

# A Standard-Compliant ICT-Architecture for Semantic Data Service Integration in Smart Grids

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**Abstract**—One of the prevailing objectives of smart grids is to facilitate automation. Established methodologies, techniques, and approaches from the IT-sector are supposed to be adopted for the energy domain. The scope of this work thus includes semantic-based integration of data services in smart grids achieved through following the proposed (S<sup>2</sup>)In-approach (Semantic Services Integration). This approach identifies standards and specifications, which are integrated in order to build the basis for the (S<sup>2</sup>)In-architecture enabling automated communication processes in future smart grids. The identification of the applied standards and specifications is based on comprehensive, previously derived requirements. The target (S<sup>2</sup>)In-architecture allows precise descriptions of desired and provided data services as well as their combination and semi-automatic execution.

**Index Terms**—Automation Technologies, Common Information Model, Information and Communication Technologies, OPC Unified Architecture, Semantic Services

## I. INTRODUCTION

Nowadays, power systems are changing worldwide. Mostly country-specific drivers, like to increase market competition or adhering to climate targets, lead to a general reenvisioning of the energy supply system. One possible solution for facing the implied challenges are smart grids [1]. They pursue the goal of increasing the efficiency of the overall energy supply system. This must be realized without threatening today's level of power quality [2]. Within such a technologically and economically sophisticated system many different stakeholders have to interact with each other. In order to solve the implied integration and interoperability problems and to realize the concept of smart grids, it is indispensable to develop a new and innovative Information and Communication Technologies (ICT) infrastructure [3]. Smart grid stakeholders have to exchange information with each other in order to provide and consume services, e.g., monitor and control devices. Hence, it is not surprising that the paradigm of Service Oriented Architectures (SOA) is

recommended for smart grid IT-architectures - especially in terms of potential adoption for a common concept of multi-utility management [5]. Moreover, it is recommended to use Internet<sup>1</sup> protocols like SOAP and IP (Internet Protocol) [2] in order to implement Web Services and thus realizing SOA. Recent developments of IT in the energy domain are similar to those in computer science a few years ago. There, the paradigm shift from monolithic systems to service orientation has already taken place. The infrastructure changed from centralized applications to the Internet as a highly distributed system. During that process, integration and interoperability problems in terms of data models, communication protocols, and interfaces had to be solved. Service Oriented Computing (SOC) and SOA aim at the implementation of systems providing comprehensive automation capabilities. In the power domain the overall system infrastructure is evolving the same way. The former centralized systems turn into distributed smart systems. However, domain-specific challenges like long investment cycles of devices and connecting legacy systems have to be faced. One of the main objectives of smart grids is increasing the degree of interoperation enabling automation based on ICT. Thus, it is advisable to analyze general IT-approaches with regard to their adaptability for smart grids.

For that reasons, and in order to cope with the introduced challenges, the (S<sup>2</sup>)In-approach (Semantic Service Integration) is presented in this contribution. The proposed architecture has been conceptually introduced in [6] and its operational realization is in the scope of this contribution. The architecture aims at providing a basis for the efficient application of communication technologies. The remainder of the contribution is therefore structured as follows:

Section II introduces the (S<sup>2</sup>)In-process model for ICT-architecture development. In Section III, the (S<sup>2</sup>)In-architecture developed corresponding to the process model is

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<sup>1</sup> RFC 6272 Internet Protocols for the Smart Grid:  
[www.rfc-editor.org/rfc/rfc6272.txt](http://www.rfc-editor.org/rfc/rfc6272.txt)

described. In Section IV, an application example is introduced in order to show the added value of the (S<sup>2</sup>)In-architecture concept. Furthermore, a prototypical implementation in context of a simulated environment is briefly introduced as a proof-of-concept in Section V. Finally, Section VI summarizes the contribution, draws the conclusions, and provides an outlook on future work.

## II. (S<sup>2</sup>)IN-PROCESS MODEL

In this section, the (S<sup>2</sup>)In-process model is introduced. In order to foster an integration of data services in smart grids, the (S<sup>2</sup>)In-approach specifies a method to model an according ICT-architecture. The resulting architecture is based on the SOA paradigm.

Fig. 1 depicts the process model of the proposed approach.

