Smart Houses in the Smart Grid and the Search for Value-added Services in the Cloud of Things Era

Stamatis Karnouskos
SAP Research, Karlsruhe, Germany
Email: stamatis.karnouskos@sap.com

Abstract—**The smart grid is an emerging paradigm based on the introduction of sophisticated information and communication technologies coupled with the energy grid. Most of the ongoing research worldwide is focused too much on the smart metering, energy visualization as well as potential residential device management which is usually turning ON/OFF appliances. Less attention has been given to the next step, i.e. challenging area of realizing new sophisticated applications that utilize the latest management capabilities brought to the table by advanced networked embedded devices, the huge amount of fine-grained data they offer and services that operate on such big data. We take a closer look here to some aspects beyond the smart metering, towards innovative value-added applications and services that take into consideration the "Cloud of Things" ecosystem and its capabilities. We investigate how the latter impacts the development of applications and the benefits as well as challenges it brings. We also look at the role of the smart meter and the current "war zones" among stakeholders in the residential environment, and try to shed some more light on their motivation and impact. Finally in order to make more tangible the benefits in the "Cloud of Things" era, we demonstrate an application that taps into the service ecosystem and offers decision support to electric appliance buyers.**

I. Introduction

The smart grid and its promise for a better more autonomous and intelligent energy infrastructure is under investigation in several research and development projects [1]. Although the foci differ partially worldwide, with some of the efforts focusing on the metering infrastructure, some others on the its core components, and others exclusively on the end-users, there is a common pursue for something that would enable better manageability and interaction with [2]–[4]. The rapid advance on information and communication technologies [5] [6] that has already been validated mostly on the Internet, is now entering the traditionally more change-resistant grid infrastructure. The latter is done in the hope to tackle complexity while in parallel decrease costs and increase efficiency.

To realise the vision of the smart grid [4], we need to have fine-grained monitoring as a first step, and then management (control) as a necessary complementarity [7]. Monitoring can only empower us with better understanding of the energy consumption or production, and allow the detection of potentially energy-hungry processes to be identified. However, if no control is available, it will be difficult to optimize the infrastructure in a dynamic and sustainable way, especially with the pace complexity increases. Hence, what is needed, is a new generation of intelligent devices and systems, that will offer a high degree of monitoring via open data, and in parallel the capability to apply sophisticated control mechanisms.The latest advances on Internet technologies, protocols and architectures proves that this can be done [8], even when we speak about very resource constrained devices e.g. GreenWave Reality (www.GreenWaveReality.com) ships WiFi-aware light bulbs that can be controlled by other devices i.e. smartphones.

It is clear that the Internet of Things whose prevalence we witness, and by extension also the IT sector [9], have a significant impact and is expected to continue playing a key role in the smart grid. However, the mindset on the energy domain is still considering the traditional context and operation modus, especially when it comes to the distribution network endpoints such as residential households, public infrastructure, smart buildings etc. As such a tremendous investment is given to develop and deploy smart metering [1]. However, the problem is that many consider that smart metering is potentially everything that the smart grid has to offer. Even today, there is no common understanding what a smart meter should offer; aspects such as "basic services" to be offered by all smart meters or even data formats for open communication of the acquired data have received (for various reasons) little attention. The same holds true for any potential "basic" management capabilities that the smart meter should have in order to be able to take the envisioned role in the smart grid ecosystem.

To make things even worse, some consider that the smart meter is the panacea, and that this is the "gateway" for any household device access and control; hence "smart meter wars" for its "ownership" are underway. We see today several stakeholders coming from the energy, the telecommunication, the facility management etc. domains that try to claim "ownership and control" over not only the smart meter itself, but in many cases also the fine-grained data it produces (which might differ from the data necessary for billing). To our opinion this is too short-sighted and lacks a clear understanding of the smart grid and its potential. Unfortunately such exhibited behaviour is due to the fact that most people either do not comprehend (or are unwilling to do so) the capabilities the current and emerging technologies are offering, hence are still thinking within the box and with the old processes that have dominated the energy sector the last decades. However, things are changing rapidly as we show, and one should focus on research and assessment of the new opportunities [7] that lie down the road.

