An Advanced Metering Infrastructure for Future Energy Networks

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Abstract. We are moving towards a highly distributed service-oriented energy infrastructure where providers and consumers heavily interact with interchangeable roles. Smart meters empower an advanced metering infrastructure which is able to react almost in real time, provide fine-grained energy production or consumption info and adapt its behavior proactively. We focus on the infrastructure itself, the role and architecture of smart meters as well as the security and business implications. Finally we discuss on research directions that need to be followed in order to effectively support the energy networks on the future.

Key Words: Service-Oriented Infrastructure, Advanced Metering, Energy Management, Information Services, Business Process

1 Introduction

In the near future, due to deregulation in the energy sector, a much more decentralized and diversified production and distribution energy infrastructure will emerge. New technologies and increased use of renewables such as biomass, solar energy and wind power will introduce a considerable number of diversified systems into the power grid, in addition to traditional large scale power plants. Consequently, the share of decentralized power generation – by industrial or private producers – will increase and have a dominating effect on existing infrastructure, technologies and business practices.

This paradigm shift will reshape the energy business sector, since new technologies and concepts will emerge as we move towards a more dynamic, service-based, market-driven infrastructure, where energy efficiency and savings can be better addressed though interactive distribution networks. A fully liberalized market will advance legacy processes, improve energy sustainability and security, create new business opportunities and have a positive impact on the citizens' everyday life.

New, highly distributed business processes will need to be established to accommodate these market evolutions and fully integrate the distributed electricity sources. The traditionally static customer process will increasingly be superseded by a very dynamic, decentralized and market-oriented process where a growing number of providers and consumers interact. A new generation of fully interactive ICT infrastructure has to be developed to support the optimal exploitation of these changed, complex business processes and to enable the efficient functioning of the deregulated energy market for the benefit of citizens and businesses.

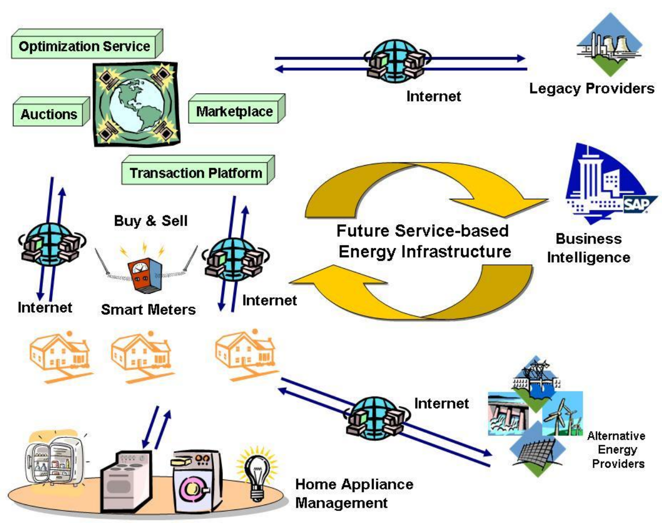

Fig. 1. Future service-oriented energy network infrastructure

As depicted in Fig. 1, the future energy network is much more dynamic. Households still connect with legacy providers, but also have a number of alternative energy sources and are not simply consumers but are able also to generate electricity. They are able to buy and sell electricity in marketplaces [6], subscribe to services that monitor in real time e.g. the energy consumption of specific devices and can take short-timed decisions based on that info. In this infrastructure energy and its associated products are a commodity that can be traded and managed in at local and global level. A key issue in the process of realizing this goal is the existence of an advanced metering infrastructure (AMI) which heavily depends on sophisticated metering devices referred to as smart meters.

Several projects [3] have been launched (among them most notably CRISP [5], SESAM [4] and SELMA [1]) that directly or indirectly contribute to aspects that touch this infrastructure. From the European Commission side, a technology platform initiative named Smart Grids [2] was launched in 2006 with the aim to envision the grid infrastructure that needs to be in place for Europe by 2020. In the new European research framework FP7, the identified issues, among of which is the creation of an advanced metering infrastructure, will be further investigated in research projects.

2 The role of smart meters

We are moving towards the "Internet of things" [9], where almost all devices will be interconnected and able to interact. The same will hold true for energy metering devices. These smart meters will be multi-utility ones, managing not only electricity but also gas, heat etc. New information-dependant intelligent energy management systems will be needed for an infrastructure capable of supporting the deregulated energy market. Smart meters will have to be installed for millions of households and companies and get connected to transaction platforms.

Smart meters provide new opportunities and challenges in networked embedded system design and electronics integration. They will be able not only to provide (near) real-time data but also process them and take decisions based on their capabilities and collaboration with external services. That in turn will have a significant impact on existing and future energy management models. Decision and policy makers will be able to base their actions on real-world, real-time data and not simple predictions. Households and companies will be able to react to market fluctuations by increasing or decreasing consumption or production, thus directly contributing to increased energy efficiency.

