Service-orientation vs. Real-Time: Integrating Smart-Homes into the Smart-Grid

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Abstract—**Building automation has grown in parallel to energy smart grids without much interaction. However, at present, these two worlds cannot remain separated any more, as long as intelligent buildings become another node of the grid. This paper shows that this integration can be performed in practice as long as a harmonized knowledge/data model for the two worlds can be defined. This paper describes how this harmonized model can be achieved, how it can be implemented as part of a smart grid node, and how it could work and be deployed in a case study.**

I. INTRODUCTION

The first ideas around the concept of smart grid and its advanced applications can be traced in the seminal work of Fred Schweppe, his research starting back in the 60s towards a dynamic national grid [1], [2], [3], [4]. The actual smart grid vision received a decisive shove in the beginning of the 90s when the UK liberalised its electric market by privatising the electricity supply industry in England and Wales. This decision has been subsequently adopted and implemented in many other countries. In most cases, the restructuring involves separating the electricity generation and retail from the natural monopoly functions of transmission and distribution [5].

Since then, the research on the diverse aspects related to the smart grid has been hectic. According to the last moves of the biggest European utilities (e.g. the PRIME alliance[1] or the Open Meter project[2]), the underlying communication architecture, at least in this continent, is getting clearer: real-time communication all over the transport and distribution grid down to the secondary substation. This structure is already under development and will be soon deployed [6]. From that point to the meter (i.e. the so-called *last mile*), including eventual data concentrators, there is a relentless fight between power-line communication (PLC) and ZigBee.

Still, independently from the physical and subsequent layers chosen, the winning paradigm at the client's side (e.g. next generation industrial automation [7] or smart buildings [8]) is service orientation, especially since the advent of the Devices Profile for Web Services (DPWS) and their standardisation by the OASIS [9]. Backed and developed by heavyweights such as ABB, SAP, Schneider Electric and Siemens[3], DPWS enables seamless integration of device-provided services via a service-oriented architecture (SOA) [10].

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[1]www.prime-alliance.org
[2]www.openmeter.com
[3]See their joint-effort EU-funded projects SOCRADES (www.socrades.eu) and IMC-AESOP (http://www.imc-aesop.eu).

Yet service orientation implies a *get-set* paradigm (say *invoke-execute*), whereas the most powerful real-time communication protocols (e.g. Data Distribution Service, DDS, an OMG standard [11] middleware with highly parametrisable Quality of Service) rely on a *publish-subscribe* mechanism.

There have been hybridisation attempts (e.g. [12]) and DPWS does present the ability of handling events but this alternative would request ignoring its natural way, conveying all the data exchange through events.

The get-set paradigm is enough for managing and coordinating intelligent devices and to achieve all tasks included in the smart building / home / industry vision [8] but it is not efficient to be integrated in the more exigent real-time smart grid architecture (apart from the fact that DPWS demands, by definition, IP connection, which cannot be assured in all smart grid scenarios and assets). Real-time is not about achieving a task in a quick fashion, but about achieving it quick in a previously known maximum time (i.e. can guarantee a response within a maximum *latency*).

Against this background, we will present an standard-based software architecture devised to integrate native DPWS-compliant devices, legacy, fieldbus-area-network-based or proprietary applications and communication protocols into the real-time smart grid architecture. We will validate our approach by illustrating real-world examples of this integration.

II. CHALLENGES

There are three 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, as follows:

- Achieve the **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[13], DLMS/COSEM[14] and CIM[15]. The harmonisation can be accomplished semantically, in case we want to later offer the possibility of using the power of ontologies[13] (e.g. to perform inference), or syntactically. In [16] they present a bridge from the IEC 61850 to DPWS but it still works under the get-set paradigm's constraints.

- Provide **abstraction upon the network protocol**: There are many different fielbus 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 [17]. In that case, similar to outs, 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.

