by M. Breuers, and A. Schroeder, FGH e.V., Germany, and S. Sucic, Power Plant and Electric Traction Engineering Inc., Croatia

Application of a Web-based Communication Protocol in Smart Grids

The energy world has changed considerably because of the still increasing share of distributed energy resources (DERs) in recent years. In addition, up to now common central injections of numerous distributed energy production units are found in the electrical network that can lead to reversals in the load flow and therefore, represents a challenge for a reliable and secure network operation.

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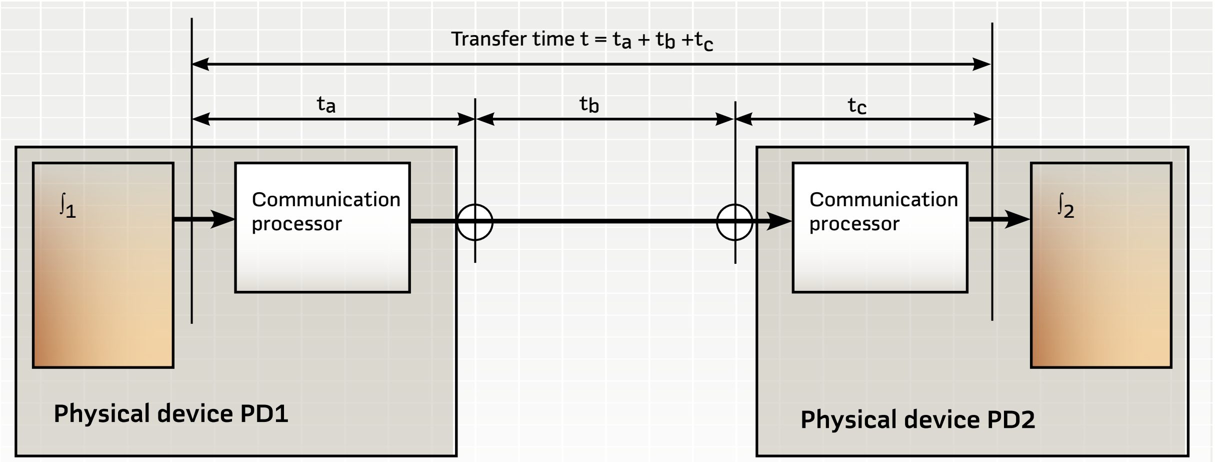
Andrea Schroeder studied Electrical Engineering at the University of Applied Science in Mannheim. Since October 1995 she has been working with FGH starting in the software development department where she was responsible for programming and maintaining the data base of the power system planning tool INTEGRAL, INTEGRAL trainings and seminars and the enhancement of the German DVG data model for power system calculations. In August 2001 Mrs Schroeder moved to the department system studies where she performed system studies with INTEGRAL and worked on the FGH-lead EU research project ScadaOnWeb. Since 2005 she has been working in the department of power equipment technology and has been involved in research projects focusing on smart grids and the IEC 61850 standard.

1 Transfer Time



A communication infrastructure with suitable and standardized smart grid communication protocols for DERs is essential in order to meet the high demands on electrical networks of the future. The EU research project OS4ES has therefore evaluated several web-based communications solutions, as they are used in the IT domain for distributed systems applications, for use in smart grids and developed a prototype for the most suitable communication protocol.

The article describes the requirements of the communication protocol that have been defined on the basis of previously identified use cases within the OS4ES research project, the evaluation process, the development and testing of the prototype and its implementation in the Open System for Energy Services (OS4ES).

With its communication interface the OS4ES system enables efficient interaction of DERs, registry and aggregators, thus making an important contribution to integrating DERs into electricity grids.

In addition, necessary extensions identified in the OS4ES project for the selected communication protocol - IEC 61850, as it is currently standardized in the standardization work group TC57 WG17, are indicated for use in smart grids.

Introduction

The EC research project OS4ES (FP7-ICT-2013-11) has developed an open system for energy services, that allows by means of a registry both the dynamic and automated integration of millions of decentralized energy resources into the grid and the aggregation and reservation of energy services.

