GREEMBED

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CPSWEEK 2010

Workshop on Green and Smart Embedded System Technology: Infrastructures, Methods and Tools

Workshop Proceedings

Edited by:

Huascar Espinoza, ESI-Tecnalia, Spain
Alberto Sangiovanni Vincentelli, University of Berkeley, USA
Roberto Passerone, University of Trento, Italy
Marco Di Natale, University of St. Ana, Italy
José Javier De Las Heras, ACCIONA, Spain
Daniela Cancila, CEA LIST, France

Organized and Funded by:

ARTEMIS eDIANA Project

FP7 Network of Excellence on Embedded Systems

FP7 COMBEST Project

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Foreword

1. Overview

Efficient production, transmission, distribution and use of energy are fundamental requirements for our modern society and the challenge of a green, low carbon economy. Embedded systems have an important role to play in increasing the energy efficiency and in reducing carbon emissions to sustainable growth. Indeed, most systems for monitoring and control of energy production, distribution and use are today interconnected and controlled by embedded devices, in areas such as industrial manufacturing, transportation systems, building automation, domestic appliances and more. This offers the opportunity for the creation of new integrated systems offering new products, processes and services with greater efficiency and better situation awareness to end-users and service and infrastructure owners.

Energy-efficient systems offer unique challenges to the embedded system community, from system-level design to dynamic and adaptive controls, optimization of architectures and communication, real-time and reliable services as well as reusable software components and systems.

Energy efficient solutions include both local and global smart solutions. Smart embedded solutions merge ubiquitous computing and the Internet of Things, i.e., the technology integration with sensors, actuators, micro-chips, micro- and nano-embedded systems that allow for collecting, filtering and producing more and more information locally, to be further consolidated and managed globally according to business functions and services. Locally, embedded systems provide information on energy consumption of every energy consuming appliance in a single location (e.g., home, building, vehicle) to be provided in real-time, in a user friendly way, thereby empowering citizens to take decisions that lead to energy savings. Globally, energy efficient solutions include smart grid concepts, which require dynamic controls for balancing and organizing production from renewable and conventional sources, negotiating, purchasing and routing power requests, but also regulating, balancing and controlling the amount of electrical power that systems consume.

From the system-level design perspective, there is a need for simulation, modelling, analysis, and monitoring methods and tools to facilitate an integrated system approach. Today, energy efficient solutions are developed by independent companies whose products or components are tested for individual performance independently of each other. An integrated system approach to the design and implementation, where these components are integrated in a way that they reduce energy consumption through cooperation, is rarely used. This often leads to significant system-level inefficiencies. System design methods and tools, including model-based solutions, must consider the growth and evolvability of hardware and software platforms, to ease the conception, development, validation and integration of new devices and services. The challenge and opportunities not only lie in the integration issue, but also in providing methods and tools for innovative solutions that satisfy government regulations, customer expectations and meet environmental challenges.

2. Objectives

GREEMBED 2010 (First Workshop on Green and Smart Embedded System Technology: Infrastructures, Methods and Tools) aims at bringing together experts, researchers, and practitioners, from the embedded systems community, who are interested on research and development of embedded system infrastructures, methods, and tools for green and smart energy-efficient applications.

The topics of the proposed workshop are extremely important from an economical and social view and yet some of them still constitute emerging research areas, possibly without well-established or recognized results and require integration of knowledge and cross-fertilization from different domains. CPS Week is an excellent opportunity to bring together people from diverse embedded systems communities, such as controls, simulation and modeling, embedded computation and communication models and algorithms, software and hardware design, languages, sensor networks, real-time systems and several applications communities. Jointly, these communities can help create a critical mass of research, development and innovation in green embedded system technologies. An open exchange of ideas and experiences will benefit the global community, leading to new insights and stimulating further development.

3. Topics

Contributions were sought in (but are not limited to) the following topics:

- Adaptive and dynamic controls for energy management (production, distribution and use)

- Design and optimization of large-scale heterogeneous architectures for reliable and real-time communication
- ICT infrastructures for energy management and smart applications.
- Pervasive and friendly user interfaces for user awareness on energy consumption and context-based system usage.
- Standards and interoperability for energy efficient and smart embedded system infrastructures.
- Systems-thinking, multi-stakeholder, and multi-disciplinary design and construction of sustainable and energy-efficient facilities.
- Analytic, simulation and prototype-based approaches to assess environmental performance of buildings, and allowing optimization and trade-off assessment based on multi-criteria constraints.
- Model-based engineering for energy-efficient embedded system infrastructure, including controls, software components and execution platform.
- Application-specific methods for design and implementation of energy-efficient infrastructures, including building applications and green vehicles.
- New business opportunities.

4. Program

The GREEMBED 2010 program is detailed in the Table of Contents (page 3). The workshop presentations feature a mix of prominent industry/research leaders and high-quality sessions.

We hope that you enjoy GREEMBED 2010.

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Alberto Sangiovanni Vincentelli, Univ. Berkeley, USA
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Juan Perez, Labein, Spain
Martin Törngren, KTH, Sweden

REEB – The European strategic research **R**oadmap to ICT enabled **E**nergy-**E**fficiency in **B**uildings and constructions

Juan Pérez
Construction Unit
TECNALIA Labein.
Derio, Spain
Juan@labein.es

Alain Zarli
Information Technologies and Knowledge Dissemination Department
Centre Scientifique et Technique du Bâtiment (CSTB)
Sophia Antipolis, France.
alain.zarli@cstb.fr

Abstract— **The REEB project is a Co-ordination action addressing the Strategic Objective: ICT for Environmental Management & Energy Efficiency for the construction sector. The project aims at providing a vision and a roadmap for co-ordinating and rationalising current and future RTD in the fields of ICT support to energy-efficiency in the built environment of tomorrow. The main outcome is a strategic research agenda that has been elaborated with the support from a European-led community dedicated to the innovative use of ICT supporting EE in Construction, bringing together the ICT community and key actors of the (Construction) Environment and Energy business sectors.**

Keywords (Energy-efficient buildings, ICT, Vision and SRA (Strategic Research Agenda))

I. INTRODUCTION

Growing concerns priorities today, especially in Europe, are environment protection and energy conservation, moreover in a context where "systems" (should they be transportation systems, industrial systems, systems empowering the built environment, etc.) are more and more complex and demanding in terms of information management: it is nowadays acknowledged that ICT (Information and Communication Technologies) is the key for a 2-way flow of both energy and information in the Energy sector as a whole (production, distribution, consumption and management). Due to its impact and the opportunities it offers, ICT is considered too as the key for a liberalised market, leading to changes in business practices in the Energy sector (in a similar way this has been the case with ICT strongly impacting the Telecom sector and market). ICT is the key for empowering people in the (built) universe in which they live, with smart e-metering and new smart e-devices, A high potential is also foreseen for ICT becoming fully pervasive in the future optimization of energy in the built environment - where "Energy-efficient smart buildings" are buildings which contain systems that manage information for an optimal operation of building energy flows over the whole building lifecycle.

In this context, REEB (the European strategic research roadmap to ICT enabled Energy-Efficiency in Buildings and construction) is an ongoing European R&D technology roadmap initiative (achieved in the context of an EC-funded Coordination Action - http://www.ict-reeb.eu) for IT to support Energy Efficiency (EE) in the built environment.

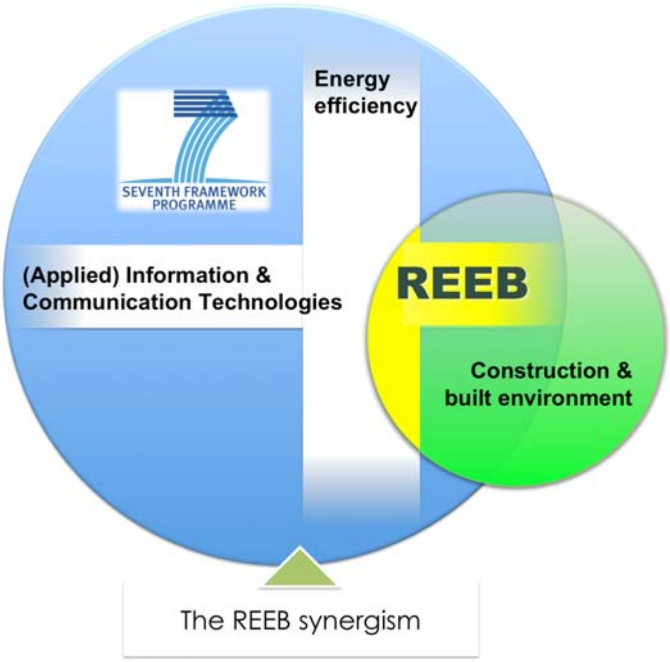

Figure 1. REEB framework

REEB has been launched as a response to the need for coordinating and rationalizing current and future RTD in Europe in the area of ICT support to EE in constructions: it has been set to develop a European-wide agreed vision and roadmap providing pathways to accelerate the adoption, take-up, development, and research of emerging and new technologies that may radically transform building

constructions and their associated services in terms of enhanced energy consumption.
This paper aims at introducing to the Vision and the Roadmap developed in REEB, after feedback and validation from many stakeholders at the crossing of ICT, Construction and Energy. REEB is a key milestone in identifying, synthesising, and prioritising a comprehensive set of agreed main problems, challenges and prescribed RTD for new ICT-based solutions related to the future delivery and use of EE facilities and buildings, in Europe and world-wide..

II. THE REEB VISION

The elaboration of the vision [1] has resulted from the crossing of inputs provided by the REEB partners, and many stakeholders having joined the International REEB Community [3], bringing together the ICT community and key actors of the (Construction) Environment and Energy business sectors. A key finding is that, while there is an emerging consensus about the key RTD issues in ICT-enabled EE of buildings, the potential impact of various technologies is not sufficiently well known. Thereby it is difficult to assess the relative importance of specific technologies, applications and systems, and it is necessary to develop a more holistic understanding of the potential effects of ICT on the EE of buildings. The vision in REEB is that the high level impacts of ICT to energy-efficient buildings are envisaged to evolve as follows (*figure 1*):

- Buildings meet the EE requirements of regulations and users – short term.
- The energy performance of buildings is optimized considering the whole life cycle – medium term.
- New business models are driven by energy efficient "prosumer" buildings at district level – long term.

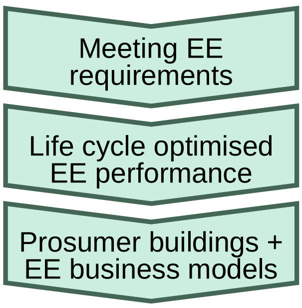

Figure 1: Envisioned evolution of energy efficient buildings

ICT is often perceived by practitioners as various specific computing and automation applications. However, ICT is also a generic enabler for integration of various processes, applications, systems and technologies: databases, collaboration & communication infrastructures, interoperability standards, knowledge management, modelling, optimisation, simulation, visualisation, etc.

REEB has identified 5 key research areas where ICT enables both new applications and integration:

- Integrated design and production management.
- Intelligent and integrated control.
- User awareness and decision support.
- Energy management & trading.
- Integration technologies.

The role of ICT in these areas is envisaged as follows:

- Life cycle approach: Integrated design teams, using interoperable model-based tools and communication/collaboration platforms optimize the whole life performance of buildings.
- Smart buildings: Most buildings will be "smart" and control themselves maintaining the required and optimal performance and responding proactively to external conditions and user behavior anticipating them, rather than reactively. Holistic operation of subsystems is supported by integrated system architectures, communication platforms, standard protocols for interoperability, sensors and wireless control technologies.
- Construction as a knowledge based industry: Industrialized solutions are available for configuring flexible new buildings as well as retrofitting existing buildings. Customized solutions are developed by configuring re-usable knowledge from catalogues within organizations and industry-wide.
- Business models and regulations are driven by user perceived value. Financing models provide incentives to stakeholder towards whole life performance of buildings. ICT tools support performance measurement, validation and holistic decision making.

III. THE REEB ROADMAP

The REEB Roadmap [2] is described under the form of 5 sub-roadmaps, providing for each category of research topics as identified in the REEB vision specific RTD challenges to face at short, medium and long term to achieve the vision. It also illustrates the long-term situation (and its evolution from now on) with the State-of-the-art and visionary scenarios of the future, and identifies drivers, barriers, impacts, and where applicable, related roadmaps developed in another context than REEB. Similarly to the REEB Vision, the methodology, leading to the REEB strategic research agenda and its various RTD priorities for ICT supported EE buildings, has been based on the integration and synthesis of inputs provided by the REEB partners and key target groups of the "ICT4EEB community" [3] including e.g. European Technology platforms and RTD projects in the 3 core areas of focus, and the European Commission. The baseline of the work is also relying on the EC policies and the visions and strategies of a

number of related initiatives (*see reference [2] for more detailed information*).
These are the main research priorities that have been identified by every sub-roadmap:

- Integrated design and production management: **Integrated engineering** (integration of various tools to support a holistic process bringing together the views of different stakeholders to address the whole life of buildings), **Design for energy efficiency tools (D4EE**) (covering a broad range of CAD and other applications for design and planning of buildings - both new and existing to be renovated - and the urban infrastructure), **Production management (**covering: contracts & supply network management; procurement; logistics; on-site and off-site production management), **Modelling** (Building modelling (BIM), district modelling, model granularities, ontologies for eeBIM, semantic mapping; Standardized Semantic Data Models), **Performance estimation** (covering various methods that are used at design stage to estimate the performance of the building for decision making and contracts e.g. simulation, wholelife costing and life cycle impact assessment).

- Intelligent and integrated control: **Automation and control** (methodologies, procedures and ICT systems that are able to manage all energy production and usage in a building, according to information received from inside the building and outside in order to ensure comfort, while optimizing the energy consumption of the building), **Monitoring** (relying on the instrumentation of the building with smart meters, other sensors, actuators, micro-chips, micro- and nano-embedded systems that allow collecting, filtering and producing information locally), **Quality of service** (covering issues such as improved diagnosis and secure communications), **Wireless sensors networks** (enabling all energy systems and conditions measurement devices to communicate).

- User awareness and decision support: **Performance management (**fine-tuning building performance indicators (accuracy, comprehensiveness, ease of use), and create tools to give support to the end-user for performance improvement (decision support), **Visualization of energy use** (ongoing research projects on this topic need to be further continued, especially through multidisciplinary pilot projects so as to work on energy efficiency incentives and adequate energy visualization presentations), **Behavioral change by real-time pricing** (new technologies for energy metering and local energy generation will considerably change the customer relationship with the energy providers. The implied change on regulation and business models offer new perspectives and need to be accompanied by new adapted ICT infrastructures).

- Energy management & trading: **Real-time response and Predictive Management** (Embedded sensing, automation and control, Secure ubiquitous communications), **Enhanced Design and Integration** (Network Planning, Plug and Play scalable integration of micro-generation and storage), **Distributed Generation and Demand Response** (Demand Response Capabilities, Low-latency communications, Load Balancing Techniques, Performance Analysis and Evaluation).

- Integration technologies: **Process integration** (collaboration support tools and business work flows), **System integration** (Plug & play; Connections, Service oriented architectures, Integration platforms+ value added services, Cabling, Gateways, Middleware, Development methods and tools (Integrated design environments (IDE), HW simulation & testing environments, UML profiles, Data modeling methods), **Interoperability & standards** (data models and real time (in-side and out-side building) communication protocols), **Knowledge sharing** (Access to knowledge, Knowledge management, Knowledge repositories (Contents; Personalization / user profiling), Knowledge mining and semantic search, Long-term data archival and recovery), **Virtualization of built environment** (Office optimization, Server virtualization).

JOIN US

REEB is not a close project**; we invite you to collaborate with us** and sending us your comments about the REEB Vision [1] and the technological roadmap [2]. Your contributions will be taken into account in the REEB book that will be issued by September 2010. We also invite you to be member of International REEB Community (IRC - http://ict-reeb.eu/irc.html), in such a way that you will be permanently updated with the last project results.

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eDIANA – Embedded Systems for Energy Efficient Buildings

Rafael Socorro
Research and Development Department
ACCIONA Infraestructures S.A.
Madrid, Spain
rafaelclaret.socorro.hernandez@acciona.es

José Javier de las Heras
Research and Development Department
ACCIONA Infraestructures S.A.
Madrid, Spain
josejavier.heras.bueno@acciona.es

Abstract— **eDIANA will provide a Reference Architecture for a network of composable, interoperable and layered embedded systems that will be instantiated to several physical architectures.**

Keywords (ICT, energy efficiency, smart building, reference architecture)

I. INTRODUCTION

According to the European Union Directive on the Energy Performance of Buildings (EPBD 2002/91/EC), buildings are responsible of more than 40% of the energy consumption in Europe.

Moreover, buildings are the largest source of CO2 emissions (about 1/3) in the EU27. The tendency shows that the total energy consumption has been rising since 1990 and will continue if strong actions are not taken. The challenge is to reduce the energy consumption (compared to 2005) and GHG emissions (compared to 1990) by 20% by 2020. In this reduction, buildings shall contribute accordingly.

ICTs and, therefore, embedded systems, as an enabling technology for energy efficiency shall, as stated by the European Commission in its communication addressing the challenge of energy efficiency through ICT, strongly contribute to the challenge. While such systems exist today, their effectiveness is often limited by a lack of interoperability, leading to fragmentation and limited overall impact. The project that is presented in this text is a strongly application-oriented initiative which is focused on the conceptualization, design, development, demonstration and validation of new devices operating in a uniform platform called eDIANA.

The eDIANA Platform is a reference model-based architecture, implemented through an open middleware including specifications, design methods, tools, standards, and procedures for platform validation and verification. eDIANA Platform will enable the interoperability of heterogeneous devices at the Cell and MacroCell levels, corresponding respectively to a living/working unit (one house, one office, etc.) and to a residential or non-residential building (usually composed of several Cells) and it will provide the hook to connect the building as a node in the producer/consumer electrical grid.

Thus, eDIANA will provide a Reference Architecture for a network of composable, interoperable and layered embedded systems that will be instantiated to several physical architectures. The eDIANA Platform realisations will then cope with a variable set of location and building specific constraints, related with parameters such as climate, Cell/MacroCell configuration (one to many, one to one etc), energy regulations etc.

II. EDIANA ARCHITECTURE

The eDIANA Reference Architecture covers all the present and future elements involved in the energy management of the house-buildings, taking into consideration the different grades or levels of comfort that those elements provide to the user.

The eDIANA Reference Architecture is a hierarchical and open architecture; it does not demand a unique implementation of its elements so it enables the addition of new components, change and update them whilst they are compliant with the architecture.

This is why the eDIANA Reference Architecture is based on components located in different levels. All the components interact with the rest of the Platform components through interfaces. These interfaces allow the communication between components in the same level or different level.

The eDIANA components are logical, their implementation can be translated to a device for each component; however this is not compulsory, several components can be implemented in the same device. The component classification and characterization plus their interfaces enable to model the architecture so that an implementation of the eDIANA architecture will admit any device that hosts an eDIANA component with its correspondent interface.

Figure 1 shows how the eDIANA Platform (EDP) interacts with the outside. The local environment interacts with the lower level of the platform, this environment refers to the elements of the building that eDIANA Platform controls to achieve the objectives of energy efficiency and user comfort.

The eDIANA Consortium would like to acknowledge the financial support of the European Commission and National Public Authorities from Spain, Netherlands, Germany, Finland and Italy under the ARTEMIS Joint Technology Initiative.

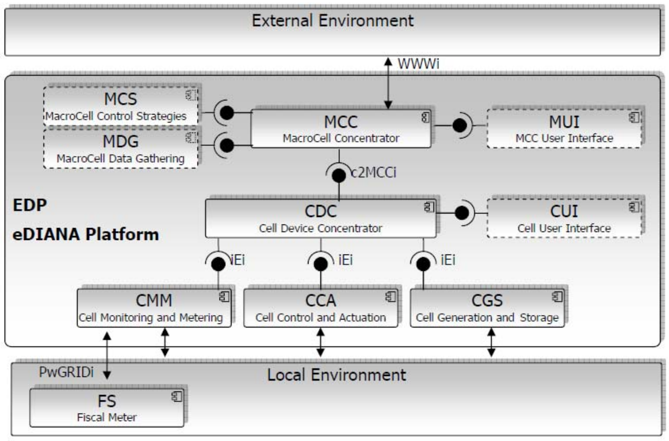

Figure 1, eDIANA Platform and external and local environment

On the other hand, the external environment interacts with the upper level of the platform, this environment refers to the building outside, in eDIANA Context the Power Grid, and the Platform remote access.

As previous sections have described, eDIANA Reference Architecture has a hierarchical organization, there are two levels that make up the eDIANA Platform (EDP), the MacroCell level and Cell level.

eDIANA Reference Architecture defines several components for each layer, attending the functionality each layer should provide. Considering a bottom-up approach and description, Cell Level integrates all components that interact with the building elements and devices: appliances, lighting, HVAC, etc. eDIANA Reference Architecture defines the next component types inside eDIANA Cell Level (see Figure 1):

- Cell Device Concentrator (CDC)
- Cell User Interface (CUI)
- Cell Monitoring and Metering (CMM)
- Cell Control and Actuation (CCA)
- Cell Generation and Storage (CGS)

An implementation of eDIANA Reference Architecture can separate these components into different devices or integrate some of them into one.

More specifically, the last three component types undertake the task of obtaining all the information about the energy consumption of all elements of the building, communicating with the Cell Device Concentrator through the iEi (intelligent Embedded interface) and executing the orders that above components and layers define.

The communication between these components is hierarchical too; CMM, CCA and CGS can only communicate with the CDC. The architecture defines a unique interface, the iEi, to accomplish this task. In the definition of this interface, the architecture will describe the functionality required by all the components that use it, although a component may not implement all the services that the complete interface provides, only the ones that concern with the component.

The Cell User Interface is another component in the Cell level. It communicates only with the CDC in order to provide Cell level information to the user of the platform.

