multiFLEX: Flexible Multi-Utility, Multi-Service Smart Metering Architecture for Energy Vectors with Active Prosumers

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Abstract: In order to move forward the vision of Smart Grid, a flexible multi-utility and multi-service metering architecture is needed to allow innovative services and utilities for the different actors playing in this scenario. To achieve this, different meters (e.g. electric, water, heating and gas meters) must be integrated into a distributed architecture in order to gather and analyse heterogeneous data. Hence, such architecture provides in real-time a complete overview of the energy consumption and production in the grid from different prospectives. From customer viewpoint, this information can be used to provide user awareness and suggest green behaviours, thus reducing energy waste. From energy operator or utility provider viewpoint, for instance such analysis can: i) improve the demand response for optimizing the energy management during peak periods; ii) profile consumer energy behaviours for predicting the short term energy demand; iii) improve energy and market efficiency. In this paper, we discuss the characteristics of this infrastructure and its expected impacts on utility providers, energy operators and customers.

1 INTRODUCTION

The electricity market was introduced in the European countries following the Directive 96/92/EC of the European Parliament and of the Council concerning "common rules for the internal market in electricity" (European Parliament, 1999). Up to now the market is working properly for big producers, retailers and users, while the small consumers and prosumers cannot access directly the market and cannot be influenced by price signals.

Distributed generation from renewable and non-programmable energy sources is becoming widespread. This requires a more flexible management of distribution grids, also involving energy storages, both at the prosumers and on the network. For these reasons, a "smarter" grid is needed by Transmission and Distribution System Operators (TSOs and DSOs) together with retailers and market operators in order to face in their activities.

A first step in this direction is the development of a flexible smart metering architecture for multiple energy vectors (multiFLEX). In some countries, smart meters are already deployed at user level. Such smart meters are nearly devoted to billing improvements. However, a new metering systems is needed to go much further by providing their contribution to various objectives such as: i) end-user affordability of electricity; ii) energy and market efficiency improvement; iii) CO_2 emissions and pollutants reduction. Hence, such flexible smart metering architecture must be able to: i) integrate the already available components and devices that can be implemented in a plug and play way; ii) combine and correlate information from meters of different services such as electricity, water, gas and district heating; iii) provide advanced services to users, DSOs and other utilities; iv) enhance the retail market. Following this view, the multiFLEX infrastructure integrates different information from heterogeneous data-sources to promote innovative services related to electricity, water, gas and district heating.

The rest of this paper is organized as follows. Section 2 reviews the relevant state of the art on distributed architectures for Smart Grid. Section 3 describes the characteristics and objectives addressed by multiFLEX. Section 4 introduces the proposed software architecture and its expected impacts are presented in Section 5. Finally, Section 6 provides the concluding remarks.

2 STATE OF THE ART ON DISTRIBUTED ARCHITECTURE FOR SMART GRIDS

In a Smart Grid scenario, different middleware solutions and service oriented architectures have been proposed to enable a pervasive monitoring and management of the the grid itself for providing services. Moreover in (Karnouskos, 2009; Warmer et al., 2009), the authors focus on the importance of exploiting a Web Services approach to establish the interoperability between Smart Home and Smart Grid contexts. Also at building level, service oriented architectures (Candido et al., 2009a; Candido et al., 2009b) and middelware solutions (Stavropoulos et al., 2013) have been proposed. Moreover, such solutions provide a set of API (Application Programming Interfaces) in order to promote the integration and the communication between Smart Buildings and Smart Grids. However, this is necessary but still not enough. Indeed, to provide services suitable for the whole Smart Grid, such as demand response, a complete and widespread overview of the grid itself is needed. Following this view in (Patti et al., 2014a), the authors propose an architecture for integrating different datasources for increasing the energy efficiency in heating distribution networks at district level.

In the power system scenario, Kim et al. present a data-centric infrastructure that exploits the publish/subscribe communication paradigm to allow decentralized monitoring and management of the grid itself (Kim et al., 2010). The GridStat middleware (Tomsovic et al., 2005; Hauser et al., 2005; Gjermundrod et al., 2009) is another solution for enabling the communication across the devices in power system. However, GridStat works with its own closed and dedicated network infrastructure (Germanus et al., 2010), which is incompatible with Internet, so new routers must be deployed. Villa et al. present the CoSGrid middleware for measuring and controlling the electrical power of heterogeneous Smart Grid infrastructures (Villa et al., 2011). It exploits a remote method invocation and an event notification approach to enable the communication. In (Patti et al., 2014b), the authors present a distributed software infrastructure for general purpose services in power systems. They reached the interoperability across heterogeneous devices and built their software architecture exploiting the LinkSmart middleware[1], which creates a secure peer-to-per network.