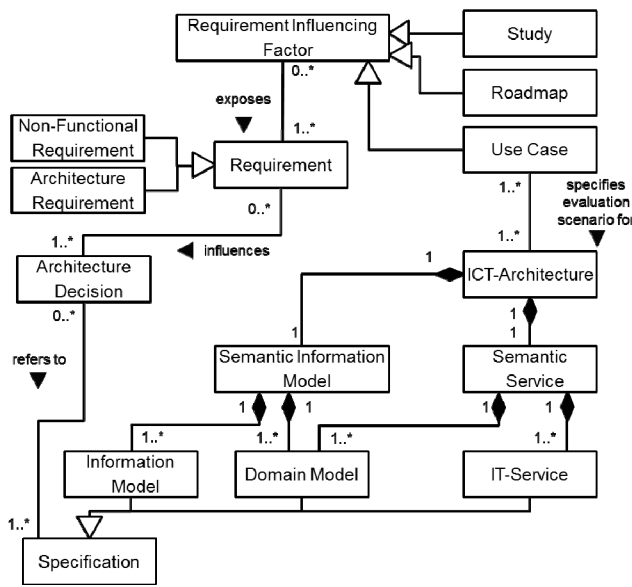


Fig. 1: (S<sup>2</sup>)In-process model

In a first step, *requirements influencing factors* in terms of well-established national, European, and international studies and roadmaps serve as basis for identifying *requirements* for an ICT-architecture. Moreover, existing use cases are considered to ensure a high level of practical relevance. Additionally, expert interviews and workshops are considered. The requirements can either be non-functional requirements (NFR) like referring to performance issues or they can relate to the architecture itself like exposing a layered structure. The main difference between the two types of requirements is that, based on the NFR, measurable requirements can be derived in order to allow their verification. However, architectural requirements specify basic *architectural design decisions*. Due to the fact that the use of standards in future smart grids will be indispensable, the design decisions focus on selecting appropriate standards and specifications. For an ICT-architecture three different aspects are considered. Firstly, it has to be analyzed *which information is intended to be exchanged* and thus how the *information model* must look

like. Secondly, it has to be clarified *how the information to be exchanged can be described in the domain of application*. This addresses the selection, extension or development of a *domain model*. Thirdly, it has to be determined *how the information can be exchanged*. This question finally deals with the specification of descriptions for *IT-services*. For each of these aspects, *standards and specifications* have to be identified in order to answer the questions as precisely as possible. Afterwards, the domain-specific semantics have to be composed with both, the information model and the IT-services. This leads to a *domain-specific semantic information model* on the one hand, and to *semantically described IT-services* on the other hand. The last step contains the final composition. The two semantically enriched and domain-specific components are integrated to obtain an *ICT-architecture* which meets the NFR identified in the beginning of the process. Use cases based on the NFR can be applied to verify the final ICT-architecture and may outline the need to iterate back to a former step of the model.

## III. (S<sup>2</sup>)IN-ARCHITECTURE

Compliant to the introduced (S<sup>2</sup>)In-process model, an ICT-architecture for smart grids has been developed. In total, about 1400 goals for smart grid ICT-architectures have been collected from 27 established studies and roadmaps. Based on that high level goals, 32 NFR and 34 architectural requirements have been derived (a detailed list of all requirements can be found in [7]). In order to meet those requirements, three established and recommended smart grid standards and specifications have been selected: The CIM as an energy domain model [8], OPC UA as an information model [9], and the Web Service Modeling Ontology (WSMO) - including its formalization language Web Service Modeling Language (WSML) and reference implementation Web Service Execution Environment (WSMX) - as an approach for modeling semantic IT-services and Semantic Web Services (SWS) [10].

The integration of the CIM with both technologies, WSMO and OPC UA is described in detail in [11]. On the one hand, OPC UA Address Spaces have been modeled based on semantics provided by CIM. On the other hand, CIM semantics is used to model an ontology in WSML. In addition, a second ontology has been designed that allows annotating information about OPC UA devices, i.e., supported profiles, security measures, and conformance units. Due to the facts that CIM includes information based on which almost all smart grid use cases can be described and that CIM provides with methodologies for model extensions in cases of missing information, the two developed semantic components are perfectly suitable for modeling and describing smart grid devices and systems. As described in [9], OPC UA servers can represent simple devices like controllers of smart grid devices such as wind or PV power plants and complex systems like Supervisory Control and Data Acquisition (SCADA) or Energy Management Systems (EMS). Furthermore, the CIM-based WSMO ontology enables to describe these smart grid devices and systems in more detail. Thus, it is possible to

exchange data among and about smart grid devices and systems using common semantics.

