MIDDLEWARE FOR ENERGY AWARE APPLIANCES

Theodore Zahariadis, PhD / CTO, zahariad@synelixis.com
Menelaos Perdikeas, PhD / Senior engineer, mperdikeas@synelixis.com
Fotis Chatzipapadopoulos, PhD / Senior engineer, fhatz@synelixis.com
Synelixis Solutions Ltd., Chalkida, Greece
Javier Lucio Ruiz Andino, Senior engineer, lucio@tid.es
Maria Angeles Barba, Senior engineer, mabr@tid.es
Telefonica Research and Development, Madrid, Spain

ABSTRACT

Efficient energy consumption, intelligent monitoring and interactive control of energy consumption in homes/residential buildings, as well as the control of energy consumed outdoors, in public or private areas are key factors to Europe's ambitious goals of sustainable development, reduction of energy demand peaks and activities related to avoidance of climate change effects. This paper proposes a solution to this problem based on minimizing white goods'/consumer electronic devices' energy consumption, balancing energy distribution and thus saving energy and reducing the service cost of the power distribution network. The basic issue in energy control is the seamless monitoring of the various energy consumption elements and devices, as well as the scheduling of their operation in order to minimize peaks, balance loads, and ultimately achieve predictable large-scale energy-consumption profiles. This paper describes our experience on the development of a user-friendly/consumer-centric middleware platform based on the OSGi framework for the control and scheduling of operation of energy-consuming appliances and service providers' access equipment. The proposed solution implements an innovative appliance control system that presents options for optimizing appliances' operation and scheduling of events. It is also able to act automatically in a single-building level depending on the model of the building embedded in the controller.

Keywords: Energy-efficient buildings, Home Automation, Load Shifting, Demand Side Management, Optimization

1. INTRODUCTION

In this paper, we propose a home automation system (together with a wider ICT infrastructure resembling in certain respects a smart grid) with the goal to target environmental sustainability, energy efficiency and new contract business models in the retail side of energy distribution. Our aim is to design, develop and evaluate an innovative, energy-aware and user-centric solution, able to provide intelligent energy monitoring/control and power demand balancing / shifting at home/building & township level. The goal of our system is to interconnect legacy professional / consumer electronic devices with a new generation of energy-aware white-goods, where multilevel hierarchic metering, control, and scheduling will be applied, based on power demand, network conditions and personal preferences.

Our solution combines innovation in a number of areas:

- <u>Intelligent personalized energy-management/control and small-scale power demand balancing platform</u>: Different users have different priorities, preferences and needs and consider the energy commodity from different viewpoints. The idea of intelligently controlled appliances has been found in market research studies to be very appealing to the greatest percentage of consumers, with at least 70% of consumers inquired finding the idea "interesting" or "very interesting" (B/S/H 2007) yet it is at the same time recognized that the right balance has to be struck between either taking too many unwarranted decisions or requiring intensive user engagement. Both extremes are unwelcomed by home consumers. The solution we propose is balanced and at the same time goes beyond mere automation by including demand-side management features and delivering electricity bill benefits to the consumer (assuming time-varying energy tariffs).

- Smart Buildings: Efficient energy management in buildings requires extensive use of communication network infrastructure as well the provision of the necessary interfaces to home appliances, local distributed generation and energy and service providers.
- Electronic market place for energy: The introduction of Smart Energy Grids and deregulation is resulting in a transformation of the European energy market. New players are appearing and the roles of incumbent players are changing. An electronic market place for energy must provide the necessary interfaces and information exchange mechanisms. It should also be open to support new applications, players and roles.
- ICT-related improvements to white goods' power consumption: According to research performed by CECED (2001) domestic appliances in the 15 EU countries in 2001 consumed about 250 TWh of electrical energy in year 2000 - about 30 TWh less than in 1990, due to the improvements of the efficiency of various products. From an architectural perspective, we envisage that all home appliances (including white goods) include ICT enhancements. This will allow the home automation software we propose to control them over open interfaces.
- Small scale renewable energy resource integrated with home network: Our solution takes advantage of the opportunity to reduce energy consumption and CO_2 emissions at home level by integrating a CPS panel, which produces energy and hot water (Giaconia et al. 2009). The CPS offers two more levers (local energy production and hot water) for energy management in order to maximize energy and environmental savings at home (Di Dio et al. 2009; Miceli et al. 2009). Clever scheduling of washing machine cycles when the temperature of hot water in the pipes is estimated to be higher (due to the solar panel) is an example of how synergistic ICT-related benefits can decrease white goods power consumption.

