The BeyWatch Conceptual Model for Demand-Side Management

Menelaos Perdikeas, Theodore Zahariadis, and Pierre Plaza

Synelixis Solutions Ltd., Farmakidou 10, Chalkida, Greece
Telefónica I+D, C/Emilio Vargas 6, 28043 Madrid, Spain
{mperdikeas,zahariad}@synelixis.com, pierre@tid.es

Abstract. The BeyWatch project designs, develops and evaluates an innovative, energy-aware and user-centric solution, able to provide intelligent energy monitoring/control and power demand balancing at home/building and larger geographical area level. The focus lies in increasing the use of ICT in power systems. We first provide a brief overview of the concepts involved. After that, we highlight one of the crucial problems of demand side management: striving to attain a balance whereby the system meaningfully influences user behavior / electricity consumption while at the same time avoiding the two extremes of either: (a) putting too much strain on consumers by forcing them to second-guess and obsessively optimize the operation of their appliances or (b) taking over control of their household. We present the BeyWatch Conceptual Model that drove the architecture definition of the BeyWatch platform which solves this conundrum. We finish with a presentation of actual architecture deployed for the trials.

Keywords: demand-side management, dynamic tariffs, home automation.

1 Introduction

The scope of the BeyWatch project [1] is quite broad. Targeting environmental sustainability, energy efficiency [2] and new power distribution/production business models, BeyWatch aims to design, develop and evaluate an innovative, energy-aware and user-centric solution, able to provide intelligent energy monitoring/control and power demand balancing at home/building & neighborhood level. The BeyWatch system interconnects 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. In addition to the above objectives, BeyWatch also targets innovations not directly related to Information and Communications Technologies (ICT) as well as the integration of combined photovoltaic / solar systems in the home power network allowing either peak hour use of locally produced energy or selling it to the external grid.

The system is thus designed to interconnect legacy/consumer electronic devices with a new generation of energy-aware white goods in a common network, where multilevel hierarchic metering, control, and scheduling will be applied, based on

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power demand, network conditions and personal preferences. By scheduling and controlling the electronic devices operation, BeyWatch aims to minimize power distribution peaks, balancing energy load in power distribution networks and ultimately achieving smooth, predictable, large-scale energy consumption profiles [3].

Moreover, BeyWatch optimizes and integrates an innovative Combined Photovoltaic - Solar (CPS) system, which will provide: a) hot water for white goods (such as dishwasher, washing machine) in order to strongly decrease energy consumption and CO_2 emissions at home by reducing/removing some heating cycles and b) generate electrical energy from Renewable Energy Sources (RES), which can be utilized at home, and during peak periods, even fed to the electricity network in a reverse power generation/ distribution business model.

BeyWatch solution combines innovation in a number of areas:

- *Intelligent personalized energy-management/control and small-scale power demand balancing platform*: Different users have different priorities, preferences, 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" [4] 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. BeyWatch proposes a solution that 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.
- *Modeling and medium-scale control of power distribution*: By providing a detailed analysis of the consumption pattern in a square block, neighborhood or larger geographical areas, BeyWatch allows the energy supplier companies to balance the energy consumption peaks using comprehensive power demand scheduling and reduce the need for out-of-schedule power imports from neighboring countries or other exigency measures.
- *Technologies for very low-cost white goods' power consumption combined with ICT*: According to research performed by CECED [5] 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. In BeyWatch, new technologies are evaluated and tested to offer significantly reduced power consumption and much more efficient power control in a new generation of energy-aware white goods. What's more important from an architecture perspective is that all home appliances (including white goods) now include ICT enhancements allowing them to be controlled by the home automation software (BeyWatch Agent) over open interfaces.
- *Small scale renewable energy resource integrated with home network*: BeyWatch 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 [6]. 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 [7][8].

