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BeyWatch

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1	Telefonica I+D	TID	Co-ordinator	Spain
2	Synelixis Solutions Ltd	Synelixis	Contractor	Greece
3	GL Group	GL	Contractor	UK
4	Electricité de France S.A.	EDF	Contractor	France
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Table of contents

Acronyms and Abbreviations

BW	**B**ey**W**atch
BWCM	**B**ey**W**atch Monitoring and Control System **C**onceptual **M**odel
CPS	**C**ombined **P**hotovoltaic **S**olar
DoW	**D**escription **o**f **W**ork
DW	**D**ish**W**asher
GUI	**G**raphical **U**ser **I**nterface
HA	**H**ome **A**utomation
HA	**H**ome **A**utomation (ZigBee profile)
ICT	**I**nformation and **C**ommunication **T**echnologies
IDL	**I**nterface **D**efinition **L**anguage
M2M	**M**achine to **M**achine
PV	**P**hoto-**V**oltaic panels
SE	**S**mart **E**nergy (ZigBee profile)
WM	**W**ashing **M**achine
RES	**R**enewable **E**nergy **S**ystem
RG	**R**esidential **G**ateway
UPnP	**U**niversal **P**lug a**n**d **P**lay
WiFi	**Wi**reless **Fi**delity
WSDL	**W**eb **S**ervices **D**escription **L**anguage

1. Introduction

Targeting environmental sustainability, energy efficiency and new power distribution/production business models, BeyWatch had set a significant objective: 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 & neighbour level. The system interconnects legacy professional/ consumer electronic devices with a new generation of energy-aware white-goods, where multilevel hierarchic metering, control, and scheduling is applied, based on power demand, network conditions and personal preferences.

Moreover, via a combined photovoltaic/solar (CPS) system, BeyWatch is able to produce hot water and energy, which is either used at home or at peak hours fed to the electricity network. The developed system functions in a two layers hierarchy:

- **Micro-management level:** based on the outdoor temperature, the power consumption demand, the power supply network conditions and the users' preferences, all the devices in the home or a building are set under local interactive monitoring and intelligent control, in order to achieve amortization of loads and peak suppression of small-scale power consumption. BeyWatch key element is also the CPS system, which provides for active energy production, especially during peak hours.
- **Medium-management level:** the local control elements are included in a hierarchical system that covers larger geographical regions (e.g. building blocks or neighbours) to provide statistical data and enable medium-level control and coordination of the energy resources.

In more details, BeyWatch energy management solution has targeted five main goals:

a) Design of ultra-low energy-consumption white-goods.
b) Implement methods, techniques and technologies to reduce the power consumption in smart/green homes/blocks/neighbours by intelligent control of electrical devices.
c) Generate hot water and electricity from RES at building level, leading to further power savings, and power production at peak hours.
d) Elaborate business plans and BSS applications that will help the users and the providers to reach mutually beneficial contracts.
e) Motivate users' awareness, towards less CO2 emissions on the whole energy value chain (production, transportation, distribution, supply) and a cleaner environment.

The BeyWatch consortium is very happy to announce via this public deliverable, that all goals have been achieved. As it will be explained in the next section, BeyWatch has designed, implemented and validated all technical objectives, while via questionnaires have tried to motivate users' awareness, towards less CO2 emissions. The BeyWatch complete solution has gained always to minimize the energy peak loads and achieve lowering the electricity bill up to 26% (given tariffs that apply today). Moreover, BeyWatch may achieve reduced energy consumption that in some cases may be up to 58,7% (Washing Machine with 60^{o}C hot water available from the CPS for a complete washing cycle). Last but not least, via BeyWatch Business Support Systems (BSS), the users and the providers may reach mutually beneficial, green contract agreements.

This deliverable highlights the major BeyWatch Technical Achievements and Results. Moreover, it summarized the lessons learned from the last 30 months of collaboration, research and experimentation in the energy efficiency domain. In BeyWatch, one of the major objectives has been to conclude to a solution that can be massively adopted. For this reason, the system has being developed conform to international performance, quality, safety and regulatory standards concerning energy distribution and telecom grade systems. The results and problems appeared during the pilot phase have been immediately evaluated, so that the system has been improved continuously.

Finally, we define possible points for optimization and enhancement of the system, once the final results of the pilot phase are available.

1.1. Organization of this document

The document is structured in the following chapters trying to describe the achievements, lesson learned and recommendations for the future work in the different BeyWatch modules and components:

- Chapter 1: This chapter with the introduction of the document.
- Chapter 2: Containing the description of the achievements, lesson learned and recommendations for the future work in the different BeyWatch appliances: Washing Machine & Dishwasher, Refrigerator, CPS, metering modules (smart meter and watchers) and software modules: Agent, Supervisor and BSS for the customer and for the utilities.
- Chapter 3: Containing the description of the achievements and lesson learned about the BeyWatch system as a whole. It also contains a subchapter with the business opportunities from the different point of views: Telco operator, Utilities – Distribution and retail and appliances manufacturers.
- Chapter 4: contains a description of the possible evolution of the complete BeyWatch system during the following years.

2. BeyWatch Sub-systems

The BeyWatch energy control and monitoring system is able 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 is applied, based on power demand, network conditions and personal preferences. By scheduling and controlling the electronic devices operation, BeyWatch minimizes power distribution peaks and helps to cope with intermittency of renewable generation (solar, wind), balancing energy load in power distribution networks and ultimately achieving predictable large-scale energy-consumption profiles.

Moreover, BeyWatch integrates an innovative combined photovoltaic/solar (CPS) system, which provides: a) hot water for white goods (such as dishwasher, washing machine) in order to strongly decrease the energy consumption and the CO_2 emissions at home by reducing/removing the heating operational cycles and b) generates electrical energy from Renewable Energy Sources (RES), which can be utilised at home, and during peak periods even fed to the electricity network in a reverse power generation/ distribution business model.

Figure 1: BeyWatch main subsystems

As can be seen in Figure 1, BeyWatch main subsystems include:

1. **Energy aware white goods:** A BeyWatch Washing Machine and a BeyWatch Dishwasher with ZigBee interfaces and energy/hot-water management capabilities and a BeyWatch Refrigerator with WiFi interface.
2. **Combined Photovoltaic Solar (CPS) System**: a BeyWatch CPS system, which provides hot water and electrical energy and is remotely controlled via a ZigBee interface
3. **Metering modules (Smart meter & Watchers):** Apart from metering modules embedded inside appliances, dedicated metering devices have been deployed as key components of BeyWatch architecture: one smart meter - at smart home scale - and a set of "watchers" (i.e. smart plugs).
4. **Agent:** a software subsystem hosted on a Residential Gateway (RG). The Agent incorporates a) the Home Energy Consumption Scheduler and optimizer, b) the Home Energy Framework and devices management and c) the Machine to Machine (M2M) communications interface.
5. **Business Support Software:** a web-based system software that enables information dissemination on energy consumption on a per customer basis. Besides the energy consumption information

dissemination and statistical information, BSS is able to initiate a social network group on energy consumption and introduce an eco-game between energy prosumers of the same city or region.

6. **Supervisor:** a software subsystem that is responsible for smooth energy control and load balancing at neighbour level and preserving customers' contract agreements.

Within this section, we summarize the technological achievements and the lessons learned from the various BeyWatch Subsystems.

2.1. Washing Machine & Dishwasher

The BeyWatch Washing Machine and Dishwasher are special designed energy-aware, remote controlled white appliances. They have the capability to get cold and pre-heated water, host a M2M wireless (ZigBee) interface for two way remote monitoring and control and feature special washing cycles that enable the washing cycles to be paused and resumed.

2.1.1. Technological Achievements

Besides the various electromechanical improvements and innovations (e.g. electronics to minimize the spikes when the system motor is activated), one of the major ICT achievements from the Washing Machine (WM) and the Dishwasher (DW) point of view has been the introduction of a way to remote monitor and control the appliance operation. A new ZigBee based embedded communications' card has been introduced into the appliances, which enables the device to send and receive information with an external management system. The BeyWatch WM and DW are able to communicate with any external monitoring and control system (in our case the BeyWatch Agent) and mainly negotiate the following issues:

- ***Scheduled operation.*** Based on current and predicted energy consumption, current and predicted electricity and hot water needs, scheduled energy price during certain periods, the Agent can remotely start, stop and pause the WM and DW operation.
- ***New Washing Cycles and pausing points.*** In order to enable pausing of the normal WM and DW operation, new washing cycles have been introduced, which enable pause of the normal operation at an optimal point in order to enable power consumption distribution and amortization in time. The criteria for these new washing cycles and pausing points have been the minimal energy consumption (e.g. avoid reheating the water), while preserving the performance of the appliance (e.g. ensure that the cloths or the dishes are still optimally washed and, of course, not damaged).
- ***Hot Water needs negotiation.*** The white good appliances are able to export and negotiate their hot water needs. By means of this, the agent can request the use of preheated water using means that optimise the energy consumption, i.e. taking advantage of renewable (solar) energy sources, or periods of time with lower energy prices. For this purpose, the combination of the information given from the washing machine and the addition of a bi-thermal water input improve the energy efficiency of the water heating, avoiding the use of the electrical resistance and benefitting from preheated water.

  In the other side, the agent can manage the information by following periods of time and pricing, in order to manage the best time to remotely start the washing programs.

2.1.1.1 The ZigBee Communications Module

By means of the ZigBee communications module, which is part of the M2M communications and the BeyWatch architecture, the following features were achieved:

- **Energy metering:** it empowers the appliance to measure instant energy consumption, permitting it to send energy consumption information to the Agent. It includes the necessary circuitry to meter energy, adapt signals and protect it from any external overcharges.
- **Power supply conditioning:** it adapts and regulates the voltage received from the communications bus to ranges more adequate to this board, for both the metering and the bridge

- **BeyWatch/ZigBee ↔ Appliance bridge:** based on a Freescale microcontroller, this part is in charge of adapting the communications protocol used with the appliance, to the ZigBee based protocol used by the BeyWatch project, and handling the machine peculiarities and extra features supported by each of them, in order for this communications interface to work transparently, for the Agent.

2.1.1.2 ZigBee Application Layer

The ZigBee Home Automation (HA) layer clusters were extended to support new appliances not considered before by the protocols. Existing capabilities were very limited and simple, and have been extended to support the more complex white goods.

The BeyWatch ZigBee stack provides:

- Plug & Play Architecture
- Adapts to any existing Fagor appliance
- Backwards compatibility, as it can be applied to existing appliances in the market
- Add-on module can handle additional work on its own, to extend appliance capabilities
- Reduces load on the network
- Multi-tasking architecture that enables other protocols in the future

Regarding the improvement of the energy efficiency by the appliances themselves, one of the most important achievements obtained in the washing process was the combination of the washing temperature reduction with the increase of the mechanical agitation, which allows the appliance to ensure the efficiency of the washing process, taking into account that the biggest amount of energy used in the washing process is due to water heating. In this way, lowering water temperature allows more energy savings.

2.1.1.3 Energy Efficiency Results

From extensive testing, we have concluded that in case washing machine uses hot water from the CPS system, the energy consumption gain is significant, both at the program cycles of 30^{o}C and at the program cycles of 60^{o}C and ranges from 38,5% up to 46,4%. Moreover, give hot water at 60^{o}C for the complete washing cycle, the reduction in energy consumption may be up to 58,7%.

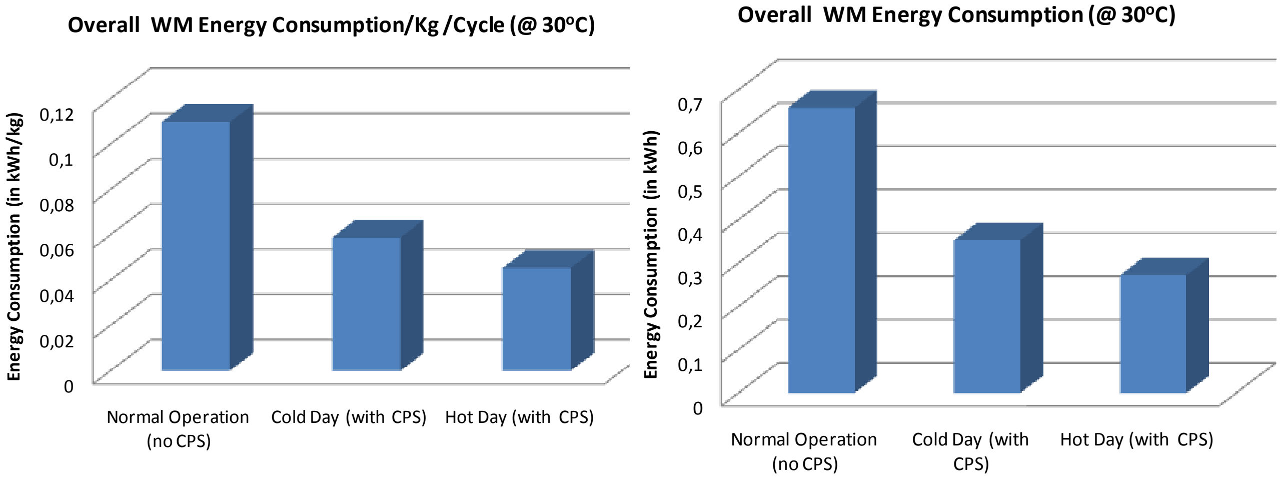


Figure 2: Washing Machine: Total energy consumption (@30^{o}C)

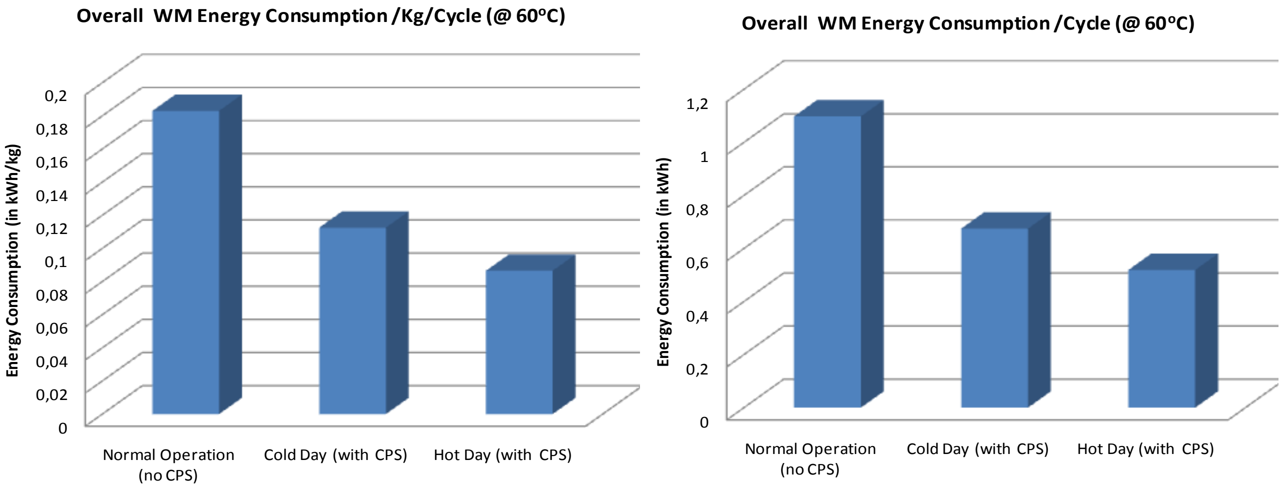


Figure 3: Washing Machine: Total energy consumption (@60°C)

Moreover, based on statistics for the year 2000 till 2020, the average number of times that a average home in EC is using the a Washing Machine program cycle @60°C is 82,25 and a program cycle @30°C is 186,25. Also assuming that in Paris, Madrid and Palermo the weather conditions would result in the following annual percentages:

Location	Average Temperature	Hot/Sunny Day	Cold/Cloudy Day
Paris	12°C	25%	75%
Madrid	14°C	60%	40%
Palermo	30°C	90%	10%

Figure 4: Percentage of average temperature variation assumed

we may see (Figure 5) the energy consumption for the washing machine is drastically reduced if hot water from the CPS is used. Moreover, if the assumption that the average number of program cycles at @30°C is more than double the number of program cycles @60°C, then even the difference in geographic area and shiny conditions does not make play a significant role. So, it is important to use directly hot water and schedule the washing machine operation at the time frame that hot water is available.

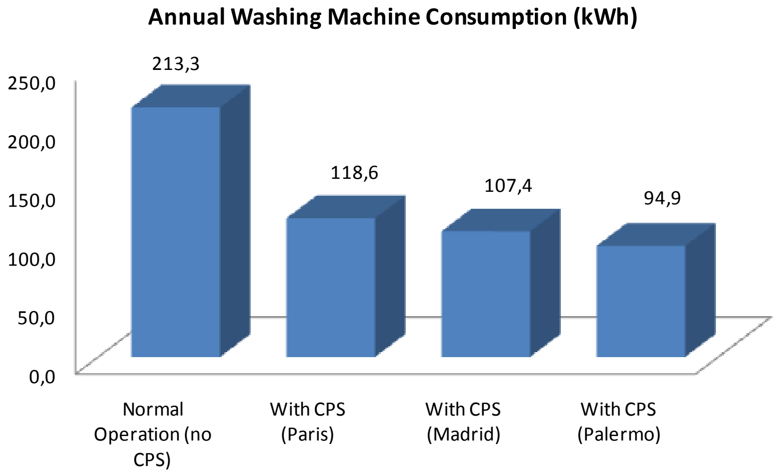


Figure 5: Annual Washing Machine energy consumption (in KWh)

With respect to the BeyWatch Dishwasher, in case hot water from the CPS system is used, the energy consumption gain is significant, both at the AUTO@65°C and INTENSIVE@70°C and ranges from 27,5%

up to 36,9%. Moreover, given hot water at 60°C for the complete washing cycle, the reduction in energy consumption may be up to 48,46%.

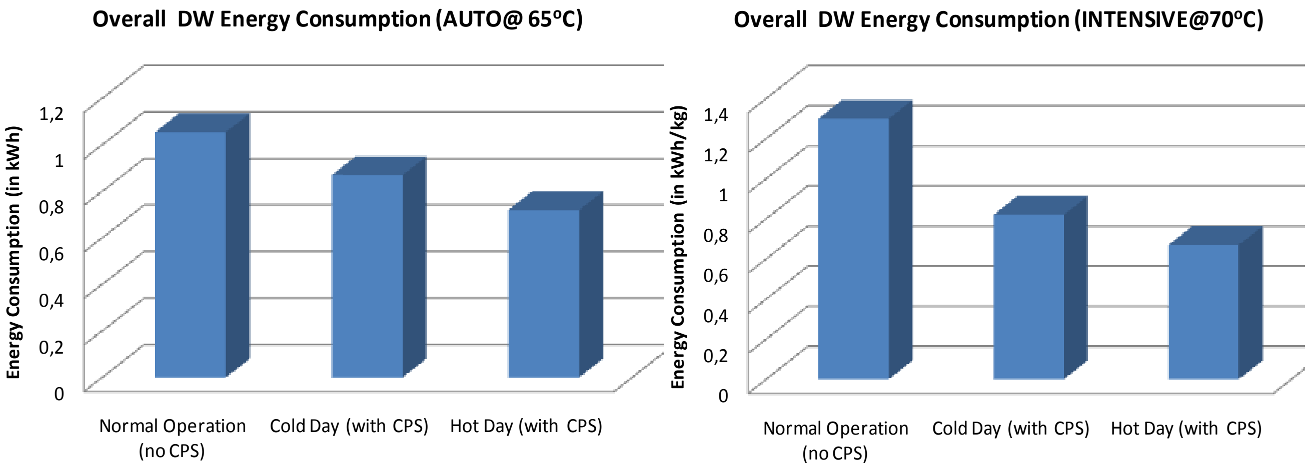


Figure 6: Dishwasher: Total energy consumption

2.1.2. Lessons learned

The lessons learned from the BeyWatch DW and WM may be summarized in the following:

2.1.2.1 M2M Communications

One of the major areas that we analysed, studied, implemented, tested and verified has been the Machine to Machine (M2M) Communications.