With plug & play interfaces based on international standards, the OS4ES systems enables smart grid actors to ad-hoc monitor and control a huge number of DERs. The communication infrastructure plays an important role in the realization of this scenario. It must fulfill all communication requirements that such a system for energy services demands. Therefore, the OS4ES project defined communication requirements for different use cases.

These requirements are based on various criteria taking into consideration the physical network and the characteristics of the communication protocol. Building on that, a protocol model has been developed incorporating technology independent functions and requirements for the data model as needed by the communicating entities.

This approach is based on the Abstract Communication Service Interface (ACSI) defined in the international standard IEC 61850. That is, all protocol functions on application level have been mapped to IEC 61850 ACSI.

The Web-based communication protocols OPC-UA (OPC Unified Architecture), IEC 61400-25 Annex A (SOAP), DPWS (Device Profile for Web Services), REST (Representational State Transfer), XMPP (Extensible Messaging and Presence Protocol) and SIP (Session Initiation Protocol) have been analyzed regarding the protocol model. After weighing the pros and cons the most suitable communication protocol has been selected and a communication prototype has been developed.

This communication prototype allows IEC 61850 communication including all services needed for the OS4ES project, and also includes services that currently go beyond the actual scope of the standard. The practicability of the communication prototype has already been tested in a variety of test cases specifically defined for the communication. In the further course of the project the communication prototype will be tested in various prototype versions of the OS4ES software for different energy services in lab and field tests based on specific test cases defined

The article describes the communication protocol requirements that have been defined on the basis of previously identified use cases.

table 1 Evaluation of use cases

Use Cases	Bandwith	Transfer Time	Real Time Requirements	Unavailability	Recovery Time
Certified Energy Market	10 to 10000	C	B	B	A
Energy Management using VPP	10 to 1000	C	B	B	C
Dwelling Information Exchange	10 to 1000	D	B	C	D
Marketization of Balance Group Management	10 to 1000	C	B	B	D
Frequency Control – Primary Control	1 to 10000	C	B	B	C
Frequency Control – Secondary Control	1 to 10000	C	B	B	C
Frequency Control – Tertiary Control	1 to 10000	C	B	B	C
Volt / Var Control – Dynamic	1 to 10000	C	A	B	A
Volt / Var Control – Static	1 to 10000	C	B	B	C
Volt / Var Optimization	1 to 10000	C	B	B	C
Dynamic Virtual Power Plant	10 to 1000	B	B	A	C
Demand Response	1 to 10000	C	B	B	B
Demand Response Management of EVs	1 to 10000	C	B	C	D

Table 1 presents the assessment matrix showing the result of the classification of all use cases according to the defined communication requirements in **table 2.**

table 2 Classification of communication requirements

	class A	class B	class C	class D
Application	Hard real time automation	Soft real time automation	Low speed messages	General purpose
Transfer time	50 - 500 ms	50 - 500 ms	500 -10^3 ms	10^3 ms <
Real time constraint	Hard real time	Soft real time	Best effort	Best effort
Unavailability	10^{-7} - 10^{-6}	10^{-5} - 10^{-4}	10^{-3}	
Recovery delay	0 (Parallel redundancy)	100 ms	1 s	10 s

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for that purpose. The knowledge gained will be shared with the responsible standardization committee

Communication Requirements

The starting point for the whole evaluation process was the definition of the most important communication requirements on basis of identified use cases like frequency control, reactive power control, energy management of static and dynamic VPPs, certified energy markets, demand response and marketization of balancing group management. Specifically, five central requirements emerged, that are relevant in the context of smart grids.

Transfer Time: This is the complete transmission time of a message including the necessary handling at both ends of the communicating entities. The time counts from the moment the sender puts the data content on top of its transmission communication stack up to the moment the receiver extracts the data from its transmission stack. (Figure 1).

Real Time Constraint: A guarantee of the time delivery influences systems requiring timely response. Not fulfilling time limits for the specific systems can cause system instability or failure. For evaluation within OS4ES two different use cases are distinguished: *Hard-real time* (meeting all timing constraints exactly) and *soft-real time* (meeting timing constraints most of the time).