- Guarantee a suitable **connection to the real-time middleware**: DPWS offers agadg rigid get-set functionality (i.e. read or write a variable of a device) as in [18]), 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[4] real-time service. This strategy will allow to perform the aggregation and coordination of services both locally and remotely in a natural way.
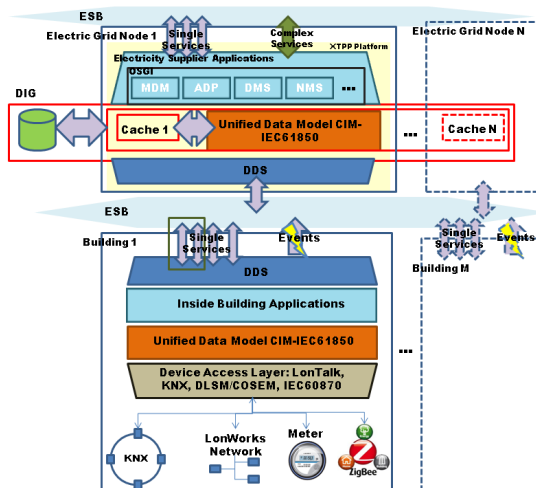
III. System Architecture

Fig. 1. System Architecture.

Fig. 1 gives a glimpse of the whole system architecture. We assume there are a number of devices at the bottom of the system connected to a field-area network or alone. They are remotely controlled by the corresponding head-end, which is connected to a real-time Data Distribution Service (DDS) bus (a Message Oriented Middle-ware standard (MOM)) [19]. The DDS bus, offers two communication types: publish/subscribe and service-oriented request/response. The applications on top of the DDS bus (such as Meter Data Management (MDMs), or Distribution Management System (DMS)) acquire the data they need to work from and through this network (it can be any eXtreme Transaction Processing Platform (XTPP)). Additionally, they offer their services to applications on top of the Enterprise Side Bus (ESB). All the data is stored on a Data

[4]www.osgi.org

Information Grid (DIG), either in real-time or not, depending on its nature. Some of the DIG is composed of distributed data caches on the nodes (including the head-ends); alternatives to this end are e.g. Oracle's Coherence or EHCache. Finally, *BigData* issues may be handled through Apache Hadoop. This paper focuses on the bottom part of the architecture, more accurately, from the real-time architecture to the devices.

On the top, we have the smart-grid communication network. The head-end is the intelligent node placed on the building that exports a number of services to the upper layer. This head-end has a predefined data model obtained from harmonizing the two main smart-grid standards' data models: CIM and IEC 61850 [20]. The head-end is connected (physically or through wireless) to a number of field-area networks controlling several gadgets such as sensors or lights, and to intelligent electric devices (IED, e.g. meters implementing either IEC 60870 (high-voltage meters) or DLMS/COSEM (all meters)). Each of these variants implements different protocols (e.g. LonWorks, KNX, BACNet, or the aforementioned IEC 60870 or DLMS/COSEM). The head-end retrieves the information from the devices or the field-area networks because it has the required libraries to conceptually *speak* to them (i.e. the head-end *understands* the protocols). Then, the head-end translates/maps the obtained information into the harmonized data model and then exports the services with this information upwards. This internal services are orchestrated and then exported as external services (eventually, they could be directly converted into external services and exported).

IV. Data Model Harmonisation

In order to unify the 61850 and CIM models, it is necessary to minutely analyse the use cases that will define the proper behaviour of the system. This procedure helps to identify the important functions and elements around which the innards of the system revolves.

There are two approaches when it comes to deal with the harmonisation between the Common Information Model (CIM), defined in IEC61970-301 and IEC61968-11, and IEC61850. The first technique proposes the construction of an unified UML model based on CIM, and extending it with concepts referent to 61850 [20]. 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 2010, in a report from EPRI to NIST [21], there is a detailed explanation on how to achieve the harmonisation between the Substation Configuration Language (SCL) and CIM, through a unified UML model. The CIM UML model provides a common semantic overview for the transmission and distribution system interfaces and extends it to include the IEC61850 concepts.

EPRI defines several high-priority use cases driven by business needs and then develops an unified model and interface definition to support those use cases. The identified general use-case is the Network Extension, adding a new part (new substation) to the existing network. The EPRI

report identifies some harmonisation issues like the lack of verb+ConductingEquipment+ concept in the SCL or the need to add a persistent ID to SCL objects, resulting in the publication of an unified UML.

