February 2002 ECN-RX-02-002

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This paper has been presented at the ISPLC-2002 conference, 27-29 March 2002, Athens, Greece

SMART: Experiences with e-Services for Smart Buildings

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ABSTRACT

Apart from communication services in homes, orchestrating utility buildings with PLC-technology provides a natural means for extending the scope of installation control and energy management systems. Implementation of this technology for establishing micro-networks in buildings and for enhancing the scope of building management systems using last-mile access to the Internet generates a promising application area.

The SMART-project focuses on disclosing this wealth of additional information as a source for an extra level of optimisation of the operational strategy of these software systems. The SMART project has the aim to show how new smart building services, such as optimisation for energy efficiency and individual comfort management, are possible on the basis of software agent-mediated electronic marketplaces. Further aim is to show how the communication and computation possibilities using the Internet and PLC can be mobilised to decrease energy consumption and cost significantly in a real-time energy-pricing environment and how more frequent feedback and new feedback mechanisms add an extra contribution to this goal . In the ISPLC-2001 conference [1] the subject of what added value can be attributed to Power-Line Communication services in managing energy consumption in buildings was dealt with. In the present paper, the first results of applying these services in a multi-disciplinary, real world, field-test context are presented. The viewpoints discussed are the hardware and software application architectural and computational aspects of a SEBOS (Smart Enhanced scope Building Optimiser Shell)-shell that yields information to existing building management and control systems. Critical, non-technical, success factors in optimally designing the interfaces of this shell to the building user community are important aspects in the SMART-project and are also discussed.

I. INTRODUCTION

The SMART project is collaboration between ECN, Kropman BV, a large HVAC Installation Company, and VUA, partly supported by the Dutch Ministry of Economic Affairs. The SMART project builds on earlier work done in the framework of the international EnerSearch consortium on agent-mediated electronic marketplaces for energy applications [2-5], and on research led by the Free University Amsterdam on multi-agent systems for automated comfort management [6]. It constitutes one of the PLC field trials that were reported in the context of the European 5th Framework IST project PALAS (Powerline as an Alternative Local AccesS, http://palas.regiocom.net) [1,7]. The SMART-project focuses on disclosing information, accessible through appropriate interfaces, from a number of sources to add to the information an existing building management system uses to operate the comfort installations of a building. Enabling technology is the wide-area and micro-scale interconnectivity that the Internet communication primitives and standard give at an ever-decreasing price. In this contribution, experiences in defining such a innovative information architecture for a SEBOS *(Smart Enhanced scope Building Optimiser Shell)*-shell are given. In designing this shell, not only technology is to be considered, but also user<> technology interaction aspects play an important role, during the usage phase of the building, as well as particularly right from the beginning, during the design phase.

II. SEBOS HARDWARE-ARCHITECTURE AND THE ROLE OF PLC

To operate a SEBOS as a service, a powerline service infrastructure consists of at least four levels,: the devices at the end-nodes, a local access node through which a building is coupled to the outside world, a concentrator or base station, which connects the powerline to the communication backbone, and the utility node, which delivers the services from the service provider, in our case a utility or a service provider.