With respect to the presented solutions, we propose multiFLEX, a multi-service and multi-utility architecture that aims at facilitating the access of multiple actors to relevant data to foster the spreading of various innovative services. As the previous solutions, it enables the communication between heterogeneous devices in the grid. In addition, multiFLEX offers a cloud-based infrastructure to collects, analyse and provide energy information from different meters. It is worth noting that multiFLEX features are not strictly related to power systems but they are opened also to other utilities such as water, heating and gas.

3 PROPOSED APPROACH

The existing applications acknowledge that metering infrastructure is an enabling technology that needs to be coupled with innovative services to reach energy management by means of rewards, automation and information. In order to reinforce customers' engagement in achieving energy efficiency, number of utilities already operate demand response and direct load control to limit and shift the peak loads. However, new services can be integrated focusing on more complex technical applications, transparent for the end-user but nevertheless with higher social impact. multiFLEX pursues the ambition of innovating this scenario exploiting:

- multi-service approach that uses information coming from electric, water, gas, district heating meters to provide general purpose services;
- substation meters to improve fault tolerance and demand response capabilities of the network, taking into account local electric storage and generation;
- advanced *Non-Intrusive Appliances Load Monitoring* (NIALM) techniques to profile user behaviours and introducing a user signature of energy consumption/production regarding electricity, gas, water and heating;
- demand response algorithms that exploit information about energy flows from the meters and the NIALM profiles.

[1] https://linksmart.eu/redmine

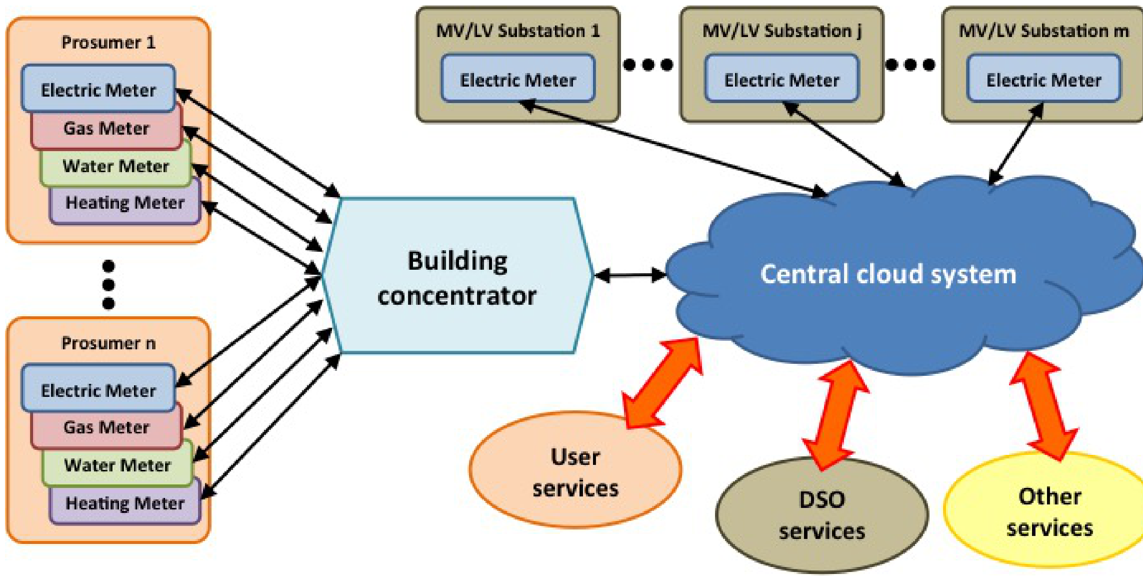

Figure 1: multiFLEX: flexible, multi-utility, multi-service metering architecture.

To achieve this, a software infrastructure to gather data from heterogeneous data-sources and to perform real-time data processing is needed. This can be achieved with a cloud system capable of aggregating and correlating such information. Finally, the resulting software infrastructure have to provide end-users with feedbacks suggestions for optimizing energy usage.