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 [22] that has developed a tool for translating between configuration files written in CIM to Substation Configuration Description (SCD), and vice versa.

V. NETWORK PROTOCOL ABSTRACTION

As mentioned before, the process of enabling interoperability between different protocols begins with the identification of the most important functions and elements of each one. Since our case of study focuses on building automation, we have conducted a research on the devices and referenced protocols that may be found in an intelligent building. This research has provided us with an insight on the classification in which the protocols could be divided, according to whether a data model is specified or not.

A. Specific purpose communication protocols

Among the communication protocols for inside building communication, we find the ones for the communication with meters. Some of them define an explicit data model, such as DLMS/COSEM (Europe-wide metering standard), specifying data structures and functionalities in the form of classes and services along with the message exchange information, where messages are constructed with these data classes, while others IEC60870 (standard adopted by the Spanish Transmission System Operator for the management of high-voltage meters) only define the structure of the exchanged messages.

In the case of the DLMS/COSEM, the protocol defines a data model and communication protocols for data exchange with metering equipment, classified in three areas:

- `Modelling`: Data model of the metering equipment as well as rules for data identification.
- `Messaging`: Communication services and protocols for mapping the elements of the data model to application protocol data units.
- `Transporting`: Services and protocols for sending messages through the communication channel.

The data model of the DLMS/COSEM comprises several *interface classes* grouped by functionality: data storage, access control and management, and time-event bound control. Taking for example the interface class `Extended Register` from the *data storage* group, which defines the way in which a consumption reading is delivered by the protocol. This class is comprised of three fields:

- `Logical name`: Identifies the register object instance.
- `Value`: Obtains the current process or statue value.
- `Scaler unit`: Provides information on the unit and the scaler of the value.

We have achieved the mapping to the IEC61850-CIM by identifying the necessary fields of a specific interface class of the DLMS/COSEM with the equivalent ones in the unified protocol. In this way, whenever there is a query or response from one protocol to the other, the intelligence in charge of achieving the interoperability is capable of converting and mapping the fields in the message of a specific protocol, to the other.

B. General-purpose communication protocols

Zigbee is a low-power, low-rate short range wireless communication used in industrial control, home automation, health care, building automation, consumer electronics and other fields. This communication technology, could be classified inside this group because it is valid to communicate with a variety of a inside building devices, defined in the previously mentioned application profiles. This technology is recently gaining a lot of popularity, due to its robustness, and the availability of cheap ZigBee *kits*. ZigBee is suitable for large-scale, delay sensitive, and not excessively large amount of data application environments.

ZigBee also offers the ability of tunnelling widely used standards like DLMS/COSEM (metering) or BACnet (building automation), enabling integration of existent deployed devices and networks.

There are other communication protocols that come from the industrial and building automation world that do not define an explicit data model, such as KNX, LonWorks, and ModBus. Mapping the values obtained through these protocols to a data model is more complex, since these protocols define the communication layer, i.e. the format of frames and messages for the communication between devices, but do not provide a common model in which to organize the different values that can be acquired and controlled.

For instance, KNX is a management system in the area of electrical installation for load switching, environmental control and security, for different types of buildings, whose objective is to ensure the monitoring and control of functions and processes such as lighting, window blinds, heating, ventilation, air-conditioning, load management, signalling, monitoring and alarms.

Communication within the KNX is done by means of messaging and the sending of a message takes place when an event occurs. The transmitter device (sensor) checks the availability of the bus and then sends the telegram. If there are no collisions, once the transmission has ended, the sensor waits for a message of acknowledgement. The frame that is transmitted through the bus contains specific information about the event and has seven fields: six related to control issues in order to achieve a reliable transmission, and a field with useful data about the commands to be executed.

Fig. 2 illustrates the mapping of FAN concepts into CIM.