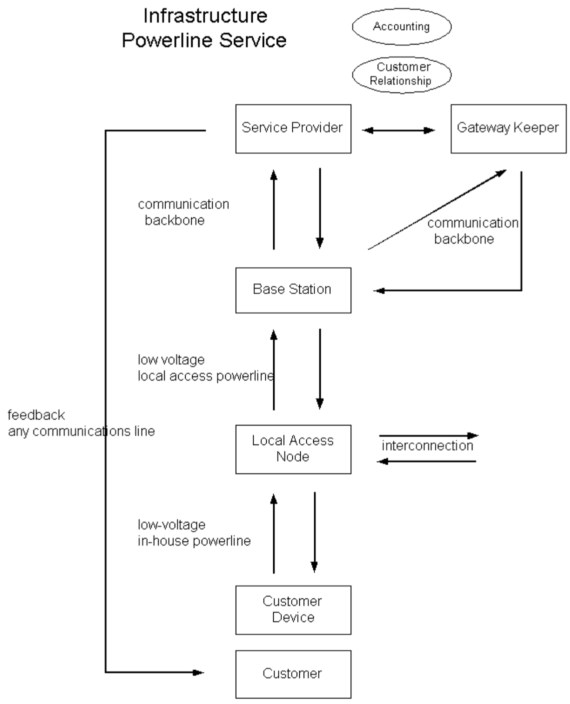

Figure 1 Hardware architecture scheme for a PLC service application

A number of requirements can be summed up for smart devices in a last-mile<> building network. A device should have a unique id to allow addressing in large hierarchical networks. In this respect, IPv6 with it's ample addressing possibilities, provides a physical and logical mapping mechanism to enable proper context definition. Adding Internet connectivity to a device should be reasonably priced and standards used in the device hard- and software architecture should not be proprietary and have the support of many vendors; a device should be self-configuring, live-insertable in the network, have self-diagnostic features and have non-volatile memory. In this way, smart devices can be seen as appliances performing services on a small scale: a smart device has a responsibility for a special task. Other components in the network can call upon the device to perform this task. An experience in the SMART-project was, that connectivity of existing building management systems is a major problem. Existing building management system were found to yield slow, very proprietary, monolytic communication protocols to parts of the installation at a very high price. A building management system is composed of a, possibly large, number of smaller control loops implemented on local controllers. In hardware architectural terms, these controllers can be substituted by more open general-purpose service gateways, now appearing on the market for residential applications. Four separate types of network structures can be seen to evolve at the moment. On the most elementary level,

1. On the most elementary level, pico-networks (e.g. see www.bluetooth.org) are aggregations of a number of devices together yielding one entity at a higher application level constituting a "device". PLC can play a comparable role in establishing low-cost micro-connectivity as wireless techniques.
2. On the micro-network level pico-networks or individual devices are coupled and operated autonomously using setpoints from a Building Management System at a higher level. The size of these nodes typically is in the range of a few segments of a building or one part of an installation. LON (e.g. see www.lonmark.org) is the standard technology for implementation and PLC is one of the narrow-band communication media for data-transport.
3. One level higher, in the local area network, the local controllers are connected. From the local area network service connections to a wide area and metropolitan networks are established. The base station, the concentrator, for PLT-applications is normally located at the transformer substation, but, in a building context, can be positioned on a central point in the building. A main task for the base station will be to act as a multiplexer for requests from the top end of the network and as an intermediate for information transfer from the lower part of the network.
4. The highest level is the WAN/Metropolitan network. From the software architecture point of view, the OSGi (e.g. see www.osgi.org) separates utility node in two roles, the service provider role and the gateway keeper role. The first party is responsible for the content of the services, the second party is responsible for the way these services are set up and rolled out in the network.

The access node is a first level of aggregation, which acts as a buffer between SOHO/office building information and applications in the outside world, run by application service providers. This access node provides local intelligence, might be able to connect different Internet access networks to multiple types of in-building networks and might deliver different e-services over one single connection. An intelligent access node, such as the residential gateway, can be used as a layer where control is based at a low point in the network. If we can deploy decisions to be taken at this level, extensive data traffic to and from the base station and the service provider is prevented. Also the service provider will not be extensively busy for individual customers, but can concentrate on integrating tasks.

Essentially, the hardware infrastructure has to provide a transparent Internet-access to all components in the micro- and macroworld. Current developments on portable Internet-based technology such as J2ME and OSGi have the promise of reaching such a connectivity at favourable rates, platform independent and with a high connectivity. Power line communication there has the advantage of fine-meshed ubiquity in the context of the building management system entities at the pico-net and micro-net level. At the service provider level, where broadband connectivity is most important, PLC has very serious competition from other data transmission techniques.

