Abstract—So far the worlds of building automation and power networks have co-existed electrically attached but without data interaction. In order to complete the smart-grid vision, we have to go further than remote metering, integrating services offered by the smart-buildings into the smart-girds’ needs. The main objective of this paper is to review latest results of the research community of industrial electronics, whose society within the IEEE, the IES, acts as the organizer of this conference. At the conference, latest advances and developments in design, modelling, simulating and implementing tools for, or systems of, sensor and/or actuator networks with advances towards user orientation, wireless connectivity, dependability, energy efficiency, context awareness and ubiquitous computing will be presented.

I. INTRODUCTION

Smart grids are a direct answer to the challenges that classical power networks have to face. The tight schema from traditional grids, where electricity flew from generators through the transport and distribution networks down to the final client has been blurred by the emergence of renewable energies at diverse voltages, dual consumer-generator roles, virtual power plants, micro-grids, moving demand (e.g. the Electric Vehicle), and so on. It does not seem that the list will come to an end in the near future. Each country has typically designed its own solutions based on historical legacies that have produced a high number of smart-grid-related protocols, as noted by EPRI and NIST [1], [2], [3]. Luckily, these institutions, together with IEC have joined efforts to issue a widely-accepted smart grid standard that satisfies all requirements. Hence, nowadays, there are two outstanding standards: CIM [4] and the IEC 61850 series. The work to harmonise them to obtain a single compatible standard is on the way [5], [6], [7].

Building automation has pursued its own way, resulting in a tangle of Field-Area Network (FAN) protocols: different communication protocols and media, varying even from region to region, each one offering a very diverse portfolio and capabilities. There have been many initiatives dealing with FAN interoperability already starting in the late 90s [8] but the truth is that, in the practice, many different FANs may co-exist in the same building each one devoted to the control of separated systems such as heating, ventilation, and air condition (HVAC), alarm, door control or lightning.

The smart-building vision is leading to a new scenario in which buildings will become an essential pillar of smart grids, with their ability to self-control their consumption (and having the so-called Zero-Energy Building as the horizon), accurately predict it and provide advanced demand-response services, among others. Needless to say, this vision needs to bridge the gap existing between the two worlds; in other words, to standardise the integration of smart-buildings into the smart grid. Completing such integration requires going further than the mere remote use of building services by the smart grid stakeholders, such as Utilities. For instance, embodying the control of a building in the daily operation planning of an Utility requires a combined approach weaving not only the management of the meter but also that of lights and eventually all the existing home-automation networks. Further, the information will flow from the Utility down to the individual devices and gadgets, and backwards; therefore, from an interoperability point of view, it must be expressed in a consistent fashion throughout the system.

II. ULTRA-LOW POWER WIRELESS SENSOR NETWORKS

The topic of wireless sensor networks is a keystone in the smart buildings. In modern constructions and private homes, many devices like lighting, heating and cooling (with temperature sensors), elevators, windows, data displays, and even household appliances like dish washers and refrigerators have to be able to communicate in order to coordinate their functionality. All of these devices can be controlled in a centralized manner if the required environment data (e.g. room temperature, number of present persons in a room, open-state of windows, doors, and refrigerator doors, etc.) is available.

Another very active area of research is automotive communication. Many systems are changed from cable-based to wireless in order to save cables and thereby weight and in the end fuel. Examples are many comfortability systems like distance sensors or safety related systems like tire pressure monitoring [9], [10]. This trend was extended recently when “Car2X” [11], [12] moved into focus of many research groups. This research is intended to help lowering the number of car accidents (and thereby the number of traffic deaths and injuries) worldwide. Car2X is an umbrella term for “Car2Environment” and “Car2Car”; the former meaning communication between cars and stationary objects, e.g. street signs, traffic lights, bridges, etc. Typical data to be communicated could be information about current traffic jams, dangerous bends, frozen-over bridges, routing changes, or traffic congestions. The latter [13], [14] focuses on communication between cars themselves. Typical data to be communicated could be information about car crashes ahead, cars braking ahead (being the electronical equivalent of the brake lights the driver can see), burst tires, and many more.

The data needed for control is collected by numerous specialized sensors and transferred to the central unit (of a
 building or car) or distributed local central units.

Nowadays, mainly two channels are used for this, namely power-line-communication (PLC) \cite{11, 12} and wireless communication. The former is easily applicable for devices which have to be connected by cable to the power grid, anyway. However, a large number of connected PLC devices lead to diverse problems from channel congestion to security issues \cite{13}. More commonly, wireless communication is used. Wireless sensor networks (WSN) do not need physical cable infrastructure and can even connect ad hoc to devices currently in reach.