In order to allow innovative services and utilities for the different actors playing in a Smart Grid context (e.g. ESCOs, DSOs, prosumers and customers) a flexible multi-utility and multi-service metering architecture is needed. As shown in Figure 1, multiFLEX integrates off-the-shelf meters placed at the users for electric, water, heating and gas metering. Such heterogeneous meters directly communicate with a building concentrator, which is in charge to enable a bidirectional communication with the central cloud system. For what concerns the electricity grid, multiFLEX also integrates off-the-shelf electric meters deployed in MV/LV (Medium Voltage/Low Voltage) substations. The central cloud system is in charge of: i) collecting data from the building concentrators, thus from the different meters at user home, and from MV/LV substation meters; ii) post-processing incoming information exploiting algorithms for data collection, fusion and mining; iii) providing a set of API and tools for general purpose services and utilities. Example of services for the prosumers are the access to historical records of the energy consumption and their analysis with saving suggestions. While, example of services for the DSOs are: i) fault detection; ii) detection of thefts; iii) demand response; iv) energy storage integration.

In order to achieve a flexible multi-service and multi-utility infrastructure, multiFLEX has to ensure real-time bidirectional communication with each meter in the Smart Grid. As shown in Figure 1, multiFLEX integrates heterogeneous meters (e.g. electric, gas, water and heating meters) deployed at users and also electric meters at MV/LV substations to monitor the whole Smart Grid and to manage the loads in real-time. Following this approach, the meters are seen as a network device connected to internet. Hence, multiFLEX enables:

- real-time readings management;
- real-time accounting activities management;
- real-time information to customers through a suitable interface structure;
- detection of energy thefts;
- near-real-time grid level and user level fault detection allowing optimal alarming and first intervention systems to be adopted;
- demand response together with optimal integration of distributed generation and storage systems.

In order to enable a non intrusive automated energy monitoring systems to profile the energy consumptions of the appliances, multiFLEX integrates in its cloud a load profiling system that leverages the NIALM technology (Zoha et al., 2012). NIALM is a signal processing technique, which discerns the energy consumption of the appliances from the aggregated data acquired from a single point of measurement. It exploits transient electricity consumption

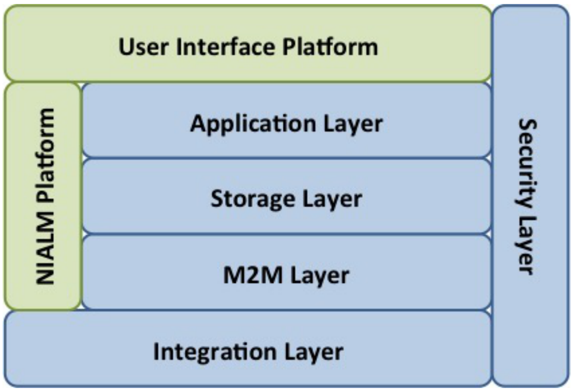

Figure 2: multiFLEX software architecture layers.

events that are used to uniquely characterize each appliance. The resulting load profiles are used for i) suggesting changing in user behaviours that will allow savings; ii) input for the demand response management system; iii) energy consumptions analysis.

4 multiFLEX SOFTWARE ARCHITECTURE

In order to address the objectives described in Section 3, we propose an innovative multi-service distributed infrastructure to allow remote management and provide new services to DSOs, prosumers and final customers. To achieve this, multiFLEX has to enable the interoperability across heterogeneous devices exploiting middleware technologies that seem to be promising along this direction (Patti et al., 2013; Patti et al., 2014b). As shown in Figure 2, the resulting architecture is organized in the following layers:

Integration Layer: it is in charge to enable the interoperability across the heterogeneous devices by abstracting a certain technology to a Web Services. Hence, it translates whatever kind of language the low-level technology speaks into Web Services.

M2M Layer: the Machine-to-Machine (M2M) Layer is responsible for data communication based on publish/subscribe approach (Eugster et al., 2003). This approach increases the scalability because it removes the interdependencies between producer and consumer of the information allowing the development of services completely independent from the systems and deployed devices. Furthermore, it allows the development of distributed applications and services that react in real-time to certain events.

Storage Layer: it collects the data coming from the meters and devices deployed across the city. multiFLEX is a modular and flexible infrastructure where heterogeneous technology can be plugged in. Hence, databases in the storage layer exploit a non-relational schema-less approach.

Application Layer: it provides a set of API, tools and distributed applications to manage and post-process the information coming from the lower layers.