Keeping on the bottom-up approach, the CDC is in charge of the communications between the Cell level and MacroCell level. This communication is made between the CDC and the MCC, through the interface c2MCCi (Cell to MacroCell Concentrator interface).

The components that the eDIANA Reference Architecture defines at MacroCell level are:

- MacroCell Concentrator (MCC)
- MacroCell Control Strategies (MCS)
- MacroCell Data Gathering (MDG)
- MCC User Interface (MUI)

The components placed in this MacroCell level interact with the external environment in order to obtain information to elaborate the necessary strategies. These strategies will take into account the external environment (data from Power Grid-PwGRIDi and external resources-WWWi) and the information of the cells that are in charge of that MacroCell when producing the recommendations to Cell Device Concentrator.

III. eDIANA Scenario Example

As it was explained before, the platform is flexible enough to be used in several kinds of buildings. A good example of this could be an apartment building, which the concrete Cell/MacroCell configuration is explained in figure 2.

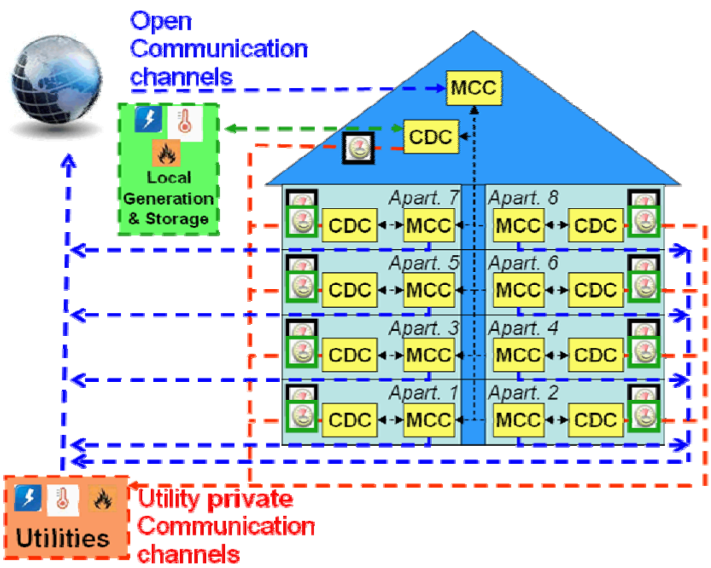

Figure 2 Apartment building with communal energy generation and storage capabilities

In an apartment building with communal local energy generation and storage capabilities the next Cell/MacroCell configuration is applied (see Figure 2):

- One MacroCell that corresponds to the building (with its MacroCell Level concentrator, Data Gathering

Component, implemented Control Strategies and User Interface devices). The building MacroCell contains:

- A cell with the communal capabilities of the building that contains:
  - A Cell level Concentrator (CDC)
  - Solar panels (Generation & Storage)
  - UI channels (User Interface)

- A MacroCell for each apartment with its MacroCell Level concentrator, Data Gathering Component, implemented Control Strategies and User Interface devices) that contains:
  - A cell that corresponds to each apartment:
    - A Cell level Concentrator (CDC)
    - Activity and presence sensors (Monitoring and Metering)
    - Devices that can be controlled by the System (Control and Actuation devices):
      - Household appliances such as dishwasher, washing machine, fridge, etc
      - Lamps and lights
    - UI channels (User Interface)

All the MCCs could interact among them in order to reach common goals, especially the MCC of the building MacroCell and the MCCs of apartments.

Finally, using the shown configuration, a simple use case is described using bullet points:

- In the morning before going to work, Frank (of the apartment 5) wakes up and puts the dishwasher and washing machine in the energy saving mode.
- The MCC of the building gets data from Forecast services: a sunny weather is expected (so sufficient energy will be generated by the solar panel).
- The MCC of each apartment gets data from Cell level concentrators (aggregated instantaneous energy consumption, aggregated estimated energy consumption, comfort related data, etc.).
- The MCC of each apartment will interact with the MCC of the building and will let it know the forecast consumption and production values for each apartment. The MCC of the building will let know the forecast energy production by communal solar panels.
- Each MCC will interact with the local electrical distribution company and will let it know the forecast consumption and production aggregated values and will get from the company information about electricity prices and costs.
- The MCC of apartment 5 knowing the real-time electricity price and forecast energy production by solar panels and applying the energy policies will let know Cells that it is a good moment to schedule to start the devices that are in the energy saving mode.
- The CDC of Apartament 5 will switch on dishwasher and washing machine.
- In the evening, when Frank (of the apartment 5) comes home. He checks the energy consumption of the day using a wall display (UI channel).
- In the evening, energy consumption is higher in most of the apartments. For instance, Tim (of the apartment 8) is at home cooking and watching TV and Frank (of the apartment 5) is working in his laptop and his children are watching a DVD.
- The MCC of each apartment that knows the real-time price of electricity (high at this moment) and has interacted with the rest of MCCs, will let know Cells that it is a good moment to reduce energy consumption.
- In each apartment, following the policies of its MCC, lights in unoccupied rooms are turned off automatically. Cell Level concentrator will get data from activity and presence sensors and will send orders to switch off lights to actuators.

Acknowledgment

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IntUBE – Intelligent Use of Buildings' Energy Information: Energy Challenge Concept

Régis Decorme
CSTB, Scientific and Technical Center for Building, France
regis.decorme@cstb.fr

Krzysztof Klobut, Teemu Vesanen and Mia Ala-Juusela
VTT Technical Research Centre of Finland, Finland

Michael Schubert and Stephan Schuele
University of Stuttgart, Germany

1. Introduction

Energy efficiency of buildings may be improved using information provided by smart meters. They enable new services aiming at making the end-user aware of its energy consumption. Our vision is a neighbourhood of independent but co-operating buildings, with common aim to maximise their energy efficiency. Smart meters are the link between the buildings and the Neighbourhood Management System (NMS) which will control the community. The NMS will analyse the measurements, loads and available power in buildings and use simulation to forecast their behaviour to provide e.g. failure detection and load management.

In this context a new concept has been developed.

2. The Building Energy Challenge Concept

The concept illustrates an intelligent use of building energy information through a contest between several office buildings within a company. The idea is to combine both "energy awareness" and "energy information benchmarking" to create an incentive scheme for energy reduction in a tertiary environment. The contest should raise a high stimulation level by rewarding good energy behaviour.

The concept principle is the following:

1. Select (at least) 2 candidates buildings belonging to the same company.
2. Equip the buildings with energy monitoring systems (smart meters and sub-meters, wireless sensors for behaviour monitoring, dashboards) for energy awareness in all office rooms.
3. Perform an energy audit to establish the (current average) reference consumption of selected buildings.
4. Explain the rules to the participants (contest duration, user guides for the dashboards…) and present the reward for the winner:
   - *Different buildings (or even teams within the buildings) will be confronted. To win the building challenge, employees must improve energy systems and desktop applications uses. Environment-friendly acts will be rewarded with a bonus and heavy consumption behaviours with a penalty to improve their understanding of and interest in energy savings.*
   - *The building (or team) that receives the smallest penalty (or the highest bonus) and which decreases its consumption the most (by at least 10%) will win the building challenge.*
5. Launch the contest, and plan regular intermediate progress reviews.
6. Elect the winner "greenest" building of the company
7. Evaluate actual energy savings, quality of user involvement in the experiment, and impact on behaviours:
   - *The overall aim of the building challenge is to reduce energy consumption by at least 10% for one whole year. The second aim is to change employees' behaviours and habits through environment-friendly acts and consumption information awareness.*
   - *It is expected that environment-friendly behaviours will become habits and have long-lasting impact: indeed it will encourage them to cut energy consumption at work and then at home.*

After the end of the competition, it has to be ensured the infrastructure could be used for further services in the building. Acting on the assumption that during the contest an as-is performance profile of the building could be identified, continuous monitoring of sensor information will enable facility managers for instance to identify necessary repair works or possible retrofit activities

Service sector is usually very wasteful with energy, having both high total energy use and low level of efficiency. In addition, personnel rarely have a good understanding or interest in energy efficiency. Through the IntUBE-concept, it is expected that information about consumption and environment-friendly acts should change employees' behaviours, and thus contribute to energy savings. Both the participants and the company are winners because, on the one hand, the first will receive a reward for their eco-friendly behaviour and, on the other hand, the company will save money thanks to energy savings.

Considering the possibility to demonstrate this concept as a real pilot case, we drafted below the typical needed equipment in a building office room for the challenge:

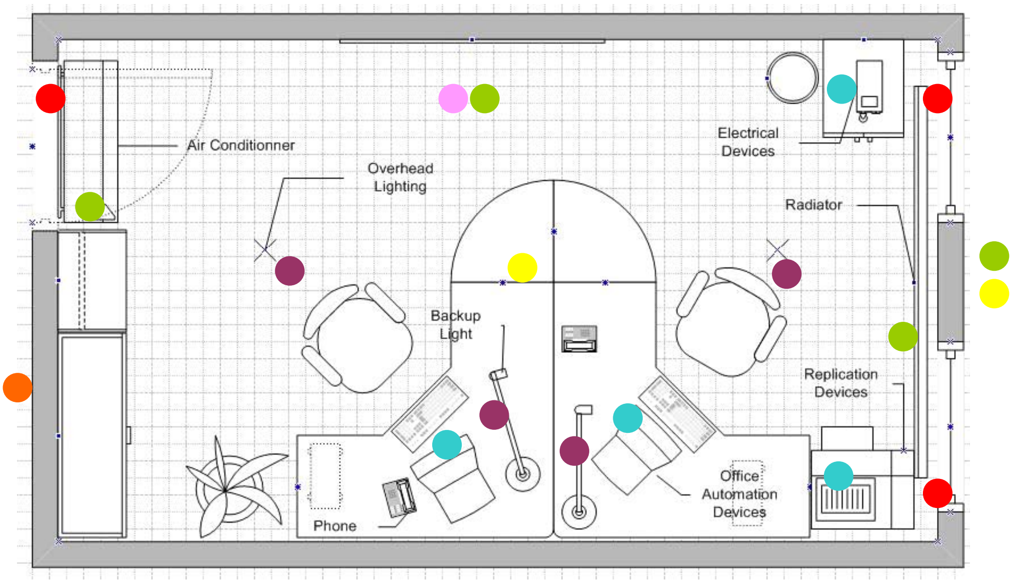

Figure 1. Needed metering equipment for a typical office room

Sensors

4 temperature sensors 4 light sensors 3 contact sensors 1 electricity meter	2 brightness sensors 1 presence sensor 4 power-detector plugs

Table 1. Examples of penalty or bonus that will be monitored during the challenge:

Penalties	Bonus
– having a window open while the heating system is on – leaving the office at the end of the day with the computer switched on – switch on the artificial light while day light is sufficient – Having a temperature lower than 26 °C with the air-conditioning on [1]	– Switch off the light each time when leaving the office – Switch off the computer when leaving the office for more than one hour – …

The building challenge technical system uses energy submeters for detailed individual and real-time energy consumption data collection, wireless sensors for detecting “energy-impacting” behaviours, ICT based displays for energy awareness, and finally an ICT OSGi platform for consumption data storage and benchmarking. [2]

Communication between the submeters, sensors and the platform is based on radio-frequency and using the ZigBee protocol [3]. The sensors measure data about building consumption and participants’ uses, so as to detect behaviours and allocate penalty or bonus, as illustrated in the Table 1.

Expected impact is at the economic level through energy savings and therefore money savings, at the technical level by enabling a building dynamic energy monitoring and by improving the knowledge on actual consumptions, but also at the social level since employees become actors of energy efficiency. The concept should furthermore stimulate long-lasting environmental-friendly behaviours.

3. Demonstration in a Real Office Building

The concept will be demonstrated in full-scale and real conditions through a new project called ECOFFICES (Energy Challenge within OFFICES), co-funded by the French region PACA and the European Regional Development Fund. The challenge will take place in a CSTB Building located in Sophia-Antipolis, and will start in September 2010.

4. Acknowledgement

This work was carried out in the project IntUBE (Intelligent Use of Buildings' Energy information) supported by the European Community's 7th Framework Programme under grant agreement n° 224286.

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BeAware – Boosting Energy Awareness

Carin Torstensson
Interactive Institute
Portgatan 3, SE-633 42 Eskilstuna, Sweden
Carin.Torstensson@tii.se

Abstract

BeAware is delivering mobile and ambient interface technologies aimed at increasing the user awareness of energy consumption at home, while boosting energy conservation practices. The net power energy saving at home is expected to be around 15%.

1. Introduction

The project, called BeAware, is a joint European research project, investigating how next generation ICT can be designed to reduce energy consumption in the home.

BeAware wishes to foster the creation of new services that turn householders into active players in energy and inspire creation of new services and products for energy awareness.

BeAware is co-funded by the European Union in the FP7/ICT program and is a three year project running from 2008 until 2011. The first integrated prototype, consisting of a mobile application and an ambient interface, will be tested in eight households during the spring 2010. Four households are placed in Italy and four in Finland. In each site, studies will be carried out in a home environment. The research is highly multidisciplinary and combines a variety of approaches in the area of user studies, user-centred design and evaluation.

2. What is innovative about the technology?

BeAware brings a high level of innovation in different fields:

- Providing the user with natural user-friendly and simple ambient and mobile technologies for increasing their energy awareness.
- Developing innovative wireless sensors, which allow measuring the power consumption of individual appliances in near-to-real-time, and identify the type of appliance (for example oven, refrigerator and water boiler) and its specific fingerprint with low energy consumption.
- Providing new services and technology tools aimed at turning householders into active players in the energy saving challenge and supporting energy awareness increase, which include: 1) visualization of detailed data attained through pervasive sensing 2) aesthetic displays using novel interfaces , 3) theoretically informed implementation of feedback that address behavior change. The problem of these three distinct streams is that they have tackled separately three aspects that should be addressed at the same time respectively: detailed data sensing, engagement through novel user interfaces, and psychological and anthropological approaches to behavior change. We aim at bridging these three areas by proposing a system that addresses detailed information provision, engagement through novel UI and theoretically informed feedback strategies.

3. How has your project become a success?

Two are the main motivations for turning the BeAware project in a concrete success:

1. Bringing the user to the centre stage. With this regard several tools for the real time monitoring of energy consumption at home have been emerging in the market (GoogleMeter, Microsoft Hohm and others). Nevertheless, despite technologically advanced, all of these have failed to be largely adopted by households, since they overwhelms the users with too much information and time-consuming tasks.

   On the contrary BeAware is delivering user-friendly technologies and concepts, driven by innovative cognitive models and social studies on the energy behaviour of the users.
2. The “openness” of all the technology layers developed (wireless sensors, web service platform, mobile and ambient interfaces), which paves the way for higher interoperability with technology components and layers developed by other vendors.

   The resulting and winning approach to the market is consequently to functionally decouple the overall technology developed within the project in different yet interoperable technology bundles, which could be adopted and integrated by different types of stakeholders in the value chain of home automation, supporting the construction of the renovation of green-oriented buildings.

4. Results and conclusion

The project is still running on its second year and the results from trial 1 will be available at the time of the conference (pilot period starting march 2010). The final results will be available next spring (2011).

The results so far can be summarized as followed

Access to total electricity consumption in the households are important input to the system but not simple/cheap/standardised to get

Our project has an innovative combination, a lot of systems (with measuring on appliances etc) are coming on the market. Other systems don't offer complete solutions with both innovative sensors and interface as well as customer tools for fostering, education through quiz and advices.

There are similarities as well as differences on the different markets in Europe. Where the Nordic countries use electricity for heating, car heaters and sauna while the Italian market has a lot of air-condition, both markets have a saving potential though.

For more information:

www.energyawareness.eu/beaware/

Energy Saving Information Platform (ENERsip)

ICT infrustucture for energy-positive buildings and neighbourhoods

Rafael Morillo
Business Development
Amplia Soluciones S.L.
Madrid, Spain
rafael.morillo@amplia.es

Boris Kantsepolsky
M2M Solutions Division
Motorola Israel Ltd
Tel-Aviv, Israel
Boris.Kantsepolsky@motorola.com

Abstract— **The main impact of ENERsip project will be the energy consumption reduction achieved by coordinating the actual users' needs with the in-buildings and neighborhoods positive-energy generation.**

Keywords (Energy, SmartGrid, ICT, Infrustructure)

I. INTRODUCTION

Over the last few decades, worldwide energy demand has increased due to industrial development and global economic growth, resulting in a simultaneous increase in global energy costs and poor environmental behavior. The Electricity Consumption breakdown in the EU was recently characterized by the European Project REMODECE (Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe). The final report published in November 2008 states that electronic loads (mostly entertainment and ICT) consume more than 22% of the electricity, a significant percentage (can be over 50%) of which is standby and other non-active modes (e.g. a router left on 24 hrs. per day). Lighting left on in unoccupied rooms is another source of waste. Other miscellaneous equipment (bread-makers, coffee-makers, microwaves, etc.) also have wasteful low power modes. Real-time consumption information allows the typical household to reduce electricity usage by 10 - 20%. Seeing the actual usage that results from existing household habits will influence most consumers to change their attitudes toward conservation and reduce overall consumption.

The main goal of the ENERsip project, recently funded by the FP7 ICT and Energy theme, is to create an adaptive, customizable, and service-oriented ENERgy monitoring and control system for energy grids and decision makers to allow reduction of energy consumption by coordinating the actual users' needs with the in-buildings and neighborhoods positive-energy generation facilities.

II. BACKGROUND

A. The ENERsip idea

The European Society is directly affected by consequences of industrial development and global economic growth, having a large impact on environmental conditions and the cost of energy. Improving energy efficiency in European buildings and businesses has become a very important goal in the European Commission. One of the main concerns of the EC in respect to energy is the increasing consumption and dependency of energy in every day's aspect. This leads to a constant increase in the dependency on energy imports, the increase of contamination and global climate change.

On this line, the EC has committed the States to convince the society, and provide them with the means to reduce energy consumption, create a culture of energy efficiency, and promote the construction of green buildings with energy co-generation. So, the energy positive terminology appears as an answer to what EC directive is looking for.

ENERsip was conceived on the idea that mixing energy, communications, control, computing and implementation of the consumption and generation elements, must be active and proactively coordinated. To bring the idea into reality, ENERsip will develop and test in real-world conditions, an open Information and Communication Technologies platform that will provide a set of tools for near real-time optimization of generation and consumption matching in buildings and neighborhoods.

ENERsip is targeted to allow the emergence of an open electricity market by using components from different suppliers, unifying their protocols and providing reliable data exchange services, thus helping reinforce European industrial and technological position in ICT-enabled energy efficiency technologies.

B. Energy generation networks are evolving…

Nowadays, energy generation, transmission and distribution networks evolve towards an increasing presence of electricity generation sources in buildings, either for proprietary consumption or for being sold to an electricity operator. As of today, most of these buildings have their own infrastructure for the generation of electricity. Sometimes, the motivation of building householders for installing these networks is achieving economic profitability via the sale of the energy; in other occasions, they may aim to implement their central hot water or central heating systems. This infrastructure is usually installed by professional companies and it is compliant with energy distributors' guidelines, but it tends to lack adequate maintenance from an energy efficient point of view.

C. … allowing end user interaction with the network…

On the other hand, the ENERsip project will help consumers manage the used energy in order to be able to save energy while maintaining desired comfort levels. For doing so, the project will provide an open service-oriented platform accessible through an intuitive interface that will enable remote control of electrical appliances be informed about near-real time consumption of energy, and even know individual consumption of each electrical appliance.

From a global perspective, the ENERsip platform will expand AMR (Automatic Meter Reading) systems beyond the meter via in-house networks to obtain information and allow smart consumption in energy-smart buildings, and beyond the sub-station into the building generation to improve energy efficiency and network integration. Thus, it will no longer just collect consumption information from the AMR system, but rather act upon that information to improve the efficiency of the energy consumption. The user will not only be informed about consumptions, but the system will also automatically help to reduce those consumptions.

D. … and helping create nation-wide smartgrids of Energy Generation Networks

Having the domestic generation network controlled, and having a detailed consumption pattern of each user, ENERsip will allow the integration of the different domestic networks within the distributor's network. This will take grid operators from a generate-sell model, to a generate-predict-sell model. The Automated Demand Response (ADR) protocol will enable the energy network to seamlessly communicate with each home network, under open standards, so that the complete energy infrastructure will work in complete harmony. A great deal of attention will be given to emerging standards for network communication, such as the OpenADR protocol.

With an open integration platform, new actors come to play within the scenario, creating small consumption generation and consumption grids, and also the emergence of new local business models. The support of these new business models is currently outside of the ENERsip project scope.

III. Technology

A. AMR and M2M in the Energy Companies

M2M technology is by no means a new concept. The trade-off for utility companies is rather to send engineers out to read meters once a period, a very labor intensive process, especially if customers are not at home, or having an electricity meter connected to an M2M module to transmit data regularly, with no need for human involvement. AMR helps make the retention process dramatically more cost-effective. With AMR installed, bills can be based on actual readings rather than estimates without incurring huge personnel costs. With utility companies largely influenced by costs and return on investment, AMR is initially being brought in where the value of customers is highest. M2M technology can definitely help utility companies to meet their three key business drivers: lowering operational costs (by making maintenance cheaper); ensuring sustainability (by monitoring key assets for instant fault reporting); and optimizing the whole process around customer management.

B. Technical limitations of existing products, processes and/or services

The current solutions in the market are based on the overall consumption of each user, on a monthly basis. These solutions are not effective because they are not providing specific information on the way the energy is consumed and the way the energy consumption may be reduced with optimized usage. Most of the technology required to implement the vision of a truly intelligent Smart Energy network has been in place for at least 10 years. Metering and communication resources were available that could support most of the concepts now being explored. The hurdles holding the development of a smarter infrastructure have been two-fold: economical and lack of internationally accepted standards.

The economical factors are quite easy to understand, in that ICT prices have been free-falling for the last 20 years, while energy prices have been steadily climbing, with only minor hiccups. Thus, it is now feasible to setup a complete communication infrastructure, with individually addressable meters, home networks, and massive data mining applied to the huge volumes of data that are generated. On the other hand, the economical feasibility of the concept has been creating pressure for the adoption of open standards that allow the emergence of a new industry around the ICT infrastructure that allows the energy infrastructure to be more efficient.