The aim in this work is to: (i) offer a better understanding on the smart house and smart grid under the prism of the "Cloud of Things" (ii) shed some light on the smart meter role and stakeholder clash, (iii) demonstrate via an example some tangible benefits of value added applications. To do so, we investigate how the smart house with the introduction of intelligent networked devices is changing the rules of the game, and try to approach current discussions on smart meter wars and assess them. Additionally we show that future research and development efforts, should be moving towards the data analytics, and assessment of information coming from the smart grid in order to realise new innovative application and services that will benefit several stakeholders. The smart grid is only viable if it offers value added services to the users, who can then enable its further development (user-pull). Finally we also portray such an application that fits into the vision towards a collaborative smart grid ecosystem, where we think the next step of innovation is going to find fruitful ground.

II. Disruptive Trend: The Cloud of Things and its Implications

Today energy data is collected from the (smart)meters, who passively monitor and measure the total of the energy consumption on the residential area. Subsequently the monitored data is communicated at regular intervals (usually 15 min) or on demand to the next level (e.g. a concentrator) or directly to a metering data platform. At some point the data reaches the enterprise system where applications can assess them. Today the killer-application for doing smart metering is the billing (as shown in the left part of Figure 1). In the short term the monitoring of energy consumption is expected also to gain ground, as the users want to be able to access in addition to billing fine-grained data (15 min resolution) for their consumption (or production) and understand their energy behaviour with the hope to adjust it in a more energy-efficient one [10].

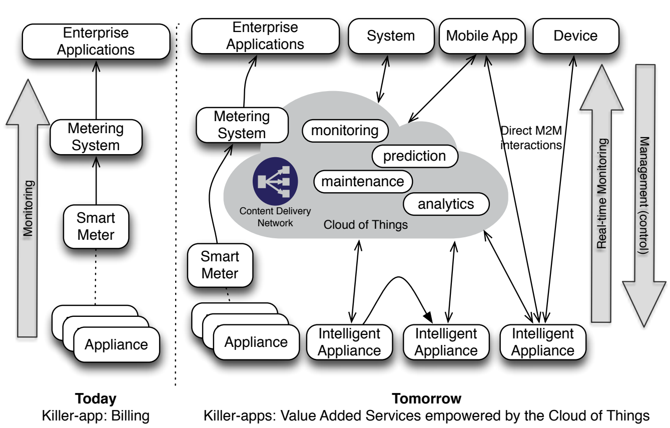

Figure 1. Towards Value Added Services based on the Cloud of Things

However, this is going to radically change in the future. Home appliances are equipped with networked embedded systems that are able to communicate (mostly) wirelessly over protocols such as ZigBee, Bluetooth, and even Wi-Fi. Although with most of them today interaction is overwhelmingly via proprietary protocols or non-standardized APIs, there are efforts to deploy and use more standardized approaches. Some of them, are even able to host web services and make part of their functionality (such as selected monitoring and control functions), available via the Internet e.g. to cloud-hosted services. This is a significant step, as now we slowly move away from gateways that are needed in order to connect these appliances with eachother and to the Internet. Thus, in practice any device that is able to connect at some point via broadband technologies, can communicate with any entity or service in the Internet. This has profound implication as seen in the right part of Figure 1.

Appliances can be equipped with cost-effective solutions and monitor not only their energy consumption, but additionally a plethora of internal states and communicate the results on Internet service providers. As an example of the new capability, the energy consumption of an appliance can now be reported to e.g. any social or analytics web service. This immediately disrupts any scenario of control from a specific stakeholder, as now any intelligent networked appliance can offer to multiple external entities energy relevant information. Additionally since such an appliance software developer will have a much better understanding of the interworkings of it, as well as access of real-time data relevant to its internal states etc. these measurements are expected to be of much better quality as well as complemented with richer domain and task specific information.

Since similar monitoring and control services can now communicate all possible information relevant to the appliance, there is a stakeholder balance shift. Now information about usage, duty cycles, current monitoring data of appliance parts etc., can empower predictive maintenance scenarios running on the device or on the cloud (or both). Of course the benefit by utilizing the Cloud of Things is that additional capabilities potentially not available at resource constraint devices can now be fully utilized taking advantage of characteristics such as virtualization, scalability, multi-tenacy, performance, lifecycle management etc. The manufacturer for instance can use such cloud based services in order to monitor the status of the deployed appliances, make software upgrades to the firmware of the devices, detect potential failures and notify the user, schedule proactive maintenance, get better insights on the usage of his appliance and enhance the product etc.