Security Layer: it provides features to enable a secure and trusted communication. It controls whether a device or service can be trusted or not. Therefore, it enables mutual authentication by providing the means to create a public key infrastructure. Furthermore, it allows cryptographic operations for message protection in order to guarantee the confidentiality between the parties.

In addition to the presented multiFLEX software architecture layers, we identified two main platforms for providing feedback and post-processed analysis to end-users:

User interface platform: it is built on top of the Application Layer. It is a user-friendly multi-service platform that provides end users' energy consumption, tips and suggestions to promote green behaviours, to reduce energy waste and related costs as well. This platform is also used by stakeholders, such as the multi-utility companies, in order to manage and control deployed meters, for instance to check system status, operating conditions and faults.

NIALM platform: It is a cloud-based data processing unit dedicated to profile the user electrical energy consumptions. It exploits energy disaggregation algorithm to discern the consumption of the appliances from the aggregated data acquired by the single meter at home. From this information, the algorithm extracts the signature patterns in order to associate each transient to a specific appliance. Then the resulting disaggregated information are made available to provide energy awareness (via the *User Interface Platform*) and to forecast more accurately the energy demand in the short term.

5 EXPECTED IMPACTS

In this section we analyse the expected impacts for the multiFLEX architecture. From a preliminary analysis, it might seem that the utility companies already offers some of the proposed features such as:

i) on-line available user profiles; ii) on-line consumption information; iii) suggestions for consumption optimization; iv) basic predictions for future consumption. However, the back-end block for data acquisition and processing is missing. Indeed, multiFLEX aims on enabling a multi-service and multi-utility platform in which different services like electricity, water, gas and district heating, converge. Following this view, multiFLEX provides end-users a complete overview of their energy consumptions in real-time. In addition, concerning the electrical consumption, multiFLEX can analyse more accurately the users load profile thanks to the NIALM platform avoiding a massive deployment of sensor devices, such as smart plugs. Therefore the impact will be important both on the provider and consumer side, for instance: i) reducing costs for the utility companies on reading the data; ii) providing real-time services to end-users; iii) detecting faults; iv) providing demand response.

The availability of real time and open data at every level of energy distribution (e.g electricity, water, gas and heating) chain will be the turning point for promoting the active involvement of end-users and fostering other working actors, such as energy managers, ESCOs and aggregators, in providing innovative services. No one of the players listed before can really make the difference without analysing and exploiting data with such a granularity as to show consumers habits, electric devices status and faults. Hence, enabling the interoperability and interconnection between different meters and multiFLEX architecture, that can be considered also as a common data-exchange platform, will foster the spreading of innovative services.

Social impacts will be strictly related to real-time data availability even at consumer level. Indeed the knowledge of each own consumptions is the starting point for other more integrated and innovative services (e.g. remote house control systems) that will change people behaviours.

Sharing information related to the development and the status of the Smart Grid has to be the objectives for its continuous expansion, stimulating a virtuous circle. DSO will benefit from a more effective operation and maintenance management systems while consumers will benefit from information of energy bad habits and more tailored energy offers.

5.1 Impacts on end users

Knowing the itemized consumption of the household devices means having the necessary actionable feedback information to propose for reducing the energy waste. multiFLEX provides dual benefits both to the end-users and to the energy providers as well. In the former case multiFLEX can provide detailed knowledge of the household consumption for each appliance and suggest personalized tips to reduce energy waste. Generally, the benefits for end-users are summarized in the following:

- knowing the disaggregated energy of the household appliances;
- discovering which appliance is the most inefficient by comparing its consumption with more efficient models present in other apartments;
- being aware of consumption for each appliance in terms of energy, money and CO_2 footprints. This can help the end-user in taking positive decisions to reduce the energy waste by 15-20% (Darby, 2006; Darby, 2008);
- comparing the disaggregated appliance consumption among different weeks, months or years;
- observing the energy consumption in real-time by mean of a smartphone applications to monitor the apartment and receive alarms whenever the energy situation in the apartment is not as expected.

5.2 Impacts on utility providers and energy operators

In view of the utility provider, multiFLEX can increase the efficiency of demand response strategies by keeping track of energy use patterns and behaviour of their customers. Hence from the energy operator and utility provider viewpoints, the main advantages are:

- profiling consumer energy behaviours in order to predict the short term energy demand;
- offering personalized pricing policies to consumers after profiling;
- providing more efficient demand response strategies to optimize the energy management during peak periods balancing the consumers' energy loads (Bergman et al., 2011).