C. ENERsip Main innovations

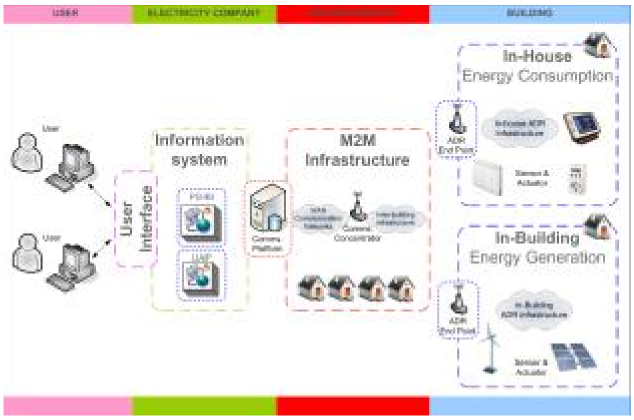

Figure 1. ENERsip Architectural Levels

The main ENERsip result is an open service-oriented platform focuses on data acquisition from the embedded wireless sensors, and integrated management of the elements included in buildings and the neighborhood's energy network. Due to this generic applicability, the ENERsip approach and architecture can be adapted to other distribution environments like water or gas. The entire solution as well as the design of the modules combining the ENERsip platform is novel and could have a high potential to extend its applicability to other domains requires real time demand-respond balancing operation.

ENERsip relies on a robust and powerful M2M infrastructure, based on intelligent embedded nodes that acquire and adapt the information to the characteristics of the communication segment, and a local execution of operations that allows the performance of remote management operations. These embedded nodes are part of the M2M network that can be remotely managed from the central stations, given that they have autonomous agents independent from the rest of the operations in the system.

The ENERsip architecture presents a Service-Oriented Architecture (SOA), which exposes software functions as usable, customized and advanced services, which can be discovered and invoked throughout the network. The use of SOA allows sharing of data and applications, and provides a flexible and standard mechanism to re-use the services, thus allowing the development of new added value services. Furthermore, SOA facilitates the collaboration between companies, given its focus on B2B environment.

From a technological point of view, ENERsip creates a new environment mixing in single framework different communication technologies, decision making software, information systems for the integration of generation-distribution networks, and interfaces with end users to make them active players in the system. Energy optimization will be brought by the inclusion of information monitoring and the application of a service-oriented approach. In addition, the usage of SOA enables an easy integration and development of new applications since SOA and Web Services are a strong programming paradigm, heavily endorsed by large integrators such as Sun, Microsoft, Oracle, SAP, and IBM.

Due to its openness and vision, ENERsip will facilitate the emergence of new business models, allowing its future integration with billing systems, ERPs, and CRMs as commonly used by utilities and distribution grids, in order to have a complete perspective of the whole lifecycle of energy consumption, user preferences, and the status of the network.

ACKNOWLEDGMENT

Thanks to all the contributors to the ENERsip proposal, whose work allowed the generation and delivery of a clear and innovative idea. The ENERsip project consists of 10 partners from Spain, Portugal, Israel, Czech Republic and Belgium. ENERsip partners according to the alphabetic order are: Amplía Soluciones S.L, AC&A (Aplicaciones de Control y Automatización), ESI (Fundación European Software), Honeywell SPOL, ISA (Intelligent Sensing Anywhere), Israel Electric Corporation, Motorola Israel Ltd. (MIL), UC3M (Universidad Carlos III De Madrid), University of Coimbra, VITO (Vlaamse Instelling voor Technologisch Onderzoek)

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Scheduling energy consumption with local renewable micro-generation and dynamic electricity prices

Onur Derin, Alberto Ferrante
ALaRI, Faculty of Informatics
University of Lugano
Lugano, Switzerland
Email: {derino, ferrante}@alari.ch

***Abstract*—The electricity market is going through a deep modification as it is moving toward the integration of smart grids. Future homes will include smarter electric devices that will be easily managed from the power consumption stand point. The capability of performing short-term negotiation of energy purchases, if introduced and if efficiently exploited, will give the user the ability to reduce energy costs.**

In this paper we discuss a scheduling problem for household tasks that will help users save money spent on their energy consumption. Our system model relies on electricity price signals, availability of locally-generated power and flexible tasks with deadlines. A case study shows that cost savings are possible but fast and efficient solutions to the scheduling problem are needed for their real world use.

***Index Terms*—scheduling; smart grid; smart home;**

I. Introduction

The electricity market is witnessing a transformation from monopolistic to a deregulated and competitive structure. Demand-supply mechanisms drive the electricity pricing in the wholesale electricity market, where the actors are generation companies, transmission operators and trading companies. Ordinary users of electricity at home do not have a say in this market. According to the current practice in some European countries (e.g., Germany and Italy), the users at home are offered with options to select their preferred electricity supplier company. However the contracts between a supplier and consumers span long terms (i.e. months, years). This incurs inefficiency in two ways. First, when agreed on a flat rate price, as the cost of producing electricity fluctuates, the production company gets varying profit margins. This reflects to the end consumer as higher bills if the company makes a over prediction and as loss for the company in the case of under prediction. Secondly, consumers may be bound to a costly contract even a cheaper supplier emerges at some point in time. Both the suppliers and consumers would benefit if it was possible to make short-term contracts that are based more on the spot price of electricity. Despite the economic convenience, studies show that customers are not very willing to take the burden to continuously change their tariffs manually [1], [2].

The aforementioned pricing mechanism brings inefficiency in pricing of electricity for consumers at home [3] and calls for the creation of a healthy retail electricity market that is based on the demand and supply of electricity. This transformation should allow for an optimization of electricity usage: from one side the users should be able to negotiate short-term (e.g., hourly based) contracts with providers with the goal of obtaining lowest energy prices; from the other side, energy providers will be able to change their prices depending on market conditions, thus optimizing, by induction, the energy usage of the users. The relation between electricity demand and electricity prices at each given interval of time will be exploited: the higher the demand, the higher the prices.

Now that the electricity grid is evolving to accommodate distributed generation from various sources of energy (e.g., wind, solar, CHP) at different scales (e.g., individual owners, virtual power plants), a transformation of the electricity market is required to embrace direct user involvement in determining the retail market price of electricity. Individuals, or consortia of individuals, will be able to run their own green electricity generator, thus leveraging on local energy micro-generation.

This new electricity market will change the way in which electric devices are used: some devices will not be started immediately on user request; the user, instead, will be able to set an earliest starting time (that may be the current time) and a deadline for the operations of these devices; the system, then, will schedule the programmed task with the goal of both satisfying the deadline and of optimizing energy costs. Some other devices, of course, will still need to be started as soon as the user requests it. For example, the user will be able to program his washing machine and to specify that the washing task should be performed at most in 10 hours. The system will then schedule the washing task to minimize energy costs and to finish in at most 10 hours. On the opposite, the user will be able to start an hair drier just by pushing a button as usual.

The short-time negotiation of electricity should be, to some extent, transparent to the users: they (either directly or with the help of experts) should set the negotiation policies and the system should be able to autonomously perform all the required operations. To enable automatic negotiation each house should be equipped with a controller. The controller should be interfaced with the electric devices at home and it should be able to capture their requests. The controller should also be able to communicate with energy providers both to obtain price updates and to negotiate short-time agreements.

This mechanism can be extended to work at building or neighborhood level by using distributed controllers.

The aforementioned controller should be able to compute the best scheduling for the programmed tasks with the goal of minimizing costs while meeting all the deadlines. In this paper we discuss this scheduling problem and we show how using the task scheduler can improve usage of energy and lower costs for the users. This approach only targets savings on what we call as flexible household tasks. These tasks amount to at most 11% of total energy consumption by end user in EU residential buildings [4].

Eßer et al discuss in [5] the scheduling problem for home appliances. They schedule home appliances a day-ahead assuming the correct knowledge of the price signal. In our work the scheduling is performed on finer grained periods of time and is done at shorter terms. Furthermore, our scheduling problem also takes into account local micro-generation of energy.

In [6], authors address the problem of scheduling hard real-time tasks in wireless sensor nodes that harvest energy and propose an optimal algorithm called lazy scheduling algorithm. The problem of scheduling tasks in a harvested power-aware way is similar to the one of scheduling tasks in presence of locally-generated power; however, in that case the problem is related to single-machine scheduling and it is not applicable to our system model.

More in general, the one of scheduling tasks on limited resources is a well known problem in many areas of computer science and of other fields. An area in which scheduling is especially important is the one of operating systems. Scheduling problems in real time operating systems are especially similar to our problem. Though, the problem of scheduling tasks of home appliances have some peculiarities that cannot be seen in any other scheduling problem.

II. System Model

We consider a set P of *price signals*, p_i, from different transmission system operators (TSOs). Each price signal is a plot of the unit price of electricity per time. The price of electricity may be changed at the beginning of every hour. Having the ability to make a contract with a different TSO, the user may be subject to the minimum price signal, p_{min}, that is given by

$$p_{min}(t) = min\{p_i(t)\}$$

An example of a minimum price signal, p_{min}, is shown in Figure 1a.

Each task J_i is specified by

- its earliest starting time (that is the current time unless specified by the user otherwise), a_i;
- its deadline, d_i;
- a boolean value, pr_i, representing whether the task is preemptable or not;
- a load power profile, L_i that is is a task-specific curve that shows the power spent by the task during its non-preempted execution.

The load power profile is necessary for characterizing the tasks by representing the power drawn by each involved device for running the considered task. Figure 2a shows some tasks with their parameters. The load power profile for a washing machine depends on the set program, its duration and the water temperature chosen by the user. Limiting the energy characterization of the task to its average or total required energy would not be realistic in this domain.

We assume that there exists a set of local power micro-generators such as photovoltaics and wind mills. Due to the nature of these resources, the power generated by them varies with time; we assume that the energy taken from these sources is not billed to the users. We denote the total locally-generated power as $P_G(t)$ as shown in Figure 1b.

We define our problem according to the system model described above: given a task set J, a price signal set P, a locally-generated power P_G, and maximum allowed consumable power at any instant as P_{max}, the system must determine a schedule of the tasks such that the total cost for their execution is minimized. This problem needs to be solved every time a new task arrives (i.e., the user wants to start a new tasks). The scheduling is re-computed on the tasks not yet executed and on the remaining part of preemptable tasks. Non preemptable tasks that are being executed when the scheduler is run are considered as fixed; the available power is changed accordingly.

III. The scheduling problem

Although the problem looks similar to a real-time operating systems scheduling problem with energy constraints, there are some differences. First of all, there is no shared device. Any task can be run in parallel as long as the total power drawn by the tasks does not exceed the electrical current capacity of the transmission cables. Moreover, scheduling theory from operating systems and operations research does not consider a mix of preemptable and non-preemptable tasks. In our case, for example, the washing machine task is non preemptable, but charging an electrical car is. In classical scheduling problems are tasks are either all preemptable or all non-preemptable.

We assume that minimum price signal, locally-generated power, and device power profile functions are piecewise constant with interval T. This assumption makes it possible to express them as a sequence of values. The time interval we are interested in for the scheduling problem is $[min(a_i), max(d_i)]$. Therefore $p_{min}[n]$ and $P_G[n]$ will be considered in this interval as a number sequence of length N, where N can be computed as follows:

$$N = \frac{(max(d_i) - min(a_i))}{T}$$

Similarly, $L_i[n]$ is a sequence of length N_L that can be computed as follows:

$$N_{L_i} = \frac{length(L_i)}{T}$$

The schedule for task J_i can be represented as $s_i[n]$, a sequence of 0s and 1s, where 1 specifies that the task is to be run in the corresponding interval and 0 for otherwise. Such a formulation will allow us to express the scheduling as an optimization problem.

Power consumed by J_i according to a schedule s_i can be obtained by

$$P_i[j] = \begin{cases} L_i[\sum_{k=1}^{j} s_i[k]] & \text{if } s_i[j] = 1 \\ 0 & \text{otherwise} \end{cases}$$

For a given schedule, the total power consumption profile for all task can then be obtained by adding individual power consumption profiles:

$$P_{tot} = \sum_i P_i$$

By subtracting the power demand from the locally-generated power gives the power to be billed:

$$P_{billed} = P - P_G$$

We assume that the unused locally-generated power is not sold to the grid or stored. Therefore negative values in P_{billed} are replaced with the value 0.

For a given price signal, the cost of the energy can be obtained with the scalar product:

$$C = P_{billed} \cdot p_{min} \cdot T$$

where p_{min} and T should be expressed in the same time unit (e.g. T is in hours if p_{min} is in €/kWh).

We identify C as the objective function to be minimized. This minimization is subject to the following constraints:

- Tasks are scheduled to start after their earliest starting time:

$$\forall J_i : \qquad a_i \leq T \cdot min\{k : s_i[k] = 1\}$$

- Tasks are scheduled to finish before their deadlines:

$$\forall J_i : \qquad d_i - T \geq T \cdot max\{k : s_i[k] = 1\}$$

- Task J_i is scheduled as many times as the length of its load power profile:

$$\sum_{k=1}^{N} s_i[k] = N_{L_i}$$

- If task J_i is not preemptable, then it should be scheduled to run all at once:

$$pr_i = 0 \Rightarrow s_i(l) = 1$$
$$\text{for } l \in [min\{k : s_i(k) = 1\}, max\{k : s_i(k) = 1\}]$$

- At no time, the total power withdrawn by all tasks exceeds the allowed maximum, P_{max}.

$$P_{tot}[k] \leq P_{max} \qquad \text{for all } k$$

IV. Use cases

The aforementioned system model and the scheduling problem can suit different scenarios. In particular, it can be used both to schedule tasks at individual home and at community level.

A. Home level

In a private home, the controller schedules the household tasks with respect to the price signals and a local microgenerator (e.g., photovoltaic panels installed on the roof). The controller will keep all the information on tasks to be run locally and it will plan task execution for the householder.

B. Community level

In a network of private homes, the controller schedules all the household tasks of the community with respect to the community-owned local generators such as wind mills and photovoltaic plants. This solution provides different advantages over the private home scheduling of tasks:

- better trading power;
- less communication/computation requirements on the infrastructure;
- less cost of the ICT infrastructure per home due to sharing;
- more predictable consumption at the community level;
- ability to impose peak demand response and balancing power policies at the community level.

Of course this solution is also subject to a number of disadvantages:

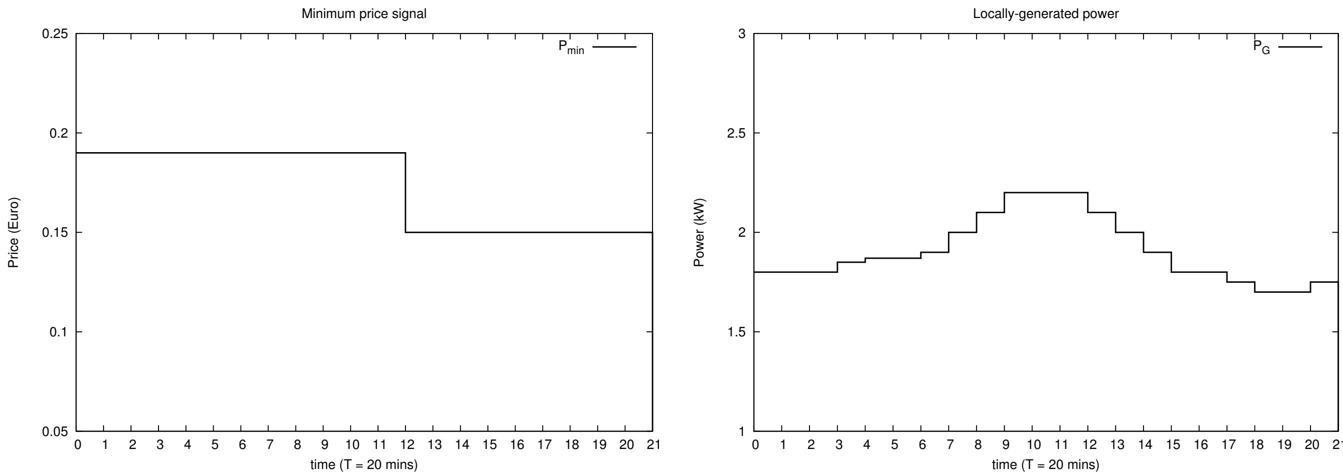
- privacy concerns due to making household tasks transparent to a shared controller;
- a community-level scheduling might provide less optimal results than home-level scheduling from the stand point of single users.

Proper solutions should be developed to overcome the aforementioned disadvantages and to exploit the advantages of this approach.

V. Case Study

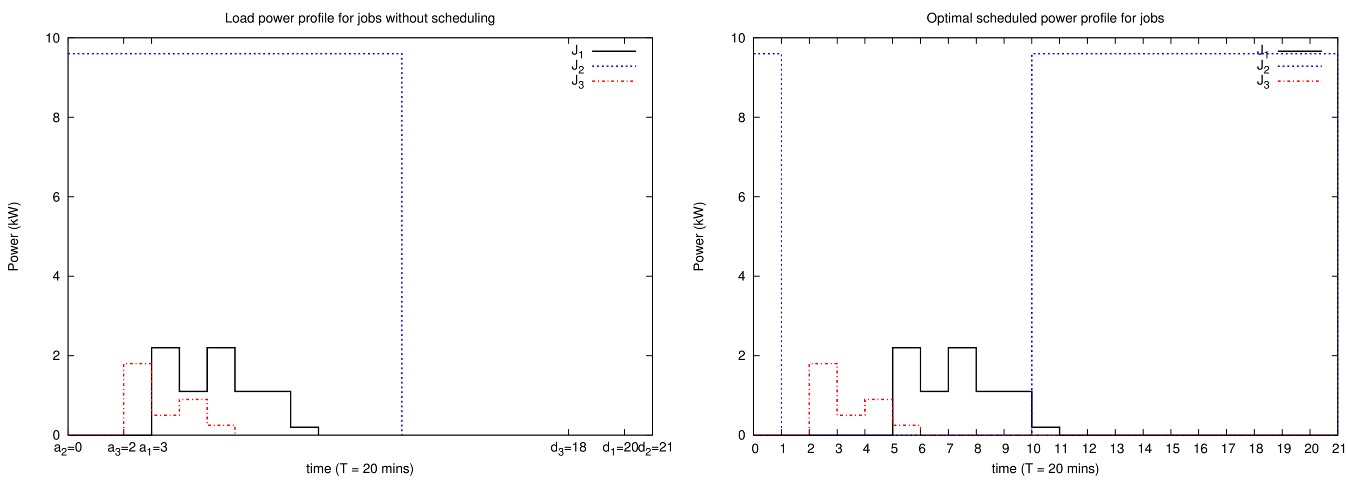
In this section we present a case study and we analyze the results obtained by applying our scheduler to the tasks with the goal of obtaining a cost saving by optimizing power consumption. The purpose of analyzing a case study is twofold: on one side we want to show how the electrical system would behave if the method proposed in this paper is adopted; on the other side we would like to show that, by scheduling the tasks correctly we could obtain a cost saving.

The case study that we considered is a normal house in a time span of 7 hours. In this time period we suppose that three activities are planned by the user. The first activity is a recharge of the batteries of an electric vehicle; the second activity is washing dishes by using a dishwasher; the third activity is using a washing machine. Table I summarizes the earliest starting times, the characteristics, and the deadlines for the different tasks. Tasks power profiles are shown in Figure



(a) (b)

Fig. 1: (a) Minimum price signal (b) Locally-generated power



(a) (b)

Fig. 2: (a) Load power profile for each task (b) Load profile with optimal scheduling

2a. Data related to the considered case studies are realistic: vehicle recharge data have been taken from the data of the Tesla car [7]; data for the washing machine correspond to the "cotton 95" program described in [8]; the dish washer power profile has been derived by the "cotton 60" profile of the same document. Total power consumption of the last two devices is in line with the power consumptions described in [9].

The vehicle recharging has been considered to be a preemptable task (i.e., it does not need to happen in subsequent instants of time); dish and clothes washing, on the opposite, have been considered to be non-preemptable tasks.

By considering the previous tasks and maximum allowed power consumption to be 15 kW, the optimal schedule has been computed by using combinatorial search. The search space was composed by 38,798,760 valid schedules. As can be noticed the search space is huge, even with a limited number of tasks and a limited time span. Our implementation of the exhaustive search executed in 35 minutes on Pentium Dual Core 1.8 GHz computer with 2 GB of RAM. This is the main problem associated with combinatorial search. A discussion on this topic is provided in Section VI.

Figure 2b shows the optimal schedule that has been obtained. The graph shows how the tasks have been scheduled to respect maximum power constraints and to provide the minimum possible cost for the user while respecting the

TABLE I: Earliest starting times, deadlines and characteristics of tasks.

Task	earliest start	deadline	total duration
Clothes washing	0:00	6:40	2h
Car recharge	0:00	7:00	4h
Dish washing	0:00	6:00	1h20'

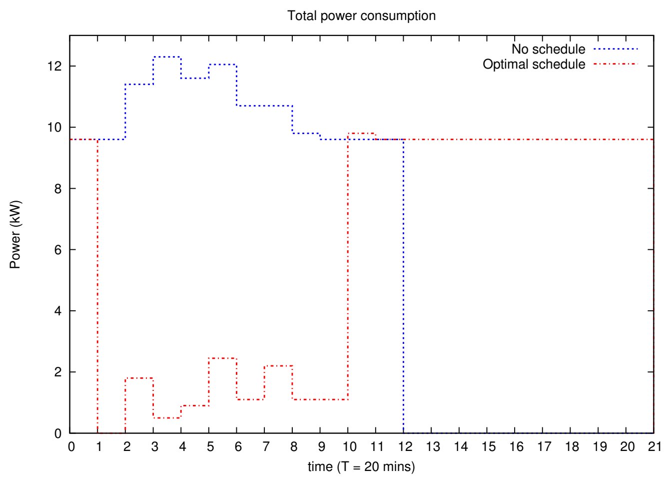


Fig. 3: Total consumed power for the cases of earliest and optimal scheduling

imposed deadlines. The car charging task is separated into two parts, one at the beginning and one after the completion of the other two non-preemptable tasks. The tasks are scheduled to use as much as possible locally-generated power, thus reducing costs for the user.

