

# Service-oriented integration of smart home and building automation systems

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**Abstract** — The main issue with smart home/building management is that products from different manufacturers are incompatible with each other, and even products of the same brand are unlikely to really interoperate. To provide a fully interoperable solution or solution which is inherently leaned towards improved interoperability, a robust architectural approach to design an underlying system is compulsory. This paper presents one of possible architectural approaches for an integrative management platform of different smart home and building automation systems. Proposed approach is devised upon service-oriented deployment principles to mediate and transform messages across a variety of systems, services and APIs. It addresses open interoperability standards and exploits the existing semantic data models to support different integration and interoperability patterns. At its core, the proposed approach is leveraged by an open software Smart Home Gateway responsible for communication with proprietary solutions and vendor data formats. Furthermore, it envisions the Canonical Data Model which serves as unified (XML-based) messaging format across the smart home management platform providing an abstraction of proprietary data semantics.

## I. INTRODUCTION

Nowadays, the main obstacle to provide smart home/building interoperability is that products from different manufacturers are incompatible with each other, and even products of the same brand are unlikely to really interoperate. True interoperability can be achieved when heterogeneous smart components can utilize data and suggest actions from and to each other. Unfortunately, while the vision of smart buildings is nothing new, agreeing on the standards between larger groups of companies has been unsuccessful, except in entertainment electronics. In the recent years many solutions for integration and interoperability of smart home and building automation systems are proposed, but they do not have a high degree of interoperability and are usually strongly technology-oriented. Innovative user-oriented services usually have to control and supervise a number of smart home devices and technical systems (e.g. lighting system, video surveillance, motion detection, power supply, etc.), within the target building or home [1]. In such a case, interfacing with numerous smart home devices, coming from different vendors, using different proprietary communication protocols, is a difficult problem to solve. Therefore, in order to support more advanced and intelligent smart home services, generic and scalable solutions are needed to be provided in terms of easy, plug-and-play interfacing with different smart home devices, monitoring equipment, etc. Such solutions should

provide means for integration with low-level devices (such as sensors and actuators), but as well with the legacy building management systems (BMS) such as, for instance, widely utilized systems for supervisory control and data acquisition (SCADA) within buildings and more complex infrastructures.

This paper presents one of possible solutions for integration and interoperability of smart home and building automation systems which is built upon central managed architecture where the sub-system interconnections can be guaranteed by a dedicated gateway. Thanks to the gateway it is possible to have an interoperability inside home or building, considering an integrated environment with a lot of devices that cooperate together as a single entities, exchanging data and providing high quality services. The proposed integration approach is heavily leveraged upon the service-oriented deployment principles which enable mediation and transformation of messages across a variety of systems, services and APIs. In order to support various integration and interoperability patterns, it addresses relevant open interoperability standards and exploits the existing semantic data models (in form of ontologies) for extraction of additional semantics and provision of common vocabulary for system components. As mentioned previously, at its core, the proposed approach is leveraged by an open software Smart Home Gateway responsible for communication with proprietary solutions and vendor data formats. Inherently, it provides embedded modules for translation from vendor data formats so that the rest of the system can understand and further process acquired data from the smart devices, sensors and metering equipment. To achieve this, the proposed solution envisions the Canonical Data Model (CDM) which serves as unified (XML-based) messaging format across the smart home management platform providing an abstraction of proprietary data semantics and common understating of the acquired data. In other words, CDM serves as a common language of the system components into which dedicated modules of the proposed Smart Home Gateway translate the data received from the low-level devices.

The remainder of this paper is organized as follows. An overview of the state of the art solutions for integration and interoperability of systems within home or building is provided in Section 2. Section 3 elaborates relevant interoperability aspects that should be taken into account and describes the proposed methodology for integration and interoperability of smart home and building automation systems. Section 4 specifies the particularities of integration platform deployment by describing the test-bed platform implemented in the Institute Mihajlo Pupin.

