this list may include electrically driven vehicles or plug-in hybrids and photovoltaic inverters equipped with additional battery storage. Three basic types of devices must be differentiated regarding energy management:

- Devices with thermal or electrical storage, which state-of-charge (SOC) must be maintained within a certain range (SOC-devices),
- Devices which carry out a fixed program with shiftable starting time (e.g. washing machine). These devices are called “Fixed Program Shift” (FPS-devices), or
- Devices which can reduce their power at high electricity prices (e.g. a dimmable lighting). These devices are called “Price-Power-Control” (PPC-devices).

Algorithms for each device type must be designed in a way that avoids avalanching effects by switching all devices at the same time. This can be achieved by small, random shifts of switching times. Furthermore, not all customers should receive exactly the same tariff, but tariffs should be varied so that the aggregated reaction of all customers supplied by the system follows a given power profile within the usual forecast uncertainty.

The optimization algorithm decides considering the preferences of the inhabitants of the building, the parameters of the devices included in the management and the information received from the central station. This means BEMI decides locally based on local and central information.

3.3.2. Algorithm for SOC Devices

The main side constraint for this algorithm is to maintain the state of charge (SOC) between zero (empty storage) and one (maximum allowed charge level) at all times. The SOC of a thermal storage is defined by the lower and upper temperature limits of the storage. E.g. for a freezer limits of -15°C and -20°C have been used in field trials. The algorithm also takes into account cost for additional switching. If this is neglected in algorithm design the optimization leads to very frequent switching in order to make use of the smallest changes in the electricity price in some cases, which is not feasible for most devices.

The algorithm also takes into account constant and variable losses from the storage as well as additional losses from higher SOC due to thermal losses of the storage as well as an economical preference function defined by the customer in case of deviations of the SOC from an optimal point (if defined by the customer, which is usually not the case for private households).

As most devices can only be switched on or off at a certain time, the optimization problem is highly non-linear. The BEMI algorithm thus calculates optimized operation times for each time interval successively so that the SOC remains in the limits defined. In order to reduce the number of switching events an additional algorithm is used in order to aggregate separate operational blocks where feasible and cost efficient.

3.3.3. Algorithm for FPS Devices

The general optimization algorithm of FPS-Devices comprises the following steps:

1. Calculation of the number of pricing intervals the device's program will take, where ton is the duration of the program and ∆t the duration of one pricing interval:

   $$n_{fps} = floor\left(\frac{t_{on}}{\Delta t}\right)$$ (Note: floor → down rounding function)

2. One additional interval for the rest if applicable:

   $$e_{rest} = \frac{t_{on}}{\Delta t} - n_{fps}$$

3. Find a starting interval i so that the total cost of the program operation is minimized:

   $$C_{fps,i} = \sum_{v=1}^{n_{fps}} \left(p_{v+i-1} \cdot P_{prog,v}\right) + e_{rest} \cdot p_{(i+n_{fps})} \cdot P_{prog,n_{fps}+1} = \min!$$

   where P_{prog} gives the power profile of the program and p the price profile.

Detailed information and a specific algorithm of each device type are available in [Nestle 2008].

3.4. Algorithm for PPC Devices

The algorithm for PPC devices just sets the power of the device according to the characteristics of a price-power-curve defined by the customer. The price-power-curve in general is a piecewise linear function which assigns device power levels to prices.

The algorithms used by an energy trader for providing price profiles for BEMIs – which will be presented in more detail here – can be divided into two sub-tasks:

- Algorithms to determine the power profile that shall be bought from/sold to various markets. This power profile must have a shape so that it will be possible for the trader to influence his customers (by appropriate price profiles) to follow the power profile acquired, which e.g. means that the profile can never exceed a certain peak power, which is limited by the power installed and additional restrictions. On the other hand the power profile acquired shall maximize the profit of the trader. In case energy consumption is only shifted by the customers, the total energy consumption per day can be regarded as fixed. In this case the trader shall buy the total energy consumed by his customers for the lowest price possible. Both objectives can be reached by using a price forecast of a lead market (usually the day-ahead market) to forecast the power profile of the customers in case they would have to pay the price profile forecasted. This is also described in Chapter 5 of D1.1. The choice how much power to buy at which market (Future, Day-ahead,…) is outside the scope of this project though also being a task of the energy trader.
- Algorithms to determine the price profile of each customer. When the power trading is done after closing of the day-ahead-market the total power profile acquired from various markets needs to be distributed to the customers. The main part of this algorithm is also the forecast of the customer behaviour. This algorithm is given in some more detail here.

The main goal of the customer pricing algorithm is to minimize the difference (as root-mean-square-error, RMS) between the power profile acquired by the trader P_{trader} and the total power profile of the customers P_{real} at the day of delivery:

$$\sqrt{\sum_{i=1}^{n_p}\left(P_{trader,i}-\sum_{v=1}^{n_g}P_{real,v,i}\right)^2}=\min!$$

where np is the number of pricing intervals per day, ng is the number of customers and Preal,v,i gives the mean power of one customer at a certain pricing interval. Usually not every customer is considered but several customers are aggregated to customer price groups. These customers always receive one common price and their power is pre-aggregated for the algorithm to increase performance. The real power of the customers is not known at the time of customer pricing, of course. So the algorithm has two main parts:

- calculation of a forecast of customer behaviour based on a certain price profile (which is also needed for the buying algorithm as described before) $P_{est}(p)$
- find a set of price profiles p_{opt} (one for each customer price group) which minimizes the difference between the P_{trader} and $P_{est}(p_{opt})$:

$$\sqrt{\sum_{i=1}^{n_p}\left(P_{trader,i}-\sum_{v=1}^{n_g}P_{est,v,i}(p_{opt,v,i})\right)^2}=\min!$$

The search for p_{opt} can be done using standard non-linear optimization tools, but has to take into account the characteristics of the customer reaction forecast. There are two main methods of customer reaction forecast:

- Attribute-based Estimation (AEM): This algorithm calculates a forecast of the customer reaction to a certain price profile based on certain attributes of the price profile such as the peak price and the relative strength of one value compared to its neighbours. The statistical reaction of each customer to a certain attribute value has to be determined by evaluation of past reactions, of course. When this technique is successful, it allows forecasting the customer reaction to an arbitrary price profile including price profiles for which no previous samples have been collected. It has been very difficult in various simulations, however, to design a method for choosing the estimation attributes that leads to reproducible satisfactory results. For this reason a second, more simple method has been developed:

- Fixed Profile Management (FPM): In this case only a limited set of price profiles is created that can be applied to each customer price group. The mean reaction to each of these price profiles is directly tested by giving these profiles to the customers and it is constantly updated by newer results based on a linear filter. As each of these price profiles has to be tested at least once (better several times), the number of profiles should be restricted, e.g. to 64. A lot of different customer price groups maximizes the degree of freedom for the total customer reaction, since an individual price profile can be selected for each single price group. So this algorithm only gives better results than the AEM algorithm if a large number of customers is included into the management. This was also indicated by simulation results. To obtain any customer reaction curve, this method needs to give different tariffs to different customer groups not only to avoid avalanching effects, but mostly to allow for flexibility in the customer reaction.

Detailed information on algorithms of the energy trader is available in [Nestle 2008]. Information on BEMI system applications in the distribution grid and a method for incentive-based voltage control is available in [Nestle/Ringelstein 2009]. A classification of BEMI system operational states is given in [Nestle/Ringelstein 2008].

References

Akkermans, H., J. Schreinemakers, and K. Kok (2004): Microeconomic distributed control: Theory and application of multi-agent electronic markets. In Proceedings of CRIS 2004 - 2nd International Conference on Critical Infrastructures.

Bendel, C. and D. Nestle (2005): Decentralized Electrical Power Generators in the Low Voltage Grid – Development of a Technical and Economical Integration Strategy, International Journal of Distributed Energy Resources, 01/2005, pp. 63-70.

Bendel, C., D. Nestle, and J. Ringelstein (2007): Bidirectional Energy Management Interface (BEMI) - Integration of the low voltage level into grid communication and control, 19th International Conference on Electricity Distribution, Vienna, Austria.

Nestle, D. (2008): Energiemanagement in der Niederspannungsversorgung mittels dezentraler Entscheidung – Konzept, Algorithmen, Kommunikation und Simulation, Ph.D Thesis at the University of Kassel in German).

Nestle, D. and J. Ringelstein (2009): Application of Bidirectional Energy Mangement Interfaces for Distribution Grid Services, 20th International Conference on Electricity Distribution, Prague, Czech Republic.

Nestle, D. and J. Ringelstein (2008): Bidirectional Energy Management Interfaces in Distribution Grid Operation – Strategy and Simulation, 3rd Conference on Integration of Renewable and Distributed Energy Resources, Nice, France.

SH/SG team (2008): High-Level System Requirements. Deliverable 1.1 of the SmartHouse/SmartGrid team.

Annex I: Detailed Description of Web Services

This document provides a description of the interaction between the DSO, the Market aggregators with the Smart House as well the various algorithms. Next a list of web services is defined as a supplementary of the Web Services defined in D2.1.

1. System Management

Aspect	Specification
Web service name	Service (and Service Implementation) Repository
Location where the web service is hosted (e.g. device, network etc)	Utility's/aggregator's information system
Web service functionality	Extended UDDI. Holds a repository of types of web services (port types) that are installed on the meters in the field. Optionally, it contains deployable implementations (e.g. executable binaries, byte code, or scripts) that can be deployed remotely on meters.
Web service input / output for action "createServiceType"	Input: description of a service type Output: none
Web service input / output for action "deleteServiceType"	Input: ID Output: none
Web service input / output for action "getServiceTypeByExternalId"	Input: ID Output: complete service type description (possibly including deployable artefacts)
Web service input / output for action "getAllServiceTypeIDs"	Input: none Output: the IDs of all currently registered types
Web service input / output for action "getServiceTypeByKeywords"	Input: a list of keywords, flag to specify searching for any or all keywords Output: all matching service types
Web service input / output for action "updateServiceType"	Input: description of a service type Output: update of service type definition
Web service nature (composite / atomic)	Atomic
Web service users	System administrators
Security/confidentiality requirements	High, contains information how to access internal
Expected frequency of use	Rarely, for system set-up and configuration
Communication channels used	Any. Possibly via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Discovery
Location where the web service is hosted (e.g. device, network etc)	At each aggregation level, from gateway to utility system
Web service functionality	Central reporting point for newly installed or automatically discovered meters. Will update the device and service repositories and monitors.
Web service input / output for action “deviceFound”	Input: complete description of the device, including offered services, address, configuration etc. Output: none
Web service input / output for action “deviceQuit”	Input: id of the device Output: none
Web service input / output for action “forceDiscovery”	Input: context information (e.g. location) Output: all devices that have been found using context information
Web service input / output for action “registerLDU”	Input: registration of a local discovery unit, the local gateway that does the discovery on a network segment Output: none
Web service input / output for action “unregisterLDU”	Input: id of the local discovery unit to unregister Output: none
Web service nature (composite / atomic)	Atomic
Web service users	For the repository the users may be administrators For service registry and discovery users are other components that want to use services
Security/confidentiality requirements	High, an attacker could get an overview of all deployed metering hardware.
Expected frequency of use	Occasionally, whenever detailed information is needed.
Communication channels used	Any. Possibly via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Device Monitoring
Location where the web service is hosted (e.g. device, network etc)	Utility’s/aggregator’s information system.
Web service functionality	Provides functions to monitor the health and status of field devices like smart meters.