As physical interface for the DW and WM, we have selected ZigBee. ZigBee is a low cost physical interface and suits perfectly into this kind of white goods applications; as such it is becoming ubiquitous. However, ZigBee also faces several limitations:

- ***Interference issues:*** We have tested that ZigBee (and in some cases even ZigBee pro) is very prone to interference and the reliability is still rather limited, especially when multiple communications interfaces are used at once or many interference sources are operating (e.g. microwave next to a washing machine). We did extensive experiments not only with BeyWatch developed devices and evaluation boards, but also with laptop dongles and off-the-shelf devices (e.g. energy watchers) and the result is that operation is not always guaranteed.

  One of the solutions followed in the development of the project for limiting interference collisions was limiting the channel masks used by the appliances to a single channel and therefore disabling channel hopping. However, it has been found that this is not the most adequate solution, given the varying cross-country regulation differences for 802.11 channel usages (WiFi), which can cause unexpected interference sources, and therefore channel hopping should never be disabled completely.

- ***Coverage range.*** ZigBee has been designed considering short range communications. However, longer communication is needed in many cases. While the Dishwasher is in most cases located in the kitchen, the washing machine is in many cases located at the cellar or a basement. If other compatible ZigBee nodes are also installed in the home, then mesh networking functions of ZigBee may be used to solve such cases. Otherwise, repeaters or bridges are needed, exponentially increasing the installation complexity, maintenance and cost. In such cases, a powerline or a WiFi interface may be much more convenient, reliable and cost effective.

- ***Compatibility.*** While ZigBee is a mature communications protocol and has been standardized to control several appliances, it was also found that still it does not cover all communication needs. We have tested both the Home Automation (HA) and the Smart Energy (SE) profile, but still there has been functionality that was not supported by the standard. It is true that the standard enables proprietary extensions to the protocols, but this leads to non-compatibilities which limit the wide deployment and protocol acceptance.

2.1.2.2 Washing operation remote control and automatic scheduling

Besides the general M2M communication issues, we also faced specific DW and WM limitations that had to be solved. In most cases the experience of the manufacturers (both Fagor and Gorenje) has significantly helped in order to face the problem from the early beginning. In more details:

- ***Hot water feeder.*** There are already a number of washing machines in the market that offer dual water supply system (both hot and cold water). However, it has been proven that in case the hot water comes from a system such as the CPS, the temperature can be much higher that the targeted one (e.g. it can be up to 80^{o}C, while many washing programs require only 30^{o}C for cloths or 60 ^{o}C for delegate dishes). In such cases, the Agent should have very good knowledge of the hot water availability and the exact temperature in order to achieve energy optimization without lowering the quality of the offered service or destroying the cloths/dishes.
- ***Pausing is not simple.*** Pausing the normal washing operation is not simple and not energy efficient by itself. Simulations have shown that pausing the washing can achieve optimised energy (both electricity and hot water) consumption and lower prices. Yet, there are two critical risks:
  - Pausing the washing may damage the cloths. Cloths and dishes that remain in the water (especially warm or hot water) for more than a maximum time interval may be damaged. The colours may be infected and/or may shrink.
  - Pausing may not be energy efficient. Indeed if pausing is not fully controlled, the energy will be lost (e.g. the water may become colder and either the quality of the washing drops or the water needs to be reheated again.

  In order to enable pausing of the normal WM and DW operation, new washing cycles have been introduced, which enable pause of the normal operation at an optimal point in order to enable power consumption distribution and amortization in time. The criteria for these new washing cycles and pausing points have been the minimal energy consumption (e.g. avoid reheating the water), while preserving the performance of the appliance (e.g. ensure that the cloths or the dishes are still optimally washed and, of course, not damaged). Moreover, the maximum time that a program is stopped is a very strict parameter and can be underestimated. Even at pausing point of a washing cycle, the washing machine needs to spin (of course at low speed) in order to avoid damaging delegate cloths.
- ***Compatibility.*** Different manufacturers have different washing cycles and programs. The exact specification of the programs is the outcome of many years of research and the point of differentiation for many manufacturers. As a result they are in most cases, proprietary, strictly confidential and most WM or DW manufacturers would not let them open or share. Without access to the programming cycles details (e.g. water quantity and temperature, detergent management, pausing point and maximum allowed pausing interval), it is very difficult for the Agent to optimize energy scheduling and be open for many manufacturers.

  In order to solve the problem, each WM or DW manufacturer that wants to be BeyWatch compatible, needs to open such communication interface at least at a machine readable format, and a compromise should be found that allows the WM and DW to define, at each washing request and according to the confidential proprietary algorithms, the optimized program schedule and related forecast energy consumption/load curve and pausing possibilities and to communicate them to the agent without revealing the algorithm itself.
- ***Reliability.*** As already explained, not reliable pausing of a washing program (pausing at the wrong point or for longer period) may influence the quality of the provided service and/or may harm the cloths/dishes. As a result, many white goods manufacturers are unwilling to provide remote control functionality, as in that case they are based on a 3rd party (home energy optimization provider) for the quality and the reputation of their products. This is why the limits and responsibilities of this white goods remote control has to be very clear : while giving to an external energy optimization system some flexibility in the energy use, the appliance itself has to remain responsible of the quality and of the performance of its primary function and may not delegate this to the external system. In a certain way, the white goods manufacturers already respected this principle when they took into account more and more environmental constraints: using less energy, less water, less detergent. The new flexibility constraint also has to comply with this principle.

2.1.2.3 Washing machine operation energy efficiency

In summary, by the development, testing and integration of the BeyWatch washing machine with the rest BeyWatch system, we have concluded to the following results:

- The energy consumption is significantly reduced by using hot water. The energy consumption reduction may range from 38,5% up to 58,7%.
- Given the assumption that the average number of program cycles at @30^{o}C is more than double the number of program cycles @60^{o}C, then even the difference in geographic area and shiny conditions do not make play a significant role.
- Programs using hot water finish much faster, saving from 10% (4 minutes@30^{o}C) to 36% (21 minutes@60^{o}C) of the washing time

2.1.2.4 Dishwasher operation energy efficiency

In summary, by the development, testing and integration of the BeyWatch dishwasher with the rest BeyWatch system, we have concluded to the following results:

- The energy consumption is significantly reduced by using hot water. The energy consumption reduction may range from 27,5% up to 36,9%. Given hot water at 60^{o}C for the complete washing cycle, the reduction in energy consumption may be up to 48,46%.
- Given the assumption that the average number of program cycles at @30^{o}C is more than double the number of program cycles @60^{o}C, then even the difference in geographic area and shiny conditions do not make play a significant role.
- Programs using hot water finish much faster, saving from 11% (6 minutes, AUTO@65^{o}C) to 29,6% (24 minutes, INTENSIVE@70^{o}C) of the washing time

2.1.3. Recommendations & Future work

The following are points for optimization and enhancement of the system:

- **Improvement of the instantaneous current consumption sensor module**

  The energy measurement in certain appliances such as washing machines and dishwashers can be more challenging due to the different wave distortions. Extra accuracy should be targeted for more accurate metering.

  Also, instantaneous current metering requires a more frequent sampling in order for this measure to be more usable for the end user.

- **Improvements on the M2M technologies**

  The ZigBee modules need to be controlled more thoroughly in order to avoid interference sources. Controlling dynamically launched channels from external WiFi (802.11) sources can provide better overall robustness to the system.

  Newer arising and proposed standards such as 802.15.7 can be considered and analysed in a near future, which could be more immune to interference sources.

- **Improvements on the mechanical washing process**

  The combination of washing temperature and mechanical agitation, for both washing machine and dishwasher should be even better. More performance test has to be developed in order to obtain more efficient design of washing programs, combining mechanical agitation, use less water and water temperature reduction in order to maintain or even improve washing efficiency while reducing energy consumption due to energy savings in heating water and increasing energy use flexibility.

  Research new technologies and systems for washing processes to reduce energy consumption, mainly intended for programs in which water is heated for the washing process,

  In the washing machine, from the total consumption of the washer, about 80% is consumed by the electrical resistance to heat water (from the consumption of the electrical resistance, 80% is for water, 10% is for the clothes and the remaining 10% is dissipated in the bucket, door and other parts, approximately), 12% is consumed by the engine and remaining 8% is consumed by the drain pump, control elements, sensors and controller (circuit board).

Similar figures are obtained for the dishwasher.

So research should focus on:

- Reduction of the energy consumption in heating the water by:
  - Improving the way that the electrical resistance heating or replaced by other non-conventional heating system.
  - Achieve recover as many thermal energy from the water being poured down the drain.
  - Develop methods of storing the energy in the water that poured down the drain, searching for harnessing energy from this water and transferring the energy to through heat exchange with the water to be heated for the washing cycle.
  - A system of heat pump water – water is proposed, that would use the sensible heat of water drained in the washing process.
  - For this purpose should also be taken into account other aspects such as the dimensions of the appliances, and costs of new elements to incorporate and possible alternatives to the electrical resistance.
- Other ways of improvement are advanced electric motor technologies, in order to reduce their consumption, though its influence on total consumption is not as important.

Finally, as an overall summary and general lesson learned is that pausing the washing would be quite difficult to be achieved if the white good manufacturer and the home energy optimization provider have not established a well trusted relationship/co-operation with a clear definition of the responsibilities.

2.2. Refrigerator/Freezer

The BeyWatch Refrigerator/Freezer is an energy-aware, remote controlled white appliance. Besides beyond the state-of the art isolation, it hosts a M2M wireless (WiFi) interface for two way remote monitoring and control and feature special capabilities to store cold in the freezer and postpone the compressor starting on demand.

2.2.1. Technological Achievements

Along with cooking and laundry washing & drying appliances, Gorenje has been producing and distributing refrigerators and freezers all over the Globe already for many decades. Research and development on the field, innovating the functionality and intensive industrial design of the appliances, always was the basis for creating the sharp competitive edge on the markets. This combined with the value-for-money philosophy, introduced Gorenje into the exclusive club of leading European producers.

In the frame of BeyWatch project, Gorenje developed a brand new two compressors refrigerator/freezer, which is one of the most energy saving appliances in the world in this moment in its class. Besides the enhanced isolation with new materials, the refrigerator/freezer introduced ICT innovation in three dimensions:

- ***New power electronics:*** The BeyWatch fridge includes new power electronics that significantly reduce energy consumption and electricity spikes when the compressors are activated.
- ***WiFi Interface:*** Besides its own intelligence, this appliance is fully capable to interconnect and to function in the intelligent energy managed home grids on all levels. The BeyWatch refrigerator includes a 802.11b WiFi communications interface, which enables it to inform the BeyWatch Agent about the instant and average energy consumption, receive instructions about different operational modes (e.g. go to fast freezing function, winter or summer mode, increase or decrease the temperature in the refrigerator or the freezer compartment, send alarms if the door is open or if the temperature is too high, etc). Moreover, the WiFi interface offers full information exchange at broadband speeds,

which (combined with a flat monitor at the fridge door) may enable a new bunch of innovative applications ranging from Internet Access to eHealth services.

- ***ICT Controlled Operation:*** When connected with the BeyWatch Agent, the BeyWatch refrigerator/ freezer may significantly contribute to the balancing of the home energy load and lowering the energy consumption at peak hours. Functions such as “storing cold” at the Freezer compartment when the tariff is low, postpone or delay fast freezing when the tariff is high, postpone or delay the switch-on function at the Refrigerator component when the tariff is high or when these is no cold demandable content in the refrigerator are some innovative ICT functions that differentiate the BeyWatch refrigerator/freezer.

2.2.2. Lessons learned

With respect to the BeyWatch refrigerator/freezer, the lessons learned may be summarized in the following:

2.2.2.1 M2M Communications

One of the major areas that we analysed, studied, implemented, tested and verified has been the Machine to Machine (M2M) Communications.

As physical interface for the refrigerator/freezer, we have selected WiFi, which is a broadband interface. As compared to ZigBee, WiFi has a much better coverage range and robustness to guarantee undisturbed operation. WiFi is stable and is hardly affected by home interferences, regardless of its surroundings. Moreover, WiFi is a very mature standard and thus physical and MAC compatibility is guaranteed. Last but not least, the WiFi broadband speed (combined with a flat monitor at the fridge door) may enable a new bunch of innovative applications ranging from Internet Access to eHealth services.

On the negative side we may highlight the following:

- ***Application Layer Standardization.*** While ZigBee was designed for Home Automation and Smart Energy Control in the home environment, WiFi was designed as a general purpose communication interface. As a result, WiFi offers full openness to design and implement any IP based application to exchange monitoring and control information.

  On the other hand, openness results to proprietary and not standardized solutions. Each manufacturer may create his own application protocol, thus compatibility at application level is very hard to be achieved.

- ***Energy/Cost.*** Due to broadband/ADSL Internet access, most houses already feature a WiFi bridge/residential gateway, so no extra communications hardware is needed. Moreover, the BeyWatch Agent may be hosted on most RG/ADSL routers.

  On the other hand, the competition in the white goods is so taught that even few Euros difference may result in a product success or failure. WiFi is not expensive; the great popularity has significantly reduced the price. However, it is still at least 2 orders of magnitude higher that ZigBee and its energy consumption is also much higher.

2.2.2.2 Freezing operation remote control and automatic scheduling

Besides the general M2M communication issues, we also faced specific refrigerator/freezer limitations that had to be solved. In most cases the experience of the manufacturers (both Fagor and Gorenje) has significantly helped in order to face the problem from the early beginning. In more details:

- ***Postponing some operations is not simple.*** Postponing or delaying some operations (e.g. fast freeze function or switch-on) is not so difficult to be achieved but it may severely risk the normal operation. Simulations have shown that postponing the freezing operation or delaying starting the compressors a couple of minutes can achieve optimised energy consumption, lower prices and avoid spikes if more than one refrigerators/freezers are connected to the same Agent.

  Moreover, the double compressors scheme is more efficient as there is one independent compressor for the R and one for the F compartment, which have quite different needs. This greatly simplifies the remote controlled operation of the compressors.

Yet, there are two critical risks:

- It may harm the normal freezing operation. Not all foods have the same sensitivity with respect to temperature. Even the same types of food have quite different behaviour. Some fruits (e.g. strawberries) are much more vulnerable than others (e.g. oranges). Other food (e.g. fish, meat, ham, cheese or milk) may easily become dangerous for the human health if not kept at the correct temperature.
- It may not always be energy efficient. Despite the enhanced isolation, the environment's temperature may significantly affect the energy consumption. Besides the risk to harm the food, in many cases, the energy needed to keep the temperature stable at the R or F compartments is less than allowing a large range of temperature alteration.

As a general result we have seen that:

- Delaying the compressor activation for a couple of seconds in order to avoid electrical spikes is easily achievable under the agent supervision. Yet, this is important mainly for the protection of electric surcharge, rather than energy consumption reduction
- Automatically postponing the normal operation and changing the frequency and length of the compressors' on/off periods during the peak hours, when the electricity price is high, may achieve better energy consumption scheduling and reduce the electricity bill. Yet, the complexity and risk of damaging the food is also high. In order to achieve optimal energy consumption and electricity savings, the refrigerator/freezer should be manually configured.

- ***Compatibility.*** Similar to the DW and WM, different manufacturers and different product families have quite different characteristics. The exact freezing schedule is the outcome of many years of research and the point of differentiation for many manufacturers. Thus, they are in most cases, proprietary and most manufacturers would not let them open or share. Without access to the freezing schedule, it is not possible for the Agent to optimize energy scheduling and be open for many manufacturers.

  In order to solve the problem, each refrigerator/freezer manufacturer that wants to be BeyWatch compatible, needs to open such communication interface at least at a machine readable format.
- ***Reliability.*** As already explained, not reliable postponing or delaying of freezing (pausing at the wrong point or for longer period) may harm the foods' quality and be even dangerous for the customers' health. As a result, many white goods manufacturers are unwilling to provide remote control functionality, as in that case they are based on a 3rd party (home energy optimization provider) for the quality and the reputation of their products. This is why the same considerations and principle stated for the WM and DW about the limits and responsibilities of the white goods remote control also applies for the fridge/freezer.

2.2.2.3 Refrigerator/Freezer operation energy efficiency

In summary, by the development, testing and integration of the BeyWatch refrigerator/freezer with the rest BeyWatch system, we have concluded to the following results:

- The energy consumption is significantly reduced mainly due to the isolation. The energy consumption reduction may be in the range of 25,6% (0,58KW/24h).
- By combining the "cold storing" and the "compressor delayed start" capabilities, we can achieve safe delays of more than 5 minutes. Yet this achievement is only applicable for reducing the power peaks rather than reducing the energy consumption, as after a compressor delayed start the energy consumed is more or less the same as normal operation.

2.2.3. Recommendations & Future work

The final lesson learned is the fact, that development work towards energy consumption reduction and flexibility is never to be concerned as completed, nevertheless, whatever already has been achieved. The possibilities on this field seem to be infinite.

Future development work in Gorenje on the field will strongly be oriented in the second lesson learned (freezing operation remote control and automatic scheduling), combined with the improving of the appliance intelligence itself, with purpose to serve better on this path every time.

2.3. Combined Photovoltaic Solar (CPS)

Within BeyWatch, a Combined Photovoltaic Solar (CPS) system was designed and implemented. The CPS system is a Renewable Energy System (RES) that produces thermal and electrical energy. In particular, it can be used to supply hot water for energy-aware white goods of the home, mainly in order to reduce or to cancel the internal heating cycles, and for general sanitary uses; this strongly reduces the home electrical energy utilization and CO2 emissions, as a direct consequence.

2.3.1. Technological Achievements

The CPS design has been based on a modular approach whose minimum cell will consider PV (photovoltaic) panel with about 1kWp of nominal peak electrical power. As for the thermal production, the CPS considers a modular design based on a 200 litres hot water tank and a temperature range spanning between 35° and 75°C. These values can be changed according to the amount of needed thermal and/or electrical energy and on the CPS physical location.

Besides the actual physical system (panels, tank etc.), the communication architecture and the hardware and software components of the CPS control and monitoring system has been designed and implemented. The system consists of two micro-slave devices (one that controls the panels and one that monitors the tank temperature) and one micro-master device has been implemented to communicate with the BeyWatch agent. The micro-slave and micro-master devices are using the RS485 protocol, while the communication between the micro-master and the Agent was based on the ZigBee protocol.

