Future Smart Home Using Intelligent Electronic Devices

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***Abstract*—The domestic consumer has to take advantage of the opportunities from the liberalized energy markets and this call for technological support, without which the changes threaten to remain rather theoretical. In this paper we discuss about Information & Communication Technology solution for the communication in the new intelligent home for the future.**

Keywords-information and communication technology (ICT); intelligent electronic devices (IED); automation

I. INTRODUCTION

The energy market for the individual consumers has been opened in several countries, although the number of consumers that have actually switched supplier in general remains quite low. This inertia is to a large extent due to the fact that technological advancements enabling the consumer to really look at electricity as a diversified product are not yet available. The subject of customer empowerment has already caught the attention of utilities, some providing incipient versions into their product or as an added-value service [1].

The classical, vertically integrated electricity system was supported by the appropriate technology, as for instance the cheap Ferraris energy meter, to be read at the customers' premises every year. At that time, choice was not an option. Today, no such single satisfactory technological solution exists, which translated into different possible future scenarios. The combination with advanced ICT [2] leads to many flexible consumer options, while retaining a very high level of safety and security of supply. Features of the new system are for example, the optimization of the consumption profile in order to avoid peaks, or to restrict the existence of peaks in the low-price periods.

Considering the above, the aim is to develop a new sustainable electrical energy system for the individual consumer that can handle the problems and opportunities of the liberalized market. In order to achieve this goal, there is more to it than just minimizing the consumption of each individual apparatus. An active, intelligent way of handling the power consumption for the individual consumer is required, to lead to an optimal configuration in real time.

The scope of this work is bordering the domain of home & building automation and that of utilities, integrating into the domestic network of home appliances advanced energy management and metering devices [3]. The physical environments targeted are households and small businesses. Their premises have a single meter connecting them to the electrical grid. The innovative approach is to integrate into such a home automation and control system components that take advantage of the changes in the energy market and help the customer to better manage the home [4] [5].

II. INTELLIGENT ELECTRICAL DEVICES

The currently envisaged future electrical residential installation is based upon an intelligent meter and is made up of intelligent electrical devices. All these devices have an intelligent digital interface besides the electrical connection to the domestic grid. The intention is to embed communication and control logic into this interface shown in Fig.1.

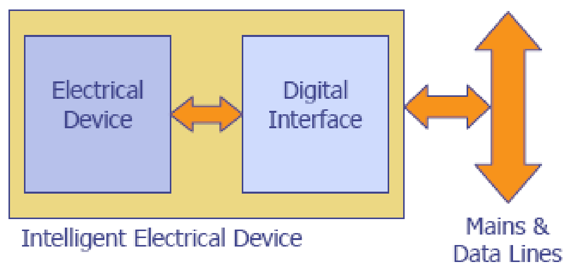

Figure 1. An intelligent electrical device is connected through an interface that embeds control and communication logic.

The intelligence implemented by the meter and the device interfaces enables the implementation of flexible consumption strategies at the customer side. Depending on the characteristics of the customer profile or of the providers in that particular area, the installation can be optimized to lower the consumption, to flatten the consumption (to avoid peaks) or to move the consumption peaks into the cheap energy time intervals. The optimization can be achieved by managing some of the consumers and products of electricity. They can be started or stopped according to specific device profiles or at least their consumption profiles are known and can be used in the global strategy.

The first step in developing the system for control of the residential electrical installation is designing the taxonomy of the considered devices. This is innovative since the proposed categorization considers today's electrical devices, as well as it accommodates tomorrow's devices as shown in Fig. 2.