2 The BeyWatch 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 [9]. We foresee that electricity companies will have an incentive to couple their offerings with additional services typically offered by telecommunication providers. This creates an incentive for both energy utilities and telecom operators to align themselves and perhaps offer synergistic service bundles that combine ICT with electricity distribution:

- Utilities will need to acquire technology and knowledge to help them develop and disseminate end devices for controlling the demand side management and to integrate the final users as an active part of the energy system, giving them the tools and services needed to make a more efficient use of energy.
- Telecom operators also need knowledge on how and why ICT are so important in the energy market and to address more effectively the sustainability challenges posed in Europe and worldwide.

The combination of both is critical in order to involve the users effectively in the energy value chain, providing them with valuable information and the tools to control their energy budget, but without overburdening them with new responsibilities and concerns.

The BeyWatch platform is indeed such a technical enabler of powerful solutions with far-reaching implications and puts in place capabilities that do not presently exist. Although the BeyWatch architecture is, in our opinion, coherently designed from principles derived from all participating disciplines, we cannot claim the prescience to know how independent market participants will best organize themselves around this architecture. On the other hand, architecture and design is driven by use cases, and defining use cases entails identifying actors and roles, and by extension, having some kind of business model framework in mind (in whose context to identify the actors and their roles / interactions). Therefore the aim of this section is to describe a rather abstract BeyWatch "business model" that has allowed us to derive a number of assumptions / functionalities which the architecture will have to implement.

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

1. *Demand side management takes place by utilizing a whole array of measures*: not just the 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 be: 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 BeyWatch 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 BeyWatch Agent / Scheduler).
3. *Households as energy producers*: in BeyWatch households are themselves energy producers. The first experimental BeyWatch system put together includes a CPS system which allows the household to generate energy. 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 (that generated at homes / offices using RES).

Given the above, Table 1 that follows juxtaposes the BeyWatch "Business Model" with traditional demand-side management business models in the electricity retailing business.

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

Aspect	Traditional way	BeyWatch way
Means available to influence 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	… 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 BeyWatch Agent 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 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 BeyWatch Conceptual Model for Demand-Side Management

With the risk of oversimplifying, the diagram in Fig. 1 that follows depicts the concept used in BeyWatch to achieve demand-side management.

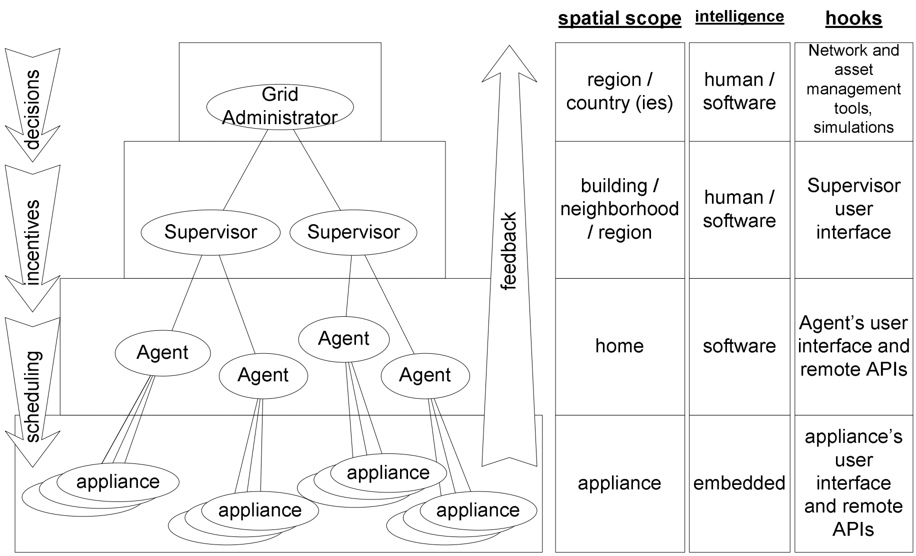

Fig. 1. BeyWatch demand-side management conceptual model

Fig. 1 is an abstract diagram yet it still identifies in a graphical way the key properties underpinning the BeyWatch approach. We refer to Fig. 1 as the BeyWatch Monitoring and Control System Conceptual Model ("BWCM").