Similarly we expect to see that a large number of devices and generally cyber-physical systems will make their functionality available on the cloud. A key motivator is the minimization of communication overhead with multiple endpoints by e.g. transmission of data to a single or limited number of points in the network, and letting the cloud to do the load-balancing and further mediation of communication. For instance, as depicted in Figure 1, a Content Delivery Network (CDN) can be used in order to get access to the generated data from locations that are far away from the infrastructure (geographically, network-wise etc.). To this end, the data acquired by the device can be offered without overconsumption of the device's resources, while in parallel better control and management can be applied. Typical examples include enabling access to the full historical data, preprocessing of information, transparently upgrading the cloud services, or even not providing access to internal systems for security reasons. This clear decoupling of "things" and the usage of their data is expected to further empower information-driven applications that can operate over federated infrastructures.

The existence of the Cloud of Things, will constrain the need for on-premise middlewares and proprietary solutions. New service providers will flourish and value added services will be created such as real-time energy monitoring, real-time billing, direct asset management, customized information services, marketplace interaction etc. This is a significant change for the energy domain, as we move away from heavy-weight monolithic applications towards much more dynamic, up-to-date and interactive ones utilizing local capabilities. By increasing visibility via near real-time acquisition and assessment of the energy related information, providing analytics on it and allowing selective management, we expect the emergence of a new generation of customized energy efficiency services.

III. The role of the Smart Meter in the smart grid

We have already indicated, that due to the rapid advances in IT technologies as well as their impact on networked embedded systems that now penetrate the area of appliances,the Smart House is significantly changing towards an ecosystem of highly interconnected things. In this setting one can easily witness that energy related information is going to be a part of the overall vast information exchanged between the device and other devices co-located in the same infrastructure or cloud based services and applications. Therefore, any solutions that do not consider a holistic view of the problem area, and focus on their narrow standalone functionality are doomed to fail in the longer run.

Within the residential area a smart meter needs to:

- Req.1: measure in high resolution energy consumed (or produced)
- Req.2: communicate the measurements to an energy metering data system
- Req.3: enable advanced energy-related scenarios as envisioned by the smart grid

From the aforementioned ones, the first two constitute basic functionalities expected from all smart meters, while the last one is vaguely defined. It is also clear that due to existing regulation, metering of energy consumed (req.1) needs to be done by a dedicated, reliable and certified device. Hence a smart meter has to be in place that offers this guaranteed functionality. This is mainly for the billing scenarios which constitute the main business case today and will remain a significant one in the future. However, energy related information will also be obtained otherwise in the future (as also depicted in Figure 1), which may not be certified at the moment or may not be that reliable, but still however can be used on several other scenarios beyond actual billing including analytics, estimated billing for avoidance of bill-shock etc.

In an infrastructure where direct access to its components is not provided, we have to result to gateways to provide that connectivity (req. 2). Many consider that the smart meter will be such a gateway that will enable access to the smart house. Various scenarios exist in which the meter is seen as an energy measurement device only (thin smart meter), while on the other side some see it as a general gateway that monitors and potentially even manages devices (fat smart meter), which implies integration of energy management capabilities (extended req. 3) and interaction with the household appliances. In-between there are also approaches that consider constellation of these where e.g. the smart meter and the energy management system are coupled (but not collocated in one device). Connectivity needs of such meter are usually considered over the traditional Power Line Communication (PLC), or even over external channels e.g. smart house's DSL connection, a separate 3G+ mobile network card etc.

