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Scope:

The capability to efficiently interact, collaborate and exchange information with business partners and within a company is one of the most important challenges of each enterprise, especially forced by the global markets and the resulting competition. Today, many software systems are completely isolated and not integrated into a homogeneous structure. This makes it hard to exchange information and to keep business information in sync. Interoperability can be defined as the ability of enterprise software and applications to interact. In Europe between 30-40% of total IT budgets is spent on issues tied to Interoperability.

This journal aims in exchanging and presenting research activities in the area of creating interoperability in business information systems. Ambition of this journal is to get an overview of current research activities as well as to offer a broad discussion in selected areas of the interoperability of heterogeneous information systems. It is proposed to connect research experts from this domain and to exchange ideas and approaches. It is our goal to connect latest research results with real-world scenarios in order to increase interoperability in business information systems.

The editors thank all reviewers for their help. This IBIS issue wouldn’t be possible without the support of our reviewers that help us to ensure a high quality.

Content

Editorial

Dear Reader,

We would like to welcome you to the latest issue of the International Journal of Interoperability in Business Information Systems (IBIS). This is a special issue on Interoperability for the Energy Sector.

Today's power networks are operated in a completely centralized fashion. Electric energy is produced by a few large power plants at very high voltages. It is distributed over long distances and transformed step-wise down onto lower voltage levels before it reaches the millions of consumers, e.g. single households, offices or factories. Operation of such power plants is scheduled based on long-term forecasts of power demand due to the enormous mechanical inertia with which such plants are only able to increase or decrease their output.

This top-down control of the grid comes at a high price: in large-scale international grids electric power may be distributed across several countries before reaching a consumer and thus result in enormous power losses. Unpredictable and typically short-term deviations from demand forecasts have to be balanced by fast and highly inefficient power plants. These plants provide so-called balancing power at peak prices due to the fact that most of the time they are operated far from peak efficiency in order to provide the power gradients needed to balance short-term demand fluctuations.

The on-going trend of integrating distributed and especially renewable power generation results in a rapid increase of such short-term fluctuations in supply situations due to the unpredictability of renewable energy sources, e.g. wind power or photovoltaic. Renewable power generation is usually installed in the form of widely dispersed small-scale plants with relatively low power output. Peaks in power consumption could theoretically be balanced with a corresponding increase in distributed power generation or vice versa (in the same geographic region with minimal power losses). However, traditional centralized power management is capable neither of identifying such situations nor of taking appropriate individual actions with millions of consumers and distributed renewable power plants connected to the grid. Modern power grids are blind to the precise supply and demand configurations on the lower voltage levels. Hence, the need for inefficient short-term balancing power increases even further.

The future electric power network, the so called Smart Grid, is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies. Smart Grids will be composed of large collections of autonomous components. Sensors and actuators, aware of their environment, with the ability to communicate freely, will have to organize themselves in order to perform the actions and services that are required for a reliable and robust power supply.

New technologies like smart meters, home automation and demand side management through web 2.0 technologies are expected to be the major cornerstones for addressing issues e.g. controlling electric vehicles or micro-CHPs which in general are more predictable than stochastic generation. Charging and de-charging of EVs may become of interest to provide significant distributed storage capacities. Yet, this may only be achieved through integrating even more ICT technology into the grid to make it smarter and to increase the overall level of automation. One of the key issues identified by Smart

Grid roadmaps all around the world are standards and interoperability issues connected with this development.

Following the Call for Contributions late last year we received numerous papers on the challenges of integrating components and devices into future Smart Grids enhancing not only power system operation but addressing energy efficiency issues as well. Out of these submissions our reviewers selected four high-quality contributions for this issue of the IBIS magazine aiming at outlining important solutions and applications of improving the integration of ICT between different systems of the grid.

Enjoy!

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Mobile Power Information System

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Abstract: This paper investigates different methods for giving users informative feedback on their electricity consumption. After comparing different methods for giving feedback a method comparing power consumption and temperatures is chosen. The purpose is to let power consumers find out how much changes in temperatures affect their consumption. A prototype mobile application has been developed and tested on the Android platform. The application retrieves temperature values and compares this to the consumption of the users. This gives the users a heating efficiency value that describes the amount of electricity used for heating. This is presented with graphs and corresponding values to the users. The results so far are promising, and future work includes a more large scale evaluation by real users.

Introduction

Electricity is used in every home today. It has become an absolute necessity for the society and it would be hard to imagine living without it. As more and more nations crave more power usage, there is a need to reduce the power consumption in particular in the industrialized countries. A way to do this in addition to using better technical solutions is to have people use electricity more efficiently [10]. Detailed information on the usage of electricity is however something that is not available for the normal users. In Norway for instance, most users currently receive a bill four times a year that gives very little information about how the electricity has been used. A reduction in consumption will result in lower bills for the users and if enough reduction is achieved it could result in fewer power plants being needed in the future. This could result in savings for the society by not having to build new power plants and by reducing the expansion on capacity on the electricity grid. A reduction also reduces the amount of CO^2 produced.

During wintertime in Norway most households use a lot of electricity for heating. Other heating sources exist, but electrical heating is the most common kind of heating and as of 2006 98% of the population had electrical ovens. The average amount of electricity used for heating is between 20 and 30% of the total electrical consumption [5]. An application that can give a measurement of how effective the heating in a house is could therefore be of high benefit for those that try to reduce their power consumption.

In the next section, we outline our research approach. Then we describe different approaches to gather information on energy usage, and existing solutions for utilizing this information. A prototype system for mobile access to this is described and evaluated on a high-level, before discussing further work on the approach.

Research Approach

During this project we seek to answer two research-questions:

1. How can an application that measures energy consumption help users reduce this?
2. What resources can we extract information from when we develop such applications?

For this project we have chosen a design-science methodology [11]. Design science provides seven guidelines, which we have adhered to in the following way:

- Guideline 1 requires that an artefact is produced during the project. In this project the artefact will be a mobile power information system as described in the 'Application' section.
- Guideline 2 demands that the project should produce a solution that can address relevant business problems. In this case energy consumption and reduction of consumption is a matter that is considered to be very important [10]. The problem is to reduce power consumption and the approach taken in this project is to improve the users' information of their consumption. This is one of several approaches to this problem [10], but is acknowledged to have potential impact [18] when done in the appropriate way.
- Guideline 3 demands that the artefact that is produced should be evaluated with well known and accepted evaluation methods to determine the results of the research. In this project the evaluation will consist of the use of scenarios and requirements that was constructed before the design and implementation of the system and is described in the 'Evaluation' section. Scenario building is a widely accepted way to generate design ideas for new systems and products and to identify the possible users and contexts of use for these systems and products. These will be used when the implementation of the system is completed to evaluate the application in real use. If the application performs the tasks and fulfil the demands that was specified by the scenarios and requirements it will indicate that the application is of appropriate quality.
- Guideline 4 stress the need for the application to be a contribution to the area it was designed for. To be a contribution an artefact should either solve an unsolved problem or it should solve a problem with an existing solution in a more effective way. The application in this project attempts to solve the problem of supporting the reduction of energy consumption of the users by

giving them information about their consumption and heating efficiency on a mobile platform. There exists similar applications [10, 15, 18], but none of these tries to solve exactly this problem by using a smart phone application.

- Guideline 5 informs that rigorous methods should be used. We use standard approaches for early stage evaluation.
- Guideline 6 requires that the design should be considered as a search process. This will inherently become iterative as a search for the optimal solution is often intractable in realistic systems. Effective design will require knowledge about both the application domain and the solution domain [11]. Therefore the process becomes iterative since better design decisions can be made with more knowledge. We foresee that additional iterations in the development of this system will happen in the future.
- Guideline 7 demands that the results are presented effectively to all audiences that have an interest in the result. To present something effectively it should be easy to understand and therefore the results from this project are presented in this paper as well as in a background report.

Approaches to Smart Metering

The common way to measure and report the amount of power consumed through a period of time varies between different countries. In Norway it is most common to read of a meter in the house yourself and report the value to your power company. In the UK the common way has been that someone from the power company comes to the house to check the power meter. In Sweden they measure the consumption by radio communication outside of the customer's house. In recent years a prepay solution where customers buy power credit through prepay cards have gained increasing popularity in some areas [14]. These methods are all very basic in the sense that they measure how much electricity that have been used, but it cannot tell anything about how or when the electricity was used. To give more accurate feedback to both the consumers and the suppliers many suggest a smarter electricity grid and so-called smart meters [4]. The goal in many of these solutions is to get either one way or two way communication between the supplier and the consumer. The difference in prices is considered to be small between these two options [14]. Giving the consumer detailed information on own use will often result in an increased awareness about their power consumption and thereby potentially lead to a decrease in total usage [18]. The exact amount of decrease varies in the different studies, but most of them are in the ranges between 3% and 10%. For instance in a study in Norway carried out in 1997 [18] one tried to investigated the effects of informative billing. They manually made more detailed bills by making a breakdown of how much electricity the different appliances consumed. This caused the consumers to increase their awareness and savings at about 10% where reported. To address the need for a smarter grid including improved measuring of consumption the EU-commission has started to design a common standard for the two way communication system [22]. In Norway NVE(Norges vassdrags- og energidirektorat) had initially planned to require smart meters by 2015 [21], but to implement a system that would most probably be in conflict with the standard that EU are designing would be unwise and they therefore decided to delay the planned date to between 2016 and 2020 [2]. On the other hand, pilots are already underway in more limited areas of the country, e.g. in the Trøndelag area, thus we look upon the possibilities with the current technological infrastructure.

Related Projects

Google PowerMeter [9] is a project started by Google in 2009. It is an energy monitoring tool that displays the user's energy consumption through the user's iGoogle site. This means that the application data is stored on the server side and computation is performed on the server side. The client side provides a view to see the data through an Internet browser. The electricity data is provided by the user's power company that transfer these to Google. This means that a smart meter and cooperation from the power company is necessary to use the PowerMeter application. The application lets you track your total energy consumption in real time and it is possible to compare the consumption to averages for different types of houses. An alternative to the PowerMeter is Footprints made by The Energy Detective (TED) [19]. This is an application that is made by the TED Company that also sells smart meters. The TED system is according to some reviews a bit difficult to install, but the Footprints application arguably gives more detailed information than PowerMeter [7]. TED also cooperates with Google so those that use Footprints can also use PowerMeter. WattVett [22] is a system that compares the energy consumption in a house with the outdoor temperature. It can calculate expected values compared to previous measuring for the house and to normal values for that kind of house. The disadvantage with WattVett is that it does not read energy consumption directly and the users have to type in their consumption. The manual for this application specifically mentions this and suggest that the user does weekly readings although this is not required. In relation to the IBM Smart City initiative [15], there are examples e.g. from Dubuque in the US of large citizens dashboards that show water and electricity consumptions in homes using smart meters and provides guidelines and incentives for residents to optimize their individual energy consumptions. In [18] a similar approach from UK is reported where specialized digital displays in the home is used to provide up to the minute information.

Feedback methods

The purpose of this project is to get experiences with giving feedback to the user that increases the awareness of the power consumption. Several methods where investigated to decide how they could provide the users with more detailed, timely information than what they have today, and these are described briefly below. Every method requires that the power consumption can be measured frequently (at least once per hour). An effective tool to use in providing feedback is a price calculation for the consumed electricity. This is effective since it is easier for people to relate to values in money than the amount of kWh that has been used. Price calculation can be performed independently of the method that is used, but more concrete feedback methods will give a more concrete price calculation.

1. Measuring at All Outlets This method measures the power consumption at all power outlets in the house. This would give the most fine-grained feedback that is possible to obtain since it is possible to determine exactly how much electricity every appliance in the house consumed. The technology to measure the consumption to almost this degree of accuracy exists today and an experiment using this kind of technology has been conducted earlier [15, 18]. By measuring every appliance and the total consumption in the home they obtain a system that can give very fine-grained feedback by telling the consumers exactly which appliance that consumed power and when. The results from [20] were a 9% decrease in consumption and the users also developed better energy-conservation awareness. For example they started to unplug appliances to reduce standby power consumption. The major drawback of a method like this is the price of the system. The article never mentions the price of the system they deployed, but according to [6] it is around $5000 which is a considerable amount of money for a normal household. (In [18] they found that 300 pound sterling to be a limit for what people would like to use on energy monitoring).This makes the feedback so expansive that it is very unlikely that it will be installed in a large part of the private houses even if it is the method that should give most effective information.

2. Measuring Consumption in Circuits By measuring the consumption in the circuits in the fuse box it would be possible to obtain a cheaper variant of the previous method. Many houses have separate circuits for large appliances such as water heater, cooker and washing machine. By measuring the circuits it would be possible to get consumption of the appliances and then the remaining consumption could be categorized as 'miscellaneous consumption'. The advantages of this method are that it is cheaper than measuring at all outlets and thereby people might be willing to pay. If each appliance has its own circuit it will also give concrete feedback for every appliance. The drawbacks of this method are that every house has different electricity circuits. This means that it will be impossible to obtain a solution that will be general and equal for all homes. Instead the users would have to set up the circuits themselves in the system and the system would have to adapt to different kinds of circuits. In houses with old circuit systems it is common to have one circuit per room and this also causes that one has other electricity sinks at the same circuits such as lights, panel heater and kitchen machines.

3. Comparison with Similar Houses To compare the power consumption of similar houses a large database that contains measuring data from many different houses is required. If the data should have any significance a large number of categories that houses can be split into and a large number of houses in each category are required. Without a large number the averages are unlikely to give a good guidance and this might give incorrect feedback to the users. Another issue with the comparison method is privacy. All the data should be anonymous and it should not be possible to determine which house any data comes from. The advantages with the comparison method are that it is a very cheap method to implement compared to the measurement methods. The costs limit themselves to a server-solution on the supplier's side and a way to measure the consumption and transfer it on the client side. The drawbacks of this method are that it can be difficult to get concrete feedback from it. It only measures the consumption of the house and compares it to the averages of similar houses. This means that it can be difficult to receive concrete feedback that makes it possible to identify appliances using unnecessary stand-by power during the night and similar issues. It does however give some indications on external conditions that might affect the total consumption. Another issue is the large amount of variables that affect the consumption. Examples of this is the number of people that live in the house, hours spent by these people in the house each day, outdoor temperatures and alternative heating sources such as heat pumps. This solution is thus almost free for consumers, but there will be some costs for the supplier of the data. It does not give concrete feedback, but it can give indications on external conditions or excessively high power consumption. The large number of variables will introduce some challenges when defining categories to group the houses into.

4. Measurement of the Minimal Consumption. Measurement of the minimal consumption is done by finding the hour during a period of at least 24 hours, with the least amount of electricity consumed. During this hour the occupants are assumed to be asleep or away from the house. The consumption is therefore only from heating, standby-appliances and other passive electricity consumers. By comparing this with minimal consumption for previous periods it is possible to determine if the unnecessary consumption has increased.

5. Comparing Consumption to Temperature. In this method the energy consumption of a house is compared to the outdoor temperature. This can give the users an indication of how effective their heating equipment is when their consumption is compared to normal values for similar houses in similar regions. It can also tell users if they are below or above expected values and thereby give an indication to whether their consumption is increasing or decreasing when the consumption is normalized according to the outdoor temperature. The advantages of this method are that it can give very concrete feedback about heating efficiency. This makes it possible for the users to calculate if it would pay off to get new heating equipment than what they currently have, e.g. switch to the partial usage of heat pumps. The drawbacks of this method are that it requires local outdoor temperatures to be effectively captured and events such as vacation-time might cause disturbance in the calculation of expected values.