In the longer term, smart meters could even be the gateway of communication of household devices with the Internet. It is expected that smart meters will have advanced local communication capabilities (e.g. Bluetooth, IrDA, ZigBee, Wibree etc) and an Internet connection (e.g. via WiFi, DSL, UMTS etc). Therefore they could both participate in local adhoc networks with other household devices and in parallel be their communication medium with the outside world. This in turn opens up some interesting issues to be researched as well as the possibility to apply new business models. The replacement of legacy meters will not be linear depending only on the cost or energy provider's intentions, but rather a dynamic one. How fast we will move towards a fully fledged advanced metering infrastructure will depend on the co-evolution of technology and business opportunities.

3 Smart meter architecture

Existing electronic metering devices support in their majority basic electronic characteristics e.g. electronic display of the meter's status and some even have connectivity capabilities e.g. they are able to submit their reading via a wireless e.g. WiFi/GPRS/IrDA or wired e.g. Ethernet communication channel. However, the existing architectures are closed, allow for very limited interaction with third party services or devices and in order to be integrated in a new application they are usually wrapped in a system-specific way. While this might still work currently, as we move to a service oriented infrastructure, this closed model will not survive. In the near future, meters will transform themselves to embedded devices with CPU, memory, and will have the capability to execute general purpose code that implements third party services. Seeing the meter as a device with computing capabilities, allows us to define a layered open architecture for smart meters as the one depicted in Fig. 2.

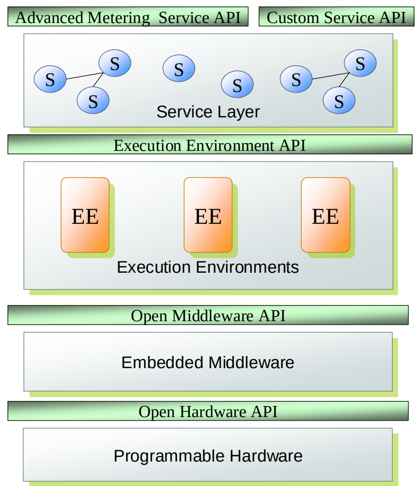

Fig. 2. Smart meter architecture

As seen, we have several layers that communicate with each other via APIs. These APIs need to be defined and standardized in order to allow for interoperable interaction.

- *Programmable hardware*: This is the lowest layer of the architecture e.g. the electricity meter and the basic software delivered by the manufacturer. In order to ease the integration of the hardware in other systems, the functionality offered has to be captured by the open hardware API. Also via the same API one is able to manage the hardware device i.e. program or configure it according to the capabilities offered.
- *Embedded middleware*: This layer is a general purpose middleware for embedded devices. Its role is to provide the capabilities for creating and support of execution environments (EE). The middleware manages the lifecycle of the EEs and is able to also capture the hardware's capabilities and offer via a multitude of APIs a finer programming environment to the EEs.
- *Execution Environments*: The execution environments (EE) are hosted by the middleware and provide specific capabilities that service providers can use to deploy their services. Each meter is expected to host at least one EE.
- *Service Layer*: Several services run in the different EEs on the metering device and offer a standard API to the applications. One service can be standalone or depend on others to provide its functionality. The API of-

fered by the services is standardized and is a uniform way of accessing, the meter's capabilities and programming it

The main motivation behind this modular approach is that each layer should be agnostic of the other layers and only depend on the specific API below it. In a heterogeneous infrastructure such as that on future energy networks, many programming languages and a plethora of implementations are expected to exist for various reasons e.g. performance, flexibility, advanced capabilities etc. However, as long as the basic standardized APIs are globally implemented, all will have a common basis which will enable their interoperability. This is expected to ease also vertical integration at customer side that may be necessary to create robust and highly distributed deployments. Furthermore the existence of an execution environment implies that the meter can adapt its behavior and be incrementally software-upgraded.