III. SEBOS SOFTWARE ARCHITECTURE

The specific objective of the SMART project is to demonstrate the technical possibilities to deliver optimal comfort to individual users in an office building taking into consideration the user awareness about sustainability and energy saving, and to improve cost effective building management. The technology of the system is based on agent-mediated communication schemes. Such novel control systems should not only improve the performance of the building, but should also offer opportunities for users (i.e., building operators and inhabitants of the building) to link individual comfort management in office buildings to energy saving and application of renewable energy. Together with energy saving, cost saving can be reached by automated selling and purchasing of energy through agent-mediated electronic marketplaces. SEBOS has a number of components. The components and interfaces that can be defined are:

- The building management portal (**BMP**). In this portal the logic of data-transfer from the outside world is defined. Essential gateway in this respect is the Internet for accessing weather forecasts and energy pricing information. In other industrial areas major efforts are underway now to describe data-dictionaries and meta-data of daily operations in XML and to establish operations to connect world-wide databases based on these models. Maintaining and validating these data becomes a major business opportunity in the near future.
- The physical building model (**PBM**). This is a physical description of the building, which is necessary to describe the behaviour of the building when several control steps are to be calculated at the optimisation level. Calculating the behaviour of the building during a complete test-reference year using a dedicated building simulation package is needed to deliver the appropriate "static" data to the optimiser. The building is subdivided into discrete, separately controllable segments for this purpose. The installation's components are modelled in PBM as well.
- The building manager interface (**BMI**). This interface enables setting certain standard and default parameters and general parameters with regard to the strategy in operating the building's HVAC-installations as a whole.
- The user interface (**BUI**). This represents the increase in inner context of SEBOS in allowing the users to gain control on aspects of the microclimate in their working environment and more global preferences for energy efficiency and usage of renewable energy sources. A more closer view on individual perceived comfort by humans is gained by using a calculated real-time Fanger-index (e.g. see www.innova.dk). A user interaction scheme similar to the DUCOZT-system is used [9] based on learning user's preferences by voting procedures.
- The BMS-interface (**BMS**). This part represents the interface to the existing building management supervisory system, not necessarily the same as the building management system. The building management supervisory system has an interface to the building management system itself in order to get access to measured values and values of sent out control signals.
- The SEBOS agent based optimisation kernel (**AOK**). In this kernel agent algorithm based optimisation leads to improved operation strategies in terms of set-points of local controllers for heating, ventilation, air composition control and lighting.

The SMART-software consists of two modules operating in concert.

1. A portable SEBOS front-end, written in Java, in which all attributes of the model and user information in the outside world context can be configured in a flexible way. The front-end contains all modules mentioned above apart from the optimisation kernel. The architecture of the front-end maximally utilises portability and OO-concepts to map the individual actors and agents from Java.
2. A generic optimiser. The optimiser is designed to yield optimal computational performance. It is written in C++/Fortran to maximally exploit the existing numerical algorithms.

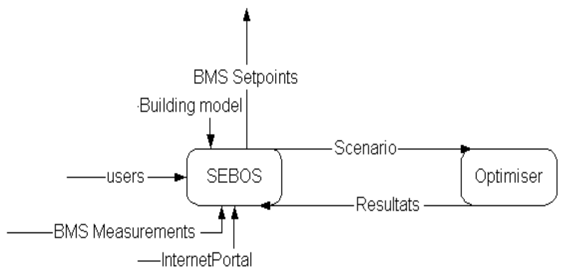

Figure 2 Scope of SEBOS and the optimiser shell

The optimiser calculation is performed with variable time-steps 24 hours ahead. In the optimisation a number of time scales are to be discriminated (Figure 3). With an increasing time-horizon, the time-steps in the optimisation become larger. The coarse optimisation cycles roughly emphasise the energy-price and buffer strategy; the fine-meshed optimisations attempt to adjust to the more real-time user preferences in the building segments in the most optimal way. Set-points for local controllers and new measured values are updated with the same frequency. Segment optimisation, aggregation of segments and installation optimisation cycles are performed in alternation.

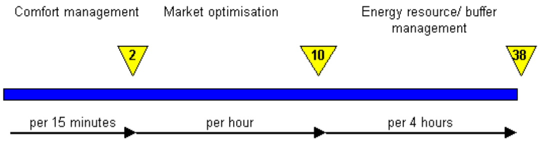

Figure 3 Optimisation timesteps

Comfort management is done on the level of segments. This comfort management is done using (partly predicted) energy prices as obtained from the market optimisation. The market optimisation in turn is done using the optimal strategy as derived from optimal buffer use taking account of optimal use of storage and renewables. On the other hand there is also a feed-forward mechanism defined: from the currently predicted demand for comfort market volumes for next periods are defined. These, then, also have an impact on the buffer strategy. The mechanism forms a layered structure.