The "Measuring at All Outlets" and "Measuring Consumption in Circuits" are very similar and only one of them should be included in a system. The "Measuring Consumption in Circuits" is considered to be better since it will have installation costs that might be affordable for most people. A system that includes this method should have a large amount of adaption possibilities in order to work effectively for most houses. Setting up these adoption possibilities would require much effort and it is difficult to decide if a good enough result could be obtained. Therefore it was decided to not include this method in the system. The comparison, heating efficiency and minimal consumption methods can be useful in combination with any of the other methods. The minimal consumption method is easy to implement and therefore it is included in the system. The comparison method is more complicated to implement. The advantages of the method are that it can be implemented with a very basic structure for categorization. Heating efficiency is probably most effective when used together with comparison since values for heating efficiency is something that people will be unfamiliar with. Comparison will give them average values which they can compare themselves to. Heating efficiency is also something that is of great interest for Norwegian conditions since a large part of the energy consumption is used to provide heating. Therefore heating efficiency is included in the system.

Table 1 below summarizes the approaches

Feedback method	**Cost**	**Timeliness of energy data**	**Precision level**	**Effect (if any reported)**	**Intervention**
1. Measure at all outlet	High	Quick	Very detailed	9%, energy-awareness	High
2. Measure in circuits	Cheaper than 1	Quick	High, but less detailed than 1	Difficult to compare with others	Relatively high, specific for each house
3. Comparison with similar houses	Cheap (if classification data is available)	Slow	Low	Reported to have more effect in certain countries than in others [18]	Need to come up with classification scheme, and classification data, privacy and critical mass issues
4. Measure minimum consumption	Cheap	Slow	Low	Limited	Low
5. Comparing consumption to temperature	Cheap	Medium	Low	Not reported, should be used together with comparison	Low, need to capture temperature data

Table 1: Overview of feedback methods

Application

To implement a system that gives users informative feedback about their electricity consumption some kind of hardware that supports a display is needed. The display should be able to show more than just the total number of kWh used. Three different alternatives were analyzed to discover strengths and weaknesses. An application on a PC (personal computer), a separate display in the house, and a mobile solution. In this project the mobile (smartphone) solution was chosen. The added mobility compared to the other solutions make this solution more attractive since one can have information available everywhere and the drawbacks of limited display size and storage size are considered to be challenges that can be dealt with. An additional bonus of added mobility is that comparison with other users of the application through physical proximity could be added in the future. They could then discuss the differences in their consumption and get more knowledge about how they could reduce their usage. Privacy and sharing of data would however be an important issue. Of practical reasons, Android was chosen as implementation platform of the prototype client. A number of scenarios of use were developed to decide more detailed requirements of the system. Scenarios describe individual users in individual usage situations and are not meant to describe the whole system functionality. The value of scenarios is that they concretise something for the purpose of analysis and communication [3, 16].In these scenarios situations where the users have a need for the functionality provided by the system is described. These scenarios ensure that the functionality in the system has a real world situation where it will be useful. The scenarios also serve as a method for evaluation of the system after the implementation is completed. Below two of the developed scenarios are described including illustrations on the developed application and important screenshots of the application when used to address the needs of the scenarios.

The user wants to check her heating efficiency Mona heard from a friend that the differences from well isolated houses to poorly isolated ones could result in huge differences on the electricity bill. She saw that there was a weather forecast with a lot of cold weather and was curious to find out how energy efficient her house was. She decided to get the PowerInformation application that was recommended to her by the same friend and starts it up to find out how efficient her house is.

1. The user starts the application
2. The user selects the desired period as the period by pushing the corresponding button
3. The user toggles the temperature button to on

Result: The application displays the heating efficiency as a marker on a scale. The users can also compare their consumption with the temperature in the graph that is displayed at the top of the page.

Discussion: The heating efficiency is provided on a scale and it should be easy for the user to identify where they are on the scale. The scale should also contain averages for apartments, row houses and detached houses, but averages were difficult to find and therefore they were not included. Fake average values could be used, but this could have caused more problems than benefits and therefore it was not implemented. If real average values had been added this would give the users a way to compare themselves to users in similar houses.

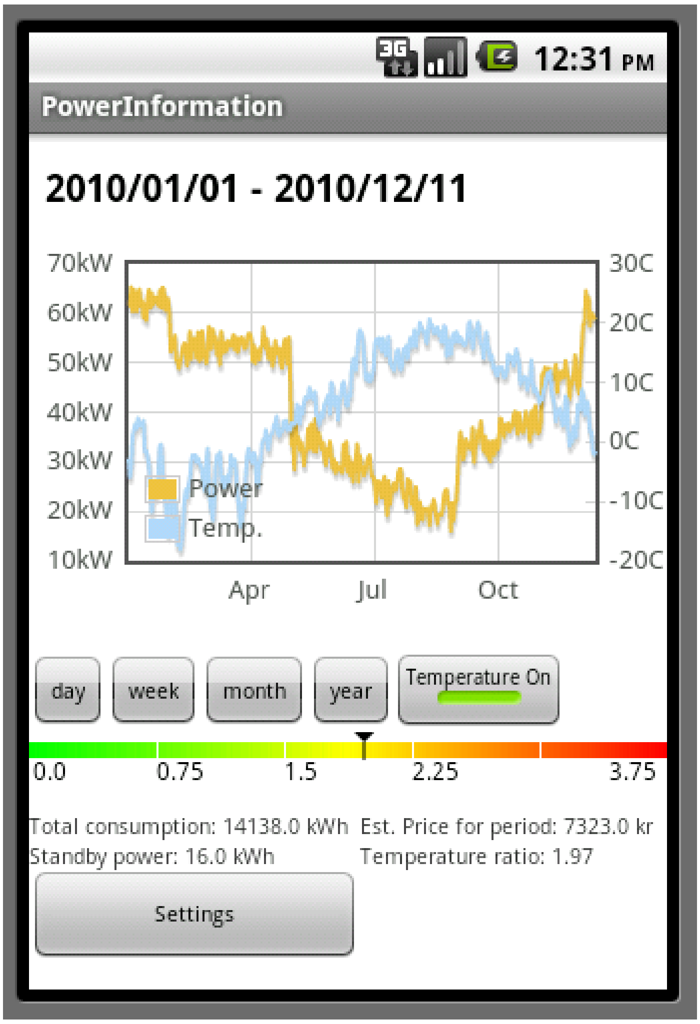

Figure 1 checking the heating efficiency

The user wants to see a detailed summary of the power consumption
Kent has recently acquired the PowerInformation application and after looking around a bit he decides that he could use some more detailed information about his consumption to see his maximum and minimum consumption. He discovers that the minimum consumption is surprisingly high and discovers that the door to the refrigerator is barely open.

1. The user starts the application
2. The user selects the desired period as the period

Result: A detailed list that displays relevant information about the period is displayed at the bottom of the screen.

Discussion: Some details for the power consumption are displayed at the bottom of the screen. The space for these details where small on the screen and therefore few details could be added. They give the users the basic numbers, but interested users might want more. In the scenario the user wanted to see minimum and maximum consumption values for the period. The standby power represents the minimum power consumption in one hour and the max hour consumption is the maximum.

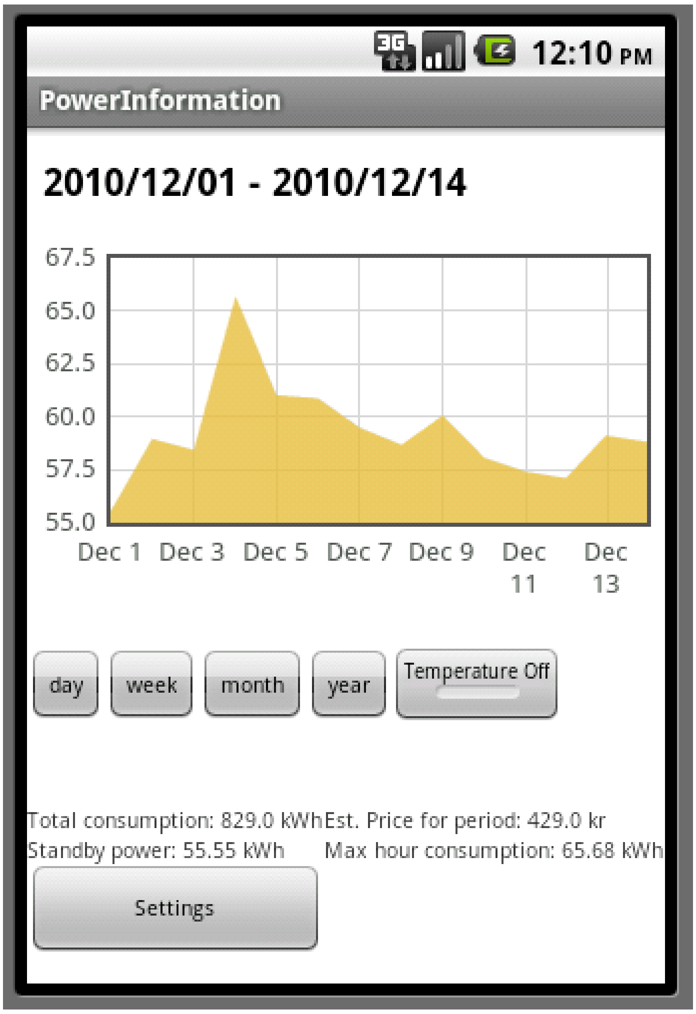

Figure 2 Detailed summary of energy use

Architecture and Implementation

For architecture to be successful it should use well known and effective architectural patterns. In this system the layered architectural pattern was chosen. The layered architecture provides the system with modifiability and portability at the potential cost of performance if data has to be moved through many layers. The below figure illustrates the architecture for the development which will be described further below

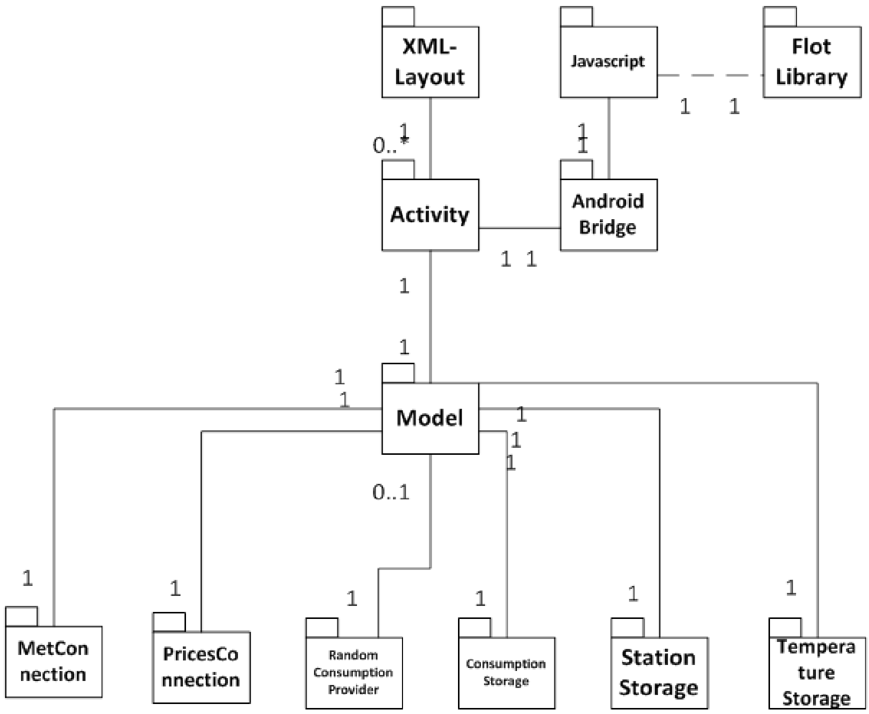

Figure 3 Modules of Power Information System

The application consists of 4 layers.

3. The storage and external resource connection layer (in the bottom of Fig 3): The storage classes create tables in the relational database and offer methods to access these tables from the model layer. The external resource connection classes offer methods to retrieve information from external resources to the model layer.
4. Model layer: The model class holds the data that is represent the system.
5. Controller layer: The activity classes handle input from the users and sends update requests to the model. They also update the layout when the model is changed. The AndroidBridge class is an interface to a JavaScript file. The flot library is an external library (indicated with the dotted line) written in JavaScript and therefore an html-file with javascript is needed to use the methods provided by the library. Flot is a pure Javascript plotting library that produces graphical plots from datasets. Most of the Java graphing libraries that are available are based on Swing and AWT which is not supported on Android.
6. Layout layer: The layout is split between the XML-files and a web-view that is filled by an html file with JavaScript. The JavaScript file uses the flot library to construct a graph from the model data.

The application uses data from two external resources, "konkuransetilsynet" [12] and wsKlima [26]. It connects to both of these through an URL connection. wsKlima offers a WSDL [25] document that will generate a stub that contains methods for connecting to all the web services offered by wsKlima. Unfortunately Android does not support SOAP which is used in the WSDL [23]. An alternative to SOAP on Android is kSoap2 [10]. Several sites indicate some problems with using kSoap2 [13, 23] and that a lot of extra work is required to make it work. Since the wsKlima already offered an URL connection as well the usage of URL was preferred. Using URL creates some extra work per method, but in this project only two methods are used. The data that is retrieved from "konkuransetilsynet" is stored in a text-file. This is handled by a manually created parser. The data that is retrieved from wsKlima is in XML-files. WsKlima is accessed for a station list and average day temperatures for one station.

Evaluation and Conclusion

The application that has been presented should be considered as a prototype. Even so the application serves some important purposes. One of these purposes was to illustrate the technical feasibility of such applications. External resources that could be used such as wsKlima and "konkurransetilsynet" where discovered and technical constraint such as having no support for SOAP on Android was identified. Another purpose is the application itself. The implemented parts of the application and their effects are summarized as following:

- With a prototype, both usability-studies and surveys investigating the expected acceptance of such solutions [8] can be conducted and areas for improvement can be found. The prototype can also be used to test if the hardware in a smartphone can support the application in its current form.
- The system currently supports the power consumption feature and the comparison between temperature and power consumption feature.
- The power consumption feature currently lacks one of the most important parts which are the real power consumption. To gain access to this cooperation with a supplier and access to either their database or information directly from the smart meter is needed. The connection to the consumption data is also something that has been done by several commercial companies [7, 9, 19] and therefore solutions to this problem already exist. We are establishing closer cooperation with local energy-providers to be able to investigate this further in the future.
- The users are able to choose amongst all the weather stations in Norway and the data from the chosen station will be used in the application. The implementation of station selection was more difficult than expected and some of the stations that are returned from the method are inactive. In addition the number of stations is in the hundreds and a better solution on how to select stations could therefore be implemented (e.g. based on geographical proximity of the station to the user to develop a default value).

As for the actual mobile applications, most identified requirements have been addressed, and it is possible to support the identified scenarios using the application, as partly illustrated above. We had two research questions that we have tried to answer in this project. Regarding the first question, we found out that multiple ways of providing the users with information of their power consumption exist. Several studies have been conducted to study the effects of giving this feedback to the users and in all of them the users' consumption had decreased. The second question is related to how the task was solved since the

resource that is used is strongly connected to the chosen solution. WsKlima and konkuransetilsynet was found as data-sources to be used in this project to give improved feedback through a mobile application.
Through this project we have found that there is currently a growing interest in the power consumption application market and that several companies are developing applications. We have discovered that there are several available resources that can be used to create a power consumption application on a Smartphone (in our case Android) and we believe that an application that includes the measurement of heating efficiency can be a great contribution for Northern countries. The field of heating efficiency is complicated and the algorithms that are used to calculate the efficiency in this application might be improved.
For further work, we are planning to team up with some of the local large scale pilots on the introduction of smart meters as part of the Wireless Trondheim triple-helix collaboration [1].