By scheduling the tasks optimally, in this case, we were able to reduce the cost about 23%: approximately €6.5 are necessary when tasks are scheduled as soon as the earliest starting time specified by the user arrives; €5.0 are necessary when tasks are scheduled optimally. Figure 3 shows the energy usage profiles obtained in the two cases. The graph shows how the optimal schedule better utilizes locally generated power and better exploits the flexibility of tasks for providing a cost saving.

VI. Discussion

The problem that we describe in this paper is very complex and it has implications on how the electricity distribution system is organized; in this section we discuss some open topics; the discussion spans from the complexity of the scheduling algorithm to the management of locally-generated energy, passing by the requirements for new appliances and the home power supply network.

A. Scheduling Algorithm

The problem of scheduling tasks in the home network is very complex as previously shown. In fact the worst case complexity of the combinatorial search is $O(2^{MN})$ where M is the number of tasks and N is the number of time slots. Thus, solution time grows exponentially with the number of combinations considered. Solving this problem in a reasonable amount of time is already very difficult even on a powerful machine; it would be impossible on an embedded system. Therefore, some heuristics need to be developed to determine sub-optimal schedules in reasonable amounts of time. The heuristics considered need to be targeted to the computational power of the system considered and to the granularity of the schedule.

A further problem is given by the fact that energy available to each user is limited in each considered period of time. This, along with the deadlines set by the user, might lead to schedulability problems: the system might not be able to schedule one or more tasks in such a way that all the constraints (maximum power, deadlines) are satisfied. Though, the only constraint that can be physically violated is the deadline imposed by the user. Proper policies, customizable by users, should be defined for the case in which some tasks cannot be scheduled. Furthermore, an admittance test (i.e., a test that allows the system to quickly notify the user if a task cannot be accepted) should be developed. Currently we employ a weak schedulability test by comparing the maximum energy that can be drawn from the grid in the total duration of tasks to the total energy required to complete all tasks.

$$P_{max} \cdot N \geq \sum_i \sum_j L_i[j]$$

B. Home Appliances and Power Supply Network

As previously mentioned, the power supply network has been undergoing a revision in the last years. The network will require some further adjustments to allow customers to perform short term negotiation of energy purchases: the energy sellers will need to implement finer grained mechanisms for energy pricing and, at the same time, they will need to provide price signals to customers. On the other side, customers will need to install suitable controllers in their buildings. These controllers should be able to read the price signals and to compute appropriate schedules for the tasks to be performed. To be able to use controllers in an effective way, home appliances will need to implement some new functionalities that will allow them to communicate with the controller and to expose the new capabilities to the users. Furthermore, the controllers will require the capability to communicate with the house metering device.

The development of interoperable embedded systems in order to enable above scenarios calls for the definition of communication standards: one for the communication between controllers and energy providers and another one for the communication among controllers, home appliances and the metering device. The definition of standards will allow multiple device and home appliance producers to design and sell compatible devices and, thus, it will boost the adoption of this technology.

C. Management of Locally-produced Energy

Locally-produced energy can, in some periods of time, be in excess with respect to the user demand. In the model of the system presented in Section II we did not consider any specific option for this excess of energy. In the reality different options are available:

- store the energy in excess: energy might be stored, but this has a cost and it leads to some inefficiencies. In this case the impact on the model of the system that we are considering will be limited to the formula used to compute the price.

- Sell the energy in excess: by installing additional apparatus and by making suitable agreements with other parties, energy in excess can be sold. Also in this case, this will influence the price computation.
- Consume the energy in excess: energy can be used to perform tasks not directly requested by the user. For example, energy in excess could be used as an alternate way to heat water or to heat the house. Energy could also be used for useless tasks (i.e., wasted). If energy is used for alternate tasks, the price formula might be modified by considering the savings obtained by using the energy in excess. If the energy in excess, instead, is wasted, the formula used for computing the price does not require any modification.

D. Distributed Management

As discussed in Section IV, task scheduling might be implemented both at single house level or in a distributed way. If each house has its own independent controller and all controllers follow the same policies, there might be cases in which all the houses (or a large part of them) schedule tasks in the same way. Thus, there might be undesired peaks in the total energy consumption. This side effect might be controlled both by using coordination and by using an appropriate pricing policy by the sellers. Some sort of coordination among distributed controllers can be used to influence task scheduling in such a way that not all houses schedule tasks in the same way. The pricing policy can be designed such that prices are dynamically dependent on the energy requests received for each period of time. In this way additional users might be discouraged in scheduling tasks for these periods and a strong peak demand might be avoided.

VII. Conclusion & Future work

In this paper we propose a scheduling problem for household tasks that will help users in saving money spent for energy and that will allow energy producers to optimize their production processes. Our system model is based on the current and future trends for the electricity markets, smart grids and smart homes.

An important challenge is to create efficient scheduling algorithms that can be run on embedded systems. These algorithms must be efficient enough to be able to calculate the optimal schedule even for a large number of tasks and long time spans. As shown in this work, by using an exhaustive search, this is impossible even on a powerful machine such as a modern personal computer. We may resort to advanced optimization techniques such as constraint programming in order to obtain optimal results and better compare the performance of our heuristics.

Future work will focus on extending the system model to cover more of the real world cases. We assume price signals to be independently determined by the supplying companies. We may involve a negotiation phase where we can gain extra savings by extending the scheduler in such a way that it adjusts the load in order to increase its bargaining power. Similarly, we can extend the model with the ability to store and sell the energy when it is in excess.

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DSM in Spain. Results from GAD Project.

Aims, Developments and Ongoing Results

Laura Moreno, Alfredo Quijano
Automation and Capital Goods, and CEO respectively
ITE
Valencia, Spain
laura.moreno@ite.es; alfredo.quijano@ite.es

Isabel Navalon
Meter Reading
Iberdrola Distribución
Madrid, Spain
isabel.navalon@iberdrola.es

Susana Bañares
Demand Response
Red Eléctrica de España
Madrid, Spain
sbanares@ree.es

Abstract— This paper will present an overview of results obtained in GAD Project. First of all as a foreword, advantages of active demand side management are analysed from Transmission System Operator, Distribution System Operator and retailer point of view. Later, results of GAD project are presented, focusing on how embedded systems approach has been used to design devices to enable active demand side management. Finally, following actions to perform are stated.

Keywords-component; Active Demand Side Management, Domestic Customer Segmentation, Customer awareness , ICT infrastructures for active demand side management

I. Introduction

In a social environment where the construction of new electrical T&D infrastructures becomes a challenge and with an increasing concern about the efficiency on energy consumption, raises GAD project.

Active demand side management can be an opportunity to optimise energy consumption at Spanish homes, and the use of electrical T&D infrastructure in our country.

To depict Spanish electrical system behaviour, we have selected the load curve of the system for 2009 January, 13th.(Figure 1). This is the day in 2009 with maximum hourly average power demand.

In this figure it can be appreciated that the relation between peak and valley for Spanish electrical system is near to 2 (1’73). This effect makes electrical infrastructures to be oversized (in fact, in Spain, in 2008 , 4100 MW were needed only to satisfy the demand of 300h of greatest demand).

The difference between peak and valley demand is even greater in domestic consumption, so this is especially evident in low voltage grids, with high penetration of domestic consumers.

Another consequence of this load pattern is the difficulty to integrate the wind power produced at night. Spain has 18.199 MW of wind power installed (December 2009). Differing some load from peak to valley hours could make easier the operation of the system in windy nights. This load profile of the system caused an extreme situation on 2009, November 8th, when at 3:59 h, 53’7% of power demand was covered with wind power production, due to the volatility of this kind of production.

For the success of demand response, end user awareness is a crucial point. Reporting end users its real time consumption and the effects of consuming at peak hours allows the end user to consume in a more environmental friendly way.

The project aim is to research on mechanisms to implant active demand side management in Spain. These mechanisms include regulatory and economic aspects as well as technology needed to implement an effective active demand side management at domestic level.

Technologically, the great challenge is the bidirectional communication with 26 million electricity meters. The management of 26 million of telecommunication nodes that moreover measure electricity, will change the electricity meter concept, requiring an actualization of its specifications.

With this framework, GAD project, funded by CDTI (Technological Development Centre of the Ministry of Science and Innovation) in the INGENIO 2010 program, pursues research and development of solutions for the optimization of electrical consumption at a domestic level. The National Strategical Consortium of the Electrical Active Demand Management is leaded by Iberdrola Distribución Eléctrica, S.A.. The rest of former companies are: Red Eléctrica de España, Unión Fenosa Distribución, Unión Fenosa Metra, Iberdrola, Orbis Tecnología Eléctrica, ZIV Medida, DIMAT, Siemens, Fagor Electrodomésticos, BSH Electrodomésticos España, Ericsson España, GTD Sistemas de Información, Foresis and Corporación Altra. On top of this, fourteen Spanish research organizations are collaborating.

The project has a duration of four years (2007-2010) and it has a budget of 23’3 M€

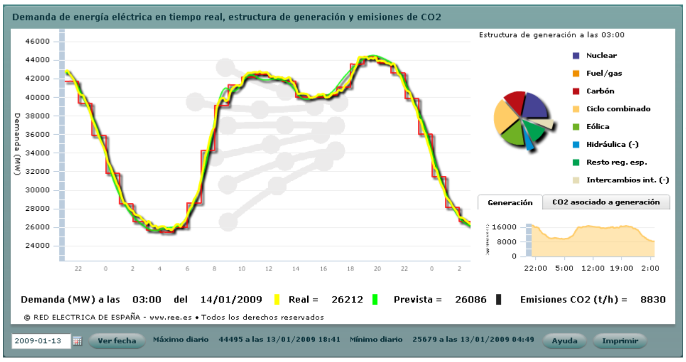

Figure 1: Load curve for 2009 January, 13th. Day with maximum hourly average power demand. Source: REE

II. AGENTS INVOLVED AND BENEFITS

A. General Benefits

Active demand side management aim is to transform electricity demand into an additional controllable variable of the electrical system management, and not a set point to follow.

ADSM can be applied in two scenarios, for planning or for operation of the system. In the first case, demand side management tools allow to defer some investments, due to the shaving of the load curve of the system, as electrical infrastructures are projected for supporting the maximum load.

In the second scenario (operation), demand side management can solve non-permanent overloads, can improve security of supply, and also can reduce loses (as losses depend on current)

Summarizing, general effects forecasted with the application of active demand side management to Spanish electrical system are:

- Infrastructures optimization
- Security of supply improvement
- Development of society awareness about generation costs in peak of demand periods
- Reduction of green house gas emissions
- Development of national industry capacities related to smart grids and smart metering.

B. Specific Benefits. TSO

Due to electricity can not be storage, TSO fuction is to assure instant equilibrium between generation and demand, coordinating generation resources and grid infrastructures in both mid and long term.

This function, traditionally with some exceptions, has been performed using generation and grid infrastructures, not acting over demand. Demand has been considered as an immovable factor in the electrical system framework: A non manageable demand to be satisfied. Nevertheless, increasing issues to develop new generation infrastructures as well as grid infrastructures has arisen due to social and environmental opposition.

GAD project is funded by CDTI (Technological Development Centre of the Ministry of Science and Innovation) in the INGENIO 2010 program

This, jointly with a new wish to increase the integration of non manageable production with quality and reliability, is pushing the sector to research and promote a manageable demand. Among the potential benefits for the TSO we can highlight:

- Contribution to the **quality and reliability improvement**. The creation of new services and tools for the demand management that can be used by TSO in critical situations, will contribute to the improvement of quality and reliability of electrical system, providing more flexibility and manageability.
- Possibility of **reducing and postponing the need of new generation and grid infrastructures**. The transfer of the peak consumption to valleys will impact in the peak reduction and therefore in a better use (efficiency) of electrical systems.(Figure 2)
- Enabling the **integration of an increasing amount of non manageable renewable generation**. The ability of giving signals to demand side to differ consumption to hours when renewable generation is higher will avoid the waste of this resources, and will enable the consumption reduction in low production hours.
- **Technical losses reduction** of electrical systems. As technical losses are proportional to the demand in a quadratic factor, the minimization of losses is achieved with a flat consumption profile.
- Contribution to the climate change mitigation. As far as active demand management improve energy efficiency, the reduction of resources used to obtain the same result impacts directly in green house effect gases emission reduction.

C. Specific Benefits. DSO

Specific benefits for distribution system operators derive from the installation of smart metering for the application of demand side management.

The installation of smart metering allows the DSO to have more visibility at low voltage grid. Also, it makes easier the management of the activation and cancellation of customer contracts, and the maintenance of the installations.

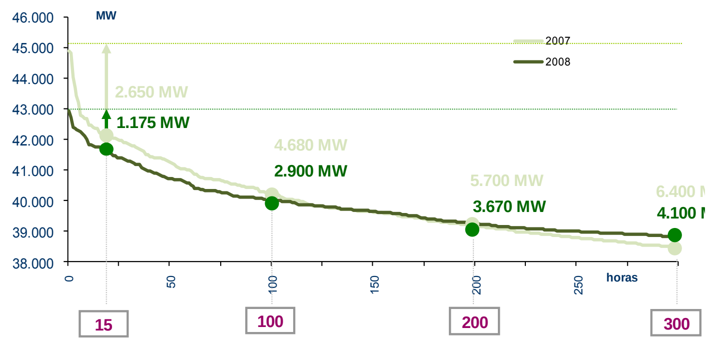

Figure 2: Monotonous curve of Spanish electrical system for 300 h of higher demand during 2007 and 2008.

Technology changes very rapidly, so the selection of one technology can be a thread. To protect the investment of distributors, the European commission has published the M/441 mandate on smart metering standards in Europe. The general objective of the mandate is to ensure European standards that will enable interoperability of utility meters (water, gas, electricity, heat), which can then improve the means by which customers' awareness of actual consumption can be raised in order to allow timely adaptation to their demands

In this framework IBERDROLA as a leader of OPEN meter Project is collaborating in the definition of this standard. The OPEN meter Project will remove the barriers for the wide scale adoption of smart metering and the building of the European Advanced Metering Infrastructure, thanks to the development of a comprehensive set of open and public standards for smart metering. The cooperation in the project of a wide circle of key European stakeholders in the field (as direct project partners or external parties), ensures the final acceptance of the results of the project.

D. Specific Benefits. Retailer

From the retailer point of view, demand side management will allow the differentiation between services offered by different retailers. This aspect is crucial with a product like electricity, that is a commodity. It is very difficult to offer something to keep customers if your product is exactly the same that the one from your competitor. Active demand side management will allow to offer different tariffs adapted to end user consumption. Moreover, it will allow retailers to improve customer service, as they will have data on customer behaviour and consumption uses.

Active demand side management also allows retailers to test new business models, based on demand bidding, as well as new tariff models like time of use, critical peak pricing, real time pricing, peak time rebate, or other models that could arise.

III. GAD Implementation Proposal

After three years research work, the consortium is proud to announce that a solution based on open standards for domestic active demand management has been designed. Following areas has been defined to reach customer houses from TSO and DSO control centers:

- Control WAN : ICT infrastructure to communicate between agents. Will be based on existing secure services.
- Core WAN: From DSO control center to secondary substation.
- ACCESS WAN: From secondary substation to customer meter.
- LAN: Network inside customer house. Allows communicating smart appliances and smart plugs with an in home controller which optimizes demand according to signals received and customer preferences.

Figure 3 shows technologies chosen for each segment.

Focusing on LAN segment, the project defines several devices at customer home, which will be able to manage the consumption of different kind of loads.

The architecture of devices at customer home, are shown on figure 4.

The different developed devices to manage the loads are:

- **DPM** (Domestic Power Manager - ORBIS): This device is the Home Controller. It will execute an algorithm which controls the consumption from electrical appliances. It receives feedback of both the electrical network and domestic appliances. Depending on price, and possible technical restrictions, the DPM moves the load consumption taking into account end-user preferences.
- **DIFU** (User Interface – ORBIS): This device is the User Interface of the system. It is connected with DPM by the Local Area Network (LAN), and shows relevant information to the user, like consumption, active loads, energy prices, CO2 emissions…
- **Electronic Meter** (ZIV) : It acts as a gateway between the distribution network, and the DPM. It also allows the automatic meter reading of domestic consumption.

In all devices developed, costs, size and energy consumption have been taken into account. Devices have been developed as embedded systems, adopting compromise solutions between processing power, and costs. Also size is a restriction, as devices will be installed in customer homes. Demand side management focused on domestic sector has only sense due to aggregation effect. To allow the businesses case to be positive, the devices have to be both cost and energy efficient as well as appealing for the end users.

Nowadays, a test facility of technology developed has been implemented. This installation shows the performance of devices from substation to customer house. (Figure 5)

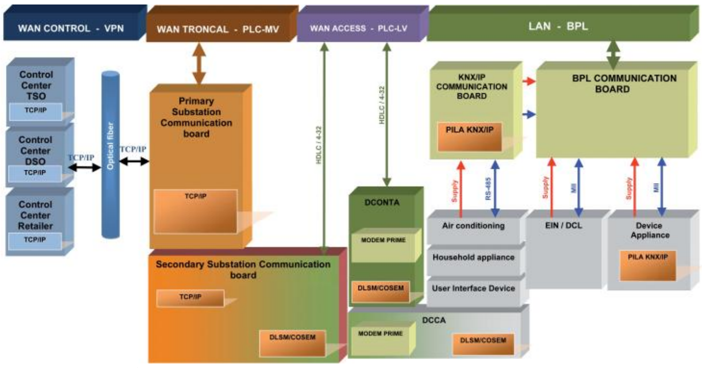

Figure 3: Communication Technologies chosen on each segment

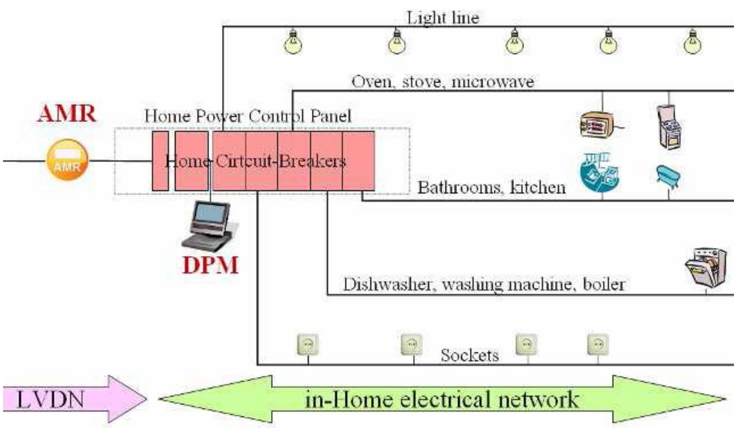

Figure 4: Architecture of devices at customer home.

Figure 5: Test Facility at ITE. GAD1. GAD Project

IV. NEXT STEPS

Once the solution has been designed, we are in the process of identifying next steps to commercialise the solution successfully. To do so, we have identified some barriers as potential threats for the implementation. Some of those barriers to overcome are:

- Standardization of protocols: active demand side management involves the use of smart appliances. Protocols used to manage the demand has to be based on open standards, as we can not ask the user to change its appliances to change from one retailer to another, that offers a different solution to manage the demand. In this direction OPEN Meter Project is defining this standard protocols. Protocols on Home Automation area are also needed.
- Evaluation of Demand side management resource. To be able to analyse the business case of domestic active demand side management, data on customer response and awareness is needed. For this reason, a representative pilot experience is needed, adapted to specificities of the country.
- New legislation to promote demand side management. Nowadays remuneration is based on km of grid constructed, without having into account demand side management. A new approach maybe is needed.
- New tariffs. In Spain, free market for domestic customers is not mature yet. Most of customers have still regulated tariffs. New tariff mechanisms that promote the customer to join active demand side programs have to be designed.
- Customer awareness. End users are blind to hourly changes in energy generation costs. We need to increase the customer awareness about the influence of its consumption on the environment.

ACKNOWLEDGMENT

This paper presents results form GAD project. All partners of the consortium have been involved in the achievement of results.

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Adopting system engineering methodology to Virtual Power Systems design flow

Slobodan Lukovic, Igor Kaitovic, Umberto Bondi
ALaRI - Faculty of Informatics - University of Lugano
Lugano, Switzerland
{slobodan.lukovic, igor.kaitovic, umberto.bondi}@usi.ch

***Abstract*—The concept of Virtual Power System (VPS) emerges as a promising response for increased concerns on secure, sustainable and at the same time 'clean' energy supply requests. This novel concept aims at boosting operational efficiency of Distributed Energy Resources (DER) but also at establishing them as an autonomous commercial actor on the open energy market. Nevertheless, VPSs are fairly complex HW/SW systems that require holistic multidisciplinary approach and also novel specification, modeling and analysis instruments to facilitate mutual understanding among stakeholders from different fields.**

We introduce UML/SysML based modeling methodology to describe such power system related issues aiming at providing an unified modeling instrument applicable for VPSs design flow. In the proposed system engineering methodology, system representation starts from a very general context description and gets refined through different levels of abstraction down to concrete embedded systems employed to perform defined tasks.

I. Introduction

Awareness to global climate changes caused by different kinds of pollution on the one side and increasing concern about sustainable energy supply on the other side have created a global sensitivity to energy efficiency as well as an interest in finding pollution-free and sustainable solutions. Pushed by such scenario, 'green' technologies are getting considered in an increasing number of fields ranging from transportation and power systems to building efficiency management. Enabling technology and main driver for realization of such envisaged concepts are information and communication structures and in particular embedded systems.