One of the most important scientific questions is the energy consumption of wireless sensors, since many of them are implemented in the form of battery-powered embedded systems. Obviously, it is important to design cheap, small devices with a long battery life. This can be achieved by a clever chip design or by power management in the running system itself \cite{15}. The use of smart compression schemes \cite{16} for communications, or even network-topology-based optimizations \cite{17}. In some approaches, the extension of battery life is achieved by means of energy harvesting. This means that energy is taken from the environment to partly or fully fuel the device in question. In buildings, e.g. ambient light can be harvested \cite{18}; in the automotive area, e.g. vibrations of the tire on the street can be exploited \cite{19}. Other approaches try to compare different possible designs and choose the most energy-saving approach (design space exploration); this is mostly done by energy consumption estimation in simulations \cite{20}. In some cases, only single chips are simulated and optimized, other approaches simulate and monitor the energy consumption of specific messages throughout the whole sensor network \cite{21}.

Another field of research is the analysis of the data sent throughout the network. There are many available wireless protocols like ZigBee, OneNet, EnOcean, 6LoWPAN, etc., so the designer of a wireless sensor has to decide which protocol to use \cite{22}. In many cases, a specific routing is proposed to enable real-time operation \cite{23}.

In order to be able to monitor the energy consumption of devices used in building automation environments, even Software-in-the-loop approaches are interesting. Typically a complete experimental set-up of a building or apartment containing household devices like refrigerators, washing machines, air conditioners, etc. is expensive and bulky, therefore specific devices are replaced by real-time simulations \cite{24}, \cite{25}.

All these optimizations make sensor networks in buildings and automotive applications useful and help enhance safety and security.

III. INTEGRATION CHALLENGES

Related to the previous section, not only should the device can communicate between them but they need to understand each other. In this sense there are tree main challenges that have to be tackled in order to achieve the integration of the diverse smart building scenario protocols into a real-time framework.

A. Harmonisation of the data model

One of the most urgent request in the smart grid is to finish with the existing protocol mess. For instance, in low-voltage meters, ANSI C.12 rules in the USA whereas COSEM (Companion Specification for Energy Metering) is the standard Europa-wide. Thus, it seems sound to unify and harmonise all standard protocols that might be used in the scenario we target at: IEC 61850 \cite{26}, DLMS/COSEM \cite{27} and CIM \cite{4}. The first technique proposes the construction of an unified UML model based on CIM, and extending it with concepts referent to 61850 \cite{26}. The second approach has to do with the maintenance of independent semantic models and the definition of the relationships between them through OWL ontology assertions. Both means require the description of the IEC61850 data model, which is not offered by the standard itself.

In the first case, the main problem comes from the fact that the length of the harmonized ontology made very difficult to use on embedded devices. A solution for this problem is presented in the series of papers \cite{28, 29, 30} where the authors present a semantically distributed system, i.e., the authors develop a framework that only put the piece of the ontology that de device understand and introducing a mechanisms to discover the rest of the infrastructures.

As stated before, the second approach maintains an independent semantic data model defined in each standard. The integration of the semantic data models is managed by the explicit definition of equality OWL axioms between classes of IEC 61850 and CIM. Following this technique, there is a recent research \cite{31} that has developed a tool for translating between configuration files written in CIM to Substation Configuration Description (SCD), and vice versa.

B. Abstraction upon the network protocol

There are many different fieldbus area protocols, communication protocols and proprietary applications that have to be abstracted seamlessly. This enterprise is not new, since it was already tackled in the late 90s connecting diverse fieldbus protocols to an IP network through a three layered gateway \cite{32}. In that case the bottom layer included fieldbus protocols, the middle one the data model layer and the upper one provided the IP connection. By analogy, the right strategy seems to be mapping each of the protocols to the data model layer obtained above.

C. Connection to the real-time middleware

DPWS offers a rigid get-set functionality (i.e. read or write a variable of a device) as in \cite{33}, converting the operations on that variable on a so-called internal service. In this way, external services are the aggregation of a number of several internal ones; in the SOA jargon, the arrangement in sequence and organisation of them is called service orchestration. This third upper layer will wrap the other two, connecting to the DDS network as an OSGI real-time service. This strategy will allow to perform the aggregation and coordination of services both locally and remotely in a natural way.

IV. SHORT TERM LOAD FORECASTING

One of the holy grains of the smart grid is achieve the so called Demand Side Response, i. e., be able to influence the consumer pattern of a consumer from the outside seamlessly. The two previous challenges are necessary conditions to this
end but when the aim is improving the overall consumption (namely, optimize in one or other sense) it is not enough as it is needed a control strategy \cite{34,35}. It is common knowledge \cite{36} that the use of a good forecast improve the optimization made for any control strategy.

Short-term load forecasting (STLF) is the tool to cope with this problem. Traditionally, STLF refers to the prediction of the load of a large region composed of several hundred of buildings and industrial consumers. In this situation, it has been measured that the the cost of deviation from the forecast can represent millions of euros of losses to the Transmission and System Operator \cite{37}. Therefore, it does not surprise the huge interest in improving the forecast accuracy (see \cite{38} for example) or the huge number of research works in this sense (see \cite{39,40,41} and \cite{42}). On the other hand, building short term load forecasting (bSTLF) is a new field of interest in the research community but it has had an hectic activity in the last years \cite{43,44,45,46,47,48} given the new possibilities of the smart grid.