Each plane of the BWCM 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, neighborhoods 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 key concepts of the BWCM are discussed in the remainder of this section.

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 spatial scope of that plan. 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 (Agent) which will (hopefully) influence that Agent's automated scheduling decisions and they are …
4. … ultimately effected by scheduling household appliances or otherwise modifying aspects of their operation (through a remote, wireless API)

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

Organizational boundaries. Moreover, as a qualification to the previous point, since, in most business models at least, the upper layers correspond to units or processes that lie within the same organization or within organizations that are closely aligned (e.g. grid administrator or grid administrator and electricity company and / or distribution company) the applicable concept is not so much one of incentives / counter-incentives, than one of decisions. Within the same organization or within aligned / cooperating organizations we see a propagation of decisions. These "decisions" are then translated into an incentive / counter-incentive structure when it becomes necessary to deal with external, independent actors (e.g. households) who are better influenced by the price mechanism or, in general, free market forces. These independent actors have their own set of priorities and motivations and operate independently of the grid administrator or the electricity company. As such, they cannot simply be coerced or told what to do but rather have to be induced to behave in a way that ensures the stability of the grid. Therefore the appropriate mechanism to bring about the intended behavior is to try to influence home energy patterns through market forces by providing a system of incentives / counter-incentives which can vary over time or in response to emergencies. These measures could for instance include modifying the energy price, imposing a power cap or other more refined measures and will of course have to be explicitly allowed as part of the contract.

Distribution of Intelligence. The intelligence (both human and software implemented) that is necessary to support this transition of decisions, incentives and scheduling through greatly differing spatial scopes is again distributed in the planes of the hierarchy. The proportion of human / software intelligence in the mix again changes in a consistent way as we move down the hierarchy. In the upper layers, decision making is left to humans with support from tools / simulations, etc. These humans are presumable grid administrator operators or specialized personnel at the electricity company. In the house component the participation of human intelligence in the functioning drops precipitously as the idea is to allow the software to do all optimizing / scheduling and have the user simply set broad guidelines and preferences. Ultimate control however, rests with the user who decides the latitude granted to the BeyWatch Agent so that a HAL-like entity does not emerge.

The BWCM is structured in the form of a multi-layered hierarchy. Obviously, any comprehensive demand-side management system will need to tie together actors and assets in vastly disparate scopes: from the power stations and the transmission and distribution networks to the actual mundane home appliances which collective generate the aggregate load that the infrastructure has to serve. Similarly, the software implementation of the BeyWatch system that implements this hierarchy of control is a complex system that encompasses a multitude of interactions between different actors, components and protocol entities in very diverse scopes. In the case of BeyWatch, it was recognized very early that the scope of the effort necessitated a clear sense of direction and approach philosophy at every level so as to yield a coherent and manageable architecture. In order to ensure that outcome, the abstract conceptual model presented above was articulated quite early in the specification of the system and proved a useful aid in deciding concrete design questions.

4 The BeyWatch Prototype Architecture for the Trials

Based on the conceptual model of Fig. 2, Fig. 3 that follows depicts the concrete technical architecture used for the BeyWatch prototype trials.

It is also easy to see that the architecture of Fig. 2 is consistent with the BWCM presented in Fig. 1.