2. THE PROPOSED BUSINESS MODEL

In a deregulated electricity market where multiple electricity companies compete for customers, the need for service / product differentiation to avoid commoditization and price-only-based competition is even more pronounced (Clarkson 2006).

Presently, in the typical case when no demand-side management solution is implemented, the relationship between the electricity company and the electricity consumers is a clean-cut producer-consumer relationship. When demand-side management is introduced the picture gets a bit more complex in that the entity responsible for the demand-side management could be the electricity company itself or another entity (e.g. the grid administrator). In a typical de-regulated electricity environment there can be many electricity producers feeding power into the grid, but the grid as a whole is a shared resource managed by the grid administrator and the stability of the grid is something that affects all market participants.

The proposed business model (or rather the proposed business model framework) is even more complex in that it introduces three additional points:

1. *Demand side management and load shifting takes place by utilizing a whole array of measures*: not just the cents / kWh price of energy but many different incentives / counterincentives that can influence (with varying degrees of effectiveness) electricity demand. Moreover, these measures are modified at real time. Such measures (in addition to the sell price of energy), can include a power ceiling, a penalized power ceiling (above which a surcharge is applied to the price), the buy price of energy, and others.
2. *Communications infrastructure*: in contrast to traditional demand-side management solutions which view the user as part of the market-driven response loop, in our solution the communication of the incentives / counterincentives takes place through an ICT infrastructure and it is taken into consideration not by a human user (who would be swamped by all this influx of information) but by a software module (the Home Energy Management System Scheduler).
3. *Households as energy producers*: we allow households to be themselves energy producers. Incentives propagated from the grid administrator can include time-varying inputs not just for the "sell price" of electricity, but also for the "buy price" meaning the system is not strictly demand-

side management but can also influence a (small but potentially critical) component of the supply side.

Given the above, Table 1 that follows juxtaposes the proposed “Business Model” with traditional demand-side management business models in the electricity retailing business. Note that in what we term "traditional way" we do not consider the case of direct load control by the electricity retailer / grid administrator as our focus is on non-compulsory approaches.

Table 1: Juxtaposing traditional demand-side management with the proposed approach.

Aspect	Traditional way	Proposed Approach
Means available to shape demand:	electricity cost (mainly)	electricity cost, but also others
Measures influencing demand …	… are announced on traditional media outlets and are received and acted upon by humans or can be fixed in a static contract structure	… are published in electronic format (web-services) and are acted upon by software
Decisions in response to these measures …	… are taken by humans (consumers) after they have been announced using traditional means (radio, TV, human-readable web pages) and are effected by manually interacting with the appliances usually locally but perhaps also remotely	… are taken by the Scheduler software (running on behalf and under the broad outlines / directions set by the consumers) after receiving notification of incentives / counter-incentives through a web services interface
Burden of “optimization” …	… is borne by the home consumer	… is transparent to the home consumer and is borne by software
Updated measures with the goal of influencing demand can be sent …	… not too frequently (usually daily) considering that human users will need to learn about them using traditional media channels	… very frequently considering that the software is always “on” and is always “listening”
Complexity of measures …	… must be low enough (usually price hikes) to allow the users to comprehend the effect their actions will have on their monthly bill and to make obvious the kind of behavior expected	… can be arbitrarily complex since an optimizing scheduler will be used to find out the optimal solution

3. THE PROPOSED CONCEPTUAL MODEL FOR DEMAND-SIDE MANAGEMENT

With the risk of oversimplifying, the diagram in Figure 1 that follows depicts the concept proposed to achieve demand-side management. Figure 1 is an abstract diagram yet it still identifies the key properties underpinning the proposed approach. We refer to Figure 1 as the Monitoring and Control System Conceptual Model (“MCSCM”).