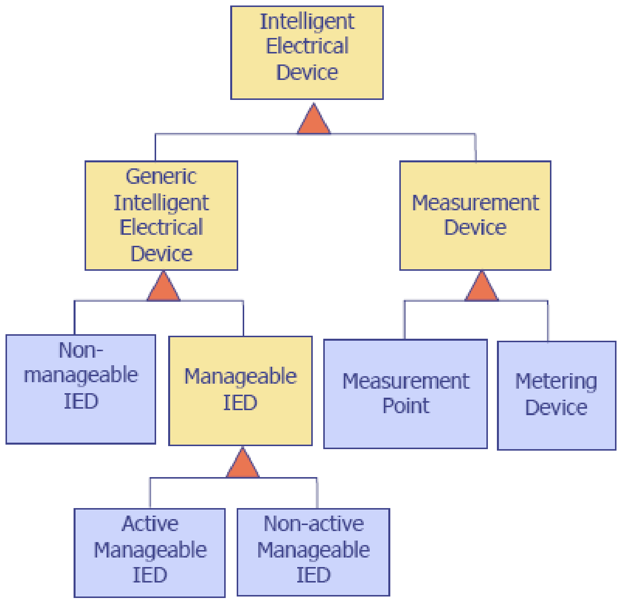

Figure 2. Taxonomy of the electrical devices in the future intelligent electrical residential systems.

All devices connected to the system are *Intelligent Electrical Devices* (IED), which can be further specialized into *Generic Electrical Devices* (Actuators & PQ Enhancers) and *Measurement Devices.* The later can be *Measurement Points* in the system and *Metering Devices.* The differences between these two are their functionalities, the measurement points only providing data, while the meters control the system and are responsible for metering. Furthermore, the electrical devices can be categorized as *Non-Manageable* and *Manageable Devices.* The first ones participate to the consumption and production of energy, but cannot be managed, whilst the manageable devices can be started or stopped or in another way controlled as the current strategy dictates it. These manageable devices can be further differentiated into *Active* and *Non-Active* according to their role into the system, whether they are consuming/producing active power or are solely PQ enhancers.

For the system developer, the key components of the taxonomy are the "leaf" nodes. They are templates to be used for implementing the interfaces for IEDs. For example, the *Non-Manageable Device* can be instantiated to any device or appliance that cannot be controlled, like the TV set. If the user starts the TV, there is nothing the system can do about it, except to meter the consumed energy. The *Measurement Point* can be implemented as devices in the network that have the task of measuring and reporting characteristics of the system. The systems we are dealing with are assumed to have only one instance implementing the *Metering Device.* It is the contact point between the domestic installation and the outside grid. The *Active Manageable Device* & *Non-Active Manageable Device* present the most complex behavior. These can describe by themselves a device, for instance a PQ enhancer unit (Filter, Capacitor Bank) is a *Non-Active Manageable Device*, and an electrical heater can be modeled as an *Active Manageable Device.* Furthermore, more complex behavior can be described by a combination of active and non-active components, in order to model appliances such as an intelligent refrigerator.

The proposed taxonomy is intended to standardize the description of the electrical devices found in a domestic system and the communication between them, in the same way, as there are standards for higher levels in the electrical network (e.g. the IEC 61850 standard for substations [7]). This modeling and categorization of entities allows for common properties to be pushed as high as possible in the hierarchy, improving the manageability of the designed system. The taxonomy supports extensibility and reusability. allowing modeling of already existent (legacy) as well as future systems.

III. HOME AUTOMATION SYSTEM

Over the past years there has been a constant development in the domain of home automation. The idea is to use the ever-growing presence of intelligent in home appliances to create a home network. Having the devices that surround us anticipates our actions and increase the level of comfort and safety is a very appealing thought. The intelligent devices are given the opportunity to communicate to each other by the appearance of new communication standards like Bluetooth (BT) [8] or the improvement of existing ones like power line communication (PLC) [9] [10]. This industry has passed from the existence of several proprietary standards towards the development of common standards with the goal of interoperability across vendors.

The existing solutions are mainly driven by the entertainment industry and home security and control. This result in most of the systems being developed with the goal of connecting entertainment appliances around the house (e.g. PC's, home cinema systems, TV sets) and the remote control and surveillance power outlets, lighting, air conditioning and various alarms (e.g. intrusion and fire detection). The energy management services offered by today's home automation systems are limited to actions like automatically turning on and off of the lights on hallways and remote metering.

The work described in this paper conceptually extends the existing building automation and control standards by the addition of intelligent energy metering and advanced energy management to their extensive set of features. The proposed extension is orthogonal to the communication protocols and technologies used in the discussed standards.