The potential of the smart meter functionality acting as a gateway has also sparked the interest of other stakeholders already active in the smart house. These already provide connectivity (e.g. the telcos offering DSL access), and hence they look at possibilities to expand their coverage by attempting to offer additionally energy management solutions that are controlled (or in strong correlation) with their current deployments. This implies for instance that some telcos try to position the DSL router as the energy gateway, or offer new systems that can act as such e.g. energy management boxes with embedded communication functionalities over mobile networks. As all stakeholders try to claim their area, unfortunately multiple solutions arise, which often complicate things for the end-user rather than providing well-designed collaborative approaches. In not a far fetched scenario each provider may wish to provide his own standalone box for his energy management scenarios, which means that one may end up with different smart meters and energy boxes for the electricity, the gas, the electric car, the various appliances at home etc. However, a more common approach is needed to avoid segmentation and such extreme scenarios.

Up to now we have not seen the long-awaited success on the development of a common platform for in-house services and management, that could potentially be a nice starting point for offering common communication and energy management capabilities. This is a result of several facts, including the lack of interoperability as well as the high heterogeneity of devices. However, in the last years significant progress has been done towards development at mass scale protocols that can be used commonly by appliances (e.g. Wi-Fi, Zigbee etc.) to interconnect; and with the increasing prevalence of Internet based integration such as the Cloud of Things, such common platforms can reside partly on the cloud. This is a significant development which implies that in-house (on-premise) platforms can be more lightweight and equally rely on a growing basis of Internet services as well as a simplified interconnection with physical devices at home area. In addition to this, we have seen the last years the development of platforms that dominate (mostly mobile) devices such as the Android, IOS and Windows, and which could be a very good starting point towards building in-house solutions. An example of such a case is the prevalence of smart TV.

Today several TV manufacturers e.g. Sony, Samsung, LG etc. offer already smart TV sets with integrated the Android platform, and users can on-the-fly install applications that enhance existing functionalities or offer new ones. Therefore, beyond the "smart meter wars" on the role of the meter itself, and beyond smart energy boxes and router discussions, new players rise (such as the smart TV ones) that can offer a common platform for development of solutions. Considering also that these platforms are not developed by the manufacturers themselves but managed by others e.g. Google for Android, one can see the benefits of decoupled co-evolution. Additionally the usage of the same platform on other devices e.g. smart phones and tablets, may ease the introduction of new applications that easily can run on multiple devices without significant modification, which will kickstart the much-wanted era of offering value added services and application for the smart grid.

As we can see, smart meters will play a role in the future, however, this role must not be overestimated as technology and stakeholder constellations within the Smart House are changing. The Smart House should be seen as an ecosystem of devices that may share information and collaborate [11] either directly or via (cloud-based) services. Therefore we need to develop new business models as well as approaches that are information-interaction centred (rather than communication-integration centred). These federated infrastructures need to be designed, developed and assessed in real-world deployments. The latter is especially important in order to achieve high user-acceptance rates and make sure that developments are user-pulled based on their real needs.

IV. Security, Trust and Privacy

The future smart grid will be information driven and rely on services to empower the interactions among its stakeholders at multiple layers. This calls for open information exchange [12] that considers issues such as interoperability, security, trust and privacy. Value added services to be offered to Prosumers will need to be developed over a federated infrastructure, where cooperation will be more eminent than ever.

Considering the advances in the networked embedded device domain, their newly acquired capabilities as well as their expected prevalence, key questions arise with respect to the security, trust and privacy issues. Security [13] is difficult to be done correctly, as it is a process coupled with risk management, depending on the scenario. In the Cloud of Things era, it is expected that state of the art security approaches can be applied at the cloud, as well as at the device level. However, as these are expected now to host more general purpose operating systems and services, the need to evolve over time to tackle attacks made against them is coming to the foreground. Most of these are typical cyber-physical systems [14], and potential misuse, will have an impact on the physical world. In the most mild scenarios, smart meters may report less energy used, and hence economic fraud. However in other scenarios, the hardware relevant limits set by the manufacturers might be overridden, and machines might misbehave or cause calamities e.g. overheating, malfunctioning etc. As such, secure lifecycle management of cyber-physical systems, especially associated with critical infrastructures will gain importance, and will be challenging.