Each plane of the MCSCM corresponds to a certain scope for control. At the base plane of the hierarchy the entities on which control is exercised are more localized, consisting, usually of single, discrete appliances. As we move up the hierarchy planes, the scope of control becomes broader extending to apartments / homes, buildings, townships and larger geographical regions. Attendant with the change in the location scope is a change in the kind of control that is possible at each plane.

Moreover, different actors are envisaged in each layer.

The two key concepts (hierarchical propagation and semantic translation) of the MCSCM are discussed below.

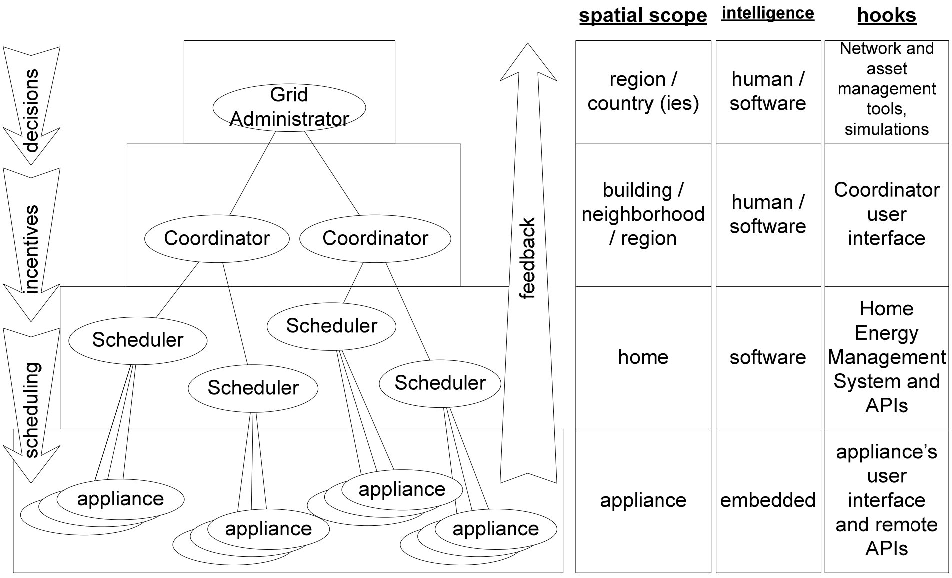

Figure 1: demand-side management conceptual model.

Hierarchical Propagation. Propagation of incentives / counterincentives for demand-side management is done in a hierarchical approach. The hierarchy is organized according to spatial scope: from larger geographical regions and agglomerations on the upper layers to neighborhoods, buildings, homes and, eventually, appliances at the lowest level.

Semantic Translation. The incentives / counterincentives measures propagate from the higher planes to the lower planes and undergo several "semantic" translations at each plane so as to be consistent with the scope of that plane. For example, a typical propagation / refinement would be the following:

1. a request to lower the total demand on a geographical area gets translated to …
2. … multiple requests to lower demand in various regions (cities, neighborhoods) that collectively comprise that area, each of which is further translated into …
3. … a set of incentive / counter-incentives, distinct for each home which will (hopefully) influence scheduling decisions and they are …
4. … ultimately effected by scheduling household appliances or otherwise modifying aspects of their operation.

Feedback then works its way up in much the same way.

4. ENABLERS REQUIRED

To flesh out an architecture that can support the requirements of the MCSCM described in the previous section the following enablers are required:

- Scalable, easy to use, reliable and secure communication services as the basis for the required Smart Energy control networks,
- Self-configuration and adaptation capabilities at different scales enabling dynamic registration and deregistration of participants,
- Ultra-reliable, potentially cloud-based control services and systems for energy flow control, integrity protection and further advanced applications,
- Easy-to-use and scalable IT-based Energy Management Systems for data collection, control and visualization purposes,
- Development of adaptable IT service portfolios to support the evolution path towards the future Smart Energy scenarios and applications.