In the following the major standards and systems in the home and building automation standards market are presented.

X-10: X-10 [11] is a industry standard for small scale applications in home automation and control. It is the ancestor of most of the power line home automation protocols (e.g. CE Bus-Consumer Electronic Bus [12] [13].) If facilitates control of household devices over the existing home wiring system. This system is widely accepted all over the world (with American & European variations) and very well supported by third party vendors.

BACnet: BACnet-A Data Communication Protocol for Building Automation and Control Networks [14]. Developed under the auspices of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), BACnet is an American national standard, a European pre-standard, and an ISO global standard (ISO 16484-5). BACnet is an open standard that is at the moment is striving to gain acceptance by the industry.

Konnex: Konnex Association [15] is the resulting association of the metering of three Associations: BCI (Batibus Association), EIBA (EIB Association) and EHSA (European Home Systems Association). The aim of Konnex Association is to promote its One-Single-Standard called KNX, built upon the technical expertise of the 3 constituent associations. The KNX standard implements the BACnet ISO standard and it is supported at European political level. Also it has a large industry support from the three associations that make up Konnex.

LonWorks: LonWorks [16] devices communicate with one another using the protocol that underlies the LonTalk Protocol-embedded in Neuron Chips found in every LonWorks device available. This implements a system that has established itself as a industry standard for building control and automation. Currently, millions of devices have been installed worldwide in thousands of LonWorks solutions. The Neuron is actually 3 8-bit processors in one. Two are optimized for executing the protocol, leaving the third for the node's application. It is therefore both a network communications processor and an application processor. Since 1999 Echelon Corporation opened the LonTalk protocol by releasing a downloadable reference implementation of this protocol for use on any processor.

Jini: Jini network technology [17] is an open architecture that enables developers to create network-centric services-whether implemented in hardware or software-that are highly adaptive to change. Jini technology can be used to build adaptive networks that are scalable, evolvable and flexible. Jini technology provides simple mechanisms which enable devices to plug together to form an impromptu community-a community put together without any planning, installation, or human intervention. Each device provides services that other devices in the community may use. Jini is emerging as a home automation technology, with various such projects under development in the framework of the Jini community [18].

IV. The Openwings Framework and Service Oriented Programming

The work described in this paper conceptually extends any of the home automation standards by adding the functionality of intelligent metering and energy management, which is increasingly relevant in the liberalized energy markets. From the presented list, we selected Jini. This selection is based on a steep learning curve and ease of development and deployment for a proof-of-concept implementation, before any investment and commitment is made regarding the hardware to be used.

In particular, a successor of Jini was chosen for the implementation, namely Openwings [19]. Openwings is an open standard which has its roots in the Jini developers' community. Openwings is a set of open systems specifications for a framework that enables the development of highly available, secure, distributed systems for mission critical applications. This framework utilizes Sun's Jini technology to provide ad-hoc integration of system components as well as increasing the interoperability in a "Systems of Systems" environment.

Besides the initial field of application, the military communications, Openwings targets also the integration of consumer electronics [20]. In this respect, our application can fully take advantage of the Openwings provisions for high availability, security, reliability, interoperability and independence of underlying layers in the communication protocols' stack.

Another reason for choosing the Openwings framework as a base for development is the innovative approach to software engineering adopted. The technology is called Service Oriented Programming (SOP) [21].

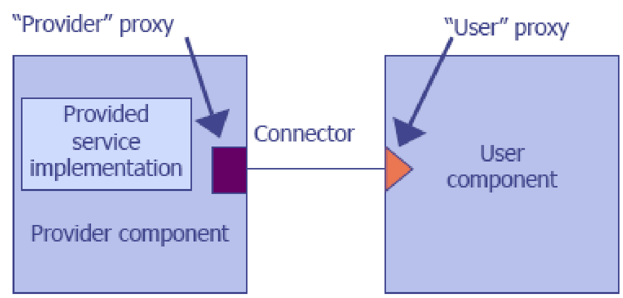

Figure 3. Provider and user proxies. The user component only needs to know the service interface and gets the proxy code that runs the provided service.