Availability: Availability applies to a repairable system that oscillates between up-time and down-time. The up-time includes the time during which the network is still operating, but impaired (due to redundancy loss). Also, maintenance itself can cause downtimes.

Recovery Delay: The recovery delay stems from recovery from network breakdown. Depending on the technology, it may vary from zero to several seconds or even minutes. When non-zero, this delay depends strongly on the topology.

Bandwidth: Network bandwidth is a measurement of bit-rate of available or consumed data communication resources expressed in bits per second or multiples of it.

> **The approach used for the development of the protocol model is based on the ACSI of the international standard IEC 61850.**

After the identification and definition of Smart Grid communication requirements they have been mapped to concrete use cases within the OS4ES project. In order to design the process as consistent and as clear as possible and to allow for a direct comparability, the requirements have been classified into classes A to D as shown in Table 2. Except for the network bandwidth that is monitored separately for each use case, each of the four classes are assigned specific limit values with which the evaluation of the various can be done.

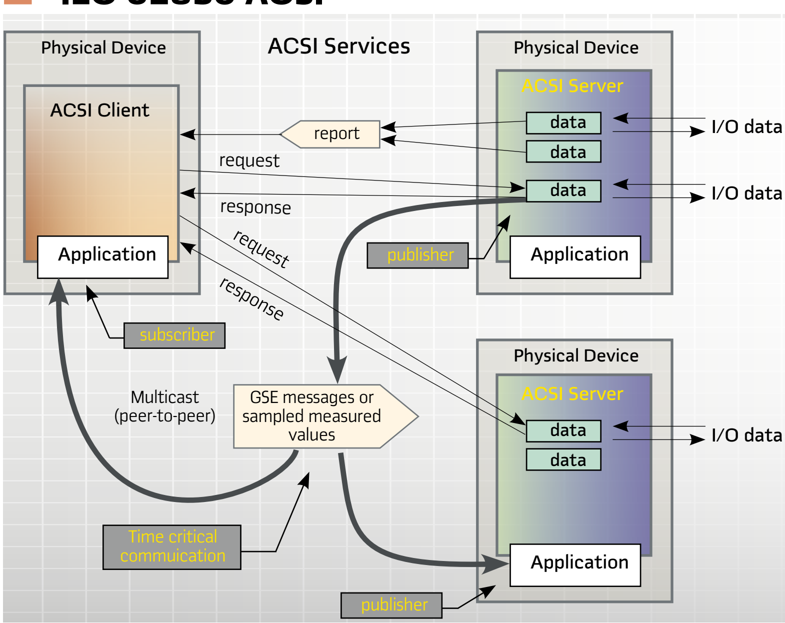
Table 1 presents the assessment matrix showing the result of the classification of all use cases according to the defined communication requirements in Table 2. Additionally, the needed bandwidth for each use cases is listed.

The Protocol Model

The approach used for the developmentof the protocol model is based on the Abstract Communication Service Interface (ACSI) of the international standard IEC 61850. Real services are mapped and defined by using object oriented modelling techniques.

The ACSI service interface uses an abstract modelling method what means that the definition is focused on the description of what the services provide. The concrete messages (and their encoding) to be exchanged between devices (how the services are built) are defined separately. This abstraction allows various mappings appropriate

2 IEC 61850 ACSI



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for different requirements and following state-of-the-art in communication technology without a need to change the protocol model. Currently, the IEC 61850 standard includes a mapping on MMS and will be extended with a Web-based mapping, published as part 8-2, in the near future.

The ACSI defines common utility services for energy automation devices. The two groups of communication services are depicted in Figure 2. One group uses a client-server model with services like control or get data values. A second group comprises a peer-to-peer model with services used for time-critical purposes (e.g. fast and reliable transmission of data between protection IEDs, from one IED to many remote IEDs) and with the sampled value services for transmissions based on a periodic basis.

The IEC 61850 ACSI forms the basis for the OS4ES protocol development. Consequently, all necessary protocol functions of the application level have been mapped to IEC 61850 ACSI services. By doing so the following two services have been identified that do not have corresponding ACSI services and are hence not covered by the IEC 61850 standard: *device registration* and *device search*. Both services have been modelled generically during the project course and the experience won is being discussed with the members of TC57 WG17 Task Force 8-2 in order to ensure that these two services are considered in future editions of the IEC 61850 standard.