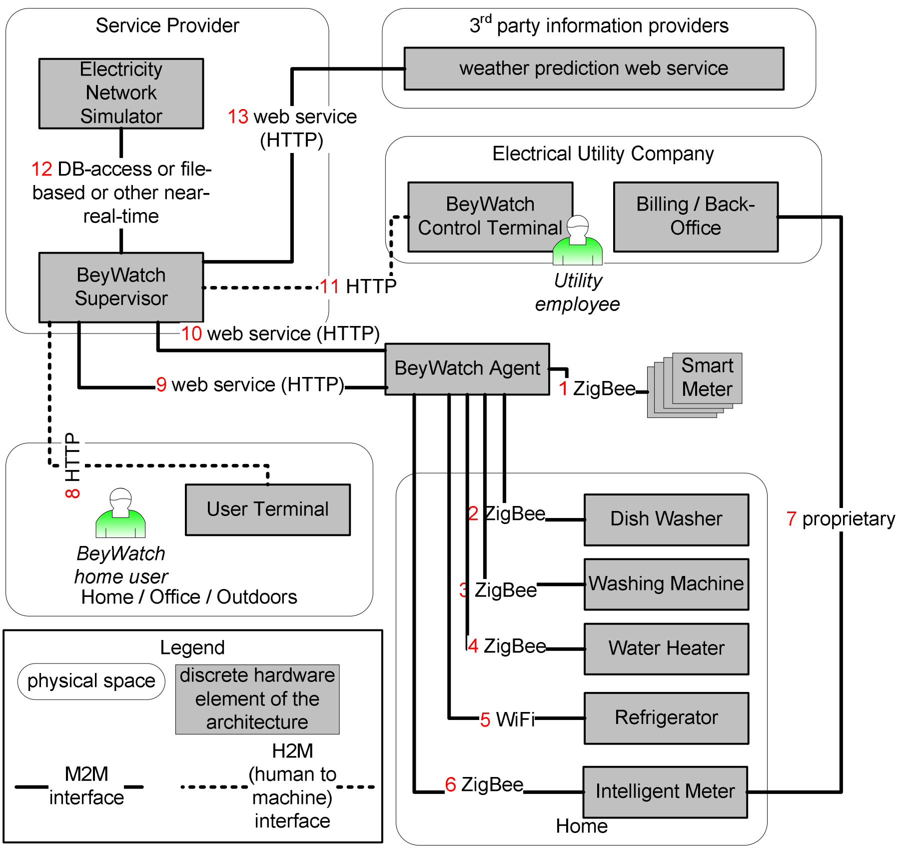

Fig. 2. BeyWatch deployment and software architecture for the trials

Demand-side management in BeyWatch is therefore 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 overtly controlled:

- Appliance level: a home appliance, seen as a single entity, represents the smallest unit at which ICT-related intelligence is injected allowing the appliance to become an actor in the BeyWatch universe. It should be noted that BeyWatch also caters for traditional, "dumb" appliances with no extra ICT-related improvements and manages to include them meaningfully in its demand flexibility planning.
- Home level: the home as an aggregation of household appliances and as the living space of a person or family which is treated as a single "customer" for provisioning, electricity consumption, and ultimately, billing.

The BeyWatch platform can be used to build a closed-loop system that enables real-time demand-side management functions together with real-time feedback on the way individual homes, neighborhoods and larger areas respond to the measures put in place. This is done by relying exclusively on an ICT infrastructure using protocols and applications built on top of the standard Internet TCP/IP stack for both delivering the incentive / counter-incentive measures to the end consumers (actually to the Agent software that is responsible for making the decisions on their behalf) and for collecting and reporting power consumption information and statistics. The technology used consists of HTTP-based web services following the REST pattern [10] and exchanging information in the form of JSON objects [11]. By providing a detailed analysis of the consumption pattern in a square block, neighborhood or larger geographical area, BeyWatch allows the energy supplier companies or the grid administrator to balance the energy consumption peaks. Comprehensive power demand scheduling then reduces the need for out-of-schedule power imports from neighboring countries or other heavy-handed emergency measures that attempt to curb consumption. By allowing real-time demand-side management and real-time feedback the BeyWatch platform can allow a gradual fine-tuning approach. It should be noted that real-time control is possible due to the existence of scheduling / optimizing software at homes (the BeyWatch Agent) that is able to respond swiftly to changing prices and other parameters and assure timely influencing of home energy patterns without requiring the home consumer to be constantly on the alert.