During the last step of the process model the two semantic components are integrated in order to obtain the final architecture. For that reason the discovery process of data services has been identified as a suitable point of integration. Therefore, the OPC UA Discovery Server has been replaced with a WSMX implementation providing comprehensive middleware capabilities. Briefly, data service providers such as different kinds of Distributed Energy Resources (DER) or systems such as EMS, Distribution Management Systems (DMS), and SCADA register themselves at WSMX. During the registration they describe both, the provided data services (control, monitoring, etc.) implemented compliant to OPC UA services and meta data such as geographical location, maintenance, and contractual information. That information is based on the CIM-based and the OPC UA meta data WSMO ontologies. Service requesters such as Virtual Power Plant (VPP) operators also use the two ontologies to describe the desired services for instance to control (generation and consumption) devices under specific conditions.

In order to realize the integration described, different OPC UA services mainly included in the Discovery Service Set have to be implemented as Web Services provided by WSMX. Hence, the basis for an automated communication based on powerful discovery concepts is laid out.

These cornerstones of the ( $S^2$ )In-architecture as well as a high-level integration approach for creating the semantic components has already been presented in [6]. The focus of this contribution and thus its additional value are among other things a structured process model for the whole architecture development process, the consideration of NFR and architecture requirements, the presentation of the final overall ICT-architecture, and a prototypical implementation of the architecture's components. Hence, this contribution provides with major improvements of the basic idea presented in [6].

#### A. Conceptual View

The main objective of the developed architecture, which is a Semantically-Enabled Service-Oriented Architectures (SESOA), is to integrate manifold types of smart grid data services (e.g., providing measured values, controlling devices, forecasts, automating processes) aiming at automation in smart grids. The proposed solution relies on annotating semantic meta data to services in order to exchange them within a server-client communication architecture. The resulting architecture allows precise descriptions of desired and provided services. Moreover, the combination and semi-automatic execution of services in smart grids is made possible.

The conceptual view on the architecture is depicted in Fig. 2. The central middleware is a Semantic Execution Environment (SEE) realized through a WSMX implementation. WSMX thereby expresses an internal SOA (middleware) including different components dealing with, e.g., discovery and mediation. Systems being service providers, requesters or even both are connected via Inter- or Intranet with WSMX. The sum of these systems is part of a utility enterprise and

represents an external SOA. This external SOA could also include further SEE in a shared message space. Service requesters, providers, and systems being both, use different Web Service endpoints of WSMX for communication purposes. The information exchanged is encoded in WSML being goal or service descriptions. All descriptions are based on the aforementioned domain and meta data ontologies which rely on CIM and OPC UA semantics. The systems being service providers are OPC UA servers. The OPC UA servers represent physical devices like wind power plants or photovoltaic units. The models of the physical devices make use of CIM semantics. They register their provided services using WSML files at the SEE. The systems being service requesters are implemented as OPC UA clients. Those systems could be, e.g., complex SCADA systems or simple monitoring or control systems. They send goal descriptions which contain information about desired services to the SEE. Finally, OPC UA allows systems to be clients and servers at the same time. These systems can be service requesters as well as providers in the ( $S^2$ )In-architecture. Their behavior depends on their certain role. Users, such specific as operators, make use of the OPC UA clients. A special type of user is the group of administrators. They maintain the SEE, its components, and registered objects like ontologies. It is also possible that OPC UA servers and clients communicate with each other directly via Web Services or the OPC UA binary technology mapping. In the following, the single components of the overall ( $S^2$ )In-architecture are described.

1) *External SOA*: The external SOA contains all ICT-systems of a utility but focuses on closed systems such as monitoring and control of physical smart grid devices like substations, any kind of power plants, and control and monitoring systems such as EMS, DMS, and SCADA-systems as well as controllable consumers. The communication (i.e. data exchange via services) takes place in Intranets of the utility enterprise or on the Internet. In both cases, technologies like SOAP, XML, WSDL, and Semantic Web Technologies are used. OPC UA communication itself already fulfills the requirements for being a SOA. The overall ( $S^2$ )In-architecture does not restrain existing smart grid communication solutions like IEC 61850 or IEC 60870. If time-critical communication is required, direct OPC UA communication is even mandatory. In such cases, the semantic information can be used to identify desired devices/servers.