A novel concept of Virtual Power System (VPS) has been introduced by the AlpEnergy research project [1] and it aims at efficient integration of DERs - Distributed Energy Resources (including energy storages and consumers) in a single entity in technical and commercial sense. A cluster created in this manner would be able to autonomously participate as an actor in energy market and trade energy still providing reliable supply and optimal energy prices for customers and producers inside it. VPS covers wide range of commercial, power system and ICT (information and communication technology) related issues. Nevertheless, due to the fact that many heterogeneous and uncontrollable generators must be coupled together with indeterministic open market conditions, such systems require complex and robust ICT solutions to support needed technical and commercial advances. This in turn could create an opportunity for development of a new generation of embedded systems in form of customized platforms that could be deployed in VPS to provide its optimal operation.

In that sense VPS represent a cross-disciplinary topic in which many fields as automation, control, finance, legislation and many more, meet. Tackling the challenge posed by system complexity and interdisciplinary cooperation, requires a holistic and standardized approach which systems engineering provides.

In this work we introduce a specification, modeling and analysis methodology for VPS design flow developed in scope of AlpEnergy project. The methodology is based on UML/SysML system engineering approach [2]. We aim at providing an instrument to cope with the complexity of the VPS providing a communication platform for stakeholders coming from different fields and at the same time facilitates analysis, simulation and design of the system.

The final result of the project would be an instrument that formally describes the system context, efficiently gathers user requirements, transfers them into system requirements and ultimately into concrete functional requirements for system components.

The paper is organized as follows: Section II, provides a review on existing solutions for DER integration and system engineering concepts. In Section III, a conceptual, general structure of VPS is presented and explained. In Section IV the system engineering, model-based design methodology is exposed, while in Section V we provide as a case study simplified UML/SysML modeling methodology which shows the design flow from context description to concrete smart-metering solutions. Finally, Section VI presents conclusions and future work.

II. State of the art

Global energy demand growth urges for evolution of modern power systems in both commercial and technical terms. The Smart Grid [3], [4] concept has emerged as a promising response to these needs. Nevertheless, such complex system will require tremendous amount of data to be collected, transmitted and processed (in real time) which will pose another challenge to underlying ICT structures. Such scenario calls for partitioning and clustering of SmartGrid in certain autonomous modules.

On the other hade, efficient integration of heterogeneous distributed energy resources represents another challenge to be tackled by power systems engineers (several international research projects are dealing with this issue). Considering these facts, Virtual Power Plants (VPP) [5], [6] have been introduced as a means to aggregate DERs and represent them as a single, autonomous entity/module inside SmartGrids. The VPP concept aims at leveraging security of energy supply coming from renewable resources with their optimal commercial exploitation. In that sense it aims at presenting DERs in form of reliable, independent actors at energy markets able to trade its produced energy in an optimal way. It interacts with electricity Distribution System Operators (DSO) and energy market according to set of defined legislative rules. Integration of various micro-plants and renewable generators into VPP which is an aggregation of DER takes into account the actual location of individual DERs in the network. VPPs will have flexibility and controllability to provide different services to energy and ancillary services markets [5]. Such concept requires novel communication, control and automation solutions at lower DER level requiring new generation of embedded systems to be developed. At the higher VPP level, novel Energy Management Systems (EMS) have to be developed.

The Virtual Power System (VPS) can be seen as an extension of VPP. It actually additionally considers integration of consumers and prosumers (producer-consumer) entities in the system with renewable generation.

Nevertheless, such complex and inter-disciplinary concepts require appropriate instruments to manage user requirements collection and design complexity. In order to efficiently manage design of complex systems many system engineering and modeling concepts and languages have been introduced. In other environments, system-level specification languages have been introduced and are by now fairly widely used. AADL [7] has been introduced mostly for the purposes of modeling complex systems in avionics and space domain with an aim of expanding to other field. SysML [8] has been introduced as an extension of UML [9] for specification and modeling of complex systems including hardware components, personnel, facilities etc. Recently MARTE [10] has been proposed as a UML profile for modeling and analysis of real-time and embedded systems.

In the scope of our project we use UML/SysML language as it is currently the most widely accepted specification instrument and modeling standard in both industry and academia. UML has been already introduced as a modeling tool for finance issues and through the CIM [11] standard in power systems engineering.

III. Virtual Power Systems overview

The Virtual Power System (VPS) concept has been developed in scope of AlpEnergy project [1] with the aim of providing an instrument for efficient aggregation of renewable resources into an entity, seen from outside as one computational, communicational and trading module able to autonomously manage its commercial exploitation. The enabling technology for such concept is considered to be ICT in particular different types of embedded systems.

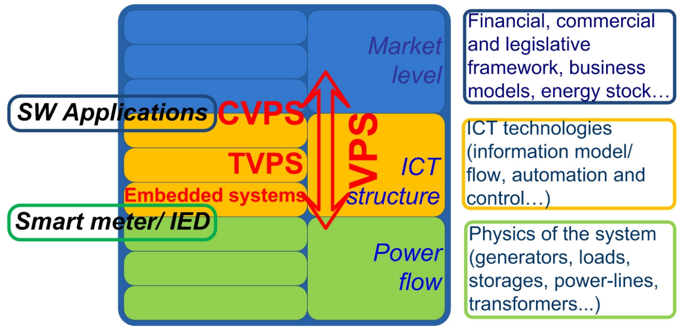

Fig. 1. VPS layered structure

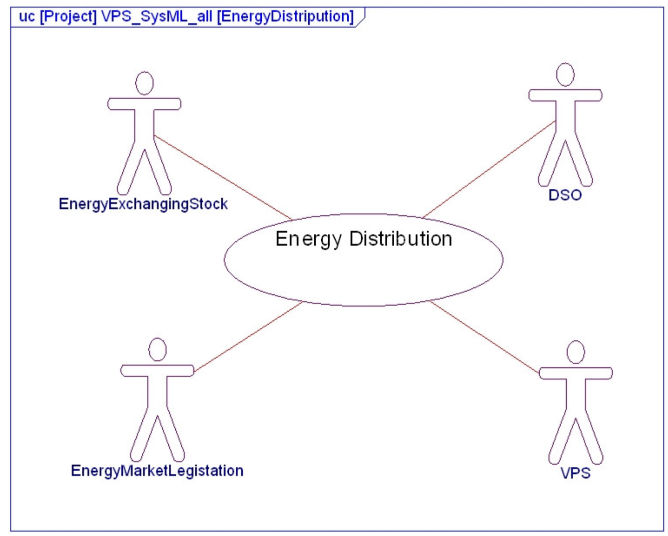

Fig. 2. VPS as an actor in energy distribution

The Virtual Power System (VPS) concept heavily relies on the VPP concept developed in [5]. The fundamental extension of VPP is the fact that VPS considers also involvement of storages, consumers and prosumers in the same system. Following its dual role to aggregate DER in a technical and commercial sense, the functionalities of VPP (and VPS accordingly) have been logically encapsulated in two entities [6]:

- Commercial VPP (CVPP/CVPS)
- Technical VPP (TVVP/TVPS)

CVPS considers DERs as commercial entities optimizing economical utilization of VPS portfolio in environment of an open electricity market [12]. In other words, the purpose of CVPS is to schedule an optimized DERs utilization and set bids to Energy Exchange Stock according to market conditions versus current and predicted demand/supply balance. The operational employment of particular DERs in technical terms is managed by the TVPS. It ensures that the power system is operated in an optimized and secure way, taking into account physical constraints and available resource. So that, in terms of service layers, TVPS is a lower layer providing services to the CVPS as a higher layer.

The place of VPS and its components is the power systems structure is represented in Figure 1. The relation of VPS with other ’external’ actors can be represented in UML fashion as in Figure 2.

IV. System engineering methodology

The remarkable complexity and interdisciplinary nature of VPS calls for standardized and unified approach to its design. Many system engineering methodologies have been developed to tackle similar problems in safety critical systems such as avionics. Considering the nature of VPS we have chosen UML/SyML based approach as this language has been widely accepted. Moreover, it is already introduced in many fields that are correlated in VPS (like finance and power systems).

The methodology starts with project context description in which basic ideas and goals of the system are defined as well as system environment situation. The next step consist of stakeholders identification which is followed by requirements determination. The efficient translation of user requirements into system ones, requires a platform for mutual communication and understanding among variety of stakeholders from different fields. Precise and clear system requirements definition and structuring is a key step towards good system design. This is the place where SysML *requirements diagrams* are showing their importance.

Once well defined and organized, system requirements (functional and non-functional) are, by means of UML/SysML instruments (i.e. *use cases*, *activity diagrams*, *block definition diagrams*, *sequence diagrams* and finally *internal block diagrams*) mapped into functional requirements of concrete system components (i.e. embedded systems to be deployed in the field).

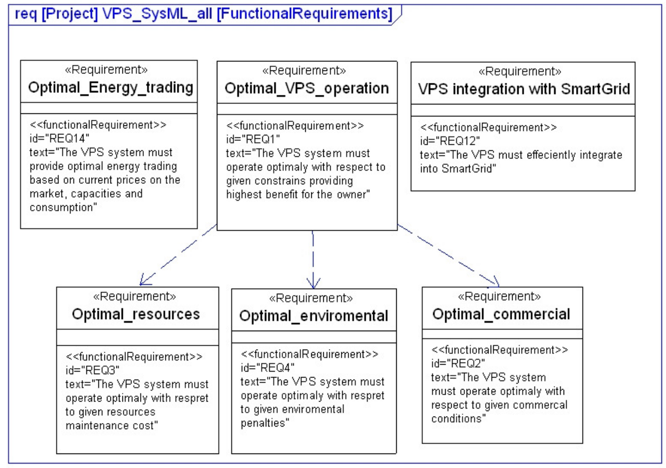

Fig. 3. Functional user requirements structure

V. Case study - system engineering approach for VPS design flow

The VPS represents a strongly interdisciplinary oriented topic. Many issues from control, automation, communication, power and electronic engineering as well as commercial, financial and legislative field are interacting in this concept. For this reason an unified and simple yet efficient approach to the topic must be adopted.

Considering the analysis of system engineering approach in previous section, we have concluded that UML/SysML based methodology can be applicable for the required needs. In the sequel we apply and show step by step the proposed approach. It is important to mention that the analysis concern only a part of VPS concept but the topics discussed are chosen as an representative subset so that simplification of the model is done without loss of generality.

A. VPS project context

In the initial phase of project design many fundamental decisions have to be taken. The subsequent design heavily depends on this step and that’s why it implicitly requires deep understanding among stakeholders. Basic ideas and goals have to be defined in a clear way and their impact on all sides concerned must be fully transparent.

At this point the project description is given in a textual form using common natural language as it is usual starting point for expressing thoughts and ideas. More formal description has to be derived through set of steps exposed later in the work.

The discussions yield project description in terms of VPS role and interaction with its environment, as follows. The basic goal of VPS is to aggregate heterogeneous, uncontrollable renewable resources (windmills, photovoltaics etc.) into single reliable entity in commercial and technical terms. In order to achieve such an aim additional energy storages and controllable generators (e.g. gas turbines) have to be introduced in the system. VPS has to interact with the rest of power systems and it is decided that it would operate at distribution level (middle and low voltages). It means that VPS would interact with Distribution System Operators (DSOs) to provide technically correct operation. On the other side, it would interact with Energy Exchange Stock in order to enable optimal economical performance of VPS.

B. Stakeholders identification and requirements determination

Based on the analysis given above, we have identified *stakeholders* involved in VPS operation. It is important to mention here that all the steps in the proposed methodology are subject to an iteration process in which some new actors or services related to VPS can be revealed and additionally inserted in the system description/model.

The selected stakeholders are listed here:

- Dispatcher
- VPS shareholders
- Distribution System Operator (DSO)
- Energy Exchange Stock
- Energy market legislation
- Local authorities
- VPS trading agent
- VPS operation manager

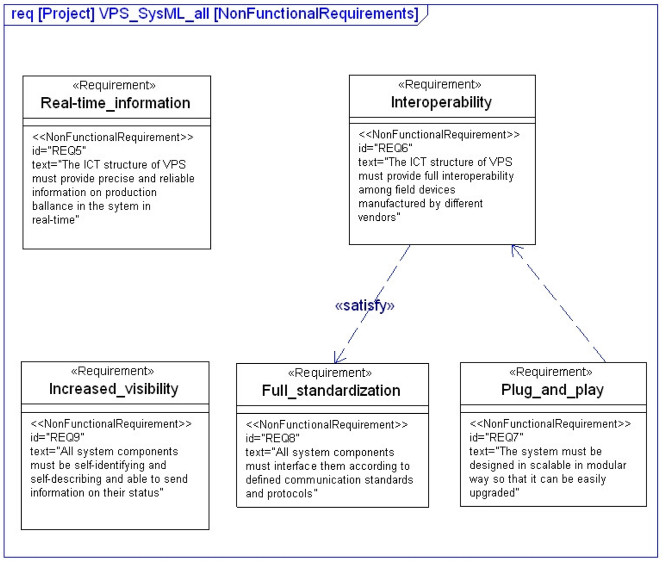

Fig. 4. Non-functional user requirements structure

Following stakeholder identification, their functional and non-functional requirements are determinated. Those requirement are at first 'coarse grain', technically imprecise and uncorrelated. In order to resolve possible collisions and to get more precise 'finer grain' requirements, further decomposition is needed. It is important to mention here that we distinguish, from the begging, between functional and non-functional requirements. As an example, we consider the selected set of VPS requirements gathered form stakeholders given in SysML form in Figures 3 and 4. Such a set of requirements represents only a simplified example that is used to show further decomposition steps. The requirements are organized and presented in a structured and hierarchical manner. This step marks the beginning of the transition process of user requirements into system ones. In a particular case, we choose to refine a requirement for 'optimal resources utilization' (given as *optimal resources* in Figure 3) by decomposing functional requirement according to [13]. Scenarios are represented as UML use case diagrams showing VPS interaction with relevant actors as given in Figure 1.

Sequence of actions that are necessary to fulfill user requirement of *optimize resources* is given in Figure 5. Based on those actions further decomposition of *optimize resources* requirement is done in order to obtain system requirements as shown in Figure 6.

C. System services description

Once we are aware of actors and system requirements we focus our attention to services that system must provide to satisfy stakeholders' demands. This actually means that we have to develop behavioral model of the system. For the sake of modeling system services and functionalities we use *use cases*. For each set of functional requirements a proper use case that refines them is defined as shown in Figures 7 and 8. this way, we have related system services (i.e. use cases) with

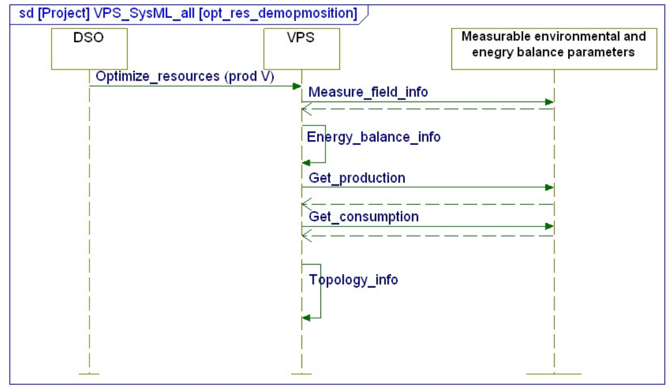

Fig. 5. Sequential diagram of 'VPS optimize resources' scenario

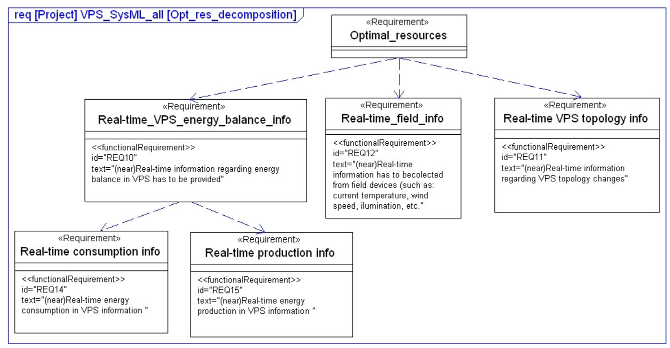

Fig. 6. System requirements obtained by decomposition of 'optimal resources' functional requirement

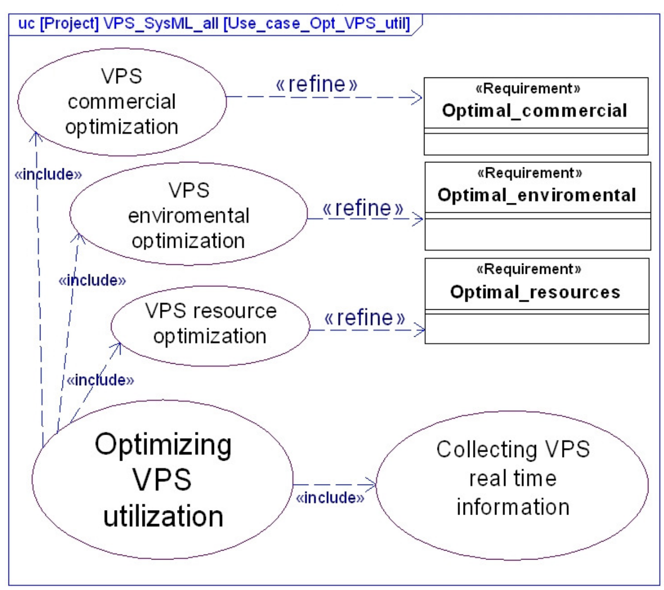

Fig. 7. Refining use cases, requirements relation

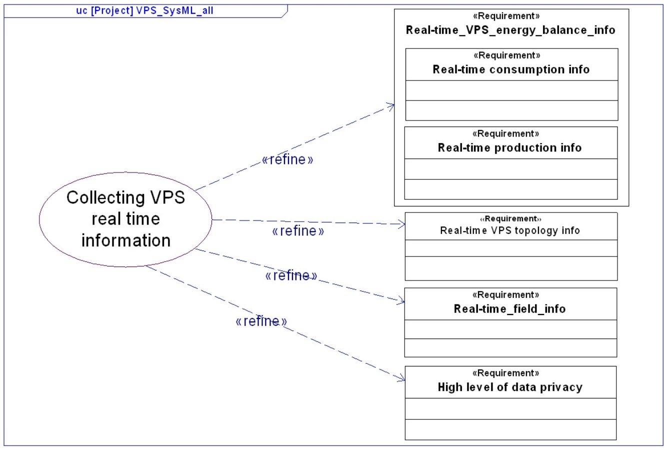

Fig. 8. Refining use cases, requirements relation

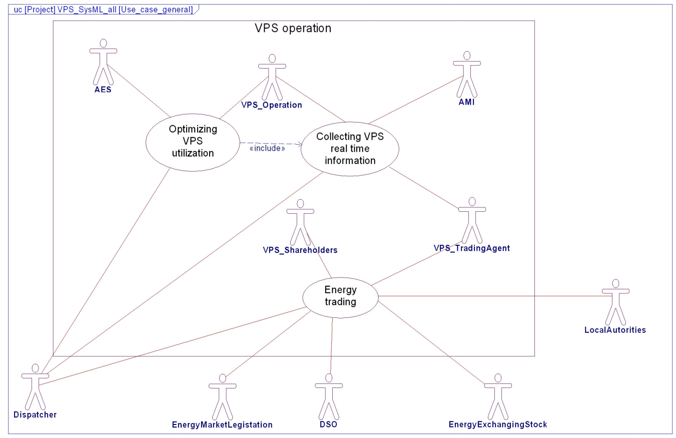

Fig. 9. VPS operation use cases

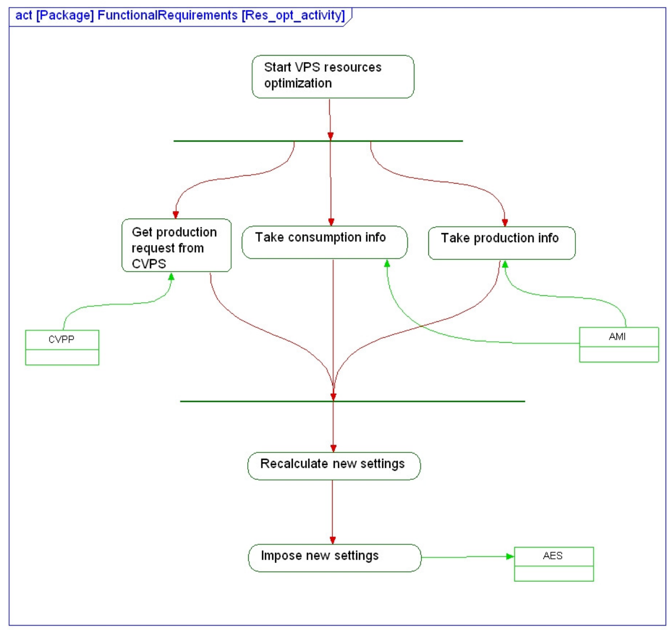

Fig. 10. VPS resources optimization activity diagram

appropriate system requirements. In Figure 9 we represent in a very general manner fundamental services (actualy use cases) that VPS must provide with related actors (stakeholders) involved in each of them.

Next step involves realization of use cases through activity diagrams. As an example we chose a use case of 'optimizing VPS resources' that is included in use case of 'optimizing VPS utilizations' (Figure 7).

Optimizing VPS resources represents system settings update done in regular time periods aimed at boosting efficiency of VPS resources utilization. These periods depend on the speed of environmental changes (i.e. pricing fluctuations, weather changes and so forth). Inside this period TVPS must recalculate new system settings based on production request from CVPS and current status of energy production/consumption (energy balance). The real-time (or 'near' real-time) information on energy balance in the system is obtained from use case 'Collecting VPS real-time information' through the Advanced Metering Infrastructure (AMI) [14] that represents a network of sensing, metering and measuring embedded system devices (i.e. sensors, smart-meters etc.). In the activity diagram in Figure 10 the resource optimization is represented through use cases flow. Activities of production/consumption information collecting (from AMI, that is represented as a component) and new request obtaining (from CPVS), are executed concurrently. The control and data flow are indicated in the diagram (represent as red and green lines respectively).

