A standard-compliant and semantic-based communication architecture for smart grids

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1 Problem Statement

Nowadays, the smart grid is a very important topic within the energy domain. The US National Institute of Standards and Technology (NIST) defines the smart grid as the modernization process from the current power grid to the power grid of the future. Whereas monitoring, protection and automatic optimization play key roles along the whole energy value chain (central and distributed generation, transmission and distribution networks, industrial users, energy storage installations, electric vehicles, households, etc.) [NIS2010]. Various national and international studies point out that a new-style Information and Communication Technologies (ICT) infrastructure is needed to realize the vision of smart grids. Furthermore, they identify a lot of ICT challenges (e.g. novel services, products and markets) and emphasize the importance of standardization in terms of integration and interoperability [RUB2010].

Within the overall context of smart grids in the energy domain this research project addresses the problem of service application. Smart grids already contain a lot of functionalities and new as well as novel ones will arise in the future. But due to missing common semantics it is not possible to find desired services in an appropriate way. This is a problem because smart grids contain of many different stakeholders. The stakeholders play various roles and have their own views on smart grids. In many cases this leads to different understandings of the same things. Furthermore, various requirements in terms of interoperability have to be considered to facilitate dynamic integrations into the complex system. Solving these problems means to increase the overall system performance and efficiency and to decrease the operating and integration costs. The use of standards is an established means to meet interoperability requirements. Meta-data annotation enables the application of semantic web services which support automatic processes and use a common semantic basis. Standardization in terms of ICT is a very important topic for smart grids and also Semantic Technologies become more and more important [USS2008]. But the combination of those standards chosen for this approach and the selected semantic web service technologies is a novel way to address the problem of a missing semantic basis for the automation and IT layer. The main critical success factors for the proposed solution will be the implementation costs related to the overall costs of the device which should be controlled, the definition of novel smart grid system services and the mediation between different ontologies which provide the common semantic basis. Therefore, thorough analyzes and many expert interviews must be part of the research. The application of semantic web services was realized within other domains and the achieved results must be considered to benefit from lessons learned and best practices. ICT standards are already used in the smart grid but not mainly focusing on semantic-based communication. The following use case shows the relevance and importance of the project:

A typical service we intent to cover would be one to choose between different weather forecasts in order to do a better load forecast for distributed generation based on wind turbines. Different companies have different services which are better or worse at different times of the year, week or day. Based on the current situation, annotated services would provide the possibility to choose the best service based on the current context.

The PhD project is at the end of the 1^{st} phase and is supervised by Prof. Dr. Dr. h.c. H.-Jürgen Appelrath, Prof. Dr. Dieter Fensel and Jun.-Prof. Dr. Sebastian Lehnhoff.

2 Main Questions of the Thesis

The following two main questions will be answered by the research project:

- How can meta data-annotation help to find appropriate functionalities within the future smart grid?
- How can appropriate services be discovered, selected and executed in an automated way?

Furthermore, the two following main challenges have to be faced:

- Showing how to realize an integrated architecture which provides a seamless communication from the business layer to the automation layer.
- Matching the two absolutely different views of the IT-domain and automation-domain.

Nowadays, a lot of approaches deal with ICT in smart grids but none of them combines established smart grid standards and semantic web services for the IT and automation layer. The research is based on the assumption that novel system services will arise for the smart grid and that those services will be provided among the smart grid stakeholders. Furthermore, the research assumes that the ICT infrastructure that is needed to operate smart grids will use internet-based communications. The most relevant issue that is out of scope of the research project is an economical analysis. Basically, costs will be taken into account for example to analyze the relation between implementation costs of the proposed solution and the overall device cost because in some cases the proposed solution could be too expensive for small or cost-critical devices like smart meters.

3 General Approach

The general approach covers design research, expert interviews as well as prototyping. To achieve the desired goals ontologies, services and communication models must be designed. Furthermore, experts must be interviewed to figure out what future system services for the smart grid will arise. To evaluate the proposed solution a reference prototype must be implemented and compared with other approaches. The target architecture with a high level of standard-compliance includes reference models as well as methods to use them. The standard-compliance leads to a reduction of integration costs for new services and applications into the smart grid and the automated services application results in a faster communication with higher performance.