Evaluation of BeyWatch solution will be executed through three main directions:

- Internal evaluation of all project objectives through simulations, laboratory trials, measurements, evaluations, etc.
- Results evaluation through laboratory trials which will be also submitted to the judgment of a number of potential users. This will especially help the consortium to evaluate the degree of acceptability of the BeyWatch system and services (or part of it) in the every-day life.
- Comparison of BeyWatch cost/benefits with other projects/solutions running in Europe. This will help decision makers evaluate and take advantage of some of the most interesting solutions in Europe in order to save energy and reduce CO_2 emissions.

Two trial sites have been selected and equipment is, at the time of this writing, in the process of installation and integration: (a) the Smart Home Demonstrator testbed provided by Telefonica I+D in Madrid and (b) the Électricité de France (EDF) laboratories near Paris which includes a complete house. Both sites are realistically furnished and decorated to create a setting that will allow evaluating the project results from the real user point of view, showing real and expected services and applications. They are both depicted in Fig. 3.

Fig. 3. TID Test-bed Equipment (left) and EDF R&D Les Renardières Multi-energy House Test Facility (right)

The TID test-bed simulates an apartment with a living room, a kitchen, a bedroom, an office and a terrace. It has installed residential gateways, users PCs, PDAs, network cameras, home fixed telephones and a LonWorks network that controls different devices from lights to water stopcock. The EDF multi-energy house is equipped with solar and PV panels, a kitchen equipped with a BeyWatch energy aware dishwasher and fridge and a BeyWatch energy aware washing machine and a solar hot water tank in the garage. In both sites, alongside existing appliances and devices, BeyWatch networking, hardware / software elements are also being installed.

These trial sites will concentrate all of the service concepts developed so far and be enhanced in the context of the BeyWatch project by adding new services (energy monitoring & peaks shaving, white goods control, water management, energy generation/distribution) as provided by the BeyWatch Supervisor and Agent and other elements of the BWCM. Electricity consumption measurements will take place to: (a) test the effects of energy efficiency on individual appliances and as a whole, and (b) gauge the power peak shaving effects of the demand-side management mechanism implemented in BeyWatch.

More specifically the following data will be measured:

- Solar radiation
- External temperature
- Hot water temperature in the storage tank
- Power produced by the Photovoltaic panel
- Power consumed by the house
- Power consumed by the fridge / freezer (both BeyWatch enhanced and not)
- Power consumed by the dishwasher (both BeyWatch enhanced and not)
- Power consumed by the washing machine (both BeyWatch enhanced and not)
- Power consumed by non-Beywatch appliances.

The behavior of the BeyWatch system will be tested according to the weather forecast and to several tariff scenarios: the use of the electricity produced by the Photovoltaic panel (either sent to the home grid or to the national distribution grid) will be determined by comparing the price at which this PV electricity can be sold to the grid against the price of the electricity coming from the grid. Furthermore, the calculation of the BeyWatch starting time for the washing machines will depend on both the weather forecast and the grid electricity tariffs.

The data collected will help to compare a home equipped with a complete BeyWatch system to a regular home. The energy produced and consumed by the trial facilities will be compared to the energy consumed by similar homes, equipped with the same appliances, but not "BeyWatch compliant", i.e. a home in which every appliance is operating independently. For instance, the energy efficiency of a BeyWatch refrigerator will be monitored, in different weather conditions and for different user requirements, and compared to the efficiency of an otherwise identical refrigerator model but without the BeyWatch electronics installed. Apart from establishing energy savings due to increased appliances efficiency or the use of the CPS, BeyWatch will also evaluate the ability of the system to respond to demand-side management measures and thus lead to (assuming a widespread deployment) smoother demand curve without very pronounced spikes. This, in itself, can produce considerable economic and environmental benefits as the peak demand determines the infrastructure requirements and leads to capital outflows and deployment of assets which then have to be maintained and are depreciated whilst idling underutilized for most of their service life time.

More subjective end-user acceptability tests will also be carried out to evaluate ease of use, intuitiveness of the interfaces, impact / disruptions in daily routine, intrusiveness and the overall "disposition" of real users vis-à-vis the system.

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