A promising approach is to leverage on the Future Internet for most of the reliability, security and scalability requirements and thus develop Future Internet-enabled ICT solutions for intelligent energy management of residential and public buildings. This is the approach of the Finseny project (Finseny 2011) and is depicted in Figure 2 that follows.

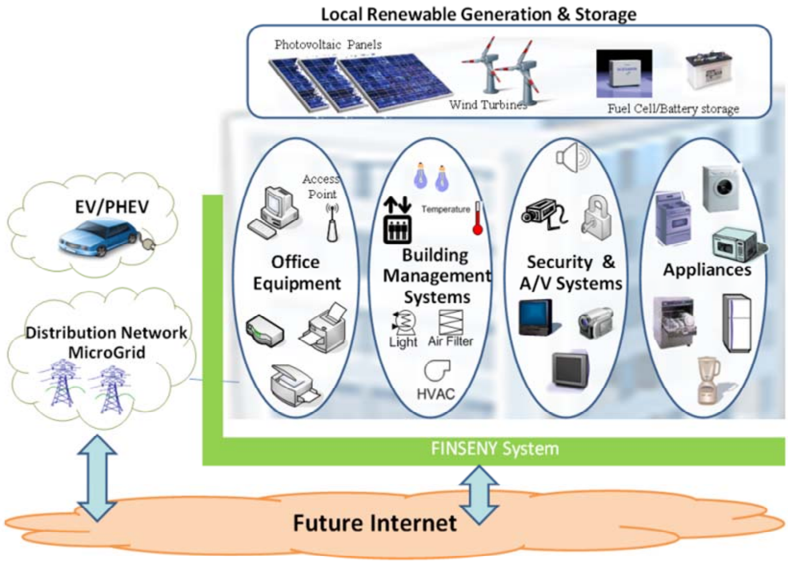

Figure 2: Leverage the future internet to build energy aware ICT solutions for buildings.

5. THE PROTOTYPE SOFTWARE ARCHITECTURE PROPOSED

Based on the conceptual model of Figure 1 and the vision of Figure 2, Figure 3 that follows depicts the technical prototype proposed.