The CPS system is then formed by two separated parts, the PV and The ST plant, even if they are seen by the rest of the system as a “unified appliance” producing energy. At this stage there is no internal interaction between the two subparts and the rest of the system. This was mainly due to the fact that nowadays there are no commercial solutions for integrated RES system whose market price is reasonable. Moreover hydraulic and electric skills are now far away each other, and as an example the production and conversion system optimization, related to the Solar Thermal, is mainly focused on specific collectors and converter systems while not taking into account the effective use of the generated thermal energy.

A joint monitoring and control of both PV and ST system can inversely optimize the overall system yield in order to satisfy the end-user energy needs.

So the main obtained goal was a local and remote monitoring of a production solar system and expressly the following achievements are listed:

- ***Data monitoring and logging:*** The reached goal was the network integration of the CPS, hence the capability to gather information related to two type of energy, giving to the agent more chances for better energy exploitation on short to medium period.

  Furthermore a better management of solar system alarms is now possible. Usually in fact only local and proprietary control systems are present; and they rarely have possibility to be read with open standards.

- ***Communication standard:*** One of the most important reached goal was the realization of a communication system compliant to a standardized protocol (ZigBee Pro in our case) till the application level.

  This goal gives to the CPS node the direct interoperability with other ZigBee based commercial systems at application level, thus regardless to the CPS electronics implementation details.

- ***Control remotization:*** All the relevant parameters can be collected regardless to the physical location of the ST and PV panels. The only physical limits are the one imposed by the wired communication protocol (RS485) that in fact can safely reach up to 1 kilometer.

2.3.2. Lessons learned

The lessons learned from the BeyWatch CPS may be summarized in the following:

2.3.2.1 M2M Communications

One of the major areas that we analysed, studied, implemented, tested and verified has been the Machine to Machine (M2M) Communications. As already explained the communication has been based on a combination of the RS485 and the ZigBee protocol. The lessons learned with respect to ZigBee are similar as the ones explained earlier in the DW/WM section.

In summary, ZigBee is a low cost physical interface and perfectly suits into the white goods applications but faces limitations with respect to the interference and the coverage. In particular:

- ***Maximum achievable distance***. The adoption of a wireless network for intra-house communications shows a not-negligible attenuation due to the presence of several nearly placed walls. Sometimes this makes communication impossible. The ZigBee protocol implements a mesh network so greatly smoothing this problem. Moreover the communication system should perform low power consumption.
- ***Protocol Interface.*** The best solution is to stick on a standardized protocol till the application level. This will give the maximum flexibility to the application developer and again the ZigBee choice is precisely within the scope.

  The only serious drawback of this solution for domestic application is the already mentioned short range and, for the CPS, even exploiting the mesh capability there are not enough routers within an apartment in order to reach the roof, where the PV and ST panels are placed and/or the basement, where usually boilers find their rooms.

  In order to give solution to the above mentioned points the CPS node was arranger with the master board, located within the Agent electromagnetic visibility range, even if the two slaves can autonomously support communication of their endpoints directly with the Agent. This can realize a totally wireless communication.

  Nevertheless the wired connection (RS485), when needed, is not a difficult task to fulfil since a structured wiring system between panels and the electric distribution point, within the house, is necessary anyway.

2.3.3. CPS operation and remote control

Besides the general M2M communication issues, we also faced specific operational limitations that had to be solved. In more details:

- ***Installation limitations:*** In many cases the CPS allocates a lot of space at the building roof. As a result, it may be difficult to apply the solution for large buildings with many families. The solution better fits for smaller houses, owned by the inhabitants.

  Another issue is the one related with the pipes that are needed for the hot water feeder. In case there are not pre-installed pipes for the hot-water during building construction, the solution may be too expensive and return on investment of the installation cost may take many years. On the other hand, for newly constructed houses, the cost is perfectly reasonable.
- ***Hot water feeder.*** The hot water from the CPS may be up to 75°C. Yet, it is hard to predict the exact temperature that the water enters the WM or the DW, as there may be large temperature losses in the path. As a result, monitoring the tank temperature is only an indication, but then a calibration process is needed based on the installation (e.g. length or the pipes, insulation of the pipes outside/inside the house) and the weather conditions.
- ***Cost.*** As already explained, the installation cost is a factor that can't be underestimated. On the other hand, the market price of the electricity generated is currently much higher as compared to the price of the electricity energy consumed. As a result, at least at the current conditions and as long as existing contracts are on-going, it would be much more profitable to sell all generated electricity rather than to use it for the home needs. These conditions however are likely to be temporary, in order to boost the installation of photovoltaic systems as the market conditions are not met yet: the price of the solar panels has been significantly decreasing for the last months and, on the other hand, the energy prices

will probably keep on increasing; thus scenarios as those considered in BeyWatch where consumption of the local generation is profitable are more than plausible in the coming years.

2.3.4. Recommendations & Future work

The BeyWatch vision has seen the CPS as a monitoring system of solar energy production, while the possibilities to have a complete control of the energy production and distribution within the generic apartment should be taken into consideration.

Some added controls may increase the resource efficiency and management. To mention a few:

- Controlled recirculation systems on the hydraulic collectors in order to increase comfort and lower water usage
- Logging information on ambient and solar collectors' temperatures in order to evaluate thermal loss and the overall efficiency of the solar circuit.
- Introduction a complete control of the ST system by carefully controlling the recirculation pump thus optimising thermal exchanges as a function of the available solar power and the circuit's losses. Nowadays this control is digital and essentially based on a fixed temperature difference.
- General increase of the number of sensors in order to have a deeper insight of the overall CPS yield and keep it in good working conditions during its lifetime.

2.4. Metering Modules (Smart Meter and Watchers)

Apart from metering modules embedded inside appliances, dedicated metering devices have been deployed as key components of BeyWatch architecture: one smart meter - at smart home scale - and a set of "watchers" (i.e. smart plugs).

2.4.1. Technological Achievements

From the various metering modules, the following technological achievements have been met:

- ***ZigBee Smart Meter:*** A standard "intelligent" electronic meter as those currently deployed in France has been used as main basic component for BeyWatch smart meter: indeed, this electronic meter makes available a line interface - RS-232 like - designed to deliver metering and tariffs information to any device connected to it. Compliantly to BeyWatch requirements, EDF has developed a ZigBee module (CC2530 chipset) that can be connected on this "customer meter data link" output of the meter, to provide metering data onto the home ZigBee subnetwork.

  A hardware platform has been designed for tests, using a basic serial line profile to implement some kind of wireless serial point-to-point (smart meter – Agent) communication. Through this kind of interface, the meter permanently broadcasts information contained in the meter internal memory : this communication mode does not benefit at all from the ZigBee application layer features. Hence, the work has evolved to make this ZigBee node conformant to the Smart Energy Profile (see below).
- ***Application Layer: Smart Energy and Home Automation ZigBee framework:*** EDF being member of the ZigBee Alliance, a particular effort has been put so that the BeyWatch ZigBee ecosystem – whenever possible - is built compliantly to ZigBee development standards (ZigBee Cluster Library and Profiles notably). As technical inputs needed for implementations, EDF has made available to the partners the ZigBee Alliance "Home Automation public profile" and "Smart Energy Profile" specifications, which detail software logics and APIs.

  Beyond this, - due to the potential risk of misunderstanding related to ZigBee technology - a "common ZigBee metering framework" has been proposed to the partners involved in ZigBee developments. Initially, this "framework" has been implemented especially for smart meters and smart plugs communications: given its plasticity and generality, it has been easily possible to apply it also for CPS source code project (TI ZigBee chipsets).

  This allows to ensure that devices embed an application layer that is fully compliant to the ZigBee – profiled - application layer and communication model, whatever the APIs implemented on this device.

Last but not least, this common source code project has been built on top of Home Automation ZigBee stack, but it has been designed to indifferently and concurrently support Smart Energy API – for metering application layer - or Home Automation API – for smart appliances application layer (for instance).

2.4.2. Lessons learned

The lessons learned from the metering modules (smart meter prototype and smart plugs third party products) and ZigBee activities may be summarized in the following:

- ***M2M Communications (WSN):*** As most WSN (wireless sensor network) communication technologies, range of ZigBee communication between two separate nodes is generally limited to a few meters. Hence, meshed architecture option is clearly and implicitly the best option for ZigBee network deployments. Except specific use cases, deploying such ZigBee networks with other topologies is some kind of nonsense.
- ***ZigBee misunderstandings:*** Despite the attractiveness of ZigBee technology, achieving a detailed common view shared by all the involved partners has not been an easy task. The first instinctive decision of implementers is generally to use ZigBee communication (IEEE 802.15.4 and ZigBee stack mechanisms) as a wireless bridge to transparently carry data frames provided by any other specific – sometimes proprietary – low level protocol. This situation obviously excludes all the benefits resulting from the ZigBee Profiles APIs (application layer), which is the reason why ZigBee is gaining attraction compared to other WSN technologies.

  Besides that, the lack of public availability of ZigBee specifications has to be considered as an obstacle to tackle those misunderstandings.
- ***Application layer:*** Beyond the apparently strict partitioning of current ZigBee Profiles (Smart Energy 1.0, Home Automation 1.0), ZigBee clustering has proven to be an efficient framework. Moreover, ZigBee development kits use has demonstrated that it is possible to surpass current official specifications, which is sometimes very useful: for instance, by allowing the coexistence of Smart Energy and Home Automation APIs on top of one same device/node.

2.4.3. Recommendations & Future work

Possible points for optimization and enhancement are the following:

- ***M2M Communications (WSN):*** As a future major trend around ubiquitous sensor network activities, a new kind of network architecture has to be evaluated: this new architecture should mix wireless and PLC technologies, whose combination seem to be the optimal solution for deploying sensor networks on a no-new-wire way.

  On a more general way – for BeyWatch-like projects - focusing technological developments related to sensor networks communications under the responsibility of one partner (for each selected technology) is a general recommendation : given the maturity of WSN technologies, it is a necessary step to guarantee quality and reliability of software developments, and allows other partners to focus on their own business API.
- ***ZigBee Security:*** BeyWatch ZigBee subnetwork has been built and implemented without any particular security consideration: ZigBee nodes are composing an “open” subnetwork. As a future activity, improvements of this situation by taking into account security requirements (network establishment) have to be planned.
- ***Application layer:*** It is critical to make the architecture evolve, in order to be compliant with the forthcoming smart metering standard: Smart Energy 2.0, evolution of current API toward a RESTful API executing on top of an IPv6 embedded stack, dedicated to sensor networks.

  A particular attention will be focused on API openness and interoperability features, notably to find a robust solution to the “Smart Energy vs. Home Automation” issue.

2.5. BeyWatch Agent

An abstract view of the BeyWatch Agent is shown in Figure 7 in order to motivate the structure of this Section. As can be seen, the BeyWatch Agent essentially comprises three parts:

- the Agent Scheduler & Controller which interfaces with the home user and the Supervisor application, described in sub-section 2.5.1
- the Appliance's management framework which provides services to the Agent Scheduler & Controller, described in sub-section 2.5.2
- the M2M communications in the home that provide the communication services to the Appliance's management framework, described in sub-section 2.5.3.

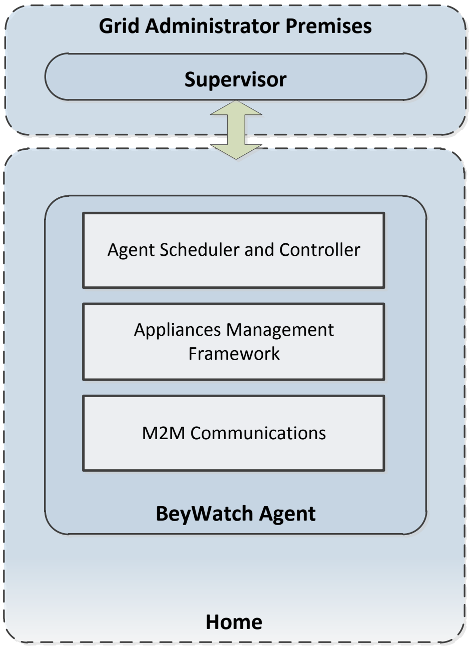


Figure 7: The three high-level components of the Agent discussed in this Section.

2.5.1. Agent Scheduler & Controller

The Agent Scheduler and Controller can be functionally conceived as one component: the component that's responsible for finding and implementing an optimal solution given the state of the house, the user requests and requirements and the prevailing or projected conditions (energy price, weather, etc.). However, structurally they are two distinct components communicating through a database as depicted in Figure 8.

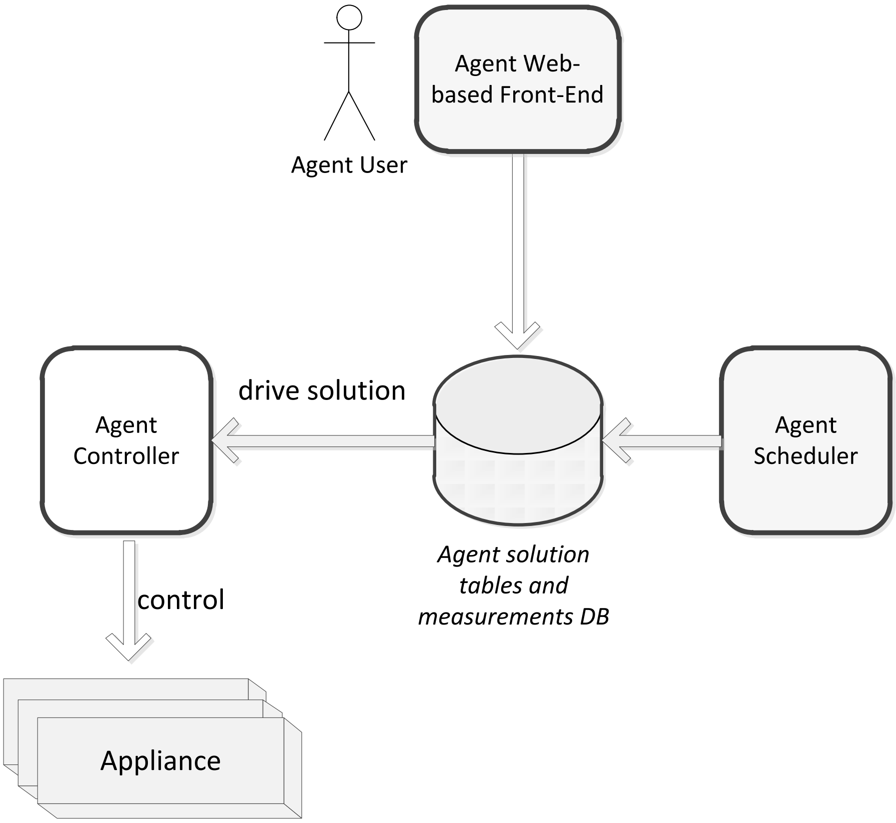


Figure 8: The Agent Controller, Scheduler and Web-based front-end communicating through shared DB access.

This arrangement also allows the various web-based front-ends that allow the user to control / interact with the Agent to use the same database to communicate with the scheduler and the controller. It should be noted that Figure 8 is a limited, abstract view of the system highlight only those components relevant for the discussion in this Section.

There is no theoretical reason why the Scheduler and the Controller couldn't be a single integrated application or whether they could not communicate with each other through a socket interface or some RPC or web-services based mechanism. The splitting them up in two different application / processes and the use of a database were technical decisions driven by implementation and testing constraints (for instance the need to facilitate independent testing and also to preserve a rich audit trail for de-bugging / optimization purposes). In fact the Agent Scheduler is further decomposed into more co-operating processes as is described in Section 2.5.1.2. The design and successful implementation of this distributed architecture was a major technical achievement of the project and one that greatly facilitated testing and independent verification prior to the deployment and integration at the Les Renardières testing site.

2.5.1.1 Summary of the Main Technical Achievements

The main achievement is the design and implementation of the BeyWatch Agent Scheduler and Controller. This module was conceived, designed and implemented from scratch and based on no previous work. 100% of the code was developed in the course of the BeyWatch project. Moreover we consider a major achievement the decomposed architecture used (see [1] for a detailed discussion of the advantages of this decomposition). The architecture of the Agent Scheduler and Controller at the end of the project is depicted in Figure 9.

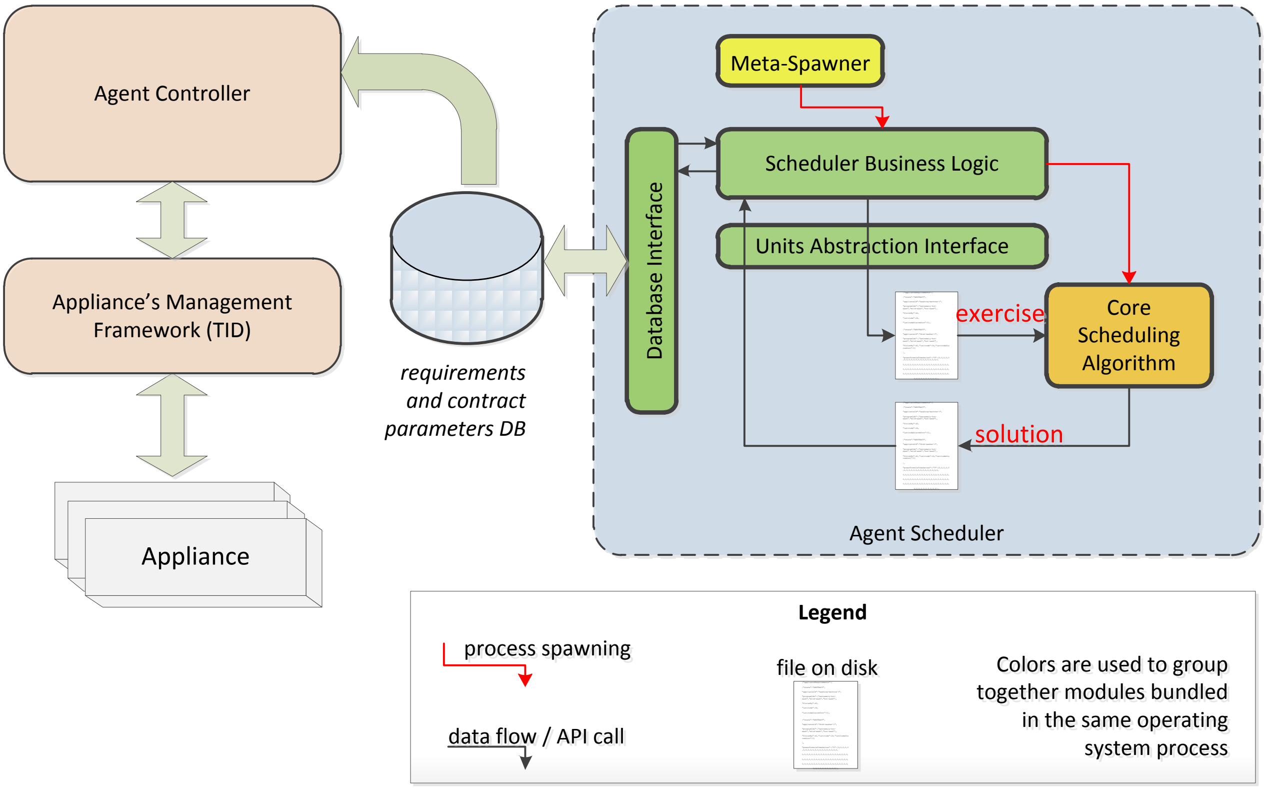


Figure 9: Breakdown of the Agent Scheduler.