Designing and developing secure, reliable and resilient software for such complex systems, especially if they are not to operate standalone but as part of larger ecosystems as envisioned in the smart grid is hard.In the Cloud of Things era, the appliances will depend on various other services, hence it will be difficult to do holistic code reviews, systematic testing and checks at design and runtime. As a result software "bugs", which may have a tangible effect on the physical world, will happen more often, while their impact will be hard to be assessed. Automatic tools that do the model checking as well as detect potential safety-critical issues will be needed. Additionally, embedded system software developers will have to posses a good understanding of modern software development and security issues beyond their domain, in order to be able to provide high-quality solutions.

Trust is another facet in the smart grid Era. Although the devices may be "secure", questions will arise on the degree of trust we place upon them, their providers and operators, as well as on the data they produce. The same will hold true for the services that they have to cooperate with, as well as the services that will depend on them. Of course also different levels of quality of cyber-physical services will exist in the Cloud of Things, and traditional approaches on trusting them as well as evaluating their performance (e.g. via recommender systems) will need to be in place. Significant work is already done in the Internet of Services, which will now have to be extended to cover cyber-physical systems and of course cover the smart grid domain. Trust on the infrastructure, its data and services will be of key importance. Recently the Stuxnet virus demonstrated that although systems were not connected to the Internet, and measurements were made by the operating machines, the valid data was captured, exchanged with false data, and had any monitoring programme and plant operator fooled. Hence, a grant challenge would be to not only secure the devices but establish the full path of trust from data acquisition to consumption in the Cloud of Things as well as the appropriate risk assessment for the area.

Finally, privacy is a key aspect, already heavily discussed in conjunction with the smart meter deployment in several European cities. The fear is that high resolution of data may reveal information about the private sphere of its producers i.e. the residents in the house. This holds true as even with aggregated energy consumption values, specific devices and their usage can be identified [15] which reveal personal habits and information. This risk will only increase in the future, when devices will emit additional information and over multiple channels. It will be difficult to enable adequate measures to manage this information in a privacy-preserving manner. Additionally there is no guarantee, that even if this is done at device, smart house or at even higher levels, that new methods will not be able to extract privacy-related information from big data sets. Although methods have been proposed before, e.g. computing with encrypted data, the right balance needs to be found between privacy, security and value added services in order not to hamper the smart grid innovations but still protect all stakeholders.

Similarly policy-controlled schemes for secure management of data produced by smart grid devices will need to be established. Many discussions are ongoing with respect to the ownership e.g. of the smart meter data. However, this is only the tip of the iceberg since, as we have seen, the smart metering data is only a minor part of the overall mass amounts of information that is going to be made available in the future not only from the smart meters but all appliances in the smart house as well as the Cloud of Things services. The exchange of this data (or parts of them), in raw or processed forms will be of vital significance in order to be able to realise new innovative smart grid application and services. However, up to now we still miss a policy-controlled access to them, for their full lifecycle. For instance the owner (e.g. the residential user) may grant access to the data to an energy provider (for generating the bill), as well as a third party service provider for delivering him analytics. However, it should be possible to revoke later access to that provider not only for the future data but also for the historical ones, once their contract is dissolved. This is going to be challenging especially considering the multiple hops as well as the intermediate processing such data will have in the envisioned Cloud of Things.

V. Towards value-added services: Energy-aware Appliance Procurement

We have already made a strong case for the Cloud of Things and how the open interactions among devices, services and users will give birth to a new generation of applications that will offer value-added functionalities. To give a better understanding, we will depict here a simple prototype mobile application that gives a taste of things to come.

In our scenario, Evelyn has a ten-year old washing machine, and is potentially interested (but not in a hurry) on a new one. Evelyn seeks an appliance that strikes the balance between functionality and cost. She often inspects potential buys when she is out shopping, but the info she gets at the shop is limited to the content on the label of the appliance, and in the best case the advice of a salesman on the preference of one machine or another. However the salesman does not have the knowledge of how Evelyn is using her washing machine. Additionally Evelyn can only take decisions with the generalized static info that she has available i.e. the price and the energy label.