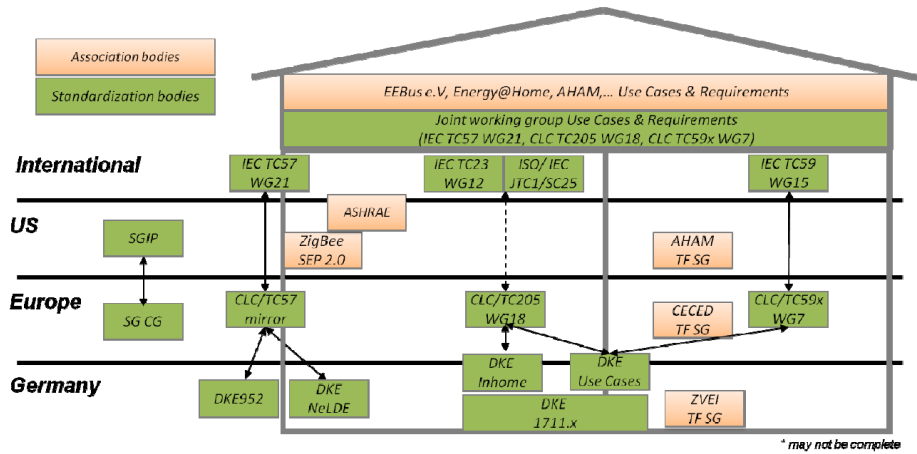


Figure 1. An overview of association and standardization bodies [11].

Finally, concluding remarks and discussion are given in Section 5.

## II. STATE OF THE ART SOLUTIONS

An extensive amount of research has been focused on smart home and building automation interoperability, as elaborated by Jarvinen and Vuorimaa [2] and reported by Jiang et al. [3]. There are many possible typologies of architectures to improve interoperability with smart home devices as investigated by Capitanelli et al. [4]. For instance, many studies have been concentrated on connecting heterogeneous devices and subsystems together, and providing a unified interface on top (such as in studies performed by Perumal et al. [5], Wang et al. [6], Tokunaga et al. [7], and Miori et al. [8]). One of the protocols for the unified high-level Web services interface is open Building Information eXchange (oBIX) (Considine [9]) proposed by the Organization for the Advancement of Structured Information Standards (OASIS). This data format is based on XML and defines, similarly to any common programming language, a small set of primitive data types for describing the data. Coyle et al. suggested a sensor fusion-based middleware for smart homes, called ConStruct (Coyle et al. [10]). Similarly to an integration platform, this solution interconnects heterogeneous devices and presents the information with a unified format, in this case, RDF. In this regard, there is a number of specifications such as OneM2M, Smart Energy Profile (SEP 2.0) and Common Information Model (CIM) that should be mentioned as efforts towards the smart home interoperability on different communication levels (while some of them overlapping).

Furthermore, a number of standardization committees such as CENELEC TC59X WG07, IEC TC57 WG21 and Open ADR Alliance are working on smart home/smart grid interoperability standards. An overview of relevant association and standardization bodies, at both international and national level (in case of US and Germany), is presented in Figure 1 [11]. Recently, the use of semantic technologies in smart environments has been suggested by many authors (such as in studies by Chen et al. [12], Wang et al. [13], and Zhang et al. [14]). Semantic technologies provide a way to represent data on a higher semantically meaningful level, and share common understanding of the concepts using ontologies. In addition, different application domains can define their own ontologies. In turn, these ontologies can link concepts

and properties to common ontologies, for example, in Linking Open Data (LOD) cloud. Various studies propose ontology-based context models for representing smart home context information semantically (Gu et al. [15], Kim and Choi [16], and Xu et al. [17]). Ontologies, such as Cobra-Ont (Chen et al. [18]) and CONON (Wang et al. [19]) have been defined to model context information. However, all these research and standardization efforts are lacking the holistic approach and should be combined to provide an adequate open-standard based architectural backbone in order to ensure the long-term interoperability with different proprietary smart home and building automation systems.

## III. PROPOSED METHODOLOGY

One of possible architectures of the platform for integration and interoperability of smart home and building automation systems was devised as part of the proposed methodology. The aim of the specified architecture was to describe how systems and components interact, while their interoperability was taken as one of the primary concerns. In devising the platform architecture conceptually, interoperability as a term related to the ICT domain was considered at the first place. However, in broader terms, interoperability can consider different aspects, such as:

- **Technical interoperability:** related to the integration of multiple heterogeneous ICT systems and services, and linking them together;
- **Semantic interoperability:** common understating of the meaning of exchanged information among involved parties (e.g. specification, relation and structure of concepts and properties utilized for data description);
- **Organizational interoperability:** orchestration of processes and actions in terms of where the data are used and transformed (e.g. shared definitions of the roles, responsibilities and interactions of involved parties).