The development of the aforementioned services and an exchange with the responsible bodies concerning this matter is a running process and has not been concluded at the time being. Currently, a solution is envisaged in which the registration will be done using a combination of defined ACSI services so that a new service would be obsolete. For the mapping of the device search no information can be provided at the time being.

Communication Protocol

By means of the communication protocol the concrete mapping of the protocol model is done and based on that the implementation takes place. The choice of a communication technology that is apt for the protocol model is therefore a crucial success factor for the OS4ES project. Considering that various potential technologies have been compared with each other and after weighing all pros and cons a final decision on the most suitable communication protocol has been taken. This is made possible by the IEC 61850 concept of the Specific Communication Service Mapping (SCSM). The SCSM defines the implementation of services and models of the IEC 61850 standard for a specific communication technology. The concept of the SCSM has been introduced to be independent from communication stacks including application protocols. That is the communication protocol can be exchanged without any modifications of the standard. Therefore the standard IEC 61850 allows for a maximum adaptability regarding future technological developments. The principle of SCSM is depicted in Figure 3.

The list of candidates for the final communication protocol comprises a broad spectrum of mature internet technologies. The following communication protocols have been evaluated in the frame of OS4ES:

A communication infrastructure with suitable and standardized smart grid communication protocols for DERs is essential in order to meet the high demands on electrical networks of the future.

Table 3 shows the evaluation results of the various candidate solutions grouped according to the respective evaluation criteria.

3 **IEC 61850 ACSI**

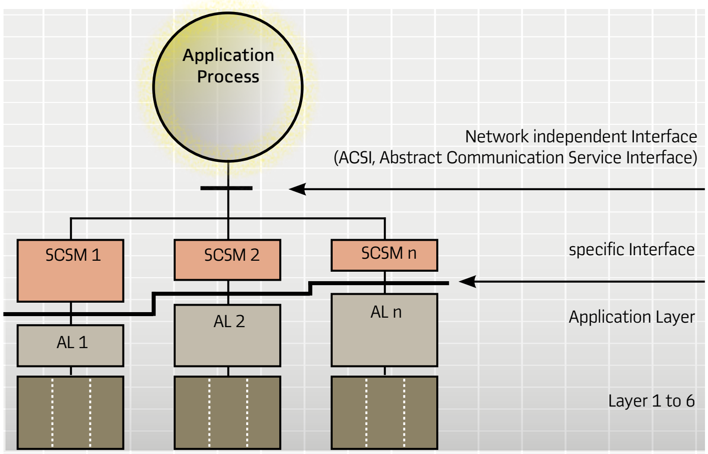

table 3 **Evaluation of the communication technology**

Middleware technology / Features	OPC UA	IEC 61400-25 Annex A	DPWS	XML over WebSocket	XMPP	SIP
Certified Energy Market	+/-	+/-	+	+	+	+
Data modelling	+	+	-	-	+	-
Data encoding	Binary/XML	XML	XML	XML	XML	Binary
Information Security	+	-	+	-	+	-
Open source implementation	+	+	+	+	+	+

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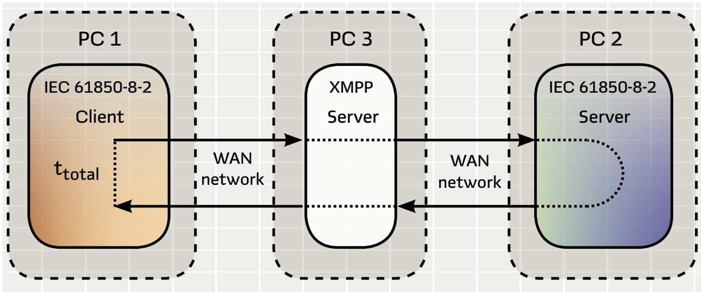
4 WAN-based testing



As can be seen, XMPP is the only communication protocol that entirely fulfills all criteria.