Figure 9 also shows the relationship of the Agent Scheduler to the Agent Controller and identifies (by using the same colour) that the Agent Controller is in fact the same operating system process with the TID Appliance's Management Framework (linked together). The Appliance's Management Framework in fact uses OSGi so is itself further decomposed but this is out of the scope of this Section.

From a development perspective the following applications were developed for this module:

- **Agent Scheduler**: console application in Java
- **Scheduler Visualization Tool**: desktop GUI application in Java / AWT (not depicted in Figure 9)
- **Agent Controller**: console application in Java
- **Agent Testing Web front-end**: web-based GUI application in JavaScript / Google Web Toolkit (not depicted in Figure 9).

The above applications were designed, implemented and tested by different developers and are maintained at the source-code repository as different software artefacts with independent lifecycles and evolution paths. This is in our view another achievement of the project: that instead of developing a single monolithic application, a decomposed architecture was defined that allowed the breaking up of the functionality into well-defined modules. These modules are self-contained and communicate with each other over rather traditional interfaces (shared database access or file-based interfaces as can be seen in Figure 9). The use of such interface methods offers three advantages:

- They can be configured to leave a persistent audit trail for trouble-shooting (especially days after the event under investigation).
- They can be self-descriptive and with very strict and clearly understood semantics. This is a rather theoretical discussion but we will note at this point that the method call or procedure call abstraction often used in web-services-like technologies (and before that in technologies like RPC, CORBA or RMI) has been criticized of having unclear semantics in cases of exceptional / border cases (like time-outs). In contrast, a file-based protocol (such as the one employed between the "Scheduler Business Logic" and the "Core Scheduling Algorithm" in Figure 9) has no such ambiguities and offers the

additional benefit of not having to rely on an external and often massive "black-box" framework for the realization of the inter-process communication nitty-gritty details.

In conclusion, the main achievements were:

- The design and implementation of a highly de-composed modular architecture
- The extensive unit testing at the development premises (which was facilitated by the open interfaces exposed by that architecture and the development of additional testing tools like the visualization application discussed in [1]).
- The successful integration at the Les Renardières testing facility of components (hardware and software) developed by different partners. Despite some setbacks and delays, the successful integration without any need for major reworking demonstrated that the interfaces between the major components (including those across organizations) were unambiguously defined and that the components under integration had been sufficiently unit-tested at their respective development environments.
- The successful operation of the system for a period of about six months, for the most part unattended and with few (less than 5) patches applied due to bugs discovered in that period.
- The speed with which we were able to trouble-shoot and fix problems thanks to the extensive logging provisions of the system. In particular, there was no incidence reported which could not be resolved and there was no need to try to re-create any erroneous condition as the log files and database audit trail provided all the information necessary to locate the bug or explain the behaviour.
- The successful integration trials and the measurements collected which demonstrated the efficient operation of the system and the cost and energy efficiencies it can bring to a household.

2.5.1.2 Lessons learned

We may split the lessons learned in two groups: a home energy optimization related and a more general software engineering one. In the first group we may highlight the following lessons:

- ***Installation and configuration are not so simple.*** Initial installation of the system is quite complex as a large number of parameters have to be configured. The communications framework of course off-loads the scheduling algorithm from the communication problems; however, each device has to be configured independently. Moreover, the market is far away from defining/adopting a common standard in each white goods behaviour[1]. On the other hand, the scheduling algorithm can optimize home energy consumption only if it has the exact knowledge of the devices behaviour or, at least, of the energy load curves related to this behaviour.

  In order to solve the problem, a configuration/behaviour discovery protocol has to be defined and adopted (in the form of an extended UPnP) and each decide manufacturer that wants to be BeyWatch compatible, would need to establish a communication interface at least at a machine readable format.
- ***Complexity.*** The home energy optimization problem is a complex multidimensional problem. Each device may have its own behaviour and constrains (e.g. different modes of operation, different consumption per mode, different states and constrains in the time that can remain in each state, etc.) so optimization can be a very complex procedure. The optimization process gets more complicated if one additionally considers the different energy tariffs, the different energy forms (both electricity and hot water) and the energy generation forecast. The human factor and behaviour supplements the puzzle.

  For example, in summer, during the noon hours (14:00-16:00), the air-conditioning is challenging the stability of the electricity network. In order to overcome the demand-response problem and discourage electricity consumption, the utility companies may increase the tariff during these peak hours. On the other hand, in case a CPS is available, the photovoltaic cells achieve maximum performance, while hot water is available from the solar panel. During that time, the home energy consumption optimization scheduler may calculate the various constrains and decide to schedule the washing machine operation during noon (e.g. the savings from the avoiding to heat the water are more than the penalty of the high

[1] One may even challenge if a common standard will ever exist as each manufacturer defines a proprietary behavior from each white good, which is also due to the high competition the product point of differentiation.

electricity cost). Yet, if we add to the equation a family that has a couple of showers, optimization based on the hot water is getting very difficult.

As a solution, it is very hard to extract strict rules. Each case is different (even each day is different) and a case by case optimization scenario should be performed. Moreover, it is better to achieve a schedule close to optimal than use extra processing power for "the" optimal scheduling.

- ***Reliability.*** As already explained, pausing or delaying the operation of the white goods may influence the quality of the provided service. As a result, most white goods manufacturers are currently unwilling to provide full remote control functionality, as in that case they will be partially based on a 3rd party (the home energy optimization provider) for the quality and the reputation of their products. But, as stated previously, the limits and responsibilities of this white goods remote control has to be very clear: while giving to an external energy optimization system some flexibility in the energy use, the appliance itself has to remain responsible of the quality and of the performance of its primary function and may not delegate this to the external system. In a certain way, the white goods manufacturers already respected this principle when they took into account more and more environmental constraints: using less energy, less water, less detergent. The new flexibility constraint also has to comply with this principle even if its concrete implementation and refinement, after the experience of the BeyWatch project, is certainly a track for future work.

  As a start, it seems much simpler and much easier to be adopted to limit the remote control and scheduling functions only to the program starting activity. In that case, the scheduler will only select the mode of operation and the starting time and will clearly leave the responsibility of the actual operation, and thus of the performance, to the white good manufacturer. Though this approach is not optimal, it may serve as a first (intermediate) step towards the adoption of the home energy optimization.

On the other hand, the development of the Agent Scheduler and Controller was a very ***intensive software engineering effort***. From this development, we may highlight the following lessons in the area of software engineering:

- ***Software integration and verification under the waterfall model was a real challenge***. The largest problem of this effort was the fact that the tight schedule of the project did not allow an iterative development process. In other words, the system was designed, implemented, unit-tested (at the development premises) and then deployed to the EDF Les Renardières site for integration testing. Figure 10 depicts the model used and provides some rough date figures.

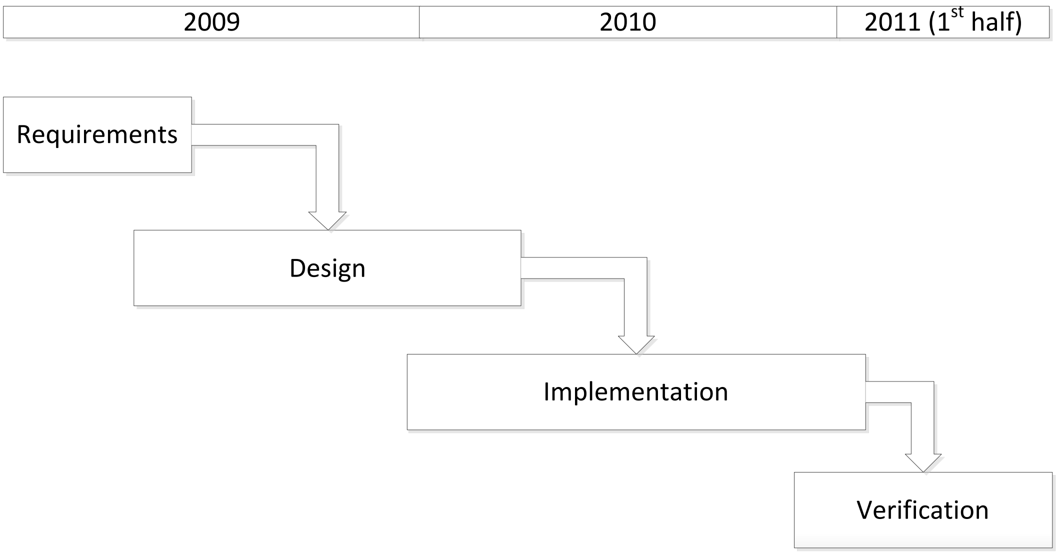


Figure 10: Rough development model for the BeyWatch Agent Scheduler and Controller.

Overlaps exist since the development of certain components could start before the overall design was finished and, in the same way, certain components were verified while others were still under development. The ability to have these overlaps and introduce some limited parallelization (which allowed for longer development times than it would otherwise have been possible) was a happy consequence of the design of the system as a highly decomposed set of cooperating processes; however it does not change the linear, sequential nature of the process. The waterfall model and the more or less sequential design process were a necessary arrangement, as the size of the components and the required time for their development did not allow an iterative development process. The linear waterfall model posed the following challenges:

- Integration testing done at the end of the project, with little room for corrective action.
- Limited feedback from actual users in a real setting until almost the end of the project.

Moreover the fact that the Agent Scheduler and Controller has strong dependencies on the Appliance's management framework (described in Section 2.5.2) and the availability of deployed M2M communications in the home (described in Section 2.5.3), combined with the sequential and linear development process means that:

- Delays in the development, integration and trouble-shooting of the dependencies would reduce the time available for verifying and trouble-shooting the Agent Scheduler and Controller at the integration site. In other words, given the 6-month period foreseen for trials and measurements there was the risk that if, for instance, the Appliance's management framework or the M2M communications with the hardware appliances required extensive trouble-shooting at the integration site then the time available for the actual on-site verification of the Agent Scheduler and Controller would be commensurately limited. This was because it is not possible to verify, as part of integration, system-wide tests, the correct behaviour of "higher layer" components until the "lower layers" are practically bug-free.
- The complex interdependencies between components developed by different partners meant that trouble-shooting at the integration site would be particularly daunting. This does not apply to the different modules in which the Agent Scheduler and Controller is broken into (since these are all provided by a single partner). Even so, the complete system integrates components coming from six different solution providers / manufacturers:
  - Agent Scheduler and Controller, and Supervisor supplied by SYN
  - Appliance's Management Framework supplied by TID
  - CPS hardware, communications and software drivers supplied by UNIPA
  - Refrigerator hardware, communications and software drivers supplied by GORENJE
  - Washing machine and Dish washer hardware, communications and software drivers supplied by FAGOR.
  - Electricity Meter Module and Watchers hardware, communications and software drivers supplied by EDF.

  To prepare for the verification risks the Agent Scheduler and Controller was designed in a much decomposed way as a system of communicating processes. These communicating processes were then extensively and individually unit-tested and verified at the Synelixis labs before shipment to Les Renardières (the interested reader can refer to [1] for more details). Additionally, the communication between the processes comprising the Agent Scheduler and Controller is done using mechanisms that leave an audit trail (e.g. shared database access or creation of file-based protocols with the files used being subsequently archived). This increases the transparency and provides an ample number of open interfaces in which to "hook" testing routines or at which to inspect / visualize the inner workings of the system.
- ***System logging during testing & validation has huge storage requirements***. The integrated system has extensive logging facilities: both file-based logging and database-logging and all logging files are archived and filed in a hierarchical date-driven tree structure. This allows testers and debuggers access to a rich trail that captures almost full snapshots of the system's state at the time each scheduling "exercise" was optimized. However, all the various archived tests and log files can potentially occupy many Gigabytes of storage space. On the other hand, in order to lower the Residential Gateway (RG) hardware cost, they have only limited storage capabilities.

  In order to overcome the problem, in the Les Renardières site deployment, two techniques were followed: a) we used one USB port of the RG to mount a 500GB external hard disk and b) log files are automatically zipped after they grow more than a couple of hours old (the log files are hourly).

Obviously, in a real production system the amount of logging would be much reduced.

- ***System controls/events are many***. The number of system controls and events can easily grow to large numbers. One may imagine at least 10-15 white and brown goods (e.g. refrigerators, freezers, washing and drying machines, dishwashers, kitchen, oven, microwave oven, heater, air-condition, TV set, DVD player/recorder, CD player/recorder, at least 4-5 lamps and reading lamps, the CPS system etc). Each one of these devices may need a number of control commands and events, while scheduled programs and events may be extended for a couple of days or even weeks. Changing some of the system parameters (e.g. manually switching on a device or consuming some hot water) would destroy the optimized schedule and a new schedule should be calculated.

  This creates the need to handle efficiently all these events in a low end system, such as a RG. To solve the problem, we have selected to use a small database on the system. The result has been very satisfactory, leading to a compact and very efficient system.

On the next figure we provide the output of some shell commands executed at the file-based logging folder at the Les Renardières trial installation at the time of this writing:

```
1.  synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps$ ls
2.  exercises  logs
3.  synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps$ cd exercises/
4.  synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps/exercises$ find . | wc -l
5.  57830
6.  synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps/exercises$ ls -l | head
7.  total 345928
8.  -rwxrwxrwx 1 root      root      10511 2011-01-24 17:42 beywatch-2011_01_24___17_42_30.input
9.  -rwxrwxrwx 1 root      root        153 2011-01-24 17:42 beywatch-2011_01_24___17_42_30.input.prog.1000
10. -rwxrwxrwx 1 root      root        153 2011-01-24 17:42 beywatch-2011_01_24___17_42_30.input.prog.1000.final
11. -rwxrwxrwx 1 root      root       4105 2011-01-24 17:42 beywatch-2011_01_24___17_42_43.input
12. -rwxrwxrwx 1 root      root         52 2011-01-24 17:42 beywatch-2011_01_24___17_42_43.input.prog.1000
13. -rwxrwxrwx 1 root      root         52 2011-01-24 17:42 beywatch-2011_01_24___17_42_43.input.prog.1000.final
14. -rwxrwxrwx 1 root      root       4105 2011-01-24 17:42 beywatch-2011_01_24___17_42_52.input
15. -rwxrwxrwx 1 root      root         52 2011-01-24 17:42 beywatch-2011_01_24___17_42_52.input.prog.1000
16. -rwxrwxrwx 1 root      root         52 2011-01-24 17:42 beywatch-2011_01_24___17_42_52.input.prog.1000.final
17. synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps/exercises$ ls -l | tail
18. -rw-r--r-- 1 synelixis synelixis    71 2011-07-07 11:19 beywatch-2011_07_07___11_19_10.input.prog.1000.final
19. -rw-r--r-- 1 synelixis synelixis 12656 2011-07-07 11:19 beywatch-2011_07_07___11_19_27.input
20. -rw-r--r-- 1 synelixis synelixis    71 2011-07-07 11:19 beywatch-2011_07_07___11_19_27.input.prog.1000
21. -rw-r--r-- 1 synelixis synelixis    71 2011-07-07 11:19 beywatch-2011_07_07___11_19_27.input.prog.1000.final
22. -rw-r--r-- 1 synelixis synelixis 12656 2011-07-07 11:19 beywatch-2011_07_07___11_19_43.input
23. -rw-r--r-- 1 synelixis synelixis    71 2011-07-07 11:19 beywatch-2011_07_07___11_19_43.input.prog.1000
24. -rw-r--r-- 1 synelixis synelixis    71 2011-07-07 11:19 beywatch-2011_07_07___11_19_43.input.prog.1000.final
25. -rw-r--r-- 1 synelixis synelixis 12656 2011-07-07 11:19 beywatch-2011_07_07___11_19_58.input
26. -rw-r--r-- 1 synelixis synelixis    71 2011-07-07 11:20 beywatch-2011_07_07___11_19_58.input.prog.1000
27. -rw-r--r-- 1 synelixis synelixis    71 2011-07-07 11:20 beywatch-2011_07_07___11_19_58.input.prog.1000.final
28. synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps/exercises$
29. synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps/exercises$
30. synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps/exercises$ cd ../logs/
31. synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps/logs$ find . | wc -l
32. 6217
33. synelixis@synelixis01:/media/Elements/BeyWatchLogsAndTemps/logs$ ls -l | head
34. total 1851908
35. -rwxrwxrwx 1 root      root        16057 2011-01-24 17:26 AlgorithmMetaSpawner_2011.01.24 (Mon) 12.log.gz
36. -rwxrwxrwx 1 root      root       378716 2011-01-24 21:02 AlgorithmMetaSpawner_2011.01.24 (Mon) 17.log.gz
37. -rwxrwxrwx 1 root      root       502018 2011-01-24 22:02 AlgorithmMetaSpawner_2011.01.24 (Mon) 18.log.gz
38. -rwxrwxrwx 1 root      root       502856 2011-01-24 23:02 AlgorithmMetaSpawner_2011.01.24 (Mon) 19.log.gz
39. -rwxrwxrwx 1 root      root       503481 2011-01-25 00:03 AlgorithmMetaSpawner_2011.01.24 (Mon) 20.log.gz
40. -rwxrwxrwx 1 root      root       503213 2011-01-25 01:03 AlgorithmMetaSpawner_2011.01.24 (Mon) 21.log.gz
41. -rwxrwxrwx 1 root      root       503365 2011-01-25 02:03 AlgorithmMetaSpawner_2011.01.24 (Mon) 22.log.gz
42. -rwxrwxrwx 1 root      root       503388 2011-01-25 03:04 AlgorithmMetaSpawner_2011.01.24 (Mon) 23.log.gz
43. -rwxrwxrwx 1 root      root       502431 2011-01-25 04:04 AlgorithmMetaSpawner_2011.01.25 (Tue) 00.log.gz
```

Figure 11: BeyWatch Agent Scheduler and Controller directory screen dump

As can be seen at the screen dump (line 5), we have created more than 57,500 "exercise" files at the live, integrated system. Each "exercise" corresponds to an optimized solution and each can be verified and visualized, independently of the rest of the system as the ".input" file contains a snapshot of the system's state at the time of the exercise. Some exercise files are depicted in lines 8 up to 27 and it can be seen that they are date and time-stamped for auditing purposes. Moreover debug logs are also available numbering more than 6,000 log files at the time of this writing (line 32) and tracking the debug and logging messages of different system components like the "algorithm meta spawner" (this is the "Meta-Spawner" component of Figure 9) in lines 35 to 43.

2.5.1.3 *Agent scheduler operation energy efficiency*

The Agent's scheduler has been proven to be one of the key BeyWatch components. The efficient configuration and operation may results in the actual BeyWatch System benefit. In general more than 30.000 test cases have run, a significant amount of data (more than 50GBytes) were collected from various probes and some indicative are displayed here. The metric that has been used to evaluate the cost benefit has been calculated in cent-cents per kWh[2].