The methodology proposed in this paper is closely related to the technical and semantical interoperability of smart home devices and building automation systems, while it sets the baseline for building the organizational interoperability (e.g. to provide high-level services to the end-user or in case of multi-stakeholders scenarios). In order to deliver such integration platform which will serve

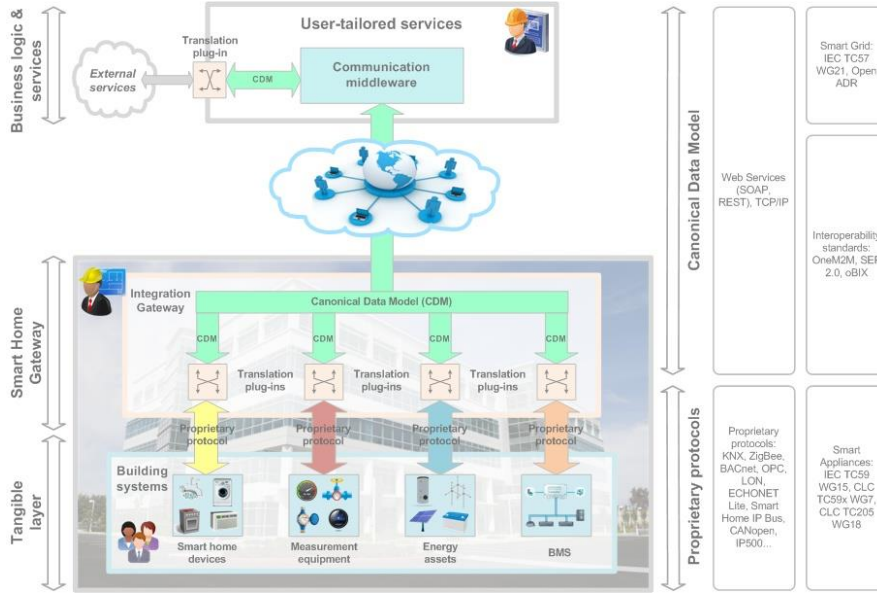


Figure 2. Architecture of proposed integration platform.

as holistic and efficient collaboration platform, the proposed methodology was aimed at the following general targets that have to be satisfied:

- development of software-based services, and
- specification of service-based interoperability domain among involved parties.

To accomplish these targets, the proposed methodology embeds interoperability support spanning technical, semantic and pragmatic interoperability.

To understand the data from different domains and interoperate with heterogeneous low-level devices, the proposed integrative management platform exploits to its maximum the potential of service-oriented deployment principles (as shown in Figure 2). Such service-oriented architecture ensures the mediation and transformation of messages across a variety of systems, services and APIs. In this way, it addresses open interoperability standards (as shown at the right-hand side of Figure 2) and supports different integration patterns, thus enabling horizontal interoperability among various heterogeneous systems and business applications. To support vertical interoperability with low-level devices and systems, the proposed approach is leveraged by an open software Smart Home Gateway responsible for communication with proprietary smart home/building solutions and vendor data formats (e.g. ZigBee, Z-wave, OPC UA, BACnet, KNX, etc.).

Following the latest trend in Internet of Things (IoT) as AIOTI [www.aioti.org], FIWARE [www.fiware.org] or OpenIoT [www.openiot.eu], an event driven architecture is also incorporated allowing the real-time distribution of data and alerts to and from any kind of cloud application. To further support such approach, specification of Canonical Data Model (CDM) is seen as a prerequisite which will serve as unified (XML-based) messaging format across the smart home/building management platform and make an abstraction of proprietary data semantics. As suggested by literature [20], deployment of ontologies, which brings a semantic layer to the smart home/building integration platform, can be useful for developing intelligent applications and supporting the

overall system interoperability. Therefore, the proposed approach envisions the exploitation of the existing semantic data models and specifications (e.g. SAREF, SESAME-S, BOnSAI, and IFC) in providing the common vocabulary for involved actors, interacting hardware and software components, and context for semantic enrichment of raw data. Furthermore, to ensure the long-term interoperability with smart home services, open interoperability standards (such as OneM2M, SEP 2.0, CIM and oBIX) are respected and followed by underlying system communication paradigms.

#### IV. TEST-BED INTEGRATION PLATFORM

For demonstration of the proposed concept of integration platform, the campus of the Institute Mihajlo Pupin (PUPIN) in Belgrade was taken as a test-bed, equipped with various metering equipment and technical systems (e.g. power supply, access control, video surveillance, etc.). For testing purposes in this paper, only integration with energy related systems and monitoring equipment was considered. At the PUPIN campus, SCADA View6000 system [21] is operating as the main BMS providing supervision and control of the underlying systems. In this regard, SCADA system was taken for integration with the proposed gateway, as it currently supervises both electrical (by PV plant) and thermal energy production (by local thermal power plant). On the other hand, electricity consumption is provided by smart power meters (i.e. non-invasive, self-powered wireless current sensors), which were not yet integrated under the SCADA system, and therefore were considered for direct communication with the gateway. Nevertheless, the proposed gateway was envisioned in flexible and scalable manner so it could be easily extended to encompass any subsequently defined metering points.