- **Service Provider**: In the ( $S^2$ )In-architecture, OPC UA servers are supposed to be interfaces to monitor and control real physical smart grid devices. The devices are represented through information models making use of semantics provided by the CIM. The servers describe their capabilities and provided services. These descriptions are WSML service descriptions and are sent to WSMX. Therefore, a Web Service is applied which is provided through WSMX. Due to the fact that the semantics for the electronic server model and the ontology used for the service descriptions are both based

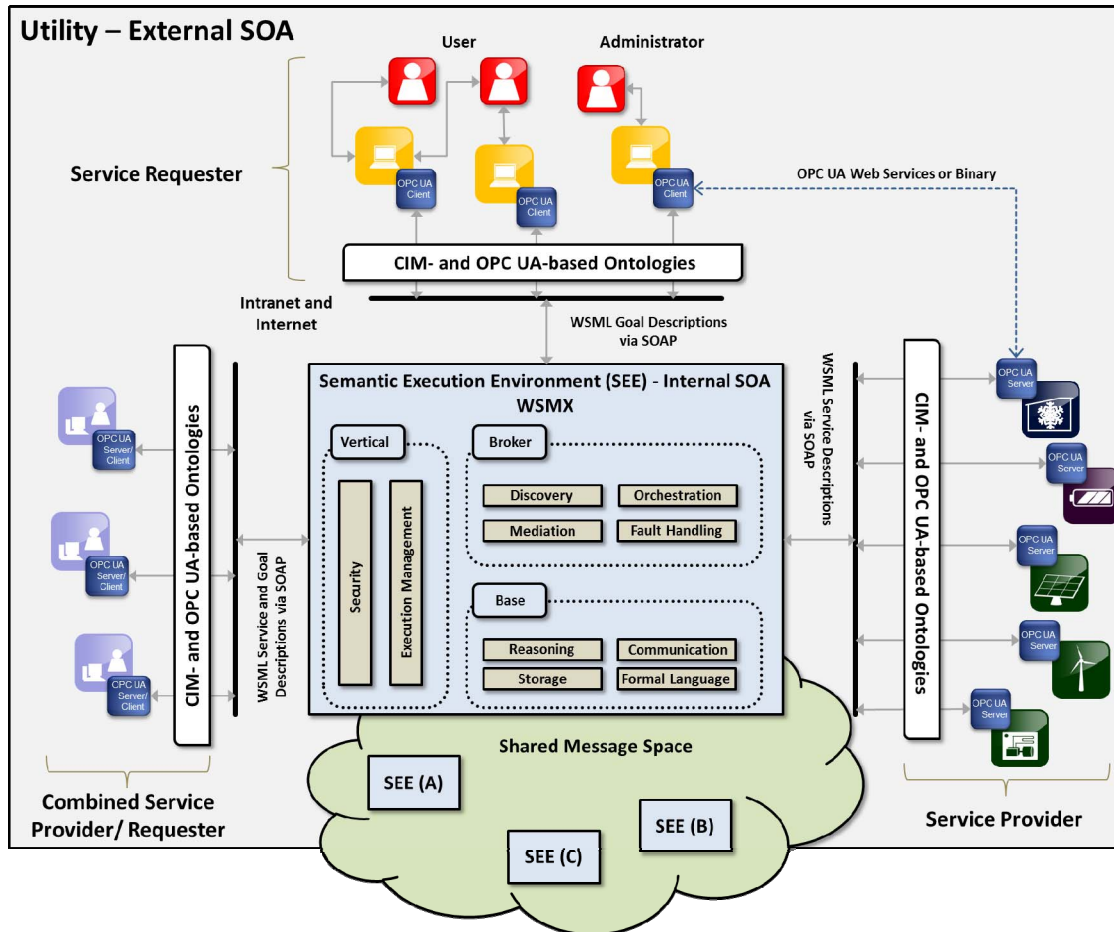


Fig. 2: Conceptual view on the target (S<sup>2</sup>)In-architecture

on CIM semantics, the description could be generated automatically. The descriptions include, e.g., information about the type of device, the supported OPC UA services in context of the related values, and meta data like geographical information.

- **Service Requester:** WSMX is used by users and administrators. **Users** are the consumers of the services made available by the service providers (e.g., VPP operators). They are realized as OPC UA clients. Like the servers, also the clients are basically extended with functionalities to communicate via SWS. The clients specify their goals as WSMX files including information about the desired functionalities (i.e. changing rotor speed of wind turbines). Web Services provided by WSMX are used to send the goals. The responses contain the endpoints of those servers that meet the defined goals. **Administrators** maintain the SEE. Different kinds of administrators are involved in the maintenance, e.g., domain experts are required to model and register required ontologies – as those previously described and based on CIM and OPC UA but also additional ontologies based on further recommended smart grid semantics like

IEC 61850. Moreover, in terms of mediation, alignments between the different smart grid ontologies have to be developed and provided (for example mapping between CIM and IEC 61850). In terms of the overall system maintenance, knowledge engineers and software engineers play key roles as well.