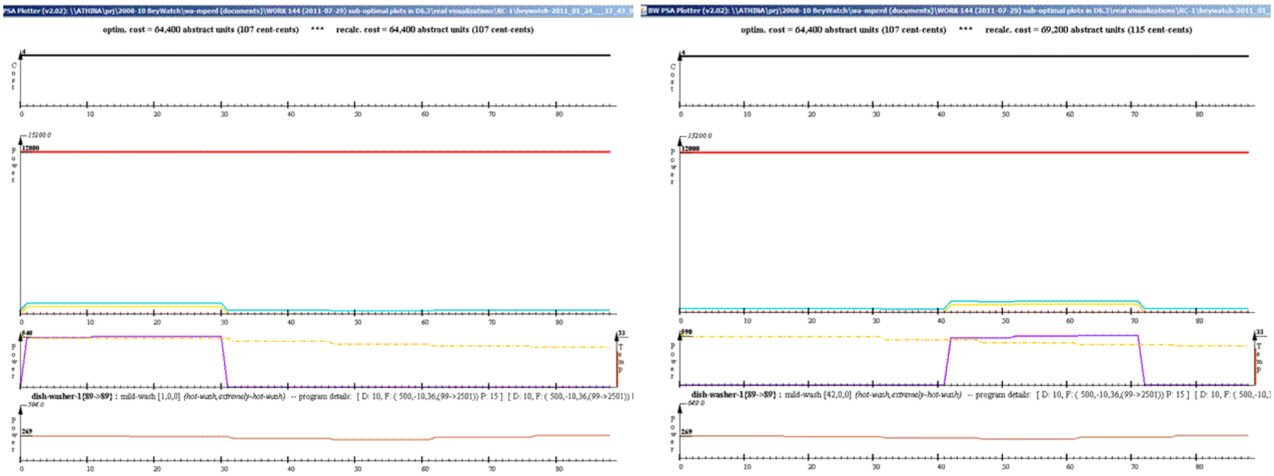


Figure 12: Optimal (left) and un-optimal (right) scheduling (Case#1, 24 January 2011)

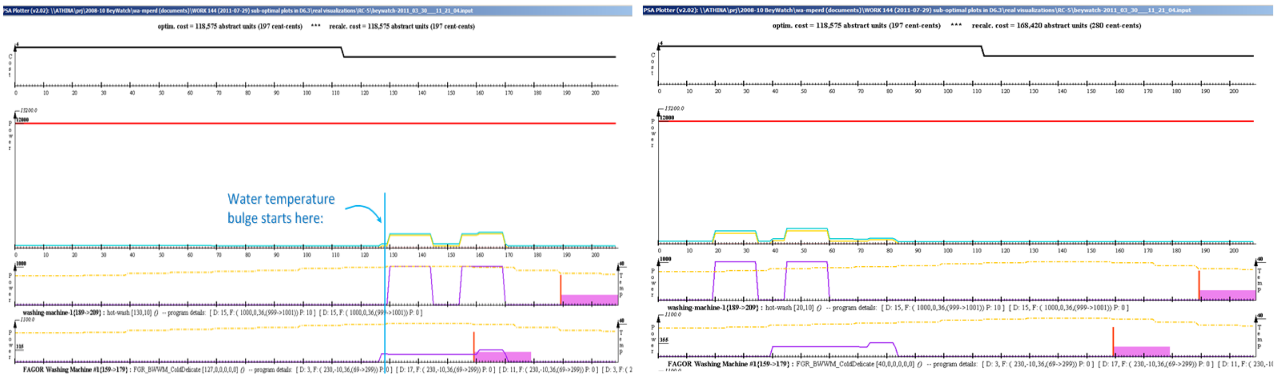


Figure 13: Optimal (left) and un-optimal (right) scheduling (Case#5, 30 March 2011)

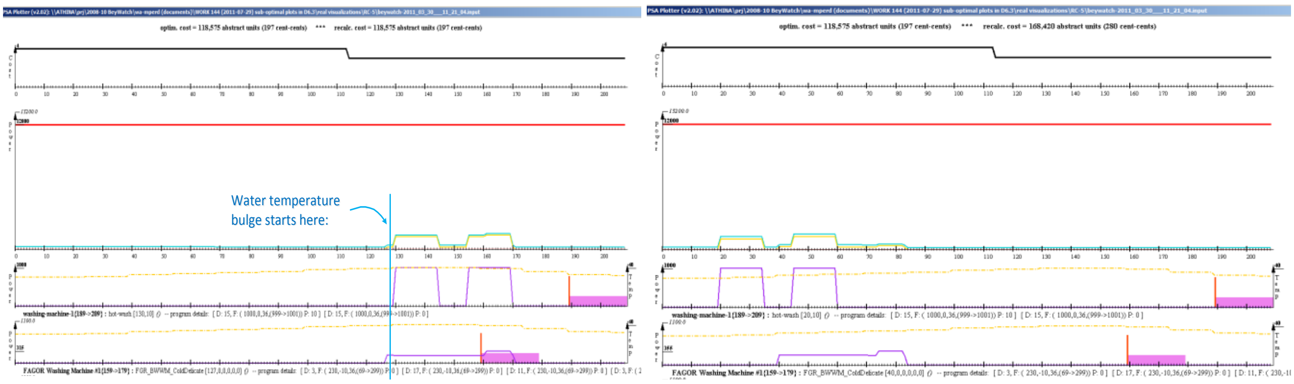


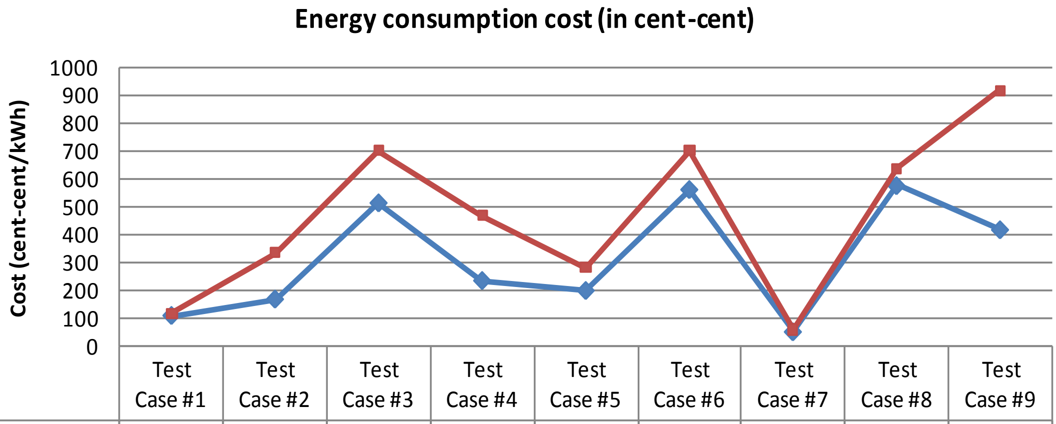
Figure 14: Optimal (left) and un-optimal (right) scheduling (Case#6, 1 April 2011)

[2] 100 cent-cent = 0,001€

The results have shown that the overall energy consumption may not always be the optimal. Yet we may achieve two things:

- Avoid power peaks (as we may always pause or postpone an activity in order to avoid a peak) and
- Reduce the electricity cost bill by at least

Figure 15 shows some indicative scenarios that demonstrate the cost saving.



	Test Case #1	Test Case #2	Test Case #3	Test Case #4	Test Case #5	Test Case #6	Test Case #7	Test Case #8	Test Case #9
BeyWatch Optimized	107	166	513	233	197	561	48	575	416
Human	115	333	700	466	280	701	58	637	916

Figure 15: Energy Consumption cost

2.5.1.4 Recommendations & Future work

As noted above the development process for the BeyWatch system has been mostly linear and despite the success of the integration and trial period, the system delivered at the end of the project should be considered a prototype. At least one additional full development iteration (requirements, design, implementation, testing) is necessary before the system can be productized. The development of the existing prototype allowed all the partners involved to think deeply about the issues, to experiment, to develop some intuition on the subject matter and to understand the problem and the universe of possible solutions better. The Unix / C pioneers Brian Kernighan and Rob Pike have famously noted in their book "The Practice of Programming" ([2]) that: *It is not usually until you've built and used a version of the program that you understand the issues well enough to get the design right*. While we feel that the design was right, the system would certainly benefit from a new iteration. The new iteration would benefit from:

- The experience gained in the course of this project
- The availability of the prototype as a tool to conduct extensive end-user tests and trials and obtain feedback.
- The availability of the prototype as a stable and tested code base (for code re-use)

The new iteration doesn't have to begin from a clean slate. The existing system is stable enough to provide a solid foundation and a lot of the existing code can be re-used. The loosely-coupled architecture of the Agent Scheduler and Controller with very clear interfaces defined between the co-operating processes allows us the possibility to perform extensive modifications in certain components while barely touching others. Also, the existence of a very extensive regression test suite with literally tens of thousands of test files (obtained during the six-month trial run at Les Renardières) can encourage extensive experimentation and re-factoring without the fear of "breaking" anything.

In what follows we identify possible areas that could be enhanced as part of a second iteration or, in general, future work on the system.

- **End-user interface:** It would be beneficial to perform large scale trial with real end-users, preferably by installing the system in their actual homes (real-life tests) and collect end-user feedback relative to all aspects of the system: the user interface experience, functionality issues, problems or suggested features, issues or remote access from a variety of terminal devices. Use that feedback to drive a second, iterative round of design and implementation.
- **Performance:** Implement the Core Scheduling Algorithm (CSA) module, which is the most resource-consuming component of the Agent Scheduler, in optimized C or C++ code. Due to the need for fast implementation, the CSA has already undergone through two incarnations in the course of the BeyWatch project:
  - As a Python program (to allow rapid prototyping).
  - As a Java program improving the system performance.

  We estimate that a C or C++ optimization could further yield performance improvement. This will be made possible not simply on account of the language[3] change but also with the coding of advanced heuristics, which will improve the algorithm performance.
- **OSGi as deployment platform**. Though flexible, the development experience from the OSGi platform was not very positive. This was not on account of bugs or technical deficiencies (on the contrary: the OSGi platform is very stable) but rather on account of introducing complexity (and hence, delays) in the development, testing and building process. The OSGi does offer some benefits of course in terms of modularization but, from a pragmatic viewpoint, it may be too complex for the benefits it delivers. Moreover, a future version of Java is likely to provide the necessary modularization and versioning feature directly at the language level thus might make OSGi (which uses extra-lingual mechanisms to provide its functionality) obsolete. Actually, this Java feature (currently a recommendation: JSR 277 "Java Module System") was originally slated for Java 7 but was left out. It is recommended to track Java evolution and upgrade the system when a module system is directly supported at the language level.
- **Security.** Security was not a major concern in BeyWatch, since the aim was not immediate commercialization but rather the development and the successful integration / trial of a prototype. However for a commercial roll-out of the system security and authentication features have to be retrofitted into the application.
- **Remote trouble-shooting**. Again, for a viable commercial product to come out of this project the Agent will have to expose remote trouble-shooting interfaces to allow support personnel to troubleshot and support home users without having to be physically present.
- **Reliability, self-configuration and self-healing** : it is a challenge yet to be achieved to have, for such an interconnected system, the same basic characteristics as those of standalone machines today, meaning :
  - **Reliability**: in no way it can be tolerated that white goods fail in their operation due to software or network problems, or due to a failure in another part of the system, and to have to reboot periodically one or several components of the system in order to fix the problem, as we are yet compelled to do so with PCs, internet box or set top box today. This is why a backup mode has been defined for the white goods in the BeyWatch service specifications (see [3]).
  - **Self-healing** : in order to achieve this reliability, and as failures may always occur despite of strict quality procedures and intensive testing, the system should embed self-healing functions in order to detect malfunctions and automatically run correction procedures in a way as transparent as possible for the user.
  - **Self-configuration**: the ability for a system to automatically recognize the different components, at the starting phase, or the introduction of a new component during the life of the system, and to take

[3] The Java compiler and the JVM used in BeyWatch already included optimizations and performance enhancements (such as hotspot optimization, just-in-time compilation and adaptive optimization) that brought the performance of Java close to the region of native code. Therefore, we estimate that the mere language change cannot yield more than a fivefold performance improvement at the most, unless also accompanied by algorithm changes.

in into account, also leads to a complexity in itself, aside from the main energy optimization function performed by the system. But it is a key of the success, as it is not conceivable to ask the home dweller to turn to be a system expert able neither to configure manually the system, nor to request a professional to come to the home to make this configuration either.

- **Forecasts**: in order to make the schedule of operation, the HESCO optimization algorithm makes an intensive use of forecasts: for the daily PV production, according to the forecasted weather and insulation, for the consumption profiles of the different appliances, which even have to be differentiated between the different programs. Some of these forecasting programs are still areas of research in order to get them more accurate and usable.
- **Sensibility**: even with better forecasts, differences between the real consumption or generation and the forecasted ones will always exist. On another hand, as it has already been pointed out, one of the major sources of disruption with the forecasted schedule is the home dweller himself. This is why the schedule has to be recomputed when a major change occurs, or if a major difference between the forecasted operation of a system and the reality is detected. But taking into account the sensibility to perturbations in the choice of the optimized schedule is also a path that should be considered: it could lead to prefer to choose schedules that seem suboptimal at a first glance but that resist much better to changes and, as a consequence, need no modification, or only slight modifications, to take this change into account, leading to a better stability of the schedule and acceptability of the dweller.

2.5.2. Appliance's management framework

The Appliance's management framework was brought to the project as pre-existing knowhow from Telefónica I+D. It was conceived and implemented for the first time from some basic modules developed as part of Telefónica I+D work in former European Projects such as: ePerSpace (FP6, IST-506775, IP project), HaH (FP6, IST-045089, STREP project) or Astrals (FP6, IST-028097, STREP project).

The main objective of the Appliance's Management Framework is to make appliances management independent from the manufacturer and M2M communications technology they use, facilitating monitoring and control of the appliances from the application layer (normally developed by service providers).

In BeyWatch, the Appliance's management framework abstracts monitoring and control procedures of real appliances from the Agent Controller depicted in Figure 16, which communicates with the Appliance's management framework through a set of well-defined APIs.

Although an initial version of the framework existed, the work carried out in BeyWatch has extended this version in order to integrate the management of the white goods from Fagor and Gorenje, the CPS from UniPa and the smart meter and energy aware smart plugs provided by EDF for the control of legacy electrical appliances.

A basic representation of the Appliance's Management Framework layered architecture is presented in the picture below:

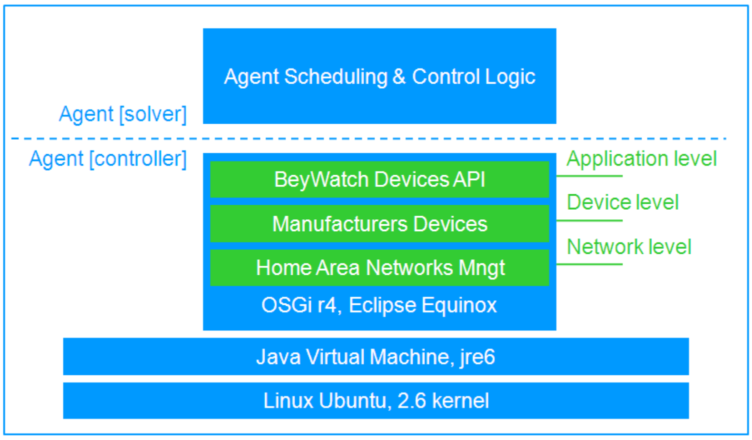


Figure 16: Appliance Management Framework – Global view

The monitoring and control of each type of appliance is implemented in 3 different layers:

- **Base driver layer:** This is the layer in charge of communicating through the corresponding hardware interface of the Agent towards the home area network the appliance is connected to. Over the corresponding network, M2M communications between the framework and the physical appliance use the corresponding protocol (either public or proprietary, depending on the appliance manufacturer). Appliances in BeyWatch communicate through Wi-Fi and ZigBee. The necessary base drivers have been developed for them.

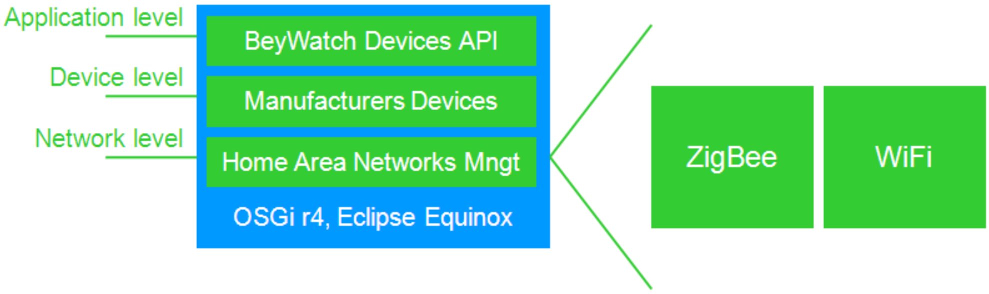


Figure 17: Appliance Management Framework – Base drivers

- **Manufacturer driver laver:** This layer provides the manufacturer implementation for accessing the various functionalities the appliance offers for its integration in more complex systems. In BeyWatch there are 3 different manufacturer's drivers: Gorenje, Fagor, UniPa-EDF, which provide the implementation for the monitoring and control of the Refrigerator, Washing machine and Dishwasher, the CPS, the smart meter from EDF and external watchers (energy aware smart plugs) respectively.

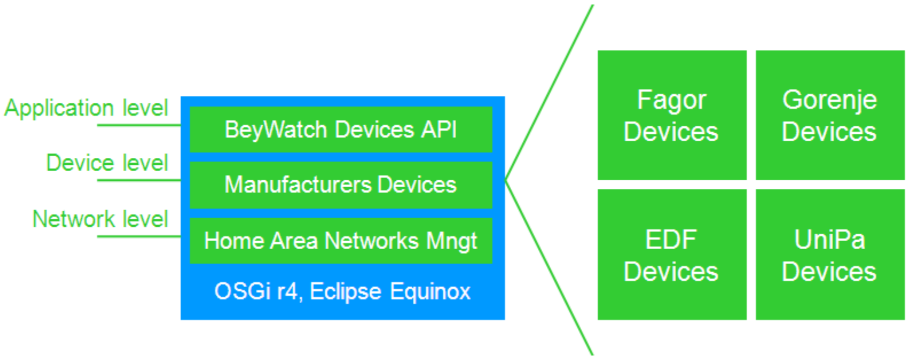


Figure 18: Appliance Management Framework – Manufacturers' drivers

- **BeyWatch appliance driver layer:** At the top of the framework it is the BeyWatch appliance driver layer, where the implementation of the BeyWatch appliance's APIs (interface with the Agent Controller) is provided. There is one driver per manufacturer again: Gorenje, Fagor, UniPa and EDF.

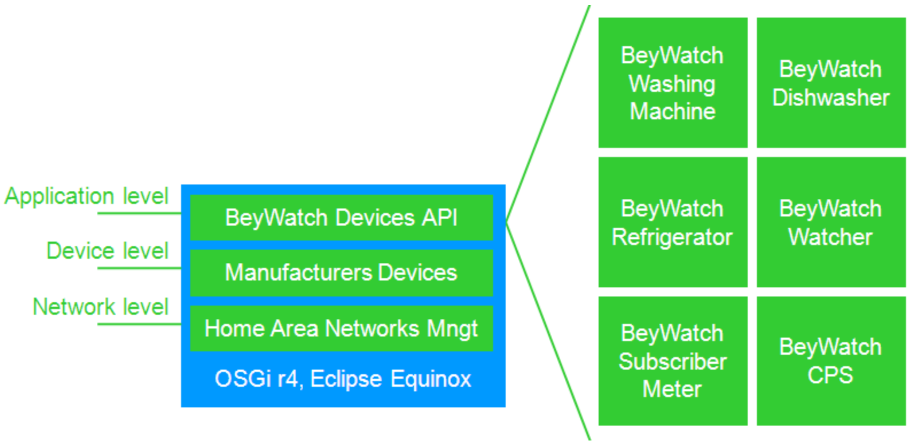


Figure 19: Appliance Management Framework – BeyWatch appliances' drivers

As stated in section 2.4.1.3 (Recommendations & Future Work for the Agent Scheduler and Controller), the Appliance's Management Framework uses OSGi technology. The modularity provided by OSGi has allowed us to integrate smoothly every module developed for BeyWatch appliance's management without interfering the rest of modules already deployed in the framework.