VI. REAL-TIME MIDDLEWARE CONNECTION

The functionalities offered by each individual device are forwarded to the upper layers transparently, regardless of communication technologies involved. Moreover these services
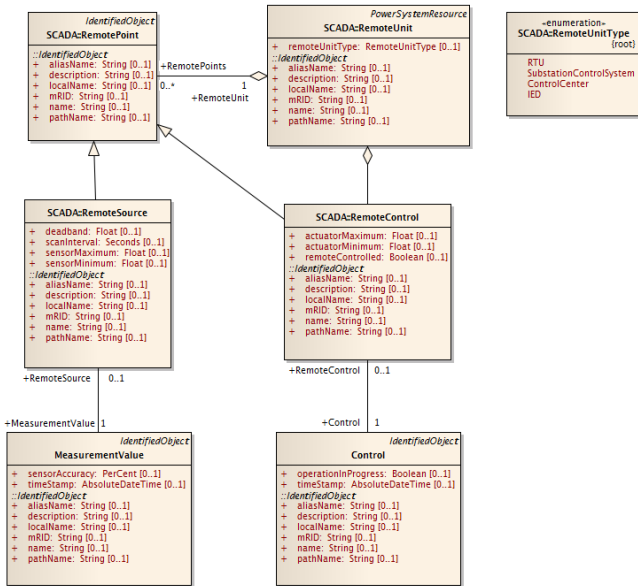
Fig. 2. CIM concepts for representing Field Area Networks

can be combined, offering aggregated services, which interact with several devices (e.g. programmable thermostat, Heat Ventilation and Air Conditioning, HVAC) to offer higher level services. Orchestration, that is, aggregated execution of services according to a logical rule, allow us to operate the building services in a specific way, managing several services in a coordinated manner as if it was a single service. This process takes place when a given event arises. This section describes how the service orchestration is implemented. For that, it may be necessary to describe some details of the XTPP platform. Some of the main guidelines behind this platform were first described in [19].

This XTPP platform makes use of OSGi[5] as container, allowing us to use OSGi potential such as the its bundling capabilities. OSGi can advantageously used to aggregate both web services and non-web services. This fact is important as this platform cannot be necessarily linked or restricted to services implemented as web services. Actually, web services can be a limitation if real time or quasi real time constraints are to be supported, as `int` this the case. Events are behind rule firing, and DDS is capable of real-time event management. Therefore DDS is responsible for this event handling and publication.

Web services can be seen analysed more in detail as an example. In the case of web services, WS-BPEL (Web Services Business Process Execution Language, available in [6] can be used to model the behaviour. In this case WSDL (Web Service Description language) can be used to define specific operations, and the sequence operation by WS-BPEL. The logic of the process is defined as rules. This is possible as RDF/OWL-DL and several reasoners are part of the platform as described also in [19]. One of the problems that may arise is that the system will produce too many events what will be difficult to handle. Therefore, a ESP/CEP engine is in charge of filtering those

events that should fire a rule and produce a service orchestration. In the case of non web services, or in the combination of web and non-web services, the OSGi service model can be directly used to implement the orchestration. The role of DDS, ESP/CEP, OWL-DL, and reasoners, is similar that in the case of web services. Finally, in both cases, web and non-web, results from the execution of the service orchestration can be published using a publishing server (e.g. http server).

VII. PROOF OF CONCEPT: REAL-TIME METER READING

In order to illustrate the integration of a smart-home into the smartgrid we propose the following scenario: publishing the active power measurements of an IEC 60870 meter in the real-time platform. To this end, we only need a PC (an embedded device would also suffice) connected to the DDS network, together with a telephone connection to communicate with the meter and another intelligent node that will subscribe to that information.

The IEC 60870 is a high-voltage meter management standard that is only widely-used in Spain (established by law). This protocol allows remote reading and manipulation of the HV-meter but is not interoperable with other more wide-established protocols (e.g. DLMS/COSEM). Therefore, the management must be achieved by means of proprietary, legacy applications that implement the protocol. Specifically, the Spanish standard for meter management is an implementation of the IEC 60870-5-102[23], detailing the communication protocol between registers or accumulators and meters. It presents three layers, namely *physical*, *link*, and *application* (taking the OSI Model as reference).