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Standardized Smart Grid Semantics using OPC UA for Communication

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Abstract: As many roadmaps and studies were developed focusing on smart grid standardization a set of core standards was identified. Some of them specify own data models and thus, create a need for harmonization to enable interoperability in terms of communications. On the level of data model integration, two data models play key roles in the future smart grid. On the one hand the Common Information Model and on the other hand IEC 61850-based models. Both were identified as core standards and are part of the IEC TC57 Seamless Integration Architecture, another recommended standard. In this contribution the OPC Unified Architecture, which is also a core standard specifying a server-client-architecture, is used to harmonize the two mentioned data models based on a common access layer. This leads to higher interoperability for, e.g., Energy Management Systems, Distribution Management Systems or SCADA systems.

Introduction

In the energy sector many studies and roadmaps are dealing with standardization for smart grids. Significant approaches were amongst others developed in the USA [NIS10], in China [SGC10] and in European countries like Germany [DKE10]. Detailed overviews on these and further approaches including the derived recommendations can be found in [Roh10] and [Usl10].
As a result, the following set of core standards was identified:

- IEC TR 62357: Reference Architecture
- IEC 61968/61970: Common Information Model for EMS and DMS
- IEC 61850: Intelligent Electronic Device (IED) Communications at Substation level and DER
- IEC 62351: Vertical security for the TR 62357

- IEC 60870: Telecontrol protocols
- IEC 62541: OPC UA – OPC Unified Architecture, Automation Standard
- IEC 62325: Market Communications using CIM

In the context of this contribution „A smart grid is an electricity network that can integrate in a cost efficient manner the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety”[1] as per the definition given by the Expert Group 1 of the EU Commission Task Force for Smart Grids.
In the context of data model harmonization and thus, fostering interoperability, this article addresses a subset of four core-standards. Interoperability on semantic level and on communication and access methods are important concerns in such complex and dynamic systems like smart grids including various different stakeholders exchanging data among each other. Harmonizing standardized data models is an issue, which is part of many important smart grid strategies, e.g., [NIS10], [DKE10]. Because of the importance of the interfaces connecting the Common Information Model (CIM) and the IEC 61850 data model, the harmonization of them is focused in different approaches like [EPR10] and [KPF05]. Specific object mappings are also represented as a key layer in the IEC TC57 Seamless Reference Architecture (see Figure 1).
Now, the development of the OPC Unified Architecture (UA) enables a new and very promising opportunity to harmonize data models. The UA specifies an abstract server-client-architecture based on a defined information model and services. The architecture provides that a domain specific information model is used to represent certain objects. Hence, a UA-server can be run, either with a CIM-based model or an IEC 61850-based model. A suitably implemented and configured UA-client however, could access both servers with the same mechanisms, independent from their data models, and make use of the information of both servers.
In the next sub-chapters the four covered standards will be introduced. Furthermore, the two mappings (CIM-UA and IEC 61850-UA) will be explained afterwards.

IEC 62357 - Seamless Integration Architecture

The Technical Report (TR) IEC 62357 helps the IEC TC57 to put their different standardization projects and series into a common context. This leads to a seamless integration architecture (SIA) for the utility domain, as shown in Figure 1. Moreover, it enables documenting and fixing inconsistencies in terms of using single standards in the overall context. Thus, the TR documents the relationships between all existing object models, services and protocols maintained by the TC57. [IEC03c]
The SIA consists of three major parts. The upper part (A) is divided into different layers and deals with business integration, data definition and applications. One of the most important components within this part is the CIM. Also the lowest layer, covering Specific Object Mappings, is of high importance, because it addresses

[1] www.cenelec.eu/aboutcenelec/whatwedo/technologysectors/smartgrids.html

amongst others the harmonization of data models and represents the interface between CIM and IEC 61850.
Beside IEC 60870, IEC 61850 is the predominant component in the lower part (B) of the SIA which consists of different pillars. Each of them addresses the communication for another category of field devices. The lower parts of the pillars specify the systems needed by the devices for communications. The lower parts are connected via Wide Area Networks (WAN) to the upper parts of the pillars, which contain standards for object models for field devices and device components, specific communication service mappings and protocol profiles.
The vertical part (C) of the SIA includes a cross-cutting standard series based on IEC 62351. It considers security as well as data management. For each layer and pillar of the rest of the SIA special requirements are met.
Currently, the IEC is working on a long term architecture vision for the SIA, going far beyond harmonization of single standards. In this vision the CIM will play a key role. [IEC03c]

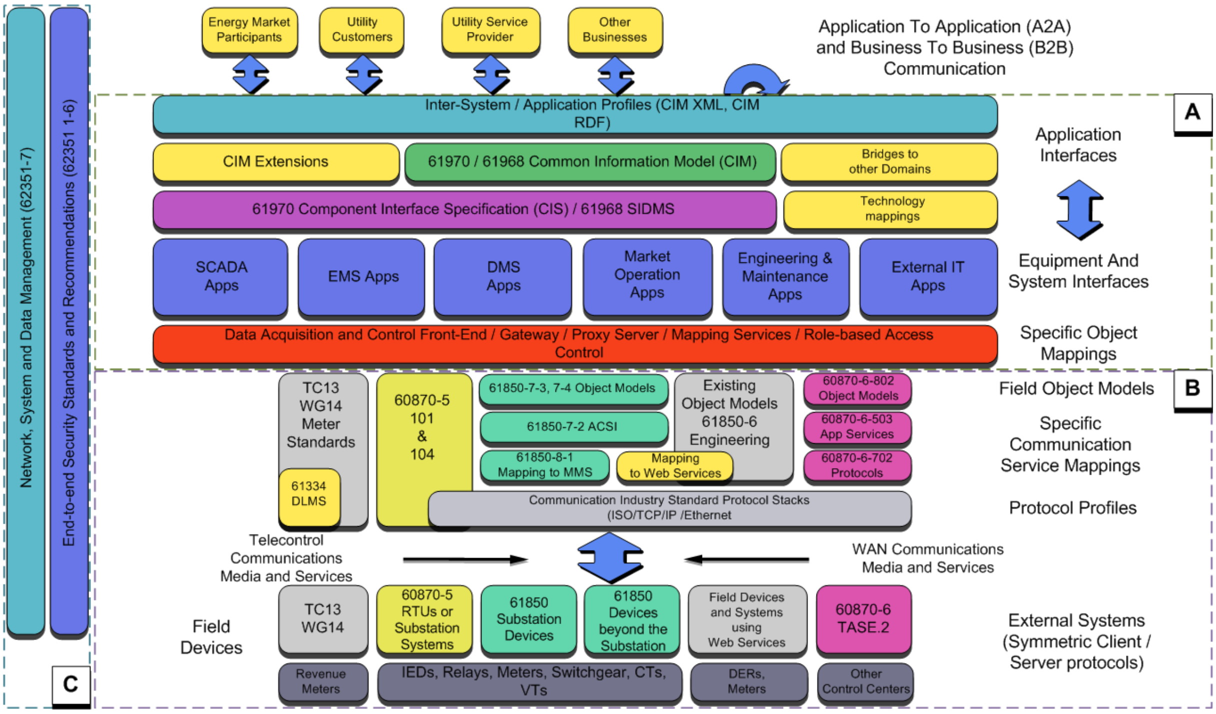

Figure 1: IEC TC57 Seamless Integration Architecture (based on [IEC03c]).

IEC 61970/61968 - Common Information Model

In the case of standardizing interfaces and data models for power system management and application integration into IT-landscapes of utilities, the IEC developed the Common Information Model (CIM). The development started in 1996 at the Electric Power Research Institute (EPRI) and was handed over to the IEC. Now, the CIM is the basis for the standard series IEC 61970 [IEC05] and IEC 61968 [IEC03b]. It is maintained as an Unified Modeling Language (UML) based model by the Cim users group[2] (CIMug).

[2] http://cimug.ucaiug.org/

The main objective of the CIM is to reduce expenditure of time and costs for integrating applications into Energy Management Systems (EMS) and Distribution Management Systems (DMS). Furthermore, it provides protection of investments and the efficient operation of those systems. Thereby, the CIM can be used as an integration framework [McM07].
Beside the Common Information Model, which is the main part of the CIM (IEC 61970-301 and IEC 61968-11), the standard series includes two more interface specifications. On the one hand the Generic Interface Definitions (GID) providing a technology-independent interface for certain types of data and on the other hand the System Interfaces for Distribution Management (SIDM) defining specific interfaces, including XML-based messages and use cases, based on the IEC 61968 function blocks.
The CIM is basically used in the context of the following three use cases [McM07]:

- Exchanging topology data: Profiles are an established means to cope with large data models by describing a specific subset of data, including all needed objects and excluding redundant ones, for considered purposes. For the CIM three large profiles are defined, consisting of a subset of CIM objects and relations: CPSM (Common Power System Model), CDPSM (Common Distribution Power System Model) und UCTE (Union for the Co-ordination of Transmission of Electricity). Also two types of serializations are specified. On the the one hand based on XML (Extensible Markup Language) and on the other hand based on RDF (Resource Description Framework). Hence, it is possible to exchange static and dynamic data, describing power systems and their states, among different systems like, GIS (Geographic Information System) and SCADA (Supervisory Control and Data Acquisition), in utilities.
- XML-based messaging: CIM semantics, defined in the data model, can be used for XML-based messages. Beside GID and SIDM, own XML schemata can be defined using CIM objects. Thus, messages based on standardized semantics enable coupling of customized systems within Service-Oriented Architectures (SOA).
- Coupling of systems: Based on the technology-independent interfaces, specified in the two standard series, standard-compliant solutions can be implemented. Those interfaces can be used directly to couple different systems. A utility, for example, buying a system, can precisely expect how and what data is provided by the system. This leads to much easier system integrations.

IEC 61850

The standard series IEC 61850 [IEC03a] was originally focusing on protection equipment and substation automation. In the meantime, it is used far beyond substations to exchange information, like switching commands, status information and measurements, within the utility domain. A continuously increasing number of exchanged data and decentralized processes led to the development of the standard series, because existing standards and vendor-specific solutions were not sufficient [OSM09].

By an integrated communication architecture, IEC 61850 covers the information exchange among and within the three typical layers: process level (transformer and switch), field level (protection and control) and substation level (operation terminal and remote control). Thereby, the following four aspects which are independent from each other but based on one another are defined [OSM09]:

- IEC 61850 communication uses standardized information, e.g., for circuit breaker, measurements, control and meta data, including self-descriptions, specified in IEC 61850-7-4. Those information are based on a set of about 20 basic data types (status, measured value, etc.), defined in IEC 61850-7-3. The information can address both, substation-specific and general aspects. Furthermore, it is intended to provide simple definitions of further information by re-using the standardized information.
- For the communication, certain services for accessing, reporting and archiving values, and controlling devices etc. are standardized in IEC 61850-7-2. They can be applied to the above mentioned standardized information as well as to any other information.
- Standardized communication networks and systems can be selected to exchange the standardized information by the standardized services as specified in IEC 61850-8-1, -9-1 and -9-2.
- The sub-standard IEC 61850-6 defines a XML-based system description language, called Substation Configuration Language (SCL). SCL enables a standardized configuration to completely describe devices by configuration files. Those files can be interpreted by the devices or their configuration tools and a system configurator.

The main objective of the IEC 61850 standard series is supporting interoperability in terms of communication among control system devices. This means to enable IEC 61850-based information exchange among two or more Intelligent Electronic Devices (IED) from different vendors. Whereas, the information can be unambiguously interpreted and used to realize the functionalities required by the applications.

IEC 62541 - OPC Unified Architecture

The OPC Unified Architecture (OPC UA) is developed by the OPC Foundation[3] and standardized by the IEC 62541 [IEC10]. Classic OPC - the predecessor of OPC UA - is well accepted and applied in industrial automation. Classic OPC is implemented in almost every system targeting industrial automation. OPC UA unifies the functionality of the classic OPC specifications and brings them to state-of-the-art technology using SOA.
Security is built into OPC UA as security requirements become more and more important in environments where automation is not running separated in an isolated environment but is connected to the office network or even the internet and attackers start to focus on automation systems [Gin10]. OPC UA provides a robust and reliable communication infrastructure having mechanisms for handling

[3] http://www.opcfoundation.org/

lost messages, failover, heartbeat, etc. With its binary encoded data, it offers a high-performing data exchange solution.
OPC UA scales very well in different directions. It can be applied on embedded devices with limited hardware resources as well as on very powerful machines like mainframes. Whereas an application running on limited hardware can only provide a limited set of data to a limited set of partners an application running on high-end hardware can provide a large amount of data with several decades of history for thousands of clients. Also the information modeling capabilities scale. An OPC UA server might provide a very simple model or a very complex model depending on the application needs. An OPC UA client can make use of the model or only access the data it needs and ignore the metadata accessible on the server.
OPC UA consists of 13 parts of which the parts three to six are in this context the most important ones. They specify abstract services like read, browse, or write for client/server communications and technology mappings for example for a web service-based communication. In addition, a meta-model (called Address Space) is defined with a very generic information model containing concepts like a base object type. This is the basis for domain specific information models. The abstract approach of OPC 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. The base principals of OPC UA information modeling are [MLD09]:

- Using object-oriented techniques including type hierarchies and inheritance
- Type information is exposed and can be accessed the same way as instances
- Full meshed network of nodes allowing information to be connected in various ways
- Extensibility regarding the type hierarchies as well as the types of references between nodes
- No limitation on how to model information in order to allow an appropriate model for the provided data by allowing various extension mechanisms
- OPC UA information modeling is always done on the server-side. The model can be accessed and modified from OPC UA clients but an OPC UA client is not required to have an integrated OPC UA information model.

This allows providing very simple as well as very complex and powerful information models. The base concepts of OPC UA are nodes that can be connected by references. Each node has attributes like a name and id. There are different node classes for different purposes, e.g. representing methods, objects for structuring the Address Space or variables containing current data. Each node class has special attributes based on their purpose. The variable, for example, contains a value attribute. Therefore OPC UA may serve as basis for generic information modeling.

Mappings

With its information modeling capabilities OPC UA offers a high potential for becoming the standardized communication infrastructure for various information models from different domains. Several information models are already defined based on OPC UA making use of the generic and powerful meta-model of OPC UA. The following information models have already been released:

- OPC UA for Devices: Defined in a combined effort of the FDT-Group, Fieldbus Foundation, HART-Communication Foundation, OPC Foundation, and PROFIBUS-Nutzerorganisation (PNO), a generic model was developed representing devices. This model is the foundation for FDI (Field Device Integration), the currently new developed solution for field device integration, combining the advantages of FDT (Field Device Tool) and EDD (Electronic Device Description).
- OPC UA Information Model for IEC 61131-3: In a joint effort of the OPC Foundation and PLCOpen and information model for the programming model of IEC 61131-3 is defined allowing a standardized mapping of function blocks, variables etc. defined in IEC 61131-3 to OPC UA.
- OPC UA for Analyzer Devices: Developed by a working group of the OPC Foundation the analyzer devices model defines a concrete model of several different types of analyzer devices like spectrometers or chromatographs.

In the following, mappings of existing information models in the power domain to OPC UA are described. These are namely the CIM and IEC 61850. By providing a mapping to OPC UA the information of those models can be made available to any OPC UA client like HMI (Human-Machine Interface), historians, etc. allowing a secure and reliable access over standard internet technology.