Web service input / output for action "startMonitoring"	Input: deviceId (start monitoring a particular device that causes problems) Output: status information that allow an identification of the problem
Web service input / output for action "stopMonitoring"	Input: key, deviceId Output: none
Web service input / output for action "getDeviceStatus"	Input: deviceId Output: device status information
Web service input / output for action "deviceFailureEvent"	Input: deviceId, call-back endpoint where notification should be delivered Output: none
Web service nature (composite / atomic)	Atomic
Web service users	System administrators, CRM system of suppliers / aggregators
Security/confidentiality requirements	High, an attacker could overload completely disable the system. By subscribing, she could receive sensitive data.
Expected frequency of use	Occasionally, whenever a meter shows anomalous behaviour.
Communication channels used	Any. Possibly via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Connect New Customer
Location where the web service is hosted (e.g. device, network etc)	Power supplier's/aggregator's information system
Web service functionality	This service initializes a new smart meter or control unit (such as a BEMI) that becomes connected to the power supplier; the characteristics of the new customer (i.e. which devices are controllable? How was his consumption in the past?) is put into the supplier's data base
Web service input / output	Input: Past consumption of the new customer, type of meter/control unit, amount and power rating of controllable devices (if information is available), standing data such as name and payment info of the customer
Web service nature (composite / atomic)	May be partitioned into several atomic services
Web service users	Power suppliers / aggregators
Security/confidentiality requirements	High, because sensitive customer data is treated
Expected frequency of use	Event-based – each time a new customer is connected to the aggregation

Communication channels used	Usual meter exchange channel for fetching technical meter data (probably DSL); data given by the customer possibly through a web portal (probably also DSL)
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Notification
Location where the web service is hosted (e.g. device, network etc)	Utility's/aggregator's information system. The notification consumer interface will be implemented and provided by many system components. One central location will be a notification broker, which will consume all events. Other components can then subscribe to that events and will be notified when a new event occurs. They have to offer this interface as well or can instruct the Notification Broker to collect the events for them for later retrieval via polling.
Web service functionality	Consumes system events, mainly automated meter readings
Web service input / output for action "notify"	Input: metering event Output: none
Web service nature (composite / atomic)	Atomic
Web service users	Meters, Data Aggregators
Security/confidentiality requirements	High, contains sensitive information
Expected frequency of use	Frequently, for each meter data
Communication channels used	Any. Possibly via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Configuration
Location where the web service is hosted (e.g. device, network etc)	Central system hosted by one of the collaborating parties storing configuration data, especially communication endpoints of the various systems that participate in the collaboration.
Web service functionality	Provides functions to get and set configuration parameters and to initialize the system after set-up.
Web service input / output for action "getConfigProperty"	Input: key Output: value

Web service input / output for action “setConfigProperty”	Input: key, value Output: none
Web service input / output for action “triggerAllConfiguration”	Input: none Output: none
Web service input / output for action “subscribeToTopic”	Input: event topic name, endpoint where to deliver notifications Output: none
Web service nature (composite / atomic)	Atomic
Web service users	Meters, Data Aggregators
Security/confidentiality requirements	High, by setting configuration parameters, an attacker can completely disable the system. By subscribing, she could receive sensitive data.
Expected frequency of use	Frequently, for each meter data
Communication channels used	Any. Possibly via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Directory Facilitator / Registry
Location where the web service is hosted (e.g. device, network etc)	Concentrator or Auctioneer location
Web service functionality	Registration of components (agents, concentrators, auctioneer) and their services in a PowerMatcher (sub-) network. It provides a unique identity to the components.
Web service input / output	Input: agent / concentrator / auctioneer address and service description Output: agent / concentrator / auctioneer identifier (unique)
Web service nature (composite / atomic)	Atomic
Web service users	PowerMatcher agents, concentrators and auctioneer need to register themselves and their services.
Security/confidentiality requirements	Preferably only authenticated components will be required to register
Expected frequency of use	Occasionally, whenever detailed information is needed.
Communication channels used	Any. Possibly and probably via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations Imbalance reduction Offering (secondary) reserve capacity to the TSO Distribution system congestion management

Aspect	Specification
Web service name	Directory Facilitator / Discovery
Location where the web service is hosted (e.g. device, network etc)	Concentrator or Auctioneer location
Web service functionality	Allows components in the PowerMatcher network to find services and communicate with other components.
Web service input / output	Input: service type + location / region ident Output: address and identifier of component with requested service
Web service nature (composite / atomic)	Atomic
Web service users	System administrators, CRM system, PowerMatcher agents, aggregators
Security/confidentiality requirements	Preferably only authenticated components will be accepted.
Expected frequency of use	Occasionally, whenever detailed information is needed.
Communication channels used	Any. Possibly and probably via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations Imbalance reduction Offering (secondary) reserve capacity to the TSO Distribution system congestion management

Aspect	Specification
Web service name	Dynamic Discovery
Location where the web service is hosted (e.g. device, network etc)	Utility's/aggregator's information system or auctioneer
Web service functionality	Central reporting point for newly installed or automatically discovered devices and services. Will update the device and service repositories and monitors.
Web service input / output for action "deviceFound"	Input: complete description of the device, including offered services, address, configuration etc. Output: none
Web service input / output for action "deviceQuit"	Input: id of the device Output: none
Web service input / output for action "forceDiscovery"	Input: context information (e.g. location) Output: all devices that have been found using context information
Web service input / output for action "registerLDU"	Input: registration of a local discovery unit, the local gateway that does the discovery on a network segment Output: none

Web service input / output for action "unregisterLDU"	Input: id of the local discovery unit to unregister Output: none
Web service nature (composite / atomic)	Atomic
Web service users	System administrators, CRM system, PowerMatcher agents, aggregators
Security/confidentiality requirements	High, an attacker could get an overview of all deployed metering hardware.
Expected frequency of use	Occasionally, whenever detailed information is needed.
Communication channels used	Any. Possibly via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations Offering (secondary) reserve capacity to the TSO Distribution system congestion management