■ *OPC-UA (OPC Unified Architecture)* - is a highly modern SOA technology and successor of one of the most influential technologies in the area of industrial automation, the so-called Open Platform Communication (OPC). In contrast to OPC based on Microsoft's COM/DCOM, OPC-UA is platform-independent and is based on open standards. Similar to the IEC 61850 concept, OPC-UA defines a series of application level services that are independent of a concrete implementation technology

■ *IEC 61400-25 Annex A (SOAP)* - This solution maps IEC 61850 ACSI services and objects to SOAP (Simple Object Access Protocol). SOAP is a network protocol for exchanging data between systems and performing remote procedure calls (RPCs). The transmission protocol is HTTP (Hypertext Transfer Protocol). SOAP is an industrial standard of the World Wide Web Consortium (W3C)

■ *DPWS (Device Profile for Web Services)* - The Device Profile for Web Services (DPWS) is a specific profile of web services providing SOA technologies for embedded systems. Various web service specifications (WS) are merged in an own profile. DPWS combines WS-Addressing, WS-Discovery, WS-MetadataExchange, WS-Eventing, WS-Security and WS-Policy

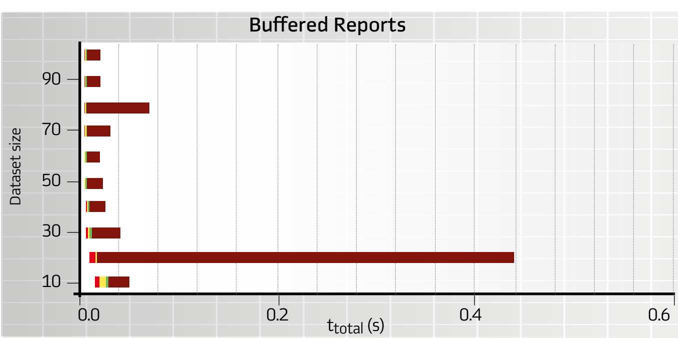
■ *XML messaging over WebSocket* - XML data transfer over WebSocket is a combination of two network technologies. Via the WebSocket protocol a persistent association between a client and a server can be established. The message transmission on top is XML encoded and in contrary to known Web service solutions like SOAP, WSDL and the related RPCs, which are as well XML based, the XML messages follow the Representational State Transfer (REST) paradigm

■ *XMPP* -The Extensible Messaging and Presence Protocol (formerly Jabber) is an open standard of a communication protocol published by the Internet Engineering Task Force (IETF) as RFC 6120, 6121 and 6122. XMPP is based on the XML standard and enables the exchange of data. It is, for example, used for Instant Messaging

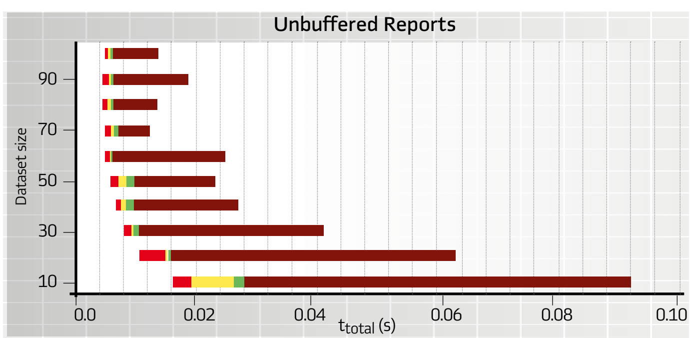
■ *SIP (Session Initiation Protocol)* - The Session Initiation Protocol was initially developed by the IETF for language tools in Internet Protocol (IP) based networks. Currently SIP offers multiple add-ons like video conferencing, streaming- and multimedia services, instant messaging, presence information, file transfer, Fax-over-IP and online-games. SIP is a text-based protocol containing many elements of the Hypertext Transfer Protocol (HTTP) and the Simple Mail Transfer Protocol (SMTP). However, it is not compatible with the latter ones

Figures 5 & 6: Testing results for buffered and unbuffered reports on the WAN.