The hardware components considered are commercial off-the-shelf (COTS) components. Combined with the openness of the standard and of the implementation this provides for wide acceptance and interoperability with other systems while also increasing the dependability of the whole system.

The SOP methodology provides support to the new perspective on applications and organizations. The view of a system-of-systems is straightforward modeled by the services' paradigm and various implementations (e.g. web services at organizational level) [22].

V. Implementation of Intelliget Electrical Domestic System

In the respect of sound software engineering guidelines the proposed system is designed with the goal of separation of functional entities (the ones that implement the application) from the other components such as the communication component or the component responsible for the enhancement of the dependability of the system. This provides for reusability, which increases the development speed (reduced time-to-market) and increase the quality of the end product by employing components already mature and thoroughly tested. Furthermore, Openwings provides for plug-and-play functioning, since the user component only needs to know the service contract (the interface) in order to run the provided service, by using a proxy to get the code and run it locally (see fig. 3). This entire process does not need any intervention at run time.

The implementation of the application using Openwings allows the developer to concentrate only on developing functional entities using built-in connectors for communication, and the existing provisions from the framework for dependability. This does not restrict in any way the freedom of choice. The framework is extended by implementing connectors for different media or protocols or implementing new strategies for recovery or increasing the dependability.

The Intelligent Electrical Device depicted in figure 4 can be the implementation of any of the specific devices identifies in the taxonomy presented in figure 2. The only constraint on the devices' implementation is the service contract. They all have to implement a minimal interface, for the rest, one being free to make his own development choices. This even allows the building of adapters for legacy components to make them able to join an Openwings system.

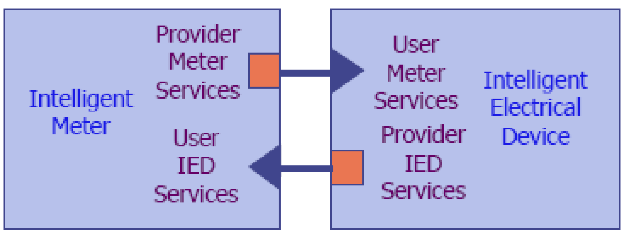

Figure 4. The modeling of the intelligent domestic electrical application using Service-Oriented Programming.

The electrical devices' intelligent interfaces implement the "levels", the marginal nodes, of the tree from figure 2. They specialize if necessary the inherent methods and add new ones. Then the newly created class of intelligent electrical devices can be instantiated to create an object, which implements a real intelligent electrical device. As an example, figure 5 shows a simplified UML [23] class dia. in which an *Intelligent Refrigerator Class* is derived from the provided *Active Manageable Device Class*.

Only a part of the data members and methods of the classes are shown in order to keep the figure as simple as possible. It shows how the *Intelligent Refrigerator* inherits all the structure (both functional and non-functional) of the *Active Manageable Device* and extends it by adding the *Internal Temperature* value and the method *Check Internal Temperature.*

To further open the intelligent domestic electrical installation implementation, the messages exchanged between entities in the system are encoded using XML [24]. This increases the interoperability and facilitates development of third party tools (e.g. web monitoring).

At architectural level it is desirable that the components deployed on intelligent electrical devices' interfaces are as light as possible. This would result in a low cost interface, which should increase the degree of acceptance into the market. On the other hand, the meter can carry more computational power as well as storage capabilities. These considerations act as constraints for the design of the components as well as the system as a whole.