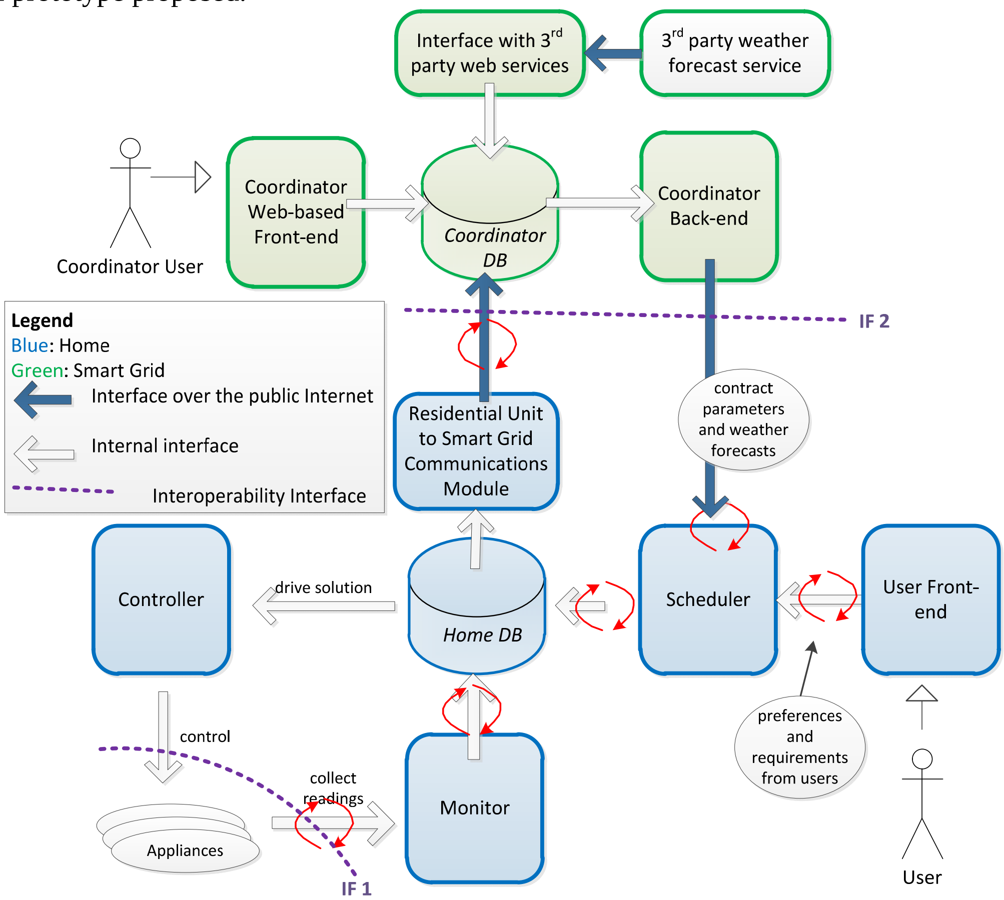

Figure 3: Technical Architecture Proposed.

It is also easy to see that the architecture of Figure 3 is consistent with the MCSCM presented in Figure 1.

Demand-side management is implemented by infusing “intelligence”, understood here to mean ICT-type intelligence in all the levels at which electricity consumption can be meaningfully assessed, monitored, influenced or controlled.

6. SEMANTIC INTEROPERABILITY

Referring to Figure 3, there are two important interfaces related to semantic interoperability within the proposed solution / framework:

- The control and monitoring interface with the actual home appliances (IF 1 in Figure 3)
- The home-grid interface (IF 2 in Figure 3).

These two interfaces and the data models they comprise are described in the sections that follow.

6.1 Appliance Control Interface

Appliances’ APIs are intended for monitoring and control of the various appliances from the Scheduler application. I.e., the APIs, which the Scheduler uses to monitor the status, get information about instant power demand (and energy spent in some cases) and control of the appliances. Appliances controlled by these APIs are: Washing Machine, Dishwasher, Refrigerator, Energy aware Smart Plug (Watcher), Smart Meter (Subscriber Meter) and CPS (Combined Photovoltaic Solar).

APIs and data model definition has been guided by four principles:

1. Simplicity - the basic APIs necessary to fulfill devices monitoring and control from the Scheduler have been defined. Extra functionality the devices might offer is not included in the framework and should be defined as extensions of the basic APIs.
2. Clarity - method and parameter names are sometimes lengthy but clearly describe the semantics and are consistent with standard Java language coding conventions.
3. Consistency - the same approach is used in all the interfaces and uniform naming conventions have been used for methods and parameters.
4. Generalizations when applicable - use of interface inheritance to capture commonalities between interfaces.

The class diagram of Figure 4 depicts the inheritance relationships among the appliances’ interfaces.