OPC UA meets CIM

The mapping of CIM to OPC UA is already discussed within the IEC who are working on a draft version of the mapping (IEC 61970-502-8). In this context CIMbaT is developed as a publicly available Enterprise Architect Add-In implemented with C# in Visual Studio supporting the generation of CIM-based Address Spaces. The overall approach of CIMbaT is introduced in [RUA10].
CIMbaT is constructed as a step-by-step wizard in which a CIM-model can be mapped to an UA Address Space. The Address Space will be written into a XML-file. The wizard also includes design-steps where the engineer can do settings for single CIM-elements. For main and default settings, such as the namespaces and the prefixes for the stereotypes needed to save UA-specific information in the CIM-UML-model, there is a XML configuration file which can be manipulated manually. The default values can also be manipulated in the first wizard step. The configuration file is needed for pre-selecting the default values in the design-steps and also for setting default values in the mapping.
In the design-steps the user gets the possibility to set OPC UA properties like IsAbstract, SupportsEvents, Historizing, DataType etc. for each CIM-class and their attributes and associations. That means, for example the engineer can override the default OPC data type integer or float. Also the decision whether a CIM-class attribute shall be mapped to a OPC Property or DataVariable is possible in the CIM-designer. The manipulable CIM-elements can be easily selected within a tree-structure.
For each setting there is a specific stereotype within the CIM-UML-model which will be added to the updated CIM-element. These UA-specific stereotypes are unique and include a value like true or false. They will be recognized in the mapping. If

the tool cannot find an UA-specific stereotype for a CIM-element, then the default values from the configuration file will be used. It is also possible to design UA Views and manage them. The Views are used for limiting the visible Nodes and References. The designed Views will also be saved as UA-specific stereotypes and mapped to an OPC View-Node. Because the changes can be saved as stereotypes in the CIM-model, the design choices are preserved without changing the CIM-Model except of the added stereotypes.
In coordination with the IEC and the decisions from the engineer the CIM-elements will be mapped as shown in Figure 2. Thereby, the two branching arrows mean that the designer can choose between different options. It depends on his flavor of modeling and on the overall environment. Merging arrows only express that different CIM-elements can be mapped to the same OPC UA structure.

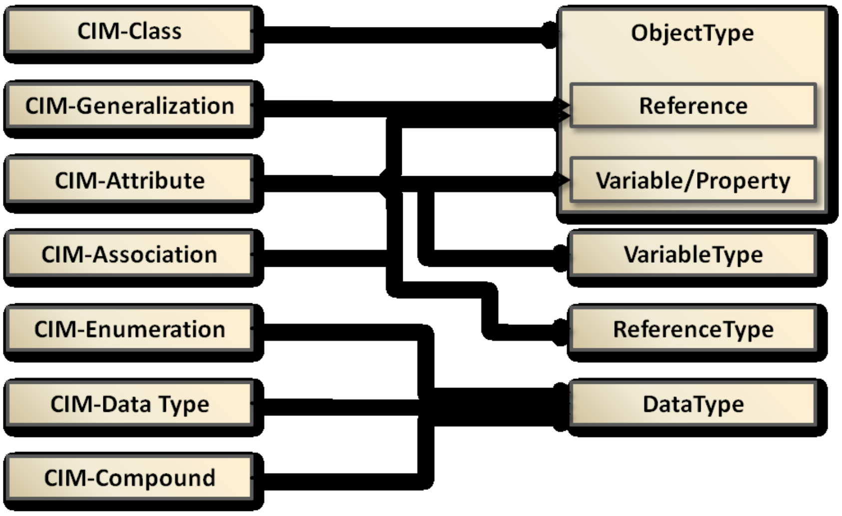

Figure 2: Mapping CIM objects to OPC UA Address Space.

OPC UA meets IEC 61850

Unlike the CIM the IEC 61850 does not only provide a simple data model but in addition mechanisms for the communication infrastructure like Functional Constraints (FC) for filtering the data, or timestamps and quality of the exchanged data. The IEC 61850 uses its own mechanisms to define its model and is not based on a pure object-oriented approach using the UML (although the latest version of the IEC 61850 uses UML to document their approach). Thus the mapping cannot be done in the same way as the CIM.
Different approaches can be chosen to map the IEC 61850 model to an OPC UA information model. For example, it has to be decided whether specific attributes of the IEC 61850 like quality and timestamp should be mapped the same way as all other attributes or handled specifically using the built-in OPC UA mechanisms having status codes and timestamps on each value. Furthermore the FC defined for attributes in IEC 61850 could be made available in OPC UA using different modeling alternatives. In this section one possibility for the mapping is introduced. For the introduced mapping the following decision were made and depicted in Figure 3:

- LN Classes as defined in IEC 61850-7-x are generally mapped onto UA object types.
- LNodeTypes are generally mapped onto UA object types subtyping the LN Class.
- LN are generally mapped onto UA objects as instances of LNodeTypes.
- LN Data as the attributes of LN are mapped onto UA objects.
- CDC are also generally mapped onto UA object types.
- CDC DataAttributes as the attributes of CDC are mapped onto UA variables.
- CDC DataAttribute Types are the types of the CDC attributes and mainly mapped onto existing UA standard data types like Integer, Float and String.
- FC are mapped onto UA objects.

To structure the objects three standard UA reference-types are used:
- HasComponent describes a part-of relationship between LN and its attributes as well as between CDC and its attributes. Furthermore it is used for the grouping by FC.
- Organizes is used to group the CDC attributes by FC.
- HasTypeDefinition connects the LN attributes with the according CDC.

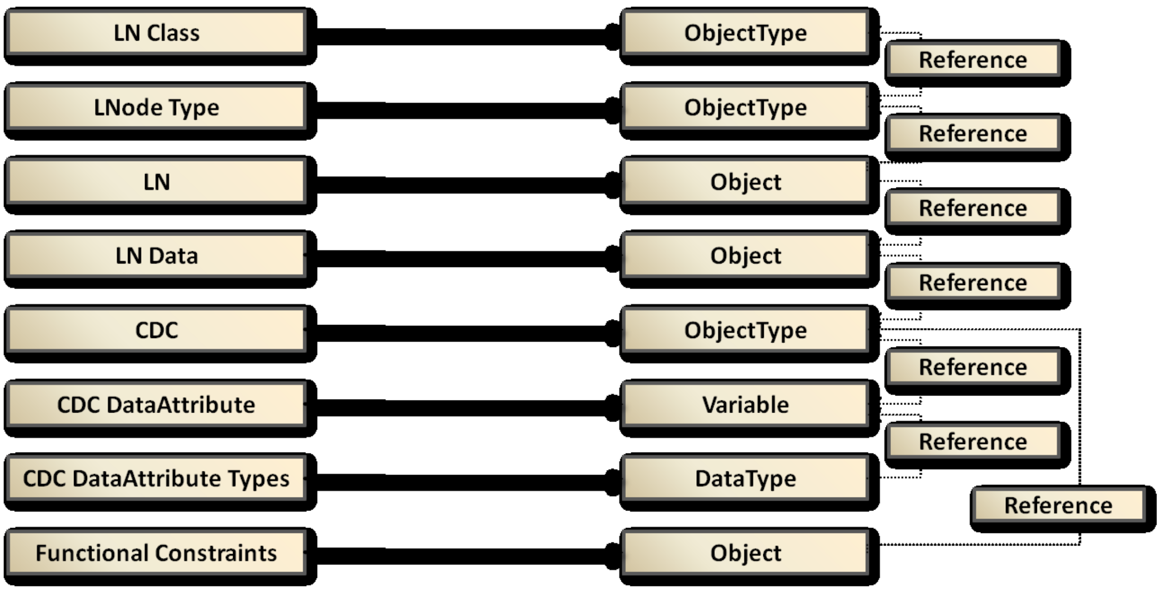

Figure 3: Mapping IEC 61850 objects to OPC UA Address Space

The example shown in Figure 4 includes the Logical Node Class (LN Class) MMXU and the Common Data Class (CDC) MV as well as their attributes. MMXU is a LN Class which shall be used for calculation of currents, voltages, powers and impedances in a three-phase system. The main use is for operative applications. The CDC MV represents measured values. We focus on only three attributes of the MMXU: TotVA (Total Apparent Power), TotVAr (Total Reactive Power) and TotW (Total Active Power). Also for the MV, we consider a limited number of attributes which can be divided by the FC. FC shall indicate the services that are allowed to be operated on a specific attribute. The attributes instMag (magnitude of a the instantaneous value of a measured value), mag (current value of instMag considering deadband), q (quality of the measured value), t (timestamp of the measured value) and range (range in which the current value of instMag is) belong to the FC MX (Measurands)

and the attributes subEna (used to enable substitution), subMag (used to substitute the data attribute instMag) and subID (shows the address of the device that made the substitution) to the FC SV (Substitution). Figure 3 shows a mapping providing FCs but making it optional whether to consider them when browsing or querying the UA Address Space by providing different paths to the variables. This is similar to modeling parameters for devices as defined in [OPC09].
The mapping shows that it is possible to expose the IEC 61850 model in OPC UA. By providing the LN Class and the LNodeTypes in the UA Address Space, it is possible that pure OPC UA clients without any previous knowledge of the IEC 61850 can make use of the type model and design for example specific HMI elements for any MMXU.

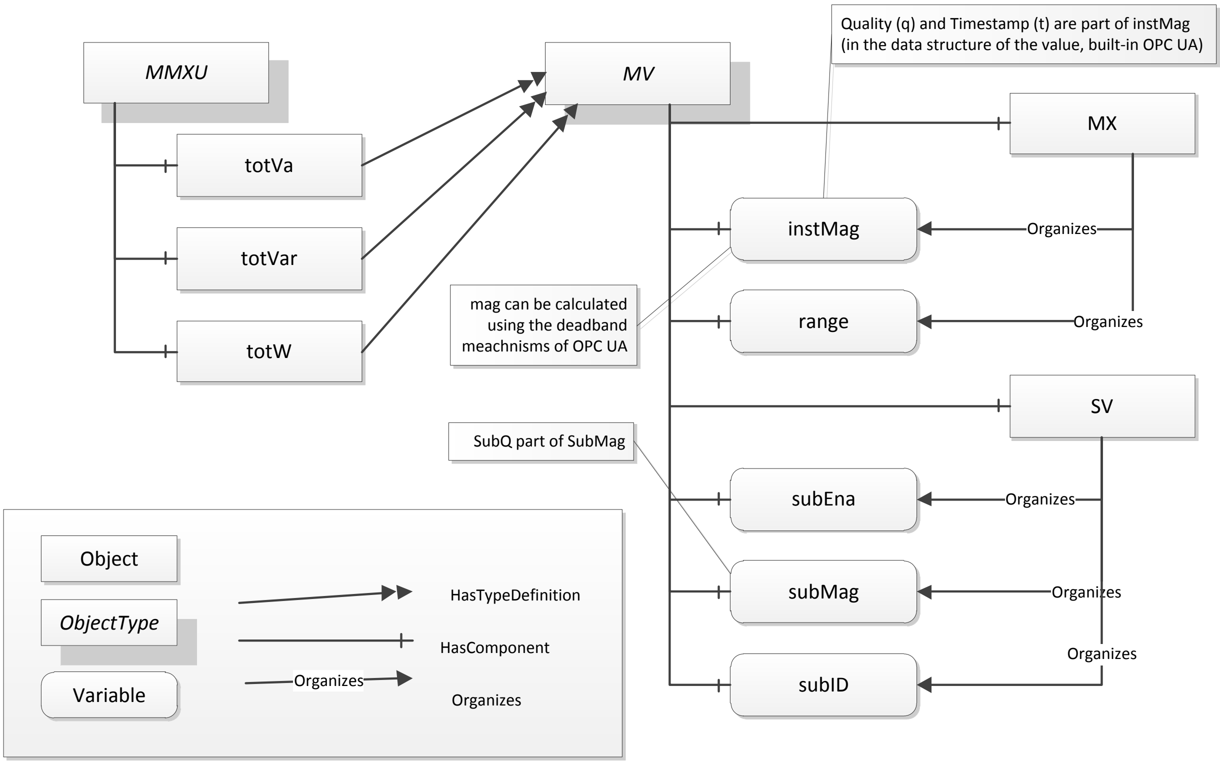

Figure 4: Concrete example of OPC UA and IEC 61850 mapping.

Conclusions and Outlook

In this paper we have presented the SIA having the CIM and IEC 61850 as integral part and the OPC UA, having its root in industrial automation. The CIM provides a pure data model based on the UML whereas the IEC 61850 defines its own model and also considers the communication.
We have shown, that the OPC UA information modeling capabilities can not only be used to define standardized information models in the domain of industrial automation by having standardized models for devices, analyzer devices and the IEC 61131-3 languages, but also for the electrical integration, mapping the CIM as well as the IEC 61850. This leads to a harmonized access layer for various data sources providing not only a standardized protocol accessing data but also allows accessing the metadata and thus, understanding the semantic of the provided data.

In order to increase this understanding it is not only useful to provide some metadata but ideally standardized metadata clearly defined and understandable by all communication partners. By using standardized information models like the CIM, this goal can be achieved.
There is a high benefit from mapping the CIM and IEC 61850 in a standardized way to OPC UA in order to provide the information of the CIM and IEC 61850 easily understandable and interoperable to the world of OPC UA providing access to HMI, historians, MES (Manufacturing Execution System), and connecting the industrial world and the power domain.
To achieve this goal, the approaches defined in this paper need to be refined, discussed in a wider range of interested participants and finally standardized in order to provide interoperability on the level of information models. The OPC Foundation currently investigates the creation of two new working groups, one providing a general mapping of UML models to OPC UA, which can be applied to the CIM, and another, defining a standardized mapping of the IEC 61850 model to OPC UA.

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Study on V2G Protocols against the Background of Demand Side Management

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Abstract: This work provides an overview on current efforts for communication between interconnected electric vehicles and supply equipments also known as Vehicle-to-Grid (V2G) communication. Such efforts are core enablers for electric vehicles being used for demand side management. Hence this work investigates the ability to adapt the EV charging process in near real-time in case of grid violations through V2G communication by rescheduling or demand-limit renegotiations. The overall benchmark scenario is defined by the identified V2G rescheduling processes in case of unpredicted critical exceedance of operational grid constraints.

Introduction

Rapid increase of decentralised renewable energy generation along with the decrease of generation of conventional power plants leads to a change in the way how future power systems will be managed. In addition to adjust the overall power generation in order to match the actual demand situation of the grid, future power systems may also enforce adjustments of the demand through *Demand Side Management (DSM)* systems [1].
Within this context V2G communication enabled electric vehicles (EVs) may serve as ideal actors for DSM because of their high battery capacities, high charging powers, comprehensive availability with increasing market penetration and their capability to quickly adapt charging currents to given demand boundaries [2]. The latter point is of high importance since the interaction between unpredictable power generation and uncontrollable loads can lead to violations of local grid restrictions such as line/ grid-component overloads or voltage band violations. In general, the faster the coordination mechanism can react to changes in the supply configuration, the more efficient use is made of the installed grid capacity leading to a better overall cost efficiency.
The following section provides a system overview and introduces currently proposed principles along with ongoing standardisation efforts for V2G communication. The paper then reviews their functional scope particularly focusing on means for enabling near real-time DSM. Currently apparent integration issues of

the proposed standards are addressed and an approach for optimising DSM mechanism for V2G is proposed before concluding the work.

Vehicle-to-Grid System Overview

This section provides an overview on the electric mobility system model and current standardisation efforts. Figure 3 highlights major entities being directly involved in the V2G interaction model for DSM: *Electric Vehicle (EV)*, *Electric Vehicle Supply Equipment (EVSE)* and various Back-End entities for *Accounting*, *Asset Management* and *Grid Integration (DSM)*.

The *V2G Front-End* as depicted in Figure 3 relates to communication between *Electric Vehicle Communication Controllers (EVCC)* and *Supply Equipment Communication Controllers (SECC)*. The scope of the *V2G Back-End* on the other side relates to communication between SECCs and various back-end systems for authentication, accounting and grid compatibility.