Upon reception of needed data and recalculation of new settings, TVPP imposes them into the system through the network of deployed actuating embedded systems (AES; i.e. Intelligent Electronic Devices (IEDs) and Programmable Logic Controllers (PLCs)).

D. System components

At this point we can start identify components (i.e. structure) of the system. For the sake of a methodology demonstration we will focus on AMI component. Below we describe its relations with the rest of the system (relating it with appropriate use cases it is involved in), using standard UML/SysML instruments.

Hence, we speak of static (structural) *block diagrams* and dynamic (behavioral) *sequence diagram* representations of interactions in the system. It is important to note that at this stage we do not distinguish between software and hardware components, they are both simply represented as blocks.

E. Optimizing VPS utilization - Block diagram

The appropriate components to realize use case given in Figure 9 have to be determinated and then represented in form of *block definition diagram*. Such a model shows relations among components and actors that are involved in realization of the use case of optimizing VPS utilization providing an insight in concrete structure of the system. The block diagram that represents these relations is given in Figure 12.

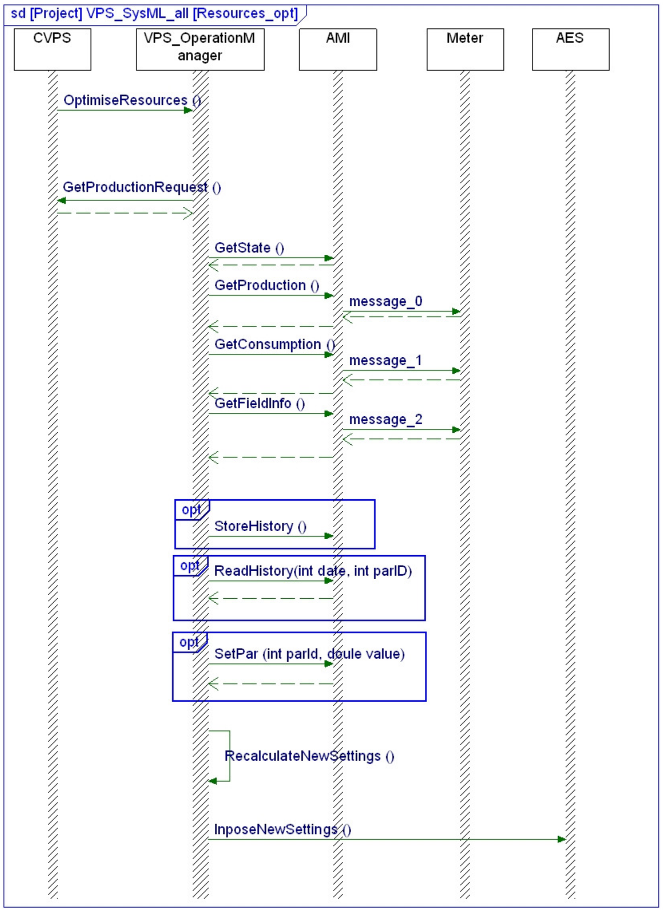

Fig. 11. VPS resources optimization sequence diagram

F. *Optimizing VPS resources - Sequence diagram*

Realization of use case of optimize VPS resources is performed through a given sequence diagram (in Figure 11) considering previously given block definition diagram. This figure shows dynamic interaction among components and actors that are involved in realization of the use case of optimize VPS resources. It provides a basic idea on system behavior.

G. *AMI internal block diagram*

Having determined all the components (of the considered use case), their relations and functionalities, we are able to propose a concrete realization for each of them. In our case we focus on a possible implementation of AMI internal structure. As an example of one possible solution for AMI we give simplified *internal block diagram* represented in Figure 13. Communication among components iis represented by *flow ports* with given flow specifications.

Internal block diagram gives a suggestion for concrete realization. These components represent concrete embedded systems (i.e. their functionalities and interconnections).

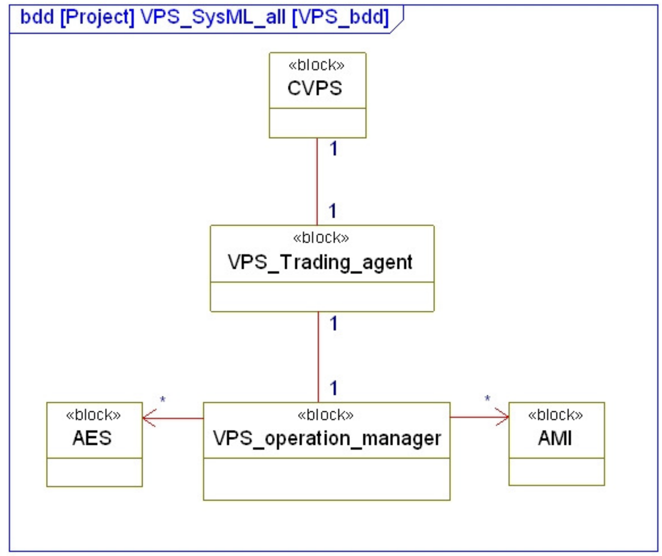

Fig. 12. VPS resources optimization block diagram

VI. Conclusion and ongoing work

VPS has been introduced as a response to growing concerns for sustainable energy supply. It is the concept developed in scope of AlpEnergy project which aims at providing an instrument for efficient aggregation of heterogeneous renewable resources into reliable commercial and technical entity able to independently acts at open energy market and interacts with other actors.

A relevant point that emerges from this and other studies is the fact that in many cases renewable resources are individually of too little relevance to be considered on the wide energy market, that they are highly heterogeneous and often not reliable from the "continued availability" point of view. As a consequence, VPP and VPS emerge as solutions to aggregating such resources and leveraging their cumulative capacities; on the other hand, this requires a strong presence of ICT supports beyond the traditional energy management ones, namely distributed and ad-hoc hardware/software solutions consisting of suitable embedded systems. If the VPP-VPS concept is adopted, the diffusion of the above recalled embedded systems reaches a critical market mass granting future investments in their design and implementation. The goal of our study is creating the background analysis and assessment for such venture. Given the complexity of of the envisioned overall systems we introduce a system engineering methodology based on UML/SysML as a specification, modeling and analysis instrument supporting mutual communication and understanding platform among variety of stakeholders from different fields. The ultimate goal of this methodology is to reach a comprehensive description, eventually leading to the functional requirements, of embedded systems to be deployed as one of enabling technologies of VPS.

Our ongoing work concerns further expansion of the methodology with the aim of providing finer grain models,

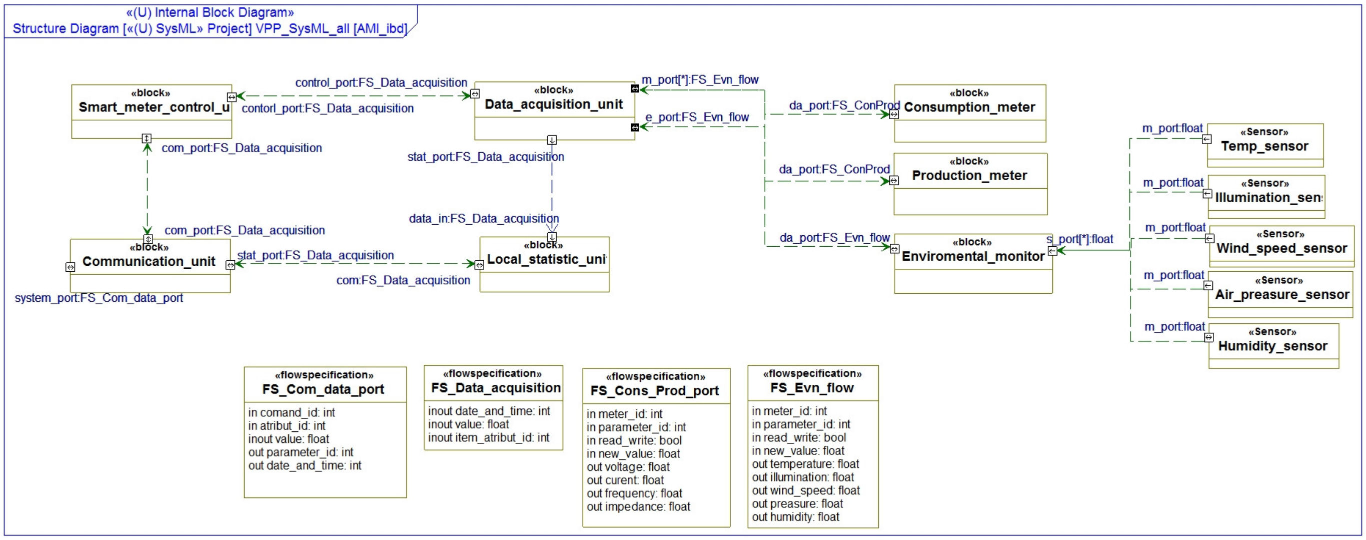

Fig. 13. AMI internal block diagram

internal block diagrams for concrete embedded systems and developing meaningful simulation strategies for developed models.

ACKNOWLEDGMENT

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Optimised Embedded Distributed Controller for Automated Lighting Systems

Alie El-Din Mady, Menouer Boubekeur and Gregory Provan

***Abstract*—The paper introduces a model-driven hybrid/multi-agent platform for the design and analysis of building automation systems. It describes an optimised parameterizable and predictive distributed control methodology for automated lighting systems. The modelling steps and the simulation results for a typical lighting system scenario are outlined throughout the paper. Moreover, the performance for the wireless network is evaluated. The contribution of the proposed lighting control strategy is highlighted by comparing it with several control techniques.**

***Index Terms*—Lighting System Control, Hybrid System, PPD-Controller, Charon, Embedded Middleware, Distributed Control.**

I. Introduction

INTELLIGENT (or smart) buildings incorporate a Building Management System (BMS) to maintain a comfortable environment in an energy-efficient manner. A typical BMS would provide a core functionality that keeps the building's climate within a specified range, automates the lighting based on occupancy, and monitors system performance and device failures.

One major source of energy inefficiency in buildings is lighting, which can account for up to 30% of total energy waste in some retail and public offices [1]. The aim of our research is to define a methodology for efficiently model and integrate building management system services, with a focus on lighting and Heating, Ventilating, and Air Conditioning (HVAC) systems. In line with the recent focus on "energy management through active control" in the energy and control community, our work provides intelligent controllers for more energy-efficient buildings.

Given the rapidly growing complexity of modern building control systems, the centralized control approach faces numerous challenges in scaling, delays associated with collecting data, inefficient energy consumption, and unstable control tendencies [2], [3] (i.e., continuously oscillating around the set points). Further, the different requirements of different services place many challenges on centralized control solutions; for example, in lighting control, reaction times are anticipated within fractions of a second, whereas in HVAC control, the process dynamics is much slower and the sampling/actuation time is much larger. Rather than adopt worst-case timing solutions in a centralized controller when integrating several processes, a distributed approach may provide an better solution for time-scale challenges, by ensuring fast response and reducing the dependency on network communication.

Our ongoing research work consists of developing an integrated platform for intelligent control of building automation systems. This platform provides, among other features, predictability, reconfiguration, distribution and building energy optimisation. As shown in Fig. 1, the system design flow starts by defining relevant scenarios to be operated within the building. These scenarios are defined using the Unified Modelling Language (UML) [4]. The UML models are interpreted using specific models for simulations and analysis purposes. At this level we allow an optimisation loop to optimise the model at an early stage of the development. When the simulation gives satisfactory results, the models are auto-translated into embeddable code to be deployed over a distributed sensor/actuator network [5].

The integration process is performed using a model-/service-based middleware [6] platform, which connects components and facilitates data exchange. In this approach, all the different components of the architecture collaborate with the requirements module to ensure that the requirements are adhered to.

The main features of our platform will be illustrated through an example of a lighting system for an office area. This example illustrates the combination of discrete-event behaviour (presence detection, light actuation levels) and hybrid properties for the luminosity control, i.e., where both discrete and continuous aspects are considered. We describe a distributed lighting control system, which is embedded in a wireless network, that is both simple and effective. The lighting system has been modelled using our hybrid/multi-agent platform; the generated code has been emulated using the Java Sun-Spot platform [7]. We study several Quality of Service (QoS) metrics of the underlying Wireless Sensor/Actuator Network (WSAN) [8] using the VisualSense tool [9]. These metrics are essential to evaluate the safety, reliability and user comfort (i.e. the difference between the sensed value and the user preference) of the overall control application.

The remainder of the paper is organized as follows: Section II provides a survey covering the related work and discusses our contribution comparing to the state of the art. The proposed Parameterizable/Predictable Distributed Controller and its specification are discussed in Section III. Section IV introduces the Charon modelling of the lighting system and Section V describes the optimisation techniques we have used. In Section VI, we outline and discuss the simulation results. We end in Section VII by giving a discussion of our work and outlining future perspectives.

Alie El-Din Mady, Menouer Boubekeur and Gregory Provan are with Cork Complex Systems Lab (CCSL), Computer Science Department, University College Cork (UCC), Cork, Ireland. website: http://www.cs.ucc.ie/ccsl/index.htm, e-mail: {mae1, m.boubekeur, g.provan}@cs.ucc.ie

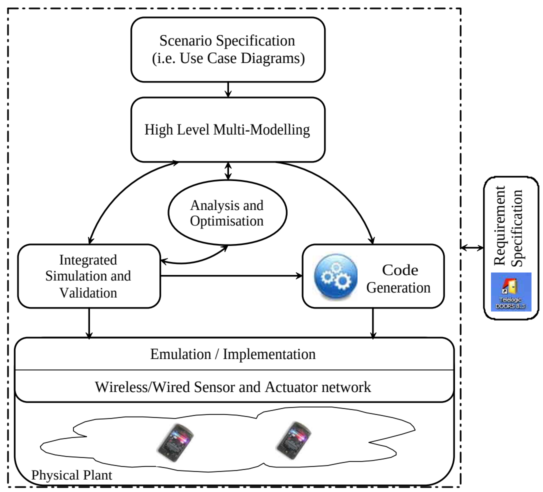


Fig. 1. System Architecture

II. Related Work

In the domain of control systems, there has been work on distributed control, especially of discrete-event systems, e.g., [10], [11]. However, this work is primarily of a theoretical nature, and has not been applied to the domain of automated energy systems. Recently, some work on distributed automation of energy systems has been appeared within the Multi-Agent Systems (MAS) community, e.g., [12]. This work focuses on the distribution of agents and on agent communication, rather than on the issues more pertinent to control theory, such as liveness, non-blocking, reachability, etc.

A wide range of research papers have considered the control of the lighting system using centralized controllers, where an optimisation engine is used to improve the energy consumption at the high level. In most cases, these approaches lack a clear modelling approach, don't consider issues such as daylight control, predictability, and reconfigurability, and use centralized controllers. However, [13] considers daylight control using an image processing technique, which is not suitable to be deployed on a limited-resource micro-controller.

Our contribution is to provide a parameterizable/predictive distributed control strategy that can improve the energy efficiency of lighting systems while guaranteeing particular levels of user comfort. We also aim to enhance the WSAN QoS through the implementation of a distributed system, thereby avoiding the previously-mentioned problems of a large-scale WSAN for the centralized control strategy, e.g., limitations in scaling and control instability. We use a simulation model to evaluate the system performance and improve the flexibility of the control strategy before deployment.

III. Parameterizable/Predictable Distributed Controller

In order to increase the control reliability, scalability, resource sharing and concurrency, a distributed control model [14] has been considered. In this context we have developed a Parameterizable and Predictable Distributed controller (called PPD-Controller) for automated lighting systems. The PPD-Controller is described throughout the following sections.

A. Lighting Model Specification

The most common lighting controller is the bounce controller, which switches the light on/off depending on the occupancy and the ambient light levels [15]. When a person is detected in the controlled area and the daylight luminance is below (above) a certain threshold, the controller turns the light on (off).

Another type of lighting control is the dimming control (manual or automatic), where the light luminance is controlled using DAC/PWM, which provides the control voltage/duty cycle as discrete values [16].

In our work we have considered an open office area with a typical architecture, as shown in Fig. 2. It contains 10 controlled zones; each zone contains one artificial light, one light sensor and one Radio-Frequency Identification (RFID) receiver. There are 4 windows/bindings on the right and left borders of the open area, and a fixed number of predefined occupant positions.

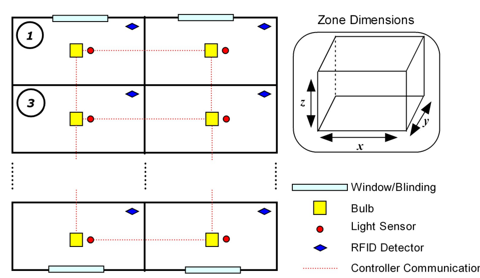


Fig. 2. Model Specification

Our lighting model includes integrated blind and lighting controls. In order to enhance the efficiency of the resulting control model, an optimisation technique has been implemented, as explained in Section V. The optimisation engine selects the light luminance and blind position depending on the user preferences and the energy consumed by the artificial light and the blinding actuators.

In brief, the lighting system scenario behaves as follows:

1. The user can switch on/off the automatic lighting system for several zones, or for the entire system (through a technician).
2. The users provide their preferences (light luminance and blinding position).
3. A person is tracked in each zone using RFID in order to service his preferences, which are ignored whenever he leaves his zone.

B. Control Strategy

In our PPD-Controller, the control functionality is distributed over 10 zones, where each zone contains one artificial light source and one light sensor. Depending on the sensor reading, the local controller modifies the artificial light source to achieve the "optimal" ambient light. It has been implemented as a closed loop controller, used to predict the next sample actuation value. The system is constructed in a modular way, for example the controllers of the zones that contain windows incorporate a separate module for blinding actuation.

In order to increase the flexibility of the control system, we have designed the controller so that a range of global parameters can be assigned and/or reassigned by users at any time. For example, the use can assign a priority parameter to specify that the occupants of a given zone have a high priority; therefore they can exert full manual control. The parameterization can also be used for setting different parameters for the distributed local controllers (i.e. considering the blinding, switching on/off the local controller, ...). This can also help with the distributed optimisation process, as will be explained later.

C. Control Model Description

In this section, we describe the overall control model. Fig. 3 shows the model of a local controller and its interactions with the environment models. The local controller modifies the light intensity inside its zone as follows:

1. The preference solver receives the user preferences for each zone, sends the optimal light luminance and blinding position back to the local optimisation engine.
2. The optimisation engine calculates the optimal actuation settings (artificial light level, blinding position) and sends them to the PI-Controller.
3. The controller actuates the artificial light and the blinding position accordingly, then go to 2 only if the preference has been changed otherwise the PI-Controller actuates only the artificial light relying on the external light and the light interference. The controller ignores blind updates triggered by minor changes in ambient light, since it leads to discomfort for the users.

The PI-Controller, as shown in Fig. 3, is used to predict the next actuation setting for the lighting level in a closed-loop fashion [17] using Eq. 1. The light-level refinement is one level, as the optimisation engine is used to recommend the initial setting for the controller. The PI-Controller has two main statuses: (a) the first is unstable when the difference between the sensed light intensity and the optimal one is greater than 70 Lux (one light actuation level), and (b) the second is stable, if the difference is less than or equal to 70 Lux.

A Light/Blinding Occlusion Preference Solver agent is used to provide the intermediate solution between several luminance/glare preferences in the same controlled zone.

$$A(t+1) = A(t) + \theta \qquad (1)$$
$$U(t) = A(t) + E(t) + I(t)$$

$$\theta = \begin{cases} \gamma - \dfrac{\beta}{\rho}, & \forall\ U(t) - S(t) > \epsilon \\ \dfrac{\beta}{\rho} - \gamma, & \forall\ S(t) - U(t) > \epsilon \\ 0, & \forall\ |S(t) - U(t)| \leq \epsilon \end{cases}$$

where: $A(t)$ is the actuation setting for light/blinding actuators, $E(t)$ is the daylight intensity (Lux), $I(t)$ is the interference light intensity (Lux), $U(t)$ is the sensed light intensity (Lux), $S(t)$ is the optimal preference settings, ϵ is the luminance level produced from a single dimming level (70 Lux), β is the maximum light intensity error (700 Lux), γ is the minimal light intensity error (0 Lux) and ρ is the total number of dimming levels (10 levels).

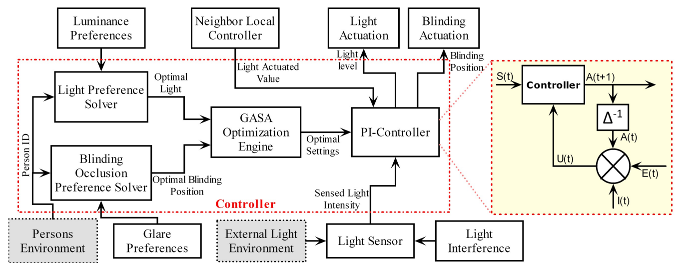


Fig. 3. Control Model

D. WSAN Deployment

We embed each PPD-Controller within a wireless node in a WSAN. Each local controller communicates with a light sensor, actuators (light, blinding), an RFID detector, and also with the neighbouring local-controllers as shown in Fig. 2. Each RFID device has been modelled as an event-driven agent fired whenever a person comes/leaves to/from the controlled zone, and then sends the occupancy status to the local controller as a binary-encoded variable. Therefore the wireless communication traffic is decreased and the RFID receiver is in a sleep mode unless an event occurred. This will induce savings in the consumed energy by RFID device which leads to increase the battery life time.

The neighbouring local-controllers communicate through message-passing their own actuation values in order for each controller to consider the expected light interference. To avoid heavy communication traffic, the communication is modelled as an event-driven that relies on the actuation update.