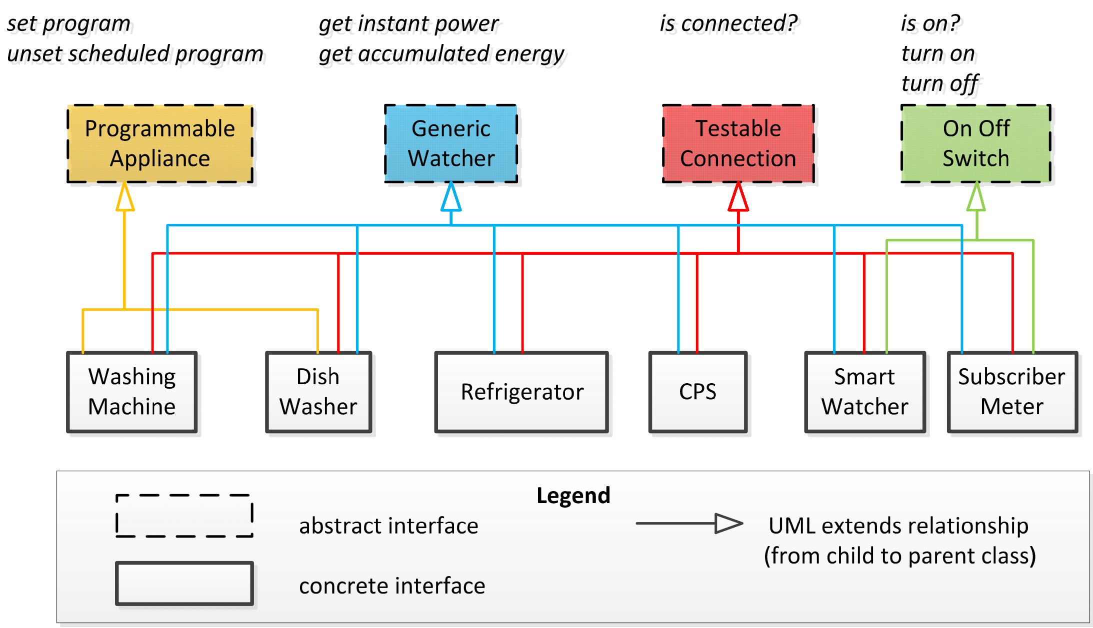

Figure 4: Appliance API schema.

The diagram of Figure 4 follows standard UML class diagram conventions except with regard to the coloring which is only done to make the inheritance relationships more readable. The actual interfaces are defined in Java and are available to system integrators as a self-contained OSGi bundle or Java JAR file to simplify integration. They are described in detail in (BeyWatch Consortium 2011).

6.2 Home / Grid Interface

This information flow is used to allow the Coordinator to update critical contract parameters in a Scheduler. Such critical contract parameters include the energy price, the power ceiling for the household as a whole and other more nuanced parameters. By updating these contract parameters the Coordinator can hope to influence the energy consumption behavior / patterns in a household and thus (when taking into consideration all households so influenced) implement demand-side management and load shifting measures on a wide geographical scale. Although the Coordinator can fan-out to an arbitrary number of Schedulers (only limited by practical / network considerations but typically thought to be in the thousands or tens of thousands), the information flow with each one of them is unique, so it is defined in the context of a single Coordinator - Scheduler communication.

6.2.1 Data Models in the Home / Grid Interface

The basic data model that is present in this flow is the contract model as the main purpose of this flow is to update critical parameters of that contract. The contract model is a purely conceptual entity that can have many possible technological bindings, all semantically the same. Possible bindings with which we have experimented include HTTP-based web services following the REST pattern (Richardson and Ruby 2007), exchanging information in the form of JSON objects (www.json.org) or database / JDBC access.

The contract is properly understood as consisting of both a meta-contract and an actual "contract instantiation". The relationship between the two is that at any given moment in time a home is under a specific instantiation of the meta-contract. An instantiation ties the meta-contract parameters to specific values, for the duration of that instantiation. The Scheduler thus experiences, over time, a succession of contract instantiations (all emanating from the same meta-contract).

6.2.2 Meta-Contract Data Model

The meta-contract model is defined by the following:

- a list of the contract parameters (e.g. price of energy, power ceiling), together with some reference values, and
- the definition of the mechanism used to constrain the possible variations in the value of each parameter. Variations of course are necessary since this is the way to implement demand-side management measures.