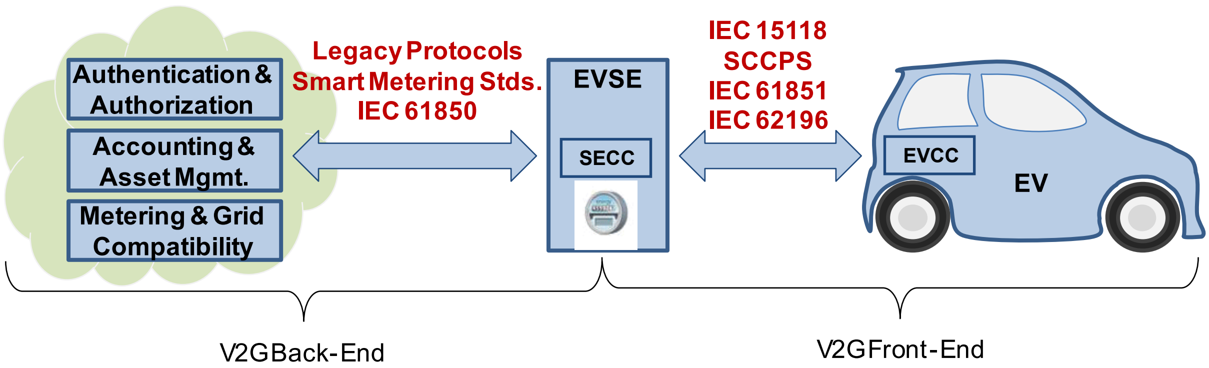

Figure 3: V2G-related Standards Overview

Concurrent V2G research and development efforts are consolidated in V2G standardisation groups. Hence, Figure 3 also provides an overview on relevant standards and pilot implementations:

- *IEC 62196* [3] is currently work in progress and defines plugs, socket outlets, vehicle connectors and vehicle inlets. The relevance of IEC 62196 with regards to the V2G communication interface is limited to physical interoperability in terms of signalling pins and connector compatibility.
- *IEC 61851* [4] standardises EV conductive charging systems based on either AC or DC and defines general EV- & EVSE-side requirements and different modes for charging.
- The *Smart Charge Communication Protocol Suite (SCCPS)* [5], [6] is part of a pilot project initiated by Daimler and RWE in 2008 in order to fill the gap of standardisation for PLC- and IP-based communication between EVs and EVSEs at that time. SCCPS was one of the core drivers in Germany leading towards establishment of the *ISO/IEC 15118 Joint Working Group (JWG)*.
- *ISO/IEC JWG 15118* [7] was formed in 2009 in order to define an international standard for more sophisticated V2G negotiations like DSM with

plug & charge user comfort. The 15118 working group is divided in five project teams working on a three part standard covering the following aspects: general terms and use case definitions (part 1), data types, message exchange patterns and intermediate layer considerations (part 2), physical and data link layer requirements (part 3) and cross layer security aspects. At the time of this writing the group published committee drafts for part 1 and 2 of the envisioned V2G standard.

The V2G Back-End focuses on integration aspects like asset and grid management. With respect to authentication/authorisation, accounting and asset management B2M legacy protocols are current state of the art. In case of grid compatibility the situation is different; particularly with regards to smart metering protocols. Interoperability between heterogeneous metering devices and DSM entities is of major importance for seamless and grid compatible integration of EVSEs into existing substation networks [8]. However, this work focuses on the evaluation of the V2G Front-End against the background of the previously described DSM use case.

V2G Communication Aspects for Demand Side Management

In this section we will detail those V2G Front-End related standards being relevant for DSM. In this regard the following three standards are reviewed: IEC 61851-1 [9], SCCPS [5], [6] and committee drafts of ISO/IEC 15118 [7].

IEC 61851-1 Low Level Communication Protocol

IEC 61851-1 [9] describes four different charging modes and defines minimal requirements to ensure safety of charging systems. All currently respected modes are listed in Tab. 1.

Charging Mode	Charging Setup
1	1 Phase 250 VAC, 3 Phase 480 VAC, 16A
2	1 Phase 205 VAC, 3 Phase 480 VAC, 32A
3	Charging with dedicated EVSE equipment
4	Charging with an external charger

Tab. 1: Charging Modes in IEC 61851

Mode 2, 3 and 4 require a dedicated - safety-related - signal that must be provided by a dedicated circuit over a dedicated Control Pilot (CP) line in the charging cable. The primary purpose of this signal is to establish a time critical *Low Level Communication (LLC)* protocol to react on safety critical system state changes like connection losses or state changes of the charger. The signal is based on a 12V *Pulse Width Modulation (PWM)* signal of 1 kHz frequency. The EV lowers the positive amplitude of the signal to encode its current connection and charger status as shown in Tab. 2.

GND-CP Voltage	State	Description
+12V (const)	A	System idle – No EV connected
+9V (1kHz PWM)	B	EV detected – Not ready to charge
+6V (1kHz PWM)	C	EV detected - Ready to charge
+3V (1kHz PWM)	D	EV detected – Ready to charge (with external air condition)

Tab. 2: EV Connection States in IEC 61851-1 without Failure States

The EVSE monitors the state of the pilot signal in order to detect whether an EV is plugged in. In this case the EVSE encodes the supported charging current using the duty cycle of the control pilot. In case the PWM duty cycle changes, the EV shall adapt to the new charging current limit within a time period of 5000ms.

PWM Duty Cycle	Description
5%	Indicates an additional high level communication
10% <= duty cycle <= 85%	Current from 6A to 51A (%x) = current[A] / 0,6
85% < duty cycle < 96%	Current from 51A to 80A (%x) = (current[A] / 2,5) + 64

Tab. 3: PWM Duty Cycle and Charge Current Mapping

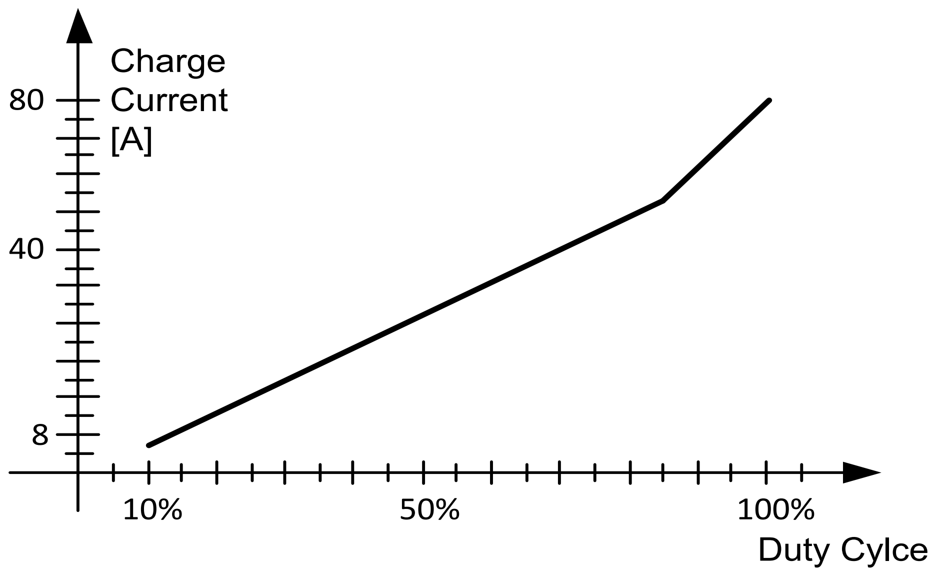

Figure 4: Current as a Function of PWM

High Level Communication Protocols

Next to the IEC 61851 LLC protocol the previously introduced *High Level Communication (HLC)* protocols - SCCPS [5], [6] and ISO/IEC 15118 [7] - provide means for advanced data exchange which is not possible with IEC 61851. Hence, they enable exchange of e.g. meter readings, tariff information and other relevant parameters for grid compatible integration of EVs into Smart Grids [10]. As opposed to IEC 61851 the HLC protocols provide smart charging means for less time critical parameters, e.g. non-individual-safety related aspects. Since SCCPS is tailored towards AC charging, this work also only considers AC charging in case of ISO/IEC 15118.

TCP/IP Stack Comparison between SCCPS and ISO/IEC 15118

Resulting from the idea to provide advanced means for data exchange between EVs and EVSEs, Figure 5 depicts the currently proposed TCP/IP stacks for both HLC protocols. At the time of this writing SCCPS is already deployed in field tests, whereas the ISO/IEC 15118 protocol definition is still work in progress. Hence both protocols and especially the ISO/IEC 15118 draft specifications are still subject to change.

SCCPS and ISO/IEC 15118 are both based upon Powerline Communications (PLC) on layer 1 and 2. Due to the wired connection between the EV and EVSE such an approach stands to reason. However, it must be considered that PLC uses the wire as a shared media and is subject to cross-talk issues similar to wireless technologies. Therefore association between two endpoints needs to be verified in scenarios where other PLC signal sources are exposed to the wire e.g. in cases where multiple EVSEs are deployed in immediate proximity. Most PLC standards cannot guarantee a valid association by the wired end-to-end interconnection. Therefore, in SCCPS an application layer resolution of this problem is enforced with a so called *Charge Point Discovery (CPD)* and *Silent Neighbourhood Broadcast (SNB)*. They influence the DHCP address assignment in a way that it can only be performed by *one* EVSE at a time and is directly linked to IEC 61851 state transitions. However, this mechanism is prone to DoS attacks. Hence, ISO/IEC 15118 favours resolving association issues on layer 1/2. In this regard Homeplug Green PHY provides a *Signal Level Attenuation Characterisation (SLAC)* mechanism [11] which ensures correct association by evaluating signal levels on-the-wire.

On the intermediate layers 3 and 4 both approaches build upon a common TCP/IP stack. Hence, besides utilisation of IPv4 in case of SCCPS and IPv6 in ISO/IEC 15118 there is no major difference between both approaches. In order to provide backward compatibility in IPv4-based network architectures, ISO/IEC 15118 also defines IPv4 support in Annex A of 15118-2. *Transport Layer Security (TLS)* is used in both cases to secure the EV-to-EVSE end-to-end connection.

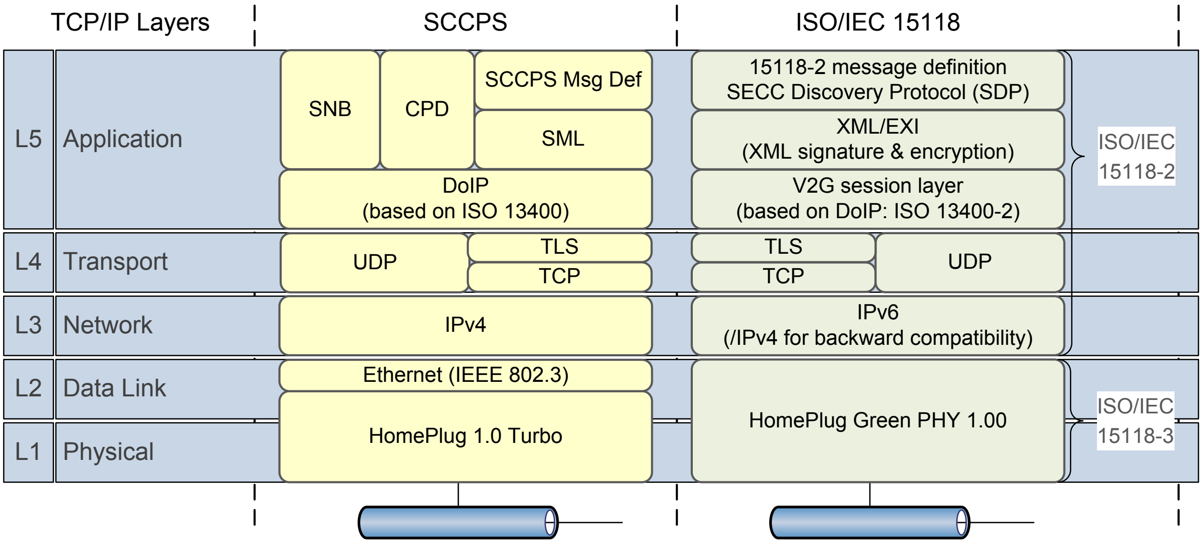

Figure 5: Overview of SCCPS and current status of ISO/IEC 15118 TCP/IP stacks

According to the current working draft of ISO/IEC15118 both protocols adopt parts of *Diagnostics over IP (DoIP)* defined in ISO 13400 for the application layer but some implementation details differ between both approaches. However, the most prominent differences appear on top of DoIP in the respective TCP/IP stacks.
SCCPS defines its message semantics based upon *ASN.1* and presents the application data through the *Smart Message Language (SML)* [12]. SCCPS defines a message structure with mandatory use of a pre-amble (*SML.Open.Response*) and post-amble (*SML.Close.Response*). The information carried in the pre- and post-amble are generic message contents not related to a specific context. The actual message context is provided with a *SML.Attention.Response*. SCCPS always combines the pre-amble, payload and post-amble into one logical entity, called *SML File*.
ISO/IEC15118 on the other side defines messages in *XML Schema* and most probably presents the application data in binary form through *Efficient XML Interchange (EXI)* which just became a W3C recommendation [13]. Each ISO/IEC 15118 message starts with a namespace declaration - due to the XML Schema based approach - followed by a message header and a message body. The header carries generic message contents necessary in every message exchange (e.g. session information, error indicators etc.). Whereas the body carries the payload of the message, which depends on the context of the message.

Application Layer Review

Both protocols share some common assumptions, requirements and basic design decisions:

- The protocols enable plug & charge user comfort and at the same time shall allow sustainable grid integration.
- The protocols assume initial parametrisation of the charging process (e.g. end-of-charge, estimated amount of energy etc.). However, they do not make any assumption on how this parameterisation is applied.

- Both protocols follow a strict client-server model for the EVCC and SECC. The EVCC represents the client whereas the SECC the server. All message exchanges are synchronous and triggered by the EVCC in order to minimise protocol complexity for the EVCC.
- A contract based relationship between a mobility provider and customer is considered but not explicitly enforced. Also incorporation of enablers for value-added services is considered.

In general, the communication process for charging is divided into two phases:

1. Service Initialisation
2. Service Handling (Default: Charging Service)

According to their relevance for DSM the messages of the protocols are briefly described and illustrated in Figure 6. For the discussion in this work security related aspects are *not* considered.