Aspect	Specification
Web service name	Device Repository
Location where the web service is hosted (e.g. device, network etc)	Utility's/aggregator's information system, central management device
Web service functionality	Provides asset management for deployed meters in the field.
Web service input / output for action "registerDevice(Type)"	Input: device or device type description Output: none
Web service input / output for action "updateDevice(Type)"	Input: updated device or device type description Output: none
Web service input / output for action "removeDevice(Type)"	Input: device ID or device type ID Output: none
Web service input / output for action "queryAllHardwareInformation"	Input: list of keywords, flag that specifies to search for any or all keywords Output: all matching devices or device types
Web service input / output for action "getTechnicalDataForCustomerDevice"	Input: customer ID Output: list of all of the customer's devices with their technical characteristics
Web service input / output for action "getConnectedDevicesForRegion"	Input: network segment Output: list of consumption devices, storage devices and generation devices (renewable, distributed)
Web service nature (composite / atomic)	Atomic
Web service users	System administrators, CRM system, DNO, aggregator, balance responsible party,… (nearly all players in SH/SG systems)

Security/confidentiality requirements	High, an attacker could get an overview of all deployed metering hardware. Confidential data.
Expected frequency of use	Occasionally, whenever detailed information is needed.
Communication channels used	Any. Possibly via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations Distribution system congestion management Distribution grid cell islanding in case of higher-system instability Black-start support for SmartHouses Offering (secondary) reserve capacity to the TSO

2. Monitoring

Aspect	Specification
Web service name	Publish
Location where the web service is hosted (e.g. device, network etc)	PowerMatcher agent or concentrator
Web service functionality	Allows external entities to communicate with the agents for monitoring.
Web service input / output	Input: none Output: monitoring information
Web service nature (composite / atomic)	Atomic
Web service users	External entities: users, operators, administrators.
Security/confidentiality requirements	Preferably only authenticated parties will be accepted by the agent.
Expected frequency of use	Limited
Communication channels used	Only narrowband communication is required. The protocol used is SOAP based and requires IP.
Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

Aspect	Specification
Web service name	Show Values for Key Performance Indicators
Location where the web service is hosted (e.g. device, network etc)	Power supplier's/aggregator's information system
Web service functionality	This service delivers all current values for the Key Performance Indicators (KPIs) to the user, so that she has

	an overview of the current status of her aggregation of customers (SmartHouses); the KPIs may comprise overall energy efficiency, total revenues, market share, number of new customers etc.
Web service input / output	Input: values delivered by other web services that calculate each KPI Output: Overview of all KPI values (table)
Web service nature (composite / atomic)	Composition of atomic web services that each calculate the value of one single KPI
Web service users	Power suppliers / aggregators
Security/confidentiality requirements	High; the data must stay confidential because it is competition relevant
Expected frequency of use	Once per month or once per quarter
Communication channels used	Service within the supplier's information system
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Service Monitor
Location where the web service is hosted (e.g. device, network etc)	Utility's/aggregator's information system
Web service functionality	Keeps an up-to-date directory of active service instances.
Web service input / output for action "getAvailableServiceInstances"	Input: service type id (as stored in service repository) Output: all available service instances (active, addressable web services) of the given type
Web service input / output for action "getServiceInstancesByContext"	Input: service type id, context (e.g. location) Output: all available service instances of the given type that match the given context information
Web service input / output for action "getServiceInstancesByDeviceID"	Input: device id Output: all service instances that are hosted by the device (meter) with the given device id.
Web service nature (composite / atomic)	Atomic
Web service users	Other software components
Security/confidentiality requirements	High, an attacker could sniff any events that happen in the whole system and could create fake events.
Expected frequency of use	Frequently, every time an event is created that should be delivered to several subscribers.
Communication channels used	Any. Likely via Internet.
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Get Network Segment Description
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get topology of a specific region
Web service input / output	Input: region identifier Output: Network topology
Web service nature (composite / atomic)	Atomic
Web service users	DNO/Aggregator/ Balance Responsible Party
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses

Aspect	Specification
Web service name	Get System Status
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Announces the current status: Instability/Congestion problem etc…
Web service input / output	Input: Segment ID List of Connected Devices List of Connected Consumers Network Segment Description Online Data Output: System Status
Web service nature (composite / atomic)	Atomic
Web service users	DNO/Aggregator/ Balance Responsible Party/VPP
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management

	Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses

3. Eventing

Aspect	Specification
Web service name	Set List of Emergency Actions
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Announces the actions list for emergency: Load shedding priority ,black start units etc
Web service input / output	Input: Segment ID List of Connected Devices List of Connected Consumers Output: List of Emergency Actions
Web service nature (composite / atomic)	composite
Web service users	DNO/Aggregator/ Balance Responsible Party/VPP/DG/Consumers
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses

Aspect	Specification
Web service name	Announce Emergency Action
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	In case of emergency send an signal to related actors
Web service input / output	Input: Input: Segment ID List of Connected Devices List of Connected Consumers Output: Emergency plan
Web service nature (composite / atomic)	composite

Web service users	DNO/Aggregator/ Balance Responsible Party/VPP/DG/Consumers
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On Event
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses

Aspect	Specification
Web service name	Eventing Service
Location where the web service is hosted (e.g. device, network etc)	Central system hosted by one of the collaborating parties and made available as a service over the internet. Devices or agents can subscribe to the events they are interested in
Web service functionality	An event can be any signal of change in the environment (within the SmartHouse, a utility or elsewhere) Create a standards-based publish-/subscribe system for web service events based on a complete implementation of the standard WS Brokered Notification
Web service input / output for action “deviceFound”	Input: see WS-Brokered Notification Spec Output: see WS-Brokered Notification Spec
Web service output for market events (e.g. PowerMatcher)	Output: e.g. bid, market results,…
Web service output for emergency alerts	Output: emergency plan
Web service nature (composite / atomic)	Atomic
Web service users	Other software components
Security/confidentiality requirements	High, an attacker could sniff any events that happen in the whole system and could create fake events.
Expected frequency of use	Frequently, every time an event is created that should be delivered to several subscribers.
Communication channels used	Any. Likely via Internet.