The extent of variations may be constrained both in scope (e.g. the price cannot be hiked more than 25%) and in time (e.g. the duration of price hikes cannot exceed more than 30% of the total time). This limitation is necessary to provide some kind of contract-backed assurance to the consumers that their reference contract parameters cannot be arbitrarily tweaked without any bounds. Similar constraints are in place for all other contract parameters. It is clear that one can devise many ways to "restrict" the changes in values of these contract parameters. Consider for instance the case of energy price. Possible formulations to restrict changes (in this case hikes) could be:

- Specify a standard hike duration, e.g. 1 hour, and a standard hike percentage, say 25%, and limit the number of hikes per day and / or per week and / or per month. One can also combine this with special rules for weekends.
- Specify a number of standard hike percentages (e.g. 20%, 50%, 100%) and a standard duration for each hike (e.g. 1 day) and again limit the hike instances per hike category per calendar year. Hike percentages can be named ("green days", "red days", "white days").
- Specify a structured, standard variation of energy price during the day (e.g. higher price during typical high-demand time intervals in a 24-hours day) and specify three different baselines to

start with. Together with some constraints on the number of high cost days this is similar to the "tempo" tariff system used in France.

The mechanism we have employed and which is described in the remainder of this section is actually flexible enough to act as a superset of all the above mechanics. Table 2 below defines the contract parameters that form part of the meta-contract.

Table 2: Meta-contract parameters.

Parameter	**Type**	**Definition**	**Typical reference values**
buy energy price	Numeric	the retail price of energy for the home consumer	13 cents / kWH
sell energy price	Numeric	the price of energy at which the grid agrees to buy energy from the home (in case of PV installations)	20 cents / kWH
power ceiling	Numeric	The total power available to the home. This is a hard limit. Consumption above that limit will not be allowed by the Scheduler.	5 kW
penalized power	Numeric	The value of power above which a surcharge on the retail price of energy will be applied to penalized further consumption. This is a soft limit. The Scheduler or the home consumer can require more power beyond that limit, but the price of energy will be commensurately higher.	3 kW
penalized energy surcharge	Numeric	This is the additional surcharge (on top of the normal 'buy energy price') that the consumer will have to pay for the energy whenever the power demanded exceeds the 'penalized power' soft limit.	3 cents / kWH
forced consumption	Boolean	This flag forces the Scheduler to direct locally produced energy from PV to the home grid as opposed to selling it to the Grid administrator.	false

Each contract parameter is given, as part of the contract, a reference value, which defines the baseline. To implement demand-side management measures the Coordinator will in all cases move that parameter value in one direction only (either upwards or downwards) for certain periods of time. The direction in which the value is forced depends on the semantics of the parameter. Put simply, in all cases there is only one obvious direction in which the value should move, in order to curb demand. E.g. in the case of price, demand is reduced only if the value of that parameter (i.e. the price) is moved up. In the case of the power ceiling, demand is reduced only if the value of that parameter (i.e. the power ceiling) is moved down. As such, to simplify discussion we will speak in terms of a particular parameter "moving away" from its reference value rather than "moving up" or "moving down" (since the direction should be obvious). Given the above, the mechanism by which demand side management measures are implemented is by having one or more of the contract parameters move away from their reference value for certain durations, within one billing period. Which parameter(s) is (are) tweaked, and by how much, is constrained by limits placed on the area defined in a time plot between the actual value of the parameter and its reference value. This area corresponds to an integral over time. Figure 5 illustrates this concept.

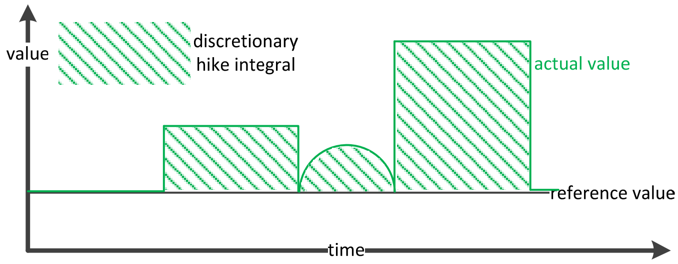

Figure 5: Calculating discretionary hikes in contract parameter values' fluctuation over time.

The mechanism therefore works by constraining the value of these integrals, per day and per calendar month. Table 3 below provides some typical values in a contract structure.