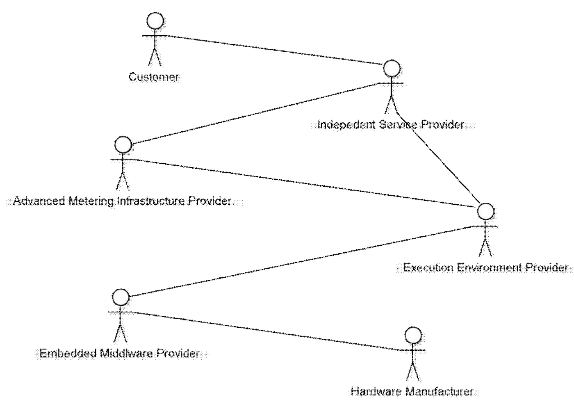

Fig. 3. AMI business model

The Business model depicted in Fig. 3 is compliant with the architecture in Fig. 2. We can clearly distinguish:

- *Hardware Manufacturer*: This is the manufacturer of the hardware devices e.g. an electricity meter, which includes also a very generic software capability that fully supports the open hardware API standard.
- *Embedded Middleware Provider*: this role is responsible for delivering the middleware that can be used with the specific hardware architecture.
- *EE provider*: This role specializes delivering EEs in different implementations and for different hardware platforms

- *Advanced Metering Infrastructure Provider*: This role is responsible for deploying and initializing the whole infrastructure. He is also responsible for providing the communication needed.
- *Independent Service Provider*: this role is responsible for creating and managing services that depend on an AMI. He is able to deploy services network wide e.g. in EEs, combine them with others e.g. enterprise services and deliver sophisticated services to the customer.
- *Customer*: This is either the end-user of the infrastructure who may be located at the edge of the information system infrastructure or assume other roles e.g. an Internet application, a connection management system etc.

4 Distributed business intelligence

The existence of smart meters that can be also accessed in a seamless and uniform way via standardized methods is a must for the future service oriented infrastructure. Assuming that smart meters will be accessed e.g. via web-services, has far reaching implications, since now business processes can actively integrate them in their execution. Smart meters can provide real-time data which can then be consumed by services, which in their turn now can act based on rapid changing context conditions Furthermore, instead of providing only their data (one-way communication), which limited their usage up to now, they can now be active and host business intelligence (bidirectional communication) which does not have to rely only on the back-end systems.

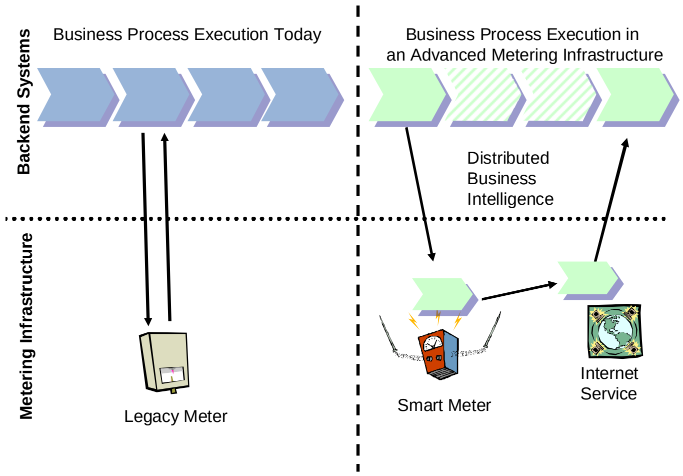

Fig. 4. Distributed business process execution

As depicted on the left side of Fig. 4, a typical business process execution in a backend system that hosts the business intelligence. At some point the meter is interrogated by the business process and its metering status is sent in a time-frame which may vary greatly since the acquisition can be done electronically or even per post. On the left side of Fig. 4 a similar process is depicted, which however assumes an advanced metering infrastructure in place. Since the meters do have computing capabilities, are able to process locally their data and take local decisions, this data does not need to be sent to the backend systems. Therefore we have a part of the business process executed outside the backend system. The business process could be even more distributed since the meter may trigger an external Internet service which will do advance the business process itself. So from the original steps (four are depicted as an example in Fig. 4) in the business process execution only two of them have been done at the backend infrastructure while two others have been executed collaboratively by the meter itself and another Internet based service. The advantages are profound i.e. more lightweight business processes which can outsource or parallelize specific execution steps, we have reduced communication overhead since the data do not have to be transferred to the backend but stay at their original source, and we are able to realize more sophisticated business processes that are highly distributed and may even partially belong to different domains. In an infrastructure where real-time data is constantly generated, needs to be processed and is composed of millions of devices (only in Europe there are more than 225 Million electricity meters), centralized processing (e.g. on backend systems) could be problematic, but such delegation of tasks and distribution of business intelligence may be another step towards more viable and better managed infrastructure.

5 Security implications

Opening up a closed infrastructure as that of energy networks and taking into account the associated business background, can not be done without well-tested security and trust models in place. Furthermore if in the longer term the smart meter evolves to a gateway for household devices, the implications are far reaching, since it is expected that any device will have its own IPv6 address and it will be possible not only to turn it on/off but constantly monitor its behavior. It is clear that several aspects have to be taken care of in order to provide a secure basis for all the implicated actors. In such a heterogeneous infrastructure as the envisioned future energy one, the author of services to be deployed in the smart meters, the entity that deploys a service, the owner of the smart meter, and the owner of the data may be different entities governed by different interest.