The proposed gateway was implemented to support two-way communication, i.e. for both data acquisition from the metering points, SCADA system or other external data services (e.g. meteorological data), and for issuing commands towards the SCADA system for performing control actions (e.g. increase the temperature



set-point). Each gateway translation plug-in was implemented as bundle-JAR file (based on OSGi specifications [22]) which was deployed under the open software OpenMUC framework [23]. For better insight into the data flow, Figure 3 represents simple schematics of the proposed gateway, depicting the communication and integration architecture deployed to acquire the designated metering points. As it can be noticed, at the gateway side, the designated REST Web service (belonging to the gateway) can forward the acquired metering values towards the high-level services (such as to the smart grid or energy management services) for further processing. At the same time, the gateway communicates with the REST Web services (via internet connection using HTTP/TCP/IP) residing at the server deployed at PUPIN premises and which perform the acquisition of metering points from SCADA system and power consumption data from smart meters.

SCADA system is responsible for supervision of metering points related to the PV plant and energy production (total actual power generated by the plant), heating system, i.e. thermal energy production and consumption (mazut level/consumption, hot water temperature/flow, radiator and air temperature points) and meteorological parameters acquired by PUPIN local meteorological station (outside temperature, wind speed, solar irradiation). As it can be seen from Figure 3, designated RTL units (ATLAS-MAX/RTL which is an advanced PLC system running on Real-Time Linux [24]) at the field side of PUPIN campus are responsible for acquisition of metering data using M-Bus communication protocol and communication with SCADA View6000 system over TCP/UDP protocol. Additionally, corresponding OpenMUC gateway parameters have been defined in order to support acquisition of indicated metering points. For retrieving the metering values stored by the SCADA View6000 system in real time, REST web service was set at designated server. Through the corresponding SQL queries carrying the information about the specific channel/variable IDs, desired metering values were retrieved and forwarded to the translation plug-in (i.e. to the designated bundle) under the OpenMUC gateway framework. In the same way as for the data acquisition, commands can be issued from the gateway towards the SCADA system for performing the control actions.

## V. CONCLUSION

To provide a fully interoperable solution or a solution which is inherently devised to better support system interoperability, a robust architectural approach to design an underlying system is compulsory. Such an approach should be able to start from a high-level system analysis considering not only the technological requirements of the system, but also the users' needs in order to abstract the low-level technical devices and systems. These aspects are fundamental to provide optimized services by exploiting smart home capabilities, and to support the overall interoperability of the high-level management system, but they are usually studied separately. Therefore, a joint approach is necessary, starting from a high-level system architecture, the specific users' requirements, to the dynamic and interoperable environment characterized by explicit but flexible relationships between home devices and exchanged data. By following this approach, proposed

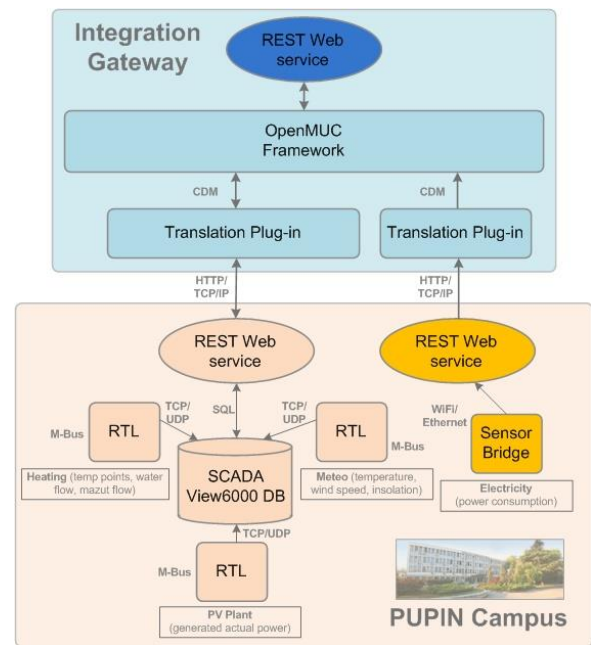


Figure 3. Gateway implementation and data flow.

integrative management platform delivers an interoperable and flexible means for integration of different smart home devices and building automation systems, tackling a number of barriers that make this integration difficult nowadays. Apart from the optimized services provided to the end users, additional benefit provided by this approach is reflected in an integrated management of technical sub-systems and home/building automation which is today most often comprised of proprietary non-interoperable solutions. In this regard, the proposed approach provides a way for integrative holistic management, i.e. orchestration of the devices and systems in most effective manner. Finally, the proposed integration platform was implemented in a scalable and adaptable manner so it could be easily replicated and deployed practically within any complex infrastructure of interest.

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