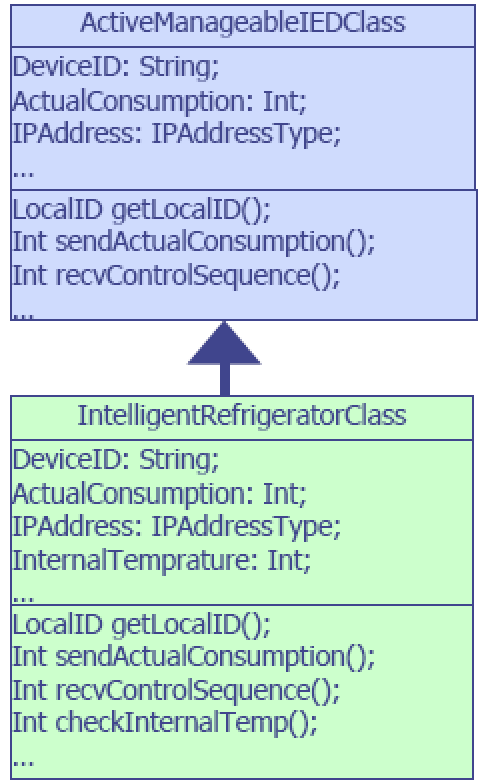

Figure 5. UML class diagram: Deriving the intelligent refrigerator class from the active manageable device class.

The communication system for the intelligent electrical system is based on two subsystems, a synchronous and an asynchronous one.

- The synchronous communication ('*pull*') mechanism, models the intelligent electrical device as a provider of information (data and control) and the meter as a user. This lays the foundation for the implementation of sending of consumption and other data from the electrical devices to the meter. This communication is triggered by events.
- The asynchronous ('*push*') mechanism models the meter as a publisher and the intelligent electrical device as a subscriber to the published services. This implements the asynchronous (independent of events) communication of configuration and control information from the meter to the intelligent electrical devices.

Once connected to the network (for the first time or after a temporary outage), the intelligent electrical device looks for the meter of the household. Being inside the house, in a controlled environment, broadcasting can be used for this. After finding the meter, the device can subscribe to the services published by it (asynchronous model of communication). In this way it can ask and receive a unique identifier. At this point, both the meter and device have knowledge of each other. From time to time (triggered by a timer), the device can now send consumption data to the meter (synchronous communication).

An implementation of the intelligent domestic electrical system implements and extends the proposed taxonomy of devices, by instantiating the "levels" nodes and it employs and extends the Openwings architecture, by implementing various new connectors for instance. Thus, it ensures flexibility both at development time and run time.

The system described so far lays the structure for a dynamic distributed system made up of dependable entities connected by dependable connections. This offers the environment for implementation of optimization algorithms for the consumption of energy. Possible optimization actions are starting or stopping certain devices at certain times or postponing their start according to the adopted optimization strategy or to the device's particular functioning profile.

VI. Dependability Attributtes

The implemented communication system is a critical infrastructure of the domestic environment. It is interdependent with the electrical installation. A very important design and operation constraint is the system should at least function as the "classical" (i.e. nowadays) electrical and metering system. Besides this, adding an ICT component to the electrical installation introduces a whole range of vulnerabilities inherent to these systems. In the following we present an analysis of the provisions included or foreseen to be part of the communication middleware for the attributes from Laprie's dependability tree: availability, reliability, maintainability, safety, confidentiality, integrity and security [6].

The needed high availability is obtained by employing the provisions from the Openwings framework. This provides for strategies at component level (Container Services [26]) like component redundancy, fail-over recovery and remote connection and entity monitoring. Any entity can check whether a connection is functional, whether an entity is functional or at what level of performance an entity is running. On top of these provisions, our system offers redundancy at communication link level by implementing several connectors, which can be used by each device. For example, if a device uses Ethernet as a primary connection and this fails (e.g. denial of service caused by some other devices sharing the media), it can switch automatically to a secondary connection, which may be power line communication (PLCC) or radio (RF).

A sensitive system such as the electrical installation needs high protection from intrusions and other type of attacks specific to ICT systems. Mechanisms need to be employed to ensure confidentiality, integrity and security. Concerning the safety of electrical installations and appliances there are very strict regulations that need to be considered.

The reliability and maintainability of the communication system are relative to the components used. These are to be evaluated at the moment of implementation of the proof of concept system.

VII. Conclusion

The presented system extends conceptually the existent building and home automation standards. It provides a flexible way to model and develop an intelligent electrical domestic installation. The intelligent electrical installation provides the customer with ways to implement strategies for minimizing energy costs by taking advantage of the changes in the liberalized energy market.

An important aspect of our work is the investigation of the dependability of distributed embedded systems built up with commercial off-the-shelf components, as well as the influence of the shared networks (connections not dedicated to one single application) on the dependability attributes of the distributed system.

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