- **Physical** layer: The IEC 60870 offers three ways to access the meters, one direct and the other two remote (via GSM modem or TCP/IP, depending on the device model and its features). We focus here on the remote GSM alternative; thus, the physical connection has been achieved through AT-HAYES commands.
- **Link** layer: This layer establishes the communication session among the meter and the external querier, assigning an unique `session id` that lasts until this communication ends. The data in this layer is exchanged in frames. The IEC 60870 lists their type and order, usually grouping them in question-answer pairs, except for the `session-open` and `session-close` frames that receive a fixed length frame with `Op.Code 0x10` (`ack`) in case the operation was successful.
- **Application** layer: Non-password protected operations include inquiring the meter and vendor id, reading current date and time, official work-schedule dates (holidays and vacations), contracted power or consumed active and reactive power (accumulated and stored since the last reading). Password-protected cover all meter configuration operations that could lead to any deceitful or defective data retrieval (e.g. changing date and time, modifying contracted power or holidays).

In [24] we presented and service-oriented approach to achieve the meter reading. Nevertheless, those architectures do not allow to integrate the meter reading process into a real-time architecture. As aforementioned in section II, there are

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[5]http://www.osgi.org

[6]http://docs.oasis-open.org/wsbpel/2.0/OS/wsbpel-v2.0-OS.html

three problems to solve to achieve this integration: data model harmonisation, network protocol abstraction and connection to the real-time middleware. The first step has been already performed by the EPRI with the harmonisation of the CIM and IEC 61850 protocols; moreover, this data-model is common for all home-automation integration scenarios.

Regarding the network protocol abstraction, IEC 60870 is an specific purpose communication protocol. Thus, it is enough to map its concepts into the harmonised CIM-IEC 61850 data model. More accurately, in this scenario it is enough to map the answer of the meter upon request (a series of `Op.Code 0x139` frames) into the corresponding CIM classes as depicted in Fig. 3, since this will be the information that will be handled to the real-time middle-ware.

In this way, the information obtained from the `Op.Code 0x139` frames is recast into a `MeterReading` message (the actual format and schema can be found in [25]). This message defines for instance the identity of the meter or meters, the reading values (as `IntervalBlocks` for the periodic reads or single `Readings` for the rest), and their respective qualities and time-stamps (as well as other important information specified within the `ReadingType` class, such as interval length of the measure, type, unit, etc.).
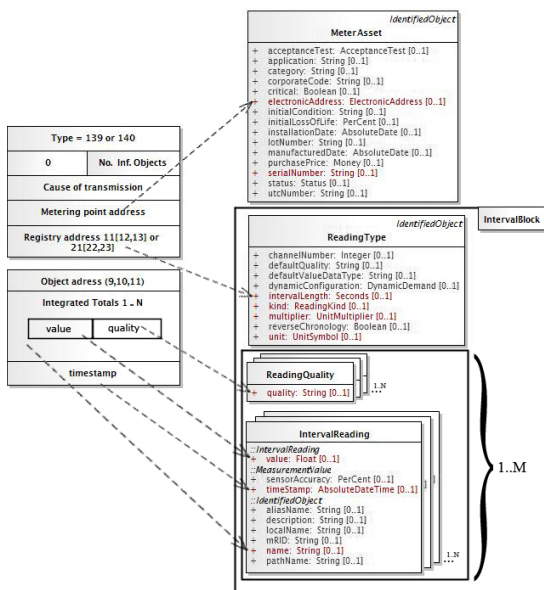

Fig. 3.   Mapping of the IEC60870 metering data into CIM classes.

According to the CIM specification [25], a meter is handled as an end device and, therefore, it is represented using the CIM `MeterAsset` class, which is a subclass of `EndDeviceAsset`. CIM also defines the message interface of an special *profile*, namely the `MeterReadings` profile, that contains all the functions to be used with a meter; we have completed it with the *CIMTool*, adding all necessary classes. This profile foresees several forms to retrieve load consumption values from a meter: periodic reads, manual, on-request, historical meter data access; we have selected the on-request modality as the equivalent for the IEC 60870 absolute integrated consumption retrieving service (`Op.Code 0x189`).

Fig. 3 shows the mapping of the `Op.Code 0x189` frame into CIM classes. Please note that there are some fields with internal information inherent to the IEC 60870 IEC 60870 that do not need to be mapped.