Related business cases	Aggregation of houses as intelligent networked collaborations Real-time imbalance reduction of a retail portfolio Offering (secondary) reserve capacity to the TSO Distribution system congestion management Distribution grid cell islanding in case of higher-system instability Black-start support from houses

Aspect	Specification
Web service name	Push Event
Location where the web service is hosted (e.g. device, network etc)	PowerMatcher agent.
Web service functionality	Allows communication with the agent to notify the agent of an event. An event can be any signal of change in the environment. Note that this environment can be a smart home, but also the control centre of a utility enterprise.
Web service input / output	Input: event notification Output: none
Web service nature (composite / atomic)	The event may trigger a bid from the agent.
Web service users	PowerMatcher agent uses this service to changes in the environment. The agent determines whether the event should lead to a new bid in the market.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the agent.
Expected frequency of use	Depending on the environment.
Communication channels used	Only narrowband communication is required.
Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

4. System Wide / Location-Based Information

Aspect	Specification
Web service name	Get Historical Energy Exchange Data
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get historical data of energy exchange from some database

Web service input / output	Input: date(s) for which the data shall be provided, products (e.g. day-ahead, intraday, PHELIX-Baseload-Month-Futures, …) Output: price [EUR/MWh] (hourly values) volume [MWh] (hourly values)
Web service nature (composite / atomic)	Atomic
Web service users	Price forecast
Security/confidentiality requirements	Confidentiality: none Security: could be signed by trusted database or energy exchange itself Preferably only authenticated components will be accepted by the component.
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Energy Exchange Price Forecast
Location where the web service is hosted (e.g. device, network etc)	Internet or Energy Trading Software
Web service functionality	Get Day-ahead Price Forecast of Central Management Device
Web service input / output	Input: date(s) for which the data shall be provided (in case the date(s) are in the past the forecast data from the past shall be provided, which might be needed to validate the quality of the forecast in the past etc.) Output: price profile [€/MWh] (hourly values)
Web service nature (composite / atomic)	Atomic
Web service users	Energy Trader
Security/confidentiality requirements	Confidentiality: none Security: could be signed by trusted database Preferably only authenticated components will be accepted by the component.
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Power Profile from Trading
Location where the web service is hosted (e.g. device, network etc)	Central Management Device (Pool-BEMI)
Web service functionality	Get total power acquired by trading for a certain date at the time of calling the service. The service should be called when the day-ahead market for the date has closed and the total power profile for the day (excluding intra-day trading) is fixed.
Web service input / output	Input: date(s) for which the data shall be provided Output: profile [kWh] (positive: Power bought that shall be delivered to customers, negative: power sold, shall be produced by DG units of customers (hourly values or finer steps depending on the market rules of each country)
Web service nature (composite / atomic)	Atomic
Web service users	Only Central Management Device
Security/confidentiality requirements	Confidentiality: none Security: could be signed by trusted database
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Weather Historical Data
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get historical data of meteorological service from some database
Web service input / output	Input: date(s) for which the historical data shall be provided, values (e.g. solar radiation, outdoor temperature, wind supply, …), spatial scope Output e.g.: solar radiation [kW/m²] (hourly values) outdoor temperature [C°] (hourly values) wind supply [kWh] (hourly values)
Web service nature (composite / atomic)	Atomic
Web service users	Price forecast, customer reaction forecast
Security/confidentiality requirements	Confidentiality: none Security: could be signed by trusted database or meteorological service itself

	Preferably only authenticated components will be accepted by the component.
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Weather Forecast
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get forecast data of meteorological service from some database
Web service input / output	Input: date(s) for which the forecast data shall be provided, values (e.g. solar radiation, outdoor temperature, wind supply, …), spatial scope Output e.g.: solar radiation [kW/m^2] (hourly values) outdoor temperature [C°] (hourly values) wind supply [kWh] (hourly values)
Web service nature (composite / atomic)	Atomic
Web service users	Price forecast, customer reaction forecast
Security/confidentiality requirements	Confidentiality: none Security: could be signed by trusted database or meteorological service itself Preferably only authenticated components will be accepted by the component.
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

Aspect	Specification
Web service name	Get Load Forecast with Standard Pricing
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get Technical data of a specific device
Web service input / output	Input: Segment ID

	Weather Data Historical (Aggregated) Meter Data Output: Load Forecast (1/4-hourly values or settlement period for each country)
Web service nature (composite / atomic)	Atomic
Web service users	DNO Aggregator/ Balance Responsible Party/VPP
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses Demand Side Management Market Participation Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Aggregated Price-based Load Forecast
Location where the web service is hosted (e.g. device, network etc)	Internet or Energy Trading Software
Web service functionality	Get Aggregated Load Forecast of Central Management Device (from some database)
Web service input / output	Input: date(s) for which the data shall be provided (at least the next two days) Output: load profile [kWh] (1/4-hourly values or settlement period for each country)
Web service nature (composite / atomic)	Composite: Get Historical Price Data Get Weather Historical Data Get Weather Forecast Get Historical (Aggregated) Meter Data
Web service users	Energy Trader
Security/confidentiality requirements	Confidentiality: none Security: could be signed by trusted database
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Wind Power Production Forecast
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get forecast of production from wind power (single wind power plant or all wind power within a region)
Web service input / output	Input: Device ID or region for which wind power production shall be forecasted Output: Production Forecast (1/4-hourly values or settlement period for each country)
Web service nature (composite / atomic)	Uses: Get Weather Data Get Meter Data of wind power plants
Web service users	Aggregator/ Balance Responsible Party/VPP
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses Demand Side Management Market Participation Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get PV Power Production Forecast
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get forecast of production from PV (single PV plant or all PV within a region)
Web service input / output	Input: Device ID or region for which PV production shall be forecasted Output: Production Forecast (1/4-hourly values or settlement period for each country)
Web service nature (composite / atomic)	Uses: Get Weather Data Get Meter Data of wind power plants
Web service users	Aggregator/ Balance Responsible Party/VPP

Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses Demand Side Management Market Participation Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Production Schedule
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	- Set Production Schedule: Giving controllable plants (e.g. CHP plant with heat storage) a production schedule - Get Production Schedule: Get schedule of controllable plant
Web service input / output	Set Production Schedule: Input: Production schedule (1/4-hourly values or settlement period for each country) Get Production Schedule: Output: Production schedule (1/4-hourly values or settlement period for each country)
Web service nature (composite / atomic)	Atomic
Web service users	Aggregator/ Balance Responsible Party/VPP
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses Demand Side Management Market Participation Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Market Forecast
Location where the web service is hosted (e.g. device, network etc)	External Component (e.g. exchange market) or Auctioneer.
Web service functionality	Allows agents in the PowerMatcher network to request for market forecasts: price and/or volume. Agents can use this information to optimize their strategies.
Web service input / output	Input: request for market forecast (incl. time and location) Output: market forecast
Web service nature (composite / atomic)	Atomic
Web service users	PowerMatcher agents. Potentially this service may be shared with other applications such as BEMI planning
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the component.
Expected frequency of use	Dependent on use - probably once per day for each agent.
Communication channels used	Only narrowband communication is required. The protocol used is SOAP based and requires IP.
Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

5. Market-Based Planning and Control

Aspect	Specification
Web service name	Trade at Power Exchange
Location where the web service is hosted (e.g. device, network etc)	Central Management Device
Web service functionality	Trade for a certain power profile at power exchange; the service may decide itself whether it trades at the day-ahead-market, at future markets or OTC
Web service input / output	Input: Power profile that shall be obtained by trading, date(s) for which power profile shall be valid Output: Power profile actually bought by trading and price paid / received [kWh] (positive: Power bought that shall be delivered to customers, negative: power sold, shall be produced by DG units of customers (hourly values or finer steps depending on the market rules of each country)
Web service nature (composite / atomic)	Atomic
Web service users	Only Central Management Device

Security/confidentiality requirements	Confidentiality: high Security: could be signed by trusted database
Expected frequency of use	1x / day (only changing values)
Communication channels used	Broadband internet
Related business cases	Demand Side Management Market Participation Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Customer Contract Data
Location where the web service is hosted (e.g. device, network etc)	Central Management Device
Web service functionality	Get Customer Contract Data from some database
Web service input / output	Input: Metering Numbers of Customers Output: Contract Details regarding Customer Price Profile (e.g. Price Cap, Mean Price, Incentive, …)
Web service nature (composite / atomic)	Atomic
Web service users	Only Central Management Device
Security/confidentiality requirements	Confidentiality: high Security: could be signed by trusted database
Expected frequency of use	1x / day (only changing values)
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Pull Market Status
Location where the web service is hosted (e.g. device, network etc)	PowerMatcher concentrator or auctioneer.
Web service functionality	Allows authenticated parties, especially the objective agent of a cluster, to retrieve market information.
Web service input / output	Input: none Output: market information (to be specified)
Web service nature (composite / atomic)	Atomic
Web service users	Objective Agent.
Security/confidentiality requirements	Preferably only authenticated parties will be accepted by the service.

Expected frequency of use	Each market operating period, i.e. 5 - 15 minutes.
Communication channels used	Only narrowband communication is required. The protocol used is SOAP based and requires IP.
Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

Aspect	Specification
Web service name	Pull Bid
Location where the web service is hosted (e.g. device, network etc)	PowerMatcher agent or concentrator
Web service functionality	Allows communication with the agent to request a bid from the agent.
Web service input / output	Input: market protocol Output: agent demand / supply bid
Web service nature (composite / atomic)	Depending on Agent type, may require services: ▪ Market Forecast ▪ Climate Forecast ▪ Pull Measurement
Web service users	PowerMatcher concentrators and auctioneers need this agent service to collect bids from their underlying components.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the agent.
Expected frequency of use	Each market operating period, i.e. 5 - 15 minutes.
Communication channels used	Only narrowband communication is required. The protocol used is SOAP based and requires IP.
Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

Aspect	Specification
Web service name	Push Bid
Location where the web service is hosted (e.g. device, network etc)	PowerMatcher concentrator or auctioneer
Web service functionality	Allows communication with a concentrator or auctioneer in order to provide a bid to this component.

Web service input / output	Input: agent/concentrator demand / supply bid Output: none
Web service nature (composite / atomic)	May trigger one of the following services: ▪ Push Bid (at concentrator) ▪ Calculate Clearing Price (at Auctioneer) followed by Push Settlement
Web service users	PowerMatcher agents and concentrators need this service to provide an event-based bid to the market.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the component.
Expected frequency of use	At each significant event in the agent environment, which can vary from 5 - 15 minutes to hours or days.
Communication channels used	Only narrowband communication is required. The protocol used is SOAP based and requires IP.
Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

Aspect	Specification
Web service name	Push Settlement
Location where the web service is hosted (e.g. device, network etc)	PowerMatcher agent or concentrator
Web service functionality	Allows communication with the agent to provide the agent with a settlement. A settlement basically is a price, which the agent uses to determine its power allocation.
Web service input / output	Input: market settlement (incl. price) Output: none
Web service nature (composite / atomic)	Atomic, although it may trigger one of the following services: ▪ Push Settlement (at Concentrator) ▪ Control (at Local Agent)
Web service users	PowerMatcher auctioneer and concentrators need this agent service to provide the agent with settlement information, consisting of real-time electricity price.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the agent.
Expected frequency of use	Each market operating period, i.e. 5 - 15 minutes.
Communication channels used	Only narrowband communication is required. The protocol used is SOAP based and requires IP.

Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

Aspect	Specification
Web service name	Calculate Prosumer Price Profiles
Location where the web service is hosted (e.g. device, network etc)	Central Management Device (Pool-BEMI)
Web service functionality	Calculate price profiles for each group of BEMIs so that forecasted consumption/generation of prosumers fits a certain power profile
Web service input / output	Input: Power profile obtained from Trading (see Get Power Profile from Trading) Output: Database reference of price profiles calculated for each group of BEMIs [€/MWh] (1/4-hourly values or settlement period for each country)
Web service nature (composite / atomic)	Composite: Get Aggregated Price-based Load Forecast Get Customer Contract Data
Web service users	Energy Management Device
Security/confidentiality requirements	Confidentiality: Authentication required Security: Transmission of prices should be signed, possibly encrypted
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Transfer Prosumer Price Profile
Location where the web service is hosted (e.g. device, network etc)	Central Management Device (Pool-BEMI)
Web service functionality	Transfer Price Profile calculated by "Calculate Prosumers' Price Profiles" to Energy Management Device (BEMI)
Web service input / output	Input: BEMI-ID to which data shall be transferred,

	database reference of price profiles Output: -
Web service nature (composite / atomic)	Atomic
Web service users	Energy Management Device
Security/confidentiality requirements	Confidentiality: Authentication required Security: Transmission of prices should be signed, possibly encrypted
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Calculate Price Signal for Desired Load Response
Location where the web service is hosted (e.g. device, network etc)	Utility's/aggregator's information system
Web service functionality	Based on historical data, the aggregator calculates what shift in load will be induced by a specific price signal (i.e. reduction by x EUR/MWh), and so derives the right price signal for achieving a specified desired load response, given the price history of the same day
Web service input / output	Input: amount of overall load reduction or increase in MW desired; time span for which the load response is desired; series of prices for the past time slots of the same day Output: price signal (increment or decrement based on current price, in EURct/kWh)
Web service nature (composite / atomic)	Composition of load response calculation for different sort of appliances (i.e. storage type, shiftable etc.)
Web service users	Power suppliers / aggregators
Security/confidentiality requirements	Low confidentiality requirements, as only aggregate figures are considered
Expected frequency of use	Event-based in cases of imbalances; max for every 15 min period
Communication channels used	Data comes from power meters via DSL; aggregated data is stored within the aggregator's/utility's information systems
Related business cases	▪ Real-time imbalance reduction of a retail portfolio ▪ Offering (secondary) reserve capacity to the TSO ▪ Distribution system congestion management ▪ Variable-tariff-based load and generation shifting in case intraday price changes are allowed

6. Device Control

Aspect	Specification
Web service name	Set Device Schedule
Location where the web service is hosted (e.g. device, network etc)	Energy Management Device (BEMI)
Web service functionality	Set Device Schedule to User Interface
Web service input / output	Input: BEMI-IDs, Device-IDs (individual operational plan for each Device) Output: operational plans [kWh] (hourly values)
Web service nature (composite / atomic)	Composite: requires Set Customer Price Profile
Web service users	User Interface, End User
Security/confidentiality requirements	Confidentiality: none Security: none
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Device Power
Location where the web service is hosted (e.g. device, network etc)	Energy Management Device (BEMI)
Web service functionality	Energy Management Device meters actual power state and writes in specific database
Web service input / output	Input: actual operational data Output: load value [kW] (secondly)
Web service nature (composite / atomic)	Atomic
Web service users	User Interface, End User
Security/confidentiality requirements	Confidentiality: none Security: none
Expected frequency of use	secondly
Communication channels used	Depends on device or switching box
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Switch Device

Location where the web service is hosted (e.g. device, network etc)	Energy Management Device (BEMI)
Web service functionality	Energy Management Device switches Devices when it makes economically sense
Web service input / output	Input: switching command Output: conformation of switching
Web service nature (composite / atomic)	Atomic
Web service users	Device, End User
Security/confidentiality requirements	Confidentiality: none Security: none
Expected frequency of use	When it makes economic sense(couple of times per day)
Communication channels used	Depends on Device or Switching Box
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Technical Data for Storage/DG Device
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get Technical data of a specific device
Web service input / output	Input: Device ID Output: Technical Characteristics of Device
Web service nature (composite / atomic)	Atomic
Web service users	DNO/Aggregator/ Balance Responsible Party/VPP
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses

Aspect	Specification
Web service name	Get List of Connected Devices
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device

Web service functionality	List of Connected DG/RES/Storage in a specific region
Web service input / output	Input: Network Segment Output: List of Customers/Storage Devices/DG/RES
Web service nature (composite / atomic)	Atomic
Web service users	DNO/Aggregator/ Balance Responsible Party
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses

Aspect	Specification
Web service name	Get List of Connected Consumers
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	List of Connected Consumers in a specific region
Web service input / output	Input: Network Segment Output: List of Customers/Storage Devises/DG/RES
Web service nature (composite / atomic)	Atomic
Web service users	DNO/Aggregator/ Balance Responsible Party
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses

Aspect	Specification
Web service name	Get Online Data for Storage/DG Device

Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get Online Data for Storage/DG Device
Web service input / output	Input: Device ID Output: Current production/status/ Production profile/ Production Schedule
Web service nature (composite / atomic)	Atomic
Web service users	DNO/Aggregator/ Balance Responsible Party/VPP
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses

Aspect	Specification
Web service name	Get Online Data for Consumer
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device
Web service functionality	Get Online Data for Consumer
Web service input / output	Input: Consumer ID Output: Current consumption/status/ consumption profile
Web service nature (composite / atomic)	Atomic
Web service users	DNO/Aggregator/ Balance Responsible Party
Security/confidentiality requirements	Confidentiality: Yes Security: could be signed by trusted database
Expected frequency of use	On call
Communication channels used	Broadband internet
Related business cases	Distribution system congestion management Distribution Grid Cell Islanding in Case of Higher-System Instability Black-Start Support from Smart Houses

Aspect	Specification
Web service name	Pull Measurement
Location where the web service is hosted (e.g. device, network etc)	Local Device.
Web service functionality	Provide analogue or digital signal; a signal may be more complex.
Web service input / output	Dependent on device type.
Web service nature (composite / atomic)	Atomic
Web service users	PowerMatcher agents. Potentially this service may be shared with other applications.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the component.
Expected frequency of use	At each significant event in the agent environment, which can vary from 1 - 15 minutes to hours or days.
Communication channels used	Only narrowband communication is required. The proposed protocol is DPWS.
Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

Aspect	Specification
Web service name	Push Control
Location where the web service is hosted (e.g. device, network etc)	Local Device.
Web service functionality	Accept analog or digital command; a command may have a more complex content.
Web service input / output	Dependent on device type.
Web service nature (composite / atomic)	Atomic
Web service users	PowerMatcher agents. Potentially this service may be shared with other applications.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the component.
Expected frequency of use	At each significant event in the agent environment, which can vary from 1 - 15 minutes to hours or days.
Communication channels used	Only narrowband communication is required. The proposed protocol is DPWS.

Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

Aspect	Specification
Web service name	Subscribe to Event
Location where the web service is hosted (e.g. device, network etc)	Local Device.
Web service functionality	Using this service components can subscribe to events, i.e. changes in the environment of the device, e.g. change of thermostat setpoint; washing machine filled for washing; etc.
Web service input / output	Dependent on device type.
Web service nature (composite / atomic)	Atomic
Web service users	PowerMatcher agents. Potentially this service may be shared with other applications.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the component.
Expected frequency of use	At the initialization of the agent.
Communication channels used	Only narrowband communication is required. The proposed protocol is DPWS.
Related business cases	PowerMatcher inspired business cases: Imbalance reduction Offering reserve capacity Congestion Management

7. Metering

Aspect	Specification
Web service name	Read Meter
Location where the web service is hosted (e.g. device, network etc)	Billing Software
Web service functionality	Read Meter and write in some database
Web service input / output	Input: Metering Numbers of Customers Output: load profile [kWh] (1/4 h values)
Web service nature (composite / atomic)	Atomic
Web service users	Only Central Management Device
Security/confidentiality requirements	Confidentiality: high

	Security: necessary
Expected frequency of use	1x / month for billing and 1/4 h values for monitoring
Communication channels used	Depends on Metering Device
Related business cases	Variable-Tariff-Based Load and Generation Shifting

Aspect	Specification
Web service name	Get Historical (Aggregated) Meter Data
Location where the web service is hosted (e.g. device, network etc)	Internet or Central Management Device (Pool-BEMI)
Web service functionality	Get historical meter data from some database
Web service input / output	Input: date(s) for which the data shall be provided, Metering Numbers, aggregated or customer data Output: power meter data [kWh] (1/4 h values)
Web service nature (composite / atomic)	Composite: requires Read Meter
Web service users	Price prediction
Security/confidentiality requirements	Confidentiality: none Security: could be signed by trusted database
Expected frequency of use	1x / day
Communication channels used	Broadband internet
Related business cases	Variable-Tariff-Based Load and Generation Shifting

8. Billing

Aspect	Specification
Web service name	Billing
Location where the web service is hosted (e.g. device, network etc)	Utility's/aggregator's information system
Web service functionality	Handles the billing process at the enterprise level. It must be possible to implement different payment schemes depending on the type of application and contract.
Web service input / output	Input: point of time of the last bill Output: bill (containing all legally required pieces of information)
Web service nature (composite / atomic)	Composite; uses • Get Price • Get Contracted Production and Consumption • Get Realized Production and Consumption • Tariff Rating

Web service users	Utility / aggregator
Security/confidentiality requirements	Medium; the bill contains financial data relevant for the customer, so a minimum level of confidentiality has to be guaranteed
Expected frequency of use	Monthly
Communication channels used	Any
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Tariff Rating
Location where the web service is hosted (e.g. device, network etc)	Utility's/aggregator's information system
Web service functionality	Maps the customer's consumption to the price applicable at the time of consumption, taking into account the type of contract that the customer has
Web service input / output	Input: • Time series of consumption from the time of the last bill onwards • Rule how the price for the consumption at a specific time is determined (from the contract) • Required price information Output: monetary amount that the customer has to pay, in the level of detail that is required for the bill
Web service nature (composite / atomic)	Atomic
Web service users	Utility / aggregator
Security/confidentiality requirements	Medium; the bill contains consumption and contract data relevant for the customer, so a minimum level of confidentiality has to be guaranteed
Expected frequency of use	Monthly
Communication channels used	Any
Related business cases	Aggregation of houses as intelligent networked collaborations

Aspect	Specification
Web service name	Get Price for Time Slot
Location where the web service is hosted (e.g. device, network etc)	To be decided. The logical place is the PowerMatcher auctioneer.

Web service functionality	Delivers the realized real-time prices. The exact format has to be decided on: either a price vector, giving (integrated) prices per period, or a more complex structure giving price changes at arbitrary times.
Web service input / output	Input: period over which the prices are requested. Output: realized price information.
Web service nature (composite / atomic)	Atomic.
Web service users	Utility / Enterprise.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the component.
Expected frequency of use	Daily to monthly.
Communication channels used	
Related business cases	All business cases involving billing.

Aspect	Specification
Web service name	Get Contracted Production and/or Consumption
Location where the web service is hosted (e.g. device, network etc)	To be decided. The logical place is the PowerMatcher agents.
Web service functionality	Delivers the contracted load over time. The exact format has to be decided on.
Web service input / output	Input: period over which the contracted load is requested. Output: contracted load information.
Web service nature (composite / atomic)	Atomic.
Web service users	Utility / Enterprise.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the component.
Expected frequency of use	Daily to monthly.
Communication channels used	
Related business cases	All business cases involving billing.

Aspect	Specification
Web service name	Get Actual Production and/or Consumption
Location where the web service is hosted (e.g. device, network etc)	Smart Metering Infrastructure
Web service functionality	Delivers the realized load over time. The exact format has to be decided on.

Web service input / output	Input: period over which the realized load is requested. Output: realized load information.
Web service nature (composite / atomic)	Atomic.
Web service users	Utility / Enterprise.
Security/confidentiality requirements	Preferably only authenticated components will be accepted by the component.
Expected frequency of use	Daily to monthly.
Communication channels used	
Related business cases	All business cases involving billing.