Modules in OSGi are composed of bundles, each bundle providing a specific functionality (or 'service', according to OSGi terminology). The Appliance's Management framework makes use of some of the basic services provided by the equinox implementation ([13]) of OSGi R4 specifications (such as the http, configuration admin, event handler and device manager services). Equinox is the open implementation of OSGi R4 that has been used for the project because of the support from the Eclipse community, with immediate integration in Eclipse IDE, and where bundles are developed as normal Eclipse plug-ins with some specific particularities).

2.5.2.1 Main technical achievements

Main technical achievements with respect to the Appliance's Management Framework are:

- **Specification of functional APIs for BeyWatch appliances**: BeyWatch appliances APIs specify a data model for each type of appliance (washing machine, dishwasher, refrigerator, CPS, smart meter and watcher) and the methods for data interchange (related to energy and control) between the service provider and actual appliances.
- **Development and integration of the various appliances' bundles**. As described in section 2.4.2, the management of each appliance involves the use of several bundles. Some of them are specific but some other implement standard functionalities that can be reused afterwards. For example, M2M communications with the CPS, the smart meter and the watchers make use of ZigBee standard application profiles Home Automation and Smart Metering. This is done by using the standard methods in ZCL library, what is modelled in OSGi by the use of a single service (ZCS) that can be used by any manufacturer bundle that needs to communicate over ZigBee with standard application profiles. This is the case in BeyWatch for EDF and UniPa manufacturer bundles.
- **Successful integration with the Agent Controller**, thanks to the correct implementation of appliances APIs.
- **Test OSGi bundles**, which are fed with BeyWatch appliances APIs to run unitary tests at a parameterized frequency and log the results in text files. This test bundles can be reused in the future for testing new appliances from different manufacturers that implement BeyWatch appliances APIs.
- **Scheduled control bundle** for the execution of the reference tests carried out in EDF testbed. This bundle is meant for scheduling the operation of devices of the 6 types supported right now in BeyWatch. The appliances can be controlled (with the needed parameters) at the desired time (in intervals of 15 minutes).
- **Energy aware RG Standardization.** BeyWatch has share its view on energy management services with the Home Gateway Initiative (HGi) BeyWatch will contribute to OSGi forums with the bundles for managing the intelligent metering device, the networked, energy-aware white goods and the RES/CPS system, while at the HGi it has contribute to the design and specification of the energy management functionalities to be added in the next version of the standard for Telco's RGs.

2.5.2.2 Lessons learned

- As already said in previous sections (white goods, Agent scheduler and controller), **the integration of appliances from different manufacturers and different M2M communications technologies is always hard**. A layered architecture like the one used by the Appliance's Management Framework is very useful to make appliances control independent from higher layers (service logic and provisioning), and it is even something necessary until M2M communications are standardized.
- **Modularity**. In the same way, modularity is a key point for developing configurable products. In the home area, it is the user at the end who will chose which are the white appliances that better suits his needs and thus, a framework like the one used in BeyWatch can be a good approach: The user buys a new appliance, the service provider installs in the framework the module needed to monitor and control it, remotely and without disturbing the user with technology integration.

- **Reliability**. The appliance management framework needs to be reliable and stable: the user must have at any time reliable information about appliances status and consumption. If communications are lost, he has to be aware of it.
- **Scalability**. The appliance management framework needs to be extensible to integrate as many manufacturers as possible and, given the heterogeneity that exists in M2M communications technologies, integrating as many technologies as needed.
- **Openness**. Clear and complete functional APIs must be provided to open the framework to manufacturers. The implementation of the API may be private, they can extend this APIs with much other functionality to differentiate from their competitors, but at least the minimum set of functionalities included in BeyWatch APIs should be fulfilled.
- **Platform independent**. There are several trends regarding the hosting of the energy management system. The framework (and the whole Agent) could run in an 'energy box', in a general purpose box (for the provision of other services apart from energy management), in an RG (including broadband connectivity), in a module coupled to the utility smart meter… all these considerations make platform independence a good point, although in the future, once this doubts are solved, performance would benefit from the re-coding of the framework for a concrete hardware platform (C, C++ instead of Java, which needs more resources in terms of memory to run).

2.5.2.3 Recommendations & Future work

The work done for the Appliances management framework could be a good starting point to feed the Internet of the Things with all kind of data from home appliances. BeyWatch RG can be the interfacing device to implement M2M communications with the devices attached to the local area networks that are managed from it.

BeyWatch work on IoT can influence the work to be done in the new PPP Future Internet projects. This PPP includes a project for developing the Future Internet Core Platform + projects for vertical Usage Cases. There are service enablers in the core platform that are common to all the usage areas + specific enablers for each one of the Usage Areas proposed. Data exchange with all kind of appliances + common data intelligence + particular data intelligence is needed to foster the development and subsequent adoption of such a platform.

Future work on the Appliance management framework must emphasize activities for:

- Performance improvement.
- Reduced size.
- Share BeyWatch appliances APIs (eeDataModels), evolve and extend the set with new types of appliances.
- Create an open library for energy efficiency service providers (bundles repository). List of appliances/devices supported and from which manufacturers.

2.5.3. M2M communications in the home

2.5.3.1 Technical Achievements

Even from the BeyWatch proposal writing, we already knew that the in home network is not stabilized and no mature technology has become dominant for the Machine to Machine (M2M) communication. As a result, we made the very correct design decision from the very beginning to logically and functionally decompose and separate the M2M communication from any other functionality and keep it hidden into the BeyWatch framework. In this way, BeyWatch solution is orthogonal to the M2M communication and open to current and emerging communication solutions.

For testing and validation purposes, we implemented mainly two M2M communication interfaces: a ZigBee (/ZigBee-pro) and a WiFi interface.

Figure 20: M2M communications – coexistence of technologies

As already explained in the section related to Washing Machine/Dishwasher the ZigBee Smart Energy and Home Automation (HA) layer clusters were extended to support new appliances not considered before by the protocols. With respect to the WiFi interface, we implemented transparent IP communication over the WiFi interface and managed to communicate with Gorenje refrigerator/freezer, while the same WiFi interface was also used for the User Interface needs.

2.5.3.2 Lessons learned

From what we have evaluated, ZigBee is a low cost physical interface and suits perfectly into the home appliances communication needs. However, in general the following lessons related to M2M have been learned:

- ***No dominant technology yet:*** Unfortunately, the M2M home communication area is still widely fragmented. ZigBee is progressing and captures a large percentage of the market but still the technology faces so many limitations (especially the interference and coverage limitations as explained latter), that cannot become dominant. WiFi communications is a good alternative, but still the cost is too high to be the dominant technology for each and every white good device. Finally, PLC/Powerline communications are still either unreliable or too expensive.
- ***Interference issues:*** We have tested that ZigBee (and in some cases even ZigBee pro) is very prone to interference and the reliability is still rather limited, especially when multiple communications interfaces are used or many interference sources are operating (e.g. microwave next to a washing machine). We did extensive experiments not only with BeyWatch developed devices and evaluation boards, but also with laptop dongles and off-the-shelf devices (e.g. energy watchers) and the result is that operation is not always guaranteed.

  On the other hand, WiFi is stable and is hardly affected by home interferences, regardless of its surroundings. Moreover, WiFi is a very mature standard and thus physical and MAC compatibility is guaranteed. So, from robustness and coverage point of view WiFi has a clear advantage.
- ***Coverage range.*** ZigBee has been designed considering short range communications. However, longer communication is needed in many cases. While the Dishwasher is in most cases located in the kitchen, the washing machine is in many cases located at the cellar or a basement and the communication with the CPS at the building roof is not possible. If other compatible ZigBee nodes are also installed in the home, then mesh networking functions of ZigBee may be used to solve such cases. Otherwise,, repeaters or bridges are needed, exponentially increasing the installation complexity, maintenance and cost. In such cases, a serial, powerline or a WiFi interface may be much more convenient, reliable and cost effective.

- ***Compatibility.*** While ZigBee is a mature communications protocol and has been standardized to control several appliances, it was also found that still it does not cover all communication needs. We have tested both the Home Automation (HA) and the Smart Energy (SE) profile, but still there has been functionality that was not supported by the standard. It is true that the standard enables proprietary extensions to the protocols, but this leads to non-compatibilities which limit the wide deployment and protocol acceptance.
- ***Application Layer Standardization.*** While ZigBee was designed for HA and SE Control in the home environment, WiFi was designed as a general purpose communication interface. As a result, WiFi offers full openness to design and implement any IP based application to exchange monitoring and control information but does not offer a standardized home automation protocol. The only protocol that could be considered is the UPnP, but it adds unnecessary complexity and communication overheads.
- ***Energy/Cost.*** Due to broadband/ADSL Internet access, most houses already feature a WiFi bridge/residential gateway, so no extra communications hardware is needed. Moreover, the BeyWatch Agent may be hosted on most RG/ADSL routers.

  On the other hand, the competition in the white goods is so taught that even few Euros difference may result in a product success or failure. WiFi is not expensive; the great popularity has significantly reduced the price. However, it is still at least 2 orders of magnitude higher that ZigBee and its energy consumption is also much higher.

2.5.3.3 Recommendations & Future work

The following are points for optimization and enhancement of the system:

- ***Keep M2M separate until they are standardized:*** Though the separation of the M2M communications may somewhat increase the cost, it is the only solution that ensures a future proof solution until a solution for M2M home communication is really standardized.
- ***Improvements on the M2M technologies:*** The ZigBee modules need to be controlled more thoroughly in order to avoid interference sources. Controlling dynamically launched channels from external WiFi (802.11) sources can provide better overall robustness to the system. Newer arising and proposed standards such as 802.15.7 can be considered and analysed in a near future, which could be more immune to interference sources.

2.6. BeyWatch Supervisor

The BeyWatch Supervisor is a software subsystem that is responsible for smooth energy control and load balancing at neighbour level and preserving customers' contract agreements. The Supervisor may be considered as the BeyWatch contribution towards the Smart Energy Grid.

2.6.1. Technological Achievements

The main technological achievement of this activity was the conceptualization, design, implementation and successful deployment of the BeyWatch Supervisor application. We include among the achievements the "conceptualization" since the project started with only a very broad and somewhat blurry definition of a Supervisor component and succeeded in circumscribing in detail a feature set for that component as well as in integrating seamlessly with the rest of the BeyWatch architecture. In particular, the project proposed the paradigm of a "BeyWatch Monitoring and Control System Conceptual Model" (BWCM) as a hierarchical structure with the Supervisor on the upper layers. The BWCM proposes a hierarchical allocation of functions with the hierarchy spanning multiple scopes simultaneously: geographical, type of software / hardware intelligence, abstractions in each layer. The BWCM has been described in detail in papers presented in the context of international conferences ([3][4]) and also in deliverable D4.1 ([5]) (where it is simply referred to as "hierarchical control structure") and is presented, for reasons of completeness of this document in Figure 21 below.

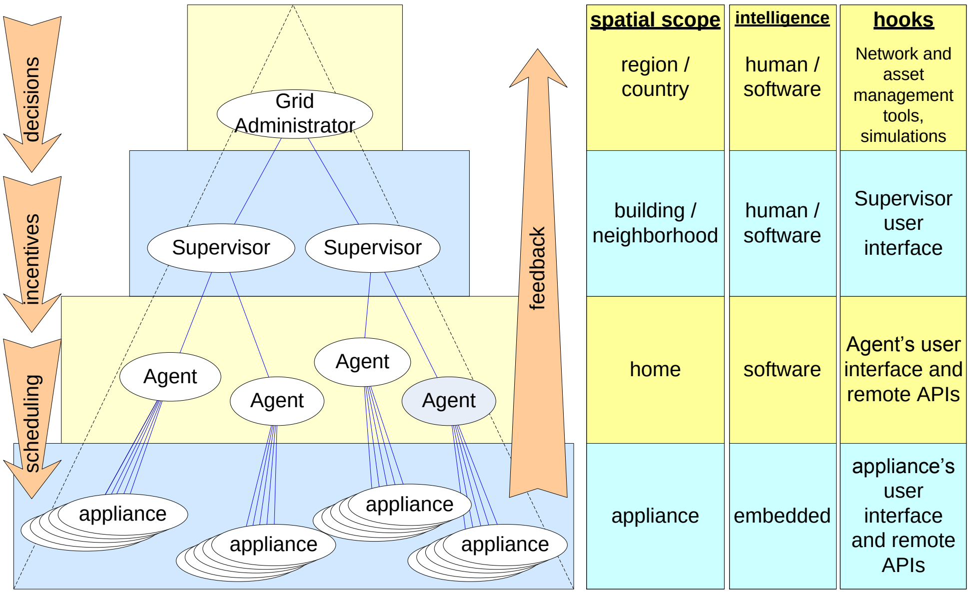


Figure 21: The BeyWatch Monitoring and Control System Conceptual Model.

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

(a) 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 neighbourhoods, buildings, homes and, eventually, appliances at the lowest level.

(b) 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, neighbourhoods) 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.

The conceptualization of the BWCM informed and, to a large extent, determined the design of the BeyWatch Supervisor and more specifically:

1. the detailed feature set of the Supervisor
2. the design of the GUI offered by the Supervisor to its human operator (since the GUI has to expose the abstractions that are pertinent at this level)
3. the BeyWatch Supervisor / Agent interface.

We consider the above model to be one of the main achievements, followed of course by the actual implementation of that software module and its successful functional integration with the rest of the BeyWatch system. The Supervisor application itself is described in detail in [6] whereas the interfaces and data models it defines to allow integration with the BeyWatch Agent are described in [4]. It is a web-based application (implemented in JavaScript / Google Web Toolkit) with a MySQL-based back-end and will not be described further in this document. In addition to the descriptions found in the references provided above, there is also a subtitled video featuring the Supervisor GUI and the way it is used to implement demand side management. It is available at: http://www.beywatch.eu/news_detail.php?id=42

Finally, in addition to the BWCM defined above and its concrete implementation (part of which is the Supervisor software application), another major achievement of this project with regard to the Supervisor application is the definition of the contract meta-model. The articulation of a contract meta-model together with an algorithm to constraint the variation of critical contract parameters (and thus enable demand-side management measures within certain limits specified on the contract) was another achievement of this activity. This mechanism is described in detail in [4] and is implemented in the GUI of the Supervisor front-end. It is by using this mechanism (and within the strictures it defines per contract class) that the Supervisor can sent the various waveforms to the Agent specifying the variation of critical contract parameters (like price, power ceiling, etc.) over time and thus influence the scheduling done by the Agent and implement demand-side management measures. The mechanism implemented in BeyWatch is far more powerful than most of the dynamic tariff systems currently employed world-wide and can in fact simulate them. This added flexibility comes with the cost of an added complexity but fortunately in BeyWatch this is acceptable as the complexity is handled by a software component (the BeyWatch Agent) and not a human user.

So to summarize, the main achievements were:

- ***Theoretical:*** the articulation of the BWCM and the definition of the contract meta-model and mechanism to constraint the variations of contract parameters over time.
- ***Development-related:*** the design, implementation and successful integration of the BeyWatch Supervisor application.

2.6.2. Lessons Learned

The lessons learned from the Supervisor may be split into two groups: one related to the energy efficiency and the first steps towards smart grid energy distribution and the second related to the development of a complex software subsystem with very demanding communication requirements.

2.6.2.1 Energy operational Efficiency

The major problem encountered in the evaluation of the BeyWatch Supervisor was the testing of the system. Rather than adopting an energy enforcement model, the supervisor follows a recommendation model supported by utility-customer energy contracts. That is based on the energy demand, the supervisor responds with a recommendation to the Agent, who tries to implement the recommendation; however, the user/customer is always allowed to override the recommendation and use more energy if needed. Of course this would result in a higher bill, but it would also break the BeyWatch demand/response model (smooth the demand instead of increase the production or transfer more power) and result in a not guaranteed avoidance of the energy consumption peaks.

In order to evaluate this behaviour, we have started from the results of the BeyWatch energy-aware devices that are shown in Figure 22. For the average temperature and sunny/cloudy days' percentages we have used the assumptions shown in Figure 4. As can be seen, the reduction is 35,6% to 40,9% (left) taking as No-BeyWatch case state-of the art Class A+ product families. Moreover, if we assume that not all white good products in a household are Class A+, the energy reduction may be even larger, while if we also calculate the energy for heating the water boiler for personal usage (e.g. shower), the energy reduction may go up to 68%.

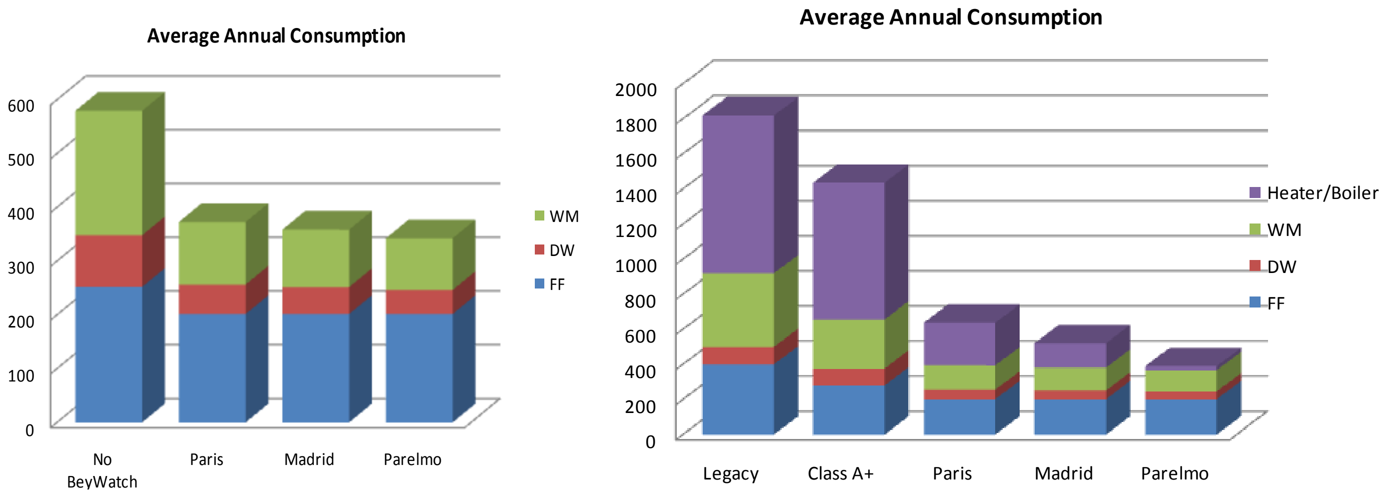


Figure 22: BeyWatch Energy-aware appliances energy reduction

Assuming that the Paris weather conditions are similar to Loughborough, we used the energy model that was implemented in WP5 and simulates the energy consumption in a neighbourhood, street and town level [14]. A number of different scenarios have been simulated, assuming different types of houses/buildings, different energy consumption models, different types of lights and white/brown appliances (both BeyWatch and non-BeyWatch, with and without CPS) and different weather and season conditions (including weekdays, weekends and vacations). Moreover, different adoption rates (AR) for the BeyWatch system were used.