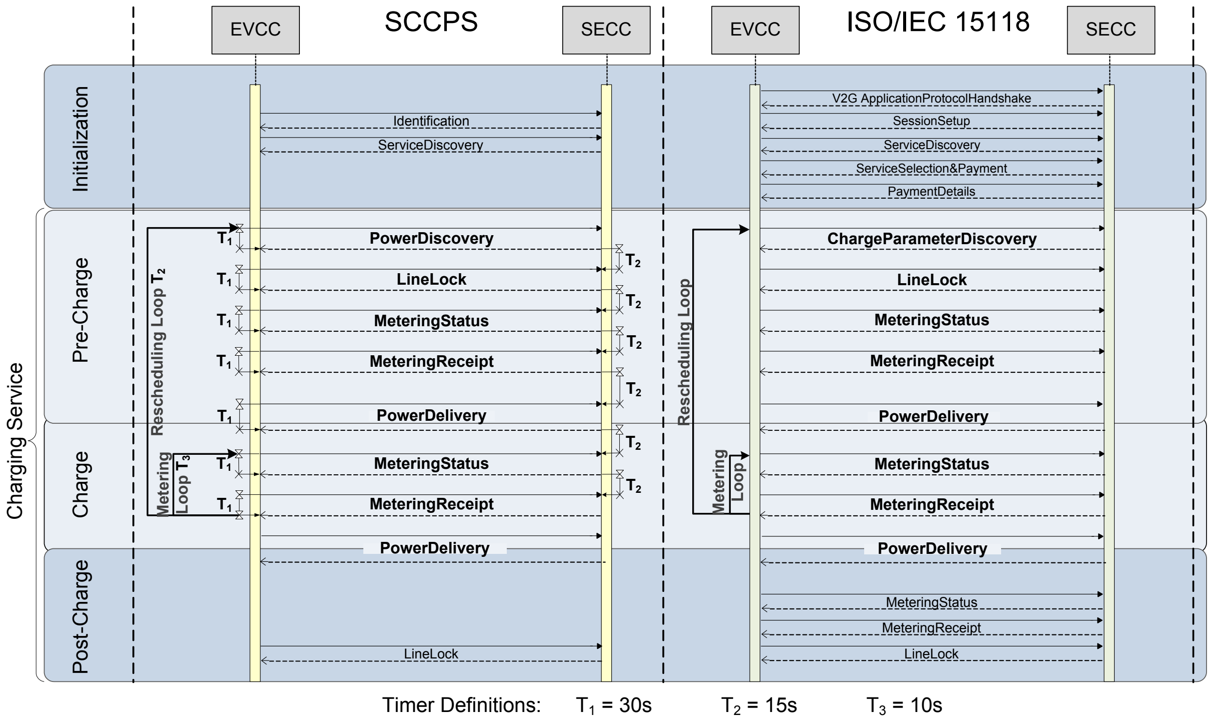

Figure 6: Comparison of Messages defined on Layer 7 for SCCPS and ISO/IEC 15118

The ISO/IEC 15118 starts communication with a handshake message identifying the exact application layer protocol (e.g. protocol version) followed by *SessionSetup*. In SCCPS these messages are combined to the *Identification* message which includes the protocol version, an unique ID and a public key. Next, the EV selects an available service from the EVSE. Besides the default *Charging Service*, the *ServiceDiscovery* may include further value added services like internet access. The main differences here are that ISO/IEC 15118 includes additional messages for the exchange of payment credentials for the selected service. For the sake of illustrating both protocols in this work, we split the *Charging Service* into three phases: *Pre-Charge*, *Charge* and *Post-Charge*.

The *pre-charge* phase starts with the exchange of general charging parameters including information on the EV-charger, estimated required energy amount and the point in time for the end of charge. The SECC response contains the name of the appropriate energy provider, applicable grid limits being derived from static EVSE limits and dynamic grid limits, as well as a list of available tariffs. A tariff is represented by a list of points in time each being associated with a cost. The EV may schedule its energy consumption according to the schedule of grid limits and costs. Following the sequence of messages the next message *LineLock* forces the EVSE to lock the charge cable in the EVSE. Locking the cable during the charge process provides additional safety as well as security means. The next step consists of the *MeteringStatus* and the *MeteringReceipt* messages. The exchange of both messages is processed as one atomic operation, where the *MeteringStatus* is used to receive the meter reading, meter-ID, and max. output power from the EVSE. The *MeteringReceipt* is used as a legal basis for billing since the EV acknowledges and digitally signs these values along with this message. After the initial meter reading exchange the EV notifies the EVSE about the selected tariff and the estimated charging plan. The EVSE responds by switching on the power if the state of the pilot signal is either *C* or *D*.
Now the *charging* phase starts, where the EV and EVSE continuously exchange *Metering Status/Receipt* messages in order to secure the billing process in case of any unexpected error conditions (see *Metering Loop* in Figure 6). Due to the adoption of the client-server architecture, the SECC cannot send a request to the EVCC in order to trigger a reschedule. Hence, if the EVSE wants to reschedule the charging plan due to changes in the current supply situation, the EVSE can indicate that by setting a flag in the *Metering Status Response* message. The EV may now continue the communication at the start of the pre-charge phase and negotiate a new charging plan (see *Rescheduling Loop* in Figure 6).
The *post-charge* phase starts with the request of the EV to switch off the power indicated by the *PowerDelivery* message. In contrast to SCCPS, ISO/IEC 15118 now requires an additional meter exchange in order to bill the exact energy amount. The communication finishes with the exchange of the *LineLock* message to unlock the charging cable.
Looking at the timing constraints for DSM, both proposed architectures depend on the application layer timers being illustrated for SCCPS in Figure 6. At the time of this writing ISO/IEC 15118 does not yet define any timers for the application layer. However, the same principles apply for application handling in the current working draft. In case of SCCPS a complete metering loop iteration can take up to:

$2T_1 + T_2 + T_3 = 85s$ (considering *worst case delays without errors*).

The same *worst case delay* for renegotiating a new set of tariffs or a new set of power demand limits takes up to:

$6T_1 + 6T_2 = 270s$.

In case the EV charger does not align to the proposed power demand limits of the EVSE, SCCPS defines a timeout of 300s for opening the contactors of the EVSE. Looking at these definitions, it becomes obvious that both approaches for AC charging do not propose mechanisms for enabling near real-time DSM. Hence, we investigate the concurrent handling of LLC and HLC in the next section in order to allow for near real-time DSM.

V2G Communication Approach enabling near Real-Time Demand Side Management

The integration of LLC and HLC is not yet finally standardized. With regards to our observation in the previous section, we suggest two different approaches for concurrent handling of LLC and HLC. Both approaches are discussed and integration issues are identified with regards to DSM. One of the introduced approaches supports long term charge schedules as proposed by ISO 15118 as well as real-time intervention. The real-time intervention may be used by the Distribution System Operator to limit the charging current in case of a local grid violation.

Part I of Figure 7 shows the first integration approach illustrating how LLC and HLC sequences are concurrently processed. After detecting an EV, signalled by pilot status B, the EVSE sets a 5% PWM duty cycle indicating support of HLC. The EV may then start the HLC by sending the initial message (see Figure 4). After sending the *PowerDelivery* message the EV may change the pilot status to C/D. The EVSE responds by switching on the power after a maximum delay of 3000ms. The PWM duty cycle remains at 5% duty cycle during the entire charging service. The pilot-signal is only used to monitor charge state transitions from C/D to B, which in turn forces the EVSE to switch off the power. The resulting delay for renegotiation of power demand limits would solely depend on the HLC protocol. According the previous section this would lead to a response time of up to 270s using the *Rescheduling Loop* (see Figure 6). Alternatively, provisioning of new grid limits can become part of the *Metering Loop* reducing the response delay to 85s. In this case however the rescheduling mechanism of the charge plan becomes an open issue since the *ChargeParameterDiscovery*/*PowerDiscovery* is bypassed.

The major difference of the second integration approach (part II in Figure 7) is that it uses the PWM duty cycle concurrently to the HLC Protocol in order to limit the charging current. This is done to achieve a near real-time response mechanism limiting the charging current in case of a decrease in supply capacity of the EVSE. Two aspects of the HLC have to be altered in response to the new handling of the pilot signal: First, the charge current limits negotiated during the *PowerDiscovery*/ *ChargeParameterDiscovery* have to be treated by the EV as non-committal, approximated values that can be overwritten during the charge process in case of unexpected grid constraints. However, these values are still used for deriving a charge schedule and allow for approximation of demands for grid operators. Second, the "maximum permissible" output power of the EVSE could be excluded from the *MeteringStatus* message, because it is now encoded in the duty cycle of the pilot signal. Parallel provisioning of this value through LLC *and* HLC would increase testing and error handling complexity. Part II of Figure 7 shows the resulting communication sequence. After the EVSE receives the *PowerDelivery* message it sets the duty cycle to the corresponding charging current. The

MeteringStatus message is still used to bill the charging process. Furthermore both sides can still force a renegotiation of the charge schedule and selected tariffs either if the supply situation changes or the user changes the overall charge preferences (e.g. end of charge or energy amount needed for next trip).

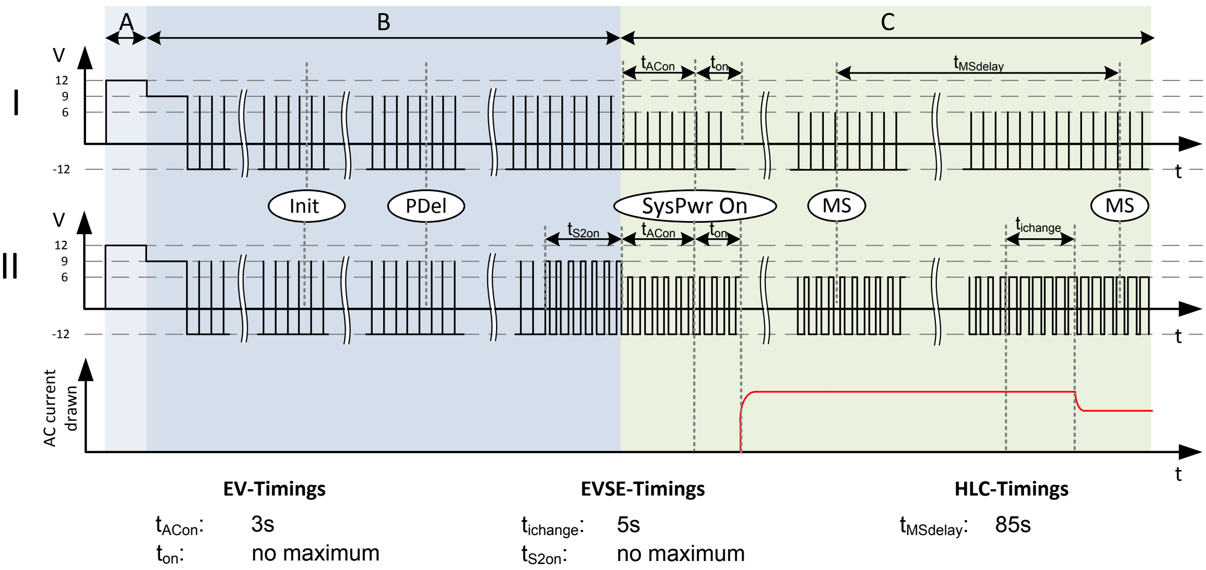

Figure 7: Timing Diagram for Integration of Low and High Level Communication

Following the second approach the latency for limiting the charging current due to an unexpected exceedance of operational grid constraints can be reduced to the response time of the charger on a PWM duty cycle change. IEC 61851 defines a maximum response delay of 5s for this process.

Conclusions & Outlook

This work analyses currently proposed standards for LLC and HLC of the V2G communication interface with regards to DSM. LLC is defined in IEC 61851 providing real-time safety mechanisms which can also be used for enabling near real-time DSM. Both investigated HLC protocols (SCCPS and ISO/IEC 15118) define advanced data exchange capabilities and share similar *principles* for application handling. However, as we showed in this work, the current status of both HLC protocol specifications does not allow for near real-time DSM.

Our analysis indicates that further standardisation efforts are required in order to integrate IEC 61851 into both HLC protocol approaches. Moreover, it was shown that the integration approach of IEC 61581 has a crucial impact on overall system response time for DSM. Furthermore the integration of IEC 61851 and any future HLC protocol has to be chosen wisely with respect to legacy support for already deployed EVs.

Acknowledgement

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All references to the *ISO/IEC 15118 V2G Communication Interface* represent current work in progress and might change for the official version of the standard.

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Using CIM for Smart Grid ICT integration

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Abstract: The eTelligence project explores and demonstrates various smart energy grid ideas by using modern ICT (information and communications technology). For this purpose, many new and heterogeneous types of smart grid systems have to be developed and integrated, such as a regional energy market, distributed energy management systems, and an advanced metering infrastructure. The future interaction scenarios of such new systems are still topics of research, which calls for an architecture easily supporting future changes. The integration capabilities of the eTelligence ICT architecture are based on standardized communication, especially using IEC 61970/61968 (Common Information Model, CIM) and an easily extensible market product description language also realized with CIM. Additionally, we present a process model for using CIM, and report our experiences from using CIM for integration.

Introduction

In an extensive field test the eTelligence project[4] [BBE09] explores and demonstrates various approaches of using modern ICT and advanced operation to improve the current energy supply system and to enable broad integration of renewable energy sources like wind, photovoltaic and biomass into the future power supply.

The IT infrastructure is responsible for collecting measurements from different sources (e.g., smart meter readings) from the field, storing these measurements, partly processing them in multiple systems and offering them to a number of other systems for further processing and for interaction/visualization purposes. It acts as a nervous system and has to be flexible towards changes. For example, the energy market place as a future utility application needs an extensible way of defining products to be traded and exchanging bids containing these products between the market participants and the market. Both purposes call for the use of a suitable standardized modeling and messaging solution. Within the project we chose the IEC CIM (Common Information Model) standard as a sophisticated approach.

[4] The project is co-funded by the German federal ministry of economics and technology (support code 01ME08010) and is part of the German E-Energy program.

This article gives information about the IT infrastructure and its design rationale, and the energy market place with a focus on the products traded. For both contexts we give a deep insight on CIM usage. We also describe both, our experience using CIM and a best practice process for supporting CIM usage. We start with a short introduction into CIM.

A short CIM Summary

In this section we briefly introduce the Common Information Model (CIM). For a deeper introduction into CIM we refer the reader to [Mc07][Us09].

In the field of standardization of system interfaces, data models for energy network management, and the integration of applications into the IT environment of an energy supply company, the IEC has adopted the Common Information Model from the Electric Power Research Institute (EPRI) as a base for the standards IEC 61968 [IEC07] and IEC 61970 [IEC09a]. This process started in 1996, and has since then been continued at international level. In the context of international standardization for electric utilities, CIM becomes increasingly relevant [EPR09, Us09]. This is, among others, reflected in the German E-Energy / Smart Grid standardization roadmap [DKE10].

The Common Information Model aims to reduce the time effort and expense associated with an integration of applications in an energy management system and to provide investment protection through the standardization in systems and the effective ensure operation of these systems [Us09].

CIM is an abstract UML model that defines a common vocabulary and a formal representation of knowledge as a set of concepts for the electric power industry. The abstract CIM model represents all the major objects of an electric utility enterprise typically needed to model the operational aspects. This model includes classes and attributes for these objects, as well as the relationships between them [IEC09a].

CIM can also be interpreted as an integration framework [Us09]. It helps to define the integration of a vertical value chain by using interfaces and data models for energy management systems. Three main use cases for CIM exist [Us09]:

- Exchange of network topologies
- Coupling of utility applications
- XML-based message exchange within a SOA (Service-oriented Architecture) using CIM-semantics

The interface reference model in IEC 61968-1 describes the use of a middleware and the information exchange model [IEC10]. By using the common semantics defined in CIM and by use of a suitable middleware, it is possible to reduce the costs for integrating power system operators’ software applications.

The eTelligence Approach of Integration

Our approach to integrating various software applications in eTelligence consists of a software architectural approach that has an emphasis on standardized communication and a corresponding structured process model for applying these standards.

Architectural Approach

The eTelligence architecture was designed in consideration of three requirements:

- **Interoperability:** As the future smart grid scenarios and systems to integrate are not clear yet, sufficient flexibility for adding new applications and interactions has to be provided.
- **Standardized communication:** Standards can potentially reduce integration costs and are therefore a core concern for smart grid infrastructures. In eTelligence it was a major goal to explore the broad application of IEC CIM and IEC 61850, which is used for field integration. Standardized communication also supports interoperability.
- **Low latency processing:** The value of information decreases with time. For instance, both the competition at energy markets and smart grid control mechanisms can benefit from low latency in end-to-end processing of sensor data information.

In the following, the major architectural means in eTelligence for satisfying these requirements are described.