Among the wireless devices, the light sensor appears to be the most critical power-consumption device. This is due to the fact that it should send frequent updates to the local controller about the light luminance. Considering that the transmitting/receiving sampling rate is adaptable, depending on the local controller status, we modelled a mechanism to save power for light sensors. When the controller is in a stable state, it sends a request to the sensor for a decrease in its sampling rate, and when the controller goes to an unstable state, it requests increasing of the sampling rate in order to reach the stabilized phase more quickly. In case the sensor is using the stable sampling rate and the controller detects an unstable state, the controller will use the last received sample until the current sampling period is finished, and the sensor sampling rate is updated. Then, the controller can then receive the new sample.

IV. Charon Modelling of the Lighting System

In order to simulate the system and evaluate its performances, the lighting system and its environment have been modelled using the Charon toolset. In this section, the hybrid models for the PPD-Controller and the environments are explained.

A. Charon Modelling of the Controller

In the Charon modelling, one agent is used for the global controller, 2 other agents have been used to model the environments (external light and presence). For each zone, 4 agents are used: RFID, light sensor, blinding controller and light controller (local controller). As mentioned earlier, the global controller sets the configuration parameters for the local controllers, e.g. activate/deactivate some controllers (i.e. blinding controller) or some functions inside a controller (i.e. considering or not the blinding). The local controller contains 2 subagents, one is used to receive and calculate the light interferences coming from the adjacent zones, whereas the other one is used to send the actuation values and trigger the optimisation engine. Each agent contains a hierarchy of modes describing the corresponding behaviour, for example the local controller mode shown in Fig. 4, describes the behaviour of a local controller.

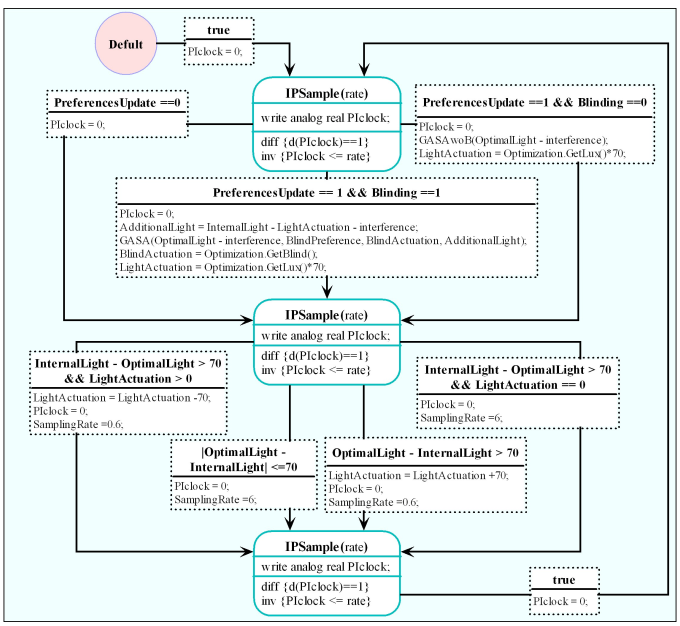


Fig. 4. Linear Hybrid Automata for the Local-Controller

B. Modelling of the Environment

There are two main environments for the lighting system, the daylight and the person movement environments. In order to verify the behaviour of the PPD-Controller, both environments have been modelled using hybrid systems, as the daylight model has continuous behaviour while the presence model has discrete behaviour.

In the daylight model shown in Fig. 5, five periods have been modeled as a first order differential equation with a constant slope (using linear hybrid automata [18]). During the first and last four hours of the day, the daylight slope and luminance are equal to zero, while during the second four hours the slope is equal to 100, which means that the maximum intensity in the day is 4000 Lux. In the next eight hours the slope is equal to zero and then goes to -100 in the following four hours, in order to reach zero luminance again at the end of the day. The light intensity that comes to the controlled zone is a percentage of the daylight intensity, this percentage relies on the dimensions of the window. In this model, 8% of the daylight is considered as the external light coming into the controlled zone [17].

The model for persons movement in the controlled zone follows a deterministic distribution with respect to the day time. In the first and last seven hours of the day, no one is in the zone, from 7:00 to 10:00 AM people arrive successively, then during the next seven hours enter or exit with a 50% probability, and finally, the next two hours people leave individually.

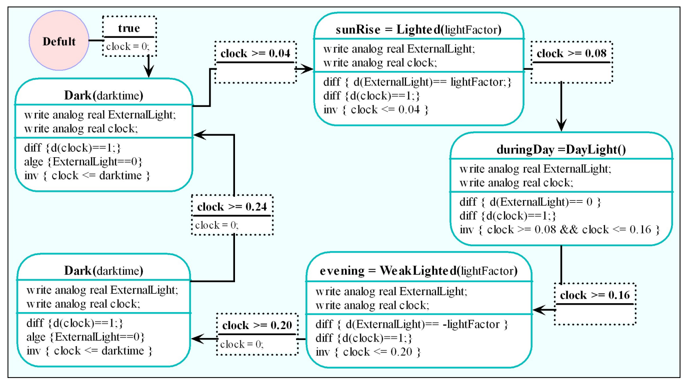


Fig. 5. Linear Hybrid Automata for the Daylight Environment

V. Distributed Optimisation Process

The control platform provides an optimisation mechanism that calculates the optimal artificial luminance level and blinding position. Each local controller includes an optimisation engine, which receives the Optimal Light (OL) and the Blinding Preference position (BF) provided by the preference solver, and sends back to the controller the optimal settings. We have chosen to use the Genetic Algorithm/Simulated Annealing (GASA) optimisation technique [19]. The stabilization of the overall optimisation process is guaranteed through a certain number of techniques including (1) linear interference predication, and (2) a scheduler for the global controller that synchronies local controllers.

A. GASA Optimisation Technique

Fig. 6 shows the GASA optimisation technique used to evaluate the artificial light luminance and blinding position in order to reach an intermediate optimal point between the user satisfaction and the energy consumption as follows:

1. Select randomly a predefined percentage (for example 10%) from the search population.
2. Calculate the cost function for each solution point.

3. Evaluate the Pareto points [20] and select the best two point which have the lowest cost function.
4. Apply the Genetic Algorithm (GA) on the two points selected previously to create a new solution point.
5. Apply the Simulated Annealing (SA) algorithm to the new population.
6. Evaluate the optimal point.
7. The algorithms stops when the calculated optimal point matches the stopping criteria, otherwise the calculated optimal point is attached to the new search population and the algorithm is repeated for another cycle.

The optimisation engine defines the User Discomfort (UD) as a function of the Blind Position Discomfort (BPD) and the Luminance Discomfort (LD). Whereas the Energy Consumption (EC) is defined as a function of the BLL and Energy Cost Factor (ECF) of the blind actuator. Blinding actuator's energy has been considered in the optimisation engine to avoid the frequent movement of the blinding which leads to user uncomforting. The corresponding metrics and equations are described below:

$$BPD = BF - BP$$
$$LD = OL - \text{External Luminance } (EL) - BLL$$
$$UD = BPD + LD$$
$$EL = \text{Estimated Total } EL\ (ETEL) - (ETEL * BP)$$
$$ETEL = Current\,EL * (100\% - Current\,BP)$$
$$EC = BLL + ECF * (Current\,BP - BP)$$

The cost function is the sum of the optimisation metrics:

$$Cost\,Function(CF) = UD + EC \quad (2)$$

The search space population contains all the possible values of the variables included in the system. Bulb Luminance Level (BLL) = {0%, 10%,:.,100%}, where 0% means that there is no light intensity and 100% is the maximum light intensity that comes from the bulb. Blinding Position (BP) = {0%, 10%,:.,100%}, where 0% means that the blinding is completely open and 100% is completely closed.

For the solution space, the optimisation engine considers all the visible solutions. Therefore, the Solution Space Population = 10 for the lighting × 10 for the blinding = 100 possible solutions.

Each solution point is a combination of two parts; each one is represented in binary format by 4 bits. The first part presents the 10 BLL possibilities and the second part is used for the 10 BP possibilities. In order to apply the GA to the best two points, the first point exchanges its BP (Blind1) part with the BLL (Lux2) part in the second point. Therefore, the improvement has been applied only on the BP in the first point and hence, the SA algorithm is applied on the BLL (Lux1) part of the best point (lowest cost function). In the SA algorithm, we consider 100% refuse for the generated point if it's cost higher than the ex-optimal one.

B. Distributed Optimisation Techniques

When considering distributed controllers with local optimisation engines, the problem of instability occurs since the decisions of the controllers are cyclical dependent. In order to avoid the control instability due to cyclic effect of interferences or at least reach a faster stable state, the following features have been used in our model:

Luminance Boundaries: In order to distribute the energy consumption over all the controlled zones, luminance boundaries have been set to limit the user's preferences of exceeding 700 Lux. This will also limit the interferences between zones.

Tuning Process: As explained earlier, the optimisation engine uses a random initial population to select the optimal setting. In order to improve the optimisation performance, the last optimal settings are added into the next search population. In this case, the optimal settings are tuned to obtain faster more accurate values. The controller is sensitive to 70 Lux margin corresponding to one dimming artificial light level. If the sensed value is more than 70 Lux different than the optimal one, the actuated light is decreased by one dimming level (70 Lux) instead of the exact Lux difference. This will diminish the interferences and then make faster the stabilization process.

Scheduling: The scheduling technique implemented in the global controller allows further improvement to overcome the instability due to the interferences. It follows the pseudo-code depicted in Fig. 7. It basically defines two sets of zones (S1, S2) where the zones of each set are interference-independent from the zones of the other set. S1 and S2 can then be executed concurrently. However this technique does not handle the potential initial instability cycle, and hence we have introduce the expected interference mechanism described next.

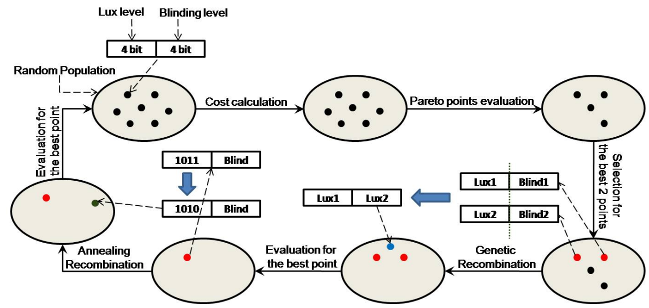


Fig. 6. GASA Optimisation Process

```
S = all zones (1 ... 10)
Z = Pick Randomly one zone form S;
Add (Z) to S1;
Add All zones dependant on Z to S2;

While ((S1 U S2) <= S)
{
    Si = All zones dependant on  S2;
    Add (Si) to S1;
    Sj = All zones dependant on  S1;
    Add (Sj) to S2;
}
Return (S1, S2);
```

Fig. 7. Pseudo-code for the Schedular

Expected Interference: In the first running cycle, a local controller does not have any information about the interferences that cause instability. To avoid this initial instability, an expected interference parameter is introduced using Linear Prediction Coding (LPC) algorithm. It is based on Weighted Least Square Error (WLSE) technique, the constant coefficients are calculated [21] using a specific equation. The 5^{th} order of the prediction filter polynomial has been considered in order to cover a week period (5 working days), moreover the first sample is considered as the average of the last week interferences. However in the initial running cycle for the overall system, the predictor does not have any value to start with, so it considers its own optimal value as it is the actuated value in the neighbour zone and then calculate the expected interference. Due to space limitations, the details of the equations are omitted in this paper, however are available in the internal report [22].

Fig. 8 shows an experimental test for the algorithm applied to a local controller for a month (20 working days). It is notable that the prediction error is always less than 70 Lux, which means that even considering the predicted values the controller will reach the correct actuation decision.

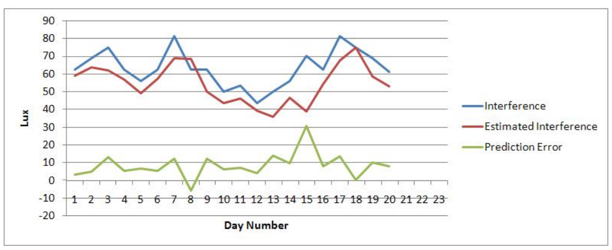


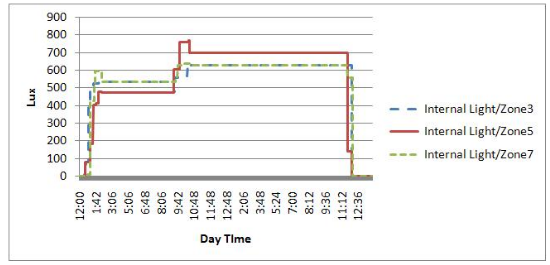
Fig. 8. Linear Prediction for the Interference During a Month

The simulation results show that due to the previous factors, the lighting controller gets stabilized after 2 cycles (maximum), however in [23] the system stability needs 100 cycles. Fig. 9(a) and Fig. 9(b) show the luminance changing in 3 neighbour zones before and after applying the aforementioned techniques, respectively.

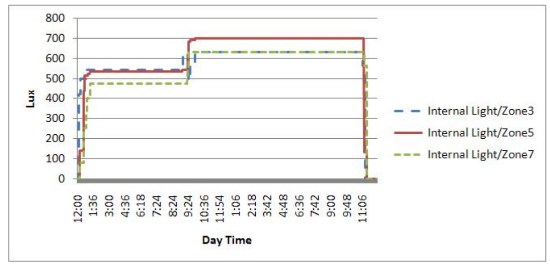
VI. Evaluation Study

In order to verify the modelling technique and show its similarity to the real environment, we compared the simulation of a 10-level dimming PI-Controller with a real scenario. The case study considers a single zone that contains an external light source (window), with 600 Lux as the maximum luminance that can be supplied and 350 Lux is the set point.

In order to evaluate the accuracy of the simulations models, we have compared our simulation results for the aforementioned model to a dataset from [17]. Fig. 10 shows light luminance variations for the experimental and the simulation model. Although we ignored several lighting factors, e.g. sky luminance distribution, window solar transmittance and visible reflectance of interior surfaces, the two curves reflect similar variations. This is mainly due to the control sensitivity, where 60 Lux sensitivity covers



(a) Before the Tuning



(b) After the Tuning

Fig. 9. Lighting Tuning Process

the influences of such factors.

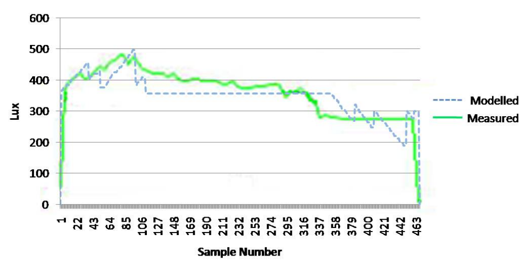


Fig. 10. Experimental Results Vs. Modelling Results

A. Lighting Baseline Models

In order to evaluate the potential improvement in power consumption, stability and response time, we have considered two control models as a baseline. These models are among the most popular control techniques, and have been applied to the same aforementioned scenario specification. In the first model scenario, called the Null model, the control strategy is based on user presence, where the controller switches the light on given a (fixed) predefined preference whenever a person is detected using Passive InfraRed (PIR) sensor. Moreover, the user can turn on/off the automatic lighting system for several zones, or for the entire system.

The second control model uses a standard PI-Controller [24] in order to predict the next actuation sample, depending on the accumulation of the pervious actuation errors, the daylight and the light interference.

B. Simulation Results

In this section we outline the simulation results for the PPD-Controller. Fig. 11 shows that the distributed control strategy has lower expected delay than the centralized one for the Null model.

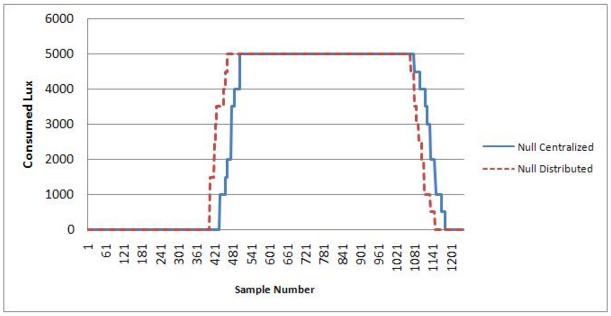


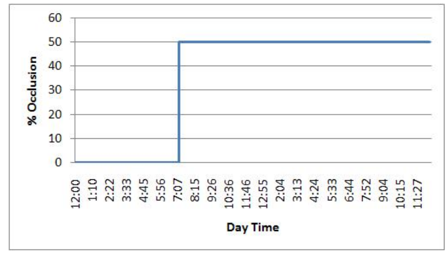
Fig. 11. Centralized Vs. Distributed Controller

In the rest of the section we describe the simulation results for single and multiple zone(s) models, the energy consumption, and the WSAN performance evaluation.

Single Zone: In the single zone lighting control, we have considered a scenario of one controlled zone with one external light source (window) as a source of daylight luminance. To allow a clear comparison of the different results, we have fixed the preferences for all the persons inside the controlled area as 50% blinding occlusion and 560 Lux (500 Lux, European law UNI EN 12464). As shown in Fig. 12(a), the GASA optimisation engine selects the optimal blinding occlusion, which affects the external light coming into the controlled zone as depicted in Fig. 12(b). During the period from 12:00-7:00 AM, no person is in the controlled zone, and then the controller switches the artificial light off. In this case the light sensor detects only the external light intensity as internal light, the controller is then in a stable state and will request the WSAN to increase its sampling period to 12 min in order to save battery power, as shown in Fig. 12(d). When people start coming at 7:00 AM, the controller actuates the artificial light to 420 Lux and requests a faster sampling rate (1/6 min), which allows the controller to reach a stable setting faster. The controller considers 70 Lux as an acceptable difference margin between the sensed internal light and a given optimal light (calculated by the preference solver). If this margin exceeds 70 Lux, the controller updates the artificial light as illustrated in Fig. 12(c), where the artificial actuation is increased to 490 Lux when (at 7:00 PM) the external light decreased to make the margin exceed 70 Lux.

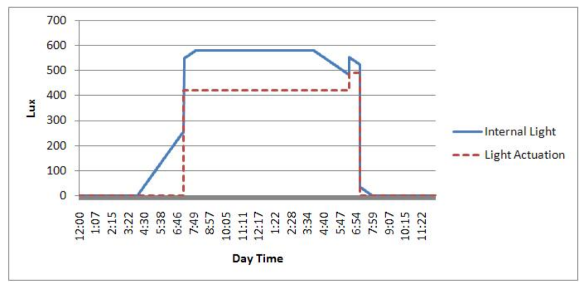
Multiple Zones: Unlike the single-zone model, the multi-zone controller considers the light interference between the different controlled zones. Fig. 13 shows the simulation results for zone 1 and zone 3. These two zones have been chosen for illustrative purposes; zone 1 has a window that provides external light, whereas zone 3 is an internal zone and it is affected by the light interference coming from zone 1 (Fig. 2). Based on the WSAN evaluation of the sampling interval for the light sensors, the minimum periods are: 36 sec in the unstable state and 6 min for the stable state. It is obvious that the internal light in zone 3 is more stable than in zone 1 which indicates an advantage for the sensor's battery power consumption by increasing its sleeping period. From the optimisation side, the GASA optimisation engine is used to select a meta-optimal point between the energy consumption and the user comfort. As notable in Fig. 13(c), the GASA optimisation engine gives 40% blinding occlusion while the user requested 50%.

Energy Saving: In order to compare between different control strategies, we have used the luminance consumption in Lux as the energy consumption metric. Fig. 14 shows the summing of Lux consumed over time in all the zones for Null, PI-Controller and PPD-Controller strategies using a constant user preference (500 Lux). This primary test concludes that the PI-Controller improves energy consumption by 29% over the Null strategy; however PPD-Controller shows a 32% improvement, and hence the PPD-Controller improves 3.1% comparing to the PI-Controller for one time change in the user preference, as

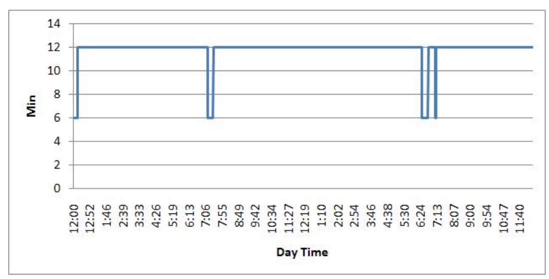


(a) Blinding Actuation

(b) External Light coming to Zone1

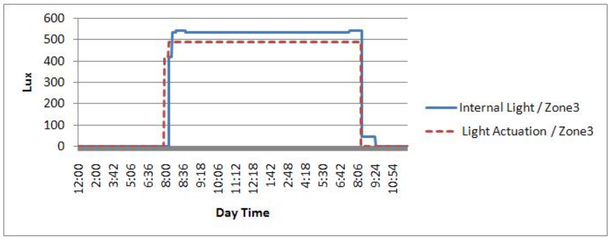


(c) Artificial Light Actuation & Internal Light

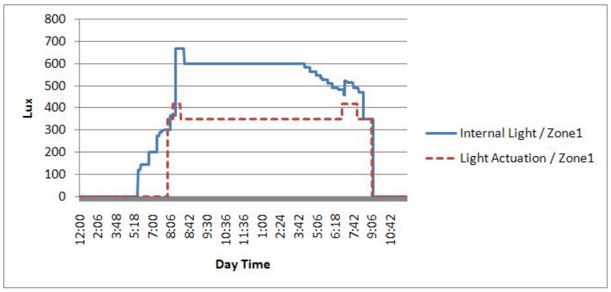


(d) Light Sensor Sampling Intervals

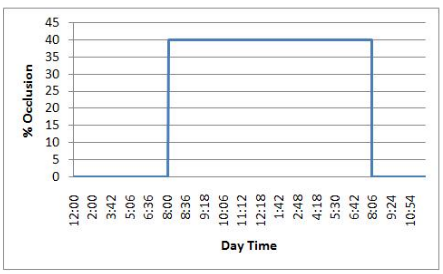
Fig. 12. Lighting Control for a Single Zone



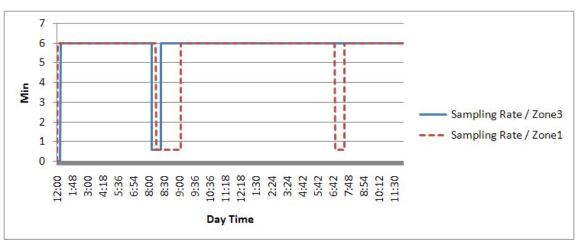
(a) Artificial Light Actuation & Internal Light/Zone3



(b) Artificial Light Actuation & Internal Light/Zone1



(c) Blinding Actuation/Zone1



(d) Light Sensor Sampling Intervals/Zone1&3

Fig. 13. Lighting Control for Multi Zones

shown in Fig. 16. In order to evaluate the optimisation engine, we consider that the minmal number of user preference changes per day is three (650, 500, 700 Lux), Fig. 15 shows the energy consumption for each strategy; the PI-Controller and PPD-Controller show 23% and 32% improvement, respectively, as shown in Fig. 16. We conclude that the optimisation engine saves nearly 3% of the energy consumption for each execution.