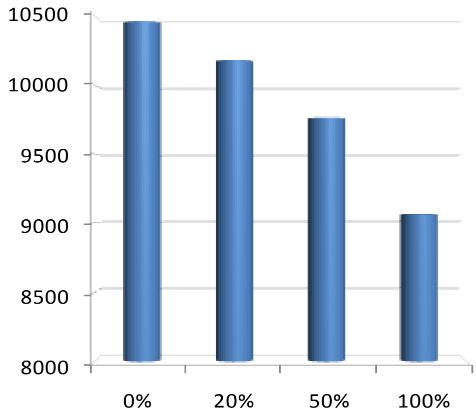


Figure 23: Annual Town Energy reduction (in MWh)

As it is shown in Figure 23, the adoption of BeyWatch by only 20% may result in 2,6% reduction of the town's annual energy consumption, while a 100% would result in approximately 14,3% reduction of the town's annual energy consumption.

Yet the most important thing is that the combination of the Supervisor and the town's Agent may result in significant reduction at the power peaks. Without taking into account any other load at the city energy distribution network, lets' assume that a citizen turns on the WM and the DW, while the FF is in operation. This may result in an additional instant peak of 6,3kW (when the WM and the DW heat water, while in parallel the FF's compressor is in operation). In a bad case scenario, within 60 minutes (the average duration of a WM and DW program) these peaks may happen 3-5 times (depending on the WM and DW program) and each one would last 4-5 minutes. Moreover, during any WM or DW program, at least a couple of 4,2kW or 3,9kW peaks respectively will happen, due to the parallel operation between the WM/DW and the FF compressor. Simulations have shown that if 60% of the WM/DW cycles take place during peak hours and the annual average of WM and DW cycles are 268 and 230 respectively per household, within the Loughborough town with the 1000 households, the network will suffer additional electricity peaks at least of 4MW with a probability of 18%. By utilizing the BeyWatch Supervisor, the probability of more than 2,5MW peaks (as a result of WM/DW and FF) is significantly reduced.

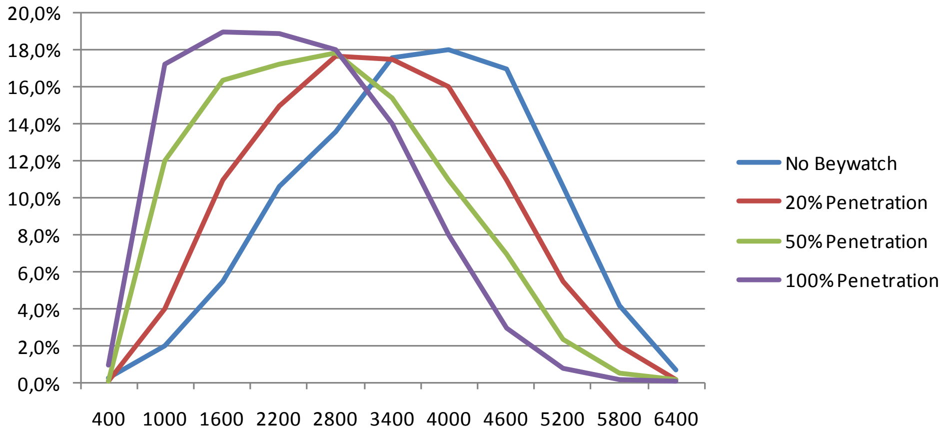


Figure 24: Annual Town Energy reduction (in MWh)

2.6.2.2 The Supervisor Communication subsystem

The BeyWatch Supervisor is an independent application that remotely interacts with a large number of BeyWatch Agents. It is therefore necessary to define and implement a mechanism for inter-process communication (IPC) among these entities. In that regard, there is currently a secular problem in the programming world which is that since the demise of CORBA: there is no generally accepted, stable, language and platform-independent formalism to define contracts and data types for remote IPC and to enable a top-down design methodology.

By top-down design methodology we mean a development strategy where a designer defines the interface of his service(s) in a language-neutral formalism, and then, based on that artefact (which is really the contract), independent software developers can communicate with his service(s) using the programming language of their choice. The last industrial-strength technology to allow that with considerable success was CORBA which used the Interface Definition Language (IDL[4]) formalism. Since the advent of the web, and more accurately, the web firewalls, CORBA deployment has been halted and this technology now mostly persists in legacy environments. It is not an exaggeration to say that this problem has been persisting for 10 years now and no generally-acclaimed solution has yet to emerge. While some may consider the WSDL (Web Services Description Language) to be the formalism that can fill the gap of IDL, in practice, WSDL support in the various tools and development environments is mostly geared towards bottom-up strategies (i.e. the WSDL is not the primary artefact like the CORBA IDL was but is rather generated or reverse engineered from the actual sources). On the other hand, and perhaps compounding this problem, IPC solutions that have been emerging in the recent years emphasize lighter and simpler approaches like plain serialization over TCP/IP sockets and may signal a return to the simplicity of 1960/1970-era state-machine driven protocols. Witness for instance the rise of technologies like Google protocol buffers ([7]) or Thrift ([8]). Most of these technologies define abstract, language-independent formalisms to define the format of the messages exchanged but in most cases the formalism only covers the data definition part and do not always provide a method abstraction at the distributed level. In fact some practitioners argue that the whole concept of a distributed method invocation is an abstraction taken too far and that the method call API is not the right abstraction to use for IPC purposes. The rationale being that it over-simplifies issues that need to be addressed at the distributed level such as timeouts, network congestion, and failures at the network stack level and so on. According to this school of thought a whole family of technologies that spans more than 40 years (RPC in the 70s, DCOM and RMI in the 90s, CORBA in the 90s/00s, SOAP-based web services in the 00s/10s) is misguided in its attempt to offer the convenient abstraction of a local method invocation when in fact, under the hood, IPC takes place. State-machine driven protocols are hard to code but are well understood, with generally accepted notations and wide deployment (in fact the Internet stack is almost exclusively powered by such protocols). Distributed

[4] In fact some similar technologies also use the rather generic term "Interface Definition Language" for the formalisms they define.

processing based on the method call paradigm is a convenient but opaque way to implement IPC, with no clear semantics covering the exceptional cases and requiring the use of extensive, black-box, third party framework.

We are mentioning the above problems to explain why it was hard to decide how to define and formalise the Supervisor - Agent communications: the bottom line is that the industry is currently at a junction and until a clear direction is taken no universally accepted solution exists. Therefore, during the integration we experimented both with REST-based web services carrying JSON encoded messages and with more traditional methods of IPC like shared database access (where at least the SQL Data Definition Language can be used to define the data models and the contract). REST-based web services can be thought of as a more lightweight version of SOAP-based web services. Moreover, a REST implementation looks more like a traditional protocol exchange. JSON is a lightweight alternative to XML with bindings for literally dozens of programming languages. Although industrial-strength, neither REST nor JSON offer an established tool-supported formalism to enable a top-down development process. Practically, this means that a protocol interface implemented with REST and JSON is defined in natural language in a human-readable document.

2.6.3. Recommendations & Future Work

As we noted above the software industry is currently at a junction where there are many competing standards and technologies for IPC with no clear winners. The Supervisor / Agent interface should be defined in an open way when the right solution becomes available. In the meantime the currently deployed implementation using shared database access is appropriate for experimentation and testing. It should be noted that this is an issue that only affects the facade of both the Supervisor and the Agent modules. The business logic and the back-end of both components (which represent 90 per cent or more of the code) are not affected.

Moreover, before a commercial roll-out is envisaged, security / privacy issues have to be considered and the application enhanced with the necessary functionality. For this prototype and since the trial took place in a controlled environment security and privacy considerations were not a major input into the design / implementation phase.

Finally, a real trial would require the active participation of actual operations personnel working for a national grid administrator who will supply use cases, identify problems experienced with currently available solutions and provide feedback on the functionality of the Supervisor application and the abstractions it exposes to its user.

2.7. BeyWatch BSS

2.7.1. Customer applications & services (User BSS)

BeyWatch BSS includes a series of tools for the two end users of the BeyWatch system: the end user and the utility user.

For the end user, Telefónica I+D has followed Customer Driven Innovation methodology in order to test BeyWatch services ideas, develop a first prototype, evaluate service functionalities provided by this prototype and finally create a service concept, which includes the functional specification of the service and a value proposition for a commercial BeyWatch energy efficiency service.

2.7.1.1 Achievements

- ***Early tests:*** These initial tests were used to get insights for the creation of a new service. BeyWatch service ideas were valued as very interesting by the two communities that were asked (parents with children and emancipated youngsters). They were also perceived as innovative and attractive, identifying as main benefits money saving (especially for parents) and ecology (especially for youngsters).

  Brakes for service adoption were the design of the appliances (watchers), the infrastructure needed (Agent platform, USB dongles for ZigBee connectivity) and the effort the customer should have to put to try to achieve more saving. To overcome those difficulties, the need to work in offering personalized consumption information, consumption alerts and automation was emphasized. Also the results from the early tests underlined the benefit from introducing an intelligent system able to achieve as much saving as possible by itself, relieving the user from the hard task of being aware of contract conditions (energy price), availability of hot water, instant power demanded by the home (in order not to overpass contracted power), etc.

- ***Validation of the initial BSS User Portal prototype***. The prototype was implemented as a web portal, which being connected to BeyWatch system instantiation at EDF testbed in Les Renardières, provides real time energy information to the user, reports and comparisons on energy consumption in the past, and a configuration page to set up the user preferences for personalization and comparisons with the community. The capabilities offered by the BSS User Portal are organized in three main pages:
    - **BeyHome**: shows detailed information on instant power and accumulated consumption in the current month for the different home appliances and in total (total consumption in the home, calculated from the data received from the smart meter). Energy production information is shown (electricity produced by the CPS and temperature of the water in the hot water tank heated by the CPS too).
    - **BeyMoney**: offers consumption reports (in total and in a per appliances basis) and consumption comparisons (for a given appliance or in total in two time periods). Comparison with other users was presented although as there is only one installation of BeyWatch with real appliances, actual consumption comparison with other users could not be performed. Only comparison of consumption with previous consumption of the user is displayed.
    - **BeyPreferences**: allows the user the personalization of contract information, house description, family habits, etc.

    BeyWatch BSS User prototype got very good global marks. The functionalities observed were **understandable** and **interesting**, and for most of the users the **service** was **very or quite new** (86,0% of the users) although **credibility had to be reinforced** (8% of the users think it is not credible at all).

    Although the service was very interesting for the 71,8% of the users, the willingness to subscribe such a service was not so high (55% would subscribe the service for sure or probably at a reasonable price) and the main reasons for not subscribing the service were:
    - Actual need (43,5%)
    - Price (58,7%)

    There were not very big statistical differences in the willingness to subscribe the service between the different segments of the sample, although it seemed to be less credible and therefore, less intention of subscription for the segment of more aged users (41-55 years old).
- ***Service Concept definition:*** The concept for a commercial BeyWatch service was composed of three essential sub-services:
    - **Monitoring and Control**: make energy visual.
    - **Reporting**: including comparatives of consumption with the community.
    - **Alerts**: configurable by the user (both conditions and mechanisms of notification).
- ***Value proposition***

    A value proposition for BeyWatch service was proposed. Energy efficiency BeyWatch service has the strength of combining utility's and Telco's expertise in energy management and communications respectively. Therefore, the value proposition states that the service should be offered by the utility as energy expert but powered by the Telco, expert in communications and with a long existing relationship with the user.

    The service should be focused on:
    - **Education**: help the user use just the energy they need guiding them in how they energy should be used.
    - **Monitoring**: Just monitoring the expenses, the saving can grow up to 20%.

- **Control**: Once the user can identify the energy drains, the service provides the user with the means to control the devices. Related to control, users accept the automatic control of some of their home appliances (such as the washing machine or the dishwasher) if that leads to a proven optimization of their total consumption. That is exactly the purpose of the BeyWatch Agent as presented before. Apart from the automatic optimization performed by the Agent, the user demand simple visual clues to show them whether it is a low tariff period or not.

Taking into account the former, the service proposed will enable the user to:

- Be aware of **energy consumption in real time:**
  - **Globally**: The service will give information of the global consumption of the house.
  - **Per appliance**: As extra feature, the user can observe the consumption of an individual appliance to look for energy sinks.
  - **From everywhere**: The user can access remotely to the service from anywhere and using different interfaces (web, mobile …)
- **Personalize the service** through a very simple questionnaire and **it will suggest him the 'extension packs' that will allow him to save more** – (EDF has the expertise to provide the best recommendations to the customer. For instance: a possible extension could include a set of watchers for the management of electrical radiators in a 'winter pack'. The management of the heating could be then delegated to the Agent, in charge of guaranteeing that the temperature in the home will always suit user preferences, and EDF could create a 'flat rate for heating', that would offer comfort to the user at a limited price while managing big loads in the manner that better matches their requirements).
  - **"Control your consumptions by managing your appliances"** (switching them on or off, automating their operation by creating programs and what is more important, relying on the service intelligence of BeyWatch (the Agent) to control them on your behalf according to your preferences, contract, habits, infrastructure at home, and environmental conditions – lighting, temperature, presence, etc).
  - **"Receive alerts"**. It is essential to be notified in real time. **Information has to reach the user at the right moment**, when he has the capability to react to cut an abnormal consumption, control his appliances or check which one is the appliance that is causing an increase in the bill. All this can be done from everywhere.
- **Modes**. Modes are the easy way for the user to establish the level of saving by default. **Eco** will automatically maximize savings, **night** will check that all the appliances are switched off, **normal** and **away**, that apart from guaranteeing that everything is ok, could include 'presence simulation' functionality for instance.
- **Reports**. The reports provided to the user make energy consumption **visual**. In this manner, it is very easy for the user to recognize consumption patterns, identify the appliances responsible for higher consumptions, split daily consumption into day and night, check whether the power contracted is adequate, etc.
- **Comparisons**. Comparisons are essential to have references for improvement. In this sense, two types of comparison are the most important for the user:
  - **Consumption comparison with previous consumptions of the user**. As far as the objective of installing BeyWatch and subscribing the service is to save money, this type of comparison is the way to visualize the level of saving.
  - **Consumption comparison with similar users** (with a similar family composition, size of house, appliances, etc). It is very interesting for the user to be able to compare his consumption with an 'optimum', with mean values (similar users using the service), and to be enabled to get in touch with those users to share experiences.

2.7.1.2 Lessons learned, Recommendations & Future work

Energy efficiency services for residential customers are perceived as new, interesting and useful. The basic rule customers follow to potentially subscribe BeyWatch services is to have the guarantee of achieving more monetary saving than the cost of the service itself.

It is also very important for them the design of the devices needed for the service. Watchers used for the prototype installation of the BeyWatch system for demonstration and evaluation are perceived as big and not very pretty. Manufacturers need to put attention to devices design while keeping price as low as possible.

In the case of BeyWatch, a possible barrier for subscription would be the replacement of the white appliances they have by new ones, as the investment should need to be amortized by the savings achieved by the service in a limited number of years. The replacement of white goods by new, high efficiency ones is being partially financed by the Government in Spain, where user validation of BeyWatch was carried out. Users are aware of that, as energy efficiency policies are well promoted ('Plan Renove'). Future regulations impose energy efficiency objectives in the residential sector to utilities. Those objectives will be translated in the offering of efficiency services to residential customers, which will be more inclined to subscribe them if the cost is very low or if they can get a percentage of the investment needed in infrastructure and equipment from the Government (or from their utility company).

Other important issue is that customers rely on their utility company for the provision of energy efficiency services. Therefore, now that the electricity market is liberalized (or being liberalized) in most of the countries, energy services should need to be provided by energy retailers (which keep the relationship with the customer), but utility-side requirements imposed to BeyWatch Agent (from BeyWatch Supervisor) need to include:

- Retailer requirements (price, dynamic tariffs, special offers, etc).
- Grid operator – distributor – requirements (global management of the grid, flatten aggregated load curve, guarantee a secure and stable supply).

Regarding interfaces between the service and the customer, a web interface is well valued, but an application for smartphones is even better as it is the 'always on' device the user has at any moment with him.

These are the 5 recommendations BeyWatch came up after service conceptualization:

- **Recommendation #1: Make it about control**

  Most users thought that monitoring was a good thing, but it didn't justify the cost. Control, in the other hand, made them feel in power and somehow was a better driver for the decision of acquiring and installing the system.

  Arguably monitoring will be a more common action in a day to day basis, but it is in the emotional distress moments when users become attached to services, and that is when control becomes important.

  There are some appliances the user wants to control always manually (air conditioning system, maybe because temperature perception is relative and changes depending on the activity for example) while some others can be controlled automatically without any concern (dishwasher, washing machine).

- **Recommendation #2: Remote Management**

  Users find difficult to understand the concept as for them it is a "black swan", something they never could have predicted or foreseen.

  But, in users' minds, there are concepts like Home Automation that already exists and are perceived as expensive but desirable. BeyWatch's remote control capabilities were perceived as something similar to Home Automation. Piggybacking on this similarity might reduce uncertainty and increase awareness.

- **Recommendation #3: Let them play**

  There is a willingness to play around with the sensors (watchers). Let them move them around and show them how the electricity is consumed in their houses.

  This will increase the awareness of energy consumption and the usefulness of such a service.

Might as well reduce the perception of the sensors as 'clutter' and incentivize the acquisition of more units.

- **Recommendation #4: Talk about the service, not its components**

  Users when confronted with the different parts didn't understand them, but when talked about the service as a whole thought it was pretty good idea.

  So, instead of focusing in the system's parts focus on the qualities of the service and its simplicity. It's not the technology what makes the users interested in it, but what they can achieve through it.

- **Recommendation #5: Education is key**

  There was an obvious lack of knowledge around things like "which appliance consumes more energy" or "is my consumption fair?"

  The service should capitalize on this by showing the user information on consumption through profiling and comparison with similar households.

  Users can be incentivized to change their usage patterns through the knowledge that they are not competitive enough. This will come through the awareness of what happens around them.

Future work on applications for the customer should be focused on the development of commercial applications together with the service provider.

2.7.2. Utility tools

The BSS Utility portal contains two different services:

- Access to BeyWatch Supervisor web interface (see section 2.5)
- Access to GL energy simulation tool web interface.

The purpose of BSS Utility tools is to enable the utility customer with the tools to rehearse the impact on energy consumption of the modifications on how the energy is consumed that he can induce (for example, facilitate the purchase of BeyWatch white appliances by the user, modify contract conditions by creating dynamic tariffs or limiting the power limit which the user can use without being penalized, etc). The utility customer uses GL energy simulation tool to get feedback on the effect produced by his action, and then command the measure that suits his needs by using the Supervisor tool.