- **Service Requester/Provider:** In the OPC UA specification the combination of servers and clients within one system is defined. For example, a SCADA-system can be a client (consuming services provided by servers representing devices like plants) or a server (providing aggregated information about measured values from different devices).

2) *Shared Message Space:* The external SOA can contain different internal SOA and thus various SEE. This is the connection point to open systems beyond the utilities' networks. The SEE can be concerned with important smart grids services like forecasting or market communications. The ICT-infrastructure of a utility can be easily integrated into an overall future smart grid communication which is based on SWS because the underlying basic infrastructure is already realized.

3) *Internal SOA*: In the following, the components of the SEE are explained under consideration of their application in the (S<sup>2</sup>)In -architecture:

- **Vertical Layer**: Functionalities from the vertical layer are crosscutting. They consume functionalities provided by the Base and Broker layers in order to coordinate and manage the overall execution process.

**Security** functionalities are concerned with, e.g., authentication, authorization, confidentiality, data encryption, traceability, and non-repudiation (e.g., related to IEC 62351). **Execution Management** organizes the execution semantics, which describe the operational behavior of the system in a formal manner.

- **Broker Layer**: The Broker layer comprises all those functionalities that are directly required in order to realize a goal-based invocation of SWS.

**Discovery** addresses matching service and goal descriptions. WSMX provides different discovery algorithms [12] that are used for the (S<sup>2</sup>)In-architecture: *keyword-based*, *lightweight discovery*, and *heavyweight discovery*.

**Mediation** is considered twofold. Within the (S<sup>2</sup>)In-architecture, the focus is on data mediation. The scope of data mediation includes data heterogeneity problems which can occur during discovery, composition, selection, and invocation of Web Services. Data mediation is required if the descriptions of services and goals are based on different information bases such as different ontologies. At design time, alignments between the differing ontologies have to be created and registered at WSMX. In the (S<sup>2</sup>)In-approach, data mediation is especially considered to cope with the various recommended smart grid data models providing differing semantics. In [13], Uslar provides ontologies which are modeled on the basis of these smart grid data models. Moreover, alignments for mapping these ontologies are provided.

The main objective of **Orchestration** is to fulfill the overall requested functionality by the cooperation of different services. For the (S<sup>2</sup>)In-approach, the choreography information is used to point to an IRI which specifies the endpoint of an OPC UA server representing a smart grid device.

Faults that occur during the execution of endpoint Web Services of WSMX are handled by the **Fault Handling** component.

- **Base Layer**: In contrast to the Broker layer, the functionalities provided by the Base layer are not directly required for goal-based invocation of SWS. In fact, **Reasoning** (WSML2Reasoner<sup>2</sup>), **Formal Languages**

(WSMO4J<sup>3</sup>), **Storage** (storing WSMO elements such as ontologies, Web Service and goal descriptions, and mediators), and **Communication** (inbound and outbound communication of WSMX [14]) are taken into account.

#### IV. APPLICATION EXAMPLE

In order to emphasize the added value of the architecture, a short application example is introduced. The concept of VPP is an essential part of future smart grids [15]. A VPP-operator has to dynamically pool different systems and devices aiming at optimizing generation and consumption or offering certain types of products. Referring to the introduced architecture, the following preconditions are given:

- All devices like controllable loads, wind turbines, combined heat and power plants and storage units provide an OPC UA interface and are implemented as UA servers.
- All servers use OPC UA profiles and service- and CIM-semantics to model the represented devices.
- All OPC UA servers that represent the devices are registered to a SEE.
- The operator uses an OPC UA client, e.g., realized as monitoring and control system to communicate with the devices.

Due to the fact, that both the OPC UA server models and the service descriptions are based on the same semantics an appropriate description can be generated (semi-)automatically and, more important, without losing information. The descriptions can comprise logical expressions providing meta data amongst others about type of the device, location, provided communication interfaces, supported data models, measurable and controllable values, technical information like the serial number, asset information like installation and maintenance dates and contractual information, e.g. for controllable loads.