It is found, that the computation time on a PC-processor is fairly large (in the order of minutes for a 5 segment-floor model), but decreases when a number of cycles have been performed.

IV. INVOLVING BUILDING DESIGNERS AND USERS

Design is a process of tunnelling, in which the number of possible choices gradually decreases as the structural features of the object designed take shape. The resulting material structures can be seen as actors or agents having the task to guide the behaviour of other actors, human as well as non-human. For instance, chimneys and shafts have to lead air molecules in directions meant by the designers, wires and switches have to guide electrons etc. That is, the structural elements translated into hardware from the blueprints on the design board, form a network of enablers and constraints for the traffic of actors that is perceived as essential for the functioning of the object designed, in our case a building. These structural elements are the reification of scenario's the designers have in mind with respect to the working of the building. Thus design can be conceived as a gradual process of *inscription* of ideas, views and ideals of designers into a coherent material order consisting of a great number of structures that act out *scripts*. A script is a thought-out material construct intended to exert specific forces on the actors who use it. For instance, a curve in a corridor forces you to change the direction in which you walk in accordance with the intentions of the building designers. These scripted structures do the real work after the designers have retreated. Scripts *prescribe* –with more or less force- the actions of other actors who pass through them by enabling certain behaviour while constraining others.

Another pair of notions that we think to be useful is *design logic* and *use(r) logic*. Design logic is the shared logic underlying the design scenario's according to which the building is supposed to work. It is the texture of reasons why the design is as it is. Design logic is a mental and a social thing at the same time. It is the outcome of a social process, of the negotiations between different actor logics brought to the design team by its members: architects, client, energy advisor, engineering consultants etc. To design a building, the actors have to accommodate their different logics while developing a shared design logic. If there is convergence between actor logics from the beginning, this will help the process of accommodation. Use(r) logic is the patchwork of conscious and unconscious intentions, interests, values, rules, habits, attitudes etc. that guides the user in its use of a product of design. Logic of users is expected to vary because of difference in sex, age, education, profession, culture, lifestyle and so on.

On the basis of this approach, the design logic underlying the building, where the SMART field experiment takes place, was reconstructed and found to be valuable clues for adding intelligent technology from the design phase onwards and for the process of involving users and mapping of software agents onto users. This is illustrated in figure 4.

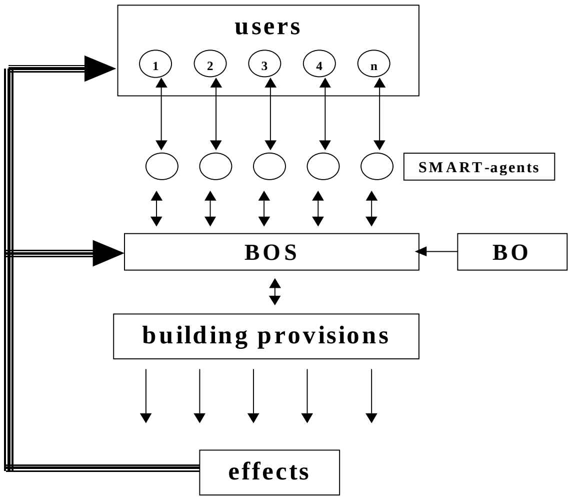

Figure 4 Relationships between individual end users (1 to n), operators, SMART-agents and building provisions in accordance with the logic of the SMART system for comfort management.

V. CONCLUSIONS

In the SMART-project a number of technical problems with enhancing the scope of building management systems have been solved and computational problems concerning the optimisation of building operation at a high level of complexity were demonstrated to be feasible with current computational resources. Connectivity and openness of existing proprietary building management systems is limited. Alternative, open architectures may yield an opportunity for using PLC especially at the pico- and micronetwork level. In physical model terms, modelling air flows remains the most difficult problem. Implementation of SMART-concepts, in terms of individualised comfort management in buildings, will be easier and more straightforward if the design of such a system is included in the design of the building from the very beginning.

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