Finally, we must tackle the third challenge: connecting to the real-time architecture. With this purpose in mind, we have tested the communication between the PC that publishes the information of the meter and another intelligent node. Our DDS architecture is based on the RTI DDS distribution. This second node is subscribed to the consumption information of the meter (published by the node attached), using the standard publish/subscribe paradigm DDS offers. DDS is message oriented with reliable and ordered delivery and specifies a number of attributes in order to better handle its delivery: *topic*, *source*, *scope*, *Quality of service parameters* and the body itself. The topic provides an insight of the content of the message in order to improve the communication. The maximum length of a packet is 64 KBits but a message can be divided in several packages (we have successfully sent up to 1 Mbyte messages).

Our approach to publish CIM-IEC 61850 information though DDS consists of inserting the CIM XML `MeterReadings` message in the `body` field of the DDS message, as illustrates in Fig. 4. Then, we inject the message in DDS using the usual publish mechanism. We have performed tests during several days publishing consumption data with different frequencies (one second, fifteen seconds, thirty seconds, one minute, five minutes and fifteen minutes) and in all the tests the subscriber received the data in 44 ms; we have also tested the same publishing scheme in a network with ten other simultaneous similar nodes and the performance does not get affected since the messages we deliver are still to small (RTI provides detailed information on bandwidth, scalability and other aspects in its website.) Therefore, we can assume that any intelligent node interested in the data published by the meter would get it 44 ms in order to build an OSGi service based on this and other informations.
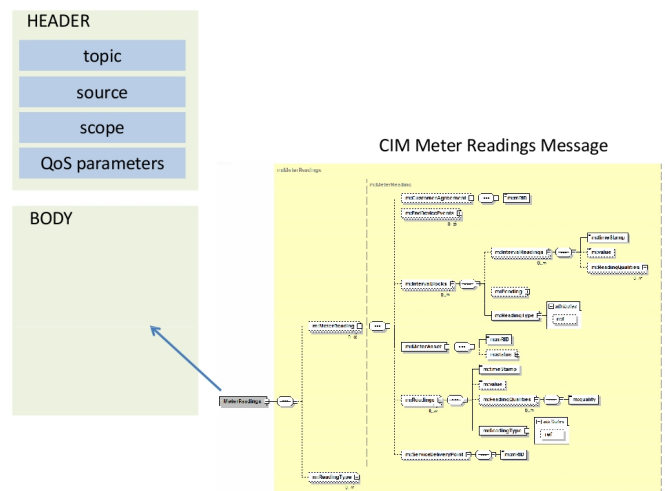

Fig. 4.   DDS message with CIM payload.

VIII. CONCLUSIONS

The revolution pushed by the smartgrids has already reached a point in which adjacent areas must be integrated in order to achieve an optimal global working way. As a result, other areas in which automation was the main character and energy used to be a second fiddle, such as building automation, cannot remain attached to the classic old schemes. In the case of building automation, a closer integration with smart grids is required since, for instance, smart homes play a key role in the smartgrid vision such as demand management or demand response.

There are still a number of problems to be solved. SOA (especially web-services) is the communication architecture that has been used so far to integrate building automation within other systems but the smartgrid cannot relay in non real-time technologies and the request-response paradigm classically offered in SOA poses an obstacle very difficult to avoid. In this paper we have described an alternative based on an OMG standard, DDS, a real-time message-oriented communication middleware based on the publish-subscribe paradigm.

Yet building automation has traditionally presented a very wide range of communication protocols that With the objective of providing useful information to applications running within the smartgrid, we have used the standard smartgrid data-model (obtained from the harmonisation of the two main smartgrid protocols: CIM and IEC 61850), addressing a multi-layer architecture in which first we map the corresponding building automation communication protocol into CIM-IEC 61850, and then, we publish the resulting CIM-IEC 61850 XML information embedded in a DDS message. As a proof of concept, we have designed an scenario in which we publish in DDS the information of an IEC 60870 meter. Future works include testing a bigger scenario including several field-area networks and offering their services to the smartgrid as OSGi services.

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