C. WSAN Performance Evaluation Results

In addition to the Hybrid/Multi-agent model explained earlier, the associated embedded Java code has been emulated using the Sun-Spot emulator [7]. The results produced by the emulator are matched to the simulation results obtained using the Charon simulator. We have also attempted to use the emulator to evaluate the network's performance; we found the tool to be inappropriate for such test, since it is dedicated to development, debugging and testing. For this reason we evaluate the WSAN QoS using a more appropriate tool, VisualSense.

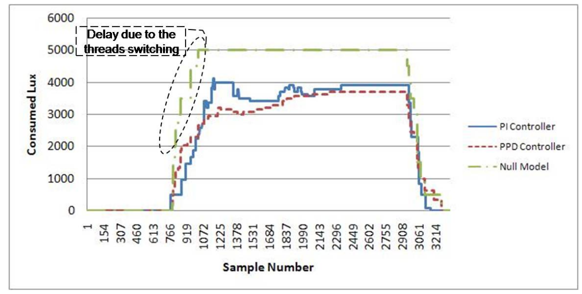


Fig. 14. Energy Consumption Using Fixed User Preference

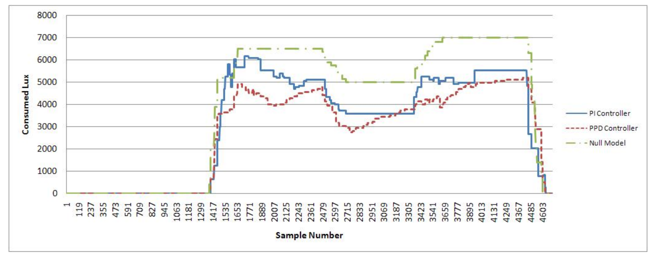


Fig. 15. Energy Consumption Using Variable User Preference

The QoS network performance metrics that we consider include buffer size, time response, packet loss (caused by packet collision), controller/receiver duty cycle, channel throughput and sensor's battery life time. Due to space limitations we show only the main results of the evaluation; a detailed description of the study is described in [22].

Table I provides the evaluation results for each model during 100 samples (100 minutes). It clearly shows that the PPD approach performs better than the centralized controller. The centralized controller has a higher collision probability in comparison to the PPD; moreover, it needs more memory to save the received requests, which leads to high controller duty-cycle and low time-response. This is due to the delay that can reach 287 minutes (479 samples and 0.6 min for service time) to serve the next request under a no drop-out strategy [25]. In relation to the battery lifetime for the sensors, all models have the same expected lifetime because of the fixed sampling rate for the sensors.

VII. Summary and Conclusion

This article described a model-based distributed controller for lighting systems, called a parameterizable and predictable distributed (PPD) controller. The parameterizable capability has been implemented through assigning global parameters, which alter the behaviours of the local controllers. The PPD-Controller incorporates an optimisation engine to compute the optimal settings for increased energy-efficient control. The local optimisations are coordinated to achieve a level of global optimlity, using some features and heuristics to guarantee better control stability. These features enable us to overcome the potential instability in our lighting model due to the limited interference of lighting levels across the zones. However, for

TABLE I
WSAN QoS

	Single Zone PPD	Multiple Zones PPD	Centralized Controller	Improvement
Packet Loss	0%	4%	8.6%	∼ 53-100%
Buffer Size	5 packets	9 packets	479 packets	∼ 98%
Controller Duty Cycle	35%	66%	100%	∼ 34-65%
Response Time (after 100 samples)	1.8 minute	3 minute	287 minutes	∼ 98-99%
Channel Throughput	0.58 packet/min	1.1 packet/min	6.46 packet/min	∼ 82-91%
Battery Life Time	79.72 days	79.72 days	79.72 days	0%

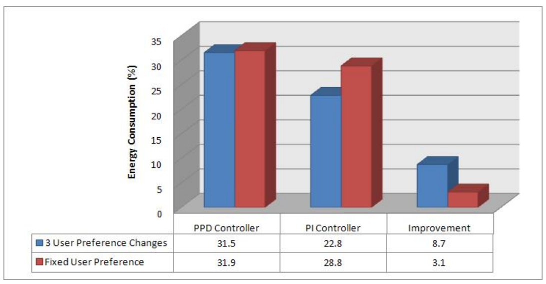


Fig. 16. Energy Saving

more interference-sensitive systems like HVAC, more sophisticated techniques are necessary .

As future work, we intend to implement a demonstration of the developed system in an actual building, the Environmental Research Institute (ERI) building, which is the ITOBO "Living Laboratory" [26]. We also intend to adapt this work to a more complex scenario including HVAC control.

Acknowledgment

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Alie El-Din Mady was born in Egypt, in 1984. He received the B.Sc. degree in electronics and communication engineering with honor degree from Alexandria University, Alexandria, Egypt, in 2006, and the M.Sc. degree in embedded system design from Università dellà Svizzera italiana, Advanced Learning and Research Institute (ALaRI), Lugano, Switzerland, in 2008. He is currently a Ph.D. researcher at Cork Complex Systems Laboratory (CCSL), University College Cork (UCC), Cork, Ireland, where he is researching aspects of embedded middleware for optimised building operations under the supervision of Prof. Gregory Provan and Dr. Menouer Boubekeur.

Menouer Boubekeur received his Ph.D. degree in computer science from the University of Joseph Fourier, Grenoble, France in 2004. He obtained his engineering degree in computer science in 1997 from the University of Es-Senia (Oran, Algeria). From 1997 to 1999 he worked as a computer science engineer at ADEM Info (Private company in Oran). He Joined IMAG institute in Grenoble where he obtained his Master degree in computer sciences in 2000. Later, he joined the VDS group of TIMA Laboratory in the University of Joseph Fourier where he obtained his PhD Degree. After being a post-doc in CEOL centre working in real-time systems analysis, he joined CCSL as a researcher in 2008. His main research interests are real time and embedded systems, modeling and formal verification methods, smart buildings and integrated software environment.

Gregory Provan is a Professor at the Computer Science Department at University College Cork (UCC), in Cork, Ireland. He is the Director of the Complex Systems Lab (http://www.cs.ucc.ie/ccsl/) at UCC. He received a BSE from Princeton University, an MSc from Stanford University, and a DPhil from Oxford University. Prior to his appointment at UCC, he spent 10 years as technical manager at Rockwell Scientific, leading the Autonomous Systems group. His research interests include model-based diagnostics, control, large-scale systems modeling, model transformation, component-based model development, embedded systems and embedded code generation.

Embedded Controllers for Increasing HVAC Energy Efficiency by Automated Fault Diagnostics

Jiří Vass, Jana Trojanová, Radek Fišera, Jiří Rojíček
Automation & Control Solutions (ACS) Laboratories
Honeywell
Prague, Czech Republic
{Jiri.Vass, Jiri.Rojicek}@Honeywell.com

Abstract— **This paper illustrates the use of embedded controllers for improving energy efficiency of commercial buildings. The next generation of intelligent controllers (such as Honeywell JACE controllers) will be capable of automatically diagnosing the faults and degradations of the Heating, Ventilation & Air Conditioning (HVAC) equipment. This paper gives an example of a diagnostic algorithm for air-handling units (AHUs), and also emphasizes the importance of data pre-processing (cleansing) to obtain reliable diagnostic results. Early detection of HVAC faults can reduce the wastage of heating/cooling energy and improve the comfort of building occupants.**

Keywords-HVAC; AFDD; embedded controller

I. INTRODUCTION

Due to increasing energy prices, building owners have become more interested in optimizing energy usage of their buildings. A major energy consumer in commercial buildings is the HVAC equipment, such as boilers, chillers, air-handling units, and their auxiliary devices (fans, pumps, valves, etc.). Therefore, correct (fault-free) operation of the HVAC equipment, together with intelligent HVAC control, is an attractive way to achieve significant energy savings and reduce CO2 emissions.

Saving energy in both commercial and industrial sector is one of the key areas where Honeywell generates its revenue. To increase HVAC energy efficiency, Honeywell is developing solutions to automatically detect any issues causing energy wastage and/or comfort compromise, such as: (a) *abrupt hardware faults* (stuck damper, leaking valve, frozen sensor), (b) *long-term performance degradation* (boiler fouling, heat exchanger scaling, air filter clogging), (c) *control inefficiencies* (oscillatory control signals, permanent setpoint offset, improper utilization of outdoor air, simultaneous heating and cooling, etc.). All detected issues are graphically depicted using intuitive online software (showing the layout of each HVAC equipment), and can be also aggregated over time to generate an automated diagnostic report (with various charts summarizing energy usage, comfort level, equipment performance, etc.). This paper contributes to the area of HVAC fault detection, which represents one of the approaches for reducing energy costs of buildings.

Building automation is one of the areas where embedded devices are used for monitoring and control of energy usage. In large building complexes (enterprises) the distributed control architecture is commonly used. An intelligent embedded controller (integration controller) communicates with (a) the supervisory system, i.e. workstation with Building Management System (BMS), such as Honeywell EBI (Enterprise Buildings Integrator™) and (b) the local (unitary or plant) controllers (responsible for control of individual pieces of equipment, such as boiler, AHU, VAV, lighting). Honeywell embedded controllers (e.g. JACE controllers [1] based on the Niagara^AX framework) are capable of integrating various building sub-systems, such as HVAC, lighting, security, fire, access control, etc. The JACE (JAVA® Application Control Engine) controllers are based on a small, compact platform allowing to integrate the functions of control, supervision, data logging, alarming, scheduling and network management with the internet connectivity and web serving capabilities. It enables the user to control and manage external devices over the internet, as well as to observe real-time information using web-based graphical views. From the energy usage viewpoint, the most important functionality of JACE controllers is the supervision of local controllers responsible for HVAC control, lighting control and power monitoring. Moreover, the next generation of embedded controllers will be also capable of performing the AFDD (Automated Fault Detection & Diagnostics) of HVAC equipment in order to minimize the energy wastage caused by abrupt mechanical faults and gradual equipment degradations.

II. AFDD ALGORITHM FOR AIR HANDLING UNITS

This paper gives a specific example of the AFDD algorithm for air-handling units. The example also illustrates that data pre-processing can be the key differentiator between a good and poor AFDD algorithm, hence a special attention is paid to the data cleansing module.

Fig.1 shows a block diagram of the AFDD algorithm consisting of four main modules (detailed description of each module is beyond the scope of this paper and can be found in [2]). The data cleansing module validates the correctness of raw input data (sensor data, control signals) and classifies the data into two categories: valid or invalid. This module increases the robustness of the AFDD system by protecting it against raw errors, and thus avoiding incorrect diagnoses.

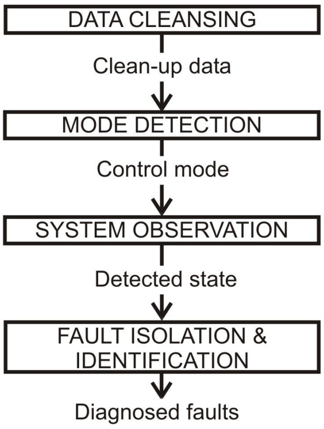

Figure 1: AFDD system for air-handling units (taken from [2]).

Typical examples of invalid sensor data are abrupt errors (outliers, missing values), while control signals are regarded as invalid in case of oscillations (large periodic fluctuations of the amplitude).

The AFDD algorithm is based on APAR (AHU Performance Assessment Rules), which is a heuristic technique (first proposed by Schein et al. [3]) based on a set of *expert rules* derived from mass and energy balances [3]. This rule-based approach can detect abrupt mechanicals faults (e.g. stuck damper, leaking valve) and other typical problems, such as communication failures and wrong control logic.

A typical diagnostic rule (for AHU operating in the heating mode) is as follows: if the supply air temperature is below its setpoint, and the heating control signal is 100% (i.e. heating valve is commanded to a fully open position), then the possible faults can be: a) stuck heating valve, b) heating failure, c) stuck/leaking cooling valve. The rules are mutually exclusive and cover all possible combinations of the input data (typically temperatures, setpoints and control signals). When a certain rule is satisfied, the probability (relevance) of the corresponding fault(s) is increased. The fault relevance is aggregated in time, which allows applying the methods of reasoning [4] in order to isolate the most likely fault. Also note that the diagnostic rules can be further enhanced by the fuzzy approach (defining fuzzy borders instead of "strict" thresholds).

The AFDD algorithm provided correct results when applied to data *without* errors, such as outliers, missing data, out-of-range data, etc. However, when applied to real data from a real building, it was unable (in some cases) to correctly diagnose the actual fault. The most common reason was an oscillating control signal that resulted in unreliable fulfillment of the expert rules. The AHU is a system with slow dynamics (e.g. after opening the heating coil valve it takes several minutes until the air temperature starts increasing). In case of an unstable control loop (e.g. control signal for heating valve oscillates between 0 and 100%), the delay caused by system dynamics is adversely affecting the system observation (i.e. when some diagnostic rule is applied the system is already in a different state). As a result, the AFDD algorithm provided unreliable system observation that resulted in wrong diagnostics. To overcome this problem, we have developed a data cleansing method capable of detecting outliers (in sensor data) and oscillations (in control signals), as shown in Fig. 2.

The outlier detector is based on EWMA (Exponentially Weighted Moving Average). For detecting the outliers, sensor signal is high-pass filtered (using EWMA), then its three-sigma limits are computed, and only the samples within these limits are regarded as valid. The oscillation detector utilizes the fact that oscillations have a periodic character, and thus increase the high-frequency content of the signal. At the same time, its variance σ^2 also increases due to a wider range of signal amplitudes. Therefore, oscillations are detected by low-pass filtering the signal (using EWMA) and comparing the standard deviation of the original and filtered signal (denoted as σ_x and σ_y, respectively). The control signal is regarded as invalid when $\sigma_x > C \cdot \sigma_y$, where C is a positive constant controlling the sensitivity of the detector. Whenever this method detected some invalid data no diagnostic rules were applied, hence the fault relevance (of all faults) was not updated. As a consequence, the calculated fault relevance became more reliable (unaffected by invalid data) and the fault reasoning method provided more consistent results.

Fig.3. illustrates an example of a fault-free AHU with an oscillating control signal (as depicted in Fig.2). The AFDD algorithm consists of 3 stages: *state observation*, *fault detection*, and *fault relevance aggregation*. If the data cleansing would not be applied (left column in Fig.3), the observation of the abnormal behavior would result in detection of multiple faults. These incorrect detections affect the outcome of the gradual fault aggregation and non-existing (hoax) faults are diagnosed. Therefore, the use of the data cleansing module protects the fault reasoning module from making wrong decisions when the data are invalid.

III. CONCLUSION

This paper illustrated the use of embedded systems for increasing energy efficiency of commercial buildings by detecting faults and degradations in the HVAC equipment. A specific example of diagnosing mechanical faults in air handling units was given. The corresponding AFDD algorithm is optimized for use in intelligent embedded controllers, such as Honeywell JACE controllers. The paper also emphasized the importance of data preprocessing to obtain better diagnostic results.

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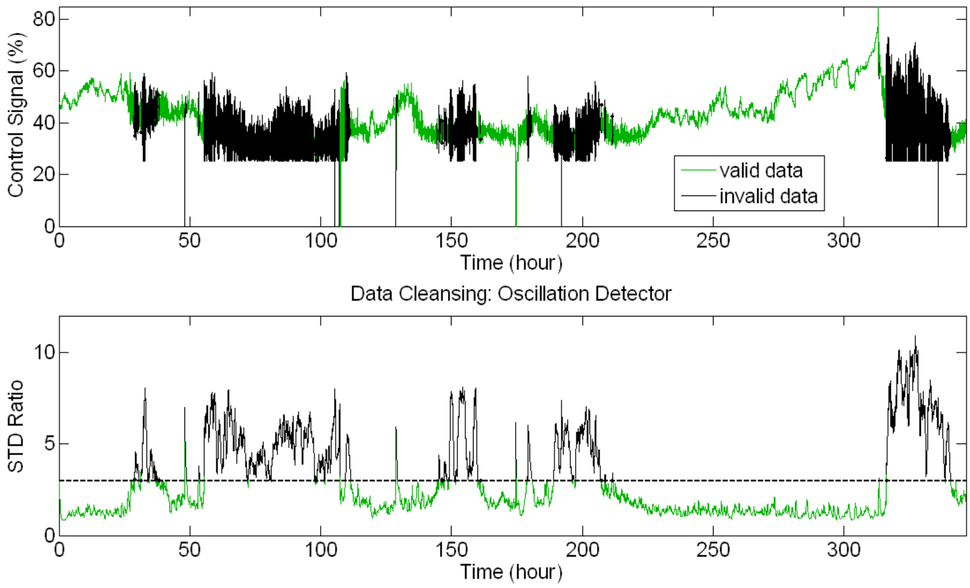

Figure 2: Data pre-processing to detect oscillations in control signals: the bottom figure shows a statistical indicator (based on standard deviation and low-pass filtering) whose high value (above the threshold) corresponds to oscillating (i.e. invalid) control signal (shown by black color in the top figure).

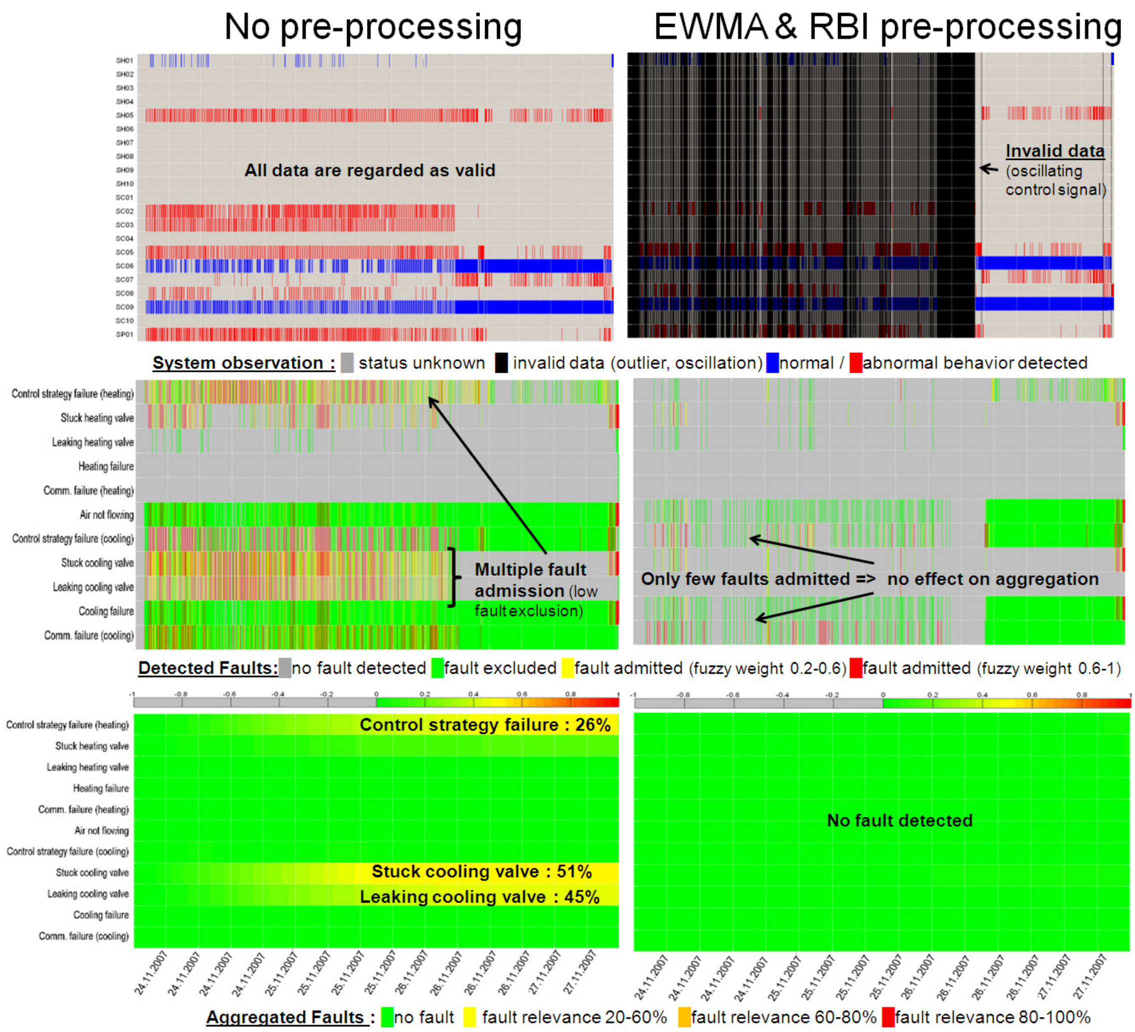

Figure 3: AFDD algorithm consisting of 3 stages: state observation (top row), fault detection (middle row), and fault relevance aggregation (bottom row). Without data pre-processing (left column images), all data are regarded as valid, which causes the AFDD algorithm to produce misleading results (non-existing faults are detected). When using data pre-processing (right column images) to detect invalid data (oscillations, outliers), the AFDD algorithm produces correct diagnosis (because fault relevancies are not updated when invalid data are detected).