4 Proposed Solution

Figure 1 shows the architecture of the proposed solution. The architecture combines three basic components ([RUA2010], [URB2010]):

- **OPC Unified Architecture:** The OPC UA is developed by the OPC Foundation and standardized by the IEC 62541. The UA is the successor of the established Classic OPC standards OPC DA (Data Access), OPC A/E (Alarms and Events) and OPC HDA (Historical Data Access) which are mainly used for process automation by exchange of real-time plant data among control devices. New requirements like platform independence and internet capability led to the development of the UA. The UA consists of 13 parts of which the parts three to six are in this context the most important ones. They specify an abstract data and information model (Address Space) which is the basis for a domain specific model, abstract service for server-client-communications and technology mappings for example for a web service-based communication. The abstract approach of the UA enables extensions of the application area, so that the focus is on general data exchange within any domain and it can be used for integrated automation concerns. [MLD2009]
- **Semantic Web Services:** SWS-approaches are further developments of the well known web services and add semantic information to the communication. Several top-down and bottom-up approaches exist. Within this research project the WSML (Web Service Modeling Language) approach is the choice. Based on an ontology the approach provides descriptions of the services on different layers. Functional and non-functional requirements as well as interface and behavioral specifications can be described. Thus, it is possible to realize an automated discovery, selection and execution of the services. [FLP2006], [FKZ2008], [dBFK2008]
- **Common Information Model:** The CIM is standardized by IEC 61970 and IEC 61968 and in general it provides a powerful integration framework. The most important part of the CIM is a large data and information model but also interfaces and technology mappings are specified. The data model is maintained in Unified Modeling Language (UML) and contains hundreds of classes including thousands of attributes and being connected by many associations. Thus, it is possible to model almost all concerns within the

energy domain. In the context of this research project the CIM provides the semantic basis for the communication. On the one hand the CIM structure will be used to design an ontology being the basis for the semantic web services and on the other hand it offers almost all information that are needed to model the domain specific UA address space. [McM2007]

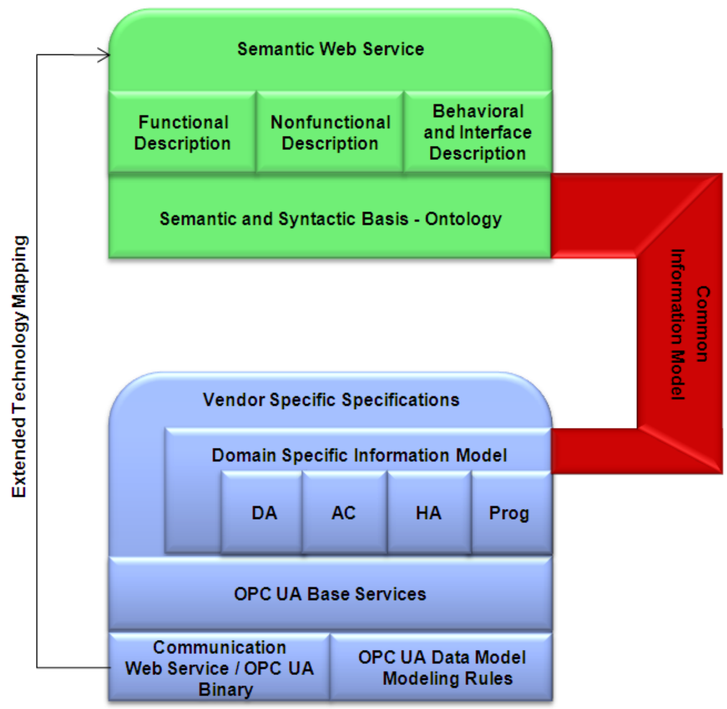

Fig. 1. Architecture of proposed solution.

In conclusion, the proposed solution includes the established CIM to provide the semantic basis *("What data is exchanged")* for the OPC UA on the automation layer *("How is the data exchanged")* and for semantic web services on the IT layer *("How is the exchanged data described")*. Hence, the architecture enables a seamless and comprehensive communication for new system services.

5 Evaluation

To evaluate the approach the architecture will be implemented prototypically and executed within a simulation environment. Therefore, it is necessary to realize an OPC UA-based server-client-architecture including simulated devices modeled on a CIM-basis. Furthermore, a semantic execution environment has to be implemented to run the semantic web services. Amongst others, it consists of a CIM-based ontology being as a semantic basis as well as mediators, goals and service descriptions. Test cases consisting of realistic system services being parts of use cases have to be identified based on expert interviews. The simulation results have to be compared with current solutions regarding performance and integration as well as interoperability issues; for example compared with simple web services or alternative automation standards like IEC 61850.

6 Future Work

So far, the focus of the project was on energy domain specific issues. The CIM was identified as an appropriate information model for the energy domain which could be used as semantic basis. Furthermore, the OPC UA as a communication standard with benefits - e.g. the abstract and object-oriented data model - compared to alternatives like IEC 61850 was the choice. The following work will be concentrated on three main areas. A detailed evaluation concept must be elaborated, appropriate system services must be identified and in the field of semantic web services the usability of the chosen approach must be tested.

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