2.7.2.1 Achievements

GL energy simulation tool has been improved in BeyWatch by:

- Updating Energy Models to reflect latest information on BeyWatch appliances consumption (Fridge-freezer, dishwasher, washing machine and CPS).
- Completing Energy Model simulations for all scenarios (2010 N Europe, Newtown N Europe and Newtown S Europe).
- Developing Network Model for northern European new town.
- Analysing Energy Model and Network Model results to check consistency.

An existing northern European town (Loughborough), with natural gas and electricity networks (gas providing all space heating and hot water demand) was chosen as a sample for the modelling exercise. A sensitivity study has been carried out to assess the impact on this existing network of introducing varying numbers of BeyWatch appliances

A northern European new town model, based on the original Loughborough model, with all houses built to high standards of thermal insulation and with modern efficient appliances has been created. Space heating, air conditioning and water heating is provided solely by electricity (heat pumps), and all domestic properties have BeyWatch appliances

Results of demand modelling have been presented at a range of levels, from individual house to neighbourhood and network level. This helps understanding of when and where demands occur on the network and helps answer the following questions:

- What are the peak demands on the network and when do they occur?

- How much can the BeyWatch appliances reduce network loads?
- What is the potential for 'peak shaving' from using BeyWatch appliances?

The network model for the current Loughborough network was assessed with demands based on 100% uptake of BeyWatch appliances to assess any benefits realised.

Additionally, a network model has been built for the northern European new town using GL Noble Denton's SynerGEE Electric software. This helps understand any network design issues associated with future networks and can be used to assess the potential infrastructure savings achievable with BeyWatch uptake.

2.7.2.2 Recommendations & Future work

A more comprehensive range of field data based on the application of BeyWatch appliances for different types of buildings and different scenarios, (e.g. family composition and usage patterns, seasonal variation) would provide more reliable validation criteria for optimizing the energy model and in-turn the SynerGEE software.

This could provide end users with more accurate simulations thus allowing them to make more informed decisions about future purchases and the associated green credentials.

By having a wide range of reliable validated database on the adoption of BeyWatch systems, both the energy model and SynerGEE software could be optimized to suit more specific requirements from end users and utilities. For a utility this could mean improved planning of future network assets thus reducing capital investment, optimizing network efficiency and minimizing disruptions to the customers.

The knowledge gained through BeyWatch is enabling GL to provide a more complete energy network end-to-end design consultancy to the utilities. For example, providing long-term energy forecasting with an associated network designed to meet those forecasts in an optimized way.

3. BeyWatch System as a whole

3.1. Achievements & lessons learned

Main achievements of the BeyWatch system have been already described in the introduction chapter (1). Apart from the technical achievements reached for each one of the subsystems that constitute the whole system, the Consortium has produced a platform which:

- Integrates successfully heterogeneous low cost energy aware products. Decoupling M2M communications from the monitoring and control part makes energy management independent from the appliances controlled and from the communications technologies that would be used for a commercial service.
- BeyWatch data models - Electricity Generation/Consumption models and simulations results are being shared with related projects as can be used as reference for further investigation and validation.
- An elegant, not intrusive and very flexible approach for Demand Side Management (Supervisor – Agent architecture, API for contract instantiation variation) has been produced, which can be of great interest for energy distributors and retailers.
- Clear insights on customer interests have been produced: Saving money, preserve the environment, get advantage of better contract conditions (being and 'active' part of the electricity system through the Agent installed at home), get access to real time information about consumption, obtain visual and understandable reports and comparisons on past consumptions, and be notified only if and when desired.

The results obtained from the work undertaken in BeyWatch can now be exploited by the telco, the utility and software vendors in different ways, as explained in section 3.2.

3.2. Business opportunities

3.2.1. Telco operator

For Telefonica, the business opportunities of BeyWatch is to offer some of the components developed in BeyWatch to enrich its Service Delivery Platform with useful tools that enable the creation of energy efficiency related services. Possible customers of Telefonica for BeyWatch outcomes are:

- **Electricity retailers**. Some of the **BeyWidgets** developed in the project can be offered to energy retailers, to help them in the creation of value added services portfolio, which allows them to compete for the end customer in the liberalized market and to promote and achieve efficiency at the same time. For example, exploitable BeyWidgets are:
  - **Energy modelling & simulation** tools: useful for energy retailers but also for electricity distributors.
  - **Washing machine / dishwasher / fridge-freezer / CPS / smart meter / external watchers BeyWidgets**: allowing energy consumption monitoring, personalization and control.
  - **Energy global monitoring**, which only needs the information available from the smart meter to offer valuable information for the user and help him to be aware of his consumption pattern.
  - **Tariff comparison**, which having the information of the consumption patter of a given user allows the energy retailer to offer better tariffs to the user (what at the same time can be very convenient for the retailer, which benefits from pushing consumption during the time they purchase electricity with lower price).
- **Third party service providers** willing to develop energy efficiency service for the end customers.

The Service Delivery Platform can be used by Telefonica itself to provide services to its customers, but it is also open to Third Party Service Providers. It comprises many modules that offer functionalities that are shared by a variety of services from different sectors (utilities, retailers, logistics, transport, environment, e-health, residential, industrial, corporations…).

- **Telefónica** itself, which populates its Service Delivery Platform with new service components that complement its service functionality offering for enterprise customers, and could offer simple energy efficiency services to its customers. The Service Delivery Platform is normally exploited in a B2B or B2B2C business models. The users of it are Telefónica customers, and cost of using the platform to provide end customer services can be fixed (monthly fee) or may depend on the usage (revenue shared model). In what regards the modules developed in BeyWatch, perhaps the most appropriate business model would be the B2B2C one in a revenue shared basis (Telefónica gives service to the electricity retailer, which offers final service to the electricity customer; a percentage of the monthly fee paid by the end customer to the retailer will go for Telefónica)

For more detailed description of the exploitation plans for Telefonica please refer to [9]

3.2.2. Utilities – Distribution and retail

As described in [9] and in [11], increasing the flexibility of the demand is a key point for the future electrical systems, both for the Transport and Distribution Networks and for the Production and associated retail. This flexibility may in particular help to cope with:

- the peak loads on the grid, that are getting higher and higher every year, pushed by the continual increase of the global energy consumption and
- the increasing but intermittent share of renewable generation means, either distributed (mostly photovoltaic) or centralized (mostly wind turbines).

It should be noticed that these two facts are much more related to power and to the time and period when power is demanded, than to energy. And that there is a gap between the commonly understood challenges in energy, often simply put as a reduction of energy consumption, whereas the flexibility of the power demand is a challenge at least as important but far less well understood, because power is more complex and even more difficult to represent and model well.

As seen in [11], dynamic tariffs such as on-peak/off-peak or Tempo tariffs have successfully existed for many years. Their success was directly linked to the flexibility of two main electricity uses: electrical heating and, overall, electrical hot water tank which is still playing a key role in the balance of the whole French electrical system.

In order to face the big challenge of the increasing peak loads and share of intermittent generation, the paradigm has to be revisited and new sources of flexibility have to be found. Fortunately, introducing the ICT in the grid and in the homes, leading to the so-called smartgrids and their “ends” - the smart homes - may help to achieve this objective[5].

To do so, every home appliance has to be investigated, to identify what intrinsic flexibility in the energy use it may bring. These intrinsic flexibilities of the appliances were worked out in the BeyWatch project and classified in [10] into four categories: energy storage, external of internal heat provision, shifting possibilities, dimming possibilities. All these categories can be found in at least one of the appliances considered in BeyWatch.

The question was then how to “reveal” this flexibility, in order for the electrical system to be able to use it in a way that is acceptable to the user. This is where the ICT have a fundamental role: their integration in the white goods is the only way, because, while adopting a flexible energy use, the appliance has to perform continuously a close control of its operation and performance, and that can’t be done externally.

[5] In the line of the first remark of this chapter, it should be noted that it is perhaps one of the main and superior goals of the smartgrids ; failing to well understand this and thinking that smartgrids are more a business opportunity for new players in the energy system than a way to cope with the 21st century challenges of the energy system could lead to miss the main target of the smartgrids and to major collapses in the future energy system.

As described in the above chapters, the BeyWatch project has shown that this integration is possible and can work, even if it leads to difficulties that have also been detailed and may sometimes lead to a partial or total re-conception of the whole appliance, in the same way as it was done for lowering their energy or water consumption. Some more work has probably to be done before having these functions in the appliances of the market, as well as trials with real users. It is also probable that some flexibility ideas haven't been investigated yet and could be in the future, as for instance, for the refrigerator, the redistribution to the fridge compartment of the cold stored in the freezer compartment, which could, with a good level of insulation and doors kept closed, lead to an energy consumption only at night when power demand and cost of energy generation is lower, as for the hot water tanks.

Then, there are also some considerations related to the Agent, regarding its progressive deployment and its costs.

- It is evident that such a complex smart system as the one considered in BeyWatch will not arrive in one shot in the homes. Instead, the appliances, that the customers mainly buy to renew their old one, will arise one by one in the homes. In the same idea, it has been seen above that the installation of a new hot water network in an existing home is complex and costly, which doesn't allow to easily generalizing the BeyWatch principle of feeding the machines with hot water. This is why it is important to be able to use the flexibility of a single appliance in the home, in the simplest and cost effective way.
- In such simple situations, which will certainly be much more than the complex ones in a short and middle term, the agent might not be mandatory: it would introduce extra complexity and extra cost difficult to justify. In such a case, the appliances should be smart enough in order to get from the smart meter the signals coming from the grid and to self-adapt to them. This would be a key need, taking into account the slow and progressive deployment of the smart appliances.
- It is also clear that, when the situation gets more and more complex, the introduction of an agent should be possible and desirable. This means for the appliances the ability to operate either with or without the control of an agent. The agent is acting as a conductor in an orchestra: when there is only one or two players, his presence is useless, but when there are many appliances playing, then he must be there to coordinate and define the global optimization that none of the appliances may define by themselves.

Last, even this way, it can be expected (see [1]) that integrating the flexibility in the appliances lead to extra costs that are not seen as worth to buy for the customers. In order to initiate the move and allow positive business cases, it could be necessary to introduce in the regulation rules about the integration of the flexible energy use of the appliances, as it was done, for example, for their energy consumption, in operation or in standby mode (see [12]).

3.2.3. Appliances manufacturer

For Gorenje, as the manufacturer and distributor of household appliances, the business opportunities for marketing of the complete BeyWatch system, seem to be rather limited and far from its core business in terms of the specific means of managing-executing it.

But nevertheless, if reflected well enough, there exists a niche, which yet differs in its characteristics from appliance producer to appliance producer, depending on his overall philosophy, different market mentalities, historical reminiscences and actual reputation on the markets.

For Gorenje for instance, the western Balkans represents the market, which merges all characteristics listed above. This fact can be good exploited for introducing the novelty, as the BeyWatch system is with no doubt. On the one hand, Gorenje enjoys advantages of its excellent reputation and trust on this market, on the other hand, western Balkans are very fast developing societies, which long to join the developed Western Europe as soon as possible, and as such are very much acceptable for innovations also on the field of energy saving. Encountering these circumstances, Gorenje with no doubt could be the first successful initiator for establishing of the intelligent energy saving grids in this area, within promoting all of the partners from the BeyWatch project.

The next for Gorenje logical step from this point could be the promotion of BeyWatch way of energy saving into Ukraine and Russia.

For FAGOR the Business opportunities are focused on the deployment of connectivity solutions developed for the washing machine and the dishwasher to all other household appliances and develop a home control device, (a Fagor specific home gateway), in order to not only manage communications within the home but also allow connectivity with the outside world (via web services, …) with an architecture flexible enough, (supporting different operating systems, programming languages, graphical user interfaces,...) to allow the addition of new services for the home control:

- Home automation network management service:
  - Exploring new ways to access the Fagor´s home automation network, with better management of the energy consumption and remote control of the appliances but also management of other devices
  - Proposing alternative ways of control for the user, using different electronic portable devices allowing connectivity trough web services
- Environmental Welfare service, keeping the home in optimum comfort conditions;
- Remote diagnostics service, offering Fagor´s customers online diagnosis of their appliances;
- Specific software updates Service;
- Security and safety services, management of technical alarm as water, gas leaks, power cut off, etc., anti-theft systems,...;
- Health care service, tracking the health of family members;
- Nutrition and dietetics service, setting up a personalized weekly menu of a family, where the oven, refrigerator and data base supported by Fagor can play an important role.

3.2.4. Software Vendors

For Synelixis Solutions BeyWatch has been the initiative to move from the home network and smart home areas to the area of Energy Management. This huge market area is extended from the efficient energy consumption at Home to the smart grid domain. Since May 2011, a commercial contract of collaboration has been signed between Synelixis and Telefonica I+D for common exploitation of the Agent Platform. Moreover, Synelixis has established strategic collaborations with software vendors in Greece in order to exploit business opportunities in this area.

In more details, based on the technical role in the BeyWatch project, Synelixis has identified the following important lesson/results:

- **Agent Platform.** Synelixis validated a number of hardware and software solutions for the BeyWatch Residential Gateway (including SW middleware and M2M physical interfaces), and has concluded to a powerful, flexible and low-cost solution, which could be directly exploited as a home energy management platform. The lesson learned is that in order to be future proof the M2M communication should be kept separate at least until a solution has become dominant or standardized.
- **Home Energy Consumption Scheduling Optimization (HECSO).** Home energy consumption scheduling is a very complex multidimensional problem, which takes into account the various energy consumption profiles of the consumer electronic devices, the energy generation profiles e.g. based on photovoltaic cells or hot-water based on solar panels (taking into account also weather forecasts) and the various tariffs and business models applied by the utility companies.

For GL the BeyWatch project has provided the opportunity to develop a more accurate energy simulation and network modelling tool with an emphasis on smart appliances using renewable power. This has opened the opportunity for new consultancy work in the development of new energy networks and future enhancement of existing networks. In particular, GL is in the process of developing the following enhanced services to better address the requirements of our customers:

- **Energy Forecasting** – accurate forecasting of energy demand from a combination of historical data, real-time data and associated scenarios stretching over several decades. This information is critical to the energy transporters and network operators as their efficient operation is highly dependent on accurate and reliable forecasts.
- **Network analysis tools** – real time impact analysis of loads on energy networks to ensure reliable supply to the end user with optimized investment in the network infrastructure over the life of the asset.
- **Energy Model** – a more comprehensive model incorporating commercial and industrial sectors could also be developed to provide a more realistic day-to-day application to handle more accurate load management. This could ease the adoption of smart tariff structures to benefit both the end user and the utilities.

4. BeyWatch Evolution

This project has been dealing only with domestic premises and **the next phase should address the incorporation of commercial and industrial buildings**. The usage patterns and energy requirements of such premises are very different to domestic ones and the knowledge gained on such work would further enhance the global energy consumption/generation profiles. This would lead to a more realistic solution to provide carbon footprint reduction within the energy market thus meeting future EU and worldwide regulations on emissions.

The work undertaken by the BeyWatch project up to now has resulted in a complete system that enables the provision of energy management services in homes. It is based on some premises:

- The house is provided with an intelligent home energy manager, the Agent, which gets requirements and data from different sources (utility – distributor or retailer, customer, weather conditions, historical consumption reports, forecasts of in-home micro-generation (electricity and hot water production), etc) to optimize the use of electricity and hot water in the without losing comfort.
- The Agent is connected via Internet with a Supervisor, in charge of managing aggregated electricity consumption in a given geographical area (which could be a building, a neighborhood, or the homes supplied by the electricity distributor or retailer in the area).
- The Agent is also connected with the smart electrical appliances in the home, which offer a monitoring and control interface that enables the Agent to make use of the
    - Producing energy (electricity and hot water generated by the PV and ST panels managed by a CPS system)
    - Storing energy (fridge-freezer)
    - Load shifting or (dishwasher, washing machine)
    - Energy dimming (electrical radiators)

  capabilities they may have, to control their operation in order to use electricity in an optimum way, minimizing the cost for the user.
- BeyWatch system assumes that the utility company (energy retailer) models electricity price (through the tariff agreed with the customer in the contract or by agreeing on a contract that allow dynamic pricing) to drive the Agent in order to use electricity when it is more convenient:
    - To flatten power demand curve.
    - To guarantee stability of the electrical system.
    - And to cope with the integration of renewable and normally intermittent generation sources (wind turbines, solar plants).
- Electricity consumption patterns for smart home appliances is known, and therefore the effect of replacing the existing normal appliances by new, more efficient and ICT enabled ones can be rehearsed, providing realistic data that might foster regulation and incentives for the adoption of this type of appliances (together with the energy management system able to get maximum benefit from them).
- The electricity smart meter, connected to the intelligent Agent developed in BeyWatch, provides almost real time knowledge on power and electricity consumption in the home. Customer's segmentation is possible based on this knowledge, energy management services can be personalized as well as the tariffs the retailer can offer to them.
- The home user perceives energy management services as very innovative and attractive, and would be willing to subscribe theses services at a reasonable price (measured in terms of monetary saving and comfort capabilities they may bring over).
    - Home users don't want to be bothered with complex decisions on when and how use the home appliances, so they are comfortable with the concept of an intelligent Agent controlling non critic appliances for them.
    - They value very well the educative component of an application that show power and energy consumption data in real time, sets the basis for comparison (what is a normal/abnormal

consumption) and helps him with personalized suggestions to improve in the way electricity is consumed.

Most of the former considerations would need to be adapted for industrial and commercial buildings, as electrical equipment existing in those buildings may offer many other possibilities for energy storage and load shifting or dimming. Moreover, the customer in those cases is very different from the residential customer, and it is normally more interested in saving money – even more in these cases as the potential for saving is much higher as it is also the consumption.

Another way of evolution of the work done in BeyWatch is in the **interface between smart grids and smart homes**. One of the main objectives of smart grids is the integration of renewables. Renewable energy has two characteristics that make its integration complex:

- They are intermittent.
- And unpredictable (at least with a high precision).

But the benefits they bring along are bigger that the difficulties they present, as these resources are unlimited and non-contaminant.

Changing the generation mix to increase the share of renewables implies not only the management of renewable generation plants but also the management of consumption (in the industry, businesses and private homes), and the tools that are (or will be available) to manage consumption in homes and buildings are:

- Storage.
- The integration and management of electric vehicles.
- And the intelligent management of shifting loads.

The evolution of BeyWatch could in the future then:

- Extend the Agent functionalities to benefit from the storage capabilities of appliances:
- Particularize the Agent for the management of the charging of the electric vehicle. Electric vehicles will be (as well as combustion vehicles are) used normally during the day, and be parked during the night. For home users with a private garage at home, electric vehicle will be re-charge during the night to get benefit from a lower tariff and contribute to increase power demand during the ‘valley hours’, when for example, electricity production from wind use to be high and power demand from residential sector is lower. Even if the charge is done at night, it has to be performed in a managed manner, from a ‘charge manager’ that could command the start of the charge at the time it is more convenient for the utility. The charge manager could be also an evolution of BeyWatch Supervisor particularized for the coordinated management of electric vehicles – not all of them can be charged at the same time - their aggregated charging should raise power demand at night in such a manner that ideally power demand will be flat.
- BeyWatch system (Supervisor-Agent-BSS) could be then the seed for planning and specifying a coordinated system that integrates smart grids and smart homes:
    - To drive storage in the homes, businesses and industries.
    - Manage electric vehicles (storage too but also a movable and mobile load)
    - And mange shiftable loads for all kind of buildings.

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