It is common practice that in the price tag of European appliances, energy efficiency info is displayed. This EU Energy Label has predefined energy indicators (from "A" to "G") indicating the energy efficiency level with A being the best down to G being the least efficient. It must be pointed out that these are general indicators and for instance for washing machines that would be calculated (at least until 2010), based on a cotton cycle at 60 °C (140 °F) with a maximum declared load of typically 6 kg. The energy efficiency index is in kWh per kilogramme of washing, assuming a cold-water supply at 15 °C. However this labelling for the average consumer like Evelyn is only a general indicator, and hence she can not really make the correct assessment in financial terms. An appliance with indicator "A" may be significantly more expensive than another with indicator "C"; but this does not directly connect with the operational cost of that appliance in Evelyn's mind. So in a dilemma on what appliance to buy, one may not have all the facts on hand to take a fully-informative decision.

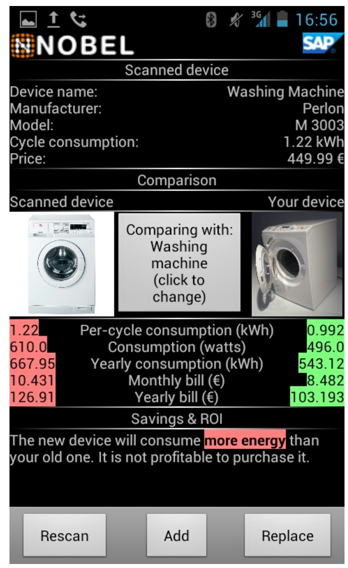

Figure 2. Research prototype indicating comparison of energy behaviour and cost estimation customized to the user's usage style

A mobile application that helps users with this dilemma has been developed. It runs on Android 2.2+ platforms and has successfully been demonstrated on both smart phones and tablets. The mobile application is able to acquire detailed information about the appliances Evelyn has at home as well as her current electricity tariff. Whenever Evelyn sees a sales prospect (or is in an electric appliance shop), she can scan the barcode on the price tag of the new appliance she inspects. Immediately in her screen information for that appliance appears (a screenshot of which can be seen in Figure 2) and is correlated with information of the appliance at home. In the immediate comparison the main decision-relevant facts are presented as well as additional information on the operational cost of the appliance based on Evelyn's washing behaviour so far, broken down to monthly and yearly cost. Now Evelyn can clearly compare her old appliance (in our demo a washing machine), with the new one she just saw on a flyer, and also correlate the energy efficiency information in a monetary way. The application assists her by clearly showing if the acquisition of a new washing machine is financially beneficial in the longer run (e.g. indicating the cost amortization period) or not e.g. if the appliance is less efficient than the one at home (case shown in Figure 2).

The steps followed in more detail in our demo can be summarized as:

- The application is started, Evelyn logs in and selects the device she has at home and wishes a comparison against
- Evelyn scans the barcode of the new appliance to be compared to the existing one at home
- At this stage several service calls are made to an online analytics service Evelyn is using, to the manufacturer web site of the new appliance, to the energy provider etc.
- An analysis is made available to the user, presenting all necessary facts.

For the mobile application to be able to offer this value added service to its user, the Cloud of Things functionalities come into play. The mobile application is able to contact other services that supply it with a list of the appliances, e.g. the washing machine, Evelyn has at home, and additionally has detailed information on how this has been operated the last months. The data comes from an analytics service hosted in the Cloud of Things, which collects data (with Evelyn's approval) and analyses it in order to show her the percentage of electricity consumed by the washing machine in relation to the overall energy consumed. Another service from her energy provider shows her current tariff and an estimate of increase in the next years. The provider of the new washing machine Evelyn is inspecting, already provides information for his products via REST services so that these can be integrated in other value added applications.

All interactions were implemented as REST services, and in our case of course we had to realize all of the aforementioned services as proof of concept. However in the future, these are expected to be provided by the relevant stakeholders. This example is just a simple application demonstrating the value added services that can exist in the future Cloud of Things empowered smart grids and its energy services [16].

VI. Conclusion

The smart grid is much more than smart metering and has the potential to have a significant impact on our everyday life, provided that we fully take advantage of its capabilities. It will be information-driven and the emerging Cloud of Things services will empower a new generation of sophisticated mash-up applications that will be fed with real-time data and will assist their users e.g. to take better decisions. However for this to happen, we need to go beyond smart metering, and investigate further on the appropriate business models, make sure that the interactions among the smart grid Things is done in an open and interoperable way, and that data acquired can be used while respecting security, trust and privacy constraints.

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