Interoperability through two Integration Buses

For maximizing interoperability, the architectural landscape is structured into three layers interconnected by two ESB (Enterprise Service Bus) layers, as illustrated in Figure 8. The bus concept ties together event-driven services using a service-oriented architecture based on open standards and messaging [Ch04]. This allows for relatively independent development cycles of individual applications.

The field communication bus collects data from various sensors throughout the smart grid and disseminates control signals to those components. Therefore, it has to be reliable in basic messaging and sufficiently scalable to support communication to a large number of devices such as sensors. In detail, it has been implemented by using both, publish-subscribe messaging middleware and request-response field communication middleware. The publish-subscribe middleware is used for 1-N distribution of sensor data. For instance smart meter readings are published to multiple applications in parallel. Request-response middleware is used for more complex interaction, e.g., for steering and control of distributed energy resources. Already at the project's beginning, it was obvious, that the field communication bus was going to be subject to many changes, since many heterogeneous sensors and even more sensor data consumers were planned to be connected. We have chosen publish-subscribe as the dominant communication pattern to avoid bottlenecks for integration tasks at the field communication bus. This allowed developers of applications that need to consume the data to easily integrate their applications, even without downtime. The integration of these applications was even more simplified by implementing sensor data streams using standardized messages (e.g., CIM-based XML messages for smart meter readings).

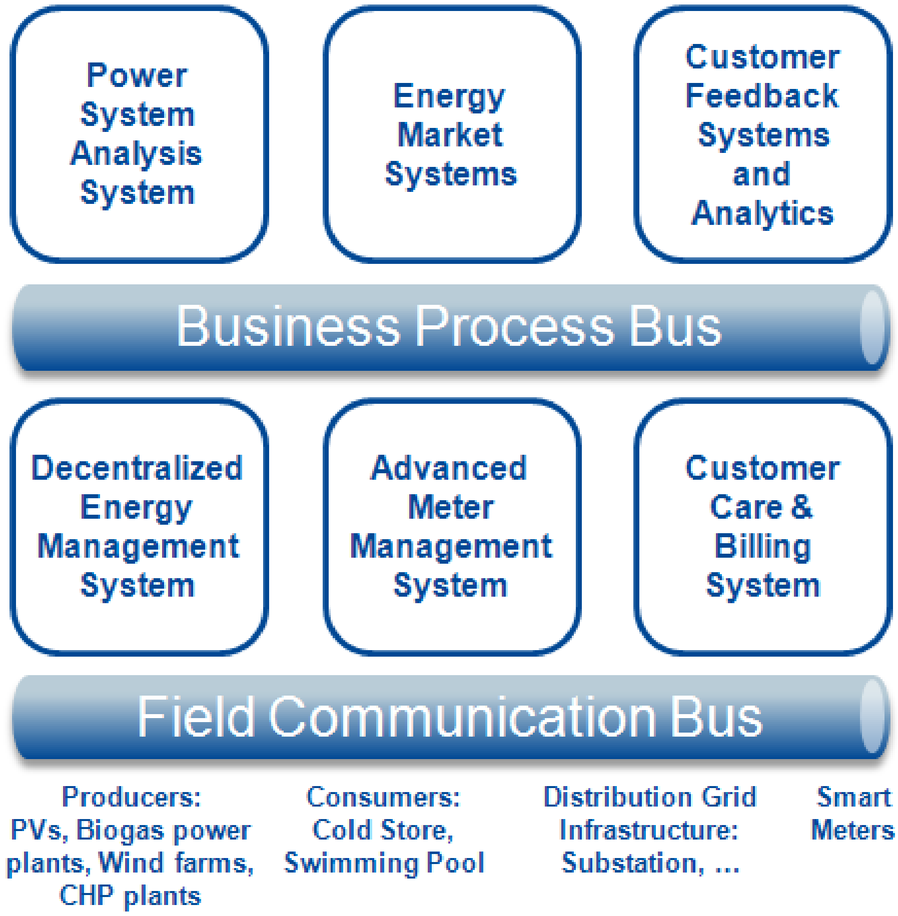

Figure 8: eTelligence architecture from a high-level conceptual viewpoint.

The second bus, denoted as business process bus implements business process execution besides plain request-response and publish-subscribe communication (e.g., user registration processes). Therefore, the bus was realized with two middleware products — one focused on plain high-performance publish-subscribe, the other focused on reliable process execution. Both request-response and publish-subscribe interaction between the business process bus and systems interacting with it are realized with IEC 61970/61968 (CIM).

Standardized Communication for Interoperability

Two standards have primarily been used in the eTelligence architecture: IEC 61970/61968 (CIM) and IEC 61850. CIM was mainly used on business level, but also in some cases for exchanging data with technical grid infrastructure (e.g., medium-sized power producers and consumers) over the field communication bus. IEC 61850 was used for communication on field infrastructure level, especially for communication with sensors in substations, medium-sized combined heat and power plants, photovoltaic plants and wind power plants.

Minimizing Latency

As mentioned above, latency requirements are an important aspect of energy management system landscapes. Especially connections between applications can have a significant impact on latencies.

In eTelligence, we selected three principles to minimize latencies: publish-subscribe communication, instant individual data item processing instead of batch processing, and parallel processing. Above, we described that we used publish-subscribe communication to simplify integration of new applications into the system. At many places in the architecture, publish-subscribe-based communication also contributes to low latency processing, compared to request-response communication. Request-response communication typically needs two messages (the request and the response), while an initialized publish-subscribe based communication requires only one message. In order to further reduce latency, data items (e.g., sensor data readings) are processed individually. In other words, no batch processing is used and each processing result is directly published to subsequent subscribers. Finally, data processing was organized such that a maximum amount of activities is executed in parallel. For instance, the field communication bus provides smart meter readings in parallel to different subscribing applications, such as data storage, billing, and infrastructure operations supervision.

Obviously, both parallel processing and instant individual processing have their disadvantages. Parallel processing can lead to synchronization issues, if the data is joined in subsequent steps. Instant individual processing (i.e., non-batch processing) is sometimes more complex (e.g., if data arrives out of order) and is often less efficient in terms of the ration between message payload size and header size.

The individual, instantaneous processing of sensor data and the broad usage of parallel processing via publish-subscribe is in contrast to a single central database paradigm. Modern SOA concepts (e.g., SAP's SOA platform called Enterprise SOA), address distributed databases, enabling that each application can be installed, configured, and used independently of other applications [He07]. At the same time, a company-wide integration strategy based on a central shared database can be problematic in terms of performance, reliability, and maintainability [SS03], especially for broad smart grid application landscapes. Therefore, our implementation explores both benefits and disadvantages of avoiding a centralized data repository in a smart grid scenario.

Methodology for efficient Integration using CIM

Since several years, we use a process model oriented methodology to realize IEC CIM-based communication interfaces together with IEC CIM-based message schemata and to coordinate the usage of different CIM schema versions within the enterprise.

Two roles are distinguished in the process model: first, a central CIM team, and second, software development projects that want to use the IEC CIM standard. The CIM team is a small company-wide expert group coordinating the evolution of shared CIM schema versions and supporting projects using CIM. The CIM team operates a central *CIM repository*, which is a file server providing several CIM model versions, CIM schema versions, extension models, CIM tools like the BTC CIMBench and used CIM message schemata in combination with versioning. Thereby, projects that share CIM models have a common place to refer to.

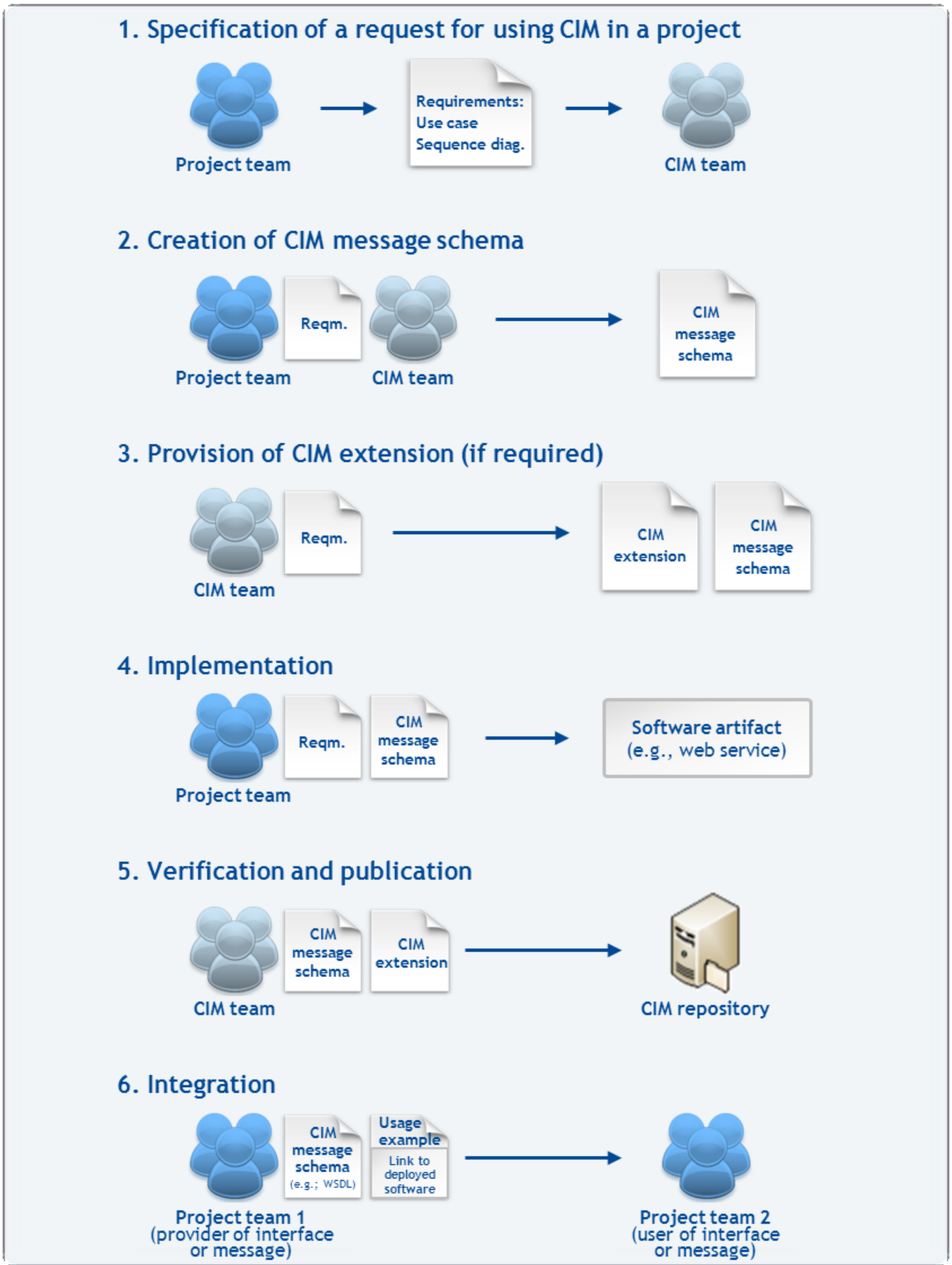

Figure 9: CIM schema process.

The process model, illustrated in Figure 9, requires a project to perform several steps in order to use CIM for messages and interfaces. In the following, the process is briefly sketched:

1. First, the project specifies the use case in which the CIM standard is to be used. This is done with UML Sequence Diagrams and a structured description that describes the use case.

2. The CIM team together with the project staff models CIM message schemata based on the project's use case specification. This provides several benefits for the project: The project members can benefit from CIM team's expert knowledge on the CIM standard, and the interfaces and message schemata will be similar to other CIM-based artifacts in other projects, since the same experts were involved. Additionally, this project step enforces an UML-based use case specification and a review (by the CIM team).
3. If needed, the CIM team provides a CIM model extension that satisfies the project requirements. This step is combined with the second step.
4. The project implements CIM standard usage and provides the resulting technical artifacts CIM message schemata and interface specification files (e.g., WSDL definitions) to the CIM team. Additionally, example messages for CIM message schemata have to be provided.
5. The CIM team checks the artifacts and deploys them to the CIM repository.
6. In case the development team provides an interface to other development teams, then both the CIM-based message schema for forward and response messages (in case of request-response) are provided together with example message instances that can directly be used at the deployed interfaces for testing.

The process for changing or extending existing artifacts and interfaces within the CIM repository is based on this process, but does not usually require to provide new use case specifications. Each change to the artifacts in the CIM repository is assigned a new schema version number and old schema versions are kept.

Furthermore, the CIM team is also a central coordinating instance for the adaptation to new CIM *model* versions. New *versions* of the CIM standard are provided by the IEC TC 57 working group about once a year. Frequent changes in the standard are a threat to interoperability and a central company-wide coordination allows reducing and controlling version conflicts. However, this does not mean that the CIM team is in charge to update the individual CIM message schemata whenever a new standard version is released.

In the eTelligence project and other projects, we experienced that the process model reduces integration costs through providing a simple step-by-step process and through specialization of the CIM expert group. We also observed that the process resulted in better interfaces and messages over the time. Obviously, the process only covers a smaller part of an integration project.

CIM in eTelligence

The previous section discussed the usage of standards and architectural principles in general in the eTelligence architecture. In the following, two more concrete examples for using CIM in the eTelligence system in the context of smart metering and market product description are presented.

Using CIM in Smart Metering

eTelligence implemented a complete electricity smart metering solution and explores new smart metering scenarios that are not yet in the market. Figure 10 sketches how smart meter data are distributed through different systems in eTelligence's ICT from a logical viewpoint. For simplicity, the two ESB (Enterprise Service Bus, e.g., [Ch04]) layers are not shown, but they organize a large part of the communication — with one major exception: interactive systems that communicate with data management systems via request-response have direct inter-system access to provide short response times. However, even in this cases, CIM-based messages are used.

Smart meters send pairs of timestamps and meter readings. In the processing chain, these messages are converted as soon as possible from a communication standard specific to power meters (SML standard) to messages conforming to the IEC CIM standard, more precisely to IEC 61868-9 meter reading and control [IEC09b]. In Figure 10 this step is performed in the field communication system.

After this, the messages are distributed in a publish-subscribe manner to four different target systems using the field communication bus. The target systems are the meter data management system (MDMS), the billing system, a live aggregation system that provides data to a public Web portal (average consumption of households), and finally to the smart meter live monitoring, performing data stream analysis in order to detect technical problems in the smart meter infrastructure in near real time. As mentioned in the previous section, data is provided in parallel to these four systems by the field communication bus enabling thereby parallel data processing. In one case, the parallel processing leads to a synchronization issue: the results from billing, i.e., determination of costs and prices for each consumption, have to be joined to data.