6 CONCLUSIONS

In this paper, we presented the characteristics and the objectives of multiFLEX, a flexible multi-utility and multi-service metering architecture for energy vectors with active prosumers. Furthermore, we discussed the benefits and the expected impacts that such architecture can have in a Smart Grid context. Indeed, multiFLEX integrates different meters into a distributed infrastructure with the aim of gathering, post-processing and analysing heterogeneous information from different meters and data-sources. Thus, multiFLEX provides an overview of both energy consumption and production in the grid from different viewpoints, fostering working actors in promoting new and innovative services.

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REFERENCES

Bergman, D., Jin, D., Juen, J., Tanaka, N., Gunter, C., and Wright, A. (2011). Distributed non-intrusive load monitoring. In *IEEE PES ISGT*.

Candido, G., Colombo, A., Barata, J., and Jammes, F. (2009a). Service-oriented infrastructure to support the deployment of evolvable production systems. *IEEE Trans. on Industrial Informatics*.

Candido, G., Jammes, F., Barata, J., and Colombo, A. (2009b). Generic management services for dpws-enabled devices. In *Proc of IEEE IECON*.

Darby, S. (2006). The effectiveness of feedback on energy consumption: A review for defra of the literature on metering, billing and direct displays. *Tech. report,Environmental Change Institute, University of Oxford*.

Darby, S. (2008). Energy feedback in buildings: improving the infrastructure for demand reduction. *Building Research & Information*.

Eugster, P. T., Felber, P. A., Guerraoui, R., and Kermarrec, A.-M. (2003). The many faces of publish/subscribe. *ACM CSUR*.

European Parliament (1999). Directive 96/92/ec concerning common rules for the internal market in electricity. In *Second report to the Concil and the Europian Parlment on harmonization requirements*.

Germanus, D., Dionysiou, I., Gjermundrod, H., Khelil, A., Suri, N., Bakken, D., and Hauser, C. (2010). Leveraging the next-generation power grid: Data sharing and associated partnerships. In *Proc. of IEEE PES*.

Gjermundrod, H., Gjermundrod, H., Bakken, D., Hauser, C., and Bose, A. (2009). Gridstat: A flexible qos-managed data dissemination framework for the power grid. *IEEE Trans. on Power Delivery*.

Hauser, C., Bakken, D., and Bose, A. (2005). A failure to communicate: next generation communication requirements, technologies, and architecture for the electric power grid. *IEEE Power and Energy Magazine*.

Karnouskos, S. (2009). The cooperative internet of things enabled smart grid. In *Proc. IEEE ISCE*.

Kim, Y.-J., Thottan, M., Kolesnikov, V., and Lee, W. (2010). A secure decentralized data-centric information infrastructure for smart grid. *IEEE Communications Magazine*.

Patti, E., Acquaviva, A., and Macii, E. (2013). Enable sensor networks interoperability in smart public spaces through a service oriented approach. In *5th IEEE IWASI*.

Patti, E., Acquaviva, A., Sciacovelli, A., Verda, V., Martellacci, D., Castagnetti, F., and Macii, E. (2014a). Towards a software infrastructure for district energy management. In *12th IEEE EUC*, pages 215–220.

Patti, E., Syrri, A., Jahn, M., Mancarella, P., Acquaviva, A., and Macii, E. (2014b). Distributed software infrastructure for general purpose services in smart grid. *IEEE Trans. on Smart Grid*, pages 1–8.

Stavropoulos, T. G., Gottis, K., Vrakas, D., and Vlahavas, I. (2013). awesome: A web service middleware for ambient intelligence. *Expert Systems with Applications*.

Tomsovic, K., Bakken, D., Venkatasubramanian, V., and Bose, A. (2005). Designing the next generation of real-time control, communication, and computations for large power systems. *Proc. of the IEEE*.

Villa, D., Martin, C., Villanueva, F., Moya, F., and Lopez, J. (2011). A dynamically reconfigurable architecture for smart grids. *IEEE Trans. on Consumer Electronics*.

Warmer, C., Kok, K., Karnouskos, S., Weidlich, A., Nestle, D., Selzman, P., Ringelstein, J., Dimeas, A., and Drenkard, S. (2009). Web services for integration of smart houses in the smart grid. In *Grid-Interop - The road to an interoperable grid*.

Zoha, A., Gluhak, A., Imran, M. A., and Rajasegarar, S. (2012). Non-intrusive load monitoring approaches for disaggregated energy sensing: A survey. In *Sensors*.