Historically, the solutions proposed have been grouped into two main branches, depending on the strategy chosen. First, statistical methods are designed to estimate a regression function that matches the points recorded in the historical load data. There exist a number of very effective ways to approach regular curves but, since load forecasting usually lacks of regularity, statistical methods alone normally present poorer results than their counterparts \cite{37,49}. Still, the most notable results have been achieved with dynamic linear or non-linear ARMAX models \cite{50}, and non-parametric regression \cite{51} with ARIMA \cite{52}.

Second, Artificial Intelligence has devised plenty of techniques, methods, and models that address risk and uncertainty (the main aspects behind prediction). Support Vector Machines (SVM) and Neural Networks (NN) \cite{53,54} are the most popular, principally due to their accuracy. Yet, despite being effective, they are usually not efficient and, additionally, they also present other drawbacks such as difficult parametrization, non-obvious selection of variables and over-fitting. Furthermore, in the praxis they normally require much historical data to discover the patterns inherent on it \cite{49,55}.

Moreover, the most widely-used method, NN, further presents more shortcomings such as a very time-consuming learning process, the risk of local minima \cite{56}, the lack of an exact rule for setting the number of hidden neurons to avoid over-fitting or under-fitting \cite{57}, the inability to generate explanations for their results, and, finally, their poor scalability \cite{58}. Lately, the research in this area has evolved to improve SVM-based models’ performance through clustering \cite{59}, or to combine regression with evolutionary algorithms for parameters settings \cite{60}.

As it can be seen, the trend is not to lay on a certain model but to address a number of them together in order for instance to take advance of their synergies or complementaries. Indeed, some methods may be successful under certain conditions whereas fail in others. In the same vein, each one has been devised with a certain goal in mind and, therefore, they offer different sort of information and precision degrees. Choosing the model whose error is minimal as the optimum may result in losing some important feedback. Model combination faces exactly this problem: it is a well-established methodology that improves the accuracy of a forecast \cite{61} and has already been already applied to other disciplines with success (see \cite{62} for a comprehensive survey).

Now, prediction methods are not the only thing that can be combined to achieve a better forecast. Adjacent buildings usually share a number of common features such as the weather, social class, or work schedule. Moreover, they would be influenced by the same special circumstances, say sportive events, festivities, and so on. In \cite{63,64} an analysis of several forecast aggregation techniques of the compounding loads of a primary substation is presented. While it is not immediate that the same techniques can be used to buildings it could represent an important improvement.

Following this vision, there have been research initiatives in which different models where applied to take advantage from common features, such as for instance, using information of adjoining sensors in a tide measurement system \cite{65} (applying gaussian processes). There, the commonalities among the sensors are evident, which is not the case. Two contiguous primary substation may supply energy to highly different neighbourhoods, resulting in completely contrary demand profiles (think of contiguous commercial and residential areas). Hence, this demanding issue is not clear and, to our knowledge, is still open since nobody has coped with it before.

V. CONCLUSION AND OUTLOOK

The research about building automation, smart grids, sensor networks, and their integration is well established within the Industrial Electronics Society of IEEE. This conference, being the flagship event of the society, annually brings together researchers from all over the planet, which fosters exchange and communication, topics that cannot be overestimated in interdisciplinary research, which arises when previously mature stand-alone fields grow together.

Recent advances in building controls can be found in the area of energy efficiency and flexibility of operation: available data are better structured so that existing information is accessible in an integrated fashion, which is a vital requirement for an integral topic like energy efficiency. Building controls and management advance with regard to exploiting flexibilities for the sake of demand side management, paving the way for integrating renewable energy sources. Methods to provide this flexibility are taken from basic information theory like ontologies, simulation and optimization, as well as artificial intelligence to handle the resulting system complexities. In a first step the building supports the smart grid, solving the energy supply issues without the need to increase grid capacities. On another level the smart city is the upcoming concept of integration: buildings, infrastructure and communication cooperate to achieve an overall optimum in the city with regards to energy efficiency, mobility and comfort.

On the other hand, mainly with respect to the electrical grid, the management of the grid, given the parameters of the new players like renewables, reached world-wide attention in research and politics. It is the interplay of new and optimized components with a new systems perspective that leads us to better efficiency and an optimized energy system. The enabling factor is information technology.
However, it can be anticipated that similar mechanisms and structures as for the electric grid will be introduced to other kind of infrastructures. A trend to distribution of services can be observed, which is the driving factor behind. From the perspective of the smart city, smart grids however also tackle individual problems, thus, they too can be considered the bottom-up approach towards the smart city.

In the future, top-down approaches, which optimize between technological, economic, legal, social, cultural, political, and structural aspects of the city will be necessary. Only as such, the vision of the smart city will become built reality.

REFERENCES


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