5 Buffered reports – process data utilization



6 Unbuffered reports – process data utilization



For evaluating the various candidate solutions possibilities for asynchronous communication (and hence event handling) have been examined as well as the support of an existing data model, which is advantageous regarding an implementation of the IEC 61850 ACSI data model. The respective encodings, both XML-encoded or binary format, as well as integrated security features serve as further assessment criteria.

In order to keep costs for a first prototype and its further development as low as possible the communication technology to be used should be an open-source solution.

Table 3 shows the evaluation results of the various candidate solutions grouped according to the respective evaluation criteria. The evaluation has been done in a three step system ranging from ‚-‘ (unsuitable), via ‚+/-‚ (partially suitable) to ‚+‘ (entirely suitable).

As can be seen, XMPP is the only communication protocol that entirely fulfills all criteria. It has therefore been selected as the communication protocol to be implemented in the OS4ES project.

Implementation Testing

The testing environment for Wide Area Network (WAN) utilized three testing machines providing IEC 61850-8-2 client, IEC 61850-8-2 server and XMPP relaying server functionalities as shown in Figure 4. A WAN network is established between Croatia (PC1 and PC2) and Greece (PC3) over public Internet.

The network topology was dependable upon Internet providers. All testing services are tested by utilizing "ping-pong" testing technique which is illustrated in the Figure 4. Depending on the testing type the parameter t_{total} represents cumulative time intervals for the simulation.

Unsolicited message testing is based on sending unbuffered and buffered reports with different dataset sizes ranging from 10 to 100 elements in a dataset. Each test has also been done for 1000 times in order to develop message delivery histograms. The parameter t_{total} represents the total time starting when the request message was sent from the IEC 61850-8-2 client in order to enable the report control block, relaying the request through the XMPP server, analyzing the request by the IEC 61850-8-2 server, sending reports by the IEC 61850-8-2 server, relaying the reports by the XMPP server and receiving reports by the IEC 61850-8-2 client.

The results are shown in quartile arrangement (1st - orange, 2nd - yellow, 3rd - green, 4th - dark red). Figure 5 and Figure 6 show testing results for buffered and unbuffered reports on the WAN.

In case of request-response message testing the parameter t_{total} represents the total time starting when the request message was sent from the IEC 61850-8-2 client, it was relayed on the XMPP server, analyzed by the IEC 61850-8-2 server, the IEC 61850-8-2 server has sent the response message that way relayed by the XMPP server and received by the IEC 61850-8-2 client

The request-response testing are done for the following MMS services:

- Read-request (Figure 7)
- Write-request (Figure 8)

Each test has been repeated 1000 times in order to develop message delivery histograms.

Current Status and Outlook

The development of an XMPP based IEC 61850 communication module has been concluded successfully.

The prototype contains all ACSI services that are relevant for OS4ES. Further services that currently do not form part of the standard, but will probably be implemented in the next edition of the standard, are developed and tested. This affects both the registration (Device Registration/ Deregistration) and the realization of queries to the registry (Device Search).

Moreover, communication specific tests (e.g. performance tests) have been conducted and all are satisfactorily completed. With specifically defined test cases the further practicability of the module will be tested for different use cases in lab and field tests during the further course of the project. The knowledge gained will be fed back to the responsible standardization bodies. ■

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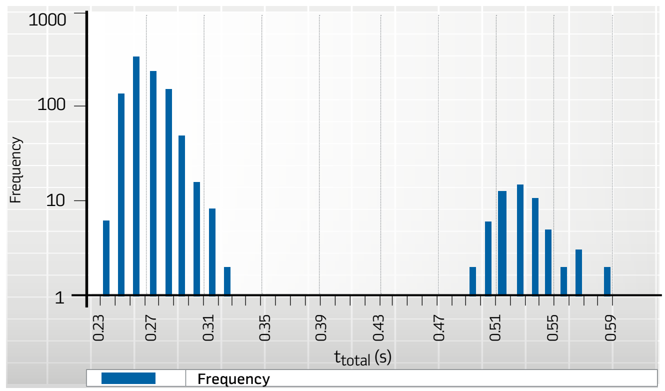
7 Read-request messages (WAN-based)



8 Write-request messages (WAN-based)