Table 3: Constraints on the integrals of discretionary hikes (example values).

Parameter	**discretionary hike per day**	**discretionary hike per month**
buy energy price	200 cent × hour / kWH	4000 cent × hour / kWH
sell energy price	300 cent × hour / kWH	5000 cent × hour / kWH
power ceiling	50 kWH	1000 kWH
penalized power	50 kWH	1000 kWH
penalized energy surcharge	250 cent × hour / kWH	7000 cent × hour / kWH
forced consumption	5 hour	100 hour

6.2.3. Contract Instantiation Model

The Contract meta-model is used to create contract instantiations. A contract instantiation simply provides the exact values of the parameters of Table 2 for a specific interval in time (hourly quarters usually). The actual, instantiated values may deviate upwards or downwards from their reference values that are given in Table 2 but the total extent of these deviations must fall within the limits identified as part of the contract (as in the example shown in Table 3). New contract instantiations are created as often as necessary. The Coordinator supplies the Scheduler(s) with many contract instantiations well in advance of the current time (typically for 24 hours ahead) so that Schedulers can schedule appliances in an optimal way. Typically as each contract instantiation covers a span of 15 minutes, it takes 96 contract instantiations to cover the span of a day. Actually, the Scheduler itself has no concept of a meta-contract. Only the Coordinator understands the meta-contract concept (and thus the limits placed on the discretionary hikes). What the Scheduler sees is a succession of contract instantiations for every hourly quarter for the next 24 or so hours. The enforcement of the meta-contract constraints of Table 3 is also part of the Coordinator implementation.

7. CONCLUSIONS

We have presented an ICT architecture that facilitates non-compulsory demand-side management measures under a time-varying electricity tariff system. The architecture manages to reconcile two apparently conflicting goals: control ultimately rests with the human consumer and at the same time the consumer is not overburdened with the need to perform constant optimizations or worry about frequent tariff changes. We have identified the future Internet enablers that can be leveraged to deploy such an architecture and have described the basic interoperability interfaces.

ACKNOWLEDGE

This work has been partially funded by European Commission and the ICT PPP project 285135 FINSENY (Future Internet Smart Energy). More info maybe found at http://www.fi-ppp-finseny.eu/

REFERENCES

B/S/H (2007) Market Research, http://www.bsh-group.com/

BeyWatch Consortium (2008) Building EnergY WATCHer, 7th framework program, ICT call 2, Description of Work, http://www.beywatch.eu/

BeyWatch Consortium (2009) BeyWatch White Paper: http://tinyurl.com/6gtj8gw

BeyWatch Consortium (2011) Deliverable D4.5: Home Energy Monitoring, Control & Scheduling Application

CECED (2001) Report on Energy Consumption of Domestic Appliances in European households, http://tinyurl.com/3aky2pv

CECED (2007) Vision on Energy Efficiency, http://tinyurl.com/2w3qrnb

Di Dio, V., et al. (2009) “A Mathematical Model to Determine the Electrical Energy Production in Photovoltaic Fields Under Mismatch Effect.” *In the International Conference on Clean Electrical Power (ICCEP) - Capri, Italy.*

FINSENY Consortium (2011) Future INternet for Smart ENergY, *Description of Work*, Large-scale Integrating Project in the Seventh Framework Program.

Giaconia, G.C. et al. (2009) “Integration of Distributed on Site Control Actions via Combined PhotoVoltaic and Solar Panels System.” *In the International Conference on Clean Electrical Power - Capri*, Italy, 9-11 June 2009.

Jim Clarkson (2006) “The Commoditization of the Electricity Market”: http://tinyurl.com/34x6fp3

Miceli, R., et al. (2009) “Impact of Novel Energy Management Actions on Household Appliances for Money Savings and CO2 Emissions Reduction.” *In the EVER 09 Electrical Vehicle and Renewable Energy Conference 2009, Monaco.*

Richardson, L., Ruby, S (2007) "RESTful Web Services". O’ Reilly Media, Cambridge.