A comprehensive threat model needs to be defined. At first it must be secured that the measurement process can not be tampered and the data measured can not be altered (or if this happens there is proof of that). The next step would be to securely transmit the data to the consuming parties. State of the art concepts can be used here e.g. encryption or digital signatures. Projects like SELMA [1] have already tackled parts of this threat as a security architecture that authenticates the measurement data, provides access security and certified software has been developed. However, since the smart meter is able to host execution environments and external entities can deploy services on it, the security model needs to be further elaborated. Issues like repudiation, masquerading, denial of service, unauthorized access need to be successfully tackled. Finally since now via the smart meter private info go beyond simple energy consumption profiling, as their correlation can reveal indication of money flow (e.g. amounts of energy produced/bought/sold), personal habits (e.g. monitoring of energy consumption per device and possibly at very fine level), and other private context info, it has to be assured that there is no misuse or unwanted exploitation of this info. On the other hand, the end-user will be able to enjoy a variety of sophisticated services and with the right tools be in full control of the personal info s/he shares with other parties, something that is not at high degree possible in practice today (but is implied by the legal framework and the contracts between the parties). Furthermore the interactions at global level will have to be investigated and security & trust must be tacked at technology and business model level. Development of appropriate security, safety and risk concepts and architectures for an advanced metering infrastructure for the future energy networks in total is not expected to be trivial.

6 Research directions

We are still in a very early era of development for the future energy network. The most commercial approaches are slowly moving towards automatic metering readers (AMR) which is the transmission of electronic data, but we are still far away from defining a common information model, standardize APIs for communication among heterogeneous services, hardware devices and applications. However one can clearly identify some issues that need to be resolved in the short and mid term in order to allow for the evolution from AMR to AMI.

First of all AMI will require interoperability at several layers as this was depicted with the proposed architecture. Therefore the need to work and agree upon basic functionality that needs to be provided at hardware level is of high priority. In the short term, developing electronic meters with a web-service interface e.g. DPWS [7] will provide them with support for secure web service messaging, discovery, description, and eventing, which in turn allows easy integration with service-oriented efforts in the business domain. Binding them successfully to enterprise services will allow existing business processes to at least integrate their readings and treat them as smart items along with other similar devices such as RFID and sensor networks. Later, in the long term, one could focus on further developing a more advanced smart meter architecture such as the one presented in this paper. Subsequently as discussed, security and trust issues will have to be investigated as early as possibly and get integrated from the scratch at any solutions to be developed, and not as late add-ons – an approach which has been proven to fain and lead to insecure systems.

Once the smart meters have been integrated in business processes, real-time high volume data will be available. It is doubtful if any backend system will be able to deal with this amount of data, therefore it has to be investigated what are the most promising models for distributing business intelligence at several layers (the last of which is the smart meter itself) and take advantage of local in-device and in-network processing and decision making. One size fits all model is not expected to be found, therefore theoretical models should be tested on real-world task specific scenarios.

Also scenarios developed nowadays for other domains will be possible to migrate to the smart meters world. As the infrastructure envisioned (depicted in Fig. 1) will allow the today's energy consumer to slip into the role of buyer and seller on online marketplaces, this will provide another domain where well-known approaches, such as the software agents, may revive. As an example a lightweight agent platform could be installed on the meter (an agency could be one of the execution environments depicted in Fig. 2), and mobile agents could take over tasks of negotiating, buying and selling electricity in energy marketplaces on behalf of the user [8].

Once the smart meters are seen as part of the business process, it will be easier to link them to production planning and energy management systems. This will allow for a more fine-grained management of the energy network overall and a better control of its multiple generation and consuming entities. It will be also possible to have due to the accurate data better models and move towards a more reliable predictive infrastructure that better manages its requirements, the available resources and their optimal usage.

It is expected that the future energy networks will be a highly dynamic ecosystem of consumer, producers, and services and be highly market-driven. This is a paradigm shift with far reaching technological, social and economic effects, whose interdependencies need to be identified, analyzed and understood.

7 Conclusions

We slowly move towards AMR, while AMI is still in its majority a research domain. However, the liberalization in the energy domain will speed-up this transition in the mid-term. There are still several research issues to be tackled in order to move towards a dynamic service oriented future energy network infrastructure. AMI based on smart readers could be the direction to follow. We have presented an architecture that was designed with the future requirements in mind, a business model that is compliant to the proposed architecture and have discussed on the security and business aspects that this new approach brings. Finally we have laid out some AMI related research directions that will have to be successfully tackled in order to enable the realization of such a dynamic infrastructure. The energy domain and its combination with ICT present tremendous challenges and opportunities for citizens and businesses in the years to come.

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