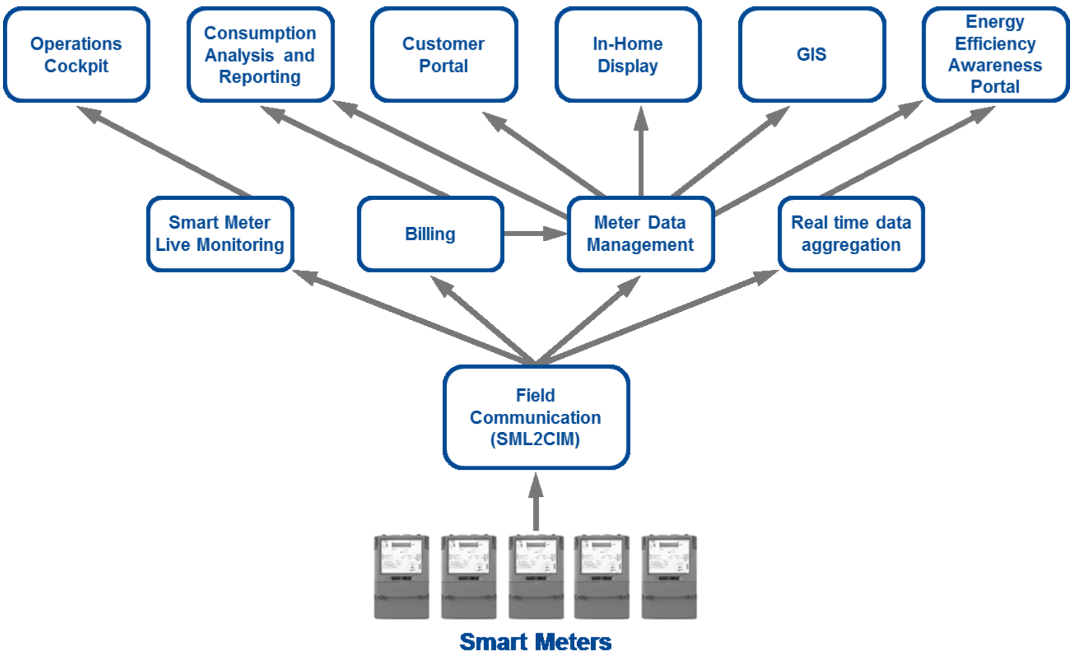

Figure 10: Logical data flow for smart metering.

In order to be able to receive data, subsystems interested in smart meter measurements need to conform to our CIM-based data model for smart meter readings and to register at subscriber at the field communication bus. This data model is stored in a company-wide repository for IEC CIM artifacts. This enabled us to develop all systems that use smart meter data independently.

Using CIM within the eTelligence Market Place

The previous section described the usage of CIM for standardizing messages of smart meter data. In the following, it is presented how CIM was used for a market product description language.

Within the eTelligence project, a regional energy market with EEX (European Energy Exchange) connection was developed, implemented and put into operation. All processes are handled automatically. Market participants interact with the market by means of software market agents who place their bids on the market place using a web service.

The following stakeholders' requirements towards products could be identified. Both, products based on active power and reactive power should be traded on the market place. Locality of generation and consumption had to be taken into account and also products should be differentiated by type of generation (e.g., from regenerative sources or from fossil fuel). Due to the project's experimental nature, it was important to keep flexibility with respect to product requirements arising later in the project.

Based on the requirements, we developed a product description language allowing definition of complex energy products for both *active power during a continuous period of time* and *reactive power during a continuous period of time*. This language uses the following additional parameters to characterize a basic product:

- is the product designated for sale by the owning party or should it be acquired by the owing party
- the minimum and the maximum amount of power traded
- the timespan of delivery
- the start and the end time of the trading period
- the product's price
- the location of delivery
- is the product an option or not

It is possible to add additional information to a product's description. The description of the basic active power product can contain information about the type of power generation, e.g., generation from renewables. Descriptions of basic reactive power products can be refined by information whether it is capacitive or inductive.

Complex products can be formed by linking basic products. They can be described as trees with basic products as leafs and link operators as inner nodes. Those operators describe how a product should be traded.

The following operators exist:
- all
- min(n), min_ordered(n)
- max(n)
- exactly(n)

For instance, min(n) applied on a set of m≥n products means that at least n of the m products given in the set have to be traded successfully on the market in order for the overall complex product to be traded. Otherwise no trade of this product or its parts shall be possible.

A detailed description of the operators and their semantics can be found in [SO10]. Using the product description language, it is possible to define products as schedules or load shifting potentials.

Example of a complex product

Figure 11 depicts a complex product as a tree. Every single node within the tree represents a product. While leaves represent basic products, inner nodes represent complex products. An inner node's label consists of a number within parentheses followed by a text and an optional additional number. The number placed within parentheses is the node's enumerative number, the root node being numbered as (1). The text, for complex products, is an operator name ("all", "min", "exactly", "max") followed by a number used as parameter to the named operator. The operator "all" does not need an argument.

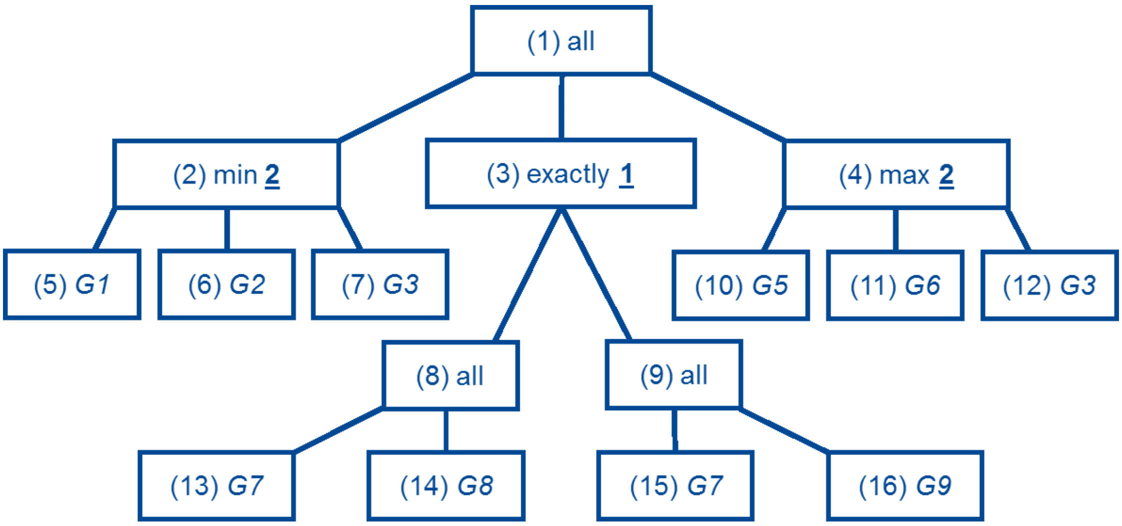

Figure 11: Complex product.

Basic products are labeled *G1* to *G9*. Same labels mean same power, e.g., for nodes (7) and (12). A basic product may be either one hour or 15 minutes of reactive power, respectively or either one hour or 15 minutes of active power, respectively. The example product defines that complex products represented by nodes (2), (3) and (4) all have to be traded successfully. The complex product represented by node (2) can be traded if a minimum of two out of the three basic products *G1*, *G2* and *G3* can be traded. The complex product represented by node (3) can be traded, if exactly one out of the two complex products from nodes (8) and (9) can be traded. Finally, the complex product represented by node (4) can only be traded if at most two out of the three basic products *G3*, *G5* and *G6* can be traded.

Embedding the eTelligence product description language in CIM

In order to embed the product description language in the IEC CIM, it was necessary to extend CIM. This was done in cooperation with the BTC CIM team and the eTelligence project partner OFFIS following the approach recommended by the CIM user group in [Co09]. Figure 12 shows the classes and enumerations used for the CIM extension. The classes which are part of the extension are labeled by <BTCExtension>.

The main task for extension was to individually decide whether an existing class could be extended for the purpose of our product description language or if a new class should be added. For example, the class GeneratingBid from the CIM Package Market Operations could be extended to the class ExtendedGeneratingBid. This class' extension, among others, contains the attributes capacitive, reactivePowerMax and reactivePowerMin, enabling a description of reactive power products. The class DeliveryTime was newly added. It serves the purpose of modeling delivery times used in a product. An in-depth description of the approach used during extension is contained in [SO10].

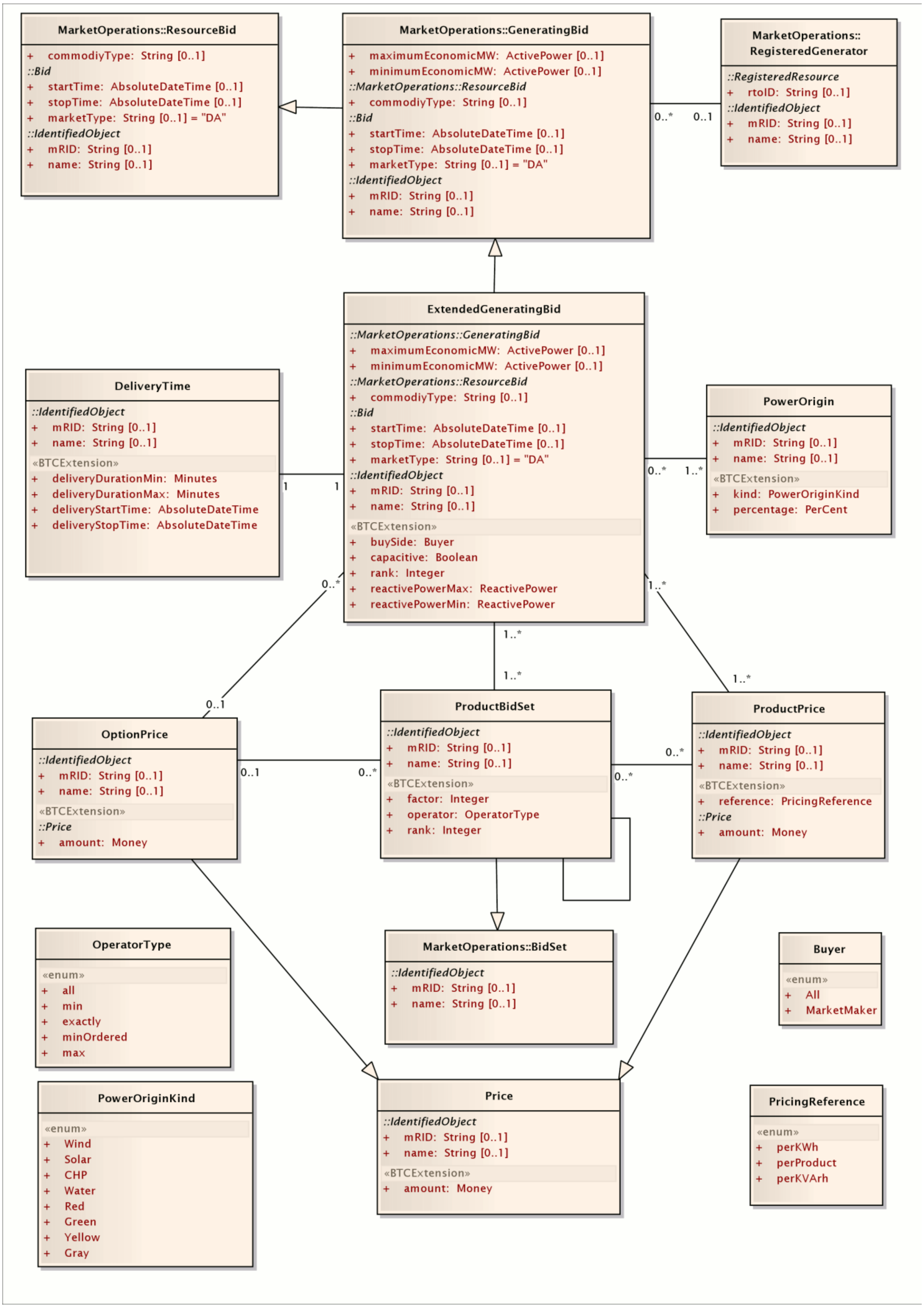

Figure 12: CIM – Extension [SO10].

The extended IEC CIM model was used to define the web service for accessing the market. This was done by generating XSD message schemata from the extended CIM using the CIM bench tool developed by BTC.

Describing bids in CIM

A product placed on the market place is called bid. Figure *13* shows a way of expressing a bid in CIM to buy reactive power using XML. Exactly one of two basic bids shall be sold. The XML message consists of a *ProductBidSet* containing two *ExtendedGeneratingBids* and an operator description. Figure 14 shows one of the two basic bids expressing that 42kVArh of capacitive reactive power can be delivered at the meter point designated Counter1 on 2009-11-17 from 03:00 to 03:15. The maximum price paid shall be 6.2 Euro cents per kVArh.

The bid is conveyed with the CIM message's payload. For reason of clearness the message header and several attributes have been omitted from the presentation.

```
<ProductBidSet>
    <factor>1</factor><operator>exactly</operator>

    <!-- First bid -->
    <ExtendedGeneratingBid>
    </ExtendedGeneratingBid>

    <!-- Second bid -->
    <ExtendedGeneratingBid>
    </ExtendedGeneratingBid>

</ProductBidSet>
```

Figure 13: Skeleton of a complex bid expressed in CIM using XML.

```
<!-- First bid -->
<ExtendedGeneratingBid>
        <RegisteredGenerator><rtoID>Counter1</rtoID></RegisteredGenerator>
        <marketType>Demand</marketType>
         <capacitive>true</capacitive>
        <reactivePowerMin>
           <multiplier>k</multiplier><unit>VArh</unit><value>42</value>
        </reactivePowerMin>
        <reactivePowerMax>
           <multiplier>k</multiplier><unit>VArh</unit><value>42</value>
        </reactivePowerMax>
        <ProductPrice>
           <amount><unit>EUR</unit></value>0.062</value></amount>
           <reference>perKVArh</reference>
        </ProductPrice>
        <DeliveryTime>
           <deliveryStartTime>
              <value>2009-11-17T03:00:00</value>
           </deliveryStartTime>
           <deliveryStopTime>
              <value>2009-11-17T03:15:00</value>
           </deliveryStopTime>
        </DeliveryTime>
     </ExtendedGeneratingBid>
```

Figure 14: Basic bid concerning reactive power expressed in CIM using XML.

Conclusions from using CIM in eTelligence

During design and implementation of the eTelligence ICT infrastructure and the eTelligence market place, an important goal was to evaluate to what extent IEC CIM can be used for integration on different system layers of a smart grid ICT.

Misunderstandings of interfaces and message schemata are a typical source of faults in large software systems. We experienced that CIM-based messages and interfaces lead to relatively few misunderstandings between development teams that “meet” at an interface. This is because of two reasons: CIM-based schemata use common domain terminology and CIM enforces mandatory attributes. For instance, sensor readings have mandatory attributes both for the measurement unit (e.g., “Watt”) and for its multiplier (e.g., “Milli”). In some sense, domain knowledge from the CIM designers becomes available whenever CIM is used. Thereby, the standard and its documentation provided valuable guidance and structuring for designing messages and interfaces.

Some partners that were initially unable to use XML-based CIM message schemata and interfaces could be easily enabled by giving example messages to them. For this reason, we adapted our process to always supply example messages with a schema. Using the example messages, partners could directly verify whether the interfaces could be accessed. This helped to discover other potential faults, such as closed firewalls.

CIM-based messages are relatively verbose and large, even with respect to other types of XML messages. For instance, already for simple messages, “Smart Meter 15 reports a meter reading of 5 kWh”, many nested XML structures are needed. These messages require more bandwidth compared to size-optimized binary communication. However, today’s infrastructures provide sufficient bandwidth capacity and computational capacity.

The full potential of CIM becomes evident when parallel development using common interfaces is required. In eTelligence, CIM allowed us to independently develop more than 15 CIM-connected components after the interfaces had been specified. This was also supported by the architectural style using publish-subscribe and message-based communication. The process described in this article ensured that CIM-based artifacts were used, reused, and maintained in a coordinated and structured way.

Using CIM extensions, we were able to realize a rather complex, extensible language for defining the products traded on the eTelligence energy market. CIM was sufficiently flexible for such a language definition approach. The transfer of the language design into CIM was a straightforward process.

Based on our experiences, we recommend using CIM whenever additional subsystems or applications need to be integrated or flexibility towards changes in communicated information is required and for complex tasks such as defining languages such as our market product definition language. Surprisingly, CIM provides benefits w.r.t. maintainability even for transporting sensor data readings on lower system layers. However, for instance due to its connectionless communication, it appeared not well-suited for control purposes within the project. Other communication methods, such as defined in the IEC 61850 standards family are better suited for this task.

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