Now, the operator can define a goal that, e.g., returns all wind turbines in a specific geographical area, which provide information about their rotor speed as well as controlling capabilities in terms of throttling. Depending on the complexity of the SEE and its implemented functionalities, the process can be automated even further. Due to service composition and orchestration functionalities the operator could add information about the new set-point to his goal description and the SEE would automatically invoke the right services. Thus, it is possible to achieve an automated communication capable of invoking complex services, which have to meet specified requirements (semi-)automatically.

#### V. PROTOTYPE OF THE ARCHITECTURE

In order to verify and evaluate the proposed (S<sup>2</sup>)In-architecture, all introduced components have been prototypically implemented. In [16], it is described in detail how OPC UA Address Spaces relying on CIM semantics have been created. Additionally, CIMbaT (CIM-based

<sup>2</sup> <http://tools.sti-innsbruck.at/wsml2reasoner>

<sup>3</sup> <http://wsmo4j.sourceforge.net>

Transformations) is introduced. CIMbaT is an add-in for Enterprise Architect, which is an UML modeling tool being used to maintain the CIM. It enables the automatic generation of CIM-based Address Spaces as well as their instantiation under consideration of specific design decisions made by the engineers. These Address Spaces serve as input for OPC UA servers. The UA servers and clients have been realized based on so-called *QuickStarts* and the OPC UA SDK 1.0 provided by the OPC UA Foundation. Based on the provided source codes, realistic simulations have been implemented for the behavior of devices represented by OPC UA servers. The used OPC UA clients primarily support data access functionalities. The integration point for the semantic descriptions is the discovery process of OPC UA clients searching for servers supporting desired functionalities. Thus, the provided client and server implementations have to be advanced in order to enable semantic-based discovery. A WSMX implementation serves as semantic server/service repository. The servers support a registration function, which directs the user to a Web-interface. Here, the WSMX endpoint, authentication information, and the WSML service description of the server can be inserted. The information is sent via Web Service to WSMX. The common server discovery function of clients has also been modified. A user can directly specify the WSML goal describing the desired functionalities and also add information regarding WSMX endpoints and authentication. This information is also sent via Web Service to the defined WSMX instance. The response includes the endpoints of all servers meeting the defined requirements. Finally, the client can select one of the endpoints from a ranked list to start establishing a connection.

Following both, the methodology and the 32 NFR provided in [7], 91 measurable requirements have been derived. Moreover, seven use cases and corresponding test cases have been specified and evaluated within the described simulation environment. It has been shown that 55 measurable NFR could be satisfied directly and 36 based on argumentation. This is due to the nature of the measurable NFR. For example, performance-related requirements depend on too many environmental aspects like hardware, communication technologies, and efficiency of software implementation so and for security-related requirements it cannot be guaranteed that every possible attack can be countered. However, it can be argued that the used technologies generally meet the performance requirements but it depends on the implementation environment. Moreover, the technologies provide with state-of-the-art security concepts, so it can be argued that they are as secure as possible.

## VI. CONCLUSION AND OUTLOOK

In this contribution the need for automation in smart grids has been motivated. Furthermore, adopting techniques and approaches from the IT has been proposed as a possible solution. In particular, the (S<sup>2</sup>)In-approach has been introduced. Firstly, a process model addressed the overall concept for the development of ICT-architectures. Secondly, an ICT-architecture has been developed following the process

model concepts. The resulting (S<sup>2</sup>)In-architecture integrates the CIM, OPC UA, and WSMO in order to annotate meta data in a server-client architecture. Based on representative, simulated use cases a prototypical implementation of the architectures' components has been verified against the NFR. Concluding, the (S<sup>2</sup>)In-architecture allows to annotate meta data to OPC UA server descriptions and thus enables a semantic based discovery of desired functionalities. Precise descriptions of OPC UA servers, which are interfaces to real devices, include information about supported profiles and services. Hence, a (semi-)automatic communication process can be realized.

In terms of communication technologies, the (S<sup>2</sup>)In-architecture uses IP-based communication as well as a binary format as defined in the OPC UA specification. The next step is to integrate further communication technologies into the simulated evaluation environment such as different bus systems. Furthermore, the simulated environment has to be transferred to real devices in order to achieve results being as realistic as possible. Finally, the WSMX reference implementation and its components have to be further analyzed. The objective of these analyses is to figure out, how WSMX can be optimized for the application in smart grids, e.g., by automatically invoking OPC UA services.

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